‘This is Ground Control’: The Invention of Mission Control Centers in the United States and Europe

by

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Abstract

This dissertation examines the invention of mission control centers by the National Aeronautics and Space Administration and the European Space Agency, particularly during the Cold War. The control rooms of Johnson Space Center in Houston, Texas, the Jet Propulsion Laboratory in Pasadena, California, and the European Space Operations Centre, in Darmstadt, Germany, lie at the heart of this discussion. The three control centers developed individually, however each contain certain similarities yet important differences based on their particular political, economic, and spaceflight, needs.

Spaceflight history normally focuses on the astronauts and spacecraft in space. This dissertation instead looks at the history of spaceflight through its ground systems, where the majority of the spaceflight work takes place. It will ask how controllers have fashioned workplaces and workspaces. While all mission control centers fulfill the same basic task of monitoring spacecraft, minor and major differences have lead to some dramatic differences in the construction of the centers. This work tackles three centers with very different missions: American human spaceflight, American robotic spaceflight, and finally European robotic spaceflight.

Both domestic and international politics play an important role in the discussion. Because space agencies require large budgets, decisions to locate space centers in certain locations involve politically-charged debates and recommendations. Internationally,

spaceflight efforts became quickly engrained in the Cold War. The Americans space program, which was large enough to pay for its projects and involved in a competition with the Soviet Union, reluctantly pursued relationships with outside space programs. The European space program, on the other hand, relied upon cooperation with other space programs due to its limited budget and fundamentally international characteristic. As budgets have lessened and the world community has changed to more acceptance of international collaboration, the dynamic has changed in spaceflight to embrace cooperative projects as essential. Each of the control centers necessarily has learned to adapt to an ever-changing political landscape.

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List of Abbreviations

ARTCC	Air Route Traffic Control Center
ASTP	Apollo-Soyuz Test Project
ATC	Air Traffic Control
CAA	Civil Aeronautics Administration
Caltech	California Institute of Technology
Capcom	Capsule Communicator or Spacecraft Communicator
CERN	European Organization for Nuclear Research
COPERS	European Preparatory Commission for Space Research
DCC	Data Computation Complex
DCR	Dedicated Control Room
DCS	Display and Control System
DOD	Department of Defense
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
EAC	European Astronaut Centre
ECC	ESTRACK Control Centre
ELDO	European Launch Development Organisation
ESA	European Space Agency
ESDAC	European Space Data Acquisition Centre
ESOC	European Space Operations Centre

ESRIN	European Space Research Institute
ESRO	European Space Research Organisation
ESTEC	European Space Research and Technology Centre
ESTRACK	European Space Tracking Network
EVA	Extra-Vehicular Activity
FAA	Federal Aviation Administration (Agency)
FCR	Flight Control Room
FCT	Flight Control Team
FD	Flight Director
FOD	Flight Operations Director
GALCIT	Guggenheim Aeronautical Laboratory at Caltech
GSFC	Goddard Space Flight Center
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEOP	Launch and Early Operations Phase or Launch and Early Orbit
MCC	Mission Control Center
MCR	Main Control Room
MOCR	Mission Operation Control Room
MOD	Mission Operations Director
MSA	Mission Support Area
MSC	Manned Spacecraft Center

MSFN	Manned Space Flight Network
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
OCC	Operations Control Centre
RKA	Russian Federal Space Agency
RTCC	Real Time Computer Complex
SCOS	Spacecraft Control and Operations System
SFOF	Space Flight Operations Facility
STADAN	Space Tracking and Data Acquisition Network
STDN	Space Tracking and Data Network
STG	Space Task Group
STS	Space Transportation System, the Space Shuttle
TDRSS	Tracking and Data Relay Satellite System
UNIVAC	Universal Automatic Computer

INTRODUCTION

Humans are social beings. They thrive on contact with other humans. The literature, both academic and fictional, surrounding the effects of isolation on a human is stunningly diverse and copious. When Neil Armstrong and Edwin "Buzz" Aldrin walked on the moon on 20 July 1969, Michael Collins orbited the moon on his own in the command module. He described this time as "the purest form of freedom." He further stated that he was "'truly alone, and absolutely isolated from any known life.'" While for many people this feeling might come with a sense of foreboding, Collins relished it, taking advantage of the situation as a pilot and his craft.[1]

Despite enjoying his isolation, he still craved contact with his crewmates on the moon. When his communications relay went down, he felt left out. Although he could not see their actions, hearing Armstrong and Aldrin made he feel like a part of the action and a part of the human experience.[2]

A human in space also requires a connection to humanity on earth. That voice on the other end of the communications link is mission control. More specifically, for the astronauts of the National Aeronautics and Space Administration, the Mission Control Center of the Johnson Space Center has been that voice for nearly fifty years.

Mission Control is much more than a voice. Mission planners and controllers develop flight plans for each mission. Controllers monitor the operations of spacecraft as

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[1] Andrew Chaikin, *A Man on the Moon, Vol. I: One Giant Leap* (Alexandria, VA: Time-Life Books, 1994), 329.

[2] Ibid., 328.

well as the bodies of astronauts themselves. In the event of an anomaly, the controllers consult with various engineers and other experts on the ground to find a solution and return the spacecraft to peak or near-peak working condition.

Any mission to space, human or robotic, represents years if not decades of work by thousands of individuals. Mission Control is therefore only the most visible part of the thousands of humans on the ground attempting to assure a successful spaceflight. Someone, whether scientist, engineer, or administration, must advocate the initial plan for each mission. Engineers design the spacecraft as well as its payload, or what it is carrying. Mission planners organize the mission. Flight dynamics experts calculate the orbits and trajectories. On manned missions, trainers prepare the astronauts. Simulation engineers train and prepare the controllers. All of this must occur before the controllers even begin to communicate with the spacecraft.

Mission Control coordinates not only missions in space, but also supports mission planning and communications networks on the ground. Despite Mission Control's obvious importance, it remains relatively unknown. To date, no one has published a major historical examination of Mission Control facilities and their functions. A few historical works have examined aspects of Mission Control, but none have focused on the control rooms.

Charles Murray and Catherine Bly Cox's *Apollo: The Race to the Moon* (1989) provides the best glimpse into the inner workings of the mission control center during the Apollo program. It includes analysis of the control room itself as well as the backup facilities, simulations, and other integral aspects of the control center. While it does analyze the Apollo program from the perspective of mission control in some instances, it remains primarily an overall history of the missions.

Histories of NASA centers are indispensible sources for placing the control centers within a physical and historical context. In particular, the official Johnson Space Center history, Henry Dethloff's *Suddenly Tomorrow Came…* (1993), and the two JPL histories, Clayton Koppes's *JPL and the American Space Program* (1982) and Peter Westwick's *Into the Black* (2007), contain some important but minimal substantive information. Because they focus on the overall picture of the centers, they can do little more than provide context for the control rooms.

Autobiographies of individuals who worked in mission control offer a different perspective on the control centers. In particular, Christopher Kraft's *Flight: My Life in Mission Control* (2001) and Gene Kranz's *Failure Is Not an Option: Mission Control from Mercury to Apollo 13 and Beyond* (2000) present personal as well as professional and authoritative insights into mission control at the Johnson Space Center. Both provide impressions of work in mission control, but they leave the reader wanting more detailed information on the rooms.

These few sources include the most detailed accounts of mission control to date. The majority of them focus on Johnson Space Center, creating an unbalanced account of mission control. This work intends to amend this bias by examining the historical significance of three primary control centers to space travel.

For the majority of people, when they hear the term "Mission Control" they think of Mission Control Center (MCC) at Johnson Space Center (JSC) in Houston, Texas.

Houston's center is just one of dozens of mission control centers for spaceflight across the world. NASA has a handful of other control rooms in various centers around the United States. The Kennedy Space Center (KSC) in Cape Canaveral, Florida, houses the Launch Control Complex and previously included the Mercury Control Center. The Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, maintains a control center for a number of satellites, including the Hubble Space Telescope. The Jet Propulsion Laboratory (JPL) in Pasadena, California, houses the Operations Control Center (OCC) for the Deep Space Network and the majority of deep space missions. These are just the most prominent examples.

Outside NASA, most major space agencies have at least one, if not multiple, control centers. The main control center for the European Space Agency (ESA) is the European Space Operations Centre (ESOC) in Darmstadt, Germany. The European Space Research Institute (ESRIN) in Frascati, Italy, also includes a control room for ESA's Earth observation satellites. Human ESA missions have still another control room at the European Astronaut Centre (EAC) in Cologne, Germany. In addition, other national European space agencies have their own control centers.

Other space agencies have constructed their own control rooms. The main control center for the Russian Federal Space Agency (RKA) is in Korolyov just outside Moscow. The Beijing Aerospace Command and Control Center serves as a control room for the China National Space Administration (CNSA). The Japanese Aerospace Exploration Agency (JAXA) maintains a control room at their Tsukuba Space Center in Tsukuba. The Indian Space Research Organization (ISRO) has a Master Control Facility in Hassan. Numerous other control centers can be found across the globe.

It would be impossible to study every one of these control centers. This dissertation therefore focuses on the control rooms at Johnson Space Center, the Jet Propulsion Laboratory, and the European Space Operations Centre. These three centers between them deal with the main focuses of space travel. How do mission control centers working with human spaceflight differ from those coordinating robotic spaceflight? How do cultural ideas of control differ between the centers of the United States and Europe? How can domestic and international political issues be reflected by the space programs in general and the control rooms in particular? What role did the Cold War have in the invention of mission control centers? And how did the control rooms adapt to the changing political landscape and the needs of the space agencies? These questions will remain at the heart of this dissertation.

American Human Missions

The story of the creation of NASA is well known. Following the first flight of an artificial satellite – the Soviet Union's *Sputnik 1* – President Dwight D. Eisenhower signed into law the National Aeronautics and Space Act, on 29 July 1958, which created a civilian space agency "devoted to peaceful purposes for the benefit of all humankind."[3] NASA's first goal was to launch men into space and bring them back to Earth successfully. The agency created Project Mercury to accomplish this goal.

For Project Mercury, NASA selected seven test pilots as the first astronauts. Alan Shepard became the first American to fly in space on 5 May 1961. On 20 February 1962,

[3] NASA Office of the General Counsel, "The National Aeronautics and Space Act, Sec. 20102 a," NASA, http://www.nasa.gov/offices/ogc/about/space_act1.html (accessed 16 January 2012).

John Glenn orbited the Earth, another American first. In all, six of the astronauts flew before the project ended in May 1963.[4]

On 25 May 1961, President John F. Kennedy pronounced a new goal for NASA: namely to send astronauts to the moon and bring them back safely by the end of the decade. This announcement sent shockwaves through the spaceflight community. NASA focused on this goal for the remainder of the 1960s.

Project Gemini, which included ten flights of two astronauts each between March 1965 and November 1966, served as a transitional program. The majority of missions under Project Gemini were aimed at demonstrating the possibility of flying to the moon. NASA had to prove that its spacecraft could rendezvous and dock with each other. The astronauts had to practice and complete successful extra-vehicular activities (EVA), better known as spacewalks. NASA completed the Gemini missions largely without incident, giving NASA the confidence it needed to move on to the next program.[5]

The Apollo program provided some of the most celebrated moments in NASA's history. It began, however, with one of its most tragic events. On the night of 27 January 1967, during what was supposed to be a routine test, a fire broke out in the Command Module of AS-204, later renamed Apollo 1, the first scheduled human mission of the Apollo program. Unable to escape, three astronauts, Gus Grissom, Ed White, and Roger

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[4] For more information on the Mercury Project, consult http://www.jsc.nasa.gov/history/mercury.htm, or the many books written on the subject including M. Scott Carpenter, et al. *We Seven* (1962); Francis French and Colin Burgess, *Into That Silent Sea: Trailblazers of the Space Era 1961-1965* (2007); Loyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury* (1966); and the stylized Tom Wolfe, *The Right Stuff* (1979).

[5] For more information on the Gemini Program, consult its website http://www.jsc.nasa.gov/history/gemini.htm, or its many books including Barton C. Hacker and James M. Grimwood, *On the Shoulders of Titans: A History of Project Gemini* (1977); James M. Grimwood and Barton C. Hacker, with Peter J. Vorzimmer, *Project Gemini Technology and Operations – A Chronology* (1969); David Michael Harland, *How NASA Learned to Fly in Space: An Exciting Account of the Gemini Missions* (2004), and David J. Shayler, *Gemini: Steps to the Moon* (2001).

Chaffee, died of asphyxiation. After months of investigation, a review board determined that the spacecraft contained too many flammable materials in a pure oxygen environment. A spark from a frayed wire had caused some of those objects to catch fire. NASA set out to fix the many problems found in the Command Module. Numerous NASA employees mark the fire as the turning point for NASA – a loss of innocence. Indeed, many see NASA's history as prefire and postfire.

The first manned Apollo flight, Apollo 7, successfully launched on 11 October 1968. The following mission, Apollo 8, was the first to orbit the moon in December 1968. Finally, on 20 July 1969, Neil Armstrong and Buzz Aldrin accomplished President Kennedy's goal by becoming the first humans to walk on the moon. By the end of 1972, a total of twelve men had walked on the lunar surface.[6] Already by 1970, public interest in spaceflight had already begun to diminish markedly, as NASA's budget continued to decline after its 1966 peak. The human portion of American spaceflight quickly needed to cope with less money at the same time that it needed more impressive accomplishments to grab the public's attention. NASA had been so focused on a single goal that having achieved it, they had difficulty transitioning to other missions.

After Apollo, many people wondered about America's next goal in space. Some advocated human missions to the planets, especially Mars. Others argued for a permanent space station in earth orbit. Still others wondered about the need for a human spaceflight program at all, stating that the country could better use the funds and scientific brainpower spent at NASA targeting other, more immediate problems on earth.

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[6] The Apollo Program is easily the most chronicled aspect of spaceflight history. Online, please consult http://www.jsc.nasa.gov/history/apollo.htm. Two of the most important program overviews are Andrew Chaikin, *A Man on the Moon: The Voyages of the Apollo Astronauts* (1994), and Charles Murray and Catherine Bly Cox, *Apollo: The Race to the Moon* (1989). Many of the most important individuals have also written memoirs, including Chris Kraft, Gene Kranz, and most of the astronauts.

In the immediate post-Apollo era, NASA's Johnson Space Center focused on two programs: Skylab and the Apollo-Soyuz Test Project (ASTP). Skylab flew as the United States' first, and so far only, space station. During 1973 and 1974, three crews of three astronauts each flew aboard the station conducting experiments ranging from earth observations to biological experiments to solar studies. The station itself remained in orbit until 1979, when it reentered the atmosphere and parts of it impacted in and around western Australia.[7] The ASTP, in 1975, marked the first joint venture between the United States and the Soviet human space programs. While not accomplishing any new goals, it did prove that two nations that were political enemies could work together.[8] To many in the space program, especially in hindsight, both served as mere holding place missions to keep the human program flying as it geared up toward its next big project, the Space Shuttle.

NASA built the Space Shuttle, more formally known as the Space Transportation System (STS), with the idea of making human spaceflight routine. The shuttle itself would be reusable, as would its solid rocket boosters. Unfortunately, NASA was not able to recover and reuse the large external tank. Though nowhere close to the totally reusable STS that NASA had envisioned, the shuttle would successfully make spaceflight more routine, if not nearly as routine as shuttle publicists envisioned. NASA originally wanted a few dozen flights each year. These plans quickly proved improbable, especially due to the large expense associated with each launch. The shuttle did prove to be uniquely

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[7] For more information on Skylab, consult http://www.jsc.nasa.gov/history/skylab.htm or its few dedicated works including Henry S. F. Cooper, Jr., *A House in Space* (1976); W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab* (1983); David J. Shayler, *Skylab: America's Space Station* (2001); and David Hitt, Owen Garriott, and Joe Kerwin, *Homesteading in Space: The Skylab Story* (2008).

[8] For more information on ASTP, consult http://www.jsc.nasa.gov/history/astp.htm, and Edward Clinton Ezell and Linda Neuman Ezell, *The Partnership: A History of the Apollo-Soyuz Test Project* (1978).

flexible, conducting numerous different types of missions including carrying satellites into orbit, docking with space stations, and serving as a scientific platform.

Five shuttles, *Columbia*, *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*, flew a total of 135 missions between 1981 and 2011. The majority of these flights occurred with little to no fanfare. Shuttle flights attracted the public's attention most intently during two tragedies. On 28 January 1986, the *Challenger* and its seven astronauts were lost mere seconds after launch. A special commission found NASA's culture and decision-making process as culpable as a failed O-ring in one of the solid rocket boosters. Historians have agreed, with James R. Hansen and Allan J. McDonald adding that the change in the contract for the solid rocket boosters to multiple companies was also a factor. After thirty-two months and numerous design and operational changes, the shuttles returned to flight.

Nearly twenty years later, on 1 February 2003, the *Columbia* broke apart during reentry, killing all seven astronauts. NASA had been aware that debris had fallen off the external tank and struck the thermal protection of shuttles during previous flights, sometimes creating substantial damage. Not until this launch had these impacts caused fatal damage. Again NASA implemented changes, including more careful inspection for damage after the spacecraft reached orbit. The shuttles began flying again twenty-nine months later, and they continued to do so for six more years.[9]

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[9] Because the Space Shuttles flew until recently, there is no definitive history of the program. Some important information can be found online at http://www.jsc.nasa.gov/history/shuttle.htm. Interesting books on the shuttle include Dennis R. Jenkins, *Space Shuttle: The History of Developing the National Space Transportation System, The Beginning through STS-75* (1996); T.A. Heppenheimer, *The Space Shuttle Decision, 1965-1972* (2002) and *Development of the Space Shuttle, 1972-1981* (2002); Allan J. McDonald with James R. Hansen, *Truth, Lies, and O-Rings: Inside the Space Shuttle Challenger Disaster* (2009); and Philip Chien, *Columbia-Final Voyage: The Last Flight of NASA's First Space Shuttle* (2006).

Along with the shuttles, NASA prepared for a more permanent presence in space. Plans for a larger space station began shortly after the demise of Skylab. As budget cuts and other issues pushed its development back, it became clear that NASA would need international partners. In the 1980s, NASA approached European space agencies, Canada, and Japan as its primary partners. In the 1990s, with the end of the Cold War, Russia became an important partner, especially due to its institutional experience operating space stations from the Salyut stations between 1971 and 1982 to *Mir* beginning in 1986. Finally, in 1998, a Russian Proton rocket launched the station's first component, *Zarya,* into low-earth orbit. Two weeks later, NASA added the American *Unity* node to the Russian module. Then, in 2000, the Russian space agency attached *Zvezda*, allowing the station to become permanently manned with its life support and living quarters. Over the next decade the space programs would add even more modules, laboratories, and solar arrays. NASA and its partners plan to complete the International Space Station (ISS) in 2012. It is expected to remain operational for at least another eight years. With the end of the shuttle flights and for the immediate future, the astronauts and cosmonauts on board will rely on the Russians to provide launches for resupply and for the exchange of crews.[10]

American Robotic Missions

[10] The space station's history continues to be written. Some sources of further information include its main website, http://www.nasa.gov/mission_pages/station/main/index.html, as well as a few books including David Michael Harland and John E. Catchpole, *Creating the International Space Station* (2002); Peter Bond, *The Continuing Story of the International Space Station* (2002); Roger D. Launius *Space Stations: Base Camps to the Stars* (2003); and John E. Catchpole, *The International Space Station: Building for the Future* (2008).

While early technological limitations limited the Jet Propulsion Laboratory to small satellites in near-earth orbit, beginning in the 1960s, JPL established itself as the premier deep space operations center in the world. JPL played an integral role in the first two successful American satellites, *Explorers 1* and *2* in 1958. These satellites included scientific instruments that, among other things, provided evidence of a radiation belt surrounding the earth, now named the Van Allen belt. JPL continued by developing the small satellites of the Pioneer program that flew by the moon in the late 1950s. The Ranger program followed Pioneer to the moon. Ranger spacecraft included cameras for the first close-up images of the lunar surface. The Mariner program of the 1960s and 1970s reached beyond the moon and included numerous probes of nearby planets Mercury, Venus, and Mars.

After 1961, as nearly all of NASA focused on the lunar landings, JPL contributed to the effort with the Surveyor program, aimed at proving the viability of soft landing on the moon. Between March 1966 and January 1968 seven unmanned spacecraft were launched, five of which successfully completed their missions.

As the Mariner missions neared completion, JPL changed the focus of its efforts to Mars. The Mars Viking missions were ambitious, with orbiters and landers. As part of its diversification, JPL also concentrated on transferring space technologies to more common domestic uses. For instance, some space technologies have been used to transform mass transit and aerospace systems, medical technologies, and alternative energies.[11]

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[11] Clayton R. Koppes, *JPL and the American Space Program: A History of the Jet Propulsion Laboratory* (New Haven: Yale University Press, 1982), 233-6.

In the mid- to late-1960s, JPL began to endorse a large-scale program to send satellites to each of the outer planets. The unique alignment of planets between 1976 and 1980 offered an opportunity: a satellite or satellites could more easily reach the outer planets within this window. Using an effect likened to a slingshot, the spacecraft would take advantage of gravitational effects. This "Grand Tour," as it was known, could speed up scientific and exploration aspects of planetary space travel. For instance, a trip to Neptune, which on its own could take up to thirty years, would only take eight years under this scheme.[12]

Based on the Grand Tour project, the JPL administration eventually agreed to the Voyager program to visit Jupiter and Saturn. The first Voyager spacecraft would fly closer to the planets and Saturn's moon Titan for maximum imaging. The second would have a more conservative approach, but JPL could adjust it if the first failed. The conservative trajectory, not coincidentally, allowed for a slingshot around Saturn to Uranus and perhaps Neptune, giving them the opportunity to revisit the idea of a Grand Tour later.

Due to the trajectories, *Voyager 2* actually launched first, on 20 August 1977, followed by *Voyager 1* on 5 September 1977. *Voyager 1* observed Jupiter and its moons from January to April 1979. It then visited Saturn in November 1980, before continuing on its extended mission to the outer areas of the solar system. *Voyager 2* encountered Jupiter in July and August 1979, Saturn in August and September 1981, Uranus in January and February 1986, and Neptune from August to October 1989. Both Voyager

[12] Koppes, 186; and James E. Long, "To the Outer Planets," *Astronautics and Aeronautics* 7 (June 1969): 32-47; Peter J. Westwick, *JPL and the American Space Program, 1976-2004* (New Haven: Yale University Press, 2007), 19; and Voyager histories.

spacecraft continue to operate and report back information on a regular basis, and are expected to do so until 2025.[13]

The amount of scientific output from Voyager continues to prove invaluable since scientists had virtually no information on the outer planets and their moons before the missions and now have a wealth of information, some of which has been surprising. The Voyager project also helped lift the public profile of JPL and NASA. The images sent from the spacecraft have attracted popular attention as well as providing scientific information.

As JPL moved into the 1980s continuing to control Voyager and Viking, NASA faced even more funding cutbacks. Consequently, JPL's next two programs consisted of single satellites. The *Magellan* spacecraft mapped Venus. JPL also sent another spacecraft to Jupiter, *Galileo.* Other promising programs were eliminated due to lack of funds, some even when they were well into development.

With the end of the Cold War came even more budget cuts and the need for more inventive ways to do more with less. NASA adopted the idea of "faster, better, cheaper" under new administrator Daniel Goldin. This approach encouraged smaller, more manageable missions that could potentially yield the same scientific breakthroughs as earlier missions.[14]

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[13] The Voyager program has received much detailed analysis, including Westwick, 18-41; Joel Davis, *Flyby: The Interplanetary Odyssey of Voyager 2* (1987); Joan Marie Verba, *Voyager: Exploring the Outer Planets* (1991); Henry C. Dethloff and Ronald A. Schorn, *Voyager's Grand Tour: To the Outer Planets and Beyond* (2003); Jon Hakkila and Adele B. Richardson, *Voyager* (2005); and Stephan J. Pyne, *Voyager: Seeking Newer Worlds in the Third Great Age of Discovery* (2010).

[14] For more on faster, better, cheaper, consult: Howard E. McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore: The Johns Hopkins University Press, 2001); and Westwick, 207-27.

During this time, Congress awarded NASA money for the Discovery program. With this program, the agency received annual allotments to divide between its various programs as NASA saw fit. This allowed NASA to avoid the need to gain separate government approval for each of its projects. This system worked in favor of the kind of projects operated by JPL. The Discovery program ultimately produced Mars Pathfinder, the first Mars lander since *Viking* and the first of many rovers, and *Stardust*, which returned samples from a comet.[15]

A series of failures complicated JPL's missions in the 1990s. First, *Mars Observer* lost communication with the ground three days before its planned rendezvous with Mars in August 1993. The exact fate of the spacecraft is still unknown. Later in the decade, perhaps the most famous robotic spaceflight failure in history occurred when the *Mars Climate Orbiter* crash landed, or, perhaps more correctly, burned up in the atmosphere, on 23 September 1999. An error in the navigation occurred when scientists input data using the English rather than the metric Newtons system in which JPL had written the software. A little over two months later, on 3 December, the *Mars Polar Lander* was also lost during its descent, probably due to an engine malfunction which caused a landing at high velocity. Those failures increased tensions and contributed to a growing myth of Mars as a spacecraft destroyer.

Some missions to Mars in the 1990s were successful. *Mars Global Surveyor* orbited the planet and provided images for almost ten years, twice the original mission length. Mars Pathfinder included a rover, *Sojourner*, which roamed the surface of the planet in 1997 and 1998. Other successful missions in the 1990s included Cassini-Huygens, a joint mission with the European Space Agency and the Italian Space Agency

[15] Westwick, 212-3; and McCurdy, *Faster, Better, Cheaper,* 6.

which flew by Venus, Jupiter, and Saturn, and continues to orbit Saturn and transmit data and images. *Stardust*, launched in early 1999, collected samples from a comet and returned those samples to earth in 2006.

JPL continues to explore and conduct experiments on Mars. *2001 Mars Odyssey* reached orbit around the planet in October 2001 and continues to map the surface. The Mars Exploration Rovers *Spirit* and *Opportunity* have explored the planet since 2004. The *Mars Reconnaissance Orbiter* has observed the planet and acted as a communications relay for the surface missions since 2006. Finally, JPL launched the Mars Science Laboratory, with its rover *Curiosity*, on 26 November 2011. It is scheduled to land in August 2012. Future missions include plans for two spacecraft in tandem orbits to study the gravitational effects of the moon, a detailed observation mission to Jupiter, as well as various other earth observation satellites and deep space telescopes. The future of JPL as the primary deep space NASA center appears to be firmly in place.

European Spaceflight

Unlike NASA, the European Space Agency (ESA) represents not one but many European national space efforts. It, therefore, must recognize the needs and the differences between its constituent countries when making decisions about operations. It has also always operated with a budget a fraction the size of NASA and must limit the size and number of missions or actively search for partners for larger projects. One other major difference arises from the lack of a substantive human spaceflight program until recently. It has never launched a spacecraft able to accommodate humans, and thus relies on other space programs to carry its astronauts into space. Since ESA remains primarily a robotic spaceflight program, with a substantial deep space history, its operations resemble JPL more closely than JSC.

In order to understand the makeup of ESA, one must first understand its roots in the immediate post-World War II era. Across Europe the war had caused devastation and destruction on the land and infrastructure. Following the war, European science and technology, especially in Germany, suffered a significant "brain drain." Rocketry pioneer Wernher von Braun, and about 120 other engineers, moved to the United States to aid its early rocketry efforts. The Soviet Union relocated another 200 engineers and scientists, most notably Helmut Grottrup.[16]

Western European nations concentrated on new emerging technologies as a way to rebuild their economies quickly and regain their standing on the international stage.[17] The European Organization for Nuclear Research (CERN) was just one of the many agencies to be founded during this time. After some years of discussion, twelve nations agreed, in 1954, to found the particle physics laboratory in Geneva.[18] CERN remains an important international organization, that has continually grown over time.[19]

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[16] John Krige and Arturo Russo, *A History of the European Space Agency, 1958-1987: Volume I: The Story of ESRO and ELDO, 1958-1973* (Noordwijk, The Netherlands: ESA Publications Division, 2000), 3.

[17] Numerous histories speak to this phenomenon, including Kristin Ross, *Fast Cars, Clean Bodies: Decolonization and the Reordering of French Culture* (1995); Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II* (1998); Hanna Schissler, ed., *The Miracle Years: A Cultural History of West Germany, 1949-1968* (2001); Arthur Marwick, *The Sixties: Cultural Revolution in Britain, France, Italy and the United States, c. 1958- c. 1974* (1998); and Paul Betts, *The Authority of Everyday Objects: A Cultural History of West German Industrial Design* (2004).

[18] CERN's twelve founding members were Belgium, Denmark, France, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, West Germany, and Yugoslavia.

[19] Current members include those listed above, excluding Yugoslavia and including the unified Germany, along with Austria, Bulgaria, the Czech Republic, Finland, Hungary, Poland, Portugal, Slovakia, and Spain. Romania will join in 2015. Observers include India, Israel, Japan, Russia, Turkey, and the United States, as well as the European Commission and UNESCO.

In the late 1950s, a number of European scientists, many of whom were closely tied to CERN, began to promote a European space organization. Edoardo Amaldi, an Italian physicist, and Pierre Victor Auger, a French atomic physicist, were two of the main catalysts for this movement. By 1961, they had successfully convinced a number of Western European governments to cooperate in creating the European Preparatory Commission for Space Research (COPERS). Out of COPERS came a proposal for a European Space Research Organization (ESRO). By its third meeting, in October 1961, COPERS had created a document referred to as the Blue Book, which outlined ESRO's organization, its purpose, and its technology needed to function. Many of these early ideas became reality.[20]

On 20 March 1964, Belgium, Denmark, France, Italy, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and West Germany officially established ESRO.[21] Europeans realized early on that individual nations did not have the financial resources to compete with the United States and the Soviet Union. The European nations cited above created ESRO to counter, but not compete against, the space agencies of the United States and the Soviet Union. By working together in ESRO they could give scientists and engineers a reason to stay in their home countries and not emigrate to one of the major powers, thus avoiding a continued "brain drain." In addition, the European

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[20] Krige and Russo, *A History of the European Space Agency, Volume I*, 48-51.

[21] It should be noted that while ESRO, and later ESA, has many of the same member states as the European Union, they do not completely overlap.

authorities recognized that involvement in space might lead to advancements in technology that could boost the economic and industrial development of their nations.[22]

As European officials met to discuss the creation of ESRO, a significant difference of opinion arose about launchers for potential satellites. Most agreed that the Europeans would need to build their own rockets to avoid dependence on other space agencies. Because it would be up to them, the more highly industrialized nations, to take charge of launcher production, Britain and France wanted a separate agency to manage the production and utilization of launchers. While others, in particular Belgium and to a lesser extent the Netherlands, Switzerland, and Italy, argued for one agency to oversee all space operations, the political persuasion of Britain and France won out. This led to the creation of the European Launch Development Organisation (ELDO) as a separate entity.[23]

The separation of space efforts did not last. On 31 May 1975, as part of a new reorganization, ESRO and ELDO combined to create the European Space Agency (ESA) (for the purposes of simplification, this dissertation will use ESA to refer to the European space agencies regardless of date).[24] The Convention for the Establishment of a European Space Agency, which oversaw the creation of ESA in 1975, stated that ESA's purpose was "to provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space

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[22] Hermann Bondi, "International Cooperation in Space," in *International Cooperation in Space Operations and Exploration*, ed. Michael Cutler (Tarzana, CA: American Astronautical Society, 1971), 3; and Krige and Russo, *A History of the European Space Agency, Volume 1*, 11.

[23] Krige and Russo, *A History of the European Space Agency, Volume I*, 36-37.

[24] *ESA Annual Report 1975* (European Space Agency, 1976), 111 and "Convention for the Establishment of a European Space Agency," European Space Operations Centre Library, Darmstadt, Germany, 52.

applications."[25] This statement affirmed a commitment to peaceful, nonmilitary, missions. Later in the document, Act XIV discussed cooperation with outside parties. A unanimous vote by all member states is required to approve any work with a foreign company or space agency.[26] All member states recognized cooperation as an integral aspect of the agency.

While the member states must be unanimous in approval of foreign cooperation, they do not always agree upon which programs to pursue. As a result, Act IV of the Conference described the funding of activities. ESA labeled all programs as either "mandatory" or "optional." Funding for mandatory programs came from all member nations in proportion to their gross national products. Each nation had a single vote on all critical matters, and each issue required a unanimous vote. Mandatory programs included technology research, education, facilities, solar system science, astronomy, and fundamental physics. Member states chose their level of involvement in optional programs, which included earth observations, telecommunications, satellite navigation, space transportation, the International Space Station and human spaceflight, robotic exploration, and microgravity research.[27]

ESA's industrial policy, outlined in Act VII, stipulated that programs had to be cost-effective, yet competitive, with equitable participation by member nations, and a preference to utilize the industry of member nations. Finally, ESA had to pursue free

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[25] "Convention for the Establishment," 53.

[26] Ibid., 60.

[27] "Convention for the Establishment," 54; Manfred Warhaut, "ESA and ESOC Overview" (Powerpoint Presentation, European Space Operations Centre, Darmstadt, Germany, 16 August 2010); and "European Space Operations Directorate: …constant vigil," BR 88, European Space Agency Headquarters Library, Paris.

competitive bidding on projects, unless that interfered with the other requirements.[28] Some of those rules caused problems for officials deciding on the contracts. It can be quite difficult to sync equitable distribution of funds with free competitive bidding and cost-effectiveness, but ESA did its best to adhere to the guidelines.

Interestingly, Act IX stated that any member could use ESA facilities for its own non-ESA programs, as long as their use did not interfere with regular ESA programs.[29] This allowed for another source of income for ESA. More fundamentally, this idea of openness had been important for ESOC in particular as it emerged on the international stage as a major control center, since it had allowed ESOC to participate in the rescue activities for non-ESA satellites. This openness could likewise enhance the spread of technological ideas considered essential to the recovery of Europe. More recently, ESOC has chosen to rent its facilities to any user who might need them. The administration cites both its proven expertise and the flexibility of its facilities when promoting the center to international customers.[30]

The ESA Council, which included two representatives from each member state, ran the overall business of the space agency. The council appointed a Director-General to serve as the highest ranking official for ESA, similar to NASA's Administrator.[31] In essence, if the ESA Council were the Board of Directors, the Director-General would be the CEO of ESA.

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[28] "Convention for the Establishment," 58-59.

[29] Ibid., 60.

[30] W. Black and D. Andrews, *ESOC Services Catalog 2000/2001* (Darmstadt, Germany: ESOC External Customer Services Unit, 2000), 4.

[31] Margaret Ann Gibbons, *The European Space Agency: Cooperation and Competition in Space* (Geneva: Graduate Institute of International Studies, 1986), 21.

The majority of ESA projects remain in near-earth orbit. Many of the early projects studied the earth and its surroundings. For instance, four ESRO spacecraft measured radiation between May 1968 and April 1974. Two GEOS satellites studied the earth's magnetosphere between April 1977 and 1982. ESA's most prolific earth observation program, Meteosat, began on 23 November 1977. Since then, two generations of satellites have provided Europe with up-to-date and highly accurate meteorological information. ESA plans to upgrade Meteosat with a third generation in the next five years. Other earth observation satellites have included the European Remote Sensing satellites, which measured ocean surface temperatures and sea winds for twenty years, beginning in 1991. One of ESOC's most famous projects, Cluster, has maintained four satellites in formation to study the effect of solar winds on the earth's magnetosphere since July 2000. The Environmental Satellite (Envisat) has flown in polar orbit since 1 March 2002 in order to examine the atmosphere, ocean, land, and ice. The Gravity Field and steady-state Ocean Circulation Explorer (GOCE) has measured the earth's gravity field since 17 March 2009. Finally, Cryosat, launched on 8 April 2010, studies the earth's ice. Many of these earth observations satellites have transitioned to ESA's ESRIN center.

The Cos-B satellite, operational between 9 August 1975 and 25 April 1982, served as ESA's first telescope observatory by studying gamma-ray sources. ESOC has since orbited a number of observatory telescopes. The European X-ray Observatory Satellite (Exosat) from May 1983 to May 1986 detected high-energy X-ray sources. Hipparcos (High precision parallax collecting satellite), August 1989 to March 1993, mapped star locations. The mid-1990s Infrared Space Observatory (ISO) used infrared technology to study interstellar dust. XMM-Newton (X-ray Multi Mirror), which has been in orbit since 10 December 1999, continues Exosat's work. Perhaps the most impressive telescope, INTEGRAL (International Gamma-Ray Astrophysics Laboratory), has observed objects in the gamma ray, X-ray, and visible spectrum since 17 October 2002. Most recently, the satellites Herschel and Planck, launched on 14 May 2009, study the origins of stars and galaxies in infrared and the cosmic microwave background radiation from the Big Bang, respectively. These telescopes have ensured ESA's reputation as a leader in astronomical observation.

In the 1980s ESOC began to reach beyond near-earth with Giotto. Launched on 2 July 1985, Giotto encountered Halley's Comet the following March. After placing the spacecraft in hibernation, ESA reawakened Giotto to observe Comet Grigg-Skjellerup in July 1992. ESA first reached out to another planet with *Mars Express* in June 2002. An orbiter continues to map the Martian surface, but a lander, named *Beagle 2*, failed to land successfully on the planet. *Venus Express* followed three years later and continues to study Venus's atmosphere. SMART-1 (Small Missions for Advanced Research in Technology) investigated the chemical makeup of the moon's surface for nearly three years beginning in September 2003. Finally, ESA returned to comet encounters with *Rosetta*. Launched 2 March 2004, Rosetta should reach Comet 67P/Churyumov-Gerasimenko in 2014 at which time it will orbit the comet while a lander, Philae, reaches the surface.

Compared to JPL, ESOC's efforts seem modest. Yet ESA has worked within its smaller budget to generate an astounding amount of scientific output. The European center has produced spacecraft in each of the three major areas of robotic spaceflight:

earth observations, astronomical telescopes, and deep space encounters. ESOC and all of ESA has firmly established itself as one of the world's space leaders.

Historiography/Methodology

No single study has focused on any of the mission control centers. In fact, because the majority of secondary sources concentrate on specific spaceflight programs, even those relating to mission control are scant, to say the least. Nevertheless, some previous studies have provided inspiration, if not information, for this work.

Spaceflight histories including Walter McDougall's seminal work *…the Heavens and the Earth* (1985) and William Burrows's *This New Ocean* (1998) provide necessary background information and context for any spaceflight history. Both focus heavily on NASA, especially human spaceflight. McDougall's work suffers due to its publication during the Cold War, which skews its perspective. Some of the analysis regarding the Soviet space program, in particular, has been proven incorrect since Soviet archives have been opened in recent decades. Burrows utilizes some of the new research to create a more complete and balanced account, though the emphasis still lies on NASA.

Works on the European Space Agency include John Krige and Arturo Russo's *A History of the European Space Agency, Volumes I and II* (2000), Roger Bonnet and Vittorio Manno's *International Cooperation in Space* (1994), Brian Harvey's *Europe's Space Programme* (2003), and Beatrice Lacoste's *Europe: Stepping Stones to Space* (1990). Like most other general histories, they focus on other aspects of spaceflight, especially the missions themselves and the men and women who traveled to space, with scant mention of the control center, although they do provide basic contextual information.

Helmuth Trischler's *The "Triple Helix" of Space* (2002) discusses the relationship of Germany and activities in space from the interwar period to Spacelab, focusing on the "triple helix" of academic research, industry, and the state. He argues that the state in Germany has always had the most influence. He further contends that the historical burden of the Third Reich and its relationship with rocketry forced Germany to emphasize international cooperation with any space-related programs following World War II. Trischler provides insight into how at least one European nation has handled spaceflight, which helps to illuminate aspects of a greater European space culture.

This dissertation does not examine the science behind spaceflight but rather how scientists and engineers use science in their work and how they create a working culture. Thus, other sources deserve attention more for their influence on the process and methodology of this dissertation than for any content they might provide. The original inspiration for this topic came from the works of sociologist Bruno Latour and historian of science Robert Kohler's *Lords of the Fly: Drosophila Genetics and the Experimental Life* (1994). Latour and Kohler focus on the social aspects of laboratories in order to investigate their scientific production. They emphasize that the room or the building is itself an important influence, an idea which will receive attention in this study.

Similarly, Lillian Hoddeson, Adrienne Kolb, and Catherine Westfall's *Fermilab: Physics, The Frontier, and Megascience* (2008) also treats the history of a scientific laboratory. They investigate the placement of the lab, its physical makeup, individual influences on the characteristics of the lab, how it is used and by whom, and changes over time. Because this study examines the physical as well as the social construction of control centers, a number of essays from Peter Galison and Emily Thompson's *The Architecture of Science* (1999) provide insight.[32] This work illuminates the relationship among scientists and architects, the users and constructors of space.

In *Epistemic Cultures: How the Sciences Make Knowledge* (1999) Karin Knorr Cetina's contention that Western societies are based on the consumption of "expert" knowledge coincides with the discussion of how data are created and shared within mission control. One part of her argument states that technical vocabularies help to define aspects of the sciences, an assertion that can be applied easily to the highly technical jargon of NASA and mission control.[33] Knorr Cetina argues that laboratories have a dual nature, that each scientist has his or her own project while working within the group dynamic of the laboratory.[34] In mission control, each person has his or her own expertise in relation to the mission but works within the concept of a unified whole. She also states that scientists go through career stages, from the student level to a full-fledged scientist.[35] Most flight controllers similarly work their way up the hierarchy in their respective fields. Finally, she discusses the importance of the laboratory leader, who must build and maintain relationships with the various members of the laboratory. The laboratory leader must also relay information from the laboratory to the outside world

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[32] In particular, consult Robert Venturi's chapter, "Thoughts on the Architecture of the Scientific Workplace: Community, Change, and Continuity," James Collins Jr.'s "The Design Process for the Human Workplace," and Thomas Gieryn's "Two Faces on Science: Building Identities for Molecular Biology and Biotechnology."

[33] Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge, MA: Harvard University Press, 1999), 117.

[34] Ibid., 216-7.

[35] Ibid., 221.

and is generally the face of the laboratory.[36] This description can apply to the flight director as well, who is the undisputed leader of mission control. The dual nature of mission control centers is another area further examined in this work.

Hugh Gusterson's *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (1996), an ethnographic examination of the Lawrence Livermore National Laboratory, is perhaps most useful since it studies a nuclear weapons research facility with parallels to mission control centers. First, Gusterson argues that understanding science, scientists, and scientific institutions is critical to any analysis of politics and power, two major components of spaceflight history.[37] He further states that analyzing nuclear institutions is critical to understanding the nuclear arms race.[38] That argument can be modified to contend that studying spaceflight institutions is necessary to understand the so-called space race more fully. In either case, they furnish a window to the greater cultural landscape of the Cold War.

A final secondary source pertains to both spaceflight history and the analysis of laboratories. Diane Vaughan's *The Challenger Launch Decision* (1996) investigates the corporate culture of NASA behind the fateful decision to launch *Challenger* on 28 January 1986. While not strictly a history, the book nevertheless provides useful historical insight. She argues that one should blame the loss more on a gradual descent into poor judgment and the triviality of organizational life than on any one person or group of people. The more that work becomes a routine, especially in high-technology

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[36] Ibid., 222-3.

[37] Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996), 5.

[38] Ibid., 5-6.

fields, the greater the chance that people will overlook the warning signs that lead to disastrous mistakes. Regarding mission control, the flight controllers, especially with long-duration missions like those beginning with Skylab, have to fight tedium and the habituation that can arise when their jobs become ordinary.

Summary

This work provides not only a historical perspective on the mission control centers at JSC, JPL, and ESOC, but also a comparative analysis of their makeup and functions. In many ways, context is key to understanding the different control centers. The first chapter, therefore, examines three space centers. JPL began as a laboratory for the United States military as well as the California Institute of Technology. NASA built JSC in the 1960s specifically as a human spaceflight center, but the organization had its origins in the NASA's earlier Space Task Group, which created Project Mercury. The European nations constructed ESOC originally as a data acquisition center before ESA added mission control to its responsibilities. Each center's history provides integral information for understanding the control centers' development.

If the first chapter provides a broader context, the second chapter narrows the focus to the structure and the space issues of the buildings that host the control rooms. Each main control room relies upon a series of support rooms and equipment. The control rooms are the central output facility for a much larger technological system. Simply put, they could not accomplish their work on their own.

The third chapter focuses on the control rooms themselves. Each has its own historical development. Each has adjusted to its ever-changing mission. This chapter will begin to examine the similarities between the control centers of JPL and ESOC while highlighting significant differences of those centers with JSC.

Chapter 4 discusses the elements of work in the control centers. Simulations train flight controllers and prepare them for the next mission. A few missions have experienced potentially dangerous problems, and the flight controllers in each instance have had to rely upon their training and knowledge to fix the situation. Another aspect is the exchange of information both within the control centers and to outsiders. Finally, although the space agencies are civilian enterprises, they all have some experience operating with the military for various reasons.

Control rooms do not communicate with spacecraft and astronauts directly. Rather, they must communicate through separate networks of antennae and other infrastructure. Chapter 5, therefore, examines the three major communications networks used by the control centers. The communication networks have also served as aspects of international relations not only with other space agencies but also with various countries around the world.

With these points in mind, my dissertation moves to Chapter 6, which investigates various aspects of international politics through the control rooms. Different sections will examine relations between the United States and Europe, Europe and Russia, and the United States and Russia. The chapter concludes with a detailed analysis of how control rooms collaborate together with the most famous example of international space relations: the International Space Station.

Other industries outside of spaceflight make use of control rooms. One of the most important is air traffic control. This work, therefore, ends with a chapter detailing the air traffic control system as an example of how another government agency has managed similar issues of control.

This dissertation concludes with a brief overview of its major arguments. Te reader will understand that there is not one way to invent mission control but many. Each center grew individually and with different styles of operations for different missions but nevertheless created important similarities. While the overall mission of the centers remains the same, particulars have changed over time due to scientific, technological, and budgetary means. The control centers have made the necessary adaptations to survive. Finally, the reader will recognize the significance of both domestic and international politics in the history of mission control. In essence, science can be thought of as politics by other means. In the end, the history of spaceflight cannot be understood fully without a greater understanding of the work completed by the ground systems in general, and mission control in particular.

CHAPTER 1

THE CENTERS

When President Dwight D. Eisenhower signed the National Aeronautics and Space Act of 1958, he created the United States's space agency as a full-fledged government entity. NASA eventually grew into one of the largest government enterprises in the country. It has both received and generated massive amounts of money. Many aspects of the nation's economy could benefit potentially from such expenditures, thus virtually every corner of the nation would vie for some piece of the proverbial pie. NASA, therefore, has become an important bargaining tool in domestic politics since its inception.

Domestically, as a rule, politicians bargain for a larger presence of government entities in their jurisdiction realizing that agencies bring jobs and money. Of course, this is the case with any large endeavor. Military contracts, for example, spur similar interest. Ideally, nations attempt to spread the wealth around so that various areas can profit from multi-billion dollar ventures. For instance, a 2003 budget analysis demonstrates how each of the fifty states and the District of Columbia received between $1.3 million and $3.79 billion for work relating to the space program. Realistically, the distribution remains uneven. States that have NASA centers naturally accrue the most money in this assessment, with the largest allotments going to Texas, California, Maryland, Florida, Virginia, and Alabama. Employees in those states perform the most work for NASA, and the money follows as a consequence.[1] But why were certain areas chosen for NASA centers? What was the role of politics in these decisions? This chapter will provide insight into the answers for these questions. Due to the extensive scope of these inquiries, these issues deserve more detailed research.

While NASA absorbed some centers from previous aerospace ventures, they built others specifically for their space activities. Their history plays a prodigious role and begins to explain how they have managed their work. Thus, their backgrounds provide an important context for understanding the physical and social construction of each space flight center.

Mission control serves as the most immediate link between spacecraft and humans on earth. To date, no spacecraft has had the capability to operate on its own without this vital connection. Since they provide a necessary service for spaceflight, these centers command interest as a potentially stable employment provider and source of funding. Politicians would naturally want such an employer in their district. Domestic politics, therefore, played a crucial role in determining the locations of each mission control.

Many of these statements ring true for ESA as well. It is a government agency, though one subservient to many national governments rather than just one. When determining the locations of spaceflight centers, ESA must consider international as well as domestic consequences. Any discussion of these factors will display more similarities with the NASA situation than differences.

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[1] NASA Acquisition Internet Service, "NASA Dollars Boost the Economies of Every State in the U.S.," NASA, http://prod.nais.nasa.gov/cgi-bin/npms.map.cgi (accessed 17 January 2012).

A major misconception about NASA is that the president plays a major role in the agency's policies and direction. As the authors of *Spaceflight and the Myth of Presidential Leadership* (1997) have demonstrated, the president actually has little to no sway in decisions made about the space agency, outside of initial requests for policies. The misconception arises from President John F. Kennedy's call to reach the moon by the end of the 1960s. People often credit Kennedy for the origins and early support of the Apollo Program, but in reality even he realized that the program was dependent upon Congressional approval.[2] The president can make suggestions, ask for a certain policy, or sign an act, but ultimately Congress has framed the majority of the spaceflight decisions and funding. More recently, John Logsdon argued in *John F. Kennedy and the Race to the Moon* (2010) that once space became a vital aspect of politics, Kennedy played a large role in deciding the course of space policy. While his interest provided support for an unprecedented budget for NASA in the early 1960s, even the president could not overcome budgetary realities beginning in 1963. This dissertation's analysis of domestic politics, therefore, need not overly concern itself with the space policy of the presidents.

This chapter analyzes the history of each of the three main spaceflight centers. It will especially highlight the role of politics in each narrative. Each center developed within a different geographical, social, and cultural context, so understanding the historical unfolding in connection to this framework will strongly inform the rest of the study. With two major descriptors, each center is either American or European, and control over either human or robotic spaceflight. This chapter will include a separate section for each of the centers arranged in a natural transition from American human to

[2] Roger D. Launius and Howard E. McCurdy, introduction to *Spaceflight and the Myth of Presidential Leadership* (Urbana, IL: University of Illinois Press, 1997), 2-4.

European robotic. Thus, it will first consider the Manned Spacecraft Center (MSC) in Houston, Texas, followed by the Jet Propulsion Laboratory (JPL), in Pasadena, California, and finally the European Space Operations Centre (ESOC) in Darmstadt, Germany.

Manned Spacecraft Center/Johnson Space Center

The roots of the mission control operations group reach back to Tidewater Virginia and the oldest of all the NASA facilities, Langley Research Center. NASA established the original Space Task Group (STG) at Langley shortly after the agency's creation on 1 October 1958. The National Advisory Committee for Aeronautics (NACA), NASA's predecessor (dating back to 1915), put one of its veteran aeronautical engineers and flight test experts, Robert Gilruth, in charge of the new STG. His mission was to develop a human spaceflight program for the United States. When the STG began work on 5 November 1958, it consisted of only fifty people: thirty-five from the Hampton, Virginia, facility, and fifteen from the Lewis Laboratory in Cleveland, Ohio.[3]

Although based in Virginia, much of STG's work occurred at the Mercury Control Center in Cape Canaveral, Florida. It was in Florida that a few members of the STG, most notably Christopher C. Kraft, the first Flight Director; Tecwyn Roberts from Wales; and John Hodge from England, were mainly responsible for designing the original Mercury Control.[4] Much of the concept came directly from Kraft, Gilruth's protégé in high-speed flight testing, who visualized the control room manned by experts in various

[3] Chris Kraft, *Flight: My Life in Mission Control* (New York: Dutton, 2001), 66.

[4] Ibid., 87.

aspects of the mission and the spacecraft. This idea arose out of Kraft's experience with test flights when a flight test engineer on the ground would monitor the flight and provide suggestions to the pilot. Before building the room, he sought the advice of various other experts, including test pilots and the new Mercury astronauts, especially Donald K. "Deke" Slayton.[5] The idea of a control room came about largely due to the need to protect the astronauts. In the case of an emergency abort, for example, controllers on the ground would need to monitor various procedures quickly and relay them to the astronauts.[6]

The practicalities of crisis response also dictated the location of the original mission control. NASA chose Cape Canaveral as the site of its first mission control largely so that a controller on site could monitor the rocket as it stood on the launch pad and during the critical first few moments of the launch. Because they could not always rely upon the early radar and telemetry systems to provide accurate information, a controller would watch the rocket in case of an emergency and the need for abort arose.

While much of the actual control work occurred at various sites around the world, where technicians and STG controllers manned remote stations with equipment to communicate with the astronauts in space, certain kinds of decisions had to be made by a central group of experts. Due to the technology of the time, the remote sites could not send information and have it expeditiously processed at Mercury Control. Thus, Mercury Control was more of a hub where controllers, experts in their fields, made crucial decisions.

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[5] Ibid., 92-93.

[6] Charles Murray and Catherine Bly Cox, *Apollo: The Race to the Moon* (New York: Simon and Schuster, 1989), 245-247.

For instance, during John Glenn's *Friendship 7* Mercury flight, a signal reported that the spacecraft's landing bag had deployed in orbit, which meant the heat shield was loose. The collective minds at Mercury Control could not authenticate the telemetry, and decided the best course was not to jettison the retrorocket pack and instead use it to hold the heat shield in place. After the flight, engineers discovered the signal had been faulty, but this instance proved the need for a central control facility where experts could work together to find the best solution for possible anomalies. Without a central control center the remote sites would make decisions on only pieces of information, and there would be no way for the various experts in the systems to meet and discuss possible courses of action.

As this example shows, if nothing else, Mercury Control served as an important training ground, a classroom of sorts, for many of the controllers who went on to work in mission control for future programs such as Apollo. Aside from Kraft, future Flight Directors like Gene Kranz, John Hodge, and Glynn Lunney, among many others, first worked in Mercury Control.[7]

The first mission controlled from Cape Canaveral was Mercury-Redstone 2, which included the first living being sent into space by NASA: Ham, a chimpanzee.[8] While some controllers had prior experience with test flights and rocketry, the space program was so new and different that it required a new set of procedures and expertise. Mercury Control essentially started from scratch, and the controllers developed their jobs

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[7] Gene Kranz, *Failure Is Not An Option: Mission Control from Mercury to Apollo 13 and Beyond* (New York: Simon and Schuster, 2000), 12.

[8] Kraft, *Flight*, 2.

along the way.[9] The technology available to them was relatively crude, including a mechanical plotting board based on estimations of the spacecraft's location. Regardless, it proved adequate for the six Mercury manned missions.

The move to Houston occurred for a number of reasons. The constant shuttling of personnel between Langley and Cape Canaveral had begun to wear on the members of the STG. Also, the facilities in Langley and the Cape were increasingly unable to cope with the needs of NASA's human spaceflight program. As it moved on from Mercury, it would confront increasingly difficult procedures in space like rendezvous and extra-vehicular activities. Mercury Control was not equipped with the technology to carry out such maneuvers. The human spaceflight program continued to grow as well, and neither the facilities at Langley nor Cape Canaveral could manage the number of employees. NASA decided that the human spaceflight program required its own administrative center, as well as a new control center.

In late 1960, NASA began to search for a location for a new human spaceflight facility. They had a series of parameters for their search. For instance, the site needed access to water transportation for large barges carrying rockets and rocket components, a moderate climate to avoid lengthy cessations of work, a nearby airport, an infrastructure of technical facilities and potential employees within a reasonable distance, an established infrastructure of higher education in close proximity, abundant electrical and water supplies, and at least 1,000 acres of land at a reasonable price.[10] Even with such specific criteria, the site selection committee received dozens of applications. They soon

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[9] Kranz, *Failure Is Not An Option*, 17.

[10] Henry C. Dethloff, *…Suddenly, Tomorrow Came: A History of the Johnson Space Center* (Houston: NASA Johnson Space Center, 1993), 38.

narrowed the search to twenty-three sites, including Jacksonville and Tampa, Florida; Baton Rouge, Shreveport, and Bogalusa, Louisiana; San Diego, San Francisco, Berkeley, Richmond, Palo Alto, and Moffett Field, California; four sites near St. Louis, Missouri; and Victoria, Corpus Christi, Liberty, Beaumont, Harlingen, and three separate sites in Houston, Texas. The selection quickly escalated into a political endeavor, with each site's congressmen and women campaigning for their district. While the committee originally favored the site in Tampa, the decision by the Air Force not to close down the Strategic Air Command operations at MacDill Air Force Base for NASA's use quickly catapulted one of the Houston sites to the forefront as the new primary choice.[11]

After an extensive search process, on 19 September 1961, NASA announced the human spaceflight program would build a new Manned Spacecraft Center (MSC) for $60 million in Houston, Texas. The land, bought from Rice University, included 1,000 acres near Clear Lake, which feeds into Galveston Bay and the Gulf of Mexico.[12] Thus, large barges could easily navigate to and from the location. NASA also obtained the rights to work out of Ellington Field, an old air base from the world wars, only seven miles northwest of the Manned Spacecraft Center location. Technical universities nearby included Louisiana State University, the University of Texas, and Texas A&M University, among many others. Finally, winter weather would not hinder operations. In short, the location met each of the site parameters.

Rice University officials were somewhat skeptical about the prospects of human spaceflight. They included a clause in the purchase negotiations stating that if the human

[11] Ibid., 39.

[12] Ibid., 33, 40.

space program failed, the land and the infrastructure would revert to the university. Hence, most of the early buildings look plain and are centered on a series of duck ponds, giving the inner area a campus-like feeling.[13]

There is some debate as to the extent of political influence on the decision to choose Houston. According to James Webb, at the time the NASA director, Lyndon B. Johnson, the Senate majority leader from 1955 to 1961 and then vice president, had little to do with Houston winning the bid. He vehemently argues that NASA based the decision solely on the merits of the location. Individuals counter-factually reading into events had overblown the political angle.[14]

Chris Kraft, among many others, disagrees. He argues that political considerations played as much a role as any other factor. The chairman of the House Appropriations Committee, Albert Thomas, was a congressman from Texas's 8th district, which includes Houston. Vice President Johnson also hailed from Texas. According to Kraft when Robert Gilruth met Webb he argued that they should keep the STG in Virginia, Webb, not so subtly, asked how Harry Byrd, a thirty-year veteran senator from Virginia, had helped the space program.[15] Political decision or no, human spaceflight operations would be moving to Houston.

Many personnel in STG did not receive the announcement to move to Houston enthusiastically. For one thing, a large number had worked at Langley before the creation of NASA, so Virginia had been their home for years. With average temperatures

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[13] Murray and Cox, *Apollo*, 245.

[14] James Webb, interview, 15 March 1985, transcript, Glennan-Webb-Seamans Project Interviews, National Air and Space Museum Archives, Suitland, MD, 109-10.

[15] Kraft, *Flight*, 149-50.

in the nineties for three months of the year, excessive humidity making the perceived temperatures even worse, and the penchant for hurricanes given its location on the Gulf of Mexico, Houston had what few would call a "moderate climate." Certainly it could be considered more extreme than Tidewater Virginia, which itself was hardly moderate in the summer. Complaining would change neither the move, nor the over-enthusiastic welcome from the native Texans. Relatively inexpensive housing (fifteen dollars per square foot of building), as well as free or deeply-discounted merchandise from some local vendors, offset at least some of the criticism.[16]

As part of their transition, the STG sent an advance team to Houston to set up temporary offices in the Gulfgate Shopping Center near downtown Houston at the intersection of Interstates 45 (the Gulf Freeway) and 610. This team reported back to Langley on the progress at the new location, sought out homes for the members, and generally prepared the STG members for their move to Houston. As the transition continued, NASA leased a series of buildings in Houston for temporary work spaces.[17] Thus human spaceflight operations work transitioned to their new home in Houston.

The question remained about if NASA also would permanently locate the mission control center there. When deciding the location of the MCC, NASA considered a number of factors. These included the site of the Gemini and Apollo project offices, the location of the Flight Operations Division, the residences of the astronauts, the location of computer facilities, the availability of communications, and the knowledge of

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[16] Dethloff, *Suddenly Tomorrow Came,* 41-42; Kraft, *Flight*, 172**.**

[17] Dethloff, *Suddenly Tomorrow Came,* 42-43, 45-46. Dethloff also provides great detail about Grace Winn, who managed much of the welcome for STG members moving to Houston.

operation preparation. NASA soon narrowed possible locations to Houston and Cape Canaveral. After deliberation, having the project offices and the astronauts next door made Houston the most obvious choice.[18] Thus, on 20 July 1962, Webb officially announced the Manned Spacecraft Center would house the Mission Control Center (MCC) for future flights, beginning with Gemini.[19] Following the flight of Gemini 3 in March 1965, mission control permanently moved to its new location in Houston.[20]

In its first three years, NASA spent about $240 million to construct the MSC. Almost half of that cost went to the construction of the Mission Control Center, the highlight of the new space center.[21] With the Mission Control Center came new communication technologies, which allowed the MCC to obtain all the spacecraft data from the network remote sites, rather than information remaining at those sites. The remote sites, therefore, quickly became obsolete, and MCC emerged as the centralized control area for human spaceflight.[22]

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[18] Robert C. Seamens, Jr., "Location of Mission Control Center," Memorandum for Administrator, 10 July 1962, MSC-Mission Control Center 4526, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[19] "NASA Mission Control Center at Houston," NASA News Release, No. 62-172, 20 July 1962, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C..

[20] Kraft, *Flight*, 214-15.

[21] Evert Clark, "New NASA Center Making Its Debut," *New York Times*, 3 June 1965, 21.

[22] Glynn S. Lunney, interview by Carol Butler, 28 January 1999, transcript, JSC Oral History Collection, 18-19.

[Image 1-1: "Aerial View of the Johnson Space Center" (10 August 1989), NASA,

http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001112.html]

Shortly after former president and space advocate Lyndon B. Johnson died in 1973, Texas Senator Lloyd Bentsen sponsored a bill to rename the MSC after Johnson. On 17 February 1973, it officially became the Lyndon Baines Johnson Space Center, or JSC. A formal dedication took place on 27 August 1973.[23] The remainder of this

[23] Dethloff, *Suddenly Tomorrow Came*, 214.

dissertation will refer to the space center in Houston as JSC regardless of date, for sake of unity and clarification.

Even after each of the spaceflight centers had been established in the locations for some time, domestic politics continued to play an important role in the centers' histories. For instance, in one of the great moments of political wrangling in spaceflight history, each of the major human spaceflight program centers in the United States fought over the right to be called the lead center for the Space Shuttle program during the late 1970s. Each had a compelling case. The Marshall Space Flight Center in Huntsville, Alabama, built and tested much of the hardware. The Kennedy Space Center had the primary launch and landing facilities as well as some astronaut training. The Johnson Space Center included primary astronaut training and mission control. After much debate, JSC was named the lead center for the shuttle, thus ensuring its primary role in NASA for the near future.

The NASA administration made this decision despite strong suggestions that with the advent of the shuttle MCC was no longer needed. The new spacecraft could fly on its own without the guidance of those on the ground. The flight controllers and operations personnel argued vehemently against this notion, asserting that mission control remained a vital ingredient for the success of all spaceflights. At the very least, they contended, it should remain in place for at least the first few flights as backup. The flight controllers won the argument, nevertheless the nature of the work carried out at JSC changed as it redefined its role for the shuttle program.[24]

[24] M.P. "Pete" Frank III, interview by Doyle McDonald, 19 August 1997, transcript, JSC Oral History Collection, 23-24.

One major change at JSC came with the creation of the Weightless Environment Training Facility (WETF). During the Apollo missions, the Saturn V had launched with such force that it created accelerations up to fifteen Gs on the human body, an acceleration up to fifteen times that of gravity. In order to prepare for the launch, NASA had had to build a centrifuge in Houston to subject the astronauts to such extreme forces. The shuttle, however, created only about three Gs of force, or about that of a roller coaster. Consequently, NASA no longer needed the centrifuge. In its place, JSC created the WETF, essentially a large pool used to simulate the near-zero gravity of space. Engineers placed mockups of space hardware in the WETF so the astronauts could practice EVAs, or spacewalks.[25] Adaptation was the key to the viability of JSC.

By the mid-1990s, as the reality of a space station became more apparent, JSC realized the WETF was too small for future operations. In response, they built the Neutral Buoyancy Laboratory (NBL), later named the Sonny Carter Training Facility, off site at the nearby Ellington Air Force Base. The tank is 202 feet (62 meters) long, 102 feet (31 meters) wide, 40 feet (12.34 meters) deep, and holds 6.2 million gallons (23.5 million liters) of water. When it was completed in 1997, it was large enough for two simultaneous simulation activities, though the space station has grown enough to outsize the tank.[26]

As it adapted to new challenges, JSC incorporated a range of activities and duties in its many support facilities. Building 1 on the campus was the Administration Building, including offices for the JSC Director and many of the other branch directors and

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[25] Dethloff, *Suddenly Tomorrow Came,* 249.

[26] "Neutral Buoyancy Laboratory," National Aeronautics and Space Administration, http://dx12.jsc.nasa.gov/site/index.shtml (accessed 17 January 2012).

managers. Building 2 consisted of an auditorium, the public affairs office, and the original visitor's center. Building 4 housed the astronaut offices. Building 5, the Jake Garn Mission Simulator and Training Facility, included dynamic shuttle simulators that can move to simulate launch and landing. Building 9, the Space Environment Simulation Laboratory, held mockups of the International Space Station, a full scale mockup of the shuttle, crew compartment mockups of the shuttle, and a training area for the robotic arms. Building 14 housed the anechoic chamber, which simulated the quiet of space. Building 17 accommodated the kitchen where specialists prepared food for spaceflight. Building 29 housed the centrifuge before NASA re-purposed it to create the WETF. Building 30 was Mission Control Center. NASA stored many of the moon rocks in laboratories in Building 31. Building 32 housed one of the largest vacuum chambers in the world. Spacecraft and components visited Building 49, the Vibration and Acoustic Test Facility, to test their ability to withstand the vibrations and sounds of launch. All of these buildings played a vital role in flight control or astronaut training, the two main elements of one of NASA's leading centers.

Following the final shuttle launch in 2011, the human spaceflight program consisted of the International Space Station and vague promises of future flights from a proposed new rocket. Despite being the home of Mission Control and astronaut training, JSC employees, not surprisingly, worry about their future. If the United States commits to the proposed human spaceflight program, JSC is poised to remain at the heart of those efforts for decades to come.

Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) in Pasadena, California, began as an interest of a few scientists and engineers at the California Institute of Technology (Caltech) and blossomed, over some decades, into one of the premier spaceflight control centers in the world.[27] The Guggenheim Aeronautical Laboratory at Caltech (GALCIT) focused on aerodynamic research. Until the mid-1930s, it dismissed rocketry as non academic. Theodore von Kármán, director of GALCIT, began to comprehend the relevance of rocketry research thanks to a series of graduate students. One of them, Frank J. Malina, led a small group of experimenters, including John W. Parsons and Edward S. Forman, to the first rocket motor tests at GALCIT in 1936 and 1937.[28]

After a few years of testing, the Army Air Corps encouraged the National Academy of Sciences to present GALCIT with a grant to research military applications for rockets, or jet propulsion, as they preferred to call it, in 1939.[29] Thus began a long relationship between the rocket scientists of Caltech and the military. With this funding, GALCIT completed the first successful jet-fuel assisted takeoff (JATO) of an airplane in

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[27] The history of the Jet Propulsion Laboratory has been extensively discussed by the two center histories, Clayton R. Koppes's *JPL and the American Space Program* (1982) and Peter J. Westwick's *Into the Black* (2007). The first two sections of this chapter, therefore, will strive to present a brief overview of the history of the center before delving into mission control itself. As a result, much of the information in these two sections comes from those sources.

[28] Theodore von Kármán with Lee Edson, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston: Little, Brown and Company, 1967), 234-48; and Frank J. Malina, "On The GALCIT Rocket Research Project, 1936-38," in Frederick C. Durant III and George S. James, eds., *First Steps Towards Space: Proceedings of the First and Second History Symposia of the International Academy of Astronautics at Belgrade, Yugoslavia, 26 September 1967, and New York, U.S.A., 16 October 1968* (Washington, D.C.: Smithsonian University Press, 1974), 113-14.

[29] Frank J. Malina, "The U.S. Army Air Corps Jet Propulsion Research Project, GALCIT Project No. 1, 1939-1946: A Memoir," in R. Cargill Hall, ed., *Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth History Symposia of the International Academy of Astronautics, Vol. II* (Washington, D.C.: National Aeronautics and Space Administration, Scientific and Technical Information Office, 1977), 154-58.

the United States on 12 August 1941 at March Field, Riverside, California.[30] Just eight months later, they accomplished another major feat. At Muroc Army Air Field, later known as Edwards Air Force Base, a successful takeoff of a Douglas A-20A marked the first American plane with permanent rocket power.[31] GALCIT made great strides with both solid and liquid propellants. Some scientists and engineers also worked on guidance and control of the missiles for more accurate deployment. Some aspects of the control included radar tracking and radio signals from the ground for any corrections to the flight path.[32] Obviously one can see already budding aspects of a primitive ground control system.

As GALCIT continued to grow and its connection with the Army Air Corps (later Army Air Forces) strengthened, its officials investigated the possibility of expanding into a larger operation within Caltech. Many of the academics at Caltech wanted to avoid connections with the military. After some contentious negotiations, the Jet Propulsion Laboratory, still considered an aspect of GALCIT, began work on guided missiles on 1 July 1944. Although the initial site remained Army Air Forces property, the close connection with Caltech continued because a large portion of its staff came from that highly acclaimed university.[33] Experiments continued in both jet engines and rockets.

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[30] Von Kármán, *The Wind and* Beyond, 250.

[31] Ibid., 254

[32] Koppes, *JPL and the American Space Program*, 44-45.

[33] Ibid., 20-21.

GALCIT made history on 11 October 1945 when a WAC Corporal rocket reached forty miles in altitude, the first rocket to escape the earth's atmosphere.[34]

Following World War II, the Army and Caltech debated their interest in continuing support of JPL. The Army viewed rocket and missile research as a top priority for future technologies. Many at Caltech had reservations about the relationship with the military, while some argued that a laboratory with government funding could be extremely beneficial for the university. On 1 April 1946, the Caltech board of trustees officially approved their continued relationship with JPL.[35] Thus, the Jet Propulsion Laboratory serves as a significant example of the growing military-industrial-university complex in the United States during the Cold War.

The connection to the military, especially during the Cold War, brought unforeseen problems for the Caltech staff. Mandatory regulations forced all scientists and engineers to undergo security screenings. The system scrutinized foreign nationals, especially the Chinese. The government classified Dr. H.S. Tsien, for instance, both as a security risk and as an undesirable alien. This occurred despite his prominent role in the creation of JPL and its subsequent success. His security risk status outweighed his alien classification, which forced him to stay at Caltech but did not allow him to work on classified materials. He did so until 1955, when the Immigration and Naturalization Service deported him to China, where he led the Chinese missile programs. Nonetheless, the connection between JPL and Caltech became an important recruiting tool for the

[34] Louis Dunn, W.B. Powell, and Howard Seifert, "Heat Transfer Studies Relating to Rocket Power Plant Development," Proceedings of Third Anglo-American Conference, 1951, 271-328; and Koppes, *JPL and the American Space Program,* 23-24.

[35] Koppes, *JPL and the American Space Program,* 25-29.

nascent laboratory. Some staff had opportunities to teach at the university, adding to the attraction of the lab.[36]

Throughout the latter half of the 1940s and the 1950s, JPL continued to make strides in both solid- and liquid-fueled rockets for the Army. These include the Corporal and Sergeant series of missiles. As Cold War tensions grew and the military-industrial complex became more entrenched, the laboratory transitioned from almost pure research and development to a more large-scale assembly of missiles. Indeed, the military applications became so intertwined that in 1953, the Army attempted to appoint an officer to command JPL. Caltech, not surprisingly, balked, and the Army rescinded the request, but the laboratory could no longer downplay its military connection.[37]

As the country transitioned into a postwar mentality, some of JPL's neighbors began to complain about the presence of what was supposed to be a temporary installation used only for the duration of the war. The lack of permanent buildings, along with the drab paint and lack of landscaping, became an eyesore for many of the local residents. Many also complained about the noise from the rocket motor testing and flashing lights at odd hours. Some officials, including Caltech president Dr. Lee DuBridge, tried to shift the focus from seemingly minor annoyances to the real problem: the Soviet Union. In doing so DuBridge caused a greater rift to grow between the laboratory and the university, especially over the military applications of its work. Meanwhile, the two sides strove to find a more permanent solution.[38]

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[36] Koppes, *JPL and the American Space Program,* 30-32; von Kármán, *The Wind and Beyond,* 308-15; and Milton Viorst, "The Bitter Tea of Dr. Tsien," *Esquire* 68 (September 1967): 125-29, 168.

[37] See Chapters 3 and 4 of Koppes, *JPL and the American Space Program*.

[38] Ibid., 48-50.

Tensions continued to mount as JPL's budget grew to more than twice that of Caltech in 1957, leading many at both sites to question the nature of their relationship. Some Caltech trustees viewed JPL as a possible hindrance to their educational mission, but they could not overlook the vast amounts of money the university received from the government via the laboratory. Instead of fully discussing their grievances, both sides eventually agreed to continue as they were in order to complete their projects in a timely manner.[39] The JPL-Caltech relationship remained contentious but not fully addressed for a few more years.

Shortly after the Soviet Union launched *Sputnik* in 1957, the United States began to work toward its own satellite launch. After some setbacks, the focus turned to Juno I, a rocket built by Wernher von Braun and the Redstone Arsenal in Huntsville, Alabama. While the rocket was ready, it still lacked a proper satellite. JPL had already worked with the Redstone Arsenal on other projects, so it naturally expressed interest in this venture. After much deliberation, NASA awarded JPL the contract to build the first American satellite.[40] JPL engineers worked around the clock, and by 31 January 1958, *Explorer 1* was ready for launch. JPL also relied on its limited tracking abilities to monitor the satellite in orbit, including an early mission control room and a few remote antennae, which they used to monitor the spacecraft.[41]

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[39] Ibid., 67-70.

[40] Koppes, *JPL and the American Space Program,* 85-86; and William H. Pickering and James H. Wilson, "Countdown to Space Exploration: A Memoir of the Jet Propulsion Laboratory, 1944-1958," in R. Cargill Hall, ed., *Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth History Symposia of the International Academy of Astronautics, Vol. II* (Washington, D.C.: National Aeronautics and Space Administration, Scientific and Technical Information Office, 1977)*,* 416-18.

[41] The control room and antennae are described more fully in chapters 3 and 5 respectively.

JPL officials next had to make an important decision about the direction of their space program. They could remain closely knit with the Army and work for a military space program. They could also side with the newly formed civilian space program, NASA. On the military side, the Army slowly downgraded its space efforts and the Air Force expanded its role. On the civilian side, there were some hints that a non-military venture was doomed for failure. To that end, JPL Director William H. Pickering even argued to the Eisenhower administration that NASA would fail without JPL as a centerpiece. After a series of negotiations, the Department of Defense agreed to allow JPL to join NASA beginning in 1959, but not without completing its work on existing programs, the most important of which was the Sergeant series of missiles.[42]

On 15 October 1958, only two weeks after the creation of NASA, the new space agency proposed to integrate JPL into the space program. President Dwight D. Eisenhower's Executive Order 10793, given on 3 December of the same year, officially transferred JPL from the United States Army to NASA.[43] On 1 January 1959, JPL officially became a part of America's civilian space program. To some, the laboratory's ambition far outstripped its ability. JPL officials envisioned a JPL-dominated NASA, with long-range plans for reaching the planets beginning within a relatively short amount of time. NASA officials, on the other hand, stressed a more subordinate role for JPL, including research and technical advice. NASA and JPL managers took some time to agree upon a middle ground.[44]

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[42] Koppes, *JPL and the American Space Program*, 96-99.

[43] Douglas J. Mudgway, *Uplink-Downlink: A History of the Deep Space Network 1957-1997* (Washington, D.C.: National Aeronautics and Space Administration, 2001), 11.

[44] Koppes, *JPL and the American Space Program,* 99.

JPL experienced difficult growing pains in the first five to ten years of its existence as a NASA center. For instance, NASA conducted business differently from what JPL had been accustomed to under the Army. It had a more restricted budget monitored with more oversight. NASA also wanted more everyday management by Pickering himself, rather than the university-like approach he had with oversight of nearly all aspects of the organization but generally staying out of day-to-day decisions.

There were also some issues that developed with the relationship among JPL, Caltech, and NASA. JPL was a NASA center, with federal funding, but Caltech still operated it. Any major changes, or any potential programs, required the approval of both Caltech and NASA. Some employees had significant difficulties with this two-pronged leadership. After some time, JPL became more comfortable in its role as one of many centers in the national space agency.[45]

[45] For more on this "Troubled Triangle," please see Koppes, *JPL and the American Space Program,* Ch. 9.

[Image 1-2: "Aerial View of JPL" (1 January 1961), NASA, http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001980.html]

The JPL expanded substantially during the mid-1960s into the campus-like facility it is today. Because the ability to expand horizontally was limited due to geographic and residential reasons, the center grew vertically. Beginning in 1962, JPL built Building 180, which housed the administration and some engineering. They added a landscaped central area just south of 180. Farther south, JPL built the Von Karman Auditorium, which abutted the main entrance to the laboratory.[46] JPL opened the Space

[46] Ibid., 216.

Flight Operations Facility (SFOF), the home of mission control, the same day as the auditorium.

Like most of the NASA centers, JPL had to prove its worth constantly in the late 1960s and 1970s as the nation's attention turned to such other issues as the Vietnam War and the Civil Rights movement. As NASA's budget shrank, JPL, like many of the other centers, had to work with less and diversify its missions in order to remain relevant. JPL also was compelled to diversify its workforce. While roughly 30 percent of the employees were either women or minorities, only a handful served in managerial positions. Perhaps one may attribute these problems to the lack of women and minority engineers in the workforce in the 1970s, but NASA also deserves some of the blame for not encouraging more aggressive recruiting.[47]

To cope with an increasingly diminishing budget during the 1980s, JPL adopted the idea of "faster, better, cheaper" under NASA administrator Daniel Goldin. With this new approach, JPL sought less ambitious missions that still provided valuable scientific outcomes. Unfortunately, under this model JPL encountered a few failed missions among the successes.

After a series of failures in the 1990s, JPL moved away from the "faster, better, cheaper" concept, focusing instead on medium-sized projects that promise more output without some of the excessive budgets of the larger programs. It has also embraced missions with international partners to help reduce costs. JPL continues to adjust to the times, and remains at the forefront of interplanetary spaceflight.

European Space Operations Centre

[47] Ibid., 215-216.

The European Space Agency (ESA) established a number of centers across the member states for various aspects of the organization's activities. ESA accepted numerous bids for the centers. France, Switzerland, and the Netherlands, for instance, expressed interest in the headquarters. The European Space Research and Technology Centre (ESTEC) proved the most sought-after center, with bids from Germany, France, the United Kingdom, Switzerland, Belgium, Italy, and the Netherlands. Interestingly, the European Space Data Acquisition Centre (ESDAC) initially only received one bid, from Germany, though the United Kingdom and Switzerland later submitted bids. ESRO officials weighed many variables while making their decisions on locations, including cost and efficiency, though perhaps most important political considerations.[48]

On 14 June 1962, the Conference of Plenipotentaries resolved the locations for the various centers.[49] Built to handle satellite development, the European Space Research and Technology Centre (ESTEC), in Noordwijk, the Netherlands, became the largest and perhaps most important center. In addition, it housed the control center for the satellite tracking and telemetry network, ESTRACK, which originally had four ground stations in Redu, Belgium; Fairbanks, Alaska; Spitzbergen, Norway; and the Falkland Islands.[50] ESTEC was responsible for the second phase of programs, that is, the transmission of data from satellites to the ground and orders from the ground to satellites.[51] ESA originally selected Delft, in the Netherlands, for its location, but this soon changed to

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[48] Krige and Russo, *A History of the European Space Agency, Volume I,* 53-54.

[49] First General Report of the European Space Research Organization (1964-1965), European Space Operations Centre Library, Darmstadt, Germany, III.1, 1.

[50] Ibid., I.6, 1.

[51] Ibid., III.4, 1-4.

nearby Noordwijk. ESA chose Kiruna, Sweden, to host ESRANGE, the sounding rocket launch area. Darmstadt, Germany, became the site of the European Space Data Acquisition Centre (ESDAC) to host the large-capacity computers used for calculations and for studying satellite data.[52] The original tasks of ESDAC included processing and analyzing data, performing orbit computations, and conducting scientific work on data from experiments. The facilities did not allow for any real-time computation.[53] During the debate regarding the location of the centers, eight members voted to situate ESDAC in Darmstadt while four others voted for Geneva, Switzerland.[54] Paris became headquarters for ESA. It then developed the European Space Research Institute (ESRIN) in Frascati, Italy, which eventually became the lead center for earth observations.

ESDAC originated as a few offices in a building run by a computer company, Das Deutsche Rechenzentrum (German Computer Centre) on Rheinstrasse, in the research and technology district of Darmstadt. In early 1964 it moved to a new office nearby in the Deutsche Buchgemeinschaft (German Book Society) on 16 Havelstrasse.[55] From its start, ESDAC claimed to have "one of the largest and most modern computer installations" anywhere.[56] Originally, ESDAC comprised the Data Processing Division and the Data Analysis Division.[57] Mission Analysis included the mathematical

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[52] First General Report of the European Research Space Organization, I.6, 1.

[53] Ibid., III.6, 1-4.

[54] Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency* (Cambridge, MA: Harvard University Press, 1994), 8.

[55] Madeleine Schäfer, *How to Survive in Space! (A light-hearted chronicle of ESOC), Volume I (1963-1986)* (Darmstadt: European Space Agency, 1997), 1.

[56] "The European Space Data Centre – An Establishment of the European Space Research Organization," ESRO 6380, European University Institute Archives, Florence, Italy, 2-3.

[57] First General Report of the European Research Space Organization, III.6, 1-4.

examination of satellite orbits, which drives the design of the satellite in its early developmental stages.[58] While ESDAC included thirty-one employees in 1965 and forty-nine by the end of 1966, the center's eight-year plan forecasted a staff increase to eighty personnel in the new facilities.[59] The staff complement had risen to 295 in 1969 and 311 in 1970.[60] In 2010, of the 2,072 total ESA staff, 244 worked in Darmstadt.[61]

By 1966, ESA executives realized that the organization was working inefficiently and needed to revamp. As a result, they created a group, led by Jan H. Bannier, director of the Netherlands Organisation for the Advancement of Pure Research (ZWO) and former chairman of CERN, in the hopes of solving these problems. Perhaps the most important and longest lasting result of the Bannier report was the recommendation that ESA situate the control center closer to the data locus, ESDAC. This would create a central location for spacecraft data and reduce redundancies in equipment and personnel. Thus, the operations control center moved from Noordwijk to Darmstadt, and ESA renamed ESDAC the European Space Operations Centre, or ESOC. This dissertation will use the acronym ESOC for the remainder of the work.

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[58] Howard Nye, *ESOC: European Space Operations Centre* (Noordwijk, The Netherlands: ESA Publications Division, 1996), 6.

[59] ESRO General Report 1966, European Space Agency Headquarters Library, Paris, 80; and First General Report of the European Space Research Organization, Fig. 4.1.

[60] ESOC Monthly Report, December 1969, ESRO 6979, European University Institute Archives, Florence, Italy; and ESOC Bi-Monthly Report for November/December 1970, ESRO 6981, European University Institute Archives, Florence, Italy.

[61] Warhaut, "ESA and ESOC Overview."

ESOC serves as a vital link between satellites and the end users.[62] It focuses on the calculating and processing of data. ESOC continually strives to remain at the forefront in computer technology in order to maintain its presence in the space program. As an example of the central role of computing technology within ESA, the ESOC Director originally held responsibility for agency-wide computer utilization.[63] ESOC's history is one of continuous technological change amid remarkable constancy in focus. This has allowed ESOC to update its hardware and other technology continuously while maintaining a high level of success in matters of control.

Howard Nye, a spacecraft operations manager and flight director, described the mandate of ESOC to "conduct mission operations for ESA satellites and to establish, operate and maintain the necessary ground segment infrastructure." He went on to explain mission operations as a "process involving operations planning, satellite monitoring and control, in-orbit navigation, and data processing and distribution."[64] These two definitions given by Nye summarize the work of ESOC, and especially the Operations Control Centre (OCC), for its more than forty years of existence, namely: planning, operating and maintaining ground segments, and data processing.

With its impending expansion as ESOC in 1966, ESA began to build new buildings and facilities in a field west of town, and just west of the railway station. The federal government of West Germany gave ESA the land for a 99-year lease with a one-time fixed price of 1 Deutsche Mark per year, a prior right to renew the lease, and a

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[62] N. Longdon and V. David, compiled and ed., *ESOC: The European Space Operations Centre* (Noordwijk, The Netherlands: ESA Publications Division, 1988).

[63] European Space Agency Bulletin, No. 1, June 1975, European Space Agency Headquarters Library, Paris, 9.

[64] Nye, *ESOC*, 2.

stipulation that the lease would end early if ESA were dissolved.[65] The contract further stipulated that the land could only be used for ESA purposes; and that if the contract did expire and the land revert, the state would compensate ESA for any permanent buildings. Finally, ESA must relinquish any natural resources or historical pieces found on the property to the local government with no compensation.[66] In order to use that land, ESA had to negotiate further with national and local authorities to clear trees as well as build an access road.[67] Almost immediately, ESA realized that ESOC would need more space. By October 1969, the local government had agreed to lease an additional 20,000 square meters for ESOC.[68]

At its new location ESA upgraded its main computer to an IBM 360/50, installed and placed on-line in September 1966.[69] Although ESA originally scheduled completion for the new facilities in mid-January 1967,[70] ESOC did not become fully operational until

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[65] Krige and Russo, *A History of the European Space Agency, Volume 1*, 384; and "Draft of Building Lease," 22 February 1963, COPERS 45, European University Institute Archives, Florence, Italy.

[66] "Contract for the Establishment of an 'Erbbaurecht' (Heritable Building Right)," 14 September 1971, ESRO 6378, European University Institute Archives, Florence, Italy, 2-5.

[67] "Note on the main points discussed during a meeting held on 11 March 1964 in Darmstadt," 19 March 1964 COPERS 45, European University Institute Archives, Florence, Italy, 2-3.

[68] Professor Auger, "Extension of the present premises of the ESRO Establishment in Darmstadt," Memorandum to German Delegation, 27 July 1967, ESRO 6379, European University Institute Archives, Florence, Italy; and "Letter to Professor Bondi from Lindner," 24 October 1969, ESRO 6379, European University Institute Archives, Florence, Italy.

[69] First General Report of the European Space Research Organization, III.6, 1-4; European Space Research Organization General Report 1966, 79; and "Report on Recent Activity at ESDAC," 8 February 1967, ESRO 6979, European University Institute Archives, Florence, Italy.

[70] European Space Research Organization General Report 1966, 78.

17 May 1968.[71] Interestingly, the local newspaper *Darmstadter Echo* referred to ESOC as the "Houston of Europe" on the first day after commissioning.[72]

ESOC originally consisted of two main buildings. The Headquarters or Administration Building included three floors with a partial basement for a total of 1,700 square meters. This building housed offices, a library, a conference room, and an area for visiting scientists. The Computer Building was 1,200 square meters on the ground and basement levels for various services focusing on the computers.[73] ESOC controlled the first missions from converted administration office space because it did not have any dedicated rooms for the control center at that time. The original control room consisted of seventy-two square meters of office space in a corner of the second floor of the Administration Building.[74] Those displaced by the control center worked out of a temporary wood building in the car park. By the end of 1967, ESA had transferred the telemetry data processing line, interface equipment between that line and the computer, the teleprinter communication links with ESTRACK ground stations, and the equipment for the network operations room to the new ESOC facilities.[75]

ESOC transferred all major control equipment to the new facilities in time for the Aurorae satellite mission in May 1968. During the Aurorae mission, ESOC's

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[71] Norman Longdon and Duc Guyenne, eds., *Twenty Years of European Cooperation in Space: An ESA Report* (Paris: European Space Agency Scientific and Technical Publications Branch, 1984), 88; and Krige and Russo, *A History of the European Space Agency, Volume 1*, 384.

[72] Norman Longdon, ed., "ESA/ESOC 25 Years," ESA BR-90, 1992, European Space Agency Library, Paris.

[73] Speech by Harry B. Gould, Site Engineer of ESDAC, 12 November 1965, European University Institute Archives, Florence, Italy.

[74] J.A. Jensen, "Milestones in ESOC's History," *ESA Bulletin* 7 (November 1976): 56.

[75] European Space Research Organization General Report 1967, European Space Agency Library, Paris, 89.

responsibility included coordinating the work of the stations as well as initiating and processing data. Its primary concern was maintaining the flow of data.[76] In 1968, ESOC established a protocol for the use of its computers by outside users. It would not charge experimenters working in cooperation with an ESA project. It would charge all others a minimal cost for the use of the equipment, pay for staff, the full cost for consumables, and a service charge. ESOC added that outside users could use their own operators if they were fully qualified, thus perhaps reducing their cost.[77] By the end of 1969, ESA realized that the current setup was difficult to use and inefficient for the agency's needs. That ESOC's area was undersized and not originally built for the purposes of a control center made a difference as well. ESOC further reasoned that a new control center would make ESOC more marketable for outside projects.[78] Construction on a new Operations Control Centre (OCC) began in February 1970. After its completion in March 1971, the administration moved from its temporary quarters permanently into their offices. ESOC was now fully operational according to the original plans.[79]

In 1971 the ESA Council released a report detailing a number of recommendations on the structure of ESOC. They began by recommending simplification of the administration. The council argued for a stronger operations management group. It further recommended that a tracking and data systems manager be

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[76] John Noyes, "ESOC's Participation in the Aurorae Mission," *ESRO/ELDO Bulletin* (April 1969 Supplement): 35.

[77] "Minutes of the Meeting held on 8/1/68 at ESOC, Darmstadt, on the use of ESOC equipment," ESRO 6912, European University Institute Archives, Florence, Italy.

[78] European Space Research Organization General Report 1969, European Space Agency Headquarters Library, Paris, 141; and "Justification for a New Control Centre Operation Building at Darmstadt," 1968(?), ESRO 6506, European University Institute Archives, Florence, Italy.

[79] Longdon and Guyenne, *Twenty Years of European Cooperation in Space* 92; and European Space Research Organization General Report 1969, 141.

named for each satellite as part of the project team directly responsible to the project manager. Finally, the council stated that ESOC should be responsible for the equipment at all the ground stations in the network, the Control Centre, and the launch ranges. The ESA administration quickly approved this report and made the appropriate changes.[80]

During the mid-1970s, ESOC also planned for the construction of a new three-story building with 3,250 square meters of total floor area, largely for the needs of the new Meteosat program. It included areas for the Meteosat computer system, control room, work areas for meteorologists, as well as a room for the new European computer system.[81] In 1980, ESOC installed electronic locks across its campus to control the use of its buildings. Employees insert a card to unlock doors to buildings and critical areas within the buildings. If needed in the future, they were able to store information concerning who was unlocking what doors. The system did not always work, especially immediately after installation.[82]

More facilities came in the late 1980s and early 1990s. In 1989 ESOC completed the first part of a building designed for extra offices and workshops, though not those directly connected with the OCC. Two years later ESOC added a 355-spot, multistory parking garage as well as a new energy center for emergency power. In 1995 contractors completed construction of Building E, which originally housed Dedicated Control Rooms (DCRs) for the ERS/Envisat, Cluster, and Huygens programs as well as areas for the

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[80] European Research Organization Council, "ESOC Structure," 8 February 1971, ESRO/C (71) 9, European University Institute Archives, Florence, Italy.

[81] European Space Research Organization General Report 1973, European Space Agency Headquarters Library, Paris, 127-29.

[82] Schäfer , *How to Survive in Space, Vol. I*, 109.

Cluster Principal Investigator (PI) and Electrical Ground Support Equipment (EGSE).[83] In 1993, ESOC built a new Flight Dynamics Room in the OCC to take advantage of new hardware upgrades.[84]

[Image 1-3: "Aerial View of ESOC" (September 1998), ESA, http://www.esa.int/externals/images/estec-photo-archive/998.jpg]

The International Organization for Standardization (ISO) is a nongovernmental organization, formed in 1946, that seeks to establish standards for the workplace. The

[83] ESA Annual Report 1990, European Space Agency Headquarters Library, Paris, 176; ESA Annual Report 1991, European Space Agency Headquarters Library, Paris, 168; and ESA Annual Report 1995, European Space Agency Headquarters Library, Paris, 121.

[84] Madeleine Schäfer, *How to Survive in Space! (A light-hearted chronicle of ESOC), Volume II (1987-1997)* (Darmstadt: European Space Agency, 1997), 137.

9001 certificate recognizes quality assurance.[85] In recognition of its impressive track record, ESOC received ISO 9001 certification on 30 November 1999. ESOC was the first ESA center to receive such an honor.[86] ESOC rightly takes pride in this award and other ESA centers have attempted to follow suit.

As an international organization ESA drew upon its many European constituents, and even from outside Europe, for its workforce. It had, therefore, a diverse working environment. Each center was equally diverse, and ESOC was certainly no exception. In this way it contrasted strikingly with the control centers of NASA, which employed Americans almost exclusively. Not surprisingly there are differences in how controllers worked in such a multinational environment compared to those in the United States.

Most Europeans consider working in an international organization normal. ESA was not unusual in that regard. Citizens of different countries worked so well together that employees tended to differentiate people more based on their divisions or departments within ESA rather than by their nationalities.[87] By acknowledging that everyone must work together in order to accomplish their jobs, individuals could easily forget any differences stemming from national pride, even during the World Cup competitions. In fact, the majority of ESA enjoyed a high level of teamwork.[88] Former

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[85] For more information on ISO, consult their detailed website: International Organization for Standardization, http://www.iso.org/iso/home.html (accessed 17 January 2012).

[86] ESA Annual Report 1999, European Space Agency Headquarters Library, Paris, 51.

[87] Schäfer , *How to Survive in Space, Vol. I*, iii.

[88] Wolfgang Wimmer, interview by author, Darmstadt, Germany, 21 October 2010.

ESOC director Felix Garcia-Castañer attributed his center's success to the dedication and enthusiasm of the employees.[89]

When compared with the locations of other ESA centers, such as Paris and Rome, Darmstadt was less well-known internationally. Even with Frankfurt relatively nearby, ESOC seemed at times distant and apart from the rest of the world. Despite that, during a ceremony commemorating the laying of the foundation stone for the new ESDAC building on 12 November 1965, Dr. Gerhard Bengeser, the Assistant Director for Administration at ESDAC, stated that he felt that "most of the staff members feel themselves at home now in this charming city which is a heaven (sic) of Science and the Arts."[90]

If they were not German, new employees adjusted to a new place of employment as well as a new country and culture. ESA employees have expressed at least minor culture shock when moving to a new area.[91] The transition could be especially taxing for families, especially if there were any language differences. While the employee spent much of his or her time working and talking in English or another common language, the family had to adjust to what can be a major language barrier. Often, parents experienced difficulties helping their children with schoolwork or speaking to their children's teachers due to language differences.[92]

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[89] Longdon, "ESA/ESOC 25 Years."

[90] Comments by Dr. Gerhard Bengeser, Assistant Director for Administration of ESDAC, 12 November 1965, ESRO 6380, European University Institute Archives, Florence, Italy.

[91] Wolfgang Hell, interview by author, Darmstadt, Germany, 20 October 2010. Hell specifically mentioned problems when moving to Italy to work at ESRIN, but the same ideas have been expressed elsewhere with ESOC and the other centers.

[92] Schäfer , *How to Survive in Space, Vol. 1*, 30-31; and Leo Hennessy, interview by author, Paris, France, 12 October 2010.

ESOC as a whole had grown from the original 2,000 square meters of building space to almost 30,000 square meters in the 1990s.[93] More than just a workplace, it served as a hub for employees from the many different European countries to come together and perhaps even bring some cultural elements of their home countries with them. ESOC had a plethora of clubs and organizations for its employees and families to give them an outlet the local community might not have been able to provide. Their diversity also showed the human side of ESOC. At any one time, there had been up to thirty-eight different clubs for various interests, including singing, golf, theatre, and soccer. There were also organizations for various cultural groups represented in ESOC's staff.[94] The Ladies' Club was one of the original clubs, organized to help wives of ESOC employees in their transitions. ESOC eventually subsumed the club into the Social Committee. The ESOC Canteen, opened in 1970, hosted many of the social events for different clubs and organizations.[95] Before it closed in 1987, the bar also served as a meeting place, or a watering-hole, for employees.[96]

Not all women associated with ESOC are relegated to the Social Committee. In fact, women have long played a major role in ESOC operations. The author of the premier ESOC memoir, Madeleine Schafer, began employment at the center only a few months after its inception. The 1969 ESRO General Report included a photograph of a

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[93] Longdon, "ESA/ESOC 25 Years."

[94] Schäfer , *How to Survive in Space, Vol. II*, 107; and Longdon, "ESA/ESOC 25 Years." Please note: the pamphlet refers to the sport as soccer, not football as might be expected.

[95] Schäfer , *How to Survive in Space, Vol. I*, 31.

[96] Schäfer, *How to Survive in Space, Vol. II*, 9-11.

female operator in the Darmstadt facilities.[97] This suggested ESOC included female controllers well before either of NASA's control centers. As a member of an international organization, ESOC had to integrate from the start both regarding gender and nationality.

ESA's 2010 budget was about 3.7 billion Euros, of which ESA returned roughly 90 percent to European industry in various ways, including research and development. ESA assured that, to the best of its abilities, there was fair distribution of research and development to each member state. The ESA Council established a new budget every three years. This multiyear approach allowed for better planning for future missions. ESOC received roughly 380 million Euros of the 2010 budget.[98]

Contractors were another way that ESA returned the investments to the countries. ESA often took into account the national origin of contractors before making decisions as to whom they should hire, although the ESRO Convention specifically stated that scientific, technical, and economic factors should take precedence over geography.[99] Many contracts were based on the largest contributor for a particular project. For instance, Germany provided funds and labor adding up to 52.6 percent of Spacelab, France 62.8 percent of Ariane, and Great Britain 56 percent of MAROTS.[100] ESA did its best to adhere to the ideas of *juste retour*, an industrial return coefficient that measured the amount of return in comparison to the amount of input.[101] This method meant that

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[97] European Space Research Organization General Report 1969, 84.

[98] Warhaut, "ESA and ESOC Overview."

[99] Krige and Russo, *A History of the European Space Agency, Volume I*, 72.

[100] Gibbons, *The European Space Agency,* 33.

[101] Bonnet and Manno, *International Cooperation in Space,* 49-50.

ESA sometimes could not accept the best proposal depending on the company's country.[102] Sometimes, though, the makeup of the contractor made it difficult to define the home country or to determine whether the business was from a member state or not.[103] Because contractors were only hired for a specific task, they allowed for ESA to spread around the money to different countries.

Limited contracts also allowed ESA to keep its permanent employment to a minimum. The individual contractors sometimes found ways to work around the limited employment. Some switched firms in order to remain at ESOC for longer periods of time, which could cause confusion for employees and for records that kept track of each individual's work status.[104] Sometimes contractors also joined ESA as staff members.[105] After all the calculations, ESA maintained that *juste retour* had successfully encouraged the member nations to contribute to the European space program.[106]

Each of the three spaceflight centers detailed here has a unique story thanks to their disparate origins. Each has dealt with its own political, economic, and social hurdles, as well as some similar issues, to accomplish its job. While JSC and ESOC were built specifically for spaceflight, so the space agencies took into account a variety of factors, including weather, proximity to ancillary facilities, and political arguments to

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[102] Hell, interview.

[103] Bonnet and Manno, *International Cooperation in Space,* 48-49.

[104] Schäfer, *How to Survive in Space, Vol. I*, 33-34.

[105] Wimmer, interview. Wimmer was a contractor from 1965 to 1970 and an ESOC staff member from 1970 to 2004. Other examples abound.

[106] Bonnet and Manno, *International Cooperation in Space,* 53.

locate those centers. JPL, on the other hand, began as a jet propulsion and missile testing laboratory with close connections to Caltech. Though its location was already set, NASA had to keep in mind other considerations, in particular its working relationship with the army, when making it a part of the space agency. The adaptability of the centers has manifested itself in their many changes. Each has added new buildings or changed existing buildings to better fit their needs. The general background information on the control centers will provide important contextual information for understanding the further development of the control center buildings and, finally, the control rooms themselves.

CHAPTER 2

CONTROL CENTER BUILDINGS

Spaceflight control requires more than just a room with computers and monitors. The control rooms are only the most visible aspect of a much larger technological system. Mission control needs supporting rooms, computer centers, data analysis areas, and communication networks, among other things, to function properly. JPL, JSC, and ESOC have each constructed a building or buildings to house the necessary components for mission control.

While each of the three space centers include infrastructure for various other aspects of spaceflight, the mission control buildings remain the focal point. Even spatially within the centers this focus becomes evident with their location at or near the hub of the respective centers. This may be expected at JSC and ESOC due to the space agencies originally constructing their campuses with a control center in mind. JPL, which had been in use for decades before the need of a control center, also placed this building in a prominent location. Surrounding buildings often supplement the work in the control centers.

Each of the control centers has a similar layout. Supporting rooms surround the primary control room, or rooms. Most of the control rooms have some kind of viewing room for families or dignitaries. The buildings also have or had a computer complex. Since constant communication with the spacecraft, or astronauts, is a necessity, they also have emergency generators either in the building or in a nearby structure. In short, the building layouts, like the geographies of the centers, reveal striking similarities.

The centers are comparable, but not identical. Each agency constructed its control center to best serve their missions. This chapter will further describe the layouts of each of the control center buildings. Through this examination, both the similarities and the critical differences will become clearer. While this chapter will discuss the control rooms themselves to some extent, a more detailed description will follow in the next chapter. As with the previous chapter, this section will begin with JSC before analyzing JPL and finally ESOC.

Mission Control Center

NASA realized it would need a new mission control center for Gemini and Apollo missions during the Mercury Program. The Mercury Control Center did not have enough capability to conduct rendezvous maneuvers, let alone anything more complex.[1] Thus, NASA built the Mission Control Center (MCC) at the new Manned Spacecraft Center in Houston, Texas.

NASA originally constructed the Mission Control Center (Building 30) in two major stages. With an almost $800,000 contract, the Peter Kiewit Sons Company built the foundation and structure. They finished their work on 29 May 1963. The Ets Hokin

[1] Christopher C. Kraft and Sigurd Sjoberg, "Gemini Mission Support," Gemini Mid-Program Conference, 23-25 February 1966, Kraft, Christopher: Biographical Data 1238, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

and Galvin Company completed the rest of the major work on the building. In all, NASA paid roughly $8 million in contracts to complete the MCC.[2]

The three-story, 90,000 square-foot building had three distinct wings. The main entrance in the Lobby Wing connected the Mission Operations Wing (MOW) to the west and the Operations Support Wing (OSW) to the east. As the name suggests, the MOW included the mission control rooms, the adjoining Staff Support Rooms (SSR), and the computer complex. NASA renamed the SSRs Multipurpose Support Rooms (MPSR) for the shuttle missions. During Gemini, Apollo, Skylab, and ASTP, when astronauts returned to earth by splashing down in the ocean, this wing also included a Recovery Control Room. This provided an area for the Department of Defense (DOD) and NASA personnel to coordinate recovery of the astronauts and their spacecraft. This wing was windowless in an attempt to make it weatherproof and to limit interruptions from outside radio waves. The windowless environment, combined with a seeming myriad of identical hallways, can be confusing even to the most seasoned flight controller, or downright labyrinthine for the visitor.[3] The OSW included offices for the controllers and support staff.[4]

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[2] NASA News Release, MSC 64-8, 11 January 1964, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[3] While touring the MCC with another NASA employee, we were grateful for our knowledgeable guide, Terry Hartman. Without him we would never have found our way. The only thing I can liken the MCC corridors to is the interior of an aircraft carrier, where a visitor must have someone to show them around or risk being lost.

[4] "MCC Mission Control Center," undated, box 4, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake.

NASA held a groundbreaking ceremony for Building 30 in April 1962. The building included the control rooms, computer complex, and support rooms.[5] The MCC, as originally conceived, consisted of three major systems. The Communications Interface System (CIS) focused on communications both within the MCC and with certain outside areas such as the NASA Communications Network (NASCOM) and simulators. The Data Computation Complex (DCC) included the mainframe computer system. Finally, the Display and Control System (DCS) handled human interface within the MCC. The majority of data, therefore, would enter the MCC and be distributed through the CIS. The DCC would then process the data, and the DCS would display it.[6]

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[5] "NASA Mission Control Center Historical Overview," 30 March 1994, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[6] Michael W. Kearney, III, "The Evolution of the Mission Control Center," *Proceedings of the IEEE* 75, no. 3 (March 1987): 399-400.

[Image 2-1: Houston MCC (28 July 2011), Author]

MCC is now 102,000 square feet, providing a remarkable amount of space for the mission control rooms as well as support rooms and offices. It originally included Mission Operation Control Rooms (MOCR) on the second and third floors. The third floor MOCR ultimately controlled forty-two flights, including Gemini 4-12, Apollo 4, 6, and 8-17, and twenty-one Space Shuttle flights, most of which were classified Department of Defense missions. The second floor MOCR controlled 114 missions, including nine for Gemini, seventeen Apollo missions, Skylab and ASTP, and eighty-three Space Shuttle flights.[7] Since NASA continuously updated the control rooms, they would trade off primary use during upgrades.

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[7] Robert D. Legler, Responses to Questions about Historical Mission Control, 7 April 1997, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

The MCC also housed the Network Interface Processor (NIP), located on the first floor. The NIP distributed incoming digital information to the needed areas of the MCC. Also on the first floor, the Data Computation Complex (DCC) compared incoming telemetry information with predictions, checking for anomalies. NASA built a Payload Operations Control Center (POCC) for Space Shuttle payload operations. The POCC included a control room, mission planning room, and six support rooms, totaling 4,000 square feet.[8] All of these support areas hosted critical elements of control for manned spaceflight.

Building 48, an emergency power building nearby, housed generators for use in the event of power failure. It also provided an air conditioning system for Building 30.[9] In the event of a catastrophic failure, the White Sands Test Facility in New Mexico included an emergency backup control room.[10] JSC prepared for any emergency, with backups and redundancies similar to the spacecraft they oversaw.

At the time of its construction, the MCC boasted the largest amount of television switching equipment worldwide. As part of that system, it included 136 television cameras and 384 television receivers. The building utilized fifty-two million feet of

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[8] "Spacelab Payload Control," NASA Fact Sheet, 1983, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[9] "Mission Control Center," NASA Facts, August 1993, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[10] The backup moved to White Sands in the 1980s. Previously it had been housed at Goddard Space Flight Center. "Mission Control Center," NASA Facts, 1986, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.; and Barbara Selby and Carolynne White, "Shuttle Emergency Mission Control Center Moves to White Sands," NASA News Release 88-101, 15 July 1988, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

wiring.[11] This allowed controllers and other employees not working inside the MOCRs to monitor the missions as they flew.

The control room and its equipment required a massive amount of computing capability. A Univac 490 computer originally ran communications as well as telemetry and trajectory information. The Univac 490 had 128 kilobytes of memory and one megabyte of head drum storage. For comparison, the iPhone 3GS has eight gigabytes of memory, or about 65,000 times as much memory.[12] The mainframe included five IBM 7094s. These were located in the Real Time Computer Complex (RTCC).[13] The RTCC processed all data and telemetry information for missions controlled in the MCC.[14] NASA originally contacted ninety-four companies on 21 March 1962 to gauge their interest in submitting a proposal to build the RTCC. Of those, twenty responded with interest.[15] Eleven companies eventually bid to build the RTCC, including the Burroughs Corporation, the Control Data Corporation, the General Electric Company (GE), International Business Machines Corporation (IBM), International Telephone & Telegraph Company (ITT), Lockheed Aircraft Corporation, Philco Corporation, Radio Corporation of America, the Raytheon Company, System Development Corporation, and

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[11] "Philco Houston Mission Control Center Press Tour," undated, box 1, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake, 2-3.

[12] 1 Gigabyte=1,048,576 Kilobytes.

[13] Kearney, "The Evolution of the Mission Control Center," 400.

[14] "IBM Tour Manned Spaceflight Control Center," 10 January 1965, box 2, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake, 3.

[15] James Stroup, "Ground Computer Complex Procurement Plan," 15 August 1962, box 2, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake.

the Wilcox Electric Company. After much deliberation, the search committee stated that three of the proposals were clearly the best, that of IBM, ITT, and GE. They considered IBM slightly more qualified because it held the contract for the Mercury Control Center. It also promised better organization as well as a more favorable cost estimate. Chris Kraft helped by arguing for IBM as well. IBM, not surprisingly, won the contract, which included design of the RTCC and its implementation, costing more than $36 million. NASA and IBM signed the contract 16 October 1962.[16]

NASA then upgraded the computers before the Apollo program. They replaced the Univac 490 with a Univac 494, and the IBM 7094s with IBM 360/75s in 1967.[17] For the shuttle, JSC installed IBM 370/168s in 1976 to take the place of the IBM 360/75s. In 1983 they added an IBM 3081 for other processes. A 1986 upgrade brought in four IBM 3083/JXs to replace the 370/168s. Another upgrade three years later included IBM 3083-KX machines.[18] MCC needed almost eighty personnel to staff the outdated mainframe computers during shuttle missions.[19]

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[16] "Selection of Contract for the Ground Computer Complex at the Integrated Mission Control Center," 1963, James C. Elms Collection, folder 5, box 1, Archives Division, Smithsonian National Air and Space Museum Archives, Suitland, MD.; "Contract Signed with IBM for Computer Equipment," NASA News Release 63-151, 12 July 1963, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.; and Kraft, *Flight*, 192-93.

[17] Kearney, "The Evolution of the Mission Control Center," 402; and "MCC Development History," compiled by Ray Loree, August 1990, box 1, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake, A-2.

[18] Other bidders included Amdahl Corp. and ViON Corp. Kenneth C. Atchison and Terry White, "NASA Selects IBM to Provide Mission Control Computers," NASA News, 29 October 1985, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.; Kearney, "The Evolution of the Mission Control Center," 405; and "MCC Development History," A-2.

[19] "Old, New Meet in Mission Control", *Countdown*, July/August 1995, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 29.

It should be noted that not all of the flight controllers welcomed new technologies, especially the first introduction of computers. This was not necessarily because they were unfamiliar with the new technology. They worried that the computers would be yet another piece of hardware that could fail, resulting in loss of data, or worse, loss of communication with the astronauts.[20]

In the 1990s, NASA realized the old MOCRs could no longer adequately handle Space Shuttle and planned Space Station operations. They built three new Flight Control Rooms (FCRs) in the southern wing of the MCC. One conducted shuttle missions, another monitored the Space Station, and the third served as a training facility. With the new FCRs came new hardware.

JSC installed Loral Instrumentation 550s with IBM RISC-6000 computers for telemetry.[21] Rather than using mainframe computers, they implemented two hundred Digital Equipment Corp. work station computers. 130,000 feet of fiber optic cable created the world's largest fiber optic local area network. The amount of memory space grew exponentially as well, including 190-gigabytes of data storage.[22] This is more than one and a half times more memory than the original UNIVAC 490.

A series of Staff Support Rooms (SSR) surrounded the operations room. Specialists occupied these rooms for the various aspects of missions and were backups

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[20] T. Rodney Loe, interview by Carol L. Butler, 30 November 2001, transcript, JSC Oral History Collection, 1.

[21] William Harwood, "NASA's New Control Center To Manage February Launch," Space News, 4-10 December 1995, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 7.

[22] William Harwood, "'Houston' of Space Flight History Catches Up With Look of Future," *Washington Post*, 16 July 1995, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., A3.

for the controllers in mission control.[23] MCC also included a Spacecraft Analysis Room (SPAN), generally acknowledged as one of the most important support rooms. SPAN housed senior engineers and controllers representing some of the major contracts for various aspects of the given mission. In essence, if a problem occurred, the flight controllers contacted SPAN. Those in the room then pared the information down to a specific question requiring an answer. The senior contractor members then consulted with their constituents for a solution. In some ways, SPAN served as an elaborate dispatcher.[24] For Skylab, NASA renamed the room the Flying Operations Management Room (FOMR).[25] After Skylab, it was renamed SPAN.[26]

Along with the contractors, SPAN contacted another room in Building 45 of JSC, the Mission Evaluation Room or MER. While SPAN identified the anomaly, MER did much of the work to solve the problem. As a result, many of the most knowledgeable and skilled engineers congregated in this room. It was so important, in fact, that many of the engineers considered the MER a step above than Mission Control. Instead of relying on advanced technology, MER depended upon its collected brain power.[27] Both SPAN and MER proved invaluable during missions, often providing necessary solutions for anomalies while the controllers focused on other issues.

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[23] M. P. Frank, "Flight Control of the Apollo Lunar-Landing Mission," 25 August 1969, Johnson Space Center History Collection at University of Houston-Clear Lake, 4.

[24] Murray and Cox, *Apollo*, 348-50.

[25] T. Rodney Loe, interview by Carol L. Butler, 7 November 2001, transcript, JSC Oral History Collection, 53.

[26] Loe, interview, 30 November 2001, 10-11.

[27] Murray and Cox, *Apollo*, 350-51.

NASA installed sleeping quarters for the flight controllers near mission control. During the early Gemini missions, the flight controllers generally stayed on campus and slept in the designated rooms between their shifts so that they would not have to spend time commuting. After the Gemini program, however, the sleeping quarters were rarely used except in extreme cases. The rooms simply were neither quiet nor comfortable, and the controllers realized the need for rest, especially during the stressful lunar missions.[28]

NASA specifically built the MCC for controlling NASA's manned missions. Like most technological elements, it required numerous updates and changes over its decades of existence. JSC still strives to provide the best resources to continue the prominence of NASA's manned spaceflight.

Space Flight Operations Facility

The Jet Propulsion Laboratory included a temporary control area used to support missile tests in the 1950s. When JPL joined NASA, the existing infrastructure clearly could not suffice for future programs. If JPL were to claim its place as NASA's primary robotic spaceflight facility, it required a more permanent control center.

JPL's Data Handling Committee wrote a report on 22 June 1961 stating that the Communications Center would not be able to handle future Ranger and Mariner missions. The Interim Report suggested that JPL upgrade its data processing, build a new facility to handle the data and flight operations, and construct the facility as soon as

[28] Gene Kranz, interview by Jo Jeffrey Kluger, 29 May 1992, Kranz, Eugene F. (NASA-Bio.) 1243, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

possible because the existing center would soon be obsolete.[29] Construction began almost immediately.

Before designing and building the Space Flight Operations Facility (SFOF), designers and engineers relied upon experience from earlier missions. First, they recognized the need for a centralized control area. They also realized the need to make some critical decisions in a short time span. Finally, they had learned some of the operating requirements for long duration missions.[30] These lessons played key roles in various aspects of SFOF.

JPL officially dedicated the Space Flight Operations Facility, as well as the Central Engineering Building, the Space Sciences Building, and the Von Kármán Auditorium, on 14 May 1964.[31] The SFOF was opened upon reception of a signal bounced off Venus, a total of 83 million miles and taking seven minutes, twenty-five seconds.[32] During the dedication, Homer E. Newell, the Associate Administrator for Space Science and Applications for NASA, remarked that its roles included collecting data from the Deep Space Network (DSN), reviewing and analyzing those data, translating data into commands for each mission, and centralizing command of missions. It necessitated constant surveillance during missions. He further mentioned that Marshall

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[29] "The Space Flight Operations Facility," *JPL Space Programs Summary* 37-20, vol. 6, Jet Propulsion Laboratory Library, Pasadena, California, 44.

[30] Press Release, History Collection 3-170e, Jet Propulsion Laboratory Library, Pasadena, California.

[31] William Pickering, "The Jet Propulsion Laboratory," *Bulletin of CIT* 73, no. 4 (19 November 1964), History Collection 3-168, Jet Propulsion Laboratory Library, Pasadena, California, 44.

[32] "Radar Signals 'Christen' SFOF," *Lab-oratory*, vol. 13, no. 10, May 1964, Jet Propulsion Laboratory Library, Pasadena, California, 3.

Johnson, Chief of the Space Flight Operations Section, played a leading role in its planning and construction.[33]

[Image 2-2: SFOF-1967 (1967), NASA, Courtesy of Jim McClure]

The SFOF currently consists of Buildings 230 and 264. Building 230 includes the Main Operations Room as well as various other supporting control rooms and offices. Building 264, originally built as offices for missions, also now includes additional supporting control rooms. Both are centrally located on the JPL campus, closer to the west main gate. Building 230 was directly north of Building 180, which was originally built as the Central Engineering Building but now serves as the Headquarters or

[33] Homer E. Newell, "Dedication Remarks," 14 May 1964, History Collection 3-170c, Jet Propulsion Laboratory, Pasadena, California.

Administration building. Building 264 stands east and south of buildings 230 and 180. The campus cafeteria lies between and to the south of buildings 180 and 264.

JPL originally designed the basement of the SFOF primarily to house equipment to help run the rest of the building, including air conditioning units, power, an emergency power system, and water heaters. The basement also held communications rooms, including communications terminal, teletype, and communications control, as well as various telemetry data and processing areas. A lobby, mission control and operations, and various other support rooms and analysis areas occupied the first floor. Office space and other control rooms made up the second floor.[34] Upon its completion, SFOF had about 55,000 square feet of operational space, with a total area of over 120,000 square feet.[35] The general layout for SFOF has remained relatively similar, though specific uses for various support rooms have changed multiple times throughout its history.

The operations room of the SFOF first controlled the Ranger 7 mission in July 1964. The mission was so historic for the center that each division of JPL received specific scheduled times when they could observe the mission from the visitors' gallery. Because the gallery had a capacity of about forty people, they had to limit the number of viewers as much as possible.[36] The gallery remains the primary location for the public to view JPL's operations room.

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[34] "The Space Flight Operations Facility," *JPL Space Programs Summary* 37-20, vol. 6, 46.

[35] "SFOF Near Ready," *Lab-oratory*, vol. 13, no. 3, October 1963, Jet Propulsion Laboratory Library, Pasadena, California, 3; and National Register of Historic Places Inventory-Nomination Form, United States Department of the Interior, NPS Form 10-900 (7-81), 15 May 1984, Jet Propulsion Laboratory Library, Pasadena, California.

[36] Memorandum from Brian Sparks to Division Chiefs and Managers, 28 July 1964, History Collection 2-281, Jet Propulsion Laboratory Library, Pasadena, California; and "The Deep Space Network," Jet Propulsion Laboratory 1965 Annual Report, Jet Propulsion Laboratory Library, Pasadena, California, 23.

Glenn Lairmore began serving as SFOF manager in February 1964. His duties included the SFOF budget, contractor management, facility development and operations, and maintenance of the Operations and Development Procedures Manual.[37] On 1 December 1964, management responsibility for SFOF transferred from the Office of Space Science Applications (OSSA) to the Office of Tracking and Data Acquisition (OTDA).[38] With these implementations, SFOF began full operation.

In 1965, costs independent from those to run missions for SFOF were approximately $8 million.[39] That same year, the SFOF first supported multiple missions simultaneously with Ranger 8, Ranger 9, and Mariner 4.[40] In order to handle the massive input of communications, JPL installed an electronic communications processor, which greatly eased the transmission of communications.[41]

In the early years of SFOF, JPL recorded the majority of data from satellites on magnetic tapes at the various DSN stations before transferring it to SFOF. Some especially vital information, however, could be transmitted immediately to SFOF and placed on magnetic tapes at JPL. Scientists and engineers had push-button control of information displayed for them in the control rooms. The Space Flight Operations Director had authority over mission control itself while the SFOF manager watched over

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[37] Memorandum from A.R. Luedecke to Senior Staff, Section Managers, etc., 5 April 1965, History Collection 2-284, Jet Propulsion Laboratory Library, Pasadena, California.

[38] Letter from NASA Headquarters to JPL, History Collection 2-175, Jet Propulsion Laboratory Library, Pasadena, California.

[39] Letter from NASA Headquarters to JPL.

[40] "The Deep Space Network," Jet Propulsion Laboratory 1965 Annual Report, 23.

[41] Mudgway, *Uplink-Downlink,* 42.

the whole facility.[42] For immediate communications between SFOF and the network stations, the center primarily used teletype, though voice communications could be used in emergencies.[43]

JPL separated mission dependent and mission independent facilities for particular missions or for all missions, respectively. Mission dependent facilities only operated for a specific mission. Independent facilities could be used by any mission. For example, the control rooms in the operations area, support areas, facilities, and communications of SFOF were all independent. Technical and control rooms in various parts of SFOF were dependent.[44]

The majority of SFOF supported the main operations room. In the Technical Areas, three teams backed up various control personnel while they were at their consoles. Space Science Analysis evaluated data from scientific experiments and issued commands. Flight Path Analysis evaluated tracking data and subsequent commands. Spacecraft Performance Analysis reviewed the condition of the satellite and issued pertinent commands.[45] These areas operated somewhat similarly to JSC's SSRs, though with more direct operational control.

The Communications Center of SFOF handled both internal and external communications, along with the DSN. This room, located in the basement of SFOF, had a Communications Center Coordinator who managed the routing of data and the use of

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[42] Press Release, HC 3-170e.

[43] "The Deep Space Network," Jet Propulsion Laboratory 1965 Annual Report, 23.

[44] "Space Flight Operations Facility," History Collection 3-169, Jet Propulsion Laboratory Library, Pasadena, California.

[45] Press Release, HC 3-170e.

internal and external communications facilities and equipment. A Central Computer Complex (CCC) on the second floor included two computer systems for primary and backup computations. The CCC Coordinator handled the overall operational management of the data processing systems. A Planetary Operations Room, also on the second floor, served as a secondary mission control during interplanetary sequences when operations required fewer personnel.[46]

SFOF also included an Uninterruptible Power System (UPS), which provided emergency power.[47] This system consisted of a series of diesel generators in the basement of SFOF. The diesel fuel was regularly replaced so as to avoid any problems with it.[48] Like JSC, JPL recognized the need for backups in the case of an emergency.

In all, SFOF, as originally designed, required fifty tons of wiring and cabling. The control rooms included 31 consoles, 100 closed circuit television (CCTV) cameras, and more than 200 television displays. Each console had the ability to select 150 contacts, and included a headset, telephone, intercom, and television. Digital displays could show up to 3,500 numbers. They had the ability to accept, process, and display 4,500 bits of real-time data, and up to 100,000 bits per second could be recorded for later use.[49] At the time, JPL utilized state-of-the-art equipment, but all of it would, naturally, undergo numerous updates throughout the years as more and better technology appeared.

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[46] Press Release, HC 3-170e; and D. A. Nelson compiled, "Engineering Planning Document No. 143: Capabilities and Procedures," 20 July 1964, History Collection 2-1871, Jet Propulsion Laboratory Library, Pasadena, California, I-1.

[47] "Project Viking '75 Mission Control and Computing Center Support Plan," 15 May 1975, Institutional Management Committee Collection, JPL 136, Box 8, Folder 83, Jet Propulsion Laboratory Library, Pasadena, California.

[48] Jim McClure and Ron Sharp, interview by author, Pasadena, California, 3 September 2010.

[49] Press Release, HC 3-170e.

During the Viking project, three computer centers supported operations. The Mission Control Computing Facility (MCCF) included three IBM 360/75 computers. This system had a one-megabyte main core with two megabytes of large core storage and 460 megabytes of disc storage. The General Purpose Computing Facility (GPCF) housed two UNIVAC 1108s. Finally, the Mission and Test Computing Facility (MTCF) held numerous UNIVAC 1219s, 1230s, and 1616s.[50]

Since Magellan, SFOF has used UNIX software with a JPL-specific overlay, supplemented with Sun Microsystems servers. This software easily supported multiple missions. It also provided homogeneity across projects, because previously each project had used its own system. That being said, some of the older missions still use their original software or hardware, such as punch cards for Galileo.[51]

While the MCC at JSC only handled one or, rarely, two subsequent missions, the SFOF regularly managed multiple missions. Due to the sheer number of missions controlled at JPL, mission operations quickly outgrew Building 230. Building 264 was constructed in 1970 and 1971 as the SFOF Systems Development Laboratory. While the original building only had two stories, plans called for six more in the near future. The two floors included 30,000 square feet of workspace, with a total potential for 120,000 square feet. From the beginning its objective was to serve as the house for mission

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[50] "Viking '75 Project Mission Control and Computing Center System Functional Capabilities," 15 March 1973, Institutional Management Committee Collection, JPL 136, box 4, folder 27, Jet Propulsion Laboratory Library, Pasadena, California; and "Viking '75 Project Mission Control and Computing Center System Progress Review," 11 October 1973, Institutional Management Committee Collection, JPL 136, box 5, folder 38, Jet Propulsion Laboratory Library, Pasadena, California.

[51] McClure and Sharp, interview.

support facilities and a natural extension of SFOF as JPL and its missions grew in size, scope, and numbers.[52]

In the early 1980s, JPL planned a much-needed upgrade to SFOF. One of the planners' biggest concerns was a limited budget. Part of the overhaul included replacing the last remaining IBM 360/75, which they estimated would cost at least $300,000.[53] The overall construction project, which ran from February 1982 to September 1984, had an early budget estimate of between $1.2 and $1.4 million.[54]

One of the most important differences between manned spaceflight missions at JSC and unmanned missions at JPL is the distance from the Earth. As missions travelled further and further away from Earth, the lapse in time for communications increased. As a result, controllers anticipated the next command for a spacecraft, sometimes many hours in advance. For instance, by 1999, a round-trip communication between Voyager and JPL then back to Voyager took more than twenty hours, which contrasts strikingly with the near-instantaneous communications with the International Space Station and other near-earth objects, or the roughly three-second delay to the moon.[55]

On 25 July 1994, the National Register of Historic Places named SFOF a National Historic Landmark, in recognition of its importance to the space program. The original form had been submitted in 1984 and stressed the building's importance to space

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[52] "A New Building Goes Up," *Lab-oratory*, vol. 20, no. 5, January-February 1971, Jet Propulsion Laboratory Library, Pasadena, California, 2.

[53] Memorandum from F.H. Felberg to R.J. Parks and P.T. Lyman, 1 April 1981, Institutional Management Committee Collection, JPL 228, box 2, folder 9, Jet Propulsion Laboratory Library, Pasadena, California.

[54] "Scope of SFOF Transition Activities," March 1981, Institutional Management Committee Collection, JPL 228, box 2, folder 9, Jet Propulsion Laboratory Library, Pasadena, California; and Memorandum from W.J. York, Jr. to J.P. Click, 20 April 1981, Institutional Management Committee Collection, JPL 228, box 2, folder 11, Jet Propulsion Laboratory Library, Pasadena, California.

[55] Mudgway, *Uplink-Downlink*, xxxv.

exploration as an extension of earlier explorers like Christopher Columbus and Samuel de Champlain. It especially highlighted the Deep Space Network control center. The space simulator in Building 150 and the twenty-six-meter (eighty-five-foot) antenna in Goldstone, California, were also made National Historic Landmarks the same day.[56]

The designation as National Historic Landmark assures the SFOF its place in history. The control rooms remain highly active with the many continuing and planned future missions. The SFOF continues to write its history.

Operations Control Centre

When ESA constructed the European Space Operations Centre in Darmstadt in 1966, it controlled missions in a series of makeshift offices in the Administration Building. Realizing the inadequacies of this arrangement, ESOC built the Operations Control Centre (OCC) as the new focal point of the organization. It began operations with the Thor Delta (TD-1) satellite in 1972.

The OCC originally covered a total of 900 square meters of floor space including main and auxiliary control rooms, an experimenter evaluation room, and an orbit operations room.[57] It also contained a training room for controllers, offices for project representatives, equipment checkers, network and spacecraft controllers and officers, an ESTRACK communications lab, and building systems.[58] Similar to JSC and JPL, the

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[56] "Lab facilities named historic landmarks," *JPL Universe*, vol. 24, no. 16, 12 August 1994, Jet Propulsion Laboratory Library, Pasadena, California, 3; and National Register of Historic Places Inventory-Nomination Form.

[57] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 92-93.

[58] European Space Research Organization General Report 1969, 141.

OCC housed diesel motors for emergency power.[59] The OCC included a 140-square-meter network operations room with two adjacent project operations rooms of comparable size. This setup mirrored those of NASA and the original control center at Noordwijk and maximized efficiency during any extended phases of missions. A 200-square-meter viewing room attached to the operations room doubled as a lecture room or a training area when the room was not being used for the Launch and Early Operations Phase (LEOP).[60]

The OCC also included a fifty-five-square-meter communications room, eighty-square-meter controller offices near the operations room, a 100 square meter area for visiting project staff and scientists, a similarly sized room for the operational project staff offices of projects for other organizations, a fifty-five-square-meter auxiliary operations room with additional equipment, fifteen-square-meter offices for the head of the network and the head of communications, twenty-five-square-meters for a kitchen and restrooms, and a sixty-five-square-meter display projection room for the rear projection system.[61] Hardware included two IBM-1802s with alphanumeric displays and hard-copy devices, a computer interface system, analogue tape recorders, a teleprinter, and closed-circuit television (CCTV).[62] ESA constructed the Operations Building to control up to four satellites simultaneously.[63] After its completion in March 1971, the administration

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[59] Manfred Warhaut, interview by author, Darmstadt, Germany, 19 October 2010.

[60] LEOP is also sometimes described as Launch and Early Orbit.

[61] “Justification for a New Control Centre Operation Building at Darmstadt.”

[62] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 93.

[63] European Space Research Organization General Report 1969, 141.

moved permanently back into their offices from their temporary wooden building and ESOC was fully operational according to the original plans.[64]

An IBM type 2260 AND system, installed in early 1970, allowed the controllers to view telemetry displays for the first time, rather than relying on the sporadic orbital determinations computed previously.[65] After the Operations Control Centre's completion in March 1971, the contractor handed over the principal equipment configuration for control to ESA in July. Over that summer, ESOC conducted extensive staff build-up and training in preparation, along with a reconstruction and reorganization of the computer centre, for the launch of HEOS-A2. While it was originally scheduled for launch in December 1971, various concerns delayed it to January 1972.[66]

In preparation for new computing requirements in the mid-1970s, ESOC conducted a general overhaul of its computing facilities between 1972 and 1974. In August 1972, they replaced the IBM 360/65 with an IBM 370/155, which included more central memory (1.5 megabytes) and more disk storage (1.2 megabytes) at a lower cost. This new mainframe also allowed for computer "time sharing" for the first time in ESA's history.[67] During this time the ESA officials also planned to install two ICL 4/72 computers, one each at ESOC and ESTEC, as part of an off-line system. They shared 4800 bits per second data link. This allowed ESOC to have a one megabyte core storage

[64] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 92, and European Space Research Organization General Report 1969, 141.

[65] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 91.

[66] European Space Research Organization General Report 1971, part 1, European Space Agency Headquarters Library, Paris, 65.

[67] European Space Research Organization General Report 1972, European Space Agency Headquarters Library, Paris, 191.

memory and 580 megabyte disk storage capacity. They originally planned these computers to become operational by January 1975, and the new IBM would be maintained until 1977.[68] By the end of 1973, ESOC had also installed an IBM 1800, so that while the 370/155 would process data transmitted from satellites, the 1800 would operate in real-time for data recovery from satellites.[69]

In 1973, ESA also agreed to allow the Netherlands Space Agency (NLR) to use the OCC and the Redu ground station to control its ANS mission, which flew from August 1974 to March 1976. ANS proved to be the first ESOC experience with onboard computers, which would not be duplicated again until Exosat in 1983. In order to accommodate this new technology, ESA installed a STAMAC communication interface system to allow for real-time keyboard telecommand.[70]

GEOS-1, in 1975, included no onboard computers, so 90 percent of the data was downloaded to the ground in real-time. The process was fully automated for the maximum scientific output, both on board the satellite and on the ground. With a new fully-automated ground system, ESA had a capability no other space agency could duplicate. The ground and satellite shared about 25,000 commands per day with a maximum delay of only ten seconds. They had only 3,500 preplanned commands because they had to continuously adapt to changing atmospheric conditions.[71] GEOS-2

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[68] European Space Research Organization General Report 1972, 191-192.

[69] European Space Research Organization General Report 1973, 123.

[70] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 94.

[71] Wimmer, interview.

flew in 1977 in a mini constellation with GEOS-1. This demonstrated capabilities that proved influential for the later Cluster.[72]

As part of its commitment to aid the development of European technological industry, ESA tried at various times, beginning in 1969, to replace their IBM systems with computers from Europe. After one more unsuccessful attempt in 1970, they placed a new request in 1971. They received three main bidders: IBM, CII + Siemens, and "Group One," a consortium including the European companies ICL, AEG-Telefunken, SAAB, CSI, and Rousing. After long negotiations, the administration agreed upon a mixed layout including real-time computers by CII + Siemens and batch computers by ICL. They also signed a separate contract for software with Rousing. Under this contract, the real-time equipment was installed by the end of 1974, though the IBM systems remained online until 1977 due to the needs of the COS-B satellite.[73] The majority of these systems did achieve acceptance on time.

Installation of the ICL 4/72 computer for batch processing began in September 1974, and the machines completed handover tests in December. CII installed one 10070 computer for real-time work in March with acceptance in June, while a second was installed in August for redundancy. The seven Siemens 330 computers, which were planned to aid real-time work, experienced problems, however, and could not become operational until January 1975. This new European system of computers led to the Multi-Satellite Support System (MSSS), which was installed in 1975 in anticipation of

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[72] Ibid.

[73] European Space Research Organization General Report 1973, 123-124.

the OTS, MAROTS, and Aerosat programs.[74] The MSSS, fully completed in 1976, allowed for the tracking of up to six satellites simultaneously.[75] This new facility supported LEOP for any and all missions while also providing an area for the routine phases of missions that did not need a specific DCR, such as OTS, MARECS-A, and GEOS. The MSSS included eight Siemens 330 primary processors and two SEL 32/7780 computers for their system.[76]

In 1975, ESOC also modified the Operations Control Centre's main room for newly launched satellites only. The administration decided to build dedicated control rooms (DCRs) for Geos and Meteosat, as well as future long-duration missions.[77] Due to changing needs and updated technology, by 1977 the Meteosat Ground Computer System (MGCS) included two ICL 2980s, six Siemens 330s, three Rousing CR80 Array Processors, and two Data General Nova 830s, an impressive set of components.[78]

New computer hardware installed in 1978 was supposed to remain functioning until 1985, but ESOC recognized major changes in computing required earlier upgrades. The price of computer facilities dropped rapidly though the price for manpower rose steadily.[79] During the 1980s ESOC continued to upgrade its computer systems to keep

[74] European Space Research Organization General Report 1974, European Space Agency Headquarters Library, Paris, 147; and D.E.B. Wilkins, "Spacecraft Organizations at ESOC," *ESA Bulletin* 20 (November 1979): 4.

[75] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 97.

[76] "ESA's Medium Term Plan for Computer Facilities," 11 April 1983, ESA 7208, European University Institute Archives, Florence, Italy, 3.

[77] European Space Agency Annual Report 1975, European Space Agency Headquarters Library, Paris, 118-19.

[78] European Space Agency Annual Report 1977, European Space Agency Headquarters Library, Paris, 150-53.

[79] "ESA's Medium Term Plan for Computer Facilities," 1.

up with technological advances. For instance, in 1980 the two CII 10070 were replaced with two SEL 32/77's to be used for simulations.[80] They also installed a DPS 66/05 system for general purpose, shared computing.[81] The following year the MGCS received an upgrade from its ICL 2980s with two Siemens 7865 computers backed by an IBM 370-148 and a CII-HB DPS/05 off-line system due to its better price and performance.[82] With the installation of the new MGCS, ESOC for the first time used representative spacecraft models as test data sources to validate the ground support systems. This quickly became standard practice when installing new systems or preparing for new missions.[83]

By 1983, the Seimens 330s in the MSSS were obsolete and accruing high maintenance costs, so they were replaced by two Gould/SEL-32/6750 mainframes, one exclusively for backup.[84] The new mainframes of the 1980s included one major technological change: they did not use punch cards. Controllers and engineers instead typed programs directly into terminals. While the mainframes may have been more user-friendly, ESOC did experience some problems with disk space. In fact, a logbook for

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[80] European Space Agency Annual Report 1980, European Space Agency Headquarters Library, Paris, 114; and "ESA's Medium Term Plan for Computer Facilities," 3.

[81] "ESA's Medium Term Plan for Computer Facilities," 2.

[82] European Space Agency Annual Report 1981, European Space Agency Headquarters Library, Paris, 119-21.

[83] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 98.

[84] "ESA's Medium Term Plan for Computer Facilities," 3, and D. Wilkins, "The European Space Operations Center's New Control Centre," *ESA Bulletin* 43 (August 1985): 24-25.

failures and crashes associated with the new mainframes was quickly abandoned because there were too many documented for the engineers to keep up with them.[85]

Between 1983 and 1985, ESOC modernized the OCC display and control facilities. The previous consoles, which had been installed in 1971 and later modified in 1976, required replacement for the new nineteen-inch color monitors, three for each console, and standard keyboards with function keys.[86] In 1986 and 1987, ESOC added two stories to the OCC to accommodate the Giotto project and staff.[87] More major computer upgrades came in 1990 with the installation of three new mainframes. The Comparex 8/90 handled mission analysis, payload data processing, and other similar programs. A Comparex 7890F supported Meteosat Data Processing and Flight Dynamics. An IBM 4381/R14 was used for general purpose computing as well as office automation.[88]

In the late 1980s, ESOC began phasing out MSSS, which was replaced by the Distributed Mission Support System (DMSS). Like MSSS, it was a computer network with the mission-dedicated computers added into its general infrastructure.[89] ESOC installed two SUN workstations in 1987. One was a SUN 3/50 with four megabytes of main memory and the other was a SUN 3/160with eight megabytes of main memory plus 141 megabytes on an internal disk. These were so successful that by 1990 ESOC had

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[85] Schäfer , *How to Survive in Space, Vol. 1*, 131, 133.

[86] Wilkins, “The European Space Operations Centre’s New Control Centre,” 24-26.

[87] European Space Agency Annual Report 1986, European Space Agency Headquarters Library, Paris, 175.

[88] European Space Agency Annual Report 1990, 136.

[89] K. Debatin, “New Ground Data-Processing System to Support the Agency’s Future Satellite Missions,” *ESA Bulletin* 53 (February 1988): 76-77.

installed seventy SUN workstations. These new workstations did pose some difficulties for the electrical installation because their hardware requirements differed from the previous workstations.[90]

Currently, the Operations Control Centre consists of two buildings, including the Main Control Room, the computer complex, various dedicated control rooms, and offices for the operations directorate. ESOC as a whole had grown from the original 2,000 square meters to almost 30,000 square meters in the 1990s.[91] ESOC consisted of a series of buildings which, for the most part, focus on satellite operations for ESA. The buildings housed administration, security, a cafeteria, library, a myriad of offices, a computer complex, and the control rooms that are the focus of this study. Generally, the workforce consisted of 50 percent flight dynamics personnel, 19 percent engineers, 33 percent operations personnel, and the final third personnel for communications.[92]

The OCC, which comprised Buildings D and E, remained the heart of ESOC. The controllers in the OCC provided scientists and experimenters with data from all instruments, information on orbit and attitude, relative distances and times, and any other critical information arriving from satellites. Those controllers also ensured the quality, quantity, and availability of the information for all users.[93] ESA remained mindful that operations included not only hardware and software, but also procedures and personnel.[94]

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[90] Schäfer , *How to Survive in Space, Vol. 2*, 17-20.

[91] Longdon, "ESA/ESOC 25 Years."

[92] Black and Andrews, *ESOC Services Catalog 2000/2001*, 4.

[93] Longdon and David, *ESOC: The European Space Operations Centre*.

[94] L. Marelli and G. Valentiny, "The Control Centre and Spacecraft Control," *ESA Bulletin* 7 (November 1976): 14.

The Main Control Room (MCR), in Building E, always had been the hub of the Operations Control Centre. It served as the central control center for critical aspects of missions, most notably LEOP. Despite its importance, it was only manned for a limited amount of time because the majority of the time missions were running ordinary operations.

During the noncritical majority of mission time, satellites were controlled in dedicated control rooms (DCRs). Originally, when only a handful of missions were flying at any one time, each had its own DCR. More recently, with the ever-increasing number of satellites to be controlled, DCRs had become control areas for families of missions, rather than single missions. Thus, a single DCR may have housed facilities for earth observations, deep space, or Mars missions. ESA had learned to use the same or similar software and hardware across families of missions, thus allowing this marriage to work more smoothly. By using the same systems for multiple missions, it also limited costs and training needed to run the missions. In many ways, ESA's limited budget and resources, especially when compared to NASA, had forced it to work more efficiently and, perhaps, more intelligently.

The OCC included an area for Flight Dynamics. This area specialized in satellite navigation, including orbit and trajectory analysis.[95] Standardization across projects was a key element for efficient work in flight dynamics. Personnel also ensured that their data was clear and unambiguous for whomever might use them. The Science Mission Support Section of Flight Dynamics handled testing and validation, mission analysis, and earth observation calculations among other things. This section was further separated

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[95] Nye, *ESOC: European Space Operations Centre*, 13.

into four teams, namely, attitude, commands, maneuvers determination, and orbits determination. The Navigation Office was named the Global Navigation Satellite Systems (GNSS) and could be used for a variety of products and tools.[96] Flight Dynamics included a Delta Differential technician who can determine the angle of the spacecraft. This capability was critical for navigation and for observations. This technology was borrowed from NASA's JPL.[97] Flight Dynamics at ESOC currently includes about seventy members, which contrasts strikingly with the two hundred to three hundred at JPL.[98]

OCC also included satellite simulators, which had been described as the "most important tool for validation."[99] Engineers used the simulators to prepare for any contingency, because trial and error was not allowed in commercial or professional ventures.[100] These simulators not only tested the hardware and the controllers, but also helped to emphasize the importance of team work rather than the individual.[101] Although early simulations were limited due to the available software and hardware, by 1977 and the GEOS mission, simulators could produce telemetry and accept telecommands from controllers to enhance the effectiveness of the training exercises.[102]

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[96] Jocelyne Landeau-Constantin, Bernhard von Weyhe, and Nicola Cebers de Sousa, compilers, *ESOC* (Noordwijk, The Netherlands: ESA Publications Division, 2007), 36.

[97] Warhaut, interview.

[98] Jurgen Fertig, interview with author, Darmstadt, Germany, 20 October 2010.

[99] Nye, *ESOC: European Space Operations Centre*, 17.

[100] Wimmer, interview.

[101] F.W. Stainer and H.P. Dworak, "Training in Satellite Ground-System Operations," *ESA Bulletin* 25 (February 1981): 68.

[102] J.J. Gujer and E. Jabs, "Use of Spacecraft Simulators at ESOC," *ESA Bulletin* 59 (August 1989): 41.

The Computer Control Centre (CCC), located within Building D of the OCC, contains the mainframes for the MCR and the various DCRs. It currently uses SUN systems, and is transferring from Linux software to Solaris. The CCC used off-the-shelf hardware which was upgraded and updated as much as the budget allows. Unlike JPL's computer center, which housed a collection of hardware from across the decades of its existence, ESOC updated all of its hardware and did not hold on to outdated equipment. Controllers in CCC worked extended shifts from 6:00 am to 10:00 pm, so it was not manned twenty-four hours per day.[103]

The main control room for the ESTRACK ground network could be found in the ESTRACK Control Centre (ECC) of Building E. The ECC typically consisted of three positions, a shift coordinator and two engineers. Shifts traded off throughout the day to maintain a presence around-the-clock. Because ESTRACK was automated, these engineers paid particular attention to any errors or problems. If needed, they could call upon emergency personnel to fix any on-site problems within the network. ESTRACK also relied upon standardized hardware and software throughout the network for maximum work output.[104]

One other area of ESOC deserves mention. Building H housed a Ground Station Reference Facility. This area could check the link between ESOC and satellites two years before launch. This allowed controllers to debug any problems in the connection.

[103] Warhaut, interview.

[104] Ibid.

This served as a simulator for ESTRACK that could be vital to diagnosing problems before they were too far removed from the ground to fix.[105]

The OCC published a series of Flight Control Procedures with instructions for normal and emergency procedures for each program. The Mission Implementation Plan served as a Bible for each program and included virtually every detail needed for that mission.[106] The Flight Operations Plan (FOP) included the sequences, in detail, for various phases of each mission.[107] The FOP especially focused on all the activities before and during LEOP.[108] The Satellite Data Operations Handbook organized information on how telemetry words and commands should be processed and displayed for the controllers. Finally, the Flight Dynamics Launch Support Document included vital information on the use of flight dynamics software during LEOP.[109]

The OCC, like JPL's SFOF, was a dynamic workplace. Not only was technology constantly upgraded, but also the rooms changed to house various missions. This flexibility had proven vital to ESOC's existence, and will serve it well in the future.

Each of the control centers includes more than just a control room. Computer complexes provide computing power, generators stand by in the case of an emergency,

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[105] Ibid.

[106] Ibid.

[107] Wilkins, "Spacecraft Operations at ESOC," 7-8.

[108] Schäfer , *How to Survive in Space, Vol. 1*, 100.

[109] Wilkins, "Spacecraft Operations at ESOC," 7-8.

and communication networks link to spacecraft. As major control centers for their respective space agencies, they have expected similarities.

The centers, however, include necessary differences to fulfill their unique missions. The MCC has a few main control rooms that are surrounded by support rooms. The SFOF includes a Main Control Room and various other control rooms located in two separate buildings. The OCC includes a main operations room with dedicated control rooms similar to the SFOF. JPL and ESOC both control robotic missions, and their control layouts are the most similar, which suggests that the type of mission is the most influential aspect for how space agencies construct their control centers. The main control rooms still deserve more attention, so they will be the focus of the next chapter.

CHAPTER 3

CONTROL ROOMS

The mission statement of mission control in Houston can be applied to the other control centers: crew safety and mission success. All decisions made by the controllers must first have those two ideas in mind; everything else is secondary. Flight controllers and their backup rooms must confidently make decisions with these principles in mind.

Although much of the work occurs in other areas of the control center, the main control rooms at each of the space centers remain the focal points. These are the locations where guests can watch the action from separate viewing rooms. When spaceflight history occurs, the news media invariably shows images of these controllers. In short, these are the rooms forever linked with the term “mission control.”

If the space centers and buildings vary based on the missions they control, naturally the main control rooms do as well. Despite some fundamental similarities, particularly staffing, each has created unique processes to complete their missions in the most efficient manner. This chapter focuses on the main control rooms.

As with the previous two chapters, this will begin with a discussion of the control rooms at JSC before analyzing JPL and ESOC. Each section will examine some of the same topics, including the controllers, how they work, the layout of the rooms, and some of the technology in the rooms. It will particularly highlight how the control rooms have adapted to various changes over the years.

Mission Operations Control Rooms to Flight Control Rooms

Cape Canaveral hosted the first control center for NASA's manned spaceflight program. The Mercury Control Center acted as a central location for operations, though much of the actual control work occurred in remote sites across the world. NASA realized that the more advanced missions of Project Gemini and the future Apollo Program necessitated a more permanent and centralized control center. The result was the Mission Control Center (MCC) in Houston, Texas.

Of the lessons learned from Mercury Control before building the Mission Operation Control Rooms (MOCR), one of the most important was the need for flexibility. NASA built Mercury Control solely to control the one-man missions. They configured each of the consoles to suit the individual controllers. They realized this style of control room would not work well for the more permanent rooms needed by an unknown number of controllers for at least the Gemini and Apollo programs.[1]

Houston's MOCR had an unexpected first experience while controlling a mission in January 1965. During liftoff of Gemini 2, a power failure occurred in Mercury Control at Cape Canaveral. When the backup controllers stationed in Houston could not hear Mercury Control, they began to track the Titan rocket. Because power could not be restored at the Cape until reentry, the Houston control center had virtually controlled the entire mission.[2] The MOCRs did not officially take over primary control until Gemini 4.

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[1] Paul Purser, interview by Robert Merrifield, 17 May 1967, transcript, Manned Spacecraft Center (MSC) History Interviews Kr-Z, folder 15, box 2, 18994, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 17.

[2] Kranz, *Failure Is Not An Option*, 125-26. FIDO Ed Pavelka contradicts this story. He states that while the Houston controllers had better information than those at Mercury Control, primary control was never handed over. Edward L. Pavelka, Jr., interview by Carol Butler, 26 April 2001, transcript, JSC Oral History Collection, 8-9.

The MCC in Houston was fully operational in time for the June 1965 flight of Gemini 4. This flight entrenched its place in history when Ed White became the first American to perform an extravehicular activity (EVA), commonly referred to as a space walk. Project Gemini served largely as a training ground for the missions to the Moon. In all, ten missions were successfully flown between 1965 and 1966. NASA felt ready for the next step.

After the Apollo 1 fire, Flight Director Gene Kranz defined mission control by two words: "tough and competent." Flight controllers would be "tough" by accepting their responsibilities and accountability for their actions. They would be "competent" by understanding their role and never taking it for granted. Those two words remain the calling card of mission control.[3] Two other words added at other times were: "discipline and morale."[4]

Since its inception, Houston has taken control of a flight as soon as it "cleared the tower." While there are a few explanations for this, one seems to be the most logical. Launch Control at Kennedy Space Center, at least for the early Gemini and Apollo launches, had a periscope to view the launch. In the event of a launch failure, as had happened somewhat frequently with early unmanned launches, the Launch Director had an abort button. One possible failure was contact with the tower. As technology improved this direct visual became less important, but the idea of handover after clearing

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[3] Kranz, *Failure Is Not An Option*, 204-205.

[4] Eugene F. Kranz, interview by Roy Neal, 19 March 1998, transcript, JSC Oral History Collection, 17.

the tower remained. Thus, there remains a Launch Control on site in Florida but Mission Control in Houston takes over primary control mere seconds after launch.[5]

Each MOCR is approximately 7,800 square feet.[6] Compared to the previous Mercury Control, Kraft described the MOCRs as spacious with faster computers and impressive support rooms nearby to keep the controllers abreast of the data transmitting from the spacecraft.[7] Philco Corporation constructed the equipment for the room, including cables and pneumatic tubes, under NASA contract NAS 9-1261. Philco had previously served as the major contractor for the Mercury Control Center; so like IBM, it had an inside advocate in Chris Kraft. The original contract from 1963 cost more than $35 million.[8]

Controllers referred to the room's lighting as "a kind of perpetual dusk." Keeping the lights low aided the viewing of the console screens.[9] Three ten-by-twenty-foot screens covered the front of the room. These screens typically showed important data on the left, a world map for tracking purposes in the center, and any live-feed from the mission on the right. The system used rear-projection equipment located in a dark room behind the screens known as the "bat cave." In 1989, NASA carefully replaced the original glass screens, which weighed 1,200 pounds. These screens highlighted one of

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[5] Gene Kranz and others, Series of Emails about "Clear the Tower," MSC-Mission Control Center 4712, 29 June 2007.

[6] NASA News Release, MSC 64-8.

[7] Kraft, *Flight*, 218-19.

[8] NASA News Release, MSC 64-8; Kraft, *Flight*, 193; and "Contractual History of Major Implementations and Operations Milestones," 10 January 1985, box 1, Mission Control Center and Real Time Computer Complex, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake.

[9] James Atwater, "The Men Who Control Our Missions to the Moon," *Saturday Evening Post* (28 December 1968/11 January 1969), MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 36.

the most important changes from the Mercury Control Center, namely, computerization. The front of the room also displayed the mission clock, the most precise measure of the mission duration.[10] Previously, controllers had tracked the missions using mechanical plot boards. The mainframe computers associated with the new MOCRs allowed the color map to display the tracking information electronically.[11] John Hodge, one of the first flight directors and designers of the MOCR, insisted that the screens at the front were merely for publicity. Visitors to the control room enjoyed looking at them, and they created a certain flair for the room, but the controllers themselves never used them. Instead they relied upon their own consoles and their support rooms.[12]

Mission plaques hang on the side walls of the MOCRs. The room controlling a particular mission had the privilege of displaying the plaque for that mission. At the end of each mission, the controllers had a plaque-hanging ceremony during which a flight controller hung the plaque. The flight directors also selected an individual honoree who had distinguished him or herself in some way during that mission.[13]

The viewing area behind the controllers was reserved for astronaut families, dignitaries, and other invited guests during missions. It seated seventy-four people.[14] This was also the closest to Mission Control that the vast majority of people would get. It

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[10] Marianne J. Dyson, "Shuttle Mission Control," JSC Shuttle Mission Control (1981-1991) 007095, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 3-5.

[11] Arnold D. Aldrich, interview by Kevin M. Rusnak, 24 June 2000, transcript, JSC Oral History Collection, 47.

[12] John D. Hodge, interview by Rebecca Wright, 18 April 1999, transcript, JSC Oral History Collection, 25.

[13] Dyson, "Shuttle Mission Control," 5.

[14] "MCC Mission Control Center," undated.

has been said that every president from Lyndon Johnson to Bill Clinton visited either the control room itself or the viewing area (George W. Bush visited as governor of Texas).

Some have described the camaraderie of the flight controllers as similar to that of a combat unit due to a friendship born out of dependency on one another to do the job, namely, to complete the mission successfully.[15] The military background of many of the early controllers made this analogy especially apropos. Chemistry among the flight controllers was especially important. The more they worked together the more they anticipated each other and communicated using an economy of words.[16] The controllers had complete trust, respect, and confidence in each other.[17]

Many of the controllers were contractors from different companies related to their position. Others were NASA employees. In fact, during the Gemini and Apollo programs nearly all of the MOCR controllers were NASA employees while contractors staffed the support rooms. The Flight Director (FD, or Flight) was always a NASA employee.[18] This difference between contractors and employees could sometimes hurt the camaraderie of the room, though the need to complete the mission often overcame any discrepancies.

The flight director truly was the center of mission control. The FD console stood in the center, with the Capcom and other command consoles nearby. The other controllers surrounded him like vague concentric circles around a focal point. Outside

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[15] Atwater, "The Men Who Control Our Missions to the Moon," 69.

[16] Eugene F. Kranz, interview by Rebecca Wright, 8 January 1999, transcript, JSC Oral History Collection, 55-56.

[17] John Aaron, interview by Kevin M. Rusnak, 26 January 2000, transcript, JSC Oral History Collection, 7.

[18] Dyson, "Shuttle Mission Control," 5-6; and Charles L. Dumis, interview by Kevin M. Rusnak, 1 March 2002, transcript, JSC Oral History Collection, 40.

the room, Staff Support Rooms (SSR) surrounded mission control, further adding to the image of concentric circles of control with the flight director at the center. The flight director had a rather simple yet complex job description, namely, to "take any action necessary for crew safety and mission success."[19]

The flight director was at all times responsible for every aspect of the mission. Any mistake could be fatal to the astronauts, and he or she would shoulder the blame. Before being thrust headlong into the fire, however, each Flight Director completed hundreds of simulations including more errors than one might fear could ever happen in a real mission. This experience was vital, not only in the case of an emergency, but also if nothing else to prove each flight director ready for the immense responsibility. Flight directors, like all controllers, fought the tendency to revert to a routine. Maintaining a sense of awareness and avoiding apathy were critical aspects of successful spaceflight.[20]

Flight controllers began by working simulations in the "back rooms." Each worked various positions in teams during year-long rotations, similar to medical students. After some years gaining experience, they finally made their way up to the front room, again honing their skills in simulations before a true mission. If they were good enough and stayed on the job long enough, they gained the opportunity to advance to the most desired position: flight director. In 2009, JSC named its eightieth flight director.[21] With only eighty flight directors in forty-five years, however, only a select few ever received

[19] Eugene F. Kranz, interview by Roy Neal, 28 April 1999, transcript, JSC Oral History Collection, 13.

[20] Michael Behar, "The Ground," *Air & Space* (October/November 2006), MSC-Mission Control 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 30-31, 35.

[21] "NASA Chooses Three New Flight Directors to Lead Mission Control," NASA Press Release 09-133, 12 June 2009, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

the coveted call-sign "Flight."[22] As Chris Kraft, the first flight director, succinctly stated: "Flight is God."[23]

[Image 3-1: Flight Director Console (28 July 2011), Author]

The amount of power and responsibility given to the flight director stands out as unique among spaceflight. The other control rooms included positions with some semblance of a FD, but none had the overall final say as at JSC. The exceptional amount of accountability inherent in manned spaceflight probably required such a role, and the men and women who have served as FD have deserved the acclaim they have received.

[22] Behar, "The Ground," 31.

[23] Kraft, *Flight*, 2.

Shortly after the move to Houston, NASA hired a new crop of flight controllers directly out of college. Many were needed to operate the new computers installed in mission control.[24] Largely due to this influx of young controllers, in 1965 the average age for a flight controller was twenty-nine.[25] As NASA added more recent college graduates during the Apollo program, the average age declined to twenty-six in 1969.[26] The youngest flight controller ever was Jackie Parker, who was only eighteen when she joined mission control in 1979 as support for the Data Processing Systems (DPS) console.[27] For the majority of the time mission control has had a relatively young average age. As controllers gained more experience, they generally moved on to more senior positions.

From early on, Mission Control strove to gather the best group of individuals possible regardless of race, religion, or any other descriptive. In fact, Gene Kranz described it as one of the first true equal opportunity government employers.[28] While it was an all-male environment for its first five years, the first women joined mission control as flight controllers in 1971.[29] It should be noted that three women worked in the Mission Planning and Analysis Division in the 1960s, a group that worked closely with

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[24] Kranz, interview, 19 March 1998, 10.

[25] Gene Bylinsky, "When the Countdown Is 1…His Pulse Is 135," *The New York Times Magazine* (15 August 1965), Kraft, Christopher: Biographical Data 1237, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 13.

[26] Kranz, interview, 28 April 1999, 41.

[27] "At 18 Years Old She Mans a Mission Control Console," NASA News Release 79-17, 19 March 1979, Parker, Jackie (NASA Bio.) 1658, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[28] Kranz, interview, 28 April 1999, 13.

[29] Kranz, *Failure Is Not An Option*, 304.

Mission Control. At least one of those women, Anne Accola, worked in the MOCR during Apollo 17, though not as an official member of the Flight Control Team.[30] Today, approximately 40 percent of flight controllers are women.[31] NASA hired the first African-American flight director, Kwatsi Alibaruhu, as part of a new class of nine in 2005, the second largest class ever, which brought the total at that time to thirty.[32] The class of 2005 also included the first two Hispanic flight directors: Ginger Kerrick and Richard Jones.[33]

Before each mission, flight directors were given certain tasks for that particular mission. While they each worked set shifts, there were typically special teams for launch, landing, and any other critical aspects of missions such as lunar landing. Each flight director then assembled the best flight control team for his or her particular task. As a result, teams at times remained relatively constant under a certain flight director, but there were still possibilities of changes before each mission.[34] Simulations were vital for the flight directors to understand how their team would work together. Some controllers became so involved and focused on their own work that they did not realize when anomalies were occurring elsewhere. The flight director needed to instill a sense of

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[30] Anne L. Accola, interview by Rebecca Wright, 16 March 2005, transcript, JSC Oral History Collection, 5, 24.

[31] Kranz, interview, 28 April 1999, 13.

[32] Behar, "The Ground," 30.

[33] Dwayne Brown, Sonja Alexander, and Kylie Clem, "First Hispanics on Duty Leading Mission Control Team," NASA News Release 05-411, 18 November 2005, MSC-Mission Control Center, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

[34] Kranz, *Failure Is Not An Option*, 257-58.

teamwork and understand that problems could only be solved by the team working in unison.[35]

The early flight directors each had a designated color that would then provide a name for their team. For instance, Gerry Griffin was gold, Gene Kranz was white, Cliff Charlesworth green, Glynn Lunney black, Milton Windler maroon, Charles Lewis bronze, Neil Hutchinson silver, Don Puddy crimson, and Phil Shaffer purple. Jay H. Greene became emerald flight because green already belonged to Charlesworth.[36] The flight directors often provided some flair for their teams. Kranz's wife made a vest for him to wear for each mission. A particularly colorful vest worn at the end of each mission designated his approval of their work. Puddy had a tendency to wear polka-dot shirts, and Shaffer striped shirts.[37]

Mission Control has had a few mascots over its years. During Skylab, Lewis's bronze team adopted "Splash Gordon," a fish onboard the space station, while Hutchinson's silver team adopted Arabella, Skylab's spider.[38] One of the most memorable was Captain Refsmmat. Named after a term used to describe equations to determine angles with reference to certain stars, this "Ideal Flight Controller" allowed the controllers to let off some steam and provided a sense of unity among the teams. It was further seen as a device to boost morale, a harkening to the military background of many

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[35] Frank, interview, 19 August 1997, 15-16.

[36] Jay H. Greene, interview by Sandra Johnson, 8 December 2004, transcript, JSC Oral History Collection, 8.

[37] Charles Lewis, interview by author, 22 September 2006, transcript, Skylab Oral History Project, University of North Texas Oral History Program, 20-21; and Kranz, interview, 8 January 1999, 24.

[38] Lewis, interview, 22 September 2006, 21.

of the early controllers.[39] Some elements of Mission Control tried to start rival mascots, such as Victor Vector and Quincy Quaternion, but neither gained the popularity of Captain Refsmmat.[40]

[Image 3-2: Apollo Mission Control from the Trench (28 July 2011), Author]

Flight control positions have changed somewhat depending on the program or even the particular mission. Mission Control consisted of a series of rows of consoles each on a slightly higher level than the one before it. The following outline provides a

[39] Kranz, *Failure Is Not An Option*, 240-42; and Edward L. Pavelka, Jr., interview by Carol Butler, 9 March 2001, transcript, JSC Oral History Collection, 1-3.

[40] Edward L. Pavelka, "The Origin of Captain Refsmmat," *MOD Focus* (October 1985), Box 7A, Mission Operations, Center Series, Johnson Space Center History Collection at University of Houston-Clear Lake, 7.

general understanding of the various console positions throughout the history of the rooms.

The first row, or "trench," included various positions concerned with the mechanics of the spacecraft. From Gemini to ASTP, the first position of the trench was the Booster Systems Engineer, "Booster," who was responsible for the rocket stages. The Booster controller came from the Marshall Space Flight Center in Huntsville, Alabama, where they built the rockets. Shortly after launch and the separation of the booster stages, Booster left the room, further adding to the position's disconnection from the rest of the MOCR. The Flight Dynamics Officer (FDO or FIDO) remained relatively constant. FIDO oversaw the velocity and trajectory of the spacecraft during all aspects of the mission. Due to the time-critical aspects of their position, FIDO was the only position in mission control, other than the Flight Director, who could abort the mission directly. Any other controller would have had to secure an abort through the FD.[41] During Gemini and Apollo, FIDO served as the leader of the trajectory team, which also included the Retrofire Officer (RETRO) and the Guidance Officer.[42] Before the shuttle program, JSC decided only one trajectory controller was needed, so they ended the RETRO position.[43] JSC merged the Guidance Officer (Guido) with the Rendezvous Procedure Officer to create the Guidance Procedure Officer (GPO, though still called "Guidance"). The GPO was concerned with the positioning of the spacecraft and any deviations from the projected location. The Guidance, Navigation, and Controls Systems

[41] Pavelka, interview, 26 April 2001, 14-15.

[42] Jay H. Greene, interview by Sandra Johnson, 10 November 2004, transcript, JSC Oral History Collection, 11.

[43] Greene, interview, 10 November 2004, 35.

Engineer (GNC) moved around in the MOCR somewhat, starting in the first row but shifting to the second row during early shuttle missions, before moving back to the first row. GNC covered navigation and some propulsion aspects in maneuvers. The Propulsion Engineer (PROP), created out of a reorganization before the Space Shuttle program, controlled all but the main engines for the shuttle.

The second row received the moniker "Systems." During the Apollo program, consoles on the left included the Flight Surgeon and Capcom. Capcom was the only controller to communicate verbally with the astronauts in space on a regular basis. The name originally stood for Capsule Communicator; but after the shuttle it was officially known as the Spacecraft Communicator. Capcom was manned always by an astronaut, because they served as that vital link between those on the ground and those in space who were familiar with all of the jargon affiliated with space travel. They even served as a sympathetic intermediary between the controllers and the astronauts in space.[44] The idea started with the remote communication sites during the Mercury program. The astronauts flew out to those remote sites and served as the communications liaison with whoever was in space. For the shuttle, the Surgeon moved to the back row and the Capcom moved to the third row. Instead, the Data Processing System Engineer (DPS) handled the onboard computers since the first flights of the shuttle. Another shuttle position, the Payloads Officer (Payloads) served as a liaison between the groups responsible for the payload, usually a contractor or scientific experimenter, and mission control.[45]

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[44] Glynn S. Lunney, interview by Roy Neal, 9 March 1998, transcript, JSC Oral History Collection, 14.

[45] Ken Peek, "History of Human Spaceflight Mission Operations," *Quest* 10:4 (2003), MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 23.

Other positions on the second row during Apollo dealt mostly with communications. Those included the Electrical, Environmental, and Communications Systems Engineer (EECOM), the Telemetry, Electrical, EVA Mobility Unit Officer, Telmu, originally Telcom, which was concerned with the electrical and environmental systems of the Lunar Module (LM) and spacesuits, and CONTROL, which handled the communications systems of the LM. JSC eventually consolidated these positions or reformed them into other positions. The Electrical Generation and Illumination Engineer (EGIL, pronounced "eagle") oversaw the power system on the shuttle. JSC created it out of some aspects of EECOM. With the shuttle, EECOM stood instead for the Environmental Engineer and Consumables Manager, who assured the life support systems and consumables. Apollo EECOM flight controller Charles L. Dumis likened the Systems controllers to plumbers. People hardly paid attention to them until something broke, then it was their job to fix it.[46]

The third row handled many of the command aspects of missions. The Integrated Communications Officer (INCO) managed the communications links with the spacecraft in space. During Gemini and Apollo, the Operations and Procedures Officer (O&P) tracked displays and the mission clock. At times, an Assistant Flight Director position served to aid the FD with some of the administrative duties. A controversial position, it functioned as assistant to the flight director.[47] The flight director had a console in the center of the third row. The Flight Activities Officer (FAO) managed the astronauts'

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[46] Dumis, interview, 1 March 2002, 16.

[47] Charles S. Harlan, interview by Kevin M. Rusnak, 14 November 2001, transcript, JSC Oral History Collection, 19-20.

schedule as they were flying. Network was concerned with ground communications. For the shuttle missions, NASA consolidated it and O&P into the Ground Controller, or GC.

The final row handled much of the liaison work for Mission Control with various outsiders. The first console in the back row rotated depending on the mission and the current aspect of the mission. Another Shuttle controller was the Mechanical, Maintenance, Arm, and Crew Systems Engineer (MMACS, pronounced "max"). The MMACS controlled the robot arm, auxiliary power, hydraulic systems, payload bay doors, and various other mechanical systems. This position was likened to an all-around mechanic for the Space Shuttle. The Booster Engineer managed the main engines of the shuttle as well as the solid rocket boosters during shuttle launches. Previously the position had monitored the engines and propellant tanks for the rockets. The Booster position was only manned during the launch phase. One more position added for shuttle operations was the Payload Deployment and Retrieval System (PDRS) Specialist. PDRS oversaw operations of the Remote Manipulator System, the robot arm of the Shuttle. The Extravehicular Activity (EVA) Specialist worked on console during all spacewalks.

[Image 3-3: Back Rows (28 July 2011), Author]

Flight Directors sometimes moved on to the Mission Operations Director (MOD) position. The MOD essentially served as a liaison between Mission Control and the outside world. Before 1983, JSC called this position the Flight Operations Director (FOD). A medical doctor stationed in Mission Control, called the Flight Surgeon, was the only console position outside of Capcom that had regular communications with the astronauts in space. Flight surgeons performed medical checks on astronauts both prior to and after missions, as well as during the mission itself. The Public Affairs Officer (PAO) was the "Voice of Mission Control." The PAO interacted with the news media, handled publicity for the mission, and was the voice heard by anyone listening to live feed from Mission Control. The Department of Defense (DOD) also had a console on the back row. This position supported recovery operations for astronauts after splashdown during programs before the shuttle, and was a key member during the various classified DOD shuttle missions.[48]

During Skylab, the FIDO and RETRO controllers generally only worked in the control center for a few hours each day. Each morning they updated the orbit calculations and assured that the station was on the correct path. Typically, they did not need to work in the MOCR for the entire day because Skylab was merely maintaining its orbit.[49]

Flight controllers generally worked nine-hour shifts, with an hour overlap on either end of the shift for updates about mission progress.[50] Typically each incoming flight controller reported one hour early to a conference room. There, one of the flight controllers from the on-duty team briefed those of the next shift for about fifteen minutes. At the same time, a member of the current team updated the incoming SSR team. After the flight controllers' briefing, each controller with an SSR reported to that team and updated them on the upcoming shift. Then, all flight controllers reported to mission control where each controller was further briefed by the outgoing controller at their

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[48] Rita Karl, "Mission Control Center Apollo," powerpoint presentation, 18 June 2001, Johnson Space Center History Collection at University of Houston-Clear Lake; and Dyson, "Shuttle Mission Control," 9-10, 18-19, 25-26, 32-33, 42-43, 49-50, 54-55, 62-63, 74-76, 87-88, 99-100, 108-109, 118-19, 127-28, 138-39, 149-50, 160-62. 171-72, 184-85.

[49] Eugene Kranz, interview by author, 22 November 2006, transcript, Skylab Oral History Project, University of North Texas Oral History Program, 22-24.

[50] James Hartsfield, "Flight Control of STS-59," NASA News, Release 94-026, 29 March 1994, MSC-Mission Control Center, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

particular console.[51] This system assured all pertinent information was passed from one team to the next and attempted to avoid any surprises.

The extended shifts during missions created a distinct atmosphere in mission control. Gene Kranz talked about a certain smell created by the controllers working in the room for hours as stale pizza and sandwiches, burnt coffee, full wastebaskets, and an energy of anticipation pervaded the atmosphere. That energy also led to a buzz of conversation, highlighted by brief dialogues of quick sentences using mission control jargon.[52]

With the original system, JSC had hardwired the command buttons and event lights on each console to specific processes. If an event light turned on, the controller pushed any of a number of command buttons to deal with the problem. Unfortunately, the console was so inflexible that if a change were needed with the buttons, it took months to reroute the sometimes thousands of wires.[53] A controller could not simply print out a screen image if he or she needed the information. Instead the controller pushed a button with the appropriate command to another console with a thirty-five-millimeter camera that took a picture of the screen and then printed out a paper containing that image. The controllers then distributed those papers through the pneumatic tube system that connected the MOCRs to various other areas of the MCC.[54]

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[51] Holkan, "Shift Change Briefing Plan," MCC Houston Standard Operating Procedures, Manned Spaceflight Center, 10 May 1965, Record Group 255, National Archives, Fort Worth, Texas, 10-2.

[52] Kranz, interview, 8 January 1999, 38.

[53] Bridget Mintz Testa, "Mission Control," *Invention & Technology* 18, no. 4 (Spring 2003), MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 17.

[54] Dyson, "Shuttle Mission Control," 14-15.

Following the Apollo program, JSC deactivated the third floor MOCR, and the second floor controlled all Skylab missions and the ASTP. In 1979, JSC reactivated the third floor for the Space Shuttle. Both MOCRs went through a major upgrade. NASA replaced the old consoles systems with a new Console Interface System (CONIS). At the same time, NASA updated the second floor consoles by removing and repainting them tan, to coordinate with the new tan carpeting and walls (the third floor MOCR has green consoles, thus the names Brown and Green MOCR). This provided a greater distinction between the two MOCRs.[55]

While mission control itself remained relatively constant throughout its history, NASA made needed upgrades as technology progressed. As JSC moved farther into space shuttle missions, it recognized some problems with the MOCR. Most notably, the infrastructure was relatively inflexible and it was growing obsolete. Also, older flight controllers, who came of age on the consoles, were steadily replaced by newer flight controllers with more computer experience. These concerns fueled the move for change and influenced the construction of the new Flight Control Rooms (FCRs).[56] By updating with off-the-shelf equipment, NASA has reportedly saved up to $30 million per year.[57]

Following the Challenger disaster, JSC once again evaluated the MCC system. More upgrades were implemented, including replacing the IBM 370/168 mainframes with four IBM 3083JXs, installed between January 1986 and September 1986. Due to its

[55] "MCC Development History," 15.

[56] Kearney, "The Evolution of the Mission Control Center," 399.

[57] "Old, New Meet in Mission Control," 29.

extensive use of the MOCR for classified shuttle flights, the DOD agreed to pay for a portion of the upgrade.[58]

Before the first desktop computers were officially installed in MOCR, some controllers had their own personal computers near their consoles. They wrote custom software for their needs, input information, and had the computer calculate solutions for them. While personal computers technically were not allowed by JSC, flight controllers became so adapt at this process that they clamored even more for increased flexibility in the mission control hardware and software.[59]

Interestingly, the third floor MOCR remained online for almost five years as JSC continued to transfer code from the old software. Finally, in October 2002, it was officially unplugged, decommissioned, and relegated to historical status. It remains a popular stop on the NASA Tram Tours of JSC.[60] The MOCRs had been designated a National Historic Landmark on 24 December 1985, twenty years after they first controlled Gemini 4.[61] This assures that they will remain intact regardless of changes to the rest of JSC.

JSC realized in the mid-1990s that the old MOCRs could no longer handle Space Shuttle operations. They also would not be acceptable for control of the planned Space Station. JSC constructed three Flight Control Rooms in the MCC. The White FCR operated Space Shuttle missions, the Blue FCR controlled the International Space

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[58] "MCC Development History," 23, A-2.

[59] Testa, "Mission Control," 21.

[60] Ibid., 24.

[61] Dyson, "Shuttle Mission Control," 1.

Station, and a third room, the Red FCR, housed simulations to train new flight controllers.

The Red FCR came online first in order to prepare controllers for the new rooms. The construction of the rooms was relatively quick, only about six months for the Red FCR. This rapid construction occurred largely due to using infrastructure already in place; therefore, there was no need to build a new building. BRSP, Inc., built the FCRs.[62]

[Image 3-4: White FCR (28 July 2011), Author]

[62] James Hartsfield, "New Mission Control Room portends increasing pace of human space flight, rapid space station expansion," *Space Center Roundup* 39, no. 18 (8 September 2000), MSC-Mission Control Center, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 1

The White FCR cost approximately $250 million to complete.[63] It began operations with STS-70 in July 1995, a mission that inserted one of the Tracking and Data Relay Satellites (TDRS) into orbit that proved vital to the communications network. The original MOCR continued to handle certain critical aspects of missions, including launch and landing, for another two years.

The White FCR had consoles in five rows with a somewhat irregular pattern, though the location of consoles remained similar to the previous MOCRs. The first row was still called the "trench" and included Trajectory, FIDO, Guidance, and GC. The second row consisted of systems controllers such as Propulsions, GNC, MMACS, and EGIL. The third row included more systems controllers like the Data Processing and System Engineer (DPS, pronounced "dips") for the computer systems, the Assembly and Checkout Officer (ACO) in charge of payloads, FAO, and EECOM. The fourth row included INCO, the Flight Director, Capcom, and PDRS for robot arm operations. Finally, the back row continued to host the PAO, MOD, Booster or an EVA controller depending on the aspect of the flight, and the Flight Surgeon.

With the International Space Station (ISS) continually manned since 1998, the Blue FCR had likewise had continuous controller presence. The Blue FCR had five rows of three consoles, with an additional console in the back right corner for the PAO. Each row included one console on the right (from the front of the room) and two on the left, with a wide walkway down the middle. The Flight Director and Capcom occupied the fourth row from the front. The majority of other positions were systems positions and

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[63] "Old, New Meet in Mission Control," 29.

special positions created to operate the ISS. Some had similar tasks as those for the shuttle, but with slightly different names and call signs.

[Image 3-5: Blue FCR (28 July 2011), Author]

A typical ISS Flight Control Team consisted of twelve to fifteen controllers, including the Flight Director. JSC designated most flight controllers and Flight Directors to work either Shuttle or ISS. When the Shuttle docked with the ISS, the Flight Director and controllers in the Blue FCR took control of virtually all operations. Thus, the ISS Flight Director had overall control for flight operations, and the Shuttle FD deferred to him or her. An ACO served as a liaison between the two FCRs.[64]

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[64] Annette P. Hasbrook, interview by Jennifer Ross-Nazzal, 21 July 2009, transcript, JSC Oral History Collection, 1-3, 24.

[Image 3-6: FCR 1 (28 July 2011), Author]

Due to a lack of space in the MCC, the Blue FCR was significantly smaller than the other mission control rooms. This problem eventually led JSC to move ISS operations to the second floor MOCR, now called FCR 1, in 2006. JSC updated FCR 1 with new blue consoles set in four rows on the same level, losing the tiered approach of the MOCRs. Looking from the front of the room, the right side included either one (front row) or two separate consoles. The left side had either three or four consoles set in long rows. This setup seemed somewhat lopsided to the visitor. The flight director and Capcom were located next to each other in the third row. Since the changeover, JSC utilized the Blue FCR only during special missions, such as STS-125, the final mission to the Hubble Space Telescope in May 2009, and STS-134, which installed the Alpha Magnetic Spectrometer (AMS-02) on the ISS in May 2011.

One important change with the new control rooms involved the basic level of adaptation. In the MOCR, the hardware required changing for upgrades. In the FCRs, personnel made most needed changes with the software, a much easier and quicker fix.[65] The FCRs also used off-the-shelf front-projection screens, which cost less than a single projector bulb for the old system, or about $75,000.[66]

JSC began a Mission Control Center Workstation, Server and Operating System Replacement (MWSOR) project in 2003 which replaced old hardware and software. With greater flexibility and more off-the-shelf aspects in the system, it decreased costs and greatly aided the overall system. JSC even began to use MCCx, a computer system that allowed flight controllers to log on and work from their home or office using a personal computer.[67] Lockheed Martin holds the current contract to operate and support the FCRs. The Facilities Development and Operations Contract (FDOC), began in 1 January 2009 and runs through 30 September 2012. It has a potential payout of almost $55 million.[68]

The essentials of Mission Control remained relatively constant throughout its history. Controllers planned for a mission, trained for a mission, then executed the

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[65] Testa, "Mission Control," 22.

[66] Harwood, "'Houston' of Space Flight History Catches Up With Look of Future," A3.

[67] Sean Wilson, "Mission Operations Evolving for Spaceflight of the Future," *Roundup*, MSC-Mission Control 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C., 6-7.

[68] NASA Modifies Mission Operations Support Contract, HQ News C09-031, 23 June 2009, MSC-Mission Control Center 4712, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

mission. The planning and training included such detail that the controllers foresaw and handled virtually any anomaly during the actual flight of the mission. The more current flight controllers could sense continuity with the past. That these essentials remained intact indicate that the early Mercury and Gemini flight control pioneers knew from the beginning how best to fly a mission.[69]

JPL Operations Room

The first control room at the Jet Propulsion Laboratory began operations in January 1956. It consisted largely of a terminal, office furniture, and some calculation equipment for data processing and orbit computations.[70] The control room also had a wall map for tracking satellites. This original control center had no digital elements.[71] It was enough, however, to control the early missions through the Ranger project. The control room utilized an IBM 704 computer for processing orbit data.

By 1961, JPL's control room for Ranger was located with the Pasadena Communications Center, which handled incoming data from the communications network. Although the two rooms were located next to each other to expedite the exchange of information, a glass wall separated them making it nearly impossible to have direct interaction. The center included an IBM 709 computer to process incoming data.[72] The center installed the new computer in 1960, which used vacuum tubes and generated so much heat that it depended on an extensive air conditioning system. The IBM 709

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[69] Hasbrook, interview, 30-31.

[70] William R. Corliss, *A History of the Deep Space Network* (Washington, D.C.: National Aeronautics and Space Administration, 1976), 8.

[71] Mudgway, *Uplink-Downlink*, 31.

[72] Corliss, *A History of the Deep Space Network*, 38-39.

lasted two years, until JPL updated it with an IBM 7090 in 1962. The next year, JPL decided to pair two computers to process the influx of information better. They installed an IBM 7040 and 7094 with a 1301 disk storage file. There were some difficulties with the IBM 7040, so JPL quickly upgraded it with an IBM 7044. Before the Ranger 5 mission, the Communications Center received an update, including push-button switching, to make data exchange more efficient.[73]

The IBM 7044 and IBM 7094 played integral roles during the Mariner missions for tracking and data processing.[74] The IBM 7094 experienced hardware and software problems during the Surveyor 1 mission, which necessitated repairs to the card decks and card readers. There were also malfunctions in the interface between the 7044 and 7094. This issue became so severe that JPL had to involve IBM in a repair that took two and one-half hours to complete.[75]

The Operations Management Plan for the Mission Control and Computing Center (MCCC) prepared for the Viking missions describes a typical setup for operations of a JPL mission. The MCCC Operations Control Team (MOCT) handled real-time flight support as well as various aspects of control, records, and analysis. The MCCC Operations Control Chief (MOCC) directed the MOCT, including scheduling, directing action in the case of an anomaly, and serving as a primary interface for operations. The Computer Operations Chief (COMPUTER CHIEF) was responsible for computer support

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[73] Ibid., 56.

[74] N. A. Renzetti, K. W. Linnes, D. L. Gordon, and T. M. Taylor, "Tracking and Data System Support for the Mariners Mars 1969 Mission, Planning Phase Through Midcourse Maneuver," Technical Memorandum 33-474, Vol. I, 15 May 1971, Jet Propulsion Laboratory Library, Pasadena, California, 15.

[75] N.A. Renzetti, "Tracking and Data System Support for *Surveyor* Missions I and II," Technical Memorandum 33-301, Vol. I, 15 July 1969, Jet Propulsion Laboratory Library, Pasadena, California, 158-59.

and operations and interactions with DSN. The Communications Chief (COMM CHIEF) managed internal communications for SFOF. The Facility Support Chief (SUPPORT CHIEF) was in charge of the general facility, including power, janitorial staff, displays, and safety. An Operations Analysis Chief monitored the operational performance and directed the MCCC Operational Analysis Team (MOAT) during the evaluation of the systems and data. The Data Processing Controller (DATA CHIEF) coordinated data processing in the Mission Support Area (MSA) as well as computer systems. The MSA also housed the Analysis Program Operations personnel and the Data Gathering and Distribution personnel. A MCCC Facility and Operations Project Engineer (FOPE) served as an interface for all the various elements of operations in the MCCC to make sure that JPL completed all requirements for the project. Finally, the MCCC Operations Manager supported the program from an overall JPL viewpoint, keeping in mind other programs and systems.[76]

The Activity Engineer (ACE) flight controller served as a type of Capcom for JPL missions. This controller took any action necessary to successfully complete the mission, so far as those actions fell within the guidelines established for the mission.[77] Any decisions based on anomalies advanced through the proper channels before sending a command.

By design, the room nearly always had low lighting, much like JSC's control rooms, allowing the controllers to view their screens better. It also aided with heat

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[76] H. W. Alcorn, preparer, "Operations Management Plan for the Mission Control and Computing Center," 1 February 1973, Viking Project Flight Operations and Mission Control Documents, box 3, folder 24, Jet Propulsion Laboratory Library, Pasadena, California.

[77] "Viking Flight Team Meeting," Mission Control Directorate Status Review, 18-21 June 1974, JPL 136, box 6, folder 48, Jet Propulsion Laboratory Library, Pasadena, California.

reduction, because the massive amount of electronics and hardware in a confined space could potentially raise temperatures, requiring increased air conditioning. Due to the low lighting, the Operations Room often was referred to as the "darkroom."[78]

Records for individual renovations at JPL are sparse if not nonexistent. By viewing images of the Operations Room over the decades, however, one quickly realizes that the layout for controllers changed frequently. In this way, JPL contrasts strikingly with JSC and ESOC where the control room layouts did not change once constructed. The reason for this difference remains largely speculative, though it may arise from the changes in missions and the variety of missions over the decades.

Beginning in 1964, controllers had individual work stations in straight rows. The open space of the Operations Room was significantly smaller, with only two or three rows of consoles. The front of the room did have the screens displaying information above glassed-in rooms for other controllers. The consoles were mostly gray-blue in color. Behind the main control area was another glassed-in area for additional controllers. The majority of consoles had two screens for displaying information or images, a telephone receiver, and push-buttons with no keyboard. Ashtrays were another must. The room also included various analysis and operations areas. Glass panes separated these areas, which JPL stated created a unified atmosphere.[79] The view screens, located at the front of the room, came from the 1964 Republican Convention, which was held in San Francisco earlier that year.[80]

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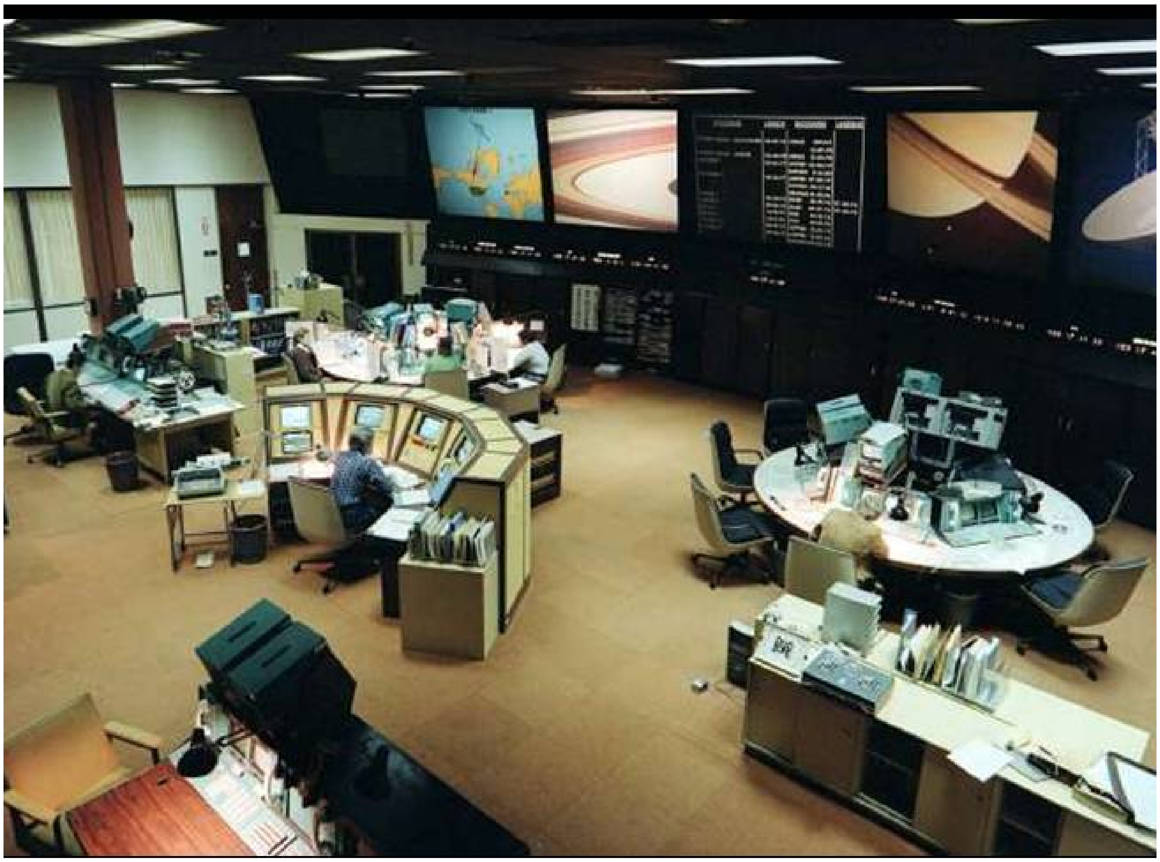
[78] McClure and Sharp, interview.

[79] "The Space Flight Operations Facility," JPL Space Programs Summary No. 37-20, Vol. 6, Jet Propulsion Laboratory Library, Pasadena, California, 61.

[80] McClure and Sharp, interview.

[Image 3-7: SFOF "Dark Room"-1964 (1964), Courtesy of Jim McClure]

By 1968, during the Surveyor program, JPL replaced some of the consoles with round table consoles and one long table in the center of the room, with some of the original consoles facing inward around the edges of the room. The new tables were largely brown and white, though the consoles themselves remained gray-blue. They covered the glassed-in rooms at the front with dark red curtains, giving the room a somber, reddish hue. Photos suggest that blue carpeting overlaid the old tile floors. They began using the round consoles, which could hold six workstations, with the Pioneer VIII, Surveyor, and Mariner missions. For Mariner, the round consoles included the communications controller, tracking chiefs, and multiple tracking stations for both Mariner and Pioneer. The long table held three stations in the rounded portion at the end of the table, which accommodated the Deep Space Instrumentation Facility (DSIF) Operations Manager, DSN Operations Manager, and the SFOF Ground Communications Facility Operations Manager.[81]



[Image 3-8: SFOF "Dark Room"-1981 (1981), Courtesy of Jim McClure]

By 1981, after the Voyager launches, JPL replaced the long table with a half-circle console holding five screens in the center of the room to join the other round consoles. They updated carpeting this time with a tan color. They also exchanged the curtains at the front of the room with a black wall, making the "darkroom" even darker. Just two years later, the round tables were gone, and only five semi-circular, five-monitor consoles remained. These consoles were yellow, and with the tan floor made the room

[81] Renzetti, et. al, "Tracking and Data System Support for the Mariners Mars 1969 Mission, Planning Phase Through Midcourse Maneuver," 46, 99-101.

nearly all yellow-tan and black. JPL has since given the round consoles to the Russians, who used them in their control center.[82] By 1986, JPL added at least three more of the rounded consoles, dramatically changing the amount of open space in the room.

In 1990, shortly after the Magellan and Galileo launches, at least one of the semi-circular consoles remained, while JPL replaced the rest with more traditional, independent and straight consoles. By 1995, following Mars Observer but before Mars Global Surveyor, all of the consoles were individual workstations much like the original setup, and again the room had taken on a blue tint. They painted the walls white, making the "darkroom" significantly brighter than ever before. There were more changes the next year, when a long line of updated consoles lined the front of the room, and individual computer monitors on large tables inhabited the center of the room. Before the launches of *Spirit* and *Opportunity* in 2003, the long line of consoles at the front remained. JPL placed the computer monitors in the center in a rounded layout closer to the current system. Some of the monitors were by this time flat-screens as well.[83]

JPL redesigned and renovated the Operations Room most recently in 2008. The SFOF managers met with designer Blaine Baggett to plan the aesthetics of the room for optimal working conditions. The current setup includes three rows of curved consoles. Each row generally has one controller overseeing each half of the computers. The curve allows the controllers to view all of their monitors and allows the rows to fit into the existing space. These consoles, designed and built by Evans Consoles, are some of the

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[82] McClure and Sharp, interview.

[83] Since much of this renovation information could not be located, much of this information is derived from a series of photographs in a slide-show history created by Jim McClure. This slide show was generously shared with the author by Mr. McClure.

few consoles that are seismically rated, a particular concern for JPL given its location in proximity to major fault lines.[84] The room is significantly darker now as well, making the "darkroom" moniker more than apt. JPL also replaced the overhead lighting with individual lights on the consoles themselves.

The room is laid out like the data flow. Information from satellites enters through the DSN control, the Network Operations Control Center (NOCC), which occupies the front of the room. It is then transferred to controllers who reroute it to its final destination, at the program's specific control area. This Data Systems Operations Team processes, catalogs, and distributes the information. It consists of only two controllers, each of whom oversees half of the computer monitors on the row. Commands are then sent from those programs through the controllers back to the front of the room and the DSN before transmission to the individual satellites.[85] In this way, any visitor with knowledge of the system can visualize the flow of information through the room quite easily.

[84] McClure and Sharp, interview.

[85] Ibid.

[Image 3-9: Operations Room (3 September 2010), Author]

The Operations Room can be described as a “throughput” facility. It processes data, leaving the analysis of information to the individual program control rooms. In essence, it is more concerned with the quality and quantity of information processed than its actual content.[86]

The screens at the front of the room continue to provide some information about current missions, including which satellites are transmitting data at what times. The programs are color coded, and the scrolling of data represents transmission. One of the screens frequently shows a slideshow of images of the Operations Room through the

[86] Ibid.

ages. The managers admit, however, that they are on display almost exclusively for the benefit of any visitors.[87]

The Critical Events Mission Support Area is connected to the side of the Operations Room. This area includes controllers and support personnel for programs during critical aspects of missions, including launch, rendezvous, and planetary landings. This is also an area for VIP's, and is usually the area filmed for news reports of missions.[88]

A glassed-in area is located under the screens at the front of the room. This area includes the DSN controllers. The design reverts back to the original layout. Over the years the glass had been covered by curtains, and then replaced with a wall. With the renovation, the designers returned to the glass to give the room a more open feeling and to more logically connect the DSN controllers with the rest of the operations controllers. The DSN is controlled by contractors, which are currently supplied by ITT. An Operations Chief serves as a supervisor for DSN control, with a Tracking Support Specialist assisting.[89]

JPL missions operate under the concept that "whoever builds, operates." This means that whatever company or contractor builds the satellite has the authority to control the mission as they see fit. They operate from an individual Mission Support Area (MSA), which serves as the control room for the majority of the mission, routine time. These rooms have also been called Project Operations Control Centers (POCC).[90]

[87] Ibid.

[88] Ibid.

[89] Ibid.

[90] Mudgway, *Uplink-Downlink*, 86.

Only critical aspects of missions will have the Operations Room as the control center. Many Mission Support Areas are located within the two buildings of SFOF; however, this is not a requirement. Companies may house their MSA anywhere they wish, including as far away as Denver, Colorado, for Lockheed Martin, and Greenbelt, Maryland, for the Goddard Space Flight Center.[91]

Similar to those at JSC, JPL controllers can be either employees or contractors. The makeup of employees to contractors varies greatly, however. Whether or not one is an employee or contractor is largely a numbers game. In fact, many switch between the two depending on the current needs of JPL or the contractor. All ACEs, in particular, must be employees.

The Mission Controller for each mission serves as the direct interface with the DSN for the processing of data. Mission Managers or Flight Directors handle the day-to-day running of missions. Most control rooms work with three to four shifts of one or two people, depending on the project and the particular job.[92] Again, the MSA's, or mission support areas, fall under the control of different entities which set their own rules for operation.

The following is one example of an MSA. The Mariner missions had 640 square meters in SFOF for operations.[93] The Mission Support Area, Room 111 on the first floor of the SFOF, included a large primary support area and four smaller rooms. In the main area, at least ten workstations were aligned in five rows. Printers, storage cabinets, and

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[91] McClure and Sharp, interview.

[92] Ibid.

[93] Renzetti, et. al, "Tracking and Data System Support for the Mariners Mars 1969 Mission, Planning Phase Through Midcourse Maneuver," 15.

other necessities skirted the perimeter of the walls. Room 111A, the Conference Room, contained a long, rectangular table in the center of the room and a chalkboard, bulletin board, and map of Mars on the walls. Room 111F, the Mission Director's Room, had three workstations, a bookcase, bulletin board, and chalk board, as well as the NASA phone. A large, circular table sat in Room 111G, the Mission Control Room. This room also had numerous storage cabinets and a printer. Finally Room 111H, the Observation Room, included a rectangular conference table and display board. Mariner also utilized a Spacecraft Performance Analysis Area, located next to Room 111. This area housed about thirty workstations, displays, storage cabinets, and a small conference room. A Principal Investigator's Area lay on the other side of the Mission Support Area. This room held about twenty-five workstations, storage, displays, and a conference table large enough for ten tables. Finally, the Flight-path Analysis Area was located adjacent to the Spacecraft Performance Analysis Area. This room had about twenty-five consoles, plotters, storage cabinets, and numerous televisions.[94]

One final difference between JPL and other centers must be mentioned. Controllers working on Mars missions observe the Martian day, or sol, which lasts forty minutes longer than a day on earth. While this proves invaluable to the mission, it can cause short-term problems for the individual controllers. Many can become disoriented and so focused on their new time cycle they have no concept of earth time. One controller even mentioned that after a close encounter with falling asleep at the wheel

[94] Renzetti, et. al, "Tracking and Data System Support for the Mariners Mars 1969 Mission, Planning Phase Through Midcourse Maneuver," 139-142.

while driving home after a shift, she brought a sleeping bag and pillow to her office to prevent another such occurrence.[95]

JPL's Operations Room differs greatly from JSC's MOCRs and FCRs. Rather than the main control room handling the majority of the work, for JPL's missions, the individual MSAs control the missions with few exceptions. A typical mission works out of the main Operations Room only during launch and other critical elements. The Operations Room generally remains unused, aside from the DSN controllers. JPL has also optimized the room to control multiple missions simultaneously, while JSC's control rooms generally only monitor a single spacecraft.

ESOC's Main Control Room

The European Space Operations Centre (ESOC) has served as the central control center for European robotic missions with some important exceptions. By 2010, ESOC functioned as a control center, in some capacity, for sixty ESA missions and fifty other missions.[96] The ground network station in Spain has operated a few missions. ESRIN (European Space Research Institute) houses the control for earth observation missions. Some missions have had control rooms in other centers, including the Goddard Space Flight Center and JPL. Manned missions are usually run through NASA's JSC or the European Astronaut Centre (EAC) in Cologne, Germany. ESOC employees have worked at JSC for a few missions, including Spacelab and Eureka.[97]

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[95] Laurence Bergreen, *Voyage to Mars: NASA's Search for Life Beyond Earth* (New York: Riverhead Books, 2000), 81-82.

[96] Warhaut, "ESA and ESOC Overview."

[97] Wimmer, interview.

Regardless of the location of their control center, the Main Control Room (MCR) of ESOC serves as the center for critical aspects, most especially the Launch and Early Operations Phase (LEOP), for virtually all European missions. In this way, it resembles JPL's Operations Room more than JSC's MOCRs and FCRs. The MCR has even been used for rescue operations for various non-ESA satellites. Indeed, the success of their rescue efforts has made ESOC a go-to stop for many commercial endeavors. The December 1998 agreement known as the "Resolution on the Distribution of Tasks and Cooperation between ESA and National Flight Operations Control Centres and Facilities," came as a major coup for ESOC. It stated that only ESOC would serve as the main control center for all future ESA missions, with the exceptions of the Columbus laboratory for the International Space Station and the Automated Transfer Vehicle (ATV).[98] The MCR has supported launch and early operations for Indian, French, German, and Italian telecommunication satellites, American and Indian meteorological satellites, Japanese earth observation satellites, and many more.[99]

While the majority of commands originate from ESOC, certain routine or emergency commands can be sent directly from the various ground network stations, depending on the established rules for that satellite.[100] The rules for each flight were written in a mission handbook that detailed procedures for nominal mission events as well as certain anomalies. In fact, each of the control centers had similar guidelines for each of their missions. At JSC, for instance, the Flight Control Team wrote a book called

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[98] European Space Agency Annual Report 1998, European Space Agency Headquarters Library, Paris, 97.

[99] Longdon, "ESA/ESOC 25 Years."

[100] H. Bath, "Operations Support," *ESA Bulletin* 2 (August 1975): 35.

the Flight Mission Rules.[101] These mission rule books served as the Bible, per se, for each mission. They allowed controllers to focus on more potentially pressing needs. It also avoided possible human factors from disturbing nominal work.

The layout of the Main Control Room has remained relatively constant over its decades of use, especially since HELIOS-2, which launched on 15 January 1976.[102] There are three rows of consoles. The first houses consoles for the majority of the controllers. Eight members of the Flight Control Team man the front row with three computer screens for each station. The second, smaller, row includes a console for the Spacecraft Operations Manager. The final row consists of two separate sections of consoles for various liaisons and other staff that need to be in the room during the critical parts of the missions. The left-side console includes stations for the Software Coordinator, on the left, and the Ground Operations Manager, on the right. The console on the right also has two stations. The Flight Operations Director has a station on the left and the Project Representative, who maintains contact with the Project Support Room with representatives from industry, sits on the right.[103] With shift workers included in the tabulation, there are roughly forty operations positions available in the MCR.[104]

The MCR has always consisted of consoles, which ESA argues, aid in tidiness and discipline.[105] Despite this relative constancy, the MCR must maintain a certain flexibility due to the ever-changing needs of the various different projects. The MCR

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[101] Frank, "Flight Control of the Apollo Lunar-Landing Mission," 3-4.

[102] Wimmer, interview.

[103] Warhaut, interview.

[104] Black and Andrews, *ESOC Services Catalog 2000/2001*, 5.

[105] Wimmer, interview.

depends on high reliability in a real-time environment, quick system response, guaranteed availability of data, and clarity of information in order to function properly and efficiently.[106]

[Image 3-10: The Main Control Room at ESA's Space Operations Centre in Darmstadt (2002), ESA, http://esamultimedia.esa.int/images/meteosat/10_O.jpg]

One major change to the room concerned Flight Dynamics. A glass wall originally separated the Flight Dynamics controllers on the left hand side of the room.

[106] J. Toussaint, coordinator, "Proposal of Organisation for the Control of In-Flight Activities," 15 October 1969, ESRO 6947, European University Institute Archives, Florence, Italy, 3; and Nye, *ESOC*, 11.

ESOC eliminated this wall to free up more space for engineers for multiple missions.[107] As a consequence, ESOC built a separate room for Flight Dynamics in the OCC.

The front of the room includes plotting maps and video screens, much like that at JSC and JPL. Below the screens are a series of clocks showing the local times for the stations of ESTRACK. The presence of those clocks reaffirms the importance of ESTRACK to the ESOC mission. A list of missions controlled from the MCR, called the Spacecraft Date Launcher, hangs along the top of the walls on the right hand side and the back wall. While it may be a less visual or symbolic remembrance than JSC's mission patches, it serves a similar purpose. The impressive list also adds as a visual reminder when ESOC may try to sell the MCR to potential space endeavor clients.

Like the previously examined control rooms, the MCR relies upon low lighting so the controllers can concentrate on their individual displays. The MCR walls are dark in color. In that way, the room resembles the Operations Room of JPL more closely than the mission control rooms of JSC. At one point, designers planned on replacing the paneling with lighter colored walls. Controllers balked at this idea. When asked why, Wolfgang Wimmer, lead Flight Operations Director (FOD) for fifteen missions, explained that the dark walls and directional lighting allowed him and others to focus on their consoles and information directly in front of them. Lighter walls might have been a distraction when the controllers could least afford to be distracted.[108]

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[107] Wimmer, interview.

[108] Ibid.

As an example of the constant upgrading to the room, ESOC installed new work stations in 1990 with more user-friendly SUN equipment.[109] ESOC refurbished and upgraded the MCR again in July 1994.[110] The original layout remained largely intact due to the wishes of the controllers themselves.[111] Again, in this way the structure of the MCR remained constant like JSC's MOCRs and FCRs but unlike JPL's Operations Room.

In 1988, the MCR began to use a new common software system compatible with any satellite, known as the Spacecraft Control and Operations System (SCOS).[112] Among other things, the SCOS brought major improvements including dedicated hardware configurations for each mission, reutilization of common software across programs, support for telemetry and telecommands, and the use of commercial management systems.[113] This system received an overhaul in 1997 with the new-generation Mission Control System, SCOS-II.[114] The change came for a number of reasons, including financial, functional, strategic, and greater flexibility. It was described as better for both "normal" and "critical" operations.[115] Only two years later ESOC

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[109] C. Mazza and J.F. Kaufeler, "A New Generation of Spacecraft Control System-'SCOS'," *ESA Bulletin* 56 (November 1988): 23.

[110] European Space Agency Annual Report 1994, European Space Agency Headquarters Library, Paris, 95.

[111] Wimmer, interview.

[112] Debatin, "New Ground Data- Processing System to Support the Agency's Future Satellite Missions," 78-79.

[113] Mazza and Kaufeler, "A New Generation of Spacecraft Control System-'SCOS'," 20.

[114] European Space Agency Annual Report 1997, European Space Agency Headquarters Library, Paris, 137.

[115] M Jones, N.C. Head, Ka. Keyte, and M. Symonds, "SCOS II: ESA's New Generation of Mission-Control System," *ESA Bulletin* 75 (August 1993): 79-84.

upgraded it again to SCOS-2000.[116] In 1999, a fear grew across corporations around the world that, when the year changed to 2000, computers using only two digits for the date would revert back to 1900, therefore causing unknown damage to their systems. SCOS-2000 served as ESOC's answer, replacing non-Y2K compliant systems.[117] ESOC always configured SCOS-2000 to be used in both testing and operations for satellites.[118]

At the same time they upgraded the various ground station computer systems of ESTRACK so that they could be fully automated from ESOC during routine operations.[119] Full automation brings a number of benefits. The systems can only perform a small number of duties independently, which reduces the risk of human error during these operations. Perhaps most important, it reduces the needed workforce and saves money. While emergency responders are required to stay within a set distance of each ground station if need arises, a limited number of individuals can oversee the majority of work in a more central location. Full automation has also changed the dynamic of shared ideas between ESA and NASA. Those in charge of NASA's Deep Space Network recently have begun to investigate automation for their network. Perhaps not surprisingly, they have examined ESTRACK closely for ideas and information on the process.[120]

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[116] European Space Agency Annual Report 1999, 45.

[117] Ibid., 68.

[118] "SCOS-2000: The Advanced Spacecraft Operations System," European Space Agency Publications.

[119] European Space Agency Annual Report 1999, 68.

[120] Paolo Ferri, interview by author, Darmstadt, Germany, 20 October 2010.

While computers and other equipment play a large role in missions, humans are still ultimately responsible for the success of the missions.[121] Each mission begins with a Ground Segment Manager (GSM), nominated to serve as the lead.[122] The Ground Segment Manager serves in a similar role as the Mission Managers of JPL, though specifically for the ground segments of the mission. He or she must prepare and procure the necessary resources for the mission.[123] The GSM must also maintain the ground segment within the proposed schedule and budget. The GSM acts as an interface between the ground segment and the project, working especially closely with the Project Manager. In certain cases, Heads of Divisions for mission families work as GSMs for multiple missions. The GSM further establishes operations concepts and facilities as well as directing operations during LEOP and certain routine phases.[124]

The MCR gains control as soon as a satellite separates from its launch vehicle, roughly ten to fifteen minutes after liftoff, to the end of early phase operations.[125] Satellite LEOP is conducted by the Flight Control Team (FCT) under the Flight Operations Director (FOD). The FOD is not directly involved in mission preparation so he usually joins later in the process, between six and nine months before launch, which contrasts strikingly with their counterparts at JSC who join the mission four years

[121] Longdon and David, *ESOC: The European Space Operations Centre*.

[122] Warhaut, interview.

[123] Howard Nye, interview by author, Paris, France, 12 October 2010.

[124] Manfred Warhaut, "ESOC in Context" (Powerpoint Presentation, European Space Operations Centre, Darmstadt, Germany, 23 November 2010).

[125] Nye, *ESOC*, 2; and Longdon and David, ESOC*: The European Space Operations Centre*.

prior.[126] The FOD must have a vast amount of experience in space operations as well as a familiarity with the ESOC operations environment.[127] The FOD relies upon a consensus from the other controllers in order to make major decisions.[128] The FCT consists mostly of specialists in satellite operations and flight dynamics, including the Spacecraft Operations Manager, the Ground Operations Manager, and the Flight Dynamics Coordinator.[129] FCTs may remain relatively constant over a short period of time or between similar missions, depending on each launch specification. A core team of approximately thirty controllers makes up the current FCT.[130] The FCT usually includes three or four on-call engineers, two or three on-call analysts, and six spacecraft controllers working shifts.[131] The LEOP team has always consisted of two shifts due to a lack of funds for a third shift. They therefore must work up to eighteen hours under high tension. Understandably, controllers may become overstressed, which leads to problems. Professional pride, however, reminds the controllers to maintain their focus and continue to work through the long shifts.[132]

The FOD serves as close a role to a Flight Director as ESOC has. A FOD has overall control of a mission, but many of the commands are sent without direct approval. The FOD is also remarkably different from the Flight Director because instead of making

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[126] Warhaut, interview, and Wimmer, interview.

[127] Schäfer , *How to Survive in Space, Vol. II*, 133.

[128] Nye, interview.

[129] Nye, *ESOC*, 20.

[130] Warhaut, interview.

[131] Schäfer , *How to Survive in Space, Vol. II*, 133.

[132] Wimmer, interview.

decisions unilaterally based on the given information, the FOD generally makes an assessment based on a consensus from the other controllers.[133] Also, due to the nature of ESOC operations, FODs often work on multiple missions simultaneously.

During the critical LEOP time, the MCR tests the satellite equipment to make sure it will function as needed. After the initial phase is complete, the MCR hands control over to the respective Dedicated Control Room (DCR), and it will only get involved again if needed for any other critical aspects of the mission. The DCR team can consist of members of the FCT.[134] Although the number of hours of use for the MCR is minor compared to the DCRs, they occur during the most important stages of the missions, therefore making it an indispensible part of spacecraft activities at ESOC. As Richard Nye, a former Spacecraft Operations Manager, stated, the quality of and access to the end product of missions relies on the effectiveness of mission operations at the MCR to recover from any anomalies during the mission.[135] Each mission is considered terminated at the moment the ground cannot remain in contact, regardless of the fate of the satellite.[136]

ESOC has repeatedly changed the dedicated control rooms over the course of their use. DCRs originally controlled one mission, hence, the term "dedicated" in their title. They also originally consisted of consoles, looking similar to the Main Control Room. More recently, the DCRs, as previously explained, have become control rooms

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[133] Nye, interview.

[134] Nye, *ESOC*, 21.

[135] Ibid., 3.

[136] Ibid., 29.

for families of missions. These families of missions allow for maximum synergy.[137] Over the past few years, ESOC has also been replacing the consoles with everyday office equipment, such as tables and desks, to aid in flexibility. The increased flexibility also has been increasingly important during the transition to control rooms for mission families. "Dedicated" control room may be a misnomer now, but the terminology remains as a link to the past.

Controllers in the DCRs keep constant vigil over their respective programs. Unlike the MCR, which is staffed only during critical parts of missions, DCR controllers, especially for observatory satellite missions, remain on post virtually all the time.[138] These controllers exhibit a "calm efficiency" during any crisis.[139]

The Meteosat Operations Control Centre (MOCC) is just one example of the many DCRs. In 1977, METEOSAT-1 became the first European weather forecast satellite. The MOCC served as the central facility for meteorological data.[140] Virtually all weather forecasts in Europe for the next few decades came from METEOSAT information. When METEOSAT moved out in the mid-1990s, ESOC partially refurbished the MOCC for potential International Space Station (ISS) operations.[141]

Another early DCR controlled the GEOS missions of the 1970s. The consoles included alphanumeric displays that displayed real-time data, a processing system,

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[137] Warhaut, interview.

[138] Longdon and David, *ESOC: The European Space Operations Centre*.

[139] "European Space Operations Directorate: …constant vigil," 1993, European Space Agency Headquarters Library, Paris.

[140] Beatrice Lacoste, *Europe: Stepping Stones to Space* (Bedfordshire, UK: Orbic, 1990), 56-62.

[141] European Space Agency Annual Report 1996, European Space Agency Headquarters Library, Paris, 131.

recorders for telemetry data as a function of time, graphical displays for data from the spacecraft or experiments, and keyboards to input information and interact with the computers. Scientists also had access to full control of any experiment.[142]

In 1994, ESOC completed construction work on a variety of DCRs for individual missions in preparation for the Cluster mission.[143] These DCRs, like the others, contained individual differences for the needs of the program within. It is interesting to note that the DCRs for Cluster as well as Earth Observations had windows, a stark change from most of the interior-roomed control rooms.[144] Nine years later ESOC added new DCRs for the SMART, Mars Express, and Rosetta programs.[145]

The Planetary Missions Control Room is one of the oldest DCRs still in use. This DCR uses consoles and so has not been upgraded to the office furniture used in most DCRs today. This DCR is the primary facility for many deep space missions.[146]

The Venus Express DCR reused various ground segment elements and operations from previous programs, which reduced both the cost and risk factors. This particular DCR has been called the Venus Express Mission Operations Centre, or VMOC. It includes a Mission Control System, a Data Disposition System to acquire and store data, a Mission Planning System, an independent Flight Dynamics System, and a Spacecraft

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[142] P.B. Lemke, "The Geos Ground System," *ESA Bulletin* 9 (May 1977): 53.

[143] European Space Agency Annual Report 1994, 95-96.

[144] European Space Agency Annual Report 1995, 89, 91.

[145] European Space Agency Annual Report 2003, European Space Agency Headquarters Library, Paris, 87.

[146] Warhaut, interview.

Simulator. The VMOC also includes the Venus Express Science Operations Centre (VSOC) for use during critical mission objectives.[147]

ESOC controllers view satellites as machines built to produce results, and they recognize that mission products must be optimized. As a result, they sometimes decide between quantity requirements and quality requirements. In some ways, controllers see themselves as a service entity, providing a product to a customer. Part of that service is knowing the time sensitivity of their different products, or data. Keeping this in mind, before the mission they calculate the maximum data output from their satellite and aim for at least 98.5 percent output. They even plan to save fuel in order to extend the life of the satellite, if possible or required.[148]

Controllers in the OCC can be grouped into a few different positions. Network Controllers make sure that those working in the DCRs maintain contact with anyone outside the DCR. Spacecraft Controllers are those continuously manning the DCRs. Orbit or Attitude Controllers assure that the latest information on the status of the satellite is available to anyone who might need it.[149]

There are two classes of controllers at ESOC. Engineers have extensive higher level education with usually a master's degree in a certain specialty. Engineers mostly work "normal" hours but they can be called in if an emergency occurs. They typically only work specific missions pertaining to their specialty. Operators and analysts, on the other hand, may have a technical degree. They work shifts and man the consoles twenty-

[147] Manfred Warhaut and Andrea Accomazzo, "Venus Express Ground Segment and Mission Operations," *ESA Bulletin* 124 (November 2005): 35-36.

[148] Wimmer, interview.

[149] Wilkins, "Spacecraft Operations at ESOC," 10.

four hours per day. These controllers follow strict procedures, calling an engineer if something goes awry.[150] In other words, engineers are specialists whereas operators and analysts are workmen. Engineers are almost always staff whereas the operators can be staff or, more likely, contractors. This can sometimes lead to further segmentation between the engineers and operators.[151] The staff to contractor ratio usually remains around one to three. Mission Operations currently includes eighty staff members and 230 contractors.[152]

One of the major differences between ESOC and JSC or JPL lies in the number of staff. ESOC consistently comments on the difference, which is sometimes by powers of ten, in team sizes. A controller team for a mission may consist of three engineers and a few technicians, while the Flight Dynamics team may include up to ten people.[153] Due to the staff differences, ESOC controllers often are required to work multiple missions at the same time. Howard Nye, for instance, served as an FOD for Giotto, the Spacecraft Operations Manager for Hippocrus, and the Spacecraft Operations Manager for Iso between 1989 and 1993.[154]

The challenge of the work often serves as a natural way to glean those who are meant to work the difficult job of controller from those who are not. Those who are committed are driven by the continuous changes induced by new missions and new technologies. The job naturally attracts the more adventurous. ESA employees must also

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[150] Nye, interview.

[151] Hennessy, interview.

[152] Warhaut, interview.

[153] Nye, interview.

[154] Ibid.

be open to different cultures due to the multinational staff. The few who cannot let go of their home nationality also usually do not last long. In fact, a feeling of statelessness can bring the ESA staff together.[155]

The operations in ESOC's Main Control Room resemble JPL's Operations Area more than JSC's control rooms. Like JPL, the MCR is generally only staffed during LEOP events. The majority of the controllers staff the DCRs which are located throughout the OCC. Finally, neither ESOC nor JPL have a figure with as much authority as JSC's Flight Directors, instead relying upon handbooks to provide commands for nominal control.

The majority of these similarities and differences most likely arrive out of the nature of the missions controlled at the different centers, along with cultural differences. Human spaceflight missions controlled at JSC are generally short-term, with the exception of Skylab and ISS. Thus, controllers usually work on console for roughly two weeks at a time. In contrast, nearly all missions flown out of JPL and ESOC extend for years or even decades. To keep a full staff on console for that long, as typically done for JSC missions, would be highly impractical. This has also led to the necessity of separate dedicated control rooms at JPL and ESOC where skeleton crews oversee normal operations. Operations also differ greatly in that JSC usually only controls one mission at a time, whereas JPL and ESOC have been operating multiple missions for decades.

[155] Hennessy, interview.

Budgets seem to have an effect on manning the consoles. In general, JSC has a larger budget than JPL, and both certainly obtain more funds than ESOC. JSC, therefore, can afford to pay controllers to remain on console whereas the other two must utilize as little staffing as possible.

At JSC, the Flight Director has complete control of the mission. He or she makes any necessary decision with the input of the other controllers. In the end, though, Flight takes full responsibility. None of the other control rooms has a single person with so much power. At JPL, the Mission Managers and Flight Directors are in charge, but they are not necessary for every decision. They also may differ to other controllers in certain instances. The Ground Segment Managers and Flight Operations Directors at ESOC operate in much the same way as JPL. They often rely upon a consensus between the controllers for commands. JPL and ESOC control rooms have authority figures, but none with the supremacy of JSC's Flight Director.

Finally, the presence of humans in space plays a large part in the staffing. Because JSC controlled spacecraft with humans on board, every decision made could have life or death consequences. The controllers remained constantly vigilant, and JSC wanted to assure all systems were continuously monitored. That is not to say that spacecraft controlled out of JPL and ESOC are any less important, just simply that the controllers do not have to concern themselves with loss of life in the event of an anomaly.

Despite these differences, the rooms include notable similarities. They each have generally utilized low lighting in order to allow controllers to focus on their consoles. Each has view screens at the front of the room that largely operate for the benefit of visitors. Both JSC and ESOC have always included consoles for the controllers, while JPL controllers have at times worked at tables instead.

The control rooms at each space center, like the buildings and centers themselves, have adapted to their roles. Their construction best fit their missions, and reflect both internal factors, such as technology, and external factors, such as economies, politics, and culture. Knowledge of the control rooms, their unique layouts, and their highly qualified personnel, underscores the singular work, advancements, and discoveries accomplished inside the control rooms at Johnson Space Center, the Jet Propulsion Laboratory and the European Space Operations Centre.

CHAPTER 4

CONTROL ROOM WORK

Mission control is more than just a room and its equipment. The men and women who work as controllers play an integral role in the successful completion of spaceflight missions. Flight controllers constantly train and gather knowledge for their positions so they can perform their duties to the fullest extent.

Flight controllers also perform more than simply nominal operations. Each mission requires hours of preparation and simulation. Each of the control centers acknowledges simulations as one of the key elements of their success. They have provided essential training for the anomalies that occur during virtually every spaceflight mission. Simulations have also allowed controllers to prepare for more serious problems where they have had to develop a "fix" to rescue a seemingly doomed spacecraft. While practice may not make perfect, it facilitates controllers in dealing with anomalous situations.

While the previous chapter focused on the physical layout of the control rooms, this chapter considers the human side of spaceflight operations. First, it describes the role of simulations in each of the control rooms. It then discusses a number of missions for each center where controllers have had to overcome various problems to rescue a spacecraft from near disaster. The next section compares the role of the military in each center. Finally, this chapter examines how information is exchanged both within the control rooms and with outsiders.

Simulations

To the public, mission control and the flight controllers exist only during missions to oversee flight operations. Working at a console during a mission is actually only a small portion of what happens in mission control rooms. Controllers train for months before each mission flies. Just to get on console, controllers must endure a long preparation time, often years. The majority of this training and preparation comes through simulations of missions.

Early simulations are meant to build a baseline for a mission. The simulators add few, if any, anomalies so that the controllers can prepare for how the mission should run. Slowly, the number and the difficulty of problems simulated are increased to test the controllers, the systems, and the procedures. In general, the simulators work with only one rule: there must be a viable solution to the problem. In other words, there are no *Kobayashi Maru* scenarios.

Simulations for NASA's human spaceflight missions began before the move to Houston. Before the Mercury missions flew, NASA administration realized the controllers needed some training or simulation of a flight to prepare for the real thing. They built a temporary training area near Mercury Control including separate rooms for each of the remote sites. Valuable lessons arose from those simulations, including the need for teamwork and discipline.[1] The simulations gradually became more sophisticated as technology improved, remaining an integral aspect of spaceflight success.

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[1] Kraft, *Flight*, 113-14.

Since the Mercury program, mission control recognized the necessity of simulations before actual flight. Chris Kraft stated it was one of the most powerful tools developed during Mercury. It provided experience for everyone involved: flight controllers, astronauts, and communications network personnel.[2] Simulations have been described as the "heart and soul" of mission control.[3] Many valuable lessons came out of the simulations. In fact, the simulation procedures served as one way to assess potential flight controllers. Flight directors and other officials evaluated how the controllers handled the experience of simulations and determined whether or not they were fit to work missions. Controllers sometimes made life-or-death decisions in mere seconds, and the simulations provided necessary practice and determined whether or not they were ready to make such decisions.[4] In many ways, the simulations, along with the flight rules, were the keys to a successful mission, from the controllers' perspectives.[5] With more recent shuttle and ISS missions, the astronauts and flight controllers together complete between 80 and 115 hours of integrated simulations. This number has grown smaller over the years as the training and simulation process became more efficient.[6]

There is a story about a simulation that may be apocryphal but nevertheless helps to show the importance of simulations. A flight controller on the lower level wanted to talk to a flight controller on the level above him in the original MOCRs. When he

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[2] Christopher C. Kraft, Jr., "Mercury Operational Experience," 30 April-2 May 1962, Record Group 255, W66-10, 306, National Archives, Fort Worth, Texas.

[3] Hodge, interview, 28.

[4] Gerald D. Griffin, interview by Doug Ward, 12 March 1999, transcript, JSC Oral History Collection, 2-3.

[5] Harlan, interview, 18-19.

[6] Hasbrook, interview, 16-17.

stepped up, he used his hand to steady himself by grabbing on to the top of the console. As he did so, he accidentally pushed a number of command buttons that sent commands directly to the spacecraft. If that had happened during a mission, any number of problems could have ensued. Because it was a simulation, the controllers learned from an honest mistake. As a result, they installed covers over the command buttons to avoid inadvertent commands.[7] This is just one example of how simulations can bring about unexpected but necessary changes to the mission control environment.

Simulations are equally necessary for the unmanned missions controlled at JPL and ESOC. In fact, ESOC has referred to simulations as the "most important tool for validation" of satellites.[8] Like the controllers of JSC, those at JPL and ESOC spend ten or more times as many hours training and simulating missions than at the console for the actual missions.

Aside from the usual computer simulations, JPL engineers preparing the various Mars rovers have undertaken extensive simulations with model rovers. Scientists and engineers have sought out various natural land formations thought to be similar to the surface of Mars. To demonstrate the possibilities of a rover on Mars, engineers drove a rover in the Arroyo Seco near Pasadena.[9] A model *Sojourner* ran through numerous tests in the Channeled Scablands in Eastern Washington state.[10] NASA scientists have deemed Iceland a Mars analogue since the Viking program of 1976. Numerous scientists

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[7] Loe, interview, 30 November 2001, 3-4

[8] Nye, *ESOC*, 17.

[9] Andrew Mishkin, *Sojourner: An Insider's View of the Mars Pathfinder Mission* (New York: Berkley Books, 2004), 76-79.

[10] Bergreen, *Voyage to Mars*, 75.

preparing for subsequent Mars programs have visited the most desolate areas of the country in an attempt to anticipate what they will encounter through the rovers on the distant planet.[11] At least one scientist also journeyed to the remote Navassa Island between Jamaica and Haiti.[12] In fact, these treks call to mind the geological expeditions of the Apollo astronauts before their visits to the lunar surface.

Most rovers have also gone through extensive testing in man-made environments. For *Sojourner*, for instance, JPL prepared a room with sand and various rocks, which appropriately enough they called the sandbox. With curtains drawn to prevent outsiders from looking in, personnel rearrange the rocks to present a different test surface. Controllers then must use the onboard cameras to take images of the environment and move the rovers around just as they would on the Martian surface, complete with a time delay.[13] Such real-life simulations can prove invaluable to the engineers and controllers as they prepare for upcoming missions.

For the *Sojourner* project, JPL first built mock rovers of various sizes, from eight inches to the size of a truck, to prove the feasibility of the mission. In this case, the primary test vehicle was the System Integration Model (SIM), better known as *Marie Curie*. After they built the actual rover, it underwent months of tests. Full tests must include simulated sun and stars, light, and temperature. For the month before launch, after the spacecraft had been placed on the launch vehicle, JPL technicians tested the DSN to assure communication links. Controllers, meanwhile, simulated practice

[11] Bergreen, *Voyage to Mars*, 4.

[12] Ibid., 252-255.

[13] Bergreen, *Voyage to Mars*, 81; and Mishkin, *Sojourner*, 127.

countdowns. Following the launch, the spacecraft flew in transit for approximately six months, during which controllers and engineers completed their final simulations. They utilized both computer simulations and model rovers in the sandbox. The Operations Team even conducted more field tests of *Marie Curie* in the Mojave Desert. By this time controllers had already transferred to the slightly different Mars time in preparation for on surface activities. When the spacecraft reached its destination, the engineers and controllers were ready for virtually any potential problem.[14]

It took some time for ESOC to produce effective simulations. Simulators during the first decade of control at ESOC were limited due to technological restrictions. In 1977, new simulators began to produce telemetry and accept telecommands for more complete and accurate simulations. These came online for the GEOS missions.[15]

ESOC also produced videos for the initial training of controllers. Those videos were not used to great extent because they were not as effective as training through simulations. ESOC also focused on simulations for training to emphasize the team rather than the individual. In the control room, controllers must always be aware of how their actions relate to the entire team. Controllers acting individually could potentially compromise the rest of the team.[16]

Rescue Missions

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[14] Bergreen, *Voyage to Mars*, 71-81. Also see Mishkin, *Sojourner*, 76-79, 92, 106, and 131-33.

[15] Gujer and Jabs, "Use of Spacecraft Simulators at ESOC," 41.

[16] Stainer and Dworak, "Training in Satellite Ground-System Operations," 67-68.

Spaceflight is risky business. Volatile chemicals are used for propellants or for other systems. The spacecraft themselves involve countless wires, switches, and other elements that must be installed with the greatest care in order to function properly. Spacecraft fly through one of the most hazardous environments known to humanity with wildly fluctuating temperatures, radiation levels, and other potential dangers. With millions of variables, problems inevitably will occur. Simulations cannot predict every possible malfunction, so controllers must be trained to react to these anomalies as best as possible. A few instances stand out as prime examples of how flight controllers have found solutions to save missions from sure disaster.

The flight controllers of JSC must always remember that their decisions can mean life or death for the astronauts in space. If a problem arose during a flight, therefore, the controllers were trained to react carefully. In fact, they were told that unless they knew exactly what was happening and how to fix it, they were to do nothing. They were to verify the complete extent of the problem before they tried to fix it, otherwise they may have made it worse. There was to be a measured balance between taking the time to recognize the entirety of the problem and to find a solution as quickly as possible. Many flight controllers point to Apollo 13 as the prime example of this theory in action.[17]

The first three days of Apollo 13's flight went by nearly perfectly. After a television broadcast on the third night, the EECOM requested a routine stir of the cryogenic tanks before the astronauts began their sleep cycle. The cryogenic tanks hold liquid oxygen and liquid hydrogen, which produce electricity, oxygen, and water, probably the three most important elements for human spaceflight. The gases would

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[17] Lunney, interview, 9 March 1998, 46.

settle into layers of different temperatures and densities, so it was vital to stir the tanks with small fans to prevent layering and allow for accurate readings.

The astronauts actually recognized something had gone wrong before the controllers. Across the control room, controllers began to see unusual readings, but most immediately presumed it was simply bad data or instrumentation problems and nothing serious. The flight director on console, Gene Kranz, did not know of any difficulties until the now famous call from astronaut Jack Swigert: "Okay, Houston, we've had a problem." Kranz asked the flight controllers for more information, but few could provide any answers.

The next few minutes were punctuated by confusion and misinformation. Mission control protocol held that controllers would not act without full knowledge of the best course of action, but reports coming in from the astronauts required some response. The immediate concern arose from one power distributor showing no power and the other continually dropping. As the EECOM talked with his support room, other flight controllers began to call those not at consoles to come to the MOCR for additional help.

One of the controllers in the Spacecraft Analysis Room phoned John Aaron, who was at his home preparing for some much needed rest. As the SPAN controller told him the status and readings, Aaron immediately recognized they had a real problem, not just faulty data. He rushed to the control center where he found it took some time to convince controllers they had a spacecraft not an instrument problem.

Not only was Apollo 13 losing power, but it was also losing oxygen. More than an hour after the accident began, flight controllers requested the astronauts close the reactant valve for Fuel Cell 1 to stop the venting of oxygen. While the crisis had been placed on temporary hold, the command module did not have enough power or oxygen to keep the astronauts alive long enough to return home. Flight controllers recommended a desperate solution: use the lunar module as an emergency "lifeboat" for the crew's return trip.

The lunar module (LM) was designed to sustain two astronauts for up to forty-five hours. Instead, it would have to keep three astronauts alive for between seventy-seven and one hundred hours.[18] Before transferring to the LM, the astronauts had to power down the command module in a matter of minutes, a procedure designed to take hours. After a successful transition, the controllers had to focus on how to bring the astronauts back safely to earth.

Gene Kranz, whose team had been on console during the first hour of the ordeal, took drastic action. He decided to take his team off console for the remainder of the mission, until reentry, so that they could focus on determining how best to overcome the many anomalies. Kranz placed John Aaron in charge of designing a procedure to power up the command module for reentry using the minimum amount of power left after the accident.

The controllers quickly agreed to use a free-return trajectory, allowing Apollo 13 to continue to the moon and using lunar gravity to propel the spacecraft back to earth. In the meantime, controllers also devised a pump to scrub the carbon dioxide levels and preserve life-saving oxygen. The astronauts and controllers worked through a number of other smaller incidents, and three days after the accident, Apollo 13 successfully returned to earth.

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[18] Andrew Chaikin, *A Man on the Moon, Vol. II: The Odyssey Continues* (Alexandria, VA: Time-Life Books, 1994), 119.

Apollo 13 has been called the "successful failure." The number of problems and failures overcome by NASA has never been equaled. In fact, the extent of the failures was so great that NASA acknowledged they could not have simulated such an accident because it would have been dismissed as not realistic.[19] While Apollo 13 is the most famous rescue mission, it was neither the first nor the last such episode.

When Neil Armstrong and Buzz Aldrin landed on the moon on Apollo 11, they cemented their place in history. Few people realize how close they came to never actually landing. As the astronauts began their descent, an alarm sounded with the designation 1202. The Guidance support room recognized this as an indication of information overload. Essentially, the computer was receiving too much information and was attempting to start from the beginning of its computation list. While this was not a normal reading, it was not so critical that the landing could not continue. The controllers told the astronauts to ignore the alarms and identify any subsequent alarms. Interestingly, the contollers knew of this situation almost solely because of a simulation with a similar reading just fifteen days earlier.

Similar alarms would register for the remainder of the landing. Although the controllers could not be certain that nothing was wrong because they did not know the cause of the alarm, the training and simulations told them that the best decision was to continue the landing. Without the fortuitous simulation two weeks prior, the controllers

[19] There are many good sources for further details on Apollo 13. In particular, please see: Murray and Cox, *Apollo,* 377-434, Chaikin, *A Man on the Moon, Vol. II,* 95-172, and Jim Lovell and Jeffrey Kluger, *Lost Moon: The Perilous Voyage of Apollo 13* (1994).

may not have known the nature of the alarm and might have incorrectly aborted the landing.[20]

While John Aaron played a major role in the recovery of Apollo 13, he actually made his mark more during the launch of Apollo 12. On 14 November 1969, Cape Canaveral experienced rainstorms to the extent that NASA considered postponing the launch. After much consultation, they decided to go ahead with the launch suspecting no major damage to the vehicle.

Thirty-six seconds after launch, Commander Pete Conrad noticed a flash outside the window. Static filled the communications. Fifty-two seconds after launch, the astronauts told mission control that they had lost power to their guidance systems. NASA would not realize until reviewing the tape that the spacecraft flying through the clouds acted like a conductor and had been struck by lightning twice, causing the electrical systems to overload and short out. Mission control continued to receive information from the Saturn V launch vehicle, but no data from the command module. There was a possibility that this lack of data resulted from problems in the ground network, but that was dismissed when the astronauts further stated that they had numerous alarms sounding and had lost all power, save emergency batteries. The situation looked dire, and Flight Director Gerry Griffin prepared to abort.

John Aaron, working the EECOM console, recognized a similarity in the errors he was reading. A year earlier, during a test of systems, his screens had registered nearly unintelligible values. Being naturally curious, he studied the test and contacted those in charge to find out the problem. With the help of other experts, he eventually found that

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[20] Murray and Cox, *Apollo*, 338-46; Chaikin, *A Man on the Moon, Vol. I*, 293-98; and James R. Hansen, *First Man: The Life of Neil A. Armstrong* (New York: Simon and Schuster, 2005), 458-75.

the power had dropped from the module and could be fixed by an obscure switch called signal-condition equipment, or SCE.

The pattern in the data caught Aaron's attention. He quickly told the Capcom to suggest the astronauts change the SCE switch from "Off" to "Aux" or "Auxiliary". After Lunar Module Pilot Alan Bean performed the switch, and the fuel cells were reset, the systems came back on and Apollo 12 was eventually allowed to complete its mission. Apollo 12 was saved in part because Aaron was the only controller who recognized the problem and the correct solution, and in part because, in another twist of fate, Bean was perhaps the only astronaut who knew the location and nature of the SCE switch.[21]

America's first space station, Skylab, provided a series of other tests for the controllers on the ground. Only a minute after the launch of the space station, the force of the launch ripped off the micrometeoroid heat shield. Nine minutes later, one solar array broke off while the other was not able to deploy fully due to an obstruction. The loss of the shield caused the station to heat up to dangerous levels, while the lack of fully deployed solar arrays limited the power in the station. The launch of the first crew, originally scheduled for the following day, was postponed ten days until engineers across NASA could devise a solution for the two problems.

During those ten days, mission control endured some of its most trying times for the Skylab mission. They had to monitor the station constantly. In order to produce the most power, the auxiliary solar panels for the telescope needed to be pointed toward the sun, but this orientation also left the area of the station missing the heat shield exposed

[21] Murray and Cox, *Apollo*, 361-69; Chaikin, *A Man on the Moon, Vol. II,* 20-23; and Nancy Conrad and Howard A. Klausner, *Rocket Man: Astronaut Pete Conrad's Incredible Ride to the Moon and Beyond* (New York: New American Library, 2005), 166-70.

and temperatures soared. The controllers then had to reorient the station in order to cool it down. These roll maneuvers had to be carefully timed to balance the power needed for the station and moderate the temperatures inside.

Once the astronauts finally began living onboard Skylab, the controllers settled into a routine. Small problems seemed to arise constantly to the extent that the men who worked on Skylab became known as "astronaut repairmen."[22] While the astronauts carried out each fix, controllers and other ground personnel had to devise the procedures.

The second crew alone had to repair the station's gyros, which maintain stability, replace the heated water dump probe, replace the tape recorders in the laboratory, remove circuits in a video tape recorder, and fix leaks in various systems.[23] One of the more amusing examples of repairing the station occurred during the first mission. While Commander Pete Conrad was outside the station for an EVA, mission control relayed a strange request. One of the batteries was not working properly, so in the age-old story of kicking or hitting something mechanical or electrical if it does not work, Conrad was told to tap the area with a hammer. When he did so, the battery sprang back to life.[24]

ESOC is perhaps the most accomplished control room for rescuing missions. While ESOC has never lost a mission, it has rescued a number of missions for other organizations.[25] The first rescue mission for ESOC occurred with TD-1A, which launched on 12 March 1972 as an astronomy satellite. By the end of May, all the tape

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[22] Thomas Y. Canby, "Skylab, Outpost on the Frontier of Space," *National Geographic* 146, no. 4 (October 1974): 457.

[23] David J. Shayler, *Skylab: America's Space Station* (London: Springer, 2001), 212.

[24] Paul J. Weitz, interview by Rebecca Wright, 26 March 2000, transcript, JSC Oral History Collection, 66.

[25] Wimmer, interview.

recorders on the satellite had failed. As a result, for about two years, ESOC personnel were required to work in seven mobile stations located around the world with an additional seventeen ground stations in order to collect as much information as possible from the direct signal downlinks.[26]

A few years later, problems during the April 1977 launch of the GEOS-1 satellite to investigate the magnetic environment in space placed the satellite in a bad orbit. Over five days of hard work, the controllers fixed the orbit to the best of their abilities, which allowed the spacecraft to continue its scientific mission.[27]

One of the most heralded efforts to come from ESOC was the Giotto program. It was originally designed and built for a close encounter with Haley's Comet. Symbolizing the potential success of increased international efforts in space, Giotto ESA controllers worked with those of NASA and Russia to locate the comet.[28] Information travelled from the Soviet Vega through NASA's DSN to ESOC, in true international cooperation.[29] After a successful rendezvous, the engineers placed it in hibernation. In 1990, controllers reactivated the satellite after four years of hibernation in order to attempt another rendezvous, this time with Comet Grigg-Skjellerup in 1992. This marked the first time that a satellite had been placed into hibernation and reactivated years later, an important accomplishment with major implications for future deep space missions. This also marked another instance of international cooperation since ESOC

[26] A. Smith, et. al, "Lost in Space?-ESOC Always Comes to the Rescue," *ESA Bulletin* 117 (February 2004): 56.

[27] Ibid., 57.

[28] European Space Agency Annual Report 1986, 132.

[29] "European Space Operations Directorate: …constant vigil," and Wimmer, interview.

controllers were able to use NASA's DSN station in Madrid to contact Giotto.[30] Giotto was a major public relations success story for ESOC.[31]

The Hipparcos mission, focusing on star measurements, remains one of the most important recoveries in spaceflight history.[32] Launched in August 1989, Hipparcos experienced the failure of an apogee boost motor shortly after liftoff, leaving the satellite stranded in its transfer orbit. Controllers worked tirelessly to implement a revised mission plan. After more than three years in orbit, Hipparcos completed all of its stated objectives.[33]

Another satellite launched in 1989, Olympus, required a rescue mission. This telecommunications satellite was controlled out of Fucino, Italy. During its mission, the satellite experienced major onboard failures and even lost 50% of its solar powers. It later began to tumble out of control after switching to safe mode. In 1991, ESOC controllers were called on to thaw its frozen batteries and propellant and regain control. After their success, Olympus continued in service until 1993.[34]

ESOC remained the most successful rescue control center in the world in the 1990s. In 1998 controllers lost contact with SOHO, a satellite which they had launched in 1995. ESA and NASA engineers working together were able to approximate the location of the satellite and pick up its signal for two to ten seconds. After three months of efforts, the controllers successfully reoriented SOHO to the sun and regained contact.

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[30] Lacoste, 142.

[31] Schäfer , *How to Survive in Space, Vol. I*, 168-169.

[32] Smith, et. al, "Lost in Space?- ESOC Always Comes to the Rescue," 58-59.

[33] Nye, *ESOC*, 4.

[34] Smith, et. al, "Lost in Space?- ESOC Always Comes to the Rescue," 59-60.

Another satellite launched in 1995, ERS-2, began to exhibit gyroscope failures in 1997. By February 2000 ESOC controllers had established a new control mode to fix the problem. Huygens, which had launched in October 1997, experienced problems with its radio link in February 2000. Again, controllers fixed the problem in September 2003. During this time, ESOC continued to help with the recovery of satellites for other entities. For instance, controllers fixed the orbit of Artemis, a Telespazio satellite launched in July 2001. ESOC also helped rescue the ETS-VII and COMETS satellites for NASDA, the Japanese space agency.[35] ETS-VII, a satellite built to test robotic rendezvous, began to spin on its axis, and in roughly five hours, ESOC was able to establish contact, uplink a software patch, and reorient the satellite. COMETS, a broadcast communication satellite, endured a partial failure during launch and could not reach its intended apogee. In order to accommodate this problem, ESOC supported NASDA with emergency assistance through ESTRACK using infrastructure from ETS-VII.[36]

Due to these rescues and the success of ESA missions in general, ESOC controllers have been lured away by various private companies in need of well-trained controllers, which can be difficult to find. Higher salaries in the private sector can serve as an especially intriguing enticement.[37] This problem plagues government organizations across the world.

From its inception, ESOC, and the earlier, ESDAC, was not only an international workplace but a fully integrated facility. Women have long played a major role in its

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[35] Ibid., 60-63.

[36] B. Battrick, ed., *Supporting Europe's Endeavours in Space: The ESA Directorate of Technical and Operational Support* (Noordwijk, The Netherlands: ESA Publications Division, 1998), 14-16.

[37] Schäfer , *How to Survive in Space, Vol. II*, 25.

operations. The ESRO General Report from 1969 includes a photograph of a female operator in the Darmstadt facilities.[38] Former ESOC director Felix Garcia-Castañer attributes the centre's success to the dedication and enthusiasm of the employees.[39]

JPL's most famous failures have been so catastrophic that fixes were impossible. Yet JPL controllers have been able to come up with alternatives. One example of controllers working around problems came with the launch of the two Voyager spacecraft. Shortly after the launch of Voyager 2, the science boom failed to fully deploy. Fortunately, the satellite and its experiments continued to work properly. More troubling, the orientation of the spacecraft erratically changed without warning. This not only caused problems for alignment, but also used up propellant at a higher rate than expected. Controllers determined that neither of these issues would cause a mission abort.

Meanwhile, engineers had time to learn from those mistakes and fix some of the problems with Voyager 1 before its launch. Interestingly, the designers had given the satellites so much autonomy that the controllers could do little more than watch and hope as Voyager 2 tried to correct itself. JPL personnel also ran into some issues as Voyager flew. Some controllers began to work on the next proposed project: Galileo. Others were so consumed with correcting problems with the Voyager spacecraft that they fell behind in their planning for the planetary encounters. Controllers had to update the onboard systems continually as the spacecraft flew farther away from the earth and the

[38] European Space Research Organization General Report 1969, 84.

[39] Longdon, "ESA/ESOC 25 Years."

sun. After some reorganization and an increased budget, Voyager eventually outperformed its original goals.[40]

Missions to Mars have overcome some near disasters as well. After Pathfinder landed on the Martian surface, for instance, the controllers recognized a potential problem. The air bags used to land the spacecraft surrounded the petal the rover would drive down. During simulations, the rover had caught on the air bags which then covered the solar panels on the rover and caused it to die. Using information gained from those tests, controllers sent commands to raise the petal, retract the air bags, and then redeploy the petals. This maneuver allowed the mission to proceed as planned.[41]

Controllers must also adapt to unexpected problems. In 2009, five years after landing Mars, the rover *Spirit* got bogged down in the Martian soil. The team attempted to free the rover for almost eight months, testing various procedures in the JPL sandbox. With the Martian winter rapidly approaching, JPL decided to save the remaining solar power and stop extrication efforts. Instead, the team used *Spirit* as a stationary platform, conducting experiments otherwise impossible with a mobile rover. For instance, it was able to test the planet's wobble, perform a concentrated study on the nearby soil, track the movement of particles by wind, and observe the atmosphere.[42] The rover continued its mission for two months until JPL lost contact on 22 March 2010. Controllers persisted in sending signals with no effect for over a year until JPL officially ended its mission on 25

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[40] Henry C. Dethloff and Ronald A. Schorn, *Voyager's Grand Tour: To the Outer Planets and Beyond* (Old Saybrook, CT: Konecky & Konecky, 2003), 138-41; and Westwick, 186-88.

[41] Bergreen, *Voyage to Mars*, 86-87.

[42] Guy Webster and Dwayne Browne, "Now a Stationary Research Platform, NASA's Mars Rover Spirit Starts a New Chapter in Red Planet Scientific Studies," 26 January 2010, Jet Propulsion Laboratory, California Institute of Technology, http://marsrover.nasa.gov/newsroom/pressreleases/20100126a.html, accessed 9 February 2012.

May 2011.[43] In the end, the rover's operations lasted more than six years, well past the planned three months. *Opportunity* continues its mission on Mars.

Role of the Military

Since its inception, NASA has had an uneven relationship with the military. While the two have worked closely together, there has always been a strict distinction between the two. In many ways the demarcation of the relationship began when President Eisenhower intentionally created a civil, nonmilitary space agency. This distance between the two paralleled the president's warning of a military-industrial complex.

Despite NASA's makeup as a civil agency, and despite Eisenhower's wish to keep it completely separate from the military, interactions abound. The early manned spaceflight programs relied upon spacecraft that splashed down in the ocean, where the United States Navy was the only organization with the infrastructure and experience to effect recoveries. Thus, the mission control center included a separate room for the Department of Defense recovery operations and the MOCRs had a console for the DOD.

Mission control has had a strong military presence due to the abundance of early controllers with military backgrounds. Some, like Gene Kranz, had flown in Korea as an Air Force pilot. Many others had worked for the military as air traffic controllers, signal operators, communications experts, or missile trackers. This common military experience created a military-like air in the room and a dedication to discipline.

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[43] Guy Webster, "NASA's Spirit Rover Completes Mission on Mars," 25 March 2011, National Aeronautics and Space Administration, http://www.nasa.gov/mission_pages/mer/news/mer20110525.html, accessed 9 February 2012; and Guy Webster and Dwayne Brown, "NASA Concludes Attempts to Contact Mars Rover Spirit," 24 May 2011, Jet Propulsion Laboratory, California Institute of Technology, http://www.jpl.nasa.gov/news/news.cfm?release=2011-156&cid=release_2011-156, accessed 9 February 2012.

Although later classes of controllers tended to have less military experience, the precedent remained largely intact.

Perhaps unknown to the general public, the military presence grew stronger during the shuttle years with numerous classified DOD missions. Controllers had to pass a security clearance in order to work those missions. The majority of the DOD missions are still classified, so specific information available remains scant, though many are believed to revolve around spy satellites.

When the Jet Propulsion Laboratory joined NASA, the center's close relationship with the military became even more contentious. There had been a long history of uneasiness between JPL, Caltech, and the military. When the laboratory became part of the civilian space agency, it naturally transitioned more toward Caltech and away from its military ties. JPL did finish projects already begun for the military, but it had little to no work with the military until the 1980s.

During the 1980s, partially as a response to the cutbacks, NASA increasingly interacted with the Department of Defense. While the shuttle flew DOD satellites into orbit and conducted other classified missions, JPL renewed its relationship with the military. This also revived many of the old arguments about the triangle between JPL, Caltech, and the military, especially regarding classified work.[44] The military presence was not as pronounced as previously, but it remained an important aspect of JPL's diversification efforts.

While NASA was created as a civilian agency with some military ties, ESA was established as a strictly civilian, or nonmilitary, venture. This joint European space

[44] The relationship between JPL and the military is covered in detail in Koppes, especially chapters 6, 8, and 9.

organization could not have any direct ties with any military aspects. They realized that some of their technology may be adapted to be used for military purposes, but their original intent must be for peaceful purposes.[45] This strict adherence to civilian uses reflects the European post-World War and Cold War mentalities. The European community realized that technology was the key to rebuilding their countries and economies, but they feared anything that might lead them back down the road to a recurrence of the previous wars. They felt that avoiding military ties altogether was the best way to accomplish those goals in the rebuilding process.

It should be noted that, in stark contrast to NASA and ESA, the Soviet control center has always had strong military ties. The center fell under various military branches, first N11-4 then the General Staff of the Strategic Missile Forces. The vast majority of controllers were military officers. Flight director equivalents included Colonel Andrey G. Karas, Colonel Amos Bolshoy, and Major General Pavel A. Agadzhanov. One exception to the rule arose with the deputy flight director, or technical leader, who was almost always a civilian from the design bureau. This heavy military presence probably occurred due to the Soviet government's need for strict control over the space agency that many of the best technical minds already worked for the military.[46]

Information Exchange

Controllers in each of the centers must process vast amounts of information. Each station, however, is just one part of a much larger organization. Even if their data seems

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[45] Krige and Russo, *A History of the European Space Agency, Vol. 1*, 16, 22-23.

[46] Asif A. Siddiqi, *Sputnik and the Soviet Space Challenge* (Gainesville, FL: University Press of Florida, 2003) 263; and Asif A. Siddiqi, *The Soviet Race with Apollo* (Gainesville, FL: University Press of Florida, 2003), 534-38.

perfect, it may hint to anomalies in other systems. If they are too focused on their own work, they may miss a critical point where their information could solve another controller's problem. Controllers must constantly communicate with each other to understand the bigger picture of the mission.

This vital aspect of mission control has already been illustrated with the Apollo 13 rescue operation. If the EECOMs had focused solely on their own data, they may have persisted in thinking that it was only an instrumentation issue. By understanding that other controllers were experiencing faulty data, and by examining the larger picture of the mission, they were able to refocus on the true nature of the accident and work towards a solution.

Flight controllers in each of the control centers must be not only good engineers, but also good operators. As Gene Kranz explained, an engineer knows how a system works theoretically. An operator must know the theory, as well as have the knowledge and experience about how systems work together to accomplish a mission. Controllers must have knowledge well beyond just their individual system and responsibilities.[47] To gain this knowledge, however, JSC, like the other control centers, does not provide formal training. Instead, the controllers needed to teach themselves the technical aspects of their systems. Many times the various controllers working the same console worked together to gain that information. They could then create a more comprehensive knowledge base that would be used to create the flight rules for each mission.[48]

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[47] Kranz, *Failure Is Not An Option*, 59.

[48] Loe, interview, 7 November 2001, 7-8.

Communicating within control rooms can be chaotic. JSC's mission control is especially famous for its nearly unintelligible voice loops, or voice communication systems. Controllers use headsets to plug in to different voice loops. For instance, if they need to talk with their support rooms they can simply switch over to their dedicated back room voice loop. Most remain on an open flight director loop where all conversations can be heard at once. At any one time there can be dozens of voices talking. To the novice, it can be disorienting or even appear to be pandemonium. Controllers must quickly learn to drown out the majority of the voices as white noise while listening for key words. If they cannot do so, they will not last long in mission control. A trained human ear remains a necessity in the seeming chaos of mission control.

Written communications could be as simple as passing a note to a nearby controller. The MOCRs of JSC utilized vacuum tubes for more formal interactions. For instance, the old consoles did not include printers, so if they needed a printed image of a screen they pressed the appropriate button and it printed in a separate room. The printer operators then placed the document in the vacuum tube and sent it to the proper controller.

Email and the internet have changed information exchange in control rooms much as they have for everyday life. Communication now is virtually instantaneous, or at least as instantaneous as the controller's access to email service. Some systems have even advanced to the point where controllers can access them online and complete their work from their home or office. While this does not invalidate the necessity of a control room, controllers will take advantage of any technology that makes their job easier.

During Gemini and Apollo, all communications between the mission control in Houston and astronauts in space were open communications. Anybody with the capability could listen to those conversations, which was most notably used by the press. Before Skylab, NASA agreed that, with an extended-duration mission, the need for private conversations might arise. There might be emergency situations that did not need to be shared with everyone, and certain communications between the astronauts and flight surgeon might need doctor-patient confidentiality. Therefore, NASA added a private line for communications with mission control.[49] This idea was met with some reservations; however, it proved to be a wise change for future missions and has continued to the present. Since JPL and ESOC do not communicate with humans in space, they do not need to maintain open communications.

All of the work in the control rooms would be for naught without the technology to relay communications to the spacecraft in space. Both NASA and ESA have constructed intricate networks of antennas and satellites to communicate with objects in space. How those systems are structured and how they have functioned provides a vital context to understand fully the complexities of mission control as the center of a large-scale technology system.

[49] NASA Press Release, 1973, Skylab Air-to-Ground 7637, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.; and James C. Fletcher, "Private Communications for Skylab," Memorandum, 3 May 1973, Skylab Air-to-Ground 7637, National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.

CHAPTER 5

COMMUNICATION NETWORKS

The control rooms are just one aspect of the ground systems of space agencies. The ground segments also include launch complexes, research and development, and the entire infrastructure that makes work in space possible. Communication networks serve as vital links between the ground segment and the spacecraft. Without the antennas, receivers, transmitters, and other equipment spread across the world, controllers could not receive data from the spacecraft nor could they communicate with the astronauts and spacecraft.

The communication networks also serve as integral aspects of international diplomacy for the space agencies. The space programs have to find appropriate areas for the equipment in friendly countries. They also must coordinate construction of and work on the antennas in the various countries. The foreign relations aspects played an especially important role during the Cold War when space programs were an avenue for the superpowers to display their prominence.

Each control room developed its own communications network. JSC has primarily used the Manned Space Flight Network (MSFN), which became the Space Tracking and Data Network (STDN) and transitioned into the Tracking and Data Relay Satellite System (TDRSS). JPL operates the Deep Space Network (DSN). ESOC has its own European Space Tracking (ESTRACK) network. Although those are their primary communication networks, each control center has utilized the others' networks at some point to monitor their missions.

Each of the networks is largely concerned with tracking spacecraft and handling communications between controllers on the ground and objects in space. The only major difference arises in the scope of their work. The STDN and TDRSS track near-earth spacecraft, especially the manned NASA programs. The DSN, as the name suggests, monitors deep space spacecraft for JPL and other space organizations. ESTRACK has the capacity to communicate with spacecraft in both near and deep space.

The accumulation of data differs greatly between near-earth and deep space missions. For deep space missions, the network generally has prolonged amounts of time of direct contact with the satellites due to the distance. Because signals must travel over vast distances, their strength decreases while there is the commensurate time difference between signal start and acquisition. Near-earth satellites, on the other hand, have much stronger signals, but the passes over antennas are much shorter. The network usually needs more stations because the decreased line of sight in comparison to deep space missions means each antenna can provides less coverage of the sky. Both types of missions have their own communications advantages and disadvantages which in turn inform the placement of the network sites. [1]

This chapter will discuss each of the networks, examining their components and the location of their communications facilities. It will also focus on the international politics of the communication networks, a vital aspect of their history. An understanding of the communications networks provides vital information about the work of the control

[1] Jay A. Holladay, interviewed by Jose Alonso, 9 July, 11 September, and 30 September 1992, transcript, Jet Propulsion Laboratory Archives Oral History Program, 39-40.

rooms and how they manage technological networks on the ground as well as controlling spacecraft.

Manned Space Flight Network to Tracking and Data Relay Satellite System

Mission control cannot speak with the astronauts directly, so some kind of intermediary is necessary to transmit communications. In order to make the links as effective as possible, NASA and other space agencies adhered to a number of considerations when setting up their networks. One of the most important was spacing the antennas in appropriate areas for the most coverage as possible. Due to the lack of land in certain areas of the earth this proved difficult, but they did their best to make up for any gaps, including using ships. Maintaining stations in foreign nations could lead to interesting international political intrigue, which meant that NASA preferred to deal with countries friendly to the United States.

NASA's manned spaceflight program used three different networks of communications for various missions. At first, the Space Tracking and Data Acquisition Network (STADAN) was based out of Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. It was primarily concerned with near-Earth orbit satellites. The Deep Space Network (DSN) is still controlled through the Jet Propulsion Laboratory. The Manned Space Flight Network (MSFN) served as the primary communications network for JSC during the Mercury, Gemini, Apollo, and Skylab missions. Following Skylab, the STADAN and MSFN merged to form the Spaceflight Tracking and Data Network (STDN). In 2009, JSC formally replaced this with the Tracking and Data Relay

Satellite System (TDRSS). The NASA Communication Network (NASCOM) served as a relay network between the antennae and the control centers for each of the networks.

STADAN began as the Minitrack Network in 1957, the first American satellite tracking network. The original Minitrack Network included six South American sites, namely: Havana, Cuba; Quito, Ecuador; Lima, Peru; Antofagasta, Chile; and Santiago, Chile. Sites in North America included the following: Blossom Point, Maryland; San Diego, California; Fort Stewart, Georgia; Coolidge Field, Antigua; and Grand Turk Island. NASA built another site in Woomera, Australia, shortly after the network came online. Over the course of its history, STADAN site locations have been fairly fluid, depending on the needs of the satellites.[2]

Minitrack was operational in time for the first Sputnik launch. After some calibrations, the different sites were able to track Sputnik, giving them some practice and experience before NASA's first satellite flights. NASA integrated Minitrack immediately, along with what would become the GSFC. Between 1958 and 1962, Minitrack made a number of changes regarding station locations. NASA added sites in Fairbanks, Alaska; East Grand Forks, Minnesota; St. John's, Newfoundland, Canada; and Winkfield, England. They also closed down the site in Antigua. NASA moved the Havana site to Fort Myers, Florida, after the Cuban Revolution.[3]

Between 1962 and 1966, Minitrack slowly transformed into STADAN with newer, bigger antennas and some consolidation of sites. Fairbanks received the first

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[2] William R. Corliss, *Histories of the Space Tracking and Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM)* (National Aeronautics and Space Administration, 1974), 3, 23-24.

[3] Ibid., 29-30, 36-37, 42-43.

twenty-six-meter antenna in 1962. As larger antennas provided better coverage and stronger signals, NASA required fewer sites. By 1965, STADAN had twenty-two sites around the world, though NASA closed six the following year. Just seven years later, NASA consolidated STADAN to ten major sites: Canberra, Australia; Fairbanks, Alaska; Goldstone, California; Quito, Ecuador; Santiago, Chile; Rosman, North Carolina; Fort Myers, Florida; Winkfield, England; Johannesburg, South Africa; and Tananarive, Madagascar.[4]

The Manned Space Flight Network had some origins in pre-NASA work but only truly began after the creation of the space agency and the beginning of Project Mercury. NASA realized that in order for their missions to have proper ground control, it would need both a network of communication antennae and a way of transferring those communications back to mission control. NASA thus created what would become the MSFN and NASCOM. On 30 July 1959, NASA contracted with Western Electric, Bell Laboratories, Bendix, Burns and Roe, and IBM, to build the first series of radars, the Mercury Network. NASA also decided to build a computer complex, consisting of a primary IBM 7090 computer and one backup, at Goddard to handle incoming communications and link to the Mercury Control Center. NASA built a backup computer center in Bermuda.[5]

NASA located network sites in Cape Canaveral, Florida, Grand Bahama Island, Grand Turk Island, Bermuda, Grand Canary Island, Kano, Nigeria, Zanzibar (Tanzania), Muchea and Woomera, Australia, Canton Island, Kauai, Hawaii, Port Arguello,

[4] Ibid., 48, 57, 61.

[5] Ibid., 86, 95, 100.

California, Guaymas, Mexico, White Sands, New Mexico, Corpus Christi, Texas, and Eglin Air Force Base, Florida. They also maintained two ships with tracking equipment in the Atlantic (*Coastal Sentry* Quebec) and Indian (*Rose Knot* Victor) Oceans. Between April 1960 and March 1961, NASA completed construction of all the sites.[6] Flight controllers staffed each of the sites, giving them valuable experience. The network worked well throughout the Mercury program.

A typical site consisted of four controllers. The Capsule Communicator served as both the Capcom and the Flight Director for their site. He communicated directly with both the astronaut in space and Mercury Control. A maintenance operations supervisor oversaw the equipment at the site. A systems monitor examined the spacecraft's systems. Finally, an aeromedical monitor processed the astronauts' medical information.[7]

Before Gemini, NASA realized the network would need more computing capabilities for future missions and installed UNIVAC 1218 computers at each of the sites. These on-site computers allowed the controllers in mission control to receive more information faster, thus greatly aiding their work. NASA also added sites in Antigua, Ascension Island, Pretoria, South Africa, Tananarive (from Zanzibar, after a revolution in 1964), Wallops Island, Virginia, and Goddard.[8] NASA stationed the two tracking ships in the Pacific Ocean for greater coverage.[9]

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[6] Ibid., 105-106, 124.

[7] Kraft, "Mercury Operational Experience."

[8] Corliss, *Histories of the Space Tracking and Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM),* 145, 147.

[9] Kranz, *Failure Is Not An Option*, 142.

As JSC transitioned to Apollo, NASA recognized an even greater demand on the network. NASA would not be able to pick up signals coming from the moon by the near-earth focusing network, at least not reliably. Also, when the Lunar Module (LM) separated from the Command/Service Module (CSM), the network would not have the capability to track both spacecraft accurately. Either the network would need a massive upgrade, or NASA would need to pair it with another network, or both. NASA eventually decided to pursue both measures. The MSFN would receive upgrades, but it would also have at least backup from the STADAN and DSN.

Because NASA already planned DSN to track lunar missions like Surveyor, the infrastructure was largely in place to aid with Apollo. NASA built twenty-six-meter antennas at the most critical MSFN sites in order to accommodate lunar communications. Many of these were near DSN sites so that they could more easily complement each other.[10]

One major change in the structure of the network came with the addition of radar ships. They stationed one ship in each of the Pacific, Atlantic, and Indian Oceans, while two served during reentry in the Pacific. The Apollo Network also utilized a series of airplanes called Apollo Range Instrumentation Aircraft (ARIA), which served as highly-mobile communication relays. The mobility of ships and aircraft was especially important for manned missions when constant communication was more crucial than for robotic spacecraft.[11] Flight controllers from Houston did not operate the various sites

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[10] Corliss, *Histories of the Space Tracking and Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM),*180.

[11] Ibid., 184-85, 204.

during Apollo. Instead each site had its own staff, usually contractors, because NASA transferred the information to mission control almost simultaneously.[12]

In the mid-1970s, following Skylab, NASA combined the STADAN and the MSFN to create a unified STDN. While this reduced costs, NASA quickly realized that the STDN remained too manpower intensive. Each remote site required operations, maintenance, and logistics personnel. Overseas locations were especially expensive. As a result, NASA sought a more cost-effective method of communications with the astronauts in space. Shortly after the creation of the STDN, NASA began to plan for a new Tracking and Data Relay Satellite System (TDRSS) as a replacement. In essence, two geosynchronous satellites could cover communications for nearly the entire orbit of a shuttle or other near-earth spacecraft. The network also included a single ground site at Goddard to consolidate the system.

With this new network, the remote sites became unnecessary, thus reducing the long-term cost. TDRSS did require a large initial cost in order to pay for the new satellites and equipment. To save money NASA contracted out the satellites. Thus, Western Union Space Communications, Inc., won the initial contract in December 1976. Western Union subcontracted the production of the satellites to TRW, Inc.[13]

NASA placed the first Tracking and Data Relay Satellite (TDRS) into orbit in 1983 during STS-6.[14] NASA then placed five more first-generation satellites built by TRW into orbit using the shuttles in the 1980s and 1990s. NASA launched three second-

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[12] Frank, "Flight Control of the Apollo Lunar-Landing Mission," 2.

[13] Robert O. Allar and Lorne M. Robinson, "Tracking and Data Relay Satellite System: Space Data System of the 80's," from William C. Hayes, Jr., ed., *Space – New Opportunities for International Ventures*, 17th Goddard Memorial Symposium, Vol. 49, (San Diego: American Aeronautical Society, 1980), 33-35.

[14] "Mission Control Center," NASA Facts, 1986.

generation satellites, built by Boeing, on Atlas rockets between 2000 and 2002. TDRSS interacts with three ground-based locations, with a new primary station in White Sands, New Mexico, and others in Guam and at Goddard. The entire system currently has eight satellites in orbit, though only three are designated as primary and thus, continuously in use. NASA placed them in a constellation in geosynchronous orbit to provide the maximum amount of coverage.[15]

The primary satellites maintain orbit on the Equator at 41 degrees west and 171 degrees west. Their geosynchronous orbits allow them to maintain 85 percent coverage for spacecraft below 1,200 kilometers (745.6 miles) altitude. Spacecraft in orbits up to 12,000 kilometers (7,456.5 miles) altitude gain complete coverage. For reference, the shuttle usually orbited at altitudes between 304 kilometers and 528 kilometers (190 to 330 miles) and the International Space Station maintains its orbit between 370 and 460 kilometers (230 to 286 miles).[16] The coverage creates a small zone of exclusion (ZOE) where the satellites cannot provide communication coverage for the shuttles or ISS. The additional TDRS in orbit can be powered up to provide an emergency bridge over the ZOE.

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[15] "TDRS H, I, J," Boeing, http://www.boeing.com/defense-space/space/bss/factsheets/601/tdrs_hij/tdrs_hij.html, accessed 9 February 2012; "Tracking and Data Relay Satellite System (TDRSS)," National Aeronautics and Space Administration, https://www.spacecomm.nasa.gov/spacecomm/programs/tdrss/default.cfm, accessed 9 February 2012; and "TDRS," Encyclopedia Astonautica, http://www.astronautix.com/craft/tdrs.htm, accessed 9 February 2012.

[16] "Reference Guide to the International Space Station," November 2010, National Aeronautics and Space Administration, http://www.nasa.gov/pdf/508318main_ISS_ref_guide_nov2010.pdf, accessed 9 February 2012, 94.

Each TDRS has ten years of attitude control fuel, so they will need to be replaced periodically.[17] NASA plans to launch two third-generation satellites beginning in the fall of 2012.[18] The TDRSS should serve human spaceflight well for at least the next decade.

Deep Space Network

The origins of JPL's Deep Space Network are contemporaneous with the launch of Sputnik by the Soviet space program. William Pickering of JPL recognized that there was too much electrical interference in the Pasadena area to track Sputnik accurately, so they had to use the San Gabriel Valley Radio Club in Temple City, approximately fourteen miles southeast of JPL. He stated that JPL needed a site in the desert with a tracking station, thus leading to the large antenna eventually built in Goldstone.[19]

Because DSN must communicate with satellites much farther away than earth orbit, it must have a different makeup from that of the manned spaceflight network. Signals are weaker, and exact locations and trajectories are more difficult. In fact, signal strength changes inversely as the square of the distance. In other words, communications from Neptune are 100 times weaker than from Mars, or ten billion times weaker than

[17] Allar and Robinson, "Tracking and Data Relay Satellite System: Space Data System of the 80's," 37-40.

[18] Amber Hinkle and Dewayne Washington, "All Systems Go for Next Communication Spacecraft," 21 November 2011, National Aeronautics and Space Administration, http://www.nasa.gov/topics/technology/features/tdrs-go.html, accessed 9 February 2012.

[19] William Pickering, Press Conference at JPL, 7 October 1957, History Collection 3-39, Jet Propulsion Laboratory Library, Pasadena, California.

with a geostationary satellite. To insure continued receptivity of radio signals DSN must constantly update its equipment, hardware and software.[20]

In general, the distance of the spacecraft being tracked and the coverage of the antennas allow JPL to utilize fewer antennas than JSC. DSN thus can be more selective in site placement. Regardless, JPL has benefited from conveniently placed allies of the United States.

Radio astronomy, the basis of tracking and data acquisition for satellites, can be traced to Karl Jansky. In 1931, this electrical engineer detected extrasolar radio signals by using a radio receiver consisting of an antenna array rotated by four Model T wheels and a motor. From such humble beginnings, tracking and detection improved dramatically over the next two decades.

By November 1958, JPL had connected an early network of antennas called Microlock to the first control room at the center. Early Microlock stations were connected to the control area through telephones and teletype. Microlock was used mainly for near-earth objects, especially missiles. JPL also established an early deep space network of antennas called Tracking and Communication Extraterrestrial (TRACE). Microlock is especially important for establishing the first series of antennas for tracking. For instance, JPL constructed four stations in 1958 for Explorer, including Cape Canaveral, Florida, Earthquake Valley, California, the University of Malaysia, Singapore, and University College in Idaban, Nigeria.[21]

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[20] Corliss, *A History of the Deep Space Network*, 1; and C. D. Edwards, Jr., C. T. Stelzried, L. J. Deutsch, and L . Swanson, "NASA's Deep-Space Telecommunications Road Map," *TMO Progress Report* 42-136 (15 February 1999): 2.

[21] Ibid., 8-12.

The early TRACE network, on the other hand, did not extend worldwide, and therefore offered only limited coverage. JPL built the first three stations in Goldstone, California, Cape Canaveral, and Mayaguez, Puerto Rico. The Goldstone site by this time did include a twenty-six-meter antenna, one of the largest at the time. JPL chose Goldstone for the center of its deep space network for a few reasons. First, it was relatively close to Pasadena. Second, its geography, essentially a bowl surrounded by hills, keeps it mostly radio silent. Perhaps most fortuitously, the United States Army owned the land, and JPL maintained a close relationship with the Army since its early days. Goldstone was ready for use by the end of 1958.[22] JPL named this first antenna Deep Space Station 11, or DSS 11. DSS 11 first tracked a satellite in March 1959 as Pioneer 4 became the first American satellite to reach the Moon.[23]

In 1958, JPL also proposed a more formal network of three stations to track deep space objects. Two stations would be constructed in Nigeria and the Philippines to work along with the station in Goldstone. Although originally accepted, later that year a Department of Defense official, Dr. Donald Quarles, questioned the two overseas locations. After further studies, JPL amended the proposal to change the locations to Spain or Portugal and Australia, both of which would increase coverage for deep space missions.

NASA built a new twenty-six-meter antenna at Goldstone in 1960 to aid in transmitting capabilities for the DSN.[24] NASA completed construction of the second

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[22] Ibid., 14-17.

[23] Mudgway, *Uplink-Downlink*, 3, 12.

[24] Ibid., 14

deep space antenna in Island Lagoon, Australia, in September 1960. A third antenna, planned for Spain, was moved to South Africa. This site, about forty miles north of Johannesburg, was completed in July 1961. With that antenna, JPL had nearly worldwide coverage, and the Deep Space Instrumentation Facility (DSIF) was born.[25] Like those of STDN, these remote sites were largely manned by contractors. Collins Radio Company, for instance, provided employees for Johannesburg.[26] Two years later, on 24 December 1963, JPL paired the DSIF with ground communications and the early SFOF to become the Deep Space Network (DSN), under the direction of Eberhardt Rechtin.[27]

NASA realized it was overworking the DSN in the mid-1960s. Meetings to schedule time on the network were often quite contentious, with priority regularly going to those with the loudest voices rather than the most pressing needs. NASA set out to build a second network of stations to be paired with the DSN.[28] As a result, NASA built another antenna for the DSN in Australia. Located in Tidbinbilla Valley, near Canberra, this antenna was complete and online by March 1965. NASA chose this site because it was relatively noise-free and there had previously been federal land set aside in the area, which made negotiations easier. Another station was built in Robledo de Chavela, Spain, near Madrid. This station was completed in July 1965. Yet another station came on line

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[25] Corliss, *A History of the Deep Space Network*, 34.

[26] Holladay, interview, 3.

[27] Corliss, *A History of the Deep Space Network*, 43, and Mudgway, *Uplink-Downlink*, 61.

[28] Mudgway, *Uplink-Downlink*, 64.

in June 1966. Located on Ascension Island, it allowed for more coverage between the Americas and Africa.[29]

These three stations provided more coverage for the network and played an integral role for DSN's backup coverage for the impending Apollo program. NASA decided to use the DSN as backup for Apollo and wanted to have as many redundancies as possible to avoid possible loss of life.[30] The DSN is also the primary communications network for projects operating greater than 10,000 miles (16,000 kilometers) from the earth. Because the moon is over 200,000 miles (322,000 kilometers) away from the earth, NASA naturally called upon the DSN for the Apollo missions, as well as other missions to the moon including Surveyor.[31] JPL further updated the Goldstone site by constructing a new sixty-four-meter (210-foot) antenna for increased deep space communications. This large antenna, named DSS 14, was finished on 16 March 1966, slightly behind schedule.[32] The new antenna proved crucial for the deep space missions in future years, beginning with the first missions to Mars.

By 1964, the DSN facilities had teletype capabilities. In fact, teletype data was directly input into the computers at the facilities, making punch cards unnecessary. Also in the mid-1960s, before the Surveyor missions to the moon, they installed a microwave system to aid communications between the network in Goldstone and JPL itself. This

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[29] Corliss, *A History of the Deep Space Network*, 77-79.

[30] Ibid., 99.

[31] N.A. Renzetti, "Tracking and Data System Support for *Surveyor* Mission V," Technical Memorandum 33-301, Vol. III, 1 December 1969, Jet Propulsion Laboratory Library, Pasadena, California, 4.

[32] Corliss, *A History of the Deep Space Network*, 82-84 and 129, and Mudgway, *Uplink-Downlink*, 45.

system compensated for the increased amount of data anticipated for Surveyor and other future projects.[33]

With the Pioneer missions in the 1960s, the DSN began supporting missions with control centers off JPL property. Ames Research Center housed the control room, and JPL provided the data, an aspect of sharing information rarely part of the STDN. Pioneer also created some problems by maintaining data transmission for years after its expected termination. JPL received the last signal from Pioneer 10 on 23 January 2003. DSN thus had to remain vigilant much longer than expected.[34] These experiences provided important expertise for JPL's future missions. In this time frame of 1965, the DSN changed from supporting single missions to multi-mission support.

During the late 1960s, the DSN became almost entirely absorbed with lunar exploration missions. This began with Surveyor and Lunar Orbiter, but it continued with the backup support of the Apollo missions. While the DSN supported multiple missions, it was not until later that it could do so simultaneously. As with elsewhere in NASA, other programs were clearly secondary to the missions to the moon. During the near-earth portions of the missions, the DSN did receive help from the Manned Space Flight Network in collecting data.[35]

As DSN supported the Apollo missions, and well into the 1970s, the DSN began to transition to more multimission compatibility. JPL added wings to each of the DSN station buildings to help support the Apollo missions. It also prepared for more

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[33] Robert H. Evans, interview by Jose Alonso, 21 and 23 September 1992, transcript, Jet Propulsion Laboratory Archives Oral History Program, 16.

[34] Corliss, *A History of the Deep Space Network*, 110-11.

[35] Ibid., 142, 150.

ambitious missions to the outer planets.[36] In order to deal with the influx of communications created by multiple missions, the DSN added a Multimission Telemetry System in 1969.[37] During this period, the DSN also consolidated its sites. The Ascension Island stations, for instance, were transferred to Goddard Space Flight Center control in November 1969. The DSN also dismantled the Woomera, Australia, station and took over the MSFN station at Honeysuckle Creek, near Canberra, in 1973. The following year, the DSN closed the station near Johannesburg, South Africa. The DSN also constructed two new sixty-four-meter antennas to supplement that at Goldstone. The first, operational in April 1973, was constructed in Tidbinbilla, Australia, also near Canberra. The second, operational in September 1973, was constructed in Robledo, Spain, near Madrid. These new antennas were named DSS 43 and DSS 63, respectively.[38]

Even with the new, larger, antennas, the DSN still utilized the twenty-six-meter antennas for a variety of reasons. For instance, after launch and during the first phases of a mission, a satellite's angular movement cannot be tracked by the large antennas. They relied upon the smaller dishes during the first phases of missions. After the satellites had been acquired and established, the DSN could switch to the sixty-four-meter antennae for the remainder of the missions.[39]

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[36] Ibid., 175.

[37] Mudgway, *Uplink-Downlink*, 45.

[38] Corliss, *A History of the Deep Space Network*, 197-200, and Mudgway, *Uplink-Downlink*, 77.

[39] Mudgway, *Uplink-Downlink*, 109.

The Surveyor missions of the mid-1960s were the first dependent solely on the DSN for communications.[40] The Mariner Mars 1969 mission conducted flybys of the planet for various observations in preparation for future missions to the planet. The SFOF was able to utilize the new sixty-four-meter antennas in order to obtain information more quickly from this mission, as well as real-time television pictures and other data.[41] In some ways, Mariner Mars 1969 proved the importance of the larger antenna and the possibility of future scientific knowledge from Mars.

To demonstrate how missions from other centers relied upon the DSN for communications, between 1961 and 1974, the DSN supported the Ranger, Mariner, Pioneer, Apollo, Surveyor, and Lunar Orbiter programs. Only Ranger, Mariner, and Surveyor were managed by JPL. Ames Research Center controlled Pioneer; Langley Research Center directed Lunar Orbiter; and JSC controlled Apollo.[42] In later years, DSN provided communications support for projects from numerous foreign space agencies including that of Japan, Russia, India, and Europe.

The Viking missions of the mid-1970s presented new issues for the DSN to handle. Two spacecraft were launched nearly simultaneously. Each spacecraft then separated into an Orbiter and Lander as it neared Mars, meaning that at times the DSN had to track four spacecraft in close proximity. The new sixty-four-meter antennas played an integral role in the success of Viking.[43] These antennas were also largely

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[40] Renzetti, "Tracking and Data System Support for *Surveyor* Missions I and II," 2.

[41] Renzetti, et. al, "Tracking and Data System Support for the Mariners Mars 1969 Mission, Planning Phase Through Midcourse Maneuver," 1-2.

[42] Mudgway, *Uplink-Downlink*, 32-33.

[43] Ibid., 97.

responsible for communications with Helios 1 for twelve years, from launch in 1974 to loss of signal due to the termination of operations by receivers in 1986.[44]

Between 1978 and 1980, three of the twenty-six-meter antennas were upgraded to thirty-four-meter (112-foot) antennas. These new antennas allowed for greater range and more coverage of different frequencies for deep space missions. The DSN added thirty-four-meter high-efficiency antennas to Goldstone and Canberra in 1984, and to Madrid in 1987. These new antennas, working with those already in place, widened the frequencies and created more flexibility in the network.[45]

In 1981, DSS 11 in Goldstone was decommissioned after supporting missions for twenty-three years, including Pioneer, Mariner, Lunar Surveyor, and Voyager, among others. The site was named a National Historic Landmark on 27 December 1985, recognizing its central contribution to so many lunar and planetary missions.[46]

In the mid to late 1980s, the DSN aided Australia and the European Space Agency to upgrade the equipment in Canberra. Because all three space organizations anticipated using these facilities in the near future, each contributed something so that Canberra could better serve a variety of space projects. The DSN similarly upgraded the stations in Spain and Goldstone simultaneously.[47]

While the sixty-four-meter antennas had performed well for a few decades, the DSN called for upgrades to its largest equipment. After some deliberation, especially regarding cost, the administration agreed to replace those three antennas with even larger

[44] Ibid., 207.

[45] Ibid., 155-58, 224-26.

[46] Ibid., 2-4.

[47] Ibid., 198.

seventy-meter (230-foot) antennas. It took almost five years to complete the new antennas, but by May 1988, the three DSN stations were finished.[48]

By the mid-1980s, the DSN's reputation had grown strong enough that it became a source of important international cooperation for JPL and NASA. Usually this cooperation came about informally, until a directive in 1991 formalized how the DSN and other communications networks conducted arrangements for the use of networks by foreign agencies.[49]

During the 1980s, NASA also worked on a reconfiguration of its communication networks. As a result, elements of the Ground Spaceflight Tracking and Data Network, operated at the Goddard Space Flight Center, were integrated into the DSN for greater coverage. This consolidation also occurred for monetary reasons as NASA continued efforts to deal with a decreasing budget.[50]

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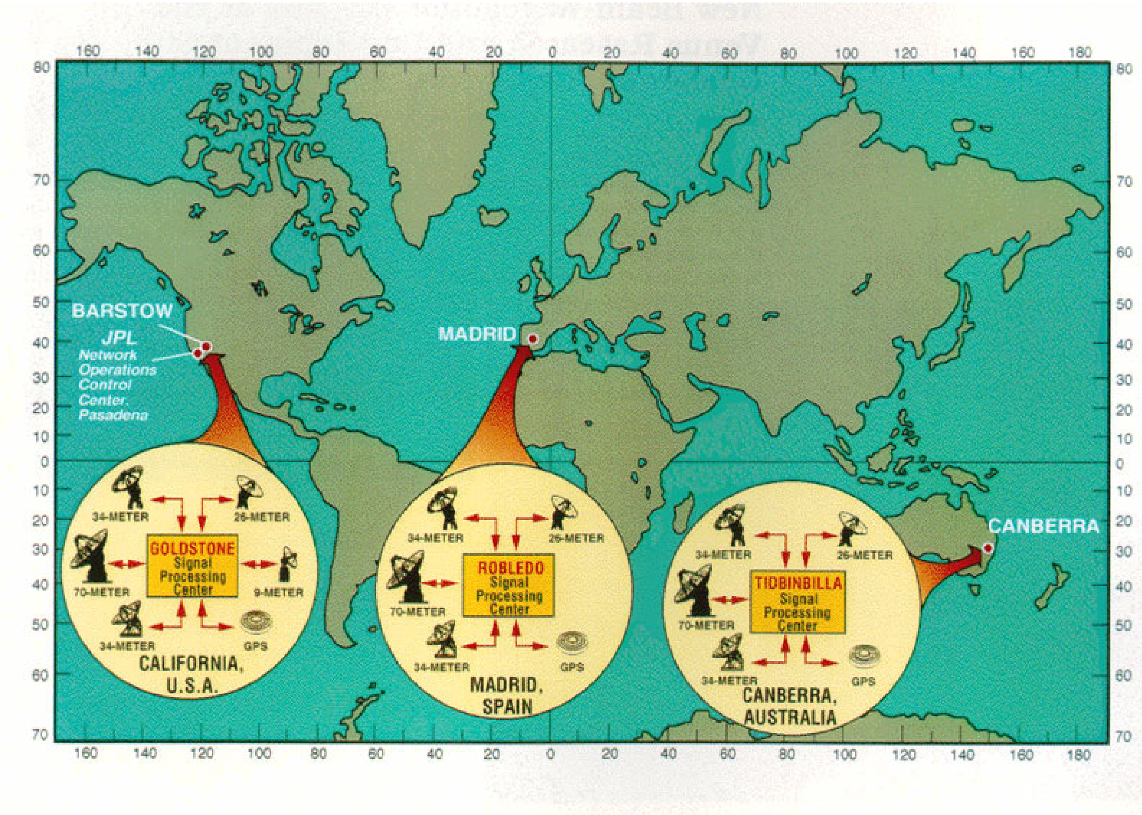
[48] Ibid., 226-30.

[49] Ibid., 221-22.

[50] Ibid., 242-245.



[Image 5-1: Deep Space Network, 1992 Configuration (1992), NASA, http://deepspace.jpl.nasa.gov/dsn/images/album/dsn73.jpg]

In the late 1990s, the DSN built new thirty-four-meter antennas at each of its sites in order to replace the oldest antennas.[51] The DSN is now sensitive enough to detect natural emissions of electromagnetic radiation, including stars, gas clouds, and even Jupiter. Naturally, JPL has sponsored analysis of DSN readings from these natural discharges.[52]

The DSN continues to serve as the most prominent antenna network for spaceflight. Its operations dominate the Operations Room of JPL. While the DSN

[51] J. W. Layland and L. L. Rauch, "The Evolution of Technology in the Deep Space Network: A History of the Advanced Systems Program," *TDA Progress Report* 42-130 (15 August 1997): 5.

[52] Mudgway, *Uplink-Downlink*, xxxvii.

remains the most famous communications network, Europe's own network has an impressive history for both deep space and near-earth communications.

ESTRACK

The importance of ESTRACK to the success of ESOC cannot be overstated. Indeed, one author has compared ESOC without ESTRACK to a carriage without a horse, or, perhaps more appropriately, a car without an engine.[53] A more contemporary comparison might be a cell phone without a tower.

ESTRACK has proven to be one of the most consistently variable aspects of ESA. Not only has the number of stations changed rapidly, but their locations have necessarily changed in order to suit mission needs. Early programs were focused on polar observations, thus the network focused on stations in higher latitudes. As the focus changed to earth observations and deep space missions, new stations in more central locations have replaced the higher altitude stations.

With early satellites remaining in high inclinations, the first ground stations needed to be located in high latitudes to maintain maximum connection. Thus, ESA selected Redu, Belgium, Spitzbergen, Norway, Fairbanks, Alaska, and the Falkland Islands for its first four ground stations. The Redu station also obliged the need for a station located near the control center at the European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands.[54] Like the other networks, ESTRACK locations proved important political tools.[55] Early in the development, ESA included a

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[53] Schäfer, *How to Survive in Space, Vol. II*, 85.

[54] First General Report of the European Space Research Organization (1964-1965), III.4, 1-4.

[55] Krige and Russo, *A History of the European Space Agency, Volume I*, 59.

two-way teleprinter to connect the ground stations with the control centre for immediate communications.[56] With the lack of high-latitude programs beginning in the mid-1970s, ESA decided to close the Falkland Islands station on 31 December 1973 and the Spitzbergen station on 16 April 1974.[57] Further changes led to the Fairbanks facility officially closing in August 1977, leaving only Redu of the original four stations. New ground stations, however, had been built in Kourou, French Guinea, Villafranca, Spain, Odenwald, Germany, Fucino, Italy, and Malindi, Kenya.[58] The Villafranca station, online on 12 May 1978, also serves as a dedicated control center.[59] The Fucino station has been used as part of ESTRACK sporadically, depending on the needs of the various programs, throughout its existence.[60] ESA built a new station in Carnarvon, Australia, in June 1980.[61] ESA added a new station to the network in Ibarak, Japan, in 1984.[62] Between 1987 and 1988, the Carnarvon station moved to Perth, Australia.[63] By 1988, ESTRACK had also added stations in Kiruna, Sweden, and Maspalomas, Canary Islands.[64]

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[56] First General Report of the European Space Research Organization (1964-1965), III.4, 8-9.

[57] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 95.

[58] European Space Agency Annual Report 1977, 147-48.

[59] Schäfer, *How to Survive in Space, Vol. II*, 92.

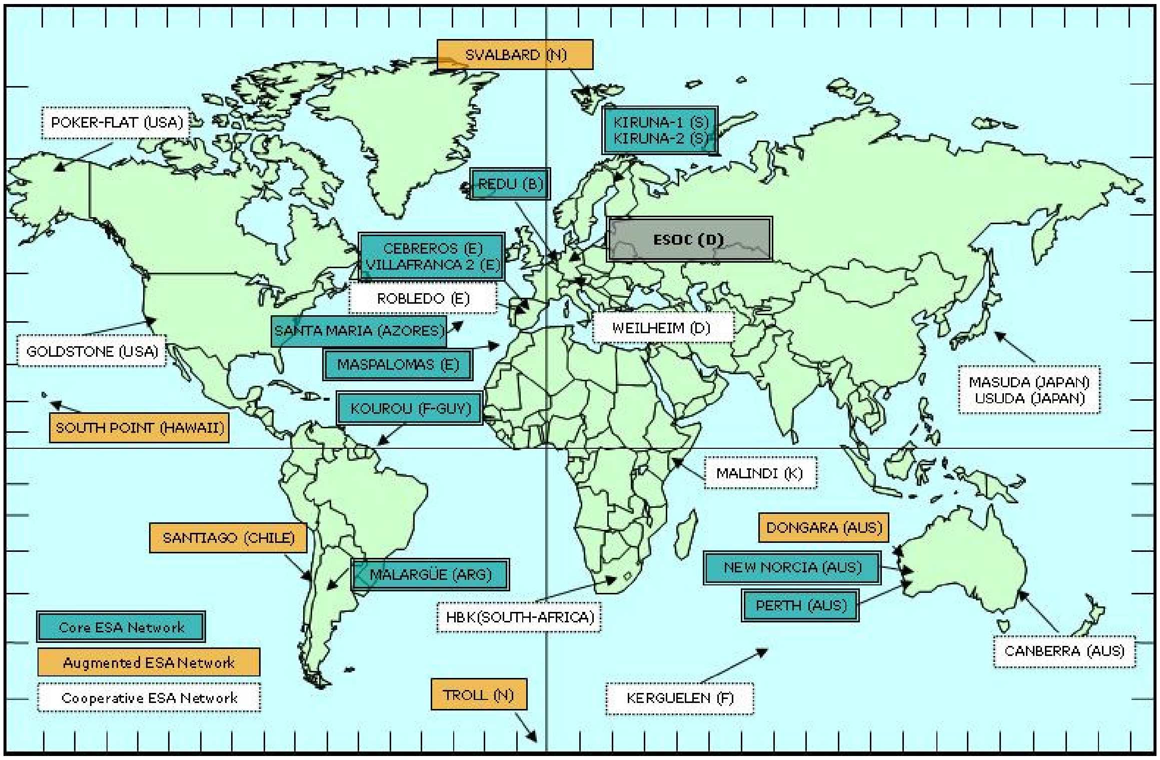
[60] Ibid., 90.

[61] Longdon and Guyenne, *Twenty Years of European Cooperation in Space*, 95.

[62] Schäfer, *How to Survive in Space, Vol. II*, 90.

[63] Ibid., 89.

[64] Longdon and David, esa f-15.



[Image 5-2: ESA Tracking Station Network (ESTRACK) (2010), ESA, Courtesy of Manfred Warhaut]

Ground stations in 2004 included those in Kiruna, Redu, Villafranca, Cebreros (Spain), Maspalomas, Kourou, and Perth. ESOC also had access to cooperative tracking and launch stations in Svalbard (Norway), Plesetsk (Russia), Baikonur (Russia), Tsukuba (Japan), Malindi, Santiago (Chile), Goldstone, and Canberra.[65] As of April 2007, ESTRACK included those same stations with the addition of New Norcia in Australia. The New Norica and Cebreros stations included thirty-five-meter (115-foot) antennae as part of the newly formed European Deep Space Network.[66] ESTRACK added a new Santa Maria Tracking Station in the Azores (Portugal) in 2008.[67]

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[65] Manfred Bertelsmeier and Gioacchino Buscami, "New Communications Solutions for ESA Ground Stations," *ESA Bulletin* 125 (February 2006): 44-49.

[66] Landeau-Constantin, von Weyhe, and Cebers de Sousa, *ESOC*, 14.

[67] European Space Agency Annual Report 2008, European Space Agency Headquarters Library, Paris 94.

Like JPL's DSN, ESTRACK has been an important conduit for relations with other space agencies. ESA has provided tracking for numerous satellites from various other space programs, including NASA, Russia, Japan, India, and China. In return, ESA has been allowed either to establish stations in those countries, such as Japan and the United States, or to use their own networks. Communications with the Japanese Ibarak station could be especially troublesome, however, because few of their controllers spoke English.[68] Perhaps most important, ESA has utilized JPL's DSN for numerous missions. In many ways this cooperation and codependence has fueled further relations between ESA and NASA. The CCSDS Space Link Extension (SLE) serves as a standard interface system between various ground stations and control centers across the world, particularly between ESOC and NASA's DSN.[69]

Tracking varies widely depending on numerous variables for each mission. As an example, a typical high-latitude orbit may be visible for ten minutes during ten out of every fourteen orbits. In stark contrast, deep space missions may have contact extending up to ten hours at a time, though blackout periods may last up to days or even weeks. The controllers must anticipate these changes in the frequency of contacts and adapt in order to maximize data return.[70] One former controller remarked that timing was critical for deep space missions.[71]

Since ESOC controls spacecraft everywhere from near-earth to deep space, ESTRACK must remain flexible to track the wide variety of altitudes. In many ways,

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[68] Schäfer, *How to Survive in Space, Vol. I*, 151-152.

[69] European Space Agency Annual Report 2002, European Space Agency Headquarters Library, Paris, 101.

[70] Nye, *ESOC*, 25.

[71] Wimmer, interview.

ESTRACK can be considered a mix of the STDN and the DSN. It must utilize larger antennas like DSN for deep space missions but it also must maintain more sites like STDN for coverage of near-earth satellites.

A typical ESTRACK ground station includes a Main Equipment Room (MER), which contains the necessary hardware for telemetry, telecommands, and data-processing, among other essential operations. An Antenna Equipment Room (AER) houses the antenna servo-system, air conditioning, and other ancillary systems such as lighting.[72] The structure and configuration of all ground stations are intentionally basic for ease of transition and upgrade.

Both ESTRACK and ESOC have gained an ever-more positive reputation over the decades. ESTRACK is especially renowned for its now remotely controlled stations. While DSN continues to operate its antennas with on-site personnel, ESTRACK has upgraded its facilities to run automatically by computers. A centralized ESTRACK Control Centre (ECC) in the Operations Control Centre oversees all ESTRACK operations. If a problem occurs that cannot be fixed from the control room, on-call technicians can reach the ground station within an hour. The fully automated remote sites have proven so effective that JPL has begun to study them as possible upgrades to their DSN ground stations.

These three communication networks are a crucial element for spaceflight. Without them, the control rooms could not monitor their spacecraft. The networks have also played an important role in another aspect of control center operations. With remote

[72] G. Servoz, “Powering the ESA Network,” *ESA Bulletin* 66 (May 1991): 86.

sites and ground stations throughout the world, they aid in the space agencies' international relations. While some of that role has already been discussed, the international politics of control centers deserves more attention.

CHAPTER 6

INTERNATIONAL POLITICS

Previous chapters have already discussed the role of domestic politics, particularly regarding the placement of the control centers. Even more important, the control rooms have played an integral role in international relations during the space age. During the Cold War, competition sometimes trumped cooperation on the international stage, especially for the two superpowers. As the Cold War dragged on, and as space budgets steadily decreased, the space agencies found it increasingly important to seek partners to complete their missions. This has culminated in the largest peacetime international effort in world history: the International Space Station.

Cooperation and competition are not mutually exclusive. NASA and ESA, for instance, have worked together while also competing in space endeavors. NASA even had moments of cooperation with its fiercest competitor, the Soviet Union, during the Cold War. By spurring each other to grow, space agencies create better partners.[1]

This leads to the most important rule of international cooperation in space. Both countries must have a mutual interest in the project with potential benefits for both partners if it is going to succeed.[2] Any one-sided project will likely not move beyond a planning stage before at least one partner cries "foul." Countries invest in space agencies

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[1] John Sakss, "NASA and International Space Cooperation," from Wayne C. Thompson and Steven W. Guerrier, eds., *Space: National Programs and International Cooperation* (Boulder, Colorado: Westview Press, 1989), 109.

[2] Ibid., 108.

expecting notable returns. The high price of spaceflight does not allow any country, regardless of size or economy, to fund ventures with no appreciable return.

The majority of the time each partner must fund its own aspect of each mission. While there are some exceptions, a country rarely pays for another's activities. Again, this is in part due to the high price of spaceflight. It also ensures a good partnership. Each country can trust the other to satisfy fully its aspect of the mission.

Roy Gibson, former Director-General of ESA, warned that national space agencies must continue to seek cooperation with each other. He feared that some only sought help when the size and scope of certain projects grew too large for one nation alone to finance. Even if national space agencies become profitable, they must continue to work together for the betterment of all humanity.[3]

This chapter examines more extensively the role of mission control in international cooperation. The first section considers the European Space Agency as a partner in space. The next analyzes NASA as an international organization. A more detailed examination of the many instances of cooperation between ESA and NASA follows. This chapter concludes with an assessment of the International Space Station as the most important example of cooperation in space. While the majority of the discussion considers the broader involvement of the space agencies, this chapter will focus as much as possible on the role of the control rooms in international cooperation.

ESA

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[3] Roy Gibson, "Space - New Opportunities for International Ventures," from William C. Hayes, Jr., ed., *Space – New Opportunities for International Ventures*, 17th Goddard Memorial Symposium, Vol. 49 (San Diego, American Aeronautical Society, 1980), 3.

Former Director-General of ESA Hermann Bondi once remarked that international cooperation was both "essential" and "difficult," but any difficulties could be "overcome with sufficient effort and determination."[4] He further argued that international cooperation is not any less difficult than obtaining the technology needed for space travel, and thus deserves as much attention and effort.[5] ESA is an unusual example of international cooperation because by its very nature it is an international organization. This chapter will discuss only interactions with other national space agencies.

That ESA relied upon international cooperation came as a natural outgrowth of post-World War II Europe. Stacia E. Zabusky discussed this concept in detail in *Launching Europe: An Ethnography of European Cooperation in Space Science*. In short, European countries surveyed the damage on the continent after two world wars and wanted to avoid such destruction again. As a result, they strove for a shared identity with the hope that commonalities would overcome any differences. Europeans also believed that they could reap more financial benefits from working together rather than as individuals. Finally, a unified Europe could negotiate with the superpowers of the United States and Soviet Union on a more equal footing than as separate countries. These three main motivations made cooperation among European nations the standard approach for economics, politics, and society.

Advanced science and technology generally entails big budgets. European nations worked together to help defray the costs. With space as one of the largest

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[4] Bondi, "International Cooperation in Space," 1.

[5] Ibid., 6.

postwar technological ventures, it made sense for the Europeans to work together in a unified space program. ESA could be considered not only a natural outcome of European politics and economics, but also of European science and technology.[6]

Some have even argued that the Cold War between the United States and Soviet Union made it inevitable for the European nations to work together in space. The perceived space race forced Europe to pursue an active space program if those countries wanted to be effective on the international scene.[7] A special commission in 1967, called the Causse Report after its chair Jean-Pierre Causse, further enumerated the necessity of international cooperation. It stated, in part, that while ESA should remain independent, it should strive for close associations with the two superpowers because ESA could not survive competing with them.[8] With these thoughts in mind, one can easily move on to the development of ESA working with outside space programs.

Since its inception, NASA has been ESA's closest international partner. Even when not collaborating on missions, the two have shared space technology and science. This special cooperative relationship receives full consideration later in this chapter.

While the extensive cooperation with NASA displayed ESA's loyalties during the Cold War, ESA did work with the Soviet Union as well. Europe's first astronauts, for instance, first flew in Soviet spacecraft. This was due largely to the fact that the Soviets flew astronauts from varied countries well before NASA did. Foreign astronauts aboard Soviet spaceflights came from Afghanistan, Syria, Vietnam, Cuba, Mongolia, East

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[6] Stacia E. Zabusky, *Launching Europe: An Ethnography of European Cooperation in Space Science* (Princeton: Princeton University Press, 1995), 5-6.

[7] Gibbons, *The European Space Agency*, 6.

[8] Krige and Russo, *A History of the European Space Agency,Volume I*, 338.

Germany, France, and Austria.[9] The first non-Soviet European in space, Vladimir Remek, flew aboard Soyuz 28 in 1978. NASA launches did not include a European astronaut until Ulf Merbold flew aboard STS-9 in 1983.

Some ESOC employees have experienced minor difficulties working with Russians. The Soviet space agency had some different ways of accomplishing their work. Some Europeans regarded the Russians as too limited in their work. The controllers and engineers did not have the freedom of those at ESA or NASA. The language barrier could be extremely difficult as well.[10] The majority of European flight controllers could communicate in at least English and French, if not also German or Italian. Few spoke Russian. That a small percentage of the Soviet controllers spoke any language other than Russian often caused tensions. Consequently, a lack of common language has often restricted international cooperation.

ESOC is one of ESA's most valuable assets for cooperation with foreign space agencies. ESA has even published an ESOC Services Catalogue to be used to attract new customers. Among other things, it highlights the expertise of their controllers and the flexibility of the control centre and ESTRACK. ESOC also emphasizes its perfect track record for European launched satellites.[11]

The control room of ESOC has supported launch and early operations for numerous foreign space agencies. Through 2000, for instance, forty-nine of the ninety-

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[9] Wayne C. Thompson, "West Germany's Space Program and the European Effort," from Wayne C. Thompson and Steven W. Guerrier, eds., *Space: National Programs and International Cooperation* (Boulder, Colorado: Westview Press, 1989), 43.

[10] Hell, interview.

[11] Black and Andrews, *ESOC Services Catalog 2000/2001*.

seven missions controlled at ESOC were for external customers.[12] By 2010 that number had grown to nearly half of the approximately 120 missions controlled at ESOC.[13] These have included telecommunications satellites for the Indian, French, German, and Italian space agencies. ESOC has also supported a meteorological satellite maintained by the United States and India as well as two earth observation satellites for Japan.[14] Paralleling the measured development of international cooperation on all matters of consequence, ESA has broadened its working relationship with space agencies as the reputation of ESOC has grown.

NASA

While the public may conceive of NASA as a national agency conducting its own projects without the help of outsiders, the space agency's charter contained numerous mentions of international cooperation. Seeking positive relationships with other space agencies has been a major goal for NASA since its inception. This section includes just a few examples of work with foreign nations, exclusive of ESA.

When NASA was created under Public Law 85-568, the National Aeronautics and Space Act of 1958, one of the objectives clearly stated was cooperation with other nations for peaceful purposes. The act "emphasized openness and scientific objectives" regarding interactions with other countries.[15] This is because the United States

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[12] Ibid., 2.

[13] Mandfed Warhaut, "ESOC and JPL Cooperation," powerpoint presentation, European Space Operations Centre, Darmstadt, Germany, 18 October 2010, 11.

[14] Longdon, "ESA/ESOC 25 Years."

[15] John M. Longdon, "U.S.-European Cooperation in Space Science: A 25-Year Perspective," *Science* 223, no. 4631 (6 January 1984): 11-14.

acknowledged it had as much to gain as to lose with international cooperation.[16] It had, therefore, been a major consideration for NASA since its inception. The political environment of the United States in particular, and the world as a whole, had played an important role in how NASA had approached international cooperation over its existence.[17]

NASA guidelines for working with other space agencies dictated that JPL and JSC must follow rules when cooperating with foreign control centers. Cooperation occurred on a project-by-project basis and is neither open-ended nor non-restrictive. The project must have mutual interests with clear scientific value for all parties. The technical agreements must be established before any political agreements as made. Each partner must take full financial responsibility for its own share of the project. Each partner must also provide full technical and managerial capabilities for its share of the work. Finally, the science from the project must be placed in the public domain.[18]

The United States had always invested in its space program far more than any other nation, with the possible exception of the Soviet Union. Since negotiations must be mutually beneficial, this led to many difficulties when attempting to cooperate with other space agencies. The gap could be rather large. For instance, in the mid-1960s, NASA's per capita expenditure exceeded $30. This figure decreased by half by the 1970s, but it still far surpassed that of European nations, for instance, which spent on average about

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[16] John Rhea, "The Need for More International Cooperation in Space," from Wayne C. Thompson and Steven W. Guerrier, eds., *Space: National Programs and International Cooperation* (Boulder, Colorado: Westview Press, 1989), 113.

[17] Longdon, "U.S-European Cooperation in Space Science," 15.

[18] Ibid., 12.

$1.50 per capita. This average never rose above $2.50 per capita.[19] Thus the size of programs between NASA and other space programs based on budget differed greatly.

NASA was initially pushed to international cooperation largely due to the need for tracking sites worldwide for better coverage to control spacecraft.[20] Both the STADAN and the DSN utilized antennas at sites across the globe. These sites could only be built in countries with favorable relations with the United States, a requirement that caused a few problems. For instance, a site in Cuba had to be moved before the Bay of Pigs invasion in 1961. Another in the former state of Zanzibar was evacuated during a political uprising in 1964. In both cases, an unfavorable government forced NASA to rethink its antenna location. Thus, ground stations have long served as a means of diplomacy for the United States. The ground station portion of the cooperation remains paramount, and both sides do their best to maintain compatible networks.[21]

The United States also viewed international cooperation as an important avenue for global markets. During the Cold War, the United States argued for a global free market economy and used numerous devices to gain advantage for their agenda in other countries. This would especially play an important role in the communications and aerospace industries.[22] Cooperation has also been viewed as the "embodiment of peace,"[23] an especially important aspect during the strain of the Cold War.

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[19] Bondi, "International Cooperation in Space," 2.

[20] Longdon, "U.S-European Cooperation in Space Science," 15.

[21] Wimmer, interview.

[22] Longdon, "U.S-European Cooperation in Space Science," 15.

[23] Zabusky, *Launching Europe*, 5.

During the early Cold War, much of the technology flow originated in the United States and transferred to Western Europe and other countries. Recognizing this, the government wanted to limit technology transfer as much as possible, sharing only a fraction of that available. The initial guidelines for space science cooperation included scientific validity, mutual interest, specific rather than general spaceflight goals, the widest dissemination of results, and individual country's responsibility for their own expenditures.[24] The scientific output of cooperative programs has been deemed so vital that any ventures without significant scientific gains are regarded as politically meaningless.[25] In many ways, space science was viewed as a benign transfer of ideas, and so it was more freely shared than others. Not everyone agreed with this sentiment, however. Some Americans did worry that working with Europeans in high technology could create stronger competition in the world market.[26] In light of the bipolar nature of the Cold War, the United States did not want to make more enemies.

As an example of NASA relations with European space agencies, the Helios project, in the mid-1970s, was a joint project between JPL and the German Space Agency to conduct solar research. The German Space Operations Center (GSOC) at Oberpfaffenhofen, near Munich, served as a primary control center for the launch phase and other aspects of the project. Thus, NASA gained greater cooperation with West Germany and more flexibility for the Deep Space Network.[27]

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[24] Longdon, "U.S-European Cooperation in Space Science," 15.

[25] Don E. Kash, *The Politics of Space Cooperation* (West Lafayette, IN: Purdue University Studies, 1967), 38.

[26] Longdon, "U.S-European Cooperation in Space Science," 15.

[27] Mudgway, *Uplink-Downlink*, 89-90.

The relationship between NASA and the Soviet space agency remains a complex story of competition and cooperation. Between the launch of *Sputnik 1* and the culmination of the Apollo program, the competition aspect of the space race dominated the landscape. Both sides challenged each other for ever-greater accomplishments as a sign of political strength. Even JPL had to refocus its efforts to aid the Apollo program. As the Cold War continued into the 1970s and 1980s, when space budgets began to decrease and the United States pursued a new foreign policy of détente, both superpowers worked more diligently with other space agencies to complete their missions. They even worked together on a few projects.

A space-related agreement between the United States and Soviet Union signed in 1972 allowed for the successful completion of, among other ventures, the Apollo-Soyuz Test Project (ASTP). ASTP culminated in the first docking between American and Soviet spacecraft. This agreement terminated in 1982, and it was not renewed due to contentious relations between the two superpowers. Despite this, the DSN worked together with the Soviet space program to gather telemetry data from their two Vega balloons at Venus in 1985. The French space agency CNES also aided this international effort.[28]

During the preparations for ASTP, various members of both space agencies' control centers visited each other for discussions on the proper course of action for the mission. When the Soviet delegation visited Houston, JSC arranged for and paid for their lodgings, as well as provided a $14 per diem. The Soviets were also granted Group

[28] Ibid., 190-191.

Hospitalization coverage in the event of an emergency. All transportation costs were paid for by the country sending the individuals.[29]

Interactions between NASA controllers and those of the Soviet space program could be difficult, even during their cooperative ASTP. At times there were issues of trust. Some NASA people had the impression that the Soviet delegation expected them to be spies from the CIA. Interestingly, this rationale came from their expectation that some of the Soviets were KGB spies. They also felt as though they were being tested at first; but as interactions increased over time, that changed to a more mature working relationship.[30] Many of the NASA delegates have also commented on how they feared that their rooms had been bugged, so they were careful about their conversations.[31] Despite their penchant for secrecy, many of the NASA controllers understood that the Russians were complex individuals like any other human. In fact, they found out rather quickly that the Russians enjoyed partying and vodka.[32] As a testimony to the increased level of cooperation and trust between the superpowers, Chuck Lewis, a Flight Director since the last Apollo missions, led the NASA flight control contingent in the Russian mission control room.[33]

One of the most difficult aspects of ASTP was the language barrier, both in space and between the control centers. A single word used by NASA could have a half-dozen

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[29] Oscar E. Anderson, “Financial Arrangements for Visiting Soviet Specialists, Memorandum,” 13 March 1974, Box 1325, Apollo Space Program Office Files, ASTP Series, Johnson Space Center History Collection at University of Houston-Clear Lake.

[30] Glynn S. Lunney, interview by Carol Butler, 30 March 1999, transcript, JSC Oral History Collection, 26-29.

[31] Pavelka, interview, 25.

[32] Frank, interview, 17-18.

[33] Lewis, interview, 40-41.

or more variations in Russian, and vice-versa. The two sides sometimes found they were arguing about a word when they actually meant the same concept. The language barrier also helped the NASA employees realize how much jargon they routinely used and how difficult it could be for outsiders to understand them.[34]

Any potential cooperation with Russia, especially during the Cold War, had to keep political consequences in mind more so than relations with allies. Even when they cooperated, they remained each other's primary competitor for science and technology. Similar political constraints have hindered greater cooperation between the United States and China, another emerging space power.[35]

As NASA began to turn to the shuttle, international cooperation became even more important. The method of cooperation changed as well. The growth in maturity and capabilities of ESA and other space agencies, the increasing cost of space missions, and the relative scarcity of funds for NASA all played a role in this collaborative transformation.[36] The European *Spacelab* and Canada's robotic arm are major examples of NASA's willingness to allow other organizations and countries to build key space components.[37] Cooperation between NASA and ESA, to be discussed in the following section, grew more complex in the 1980s and 1990s as both agencies adapted and grew.[38]

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[34] Frank, interview, 19

[35] Sakss, "NASA and International Space Cooperation," 108-109.

[36] Longdon, "U.S-European Cooperation in Space Science," 11.

[37] Committee on International Space Programs, National Research Council, and European Space Science Committee, European Space Foundation, *U.S.-European Collaboration in Space Science* (Washington, D.C.: National Academy Press, 1998), 19.

[38] Longdon, "U.S-European Cooperation in Space Science," 14.

Like JSC's human spaceflight program, JPL has worked more diligently in the new millennium toward international cooperation with projects such as the Gravity Recovery and Climate Experiment (GRACE) with the Germany Space Agency and the Ocean Surface Topography Mission (OSTM) with the French Space Agency.

NASA and ESA

NASA has been as the closest non-European partner for ESA.[39] Conversely, ESA has been "NASA's foremost partner" in space.[40] ESA's main publication in February 1972 even showcased an open invitation from NASA for ESA staff to visit various centers in the United States.[41] The following year, ESA created an ESA Washington Office in NASA's Headquarters to foster "strong cooperative ties."[42] By 1991 the Washington Office remained small, employing only four people.[43] Despite its size, it is still a crucial link between two of the largest space agencies.

From its foundation, NASA has recognized Europe as its primary, though not exclusive, partner in space.[44] In fact, to demonstrate the special relationship between the two, NASA launched ESA's first two satellites in 1968 for free as a "christening gift."[45] The United States gained more influence in Europe largely due to the Soviet Union's self-imposed isolation, at least regarding technology transfer. Much of Europe viewed

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[39] Bondi, "International Cooperation in Space," 75.

[40] Sakss, "NASA and International Space Cooperation," 106.

[41] *ESRO/ELDO Bulletin* 17 (February 1972), European Space Agency Headquarters Library, Paris, 36.

[42] European Space Agency Annual Report 1992, European Space Agency Headquarters Library, Paris, 191.

[43] Ibid., 191.

[44] Longdon, "U.S-European Cooperation in Space Science," 11.

[45] Krige and Russo, *A History of the European Space Agency, Volume I*, 75.

technology as a way to resurrect their economy and industry and thus placed high priority on advances in technology. They also wanted to avoid a technology gap as much as possible.[46] A close relationship with NASA, and the sharing of technology, played a key role in preventing or diminishing any such gap.

ESOC has primarily worked with JPL because they both focus on robotic spacecraft. The cooperation between DSN and ESTRACK has provided further avenues for close cooperation. The Space Link Extension Services (SLES), established near the start of the new millennium, allows for JPL and ESOC to use each other's ground station networks more easily. This is a first-of-its-kind link of extraordinary international cooperation.[47] Many ESOC controllers and engineers have expressed a great working relationship with those at JPL. Some have even worked together enough that they consider each other friends.[48] Those friendships would never take precedence over their individual projects.

As with other examples of international cooperation, for each instance of NASA and ESA working together, the parties must approve a Memorandum of Understanding (MOU) that explicitly states how they will work together and what they will share. More recently they have used more generic and overarching Technical Assistance Agreements (TAA) to avoid the need for a specific MOU.[49] TAAs work similar to NASA's Discovery program in that the federal government approved a set of regulations and NASA was allowed to make specific decisions within those guidelines.

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[46] Committee on International Space Programs, etc., 16.

[47] Black and Andrews, *ESOC Services Catalog 2000/2001*, 7.

[48] Hell, interview.

[49] Fertig, interview.

MOUs present an interesting and important distinction between NASA and ESA. NASA is a national agency under the jurisdiction of the government of the United States. ESA, on the other hand, is an international organization under the jurisdiction of international law.[50] The ESA Convention grants the space agency the power to create and sustain treaties with other governments, representatives, or agencies. In effect, the Director-General would initiate any treaty and it would require unanimous approval by the members of the Council. This leaves ESA and NASA, and in fact any other national space agency, on unequal grounds. NASA cannot sign a treaty, a formal, binding document, on its own. MOUs and other arrangements are thus necessary.

With MOUs attaining a status less formal than treaties, they can lead to undesirable, even damaging consequences. If ESA and NASA had the ability to sign a formal treaty to conduct a program, the two partners would be required to complete that agreement regardless of any unforeseen complications. Because the two space agencies can only conduct informal agreements, MOUs are not as strictly binding. NASA regards MOUs as executive agreements that do not require Senate approval. NASA has even included clauses stating that each partner will make their “best effort” to complete the project, thus weakening any binding characteristics.[51]

The International Solar-Polar Mission (ISPM) provides an excellent example of the vagaries and misunderstandings that can come about due to the lack of formal treaties. NASA and ESA signed an MOU in 1979 for a mission that would involve each

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[50] Since ESA has a degree of sovereignty, its employees are granted diplomatic immunity, though ESA reserves the right to disallow said immunity if an employee commits a crime.

[51] For more on this discussion of treaties versus MOUs, please see Gibbons, *The European Space Agency*, 50-75.

agency constructing a satellite to be placed in solar orbit over its poles. ESA obtained the funds for its satellite nearly immediately. NASA waited until 1981, at which point budget cuts made it impossible for the space agency to pursue its satellite. NASA declined its role in ISPM on the grounds of lack of funds and "best efforts," as detailed in the MOU. ESA and other European officials protested that they had a formal agreement to complete the mission. NASA countered that each side signed the MOU with full knowledge of the conditional clause. In the end, ESA continued its project under the new name *Ulysses* and proceeded to conduct future cooperation with NASA with a degree of distrust.[52] Surprisingly, JPL housed a Dedicated Control Room (DCR) for the *Ulysses* mission, staffed by ESA employees.[53]

Similar to their relationships with the Soviet Union, though on a different scale, ESA and NASA cooperated and competed with each other simultaneously.[54] That being said, most ESA employees view their relationship with NASA, and vice-versa, as a good and cooperative partnership.[55] It remains an "intensive collaboration."[56]

Since the inception of ESA, English has served as the official language, despite it being the primary language for approximately only 15 percent of its employees.[57] There were a few reasons for the choice. English was recognized as the major language for international commerce. It would not favor any of the major continental member states.

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[52] Gibbons, *The European Space Agency*, 80-83.

[53] Longdon, "ESA/ESOC 25 Years."

[54] Committee on International Space Programs, etc., 22.

[55] Wimmer, interview.

[56] Warhaut, "ESOC and JPL Cooperation."

[57] Longdon, "International Cooperation in Space," 45-46.

Perhaps most important, English would make interactions with NASA, particularly in terms of the control centers, more fluid. French served as another official language, so ESA staff members were expected to speak both languages. Because those languages were not the native tongues for a large portion of the ESA staff, they were required to learn a more technical and less conversational common version of the languages. This challenged the native speakers. Irish or British staff members, for instance, had to learn to avoid using cultural idioms that others might not understand.[58]

The politics of space was especially important during the Cold War. Much of the United States' government's actions during the Cold War should be regarded in light of how it affected its relationship with the Soviet Union. As such, the government considered it "political goodwill" if NASA could be shown publicly cooperating with European efforts in space. These actions resonated domestically as well as internationally. Americans were comforted knowing that the alliance with Western European nations was growing. Western Europeans continued to view the United States as a closer and more viable ally than the Soviet Union. The NASA Task Force of 1987 agreed that cooperation was motivated primarily by foreign policy decisions.[59]

Much of the cooperation between NASA and ESA began in 1965. Arnold W. Frutkin, the NASA Assistant Administrator for International Affairs, and Pierre Auger of ESA began informal talks regarding NASA launching ESA satellites with compensation. They agreed that ESA would give NASA any information about spacecraft performance generated by the launch. The following year, NASA approved an MOU with ESA stating

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[58] Nye, interview.

[59] Committee on International Space Programs, etc., 15.

that NASA would provide reimbursable launch services. Each launch would require a separate contract and a designated Project Manager to coordinate all interactions.[60]

After the Apollo program, a number of changes affected international cooperation, particularly between the United States and Europe. The United States government greatly diminished NASA's budget. NASA encouraged ESA to take a larger role in space, which coincided with growth at ESA. The United States also acknowledged a growing concern about sharing potentially sensitive technology with other nations.[61]

In a prime example of cooperation leading to competition, and in an effort to break its reliance upon other space agencies to launch its spacecraft, ESA embarked on perhaps its most ambitious solo project in 1973: Ariane, an expendable launch vehicle. The first successful launch on 24 December 1979 broke NASA's monopoly on commercial launch services in the West. The five generations of Ariane have allowed ESA to compete with NASA for other organizations' launches.[62]

Perhaps the most impressive robotic spaceflight collaboration between NASA and ESA came with *Cassini-Huygens*. Following more than a decade of development, *Cassini* launched on 15 October 1997 at Cape Canaveral. The satellite and probe arrived at Saturn on 1 July 2004. On 25 December 2004, the *Huygens* probe, developed by ESA, separated from NASA's *Cassini* to enter the atmosphere of Saturn's moon Titan. The

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[60] Letter from Arnold W. Frutkin to Pierre Auger, 22 July 1965, ESRO 6921, European University Institute Archives, Florence; and MOU between the European Space Research Organization and the National Aeronautics and Space Administration Concerning the Furnishing of Satellite Launching and Associated Services, 11 February 1966, ESRO 6921, European University Institute Archives, Florence.

[61] Longdon, "U.S.-European Cooperation in Space Science," 12-13.

[62] Committee on International Space Programs, etc., 21; and Longdon, "U.S-European Cooperation in Space Science," 11.

two space agencies then controlled their respective spacecraft, with JPL overseeing the *Cassini* orbiter and ESOC monitoring the *Huygens* probe. ESOC had also sent commands to the probe from its specially developed Huygens Probe Operations Centre (HPOC) once every few weeks during the seven years between launch and arrival. *Huygens* successfully landed on the surface of Titan on 14 January 2005 and continued to send data and images for ninety minutes. This remains the only landing on an outer solar system planet. *Cassini* is scheduled to remain in orbit until 2017.[63]

Spacelab is perhaps the most important collaboration between ESA and NASA for human spaceflight before the ISS. In many ways *Spacelab*, like many other projects from this time, grew out of NASA's decreasing budget. In the 1970s and 1980s, NASA's human spaceflight program spent so much of its budget on the development and launching of the space shuttle it had to find partners to develop the scientific projects to be pursued in space. ESA and NASA signed an MOU in 1973 in which ESA agreed to build a space laboratory to be launched multiple times by the shuttle. While ESA built the actual laboratory, other space agencies, including those of Germany and Japan, eventually equipped *Spacelab* with experiment racks and platforms. *Spacelab* launched twenty-two times between 1983 and 1998, making it the primary scientific platform for the shuttle program.[64]

The United States government reduced post-Cold War NASA's budget even more. Foreign policy and economics emphasized international cooperation. NASA was also forced to focus on smaller, more affordable projects and a quicker turnaround of

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[63] Battrick, *Supporting Europe's Endeavours in Space,* 11-13.

[64] Brian Harvey, *The Japanese and Indian Space Programmes: Two Roads into Space* (London: Springer-Praxis, 2000), 79.

output and results.[65] This led to the "faster, better, cheaper" initiative at NASA. Many of the ESOC controllers reviled NASA's new mission statement as amateurish and an insult to spaceflight professionals. They have pointed to the numerous failures in low-cost projects, and their own spotless performance with their medium-cost missions, as proof.[66] Changes in policy, however, did not hinder collaboration.

NASA continued to recognize the need for cooperation between the United States and Europe. Daniel Goldin, the NASA administrator who advocated "faster, better, cheaper," spoke of a "common destiny in space" and that the relationship with ESA was "vital to the U.S. space program." He further stated that they "must complement one another" and that they must strive for "a bold vision, a common set of objectives that will allow (them) to work in space together, not separately."[67] Not surprisingly, he focused on ideas of cooperation while downplaying potential competition. Increasingly NASA realized that, in order to accomplish their goals with a depleted budget, it would depend on international partners in space.

Following the tragic events of 11 September 2001, the free exchange of information between ESA and NASA came to a halt due to the restrictions placed upon international information exchange by the new Homeland Security Department and the Patriot Act.[68] ESA and NASA came to an agreement in 2007 for mutual help to circumvent bureaucratic approval. A technical agreement between ESOC and JPL was

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[65] Committee on International Space Programs, etc., 23.

[66] Wimmer, interview.

[67] Letter from Daniel S. Goldin, NASA Administrator to Jean-Martin Luton Director-General ESA, 2 November 1992, ESA 15754, European University Institute Archives, Florence.

[68] Warhaut, interview; and Ferri, interview.

signed by the United States State Department.[69] Despite these advances, sharing information remains largely one-sided, now from ESA to NASA, with more limitations on how freely NASA may communicate.

One final example of the dynamic cooperation and competition between NASA and ESA was Giotto. When ESOC first decided to expand into interplanetary missions with Giotto in 1985, it benefitted from JPL's early success with such missions. ESOC could learn from their experience, especially with the difficulties dealing with deep space communications. More recently, JPL has come back to gain information about ESOC's Ground Station Network. JPL is especially interested in ESOC's ability to operate its ESTRACK stations remotely, an ability that JPL's DSN does not have. ESOC's expertise in automation reduces the chances for error under nominal conditions by eliminating human error. If there are problems or deviations, each station is required to have at least one controller on call and within two hours of the station at all times.[70] As Manfred Warhaut, an ESOC veteran, describes it, in many ways there has been a benefit from "cross-fertilization" between NASA and ESOC.[71]

International Space Station

International cooperation has grown increasingly important for space agencies coping with decreasing budgets and increasing public expectations. No other project highlights this change in space policies more than the International Space Station (ISS).

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[69] Warhaut, interview.

[70] Hell, interview.

[71] Warhaut, interview.

The ISS is the largest peacetime international endeavor in human history. It is also the most impressive example of multinational collaboration in space history. For this reason, it will serve as the primary case study for international cooperation in space.

The ISS story begins with NASA's proposed Space Station *Freedom*. In 1984 President Ronald Reagan announced his wishes for a permanent presence in space with a new space station. Over the next year, NASA engineers began to design a station with multiple modules for experiments, power, and habitation. As the project, and hence the need for funds, grew, NASA reached out to other space agencies to contribute to an international effort.

NASA approached ESA, Canada, and Japan in 1985 to join the space station effort. ESA agreed to construct a permanent scientific laboratory, somewhat like *Spacelab*. Canada would create a robotic arm for servicing the outside of the station. Japan would build a scientific laboratory that would include a small robotic arm and an area exposed to space for experimentation. While JSC's Mission Control Center would serve as the overall control room for space station operations, each space agency agreed to build its own control center to oversee its contribution. Japan, for instance, built a Space Station Operations Facility at the Tsukuba Space Centre in the Ibaraki Prefecture, completed in 1996.[72]

On 11 February 1988, the NASA Space Station Working Group and the ESA Council drafted an MOU regarding a proposed space station and enumerating each space agency's contribution to the space station. The low-earth orbit station would remain flexible for a number of projects, including science, earth observations, storage, and

[72] Harvey, *The Japanese and Indian Space Programmes*, 89.

service as a staging base for future space efforts. The use of the station and its elements would be equitable for each involved organization. They also debated issues on operations, safety, the crew, and communications, among other things.[73]

After a series of redesigns, and saddled with an ever-increasing budget, NASA finally cancelled the *Freedom* project in 1993.[74] NASA and the other space agencies would instead continue in their efforts to build an even larger space station, this time with the help of the post-Cold War Russian space agency. Russia, in fact, would be a major partner, contributing five separate modules. Aside from those additions, approximately 75 percent of the previous space station concept would remain. The orbit would also be changed to accommodate the Russian launch area better. The partners eventually renamed the new project: the International Space Station.

Russia's inclusion in the ISS did spark some controversy, beyond the implications of former enemies working so closely together. ESA, Canada, and Japan each expressed dismay with NASA for not consulting them before making such a drastic decision. Some officials remarked that it showed American arrogance. Others saw it as a lack of respect for their partnership status. NASA eventually smoothed over any problems, and the various space agencies completed their contributions to the ISS.

Russia launched the first component, *Zarya*, into orbit on 20 November 1998. This central piece provided power, control, communications, and docking capabilities for the early construction phases. NASA's *Unity* module, a connecting node akin to a

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[73] European Space Agency Council and Space Station Working Group, Draft Memorandum of Understanding between NASA and ESA, 11 February 1988, ESA 12238, European University Institute Archives, Florence.

[74] For more information on Space Station *Freedom*, consult Roger D. Launius, *Space Stations: Base Camps to the Stars* (Old Saybrook, CT: Konecky & Konecky, 2003), 111-41; and David M. Harland and John E. Catchpole, *Creating the International Space* Station (London: Springer-Praxis, 2002), 88-102 and 113-42.

hallway, joined *Zarya* on 6 December 1998. Financial problems for the Russian space agency continually created problems for the ISS, pushing back schedules and causing others, especially NASA, to provide monetary help.

After a delay of almost a year, Russia finally launched *Zvezda* on 12 July 2000. This critical module included life support, navigation, propulsion, and living quarters. This allowed the first crew to begin living onboard the ISS on 31 October 2000. Since that date, humanity has continuously had a presence in space.

Construction of the ISS remained relatively steady for the next two years. NASA launched the scientific laboratory *Destiny* on 7 February 2001. Canada attached its robotic arm in April 2001. NASA's airlock *Quest*, added in July 2001, allowed the astronauts to conduct extensive EVAs. Russia's *Pirs*, which includes more docking ports and an airlock for Russian cosmonaut suits, was launched on 14 September 2001. The ISS also grew with various additions to the truss system and solar arrays. Additions came to a halt, however, after the loss of the shuttle *Columbia* on 1 February 2003.

When NASA placed the shuttle fleet on hold to determine the cause of the *Columbia* disaster, it also meant slowing down assembly of the ISS. For more than two years, only Russian rockets could replace crews and conduct resupply missions. Full work on the station began again with the addition of External Stowage Platform (ESP)-2 on 26 July 2005. Shortly thereafter, NASA announced the planned retirement of the space shuttle fleet in 2011, placing a formal deadline to complete the ISS.

ESA's laboratory, *Columbus*, finally joined the station in February 2008. Japan's laboratory, *Kibo*, required three different launches for its components in March and May 2008 and July 2009. Russia added one small research module, *Poisk*, in November 2009, and another, *Rassvet*, in May 2010. NASA also contributed two more nodes, *Harmony* in October 2007 and *Tranquility* in February 2010, as well as completing the truss structure and solar arrays. With the STS-134 mission, the international team completed assembly of the ISS in May 2011.

One other European contribution requires mentioning. The Italian Space Agency built three Multi-Purpose Logistics Modules (MPLM): *Leonardo, Raffaello,* and *Donatello*. Designed to fit inside the cargo bay of the Shuttle, MPLMs served as large shipping containers for cargo to the ISS. Between March 2001 and July 2011, these MPLMs flew a total of twelve times. In early 2011, NASA reconfigured *Leonardo* as a Permanent Multipurpose Module, providing storage for supplies and waste for the station. *Leonardo* joined the ISS permanently on 1 March 2011.

Each partner was required to build a control center to monitor its components. Japan has its control center in Tsukuba. Canada monitors the robotic arm from the Mobile Servicing System Operations Complex (MOC) in Saint-Hubert, Quebec. ESA built a Columbus Control Centre in Oberpfaffenhofen, Germany. Because Russia built two of the first three components, primary control began at the Russian control center near Moscow. ISS control currently resides in JSC's Mission Control Center.[75]

Space has a complex history of international cooperation and competition. Adversaries have become partners, and vice-versa. Sometimes space agencies work together on one project while competing in another area. The control centers and the flight controllers have played a crucial role in this story. Any time space agencies

[75] For more information on the International Space Station, consult Launius, *Space Stations*, 175-238; and Harland and Catchpole, *Creating the International Space Station*.

collaborate on a mission, be it Giotto, ASTP, or ISS, the controllers must also work together to monitor the spacecraft. While space agencies will continue to pursue their own projects, the International Space Station stands as the prime example of the necessity for countries to work together as they reach beyond earth.

CHAPTER 7

AIR TRAFFIC CONTROL

Space programs are just one of the most well-known examples of organizations with control centers. Nearly all major transportation networks rely upon some kind of control center to organize their movement. Even particularly busy roadways, like city streets, have controllers to react to congestion or accidents.

Perhaps the most similar transportation technology to spaceflight is the airplane. Air traffic control was one of the first organized networks for controlling transportation technology. Like mission control for spaceflight, air traffic control systems have a similar basic makeup but must adapt to their particular needs.

This chapter focuses on one specific air traffic control system: American civilian air traffic control. Where needed other control systems, like American military air traffic control, will be mentioned to illuminate major differences. This chapter will examine how another major government agency has invented a system of control, and how important distinctions in the technology they are monitoring have manifested differences in the system itself.

History of Air Traffic Control

The history of air traffic control (ATC) has been detailed elsewhere, so a brief recounting is all that is needed here.[1] Communications between the ground and an

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[1] Historical information in this chapter comes from a variety of sources, most notably Paul Garrison's *How the Air Traffic Control System Works* (1979), Glen A. Gilbert's *Air Traffic Control* (1945), Robert

airplane or between airplanes began early in the development of powered flight. E.N. Pickerall was the first pilot to talk to someone on the ground via radio on August 4, 1910. Plane-to-plane communications began in 1914. During the 1920s, various organizations attempted to set up radio beacons or other communication centers along flight paths, with varying degrees of success.[2]

Archie W. League first began controlling flights at Lambert Field in St. Louis in 1929. He used two flags, one red and one checkered, to alert pilots. In 1930, Cleveland built and began operating the first control tower using signal lights and a two-way radio. The following year, Cleveland began to keep track of all scheduled arrival and departure times to aid controllers. Within six years, at least twenty cities operated control towers at their airports.

After its creation in 1915, the NACA began to push for federal regulations for air traffic and safety, which partially aided in the creation of a federal ATC system.[3] During a November 1935 Bureau of Air Commerce meeting, the airlines agreed to operate their own traffic control until the bureau could establish a more permanent system within 90 to 120 days.[4] Indeed, this adds a point of connection between ATC and spaceflight mission control because the NACA as the forerunner of NASA played an integral role in the formation of ATC guidelines. In 1938, the Civil Aeronautics Act stipulated that all air traffic controllers had to be certified by the new Civil Aeronautics Agency (CAA). The

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Burkhardt's *The Federal Aviation Administration* (1967), and http://www.centennialofflight.gov/essay/Government_Role/Air_traffic_control/POL15.htm.

[2] Frank Burnham, *Cleared to Land!: The FAA Story* (Fallbrook, CA: Aero Publishers, 1977), 38-44.

[3] Robert Burkhardt, *The Federal Aviation Administration* (New York: F. A. Praeger, 1967), 5-6.

[4] Nick A. Komons, *Bonfires to Beacons: Federal Civil Aviation Policy Under the Air Commerce Act, 1926-1938* (Washington, D.C.: U.S. Department of Transportation, 1978), 304-5.

control towers remained under municipal authorities for three more years, until they too were placed under the auspices of the national government.

In the meantime, Earl Ward and Glen Gilbert gained primary responsibility for establishing the ATC system. With the new system, each station had a manager, an assistant manager, and three controllers on overlapping shifts. Shifts varied between one and three controllers depending on the density of traffic. Each station also included a blackboard, a large table map, a teletype machines, and a telephone, though due to a lack of funding there was no uniformity in the types of each piece of equipment between the stations. True standardization did not begin until CAA engineer C.E. Wise and Lee Warren designed and built the new station in Washington, D.C., in 1938. That center became the blueprint for all new ATC buildings. The original three duties of controllers included dispatcher, coordinator, and calculator. The controllers communicated with pilots through the dispatchers, somewhat like mission controllers communicating with the astronauts through Capcom.[5] An important step in international aviation occurred in 1944 with the formation of the Provisional International Civil Aviation Organization (PICAO, now ICAO). The PICAO, headquartered in Chicago, set many standards for international air travel, including ATC.[6] Between 1946 and 1950, forty-nine airports installed radar, which was first used in Indianapolis. Twenty years after the creation of the CAA, the new Federal Aviation Agency (FAA) gained responsibility for regulating air traffic control with stricter safety guidelines. The FAA was given complete control of American airspace, with the understanding that the military may require priority in times

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[5] Ibid., 309-11, 314.

[6] Arnold Field, *International Air Traffic Control: Management of the World's Airspace* (Oxford: Pergamon Press, 1985), 15-16.

of need. The FAA soon introduced computers to ATC. Some centers installed UNIVACs (Universal Automatic Computer) for tasks such as the creation of flight progress strips, information exchange between centers, and other paperwork. The 1966 Transportation Act created the Department of Transportation, which included the FAA. Under this act, the agency became an administration, thus allowing the acronym to remain. Other advances in the 1960s included the automatic data interchange system (ADIS), a new organization of airspace, the automated terminal radar system (ARTS), and the creation of a new, model en route control center in Jacksonville, Florida, that showcased other new automated technologies being integrated into the ATC system.[7]

Makeup

While the airport control tower is the most visible and most publicly recognizable symbol of air traffic control, ATC actually consists of a myriad of control rooms working together to allow pilots to complete their flights safely in a timely manner. During every flight, each pilot will talk to a number of different controllers in different rooms from airport to airport. Air traffic control consists of ground control, local or air control, clearance delivery, approach control, and en-route or area control (ARTCC). The Air Traffic Control System Command Center (ATCSCC) in Herndon, Virginia, is the overall command center for air traffic in the United States. Though the Atlantic and Pacific Oceans are largely radar-free, centers in New York and Oakland handle the ATC needs in the respective oceans.[8] ATC in 1946 included 113 airport towers and twenty-four en

[7] Burnham, *Cleared to Land*, 58-60.

[8] Christopher D. Wickens, Anne S. Mavor, and James P. McGee, eds., *Flight to the Future: Human Factors of Air Traffic Control* (Washington, D.C.: National Academy Press, 1997), 45.

route centers.[9] By 1960, there were a total of 646 ATC facilities, including 228 airport towers, 339 flight service stations, thirty-five en route centers, thirty-four military control facilities, and ten international centers.[10] A brief overview of each aspect of ATC follows.

Airport Tower

Interestingly, control towers have been in existence the longest of any aspect of ATC, but have changed the least over time.[11] Control towers were first equipped with lights that could be changed from red to yellow to green in order to indicate clearance for pilots. As radios became more prevalent, they slowly took the place of lights. During the 1960s, the FAA created a standard tower configuration that has remained relatively stable in the following decades. By the 1980s, towers contained radios, barometers, wind direction and velocity instruments, a clock with Greenwich Mean Time (also known as Zulu Time), a direct-line telephone to the nearest ARTCC, and at least one other outside telephone line, especially for use in the case of emergencies. Tower controllers rely on eyesight, but they can also use airport surface detection equipment (ASDE) and digital brite (DBRITE), a type of radar. A chief airport traffic controller oversees all aspects of ATC in the tower, similar to JSC's flight director.[12]

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[9] Glen A. Gilbert, *Air Traffic Control: The Uncrowded Sky* (Washington, D.C.: Smithsonian Institution Press, 1973), 11.

[10] Burkhardt, *The Federal Aviation Administration*, 73.

[11] Edmund Spring, "One Air Traffic Control Specialist's Perspective of Air Traffic Control Human Factors," in *Human Factors in Air Traffic Control,* ed., Mark W. Smolensky and Earl S. Stein (San Diego: Academic Press, 1998), 2.

[12] Paul Garrison, *How the Air Traffic Control System Works* (Blue Ridge Summit, PA: TAB Books, 1979), 105-108; Glen A. Gilbert, *Air Traffic Control* (Chicago: Ziff-Davis Publishing Company, 1945), 93; and Wickens, Mavor, and McGee, *Flight to the Future*, 35.

Due to their reliance on eyesight, the towers must have large amounts of glass to view the surrounding area. This leads to problems varying seasonally and even daily. Over time, the glass has been tinted and angled in an attempt to lessen glare. More important, the heat from the sun can affect the comfort levels of controllers. Perhaps counter-intuitively, this is more important in the winter than in the summer. Modern air conditioning largely overcomes any problems in the summer. In the winter, however, one side of the tower may become more uncomfortable due to the heat from the sun added to the artificially generated heat in the tower.[13] This reliance on eyesight contrasts strikingly with spaceflight mission control. Flight controllers cannot look out a window and see the spacecraft. Instead they rely almost exclusively on spacecraft information relayed via the communication networks to their consoles or computers.

Heavily trafficked airports also use an Automatic Terminal Information Service (ATIS) to provide information to pilots. The ATIS is a continuous broadcast with important information including wind, visibility, weather, active runways, construction, and control frequencies. It is updated every hour, or more frequently if need be, with the most accurate information available. It repeats every thirty to forty-five seconds. Most major airports have separate reports for arriving and departing flights in order to keep the message as brief as possible While not directly linked to tower control, it does make controllers' jobs easier by eliminating their need to repeat this basic information continuously and to focus on controlling the ground and airspace.[14]

Clearance Delivery

[13] Spring, "One Air Traffic Control Specialist's Perspective of Air Traffic Control Human Factors," 2-3.

[14] Garrison, *How the Air Traffic Control System Works*, 35; and Milovan S. Brenlove, *The Air Traffic System: A Commonsense Guide* (Ames, IA: Iowa State University Press, 1987), 4-5.

The clearance delivery station, located in the tower, allows pilots to proceed into controlled airspace. Many pilots access this controller directly after checking the ATIS. In smaller airports, clearance delivery is often combined with ground control. One of the most important responsibilities of this position is relating the departure control frequency to the pilot before granting clearance.[15]

Ground Control

The ground controller's main responsibility is aircraft movement while taxiing to and from the runway. Depending on the size of the airport, ground control may consist of between one and three individuals concerned with a specific area of the runways. Ground control has been likened to a traffic cop, though on a much larger scale. These controllers rely almost exclusively on their sight through the large windows of the control tower. At times this can be confusing, since from a distance many airliners look similar.[16]

Local or Air Control

Most pilots refer to local control as tower control or just tower. This position must separate and sequence aircraft within a certain vicinity of the airport. They separate aircraft in order to keep them a designated safe distance apart. Sequencing simply means creating an order for the aircraft, meaning the pilots themselves must maintain a safe distance. Local control generally gives priority to incoming aircraft before those departing. Aircraft operating only within the flight pattern, like practicing touch-and-goes, are last in priority. These controllers mostly rely on their views out of the tower

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[15] Brenlove, *The Air Traffic System*, 6-9.

[16] Ibid., 10-12.

windows, though instruments such as radar may be utilized in certain circumstances such as poor weather. Some airports also use a system called Airport Movement Area Safety System (AMASS) that locates ground vehicles as well as aircraft and can warn of potential accidents.[17] While ground control talks to the pilots, local control is ultimately in charge of the runways, and only those operators can authorize movement on the runways. This can lead to a sometimes awkward relationship between ground and local control, making inter-controller communication vital to a smooth and safe operation.[18]

Approach Control

Approach controllers work in the aptly-named Terminal Radar Approach Control (TRACON), a windowless radar room often located in the tower but sometimes off-site. Somewhat confusingly, approach control consists of both approach controllers and departure controllers. Each TRACON consists of between two and twenty or more controllers, depending on the size of the airport. Approach control covers the area within roughly fifty miles of the given airport. Of the tower positions, approach control works most closely with en-route control.[19] TRACON controllers utilize voice communications, flight strips, and the flight data input/output (FDIO) computer system to accomplish their jobs. While flight strips are still in use, more TRACON facilities have been using automated radar terminal systems (ARTS) that handle many of the same jobs as the flight strips.[20] Some tests have shown, however, that flight strips, and the

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[17] Ibid., 14-19.

[18] Milovan S. Brenlove, *Vectors to Spare: The Life of an Air Traffic Controller* (Ames, IA: Iowa State University Press, 1993), 86-87.

[19] Brenlove, *The Air Traffic System*, 21-25.

[20] Wickens, Mavor, and McGee, *Flight to the Future*, 36-42.

manipulation of those strips, are an essential part of a controller's memory and allow the controller to complete the task better.[21] The working environment within TRACON is flexible. The number of controllers at a particular station working a particular task can be adjusted according to needs. This flexibility increases the efficiency of ATC.[22] Controllers working in TRACON also usually rotate their positions. Some have suggested that this hurts them because they have a difficult time remaining at their best in each position. Others argue that this helps with team unity by allowing each member to understand the difficulties that the others face at their positions.[23]

En-route or Area Control

En-route or area control centers have also been labeled air route traffic control centers. These centers control large swaths of land, perhaps a few hundred miles, between airports. En-route centers are located in Boston, New York City, Washington, D.C., Cleveland, Atlanta, Jacksonville, Miami, Houston, Fort Worth, Memphis, Indianapolis, Kansas City, Chicago, Minneapolis, Denver, Albuquerque, Salt Lake City, Seattle, Oakland, Los Angeles, Anchorage, and Honolulu. They have changed greatly since the first en-route centers were built in Newark, Chicago, and Cleveland between 1935 and 1936.[24] A total of eight were in use by the end of 1937, twelve by 1939, and

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[21] Renate J. Roske-Hofstrand and Elizabeth D. Murphy, "Human Information Processing in Air Traffic Control," in *Human Factors in Air Traffic Control,* ed., Mark W. Smolensky and Earl S. Stein (San Diego: Academic Press, 1998), 73-75.

[22] Wickens, Mavor, and McGee, *Flight to the Future*, 44.

[23] Spring, "One Air Traffic Control Specialist's Perspective of Air Traffic Control Human Factors," 6.

[24] Garrison, *How the Air Traffic Control System Works*, 24.

twenty-three by the end of 1942.[25] Controllers in these large, windowless rooms rely on radar scopes to perform their jobs. Some ARTCCs are so large that multiple rooms are necessary to house all of the needed control stations. These centers usually contain about fifty radarscopes and one hundred or more controllers at any given time.[26] These control rooms are generally more relaxed then airport control rooms, though foul weather or other disturbances may sully the mood.[27] The flight data and radar information are collected through FDIO and then processed through an automated HOST system. While the software was developed in the 1960s, the hardware was updated in the 1980s. En-route controllers utilize a plan view display (PVD), which is a digitized representation of the airways and all tracked objects.[28]

Air Traffic Control System Command Center

Located in Herndon, Virginia, the ATCSCC is in charge of the overall flow of the airways in the United States. This is an example of how communication and coordination between facilities is as important as between controllers and pilots.[29] The ATCSCC is the center most similar to mission control. It oversees all air traffic, and coordinates the network of other centers. The en-route centers and airport towers in this system function more like dedicated control rooms or communication network remote

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[25] The first eight were Newark, Chicago, Cleveland, Detroit, Pittsburgh, Burbank (CA), Washington, DC, and Oakland. The following fifteen were located in Salt Lake City, Fort Worth, St. Louis, Atlanta, Seattle, Cincinnati, Jacksonville, Boston, Memphis, San Antonio, Minneapolis, Kansas City, Albuquerque, Great Falls (MT), and Denver. Gilbert, *Air Traffic Control* (1945), 7-13.

[26] Garrison, *How the Air Traffic Control System Works*, 113-114; and Brenlove, *The Air Traffic System*, 25-28.

[27] Garrison, *How the Air Traffic Control System Works*, 114.

[28] Wickens, Mavor, and McGee, *Flight to the Future*, 45-46.

[29] Ibid., 21.

sites, sending information back to the main control room. Any mandate from the director of the ATCSCC must be followed by the other centers, again akin to a flight director and his flight controllers.

Controllers

The first controllers had a number of qualifications before they would be accepted as applicants. They had to be at least twenty-one years of age, of good moral character, literate in English with a clear speaking voice, and a loyal citizen of the United States or of another friendly government. Applicants also had to pass physical examinations along with the other examinations. Finally, up until 1941 controllers were required to have 500 hours of flight time or similar aircraft operating experience. Controller salaries in the mid-1940s ranged from $1,800 to $4,100 ($21,600 to $49,200 in current dollars), depending on experience and position.[30] By 1941, 300 personnel staffed the fourteen en-route centers, while around 150 controllers worked airport traffic. Between 1941 and 1942, seven training centers were built across the nation to coincide with a large recruiting drive that for the first time included women. This resulted in an increase to 1,800 controllers in five years.[31] The controller training campus in Oklahoma City was established in 1946 after its move from Houston. It officially became the primary location for controller training after the foundation of the FAA in 1958. In 1978 it was

[30] Gilbert, *Air Traffic Control* (1945), 5-6, 27, 30. Salary adjustment from Historical Currency Conversions, http://futureboy.homeip.net/fsp/dollar.fsp (accessed 26 January 2010).

[31] Gilbert, *Air Traffic Control* (1973), 11.

renamed the Mike Monroney Aeronautical Center after an influential senator.[32] Through the first decade of its inception as the primary training location, roughly 1,500 students per year were educated in Oklahoma City.[33] The FAA employed 12,000 controllers by 1967.[34] In the early 1970s, most controllers began between the ages of twenty-one and twenty-six, requiring between two and three years of total training to be recognized as full-fledged controllers.[35] The average controller in the late 1970s was a man or woman between the ages of thirty and forty working forty hours a week and earning roughly $35,000 ($107,000 in current dollars) a year. Over 16,000 controllers worked in the various ATC capacities at that time. Applicants had to be under thirty-one years old with some educational requirements before joining the Mike Monroney Aeronautical Center. Most ATC sites run on shifts, dependent on the particular needs of that center. Controllers have a mandatory retirement age of fifty-five.[36]

Milovan S. Brenlove, a former air traffic controller, states that ATC is a job most people could not or would not be able to do. He further describes controllers as "intelligent, articulate, and courageous" but "irreverent, comical and extremely independent misfits" who get the job done "in spite of themselves."[37] One essential

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[32] Oklahoma Historical Society's Encyclopedia of Oklahoma History & Culture, "Mike Monroney Aeronautical Center," Oklahoma State University, http://digital.library.okstate.edu/encyclopedia/entries/M/MI015.html (accessed 26 January 2010).

[33] Burkhardt, *The Federal Aviation Administration*, 67.

[34] Ibid., v.

[35] Gilbert, *Air Traffic Control* (1973), 20.

[36] Garrison, *How the Air Traffic Control System Works*, 143-44. Salary adjustment from Historical Currency Conversions.

[37] Brenlove, *Vectors to Spare*, ix. Brenlove worked as a controller for almost fifteen years, until 1987, in the airport towers of Toledo, Minneapolis, and Pittsburgh.

characteristic of a good controller is the ability to envision the big picture of the airways and the movements of planes.[38] As a result, the FAA continually monitors the mental workload of controllers in an effort to keep that at peak performance. Obviously, it is a high-stress job, and any lapse in judgment or ability can lead to disaster.[39] That being said, Brenlove counters that "no matter how much you screw up, [it is] hard as hell to run two airplanes together."[40] If an accident does occur during a controller's shift, he or she must learn to cope with that accident. Regardless of their role in the accident, most will have to contend with some slight apprehension the next time a similar situation occurs. Brenlove admits that losing a pilot during the course of work means "losing that sense of immortal infallibility" that most controllers naturally have.[41]

While ATC is basically the same at every location, centers each have their own slight variations in how the job is accomplished best. Thus, when a controller begins a job at a new location, even for a veteran, there is a period of acclimatization. The controller must become familiar with his or her new colleagues as well as any idiosyncrasies for that location.[42]

Information

One of the most difficult aspects of ATC involves "information processing." Renate J. Roske-Hofstrand and Elizabeth D. Murphy explain that this includes "such

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[38] Wickens, Mavor, and McGee, *Flight to the Future*, 92.

[39] Ibid., 113-15.

[40] Brenlove, *Vectors to Spare*, xi.

[41] Ibid., 17, 27.

[42] Ibid., 89, 130.

constructs as planning, problem solving, decision making, conceptualization, and other knowledge manipulation processes directly related to the execution of an air traffic controller's job activities."[43] They go on to state that the ATC environment is so filled with information and stimulus that the controller's mental processing capabilities are the most important determinant of their ability to work in the environment. In fact, many errors have been traced back to problems in controller information processing.[44] The necessity for peak information processing ability is certainly one important reason why ATC depends on younger individuals for the most demanding jobs.

Teamwork and communication are essential aspects of ATC. One of the most important devises for tracking airplanes are flight paper strips. Though these have been in use for decades, and more advanced sources of information are available, they remain essential pieces of ATC. These strips are a physical representation of each aircraft and where they are in their flight sequence. Within the airport control tower, these strips are physically moved around the workstations to show where each particular airplane is located in the terminal.[45]

Vocal communications remain the most important type of communication for controllers. Controllers and pilots rely upon standardized phrasing for more efficient and helpful communications. ATC uses party lines, where all controllers and pilots have access to all communications, in order to help all those involved create a mental picture of the airport and the airways.[46] Mission control likewise utilizes a party line system so

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[43] Roske-Hofstrand and Murphy, "Human Information Processing in Air Traffic Control," 65.

[44] Ibid., 68-72.

[45] Wickens, Mavor, and McGee, *Flight to the Future*, 36, 135.

[46] Ibid., 36.

that all controllers can maintain an understanding of the overall picture of the mission. Controllers in both ATC and mission control learn how to zone into and out of conversations to glean the information they need to accomplish their jobs.[47] TRACON handoffs are exchanged via computer.[48]

It is also important to remember that air traffic controllers for the most part do not personally know the pilots with whom they speak. Controllers can glean information just from the pilot's voice, including nationality or accent, the level of calm in the pilot, and gender. All of these clues can aid in their job.[49]

Communication is also a critical aspect of relationships between civil and military air control. For instance, civil controllers must understand areas of restricted flight. They also must understand when military flights need and deserve priority over civil air traffic. This understanding and communication will help safeguard both military and civilian flights and increase ATC safety and efficiency.[50]

While the Flight Director has the final say for American human spaceflight operations, it is important to remember that ultimately controllers can only give advice to pilots. The vast majority of times pilots agree with that advice, but they do not have to acquiesce. This unusual situation lends itself to an uneasy relationship between controllers and pilots. Many pilots only grudgingly recognize the importance of controllers, but nevertheless usually follow their guidance. That being said, some

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[47] Roske-Hofstrand and Murphy, "Human Information Processing in Air Traffic Control," 76.

[48] Wickens, Mavor, and McGee, *Flight to the Future*, 43.

[49] Roske-Hofstrand and Murphy, "Human Information Processing in Air Traffic Control," 76.

[50] Field, *International Air Traffic Control*, 23-25, 160-70.

controllers work a certain position long enough and encounter a pilot enough times that a kind of personal relationship, though one based on a lack of in-person interactions, can develop.[51] This relationship can lead to a better understanding and consequently a more efficient working environment.

Air traffic control is an imperfect analogy to spaceflight mission control, but it provides interesting and important comparisons. Both have grown out of large government agencies. Both serve as a tether to the ground for flying vehicles. Both have a central command location with support centers in various strategic locations. The biggest difference can be seen in the level of command. Air traffic controllers monitor and recommend actions, with which pilots usually comply. Spaceflight controllers have the final say in command of spacecraft. In the end, ATC serves as an informative case study of other ideas for control.

[51] Brenlove, *Vectors to Spare*, 41, 56-60.

CONCLUSION

Flight controllers rightly take pride in their jobs. When I have had the privilege to interview some controllers, they needed little prompting to talk about their jobs, which they see as on the cutting edge of history and technology. During my research, I did encounter interesting differences between the American and European space agencies. Johnson Space Center has most completely preserved its history. So much information is available, in fact, that it could dominate any comparative analysis with another spaceflight center or centers. The history collection has also done an exceptionally good job of providing oral histories of a variety of individuals.

The Jet Propulsion Laboratory and European Space Operations Centre have spotty historical records. The controllers even commented that they would like more attention paid to their histories so that the public could understand how much work they have put into their jobs. After hearing those comments, I became more resolved to complete this work.

There is one more important difference I noticed in my research experience. The American controllers tend to talk openly only after they have retired. This may be a natural extension of the classified nature of some of their work. It also may be a result of a national space agency that tends to be more reluctant about working with outside organizations.

The European Space Agency employees were some of the most accommodating individuals I met during my research. Each talked in depth about their job, both in the past and in the present. Each also went out of their way to help me contact other individuals who potentially could help me. I noticed little to no hesitation to discuss any aspect of their work. I attributed this to a few possible reasons. As an international organization, ESA, from its inception, has tried to work freely with others. While certain information sharing is not completely open, it usually is more so than NASA. Also, as one interviewee explained to me, ESA for a long time attempted to stay under the radar. The logic was that the fewer the number of people who paid attention to ESA, the less chance ESA would be cut. Now that it feels as though it has established itself as a vital aspect of Europe, ESA has begun to step out more into the spotlight, actively seeking media attention for all of its accomplishments. Perhaps employees have either been told this or intuitively noticed a difference and saw my interest in their work as one more outlet for their story. In any case, the people in each of the centers helped the research for this project and ultimately made its completion possible.

Adaptability remains a key to the success of the control rooms. The SFOF prepares for increased media interest as the Mars Science Laboratory nears its destination. The OCC anticipates more launches with the new Vega rocket. The FCRs now stand in stark contrast. One monitors the ISS while the other waits in limbo after the retirement of the space shuttles. For the immediate future, mission control will remain the vital link between spacecraft and their homes on earth.

While the space agencies constructed their control centers independently and in disparate situations, each has taken on remarkable similarities. Each has a main control room or rooms with support areas surrounding. Each has developed control systems for their computers or consoles for their particular needs. Each has a larger infrastructure to support the control rooms, including a communications network to transmit signals to and from the spacecraft. The communications networks in each case have served as aspects of international relations for their parent space agencies, in particular during the Cold War. Each control room has expert, well trained, and highly professional controllers for various systems, with a form of team leader to oversee all the work. Simulations train the controllers and help prepare them for possible anomalies. Accidents do happen, and controllers in each control center have worked to fix those problems and rescue missions that would fail without their diligence. Control rooms remain the most prominent aspect of space flight, whether it be human or robotic, American or European.

Differences between human and robotic missions, in particular, have led to important distinctions between the control rooms. At JSC, the center for American human spaceflight, controllers must constantly monitor astronauts while they are in space. Mistakes can mean life or death. At both JPL and ESOC, robotic missions tend to be longer. The main control rooms are usually only used for vital aspects of missions such as launch, rendezvous, and landing. During other times missions are monitored by a skeleton crew of controllers in separate dedicated control rooms.

Each of the control rooms have accepted new technologies as vital to accomplishing their missions, though sometimes reluctantly. At JSC controllers brought personal computers into the MOCRs, demonstrating their flexibility and contributing to the move toward the new FCRs. The new control rooms utilize off-the-shelf computers and even have software to monitor spacecraft from outside the FCRs. One ESOC controller commented that the early MOCRs were antiques with limited functionality. At least the new FCRs are more flexible and closer to those at ESOC.[1] ESOC continues to use consoles in their Main Control Room, but the Dedicated Control Rooms are state-of-the-art computer laboratories. The central computer centers of ESOC and JPL contrast drastically in their makeup. JPL updates its mainframe for new missions but keeps old hardware on hand to control its older missions like Voyager. ESOC, on the other hand, only uses the newest mainframe computers to oversee all of its missions.

As one ESA employee articulated, everything in Europe is older than in America, except the space programs.[2] Throughout much of their histories, technology and information exchange was one way: east across the Atlantic. Now NASA understands that it can learn from a smaller space program that has accomplished its goals despite budgets and employee numbers fractions of that of NASA.[3] ESA has long automated many of its processes, particularly the remote ESTRACK stations. Now JPL has begun to ponder a move in that direction, and it looks to ESOC for guidance. This may be the most direct example of technology transfer between mission control centers in this brief history. Space agencies will continue to seek more cooperation with each other as budgets decrease and public expectations increase.

Unlike other types of control rooms, spaceflight control rooms tend to be more actively involved with controlling their vehicles. Air traffic controllers can only give recommendations to pilots. People working in traffic control systems react to actions on

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[1] Wimmer, interview.

[2] Fertig, interview.

[3] Wimmer estimated the usual ratio of 1:5, ESOC to NASA employees per mission.

the streets. Spaceflight controllers, at times, only monitor their spacecraft; but in most vital instances, they send commands to spacecraft, tell astronauts how to accomplish their missions, and most importantly develop responses to emergencies and accidents in spacecraft.

Flight Directors of JSC have particular power when dealing with American human spaceflight missions. Controllers and astronauts provide insight, but the FD makes the final decision. The other control rooms have positions similar to the Flight Director, but without the same amount of autonomy. In general, they make decisions with the other controllers or with deference to other experts.

It is true that technological advances have allowed for more autonomy in onboard computers. The actual control by controllers on the ground has diminished with each new generation of software and hardware. A presence on the ground remains necessary, for both human and robotic missions. In each case, engineers on the ground are best suited to fix anomalies that inevitably occur in the hazards of spaceflight. As Chris Kraft, John Hodge, and Gene Kranz have commented, ground control is necessary because spacecraft are pushed to the limit. Flight controllers are primarily there to "monitor, evaluate, recommend – if necessary – command" the vehicles.[4] Controllers want to be hands-off as much as possible and only take control if required.

With the ISS, controllers on the ground monitor systems, freeing up the astronauts to do other work. Without the assistance of the ground, ISS habitants would not even have enough time to babysit the station let alone accomplish scientific goals. The space

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[4] Christopher C. Kraft, Jr., John D. Hodge, and Eugene F. Kranz, "Mission Control for Manned Space Flight," NASA Fact Sheet 170, 23 April 1963, Box 53, General History, General Reference, Johnson Space Center History Collection at University of Houston-Clear Lake.

agencies have yet to develop the technology needed to fully automate spacecraft. While the space agencies are working towards less dependence on mission control, they remain a necessary aspect of all spaceflight. As one ESA General Report stated, operators are the shepherds, satellites the sheep.[5]

A statement by Chris Kraft specifically about the flight controllers of the MOCR sums up the significance of the men and women of any of the mission controls.

> My flight controllers are too often unsung heroes. No mission then or now could be flown without the dedication, professionalism, and raw intelligence of the men and women who work the consoles. They are an American treasure.[6]

[5] ESA Annual Report 1991, 151.

[6] Kraft, *Flight*, 352.

BIBLIOGRAPHY

Archives

European Space Agency Headquarters Library, Paris, France.

European Space Operations Centre Library, Darmstadt, Germany.

European University Institute Archives, Florence, Italy.

Jet Propulsion Laboratory Library, Pasadena, California.

Johnson Space Center Collection at University of Houston-Clear Lake, Houston, Texas.

National Aeronautics and Space Administration Headquarters, Washington, D.C.

National Archives, Southwest Region, Fort Worth, Texas.

National Archives, Pacific Region, Riverside, California.

Smithsonian National Air and Space Museum Archives, Suitland, Maryland.

Primary Sources

Battrick, B., ed. *Supporting Europe's Endeavours in Space: The ESA Directorate of Technical and Operational Support.* Noordwijk, The Netherlands: ESA Publications Division, 1998.

Black, W., and D. Andrews. *ESOC Services Catalog 2000/2001.* Darmstadt, Germany: ESOC External Customer Services Unit, 2000.

"Convention for the Establishment of a European Space Agency." European Space Operations Centre Library, Darmstadt, Germany.

"European Space Operations Directorate: …constant vigil." BR 88, European Space Agency Headquarters Library, Paris.

Warhaut, Manfred. "ESA and ESOC Overview." Powerpoint Presentation. European Space Operations Centre, Darmstadt, Germany, 16 August 2010.

Warhaut, Mandfed. “ESOC and JPL Cooperation.” Powerpoint Presentation. European Space Operations Centre, Darmstadt, Germany, 18 October 2010.

Warhaut, Manfred. “ESOC in Context.” Powerpoint Presentation. European Space Operations Centre, Darmstadt, Germany, 23 November 2010

Interviews

Aaron, John. Interview by Kevin M. Rusnak. 26 January 2000. Transcript. JSC Oral History Collection.

Accola, Anne L. Interview by Rebecca Wright. 16 March 2005. Transcript. JSC Oral History Collection.

Aldrich, Arnold D. Interview by Kevin M. Rusnak. 24 June 2000. Transcript. JSC Oral History Collection.

Dumis, Charles L. Interview by Kevin M. Rusnak. 1 March 2002. Transcript. JSC Oral History Collection.

Evans, Robert H. Interview by Jose Alonso. 21 and 23 September 1992. Transcript. Jet Propulsion Laboratory Archives Oral History Program.

Ferri, Paolo. Interview by author. Darmstadt, Germany. 20 October 2010.

Fertig, Jurgen. Interview by author. Darmstadt, Germany. 20 October 2010.

Frank, M.P. “Pete,” III. Interview by Doyle McDonald. 19 August 1997. Transcript. JSC Oral History Collection.

Greene, Jay H. Interview by Sandra Johnson. 10 November 2004. Transcript. JSC Oral History Collection.

Greene, Jay H. Interview by Sandra Johnson. 8 December 2004. Transcript. JSC Oral History Collection.

Griffin, Gerald D. Interview by Doug Ward. 12 March 1999. Transcript. JSC Oral History Collection.

Harlan, Charles S. Interview by Kevin M. Rusnak. 14 November 2001. Transcript. JSC Oral History Collection.

Hasbrook, Annette P. Interview by Jennifer Ross-Nazzal. 21 July 2009. Transcript. JSC Oral History Collection.

Hell, Wolfgang. Interview by author. Darmstadt, Germany. 20 October 2010.

Hennessy, Leo. Interview by author. Paris, France. 12 October 2010.

Hodge, John D. Interview by Rebecca Wright. 18 April 1999. Transcript. JSC Oral History Collection.

Holladay, Jay A. Interviewed by Jose Alonso. 9 July, 11 September, and 30 September 1992. Transcript. Jet Propulsion Laboratory Archives Oral History Program.

Kranz, Eugene F. Interview by Roy Neal. 19 March 1998. Transcript. JSC Oral History Collection.

Kranz, Eugene F. Interview by Rebecca Wright. 8 January 1999. Transcript. JSC Oral History Collection.

Kranz, Eugene F. Interview by Roy Neal. 28 April 1999. Transcript. JSC Oral History Collection.

Kranz, Eugene. Interview by author. 22 November 2006. Transcript. Skylab Oral History Project, University of North Texas Oral History Program.

Lewis, Charles. Interview by author. 22 September 2006. Transcript. Skylab Oral History Project, University of North Texas Oral History Program.

Loe, T. Rodney. Interview by Carol L. Butler. 7 November 2001. Transcript. JSC Oral History Collection.

Loe, T. Rodney. Interview by Carol L. Butler. 30 November 2001. Transcript. JSC Oral History Collection.

Lunney, Glynn S. Interview by Roy Neal. 9 March 1998. Transcript. JSC Oral History Collection.

Lunney, Glynn S. Interview by Carol Butler. 28 January 1999. Transcript. JSC Oral History Collection.

Lunney, Glynn S. Interview by Carol Butler. 30 March 1999. Transcript. JSC Oral History Collection.

McClure, Jim and Ron Sharp. Interview by author. Pasadena, California. 3 September 2010.

Nye, Howard. Interview by author. Paris, France. 12 October 2010.

Pavelka, Edward L., Jr. Interview by Carol Butler. 9 March 2001. Transcript. JSC Oral History Collection.

Pavelka, Edward L., Jr. Interview by Carol Butler. 26 April 2001. Transcript. JSC Oral History Collection.

Purser, Paul. Interview by Robert Merrifield. 17 May 1967. Transcript. Manned Spacecraft Center (MSC) History Interviews Kr-Z, Folder 15, Box 2, 18994. National Aeronautics and Space Administration Headquarters Archives, Washington, D.C.,

Warhaut, Manfred. Interview by author. Darmstadt, Germany. 19 October 2010.

Webb, James Webb. Interview. 15 March 1985. Transcript. Glennan-Webb-Seamans Project Interviews. National Air and Space Museum Archives, Suitland, MD.

Weitz, Paul J. Interview by Rebecca Wright. 26 March 2000. Transcript. JSC Oral History Collection.

Wimmer, Wolfgang. Interview by author. Darmstadt, Germany. 21 October 2010.

Secondary Sources

Books

Bergreen, Laurence. *Voyage to Mars: NASA's Search for Life Beyond Earth*. New York: Riverhead Books, 2000.

Black, W., and D. Andrews. *ESOC Services Catalog 2000/2001.* Darmstadt, Germany: ESOC External Customer Services Unit, 2000.

Bondi, Hermann. "International Cooperation in Space." In *International Cooperation in Space Operations and Exploration*, edited by Michael Cutler, 1-6. Tarzana, CA: American Astronautical Society, 1971.

Bonnet, Roger M., and Vittorio Manno. *International Cooperation in Space: The Example of the European Space Agency.* Cambridge, MA: Harvard University Press, 1994.

Brenlove, Milovan S. *The Air Traffic System: A Commonsense Guide.* Ames, IA: Iowa State University Press, 1987.

Brenlove, Milovan S. *Vectors to Spare: The Life of an Air Traffic Controller.* Ames, IA: Iowa State University Press, 1993.

Burkhardt, Robert. *The Federal Aviation Administration.* New York: F. A. Praeger, 1967.

Burnham, Frank. *Cleared to Land!: The FAA Story.* Fallbrook, CA: Aero Publishers, 1977.

Chaikin, Andrew. *A Man on the Moon, Vol. I: One Giant Leap.* Alexandria, VA: Time-Life Books, 1994.

Chaikin, Andrew. *A Man on the Moon, Vol. II: The Odyssey Continues.* Alexandria, VA: Time-Life Books, 1994.

Committee on International Space Programs, National Research Council, and European Space Science Committee, European Space Foundation. *U.S.-European Collaboration in Space Science*. Washington, D.C.: National Academy Press, 1998.

Conrad, Nancy, and Howard A. Klausner. *Rocket Man: Astronaut Pete Conrad's Incredible Ride to the Moon and Beyond.* New York: New American Library, 2005.

Corliss, William R. *Histories of the Space Tracking and Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM).* National Aeronautics and Space Administration, 1974.

Corliss, William R. *A History of the Deep Space Network.* Washington, D.C.: National Aeronautics and Space Administration, 1976.

Dethloff, Henry C. *…Suddenly, Tomorrow Came: A History of the Johnson Space Center.* Houston: NASA Johnson Space Center, 1993.

Dethloff, Henry C., and Ronald A. Schorn. *Voyager's Grand Tour: To the Outer Planets and Beyond.* Old Saybrook, CT: Konecky & Konecky, 2003.

Durant, Frederick C., III, and George S. James, eds. *First Steps Towards Space: Proceedings of the First and Second History Symposia of the International Academy of Astronautics at Belgrade, Yugoslavia, 26 September 1967, and New York, U.S.A., 16 October 1968.* Washington: Smithsonian University Press, 1974.

Field, Arnold. *International Air Traffic Control: Management of the World's Airspace.* Oxford: Pergamon Press, 1985.

Garrison, Paul. *How the Air Traffic Control System Works.* Blue Ridge Summit, PA: TAB Books, 1979.

Gilbert, Glen A. *Air Traffic Control.* Chicago: Ziff-Davis Publishing Company, 1945.

Gilbert, Glen A. *Air Traffic Control: The Uncrowded Sky.* Washington, D.C.: Smithsonian Institution Press, 1973.

Gusterson, Hugh. *Nuclear Rites: A Weapons Laboratory at the End of the Cold War.* Berkeley: University of California Press, 1996.

Hall, R. Cargill, ed. *Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth History Symposia of the International Academy of*

Astronautics, Vol. II. Washington: National Aeronautics and Space Administration, Scientific and Technical Information Office, 1977.

Hansen, James R. *First Man: The Life of Neil A. Armstrong.* New York: Simon and Schuster, 2005.

Harland, David M., and John E. Catchpole. *Creating the International Space* Station. London: Springer-Praxis, 2002.

Harvey, Brian. *The Japanese and Indian Space Programmes: Two Roads into Space.* London: Springer-Praxis, 2000.

Hayes, William C., Jr., ed. *Space – New Opportunities for International Ventures*. 17th Goddard Memorial Symposium, Vol. 49. San Diego: American Aeronautical Society, 1980.

Kash, Don E. *The Politics of Space Cooperation.* West Lafayette, IN: Purdue University Studies, 1967.

Knorr Cetina, Karin. *Epistemic Cultures: How the Sciences Make Knowledge.* Cambridge, MA: Harvard University Press, 1999.

Komons, Nick A. *Bonfires to Beacons: Federal Civil Aviation Policy under the Air Commerce Act, 1926-1938.* Washington, D.C.: U.S. Department of Transportation, 1978.

Koppes, Clayton R. *JPL and the American Space Program: A History of the Jet Propulsion Laboratory.* New Haven: Yale University Press, 1982.

Kraft, Chris. *Flight: My Life in Mission Control.* New York: Dutton, 2001.

Kranz, Gene. *Failure Is Not An Option: Mission Control from Mercury to Apollo 13 and Beyond.* New York: Simon and Schuster, 2000.

Krige, John, and Arturo Russo. *A History of the European Space Agency, 1958-1987: Volume I: The Story of ESRO and ELDO, 1958-1973.* Noordwijk, The Netherlands: ESA Publications Division, 2000.

Lacoste, Beatrice. *Europe: Stepping Stones to Space*. Bedfordshire, UK: Orbic, 1990.

Landeau-Constantin, Jocelyne, Bernhard von Weyhe, and Nicola Cebers de Sousa, compilers. *ESOC.* Noordwijk, The Netherlands: ESA Publications Division, 2007.

Launius, Roger D., and Howard E. McCurdy, eds. *Spaceflight and the Myth of Presidential Leadership*. Urbana, IL: University of Illinois Press, 1997.

Launius, Roger D. *Space Stations: Base Camps to the Stars.* Old Saybrook, CT: Konecky & Konecky, 2003.

Longdon, Norman, and V. David, compiled and ed. *ESOC: The European Space Operations Centre.* Noordwijk, The Netherlands: ESA Publications Division, 1988.

Longdon, Norman, and Duc Guyenne, eds. *Twenty Years of European Cooperation in Space: An ESA Report.* Paris: European Space Agency Scientific and Technical Publications Branch, 1984.

McCurdy, Howard E. *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program*. Baltimore: The Johns Hopkins University Press, 2001.

Mishkin, Andrew. *Sojourner: An Insider's View of the Mars Pathfinder Mission.* New York: Berkley Books, 2004.

Mudgway, Douglas J. *Uplink-Downlink: A History of the Deep Space Network 1957-1997.* Washington: National Aeronautics and Space Administration, 2001.

Murray, Charles, and Catherine Bly Cox. *Apollo: The Race to the Moon.* New York: Simon and Schuster, 1989.

Nye, Howard. *ESOC: European Space Operations Centre.* Noordwijk, The Netherlands: ESA Publications Division, 1996.

Schäfer, Madeleine. *How to Survive in Space! (A light-hearted chronicle of ESOC), Volume I (1963-1986).* Darmstadt: European Space Agency, 1997.

Schäfer, Madeleine. *How to Survive in Space! (A light-hearted chronicle of ESOC), Volume II (1987-1997).* Darmstadt: European Space Agency, 1997.

Shayler, David J. *Skylab: America's Space Station.* London: Springer, 2001.

Siddiqi, Asif A. *The Soviet Race with Apollo.* Gainesville, FL: University Press of Florida, 2003.

Siddiqi, Asif A. *Sputnik and the Soviet Space Challenge.* Gainesville, FL: University Press of Florida, 2003.

Smolensky, Mark W., and Earl S. Stein, eds. *Human Factors in Air Traffic Control.* San Diego: Academic Press, 1998.

Thompson, Wayne C., and Steven W. Guerrier, eds. *Space: National Programs and International Cooperation*. Boulder, Colorado: Westview Press, 1989.

von Kármán, Theodore, with Lee Edson. *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space*. Boston: Little, Brown and Company, 1967.

Westwick, Peter J. *JPL and the American Space Program, 1976-2004.* New Haven: Yale University Press, 2007.

Wickens, Christopher D., Anne S. Mavor, and James P. McGee, eds. *Flight to the Future: Human Factors of Air Traffic Control.* Washington, D.C.: National Academy Press, 1997.

Zabusky, Stacia E. *Launching Europe: An Ethnography of European Cooperation in Space Science.* Princeton: Princeton University Press, 1995.

Journal Articles

Canby, Thomas Y. "Skylab, Outpost on the Frontier of Space." *National Geographic* 146, no. 4 (October 1974): 441-469.

Edwards, C. D., Jr., C. T. Stelzried, L. J. Deutsch, and L . Swanson. "NASA's Deep-Space Telecommunications Road Map." *TMO Progress Report* 42-136 (15 February 1999): 1-20.

Kearney, Michael W., III. "The Evolution of the Mission Control Center." *Proceedings of the IEEE* 75, no. 3 (March 1987): 399-416.

Layland, J. W., and L. L. Rauch. "The Evolution of Technology in the Deep Space Network: A History of the Advanced Systems Program." *TDA Progress Report* 42-130 (15 August 1997): 1-44.

Long, James E. "To the Outer Planets." *Astronautics and Aeronautics* 7 (June 1969): 32-47.

Longdon, John M. "U.S.-European Cooperation in Space Science: A 25-Year Perspective." *Science* 223, no. 4631 (6 January 1984): 11-16.

Viorst, Milton. "The Bitter Tea of Dr. Tsien." *Esquire* 68 (September 1967): 125-129, 168.

Other Publications

Clark, Evert. "New NASA Center Making Its Debut." *New York Times*, 3 June 1965, 21.

Dunn, Louis, W.B. Powell, and Howard Seifert. "Heat Transfer Studies Relating to Rocket Power Plant Development." Proceedings of Third Anglo-American Conference, 1951, 271-328.

Gibbons, Margaret Ann. *The European Space Agency: Cooperation and Competition in Space.* Geneva: Graduate Institute of International Studies, 1986.

"SCOS-2000: The Advanced Spacecraft Operations System." European Space Agency Publications.

Websites

Hinkle, Amber, and Dewayne Washington. "All Systems Go for Next Communication Spacecraft." 21 November 2011. National Aeronautics and Space Administration. http://www.nasa.gov/topics/technology/features/tdrs-go.html (accessed 9 February 2012).

NASA Acquisition Internet Service. "NASA Dollars Boost the Economies of Every State in the U.S." NASA. http://prod.nais.nasa.gov/cgi-bin/npms.map.cgi (accessed 17 January 2012).

NASA Office of the General Counsel. "The National Aeronautics and Space Act, Sec. 20102 a." NASA. http://www.nasa.gov/offices/ogc/about/space_act1.html (accessed 16 January 2012).

"Neutral Buoyancy Laboratory." National Aeronautics and Space Administration. http://dx12.jsc.nasa.gov/site/index.shtml (accessed 17 January 2012).

Oklahoma Historical Society's Encyclopedia of Oklahoma History & Culture. "Mike Monroney Aeronautical Center." Oklahoma State University. http://digital.library.okstate.edu/encyclopedia/entries/M/MI015.html (accessed 26 January 2010).

"Reference Guide to the International Space Station." November 2010. National Aeronautics and Space Administration. http://www.nasa.gov/pdf/508318main_ISS_ref_guide_nov2010.pdf (accessed 9 February 2012).

"TDRS." Encyclopedia Astonautica. http://www.astronautix.com/craft/tdrs.htm (accessed 9 February 2012).

"TDRS H, I, J." Boeing. http://www.boeing.com/defense-space/space/bss/factsheets/601/tdrs_hij/tdrs_hij.html (accessed 9 February 2012).

"Tracking and Data Relay Satellite System (TDRSS)." National Aeronautics and Space Administration.

https://www.spacecomm.nasa.gov/spacecomm/programs/tdrss/default.cfm (accessed 9 February 2012).

Webster, Guy. "NASA's Spirit Rover Completes Mission on Mars." 25 March 2011. National Aeronautics and Space Administration. http://www.nasa.gov/mission_pages/mer/news/mer20110525.html (accessed 9 February 2012).

Webster, Guy, and Dwayne Brown. "NASA Concludes Attempts to Contact Mars Rover Spirit." 24 May 2011. Jet Propulsion Laboratory, California Institute of Technology. http://www.jpl.nasa.gov/news/news.cfm?release=2011-156&cid=release_2011-156 (accessed 9 February 2012).

Webster, Guy, and Dwayne Browne. "Now a Stationary Research Platform, NASA's Mars Rover Spirit Starts a New Chapter in Red Planet Scientific Studies." 26 January 2010. Jet Propulsion Laboratory, California Institute of Technology. http://marsrover.nasa.gov/newsroom/pressreleases/20100126a.html (accessed 9 February 2012).