Iterative and Incremental System Lifecycle Development

by

Gregory Erroll Bew

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Approved by

Drew Hamilton, Chair, Professor of Computer Science and Software Engineering
Jerry Davis, Professor of Industrial and Systems Engineering
Richard Sesek, Professor of Industrial and Systems Engineering

Abstract

One of the fundamental changes in our technologically advanced society is the breadth of technologies available and the diverse backgrounds, experiences, and skillsets of the many inventors and developers. Traditional forms of systems engineering limit flexibility and the ability to react to emerging requirements by selecting one alternative to serve as a system, then committing to improving that technology until it can be all things, to all people. Often, years later, budgets have failed and the useful life of the technology is almost over. This paper suggests an iterative and incremental development approach that takes widely varying technologies and systems into account, nests them together to create a series of systems that are progressively more advanced and refined for usability, and that takes advantage of what is available now, all while planning development for future technologies. In order to test this process, a case study was conducted. It serves as a practical example of the proposed iterative and incremental system lifecycle approach. It was found that this method could save lives, drastically shorten fielding time for new capabilities, and increase user refinement of current systems as well as future alternatives.

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List of Abbreviations

CAB	Combined Arms Battalion
COE	Contemporary Operating Environment
COTS	Commercial Off The Shelf
DAU	Defense Acquisition University
DOD	Department of Defense
FFBD	Functional Flow Block Diagram
GWOT	Global War on Terrorism
IED	Improvised Explosive Device
IV	Inter-Visibility
MOS	Military Occupational Specialty
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
SOS	System of Systems
TRL	Technology Readiness Level
TTP(s)	Tactics, Techniques, and Procedure(s)
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
VTOL	Vertical Takeoff and Landing

Chapter 1: Introduction

The development of systems through the use of multidisciplinary teams that factor in the entire product lifecycle is known as Systems Engineering. The use of systems engineering in industry is wide spread and accepted as the standard system development solution. While systems engineering itself may be solidly established, the design of the lifecycle is often disputed with most people choosing between either a “waterfall”” approach, or the “V” approach. While both of these approaches attempt to illustrate a conscious effort to move forward phase by phase, neither provides an appropriate demonstration of the ability to refine they system from the bottom up through the development and fielding process.

An organization using systems engineering is most likely trying to develop a robust system with the most current technology that will provide value and capabilities. The development of many complex systems leads to large, effective, and robust systems that are quite expensive. Due to this expense, the organization’s success becomes tied to the effective use of the system, and backend savings through the planning cycle. The disadvantage to this is that the systems are often high priced, technical machines, created by a group of expert engineers. Why is this a disadvantage? Some engineers develop systems that are technically advanced and meet a series of qualitative measures about usability, but they do not always translate well to the user. These engineers turn over an expensive system that is not intuitive to use and that users do not understand, slowing the adoption rate of the system. The system is not complete until the users are trained to use it, and these technical systems may require extensive training time. Once trained, users can then aid in system operation and refinement.

The methodology proposed in this thesis is to use an iterative and incremental systems engineering approach where system users are identified and requirements are validated at each level of the organization: tactical, operational, and strategic. This will ensure that requirements at the user level can be identified and separated from requirements desired by higher level stakeholders. These tactical requirements can then be evaluated on currently available solutions or solutions that take fewer resources to develop and field, creating a stop gap measure to provide an incremental solution while a more robust system is developed to meet all of the stakeholders' desires. Additionally greater weight should be placed on lower priced alternatives that can be widely used and distributed. This also puts early iterations of a system's capabilities in users' hands, thus providing the opportunity for feedback on performance which aids future development. Outside of the product lifecycle, this also lends to higher adoption of the technology as the users of the early iterations of the system can create tactics techniques and procedures to incorporate the system into their daily routines and missions. This adoption will lead to a system that is not only technically impressive, but also more quickly adopted upon fielding.

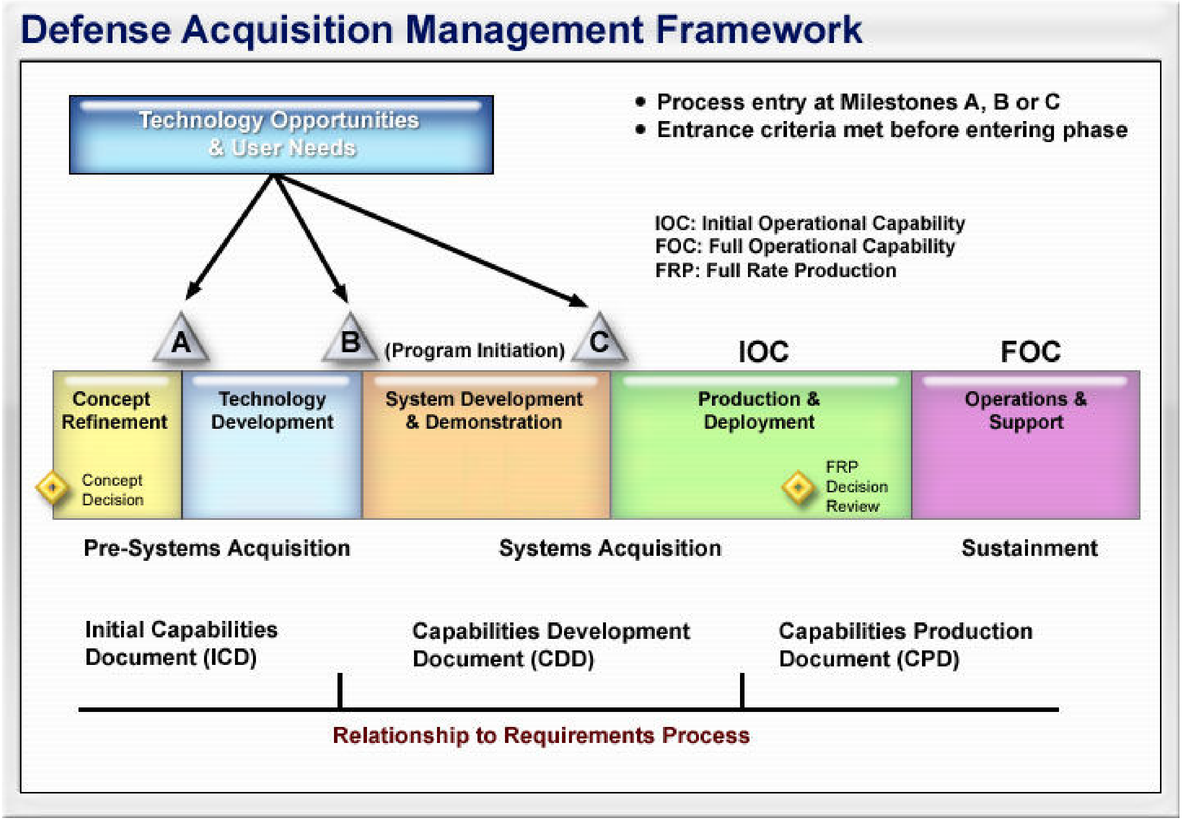
The benefit of the methodology will be systems that are fielded faster by employing a stepwise approach. This will give the user a chance to offer feedback on performance and human factors considerations such as transportation, operation, and stress. Particularly, when applied to the defense acquisition framework, the faster development will also have human capital implications since providing extra capabilities more quickly to users will yield benefits sooner rather than later. Current systems are often slow, ambiguous, disjointed, and inefficient. Typically, the solutions generated are quickly outdated, users are not properly integrated, and time is wasted as requirements creep due to pressures from stakeholders who are often out of touch.

I propose replacing these systems with an iterative and incremental approach to system development. This method will save time, money, and lives. Capabilities can be fielded as they are ready in the form of stop gap alternatives.

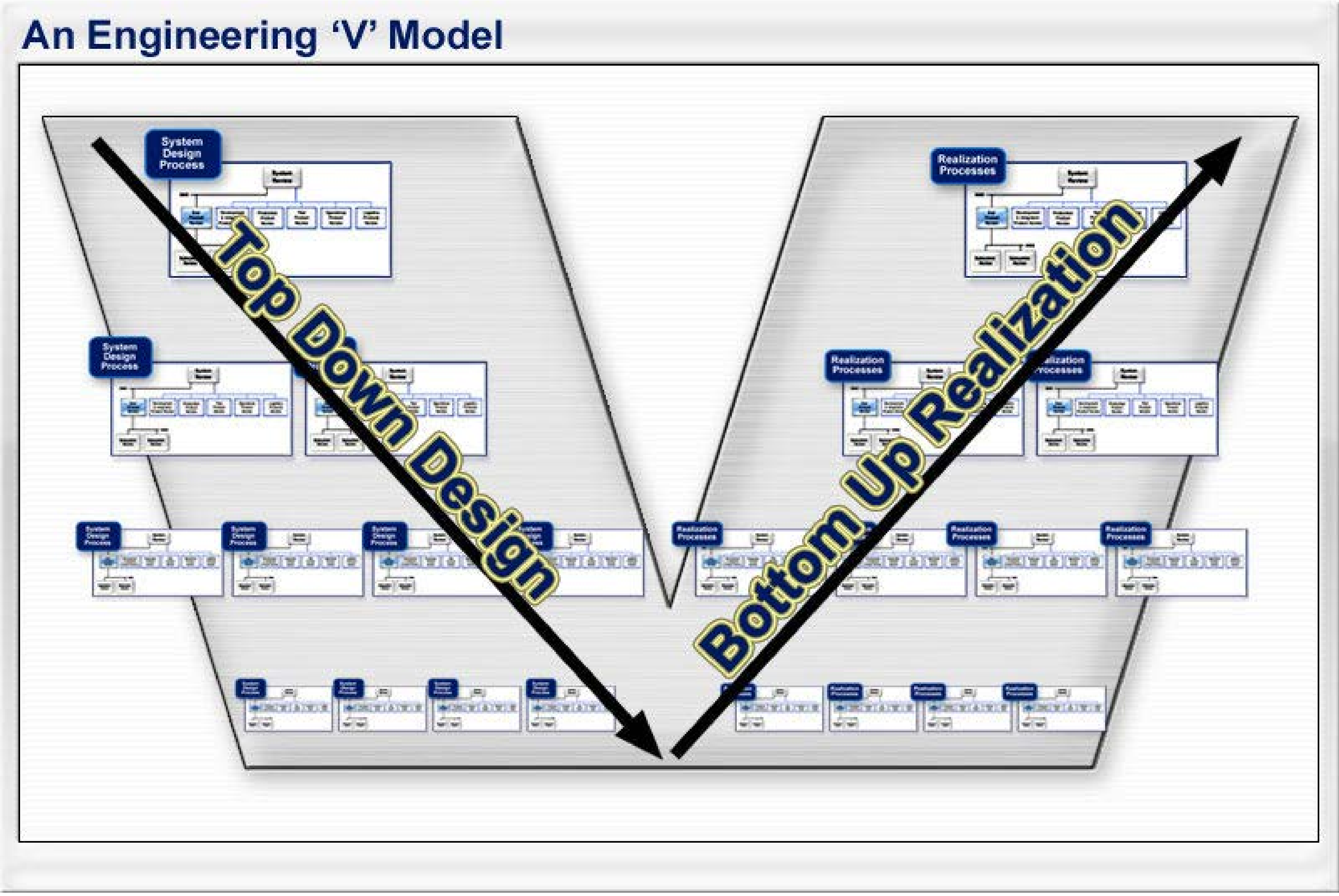
Chapter 2: Literature Review

For this thesis, I reviewed research in several areas including the defense acquisition system, systems engineering lifecycles, human factors of equipment use, human capital costs, usable security, phased implementation, decision making algorithms, stakeholder identification, quad rotor copter design, and varying test and evaluation procedures. In this section of the proposal, I present the references used as well as a brief explanation of how these sources relate to the proposed research. The literature review topics are separated into four categories: Engineering focused, User focused, Acquisition focused, and UAV focused.

The first review in the engineering background category is a defense acquisition overview focused at laying the groundwork for the DOD’s system’s engineering technical processes. It provides a broad overview of systems engineering in a learning model focused on DOD



professionals and project managers. This article explains a “V” shaped engineering model that uses Top Down Design, with Bottom Up realizations to create a system. Systems engineering plans are discussed as the roadmap of development leading to robust system design architectures. The article ends with an explanation of evolutionary acquisition of IT dominated systems. This allows for an initial core capability to be fielded that is improved over time by user feedback. This should not be limited to just information technology as the multidisciplinary nature of systems increasingly relies on the development and integration of technology that is rapidly advancing. As the lines between IT and the combat environment merge, this should be pushed to more front line systems and development mindset [10].



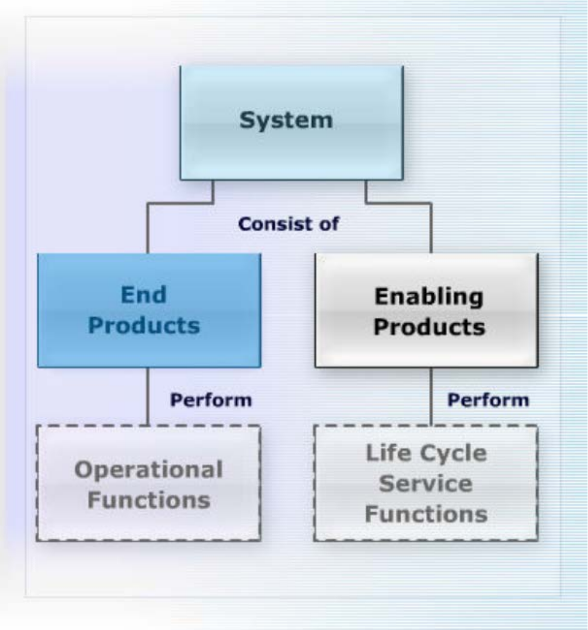
The second article addresses the low cost alternatives that are rapidly becoming available for sensor networks as more wireless technologies are developed. While wireless sensors nodes may be low cost with current technologies, they are still prohibitively expensive to field in large numbers. Until the time that these nodes can be produced at a lower price it will not be fiscally responsible to use wireless sensor nodes in the quantities necessary to make systems technically possible. Since many hurdles listed exist (cost, topography, power consumption, fault tolerance, and hardware) these solutions are not ready to be fielded [2].

The next article addresses the common issue of “requirements creep”: the tendency of a system’s scope or operational requirements to change over time, without consideration for changes in schedule or budget. This article focuses on strategies to mitigate requirements change through the project lifecycle. Identifying requirements accurately early on is the prime way to stabilize requirements through the project to reduce creep. Other system mitigation techniques are addressed, such as change control boards and requirements inspection. Of particular interest here is the brief description of joint application design and prototypes. These two suggestions, implemented together can have a major impact on this project by identifying the right users and incrementally fielding more robust solutions as time and funds allow [17].

An article by Ross, Rhodes, and Hastings [26] then discusses robust designs that are adaptable over time to increase flexibility and usefulness. Additionally, the thought of evaluating the value of the system to the stakeholder over time is presented. This method of assessing value over time ties in well with requirement creep, because the requirements can stay fixed for short stages, then be refined together with progressively larger pieces of the system evaluation. Building on this article, is an article that approaches prototyping as a different process than traditional lifecycle development. User interviews found that participants liked prototyping because it made the system feel “real” to them and granted a common baseline. Additionally quantitative comparisons of the outcomes indicated an advance to prototyping [28].

A final paper provides a critical review of literature that supports adding rigorous methodologies in systems development. The belief is that the pressures of the methods implemented actually retard the growth and development of systems and make it harder to adapt throughout the process[12]. This supports the article by Boehm & Lane[7] that addresses the many challenges to integrating systems from complex multi-owner situations, rapid change, reused components, and emergent requirements. It suggests an incremental commitment model the can be concurrently engineered throughout the development timeline. These concurrent phases are anchored together at each milestone review. The challenge to progress is identified as the path of least resistance leading to legacy regulations and then to sequential engineering and development processes.

The next section begins with an article that highlights the importance of understanding user requirements but also acknowledges the difficulty in complex organizations with many stakeholders. Additionally, users tend to think in traditional ways about how they have done things previously and, therefore, sometimes do not recognize potential improvements. A tactic to help this involves presenting users with use cases so they can see examples of the new system as well as prototyping to get users hands on a demonstration version of the system to allow bottom up refinement [23]. Further, review of the literature involving users in the design process yielded an article that discusses the importance of identifying representative



users when creating a design as well and involving their feedback in the design process so that the user and system interaction is as intuitive as possible [1]. These traits will help shorten testing and training time to get the system into operation and fully utilized. The article also poses a list of advantages and disadvantages of user centered design, but finds user centered designs integrate faster, require less redesign, are more creative, and are both more efficient and more effective.

The next article explains the difficulty of providing context for development involved with the user's needs and environment they operate in. User requirements most often are composed of lists of technical requirements and are technology based, which technical designers find easier to use to explain system needs. Users should be presented with prototypes, mock ups, and engineering models to provide feedback about their needs instead of view technical specifications that they may not understand [21].

Focusing on the human element of systems, an article was reviewed that discusses the operational and strategic level optimization of flight planning taking into account the human element required to operate UAVs. This first of its kind article takes into account that without a person to digest the information and take action on what the UAV has provided, there is no utility in the UAV being in the air in the first place [25]. This is followed by an article that focuses on human capital as a strategic variable in the development of management control systems. This article provides lessons on the high value of human capital and its effect on the cost-benefit analysis of a system. These lessons are relevant to any systems' discussion that has potentially high human capital costs [33].

This first article in the next section is a report to the Department of Defense (DOD) from an appointed review board suggesting that acquisitions be developed using concurrent engineering in the future setting the stage for today's systems engineering community. Of interest is the panel’s evaluation that the benefits of concurrent engineering are real, but that the benefits to the Department of Defense directly will have to be determined after the approach is implemented because of the complexity of federal laws regarding acquisition which many feel have stagnated the process with excessive regulations, fragmented responsibility, and duplicative functions [34].

The next article is from testimony recorded by the Government Accountability Office (GAO) discussing how improving planning on the acquisition of UAVs can help address future challenges. While current UAV operations have been deemed successful, there is a lack of interoperability between systems and a capability gap that stems from, in the office’s opinion, a lack of a joint UAV acquisition and development plan. While the points in the article are valid, there is a large gap in understanding of what “use in combat” describes. These strategic and operational views of the battlefield still ignore much of the potential gain that can be accomplished at the tactical level where fixed wing, key hole views of the battlefield are less useful and assets can be much more effective at saving lives as opposed to gaining information for decision makers[9].

This article discusses the difference between equipping versus fielding. There is a value to procuring existing technologies and putting them in the hands of the people that need them to perform their job or mission as safely and effectively as possible. Equipping allows that process to happen, whereas fielding implies taking time to research, develop, and field a robust solution to the problem. Equipping while preparing a fieldable alternative is the solution suggested in this article[19].

The next paper is a software focused review of the Incremental Commitment Model (ICM). As previously noted, many of these rapid fielding software and information technology practices such as ICM can and should be applied to systems engineering. This article recommends that commercially or open-source alternatives that exist should be used to help fill competitive gaps while businesses work to create solutions to keep pace in the marketplace. This idea can be well translated to DOD where solutions should be adopted that can help win our nations battles and save lives, even though they might not be the “best” possible solutions, they represent the best available solution. These authors suggest that existing “best” solutions be used as a measure to help close the gap until more sophisticated technologies are developed for the strategic, operational, and tactical requirements that must be satisfied [20].

The next paper analyzes the US Army’s acquisition strategy for unmanned aerial vehicles (UAVs) and examines the strengths and limitations to the fielding of the Shadow unmanned aerial system (UAS) to the brigade level. While the shadow pushes many advanced capabilities down to a lower level of command, it does not provide the flexibility needed at the lowest level of war. The asset has a large logistics footprint, a $3 million price tag, and a limited number of airframes to deploy. This article suggests using smaller, less expensive systems that can be fielded in larger numbers to gather intelligence at a greater rate [30].

Now focusing on UAV reviews, the first document is the US Army’s roadmap for UAS development and fielding through 2035. In this article, the army expresses its desire to continue to develop robust and flexible systems for the warfighter, but at the tactical level there are no significant capability changes until the 2022 proposed Nano UAS fielding. Until then, tactical level systems will still rely on units that have a single expensive system to navigate around the battlefield for reconnaissance. There is one vertical takeoff and landing (VTOL) system the Army expects to field but it is another heavy alternative that will put a weight burden soldiers. This system will be difficult to transport due to its size and weight, and difficult for Soldiers to handle and deploy [31].

The General Accounting Office issued a review of the US Army’s roadmap document and suggested that there is not enough oversight in the fielding and integration of UAV systems in the Army. Though there is a vision in place, the opinion is that more oversight is needed to ensure that the investment into these systems is properly used by filling in some missing information with detailed plans and usage guidelines [9]. This article indicates some of the intense oversight which can actually stunt the development process as mention above [34].

The next article discusses an interesting approach to UAV target acquisition and engagement assuming that the use of lethal force will be delegated to an automated assignment system in a system of cooperating UAVs to maximize coverage and, theoretically, effects the battlefield by allowing an assignment problem algorithm to choose the actions. While theoretically possible, this entire premise ignores effects based operations and the effects commanders are looking to achieve in their area of operations [16]. Along the same line of thought, with the same shortfalls is an article that discusses an approach to help route UAVs with changes in Situational Awareness (SA) to ensure proper task assignment optimization. Integer programming models are used to optimize the situational awareness provided by overlapping multiple assets to ensure maximum coverage. A concern with this line of reasoning is that SA is situational awareness, not situational observation, just because there is coverage does not mean there is any understanding. Also, complex computations take time and require processing power, which translates to weight, heat, and battery drain. Simple systems can let the person be the filter and synthesize data into knowledge that can be passed to higher echelons [4]. Constant observation is of no utility if there is not a person there to observe and interpret the information being presented.

An article by the same author further proposes removing all person controlled elements from the control of UAV systems to optimize their utilization and flight time using different algorithms and linear programing techniques. Again, this lacks any practical knowledge of the situation and the observation and subsequent interpretation ability of pilots for targets of opportunity of dynamic rerouting of assets. It also assumes random assignment by chain of command and does not take into account the scheduler’s rationale for requesting assets. While weighted importance could be assigned to tasks, there is no currently solution to programmatically represent the relationship of tasks and their importance to overall mission success [15].

Chapter 3: Incremental and Iterative System Lifecycle

The current approaches of both the systems engineering “V” and the waterfall method lead to slow development and a lack of opportunity for user refinement. The slow development comes largely from the cradle to the grave development that occurs within the system process. The technology transition from emerging technology to application lacks the practical knowledge necessary to make a seamless transition from development to implementation.

The development of technology often happens in isolation of user requirements that pull a system forward, so a direct translation of the “pushed” technology into a “pulled” application is not straightforward. “Push” describes a scenario where technology is created, advanced, or invented without a specific demand or requirement to meet. “Pull” describes a scenario where a demand exists and a user needs technology for a specific purpose. Many engineers and designers that evolve these new technologies have areas of interest or emphasis of their own, that may create a bounded perspective that skews their perception of how the technology they have developed is used or will be adapted. These professionals know how they *meant* it to be used, and that may create bias in the outcome and progression of the technology. The already slowed process then does not give the actual users a chance to refine the technology until late in the development process. First the engineers must determine how to adapt the latest technology to the problem presented, then the stakeholders have to guide the development along and determine a course of action, finally after more development and technology integration, users may finally have the opportunity to see a prototype that is so far along in the development process in terms of time and resources that is it not easily moldable to the feedback provided. Add to this that the latest technology is not necessarily the best option. Often unproven and unrefined, the development time it takes to make technology reliable further slows the process and adds expense. The expectations of stakeholders do not often equate with the expectations of users. In defense particularly, generational, military occupational specialty (MOS), experience in the contemporary operating environment (COE) at the appropriate level, all vary greatly from the stakeholder level to the user level.

Further corrupting the current process is the use of poorly defined and restrictive technology readiness levels. This leads to systems where technologies are not deemed “ready” for use until certain performance levels are met, and creates an environment where instead of thinking about capabilities to meet requirements, the process is more about selecting parts that are ready to try to adapt to capabilities.

“Cradle to grave vision and planning” is essential to a system’s development and fielding, but only as applied to the system itself, not the technologies that are applied to meet the capabilities required by the user.

The solution to this problem is an iterative and incremental waterfall systems lifecycle. This lifecycle combines push and pull together into an integrated model. The first waterfall is a push driven phase, with the second and subsequent phases pulled along by tactics techniques and procedures (TTPs) and user refinement gained from the prior phase(s).

Iterative and Incremental waterfall systems lifecycle approach

This method looks like the traditional Waterfall structure with feedback loops that contain modular system iteration cycles to conduct as needed after the design phase. This is a system of systems approach to developing and fielding technologies. The number of iterations is determined during the requirements and design stages. The number of waterfalls is determined by the number necessary to provide capabilities and continue improvement until end state. Each situation will be different and the number of waterfalls will have to be feasible for the current technology readiness levels (TRLs) of the current alternatives compared to the TRLs of the alternatives that will be fielded in future iterations. Depending on the level of the future technology TRLs, the amount of time to develop those to a usable level will vary.

Using the existing view from the Defense Acquisition University above, instead a system only consisting of Enabling Products that support an end product, we will add a parent branch for enabling systems that are used to further the lifecycle to the end state system that is the terminal objective of the process.

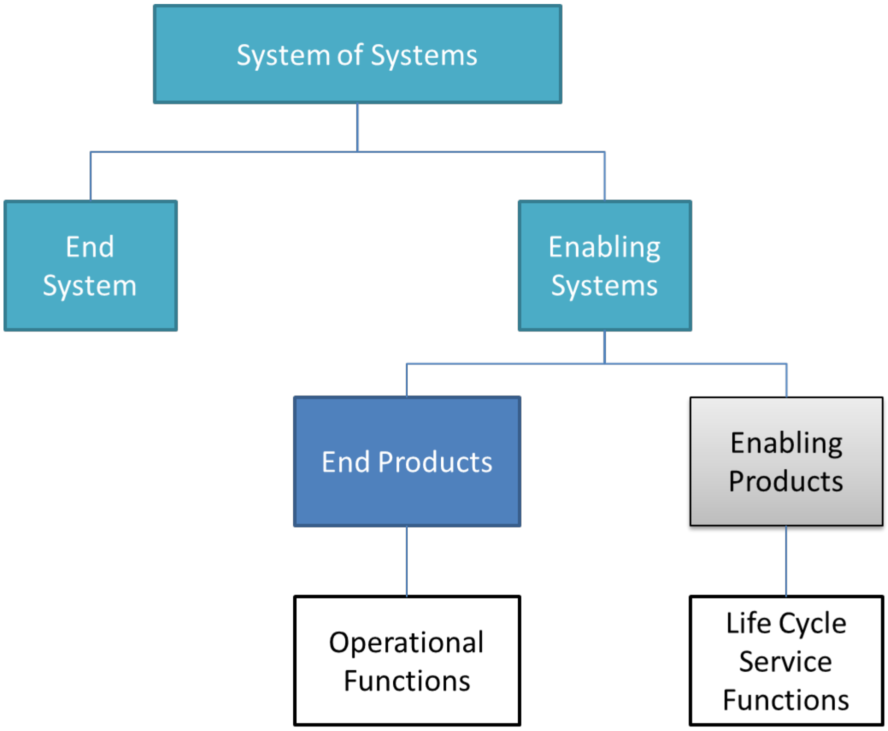


Figure 4 - System of Enabling Systems

There are two major advantages to this approach of systems development. First, this rapid fielding of an alternative can provide a new capability to the stakeholder or user that will have immediate cost benefits. Second, this method allows for user refinement through the development of TTPs that can be used to refine future alternative cycles in the waterfall. Since there are iterative cycles, iterative prototypes and solutions are fielded allowing a much broader user experience and feedback opportunity for improvement. The more users that experience immediate and intermediate alternatives, the more refinement of the stakeholder's initial requirements occur, leading to a more robust, usable system that has user buy-in and a high adoption rate.

Just as in any systems engineering endeavor, an interdisciplinary team is vital to the success of this method. The team structure in this method should be divided into two principle groups, the developers and the executers. While one team is developing the future alternatives, one team is implementing the current feasible and cost-effective alternatives.

Two Phases

1) Conduct Requirement Analysis and Design

First, conduct requirement analysis and design for the immediately available alternative, then proceed to the next alternative.

This method begins with the requirements analysis done for the system. Once the initial requirements analysis is complete, a feasibility study will be conducted with current commercial off the shelf (COTS) alternatives and mature TRL technologies in the design phase. These results will help determine what the "good enough" metrics are from the user's perspective so an alternative that is reproducible and repeatable can be fielded to users immediately to fill a capabilities gap. The number of waterfalls employed will determine the number of cycles required to complete the first step. The number of cycles is the number of alternatives that will be implemented during the life of the system development process. Simultaneous with the beginning of the design for a subsequent alternative, the preceding alternative waterfall begins with the implementation of that system.

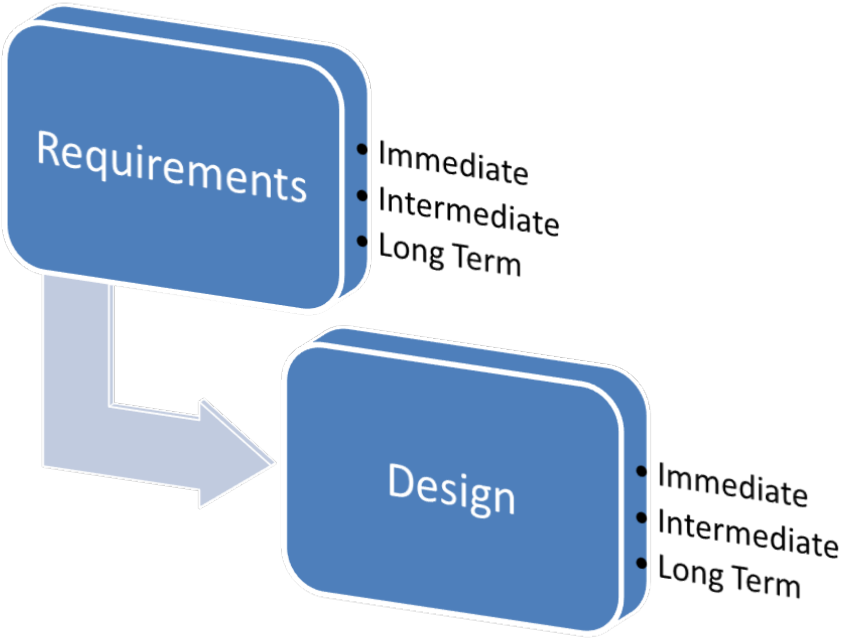


Figure 5 - Requirement Analysis and Design Iteration

2) Child Waterfall Iterations

Each waterfall contains stages for the implementation, validation and verification, fielding, and maintenance of the system at that level. These nested systems and waterfalls together create the iterative approach that will lead to a more responsive and faster fielding process. The waterfalls lead to the next waterfall during the end of the fielding and beginning of maintenance. Each alternative will be maintained until it is completely replaced by the subsequent alternative in the waterfall.

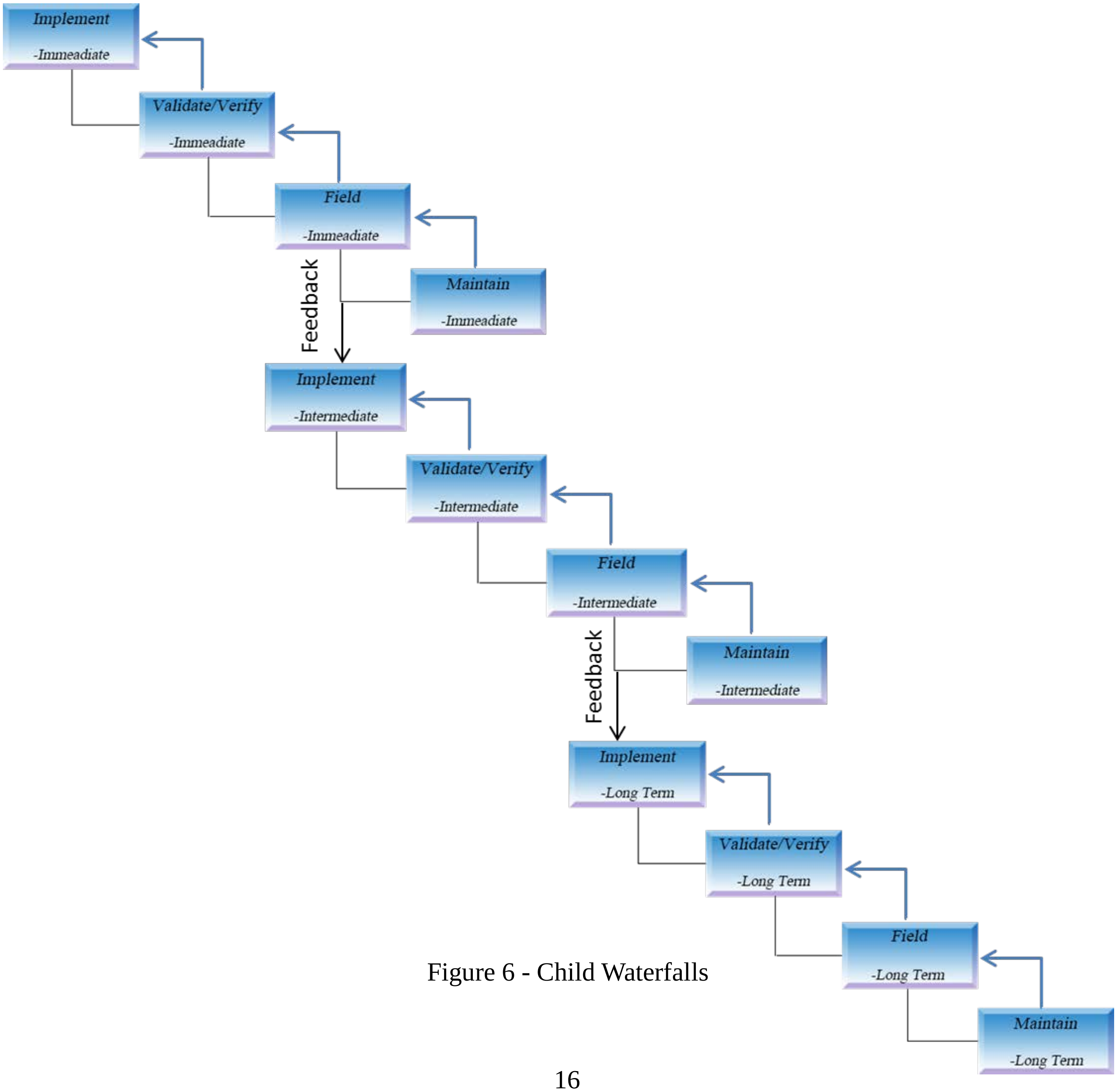


Figure 6 - Child Waterfalls

Comparison to other methodologies

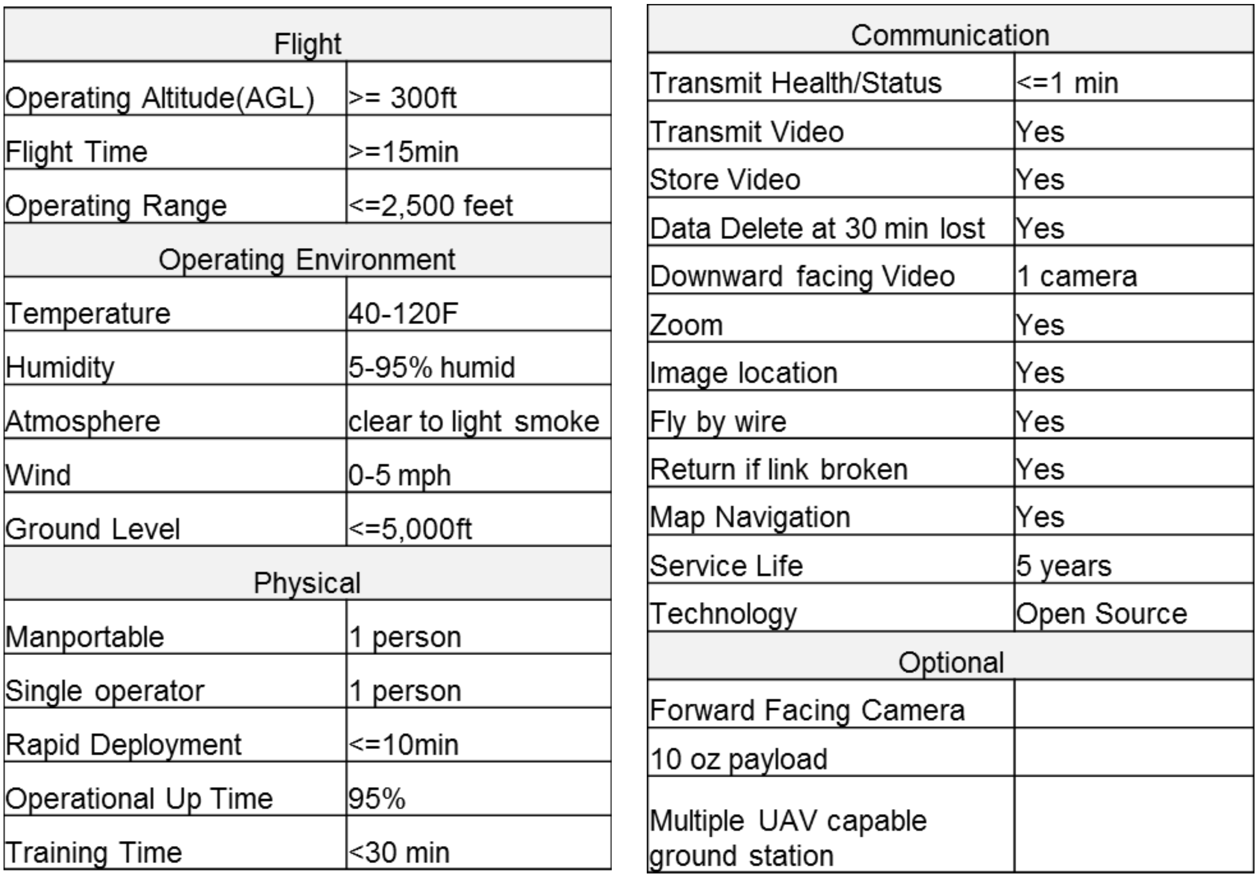
As a hybrid methodology, the iterative and incremental system lifecycle has many similarities to other lifecycles. Like evolutionary system design, the iterative and incremental lifecycle works to field solutions in pieces that are progressively better. The spiral system development model's link is the continuous feedback driving development of the product along. The thing that separates the iterative and incremental approach is the change in perspective on the lifecycle. Instead of focusing on the improvement of one system, we are going to view the "system" as a system of systems. Fielding determinations are based upon technology readiness levels and the desire to provide capabilities immediately, while refining our systems to make them more robust, over time. This refinement will not be isolated to making improvements to the current technology being used, or just replacing components and upgrading a single system; but developing technologies that were previously not mature enough in the past to provide a capability. As these technologies advance, each successive alternative fielded is more robust, and driven by user feedback from the system already in use. In a nested system of systems approach, as technologies mature, they can be incorporated into future alternatives and therefore not delay development of the current alternative being fielded. While other methodologies put together a "puzzle" piece-by-piece until it is complete, the iterative and incremental system lifecycle puts together a series of puzzles, each of which gets more complex and targeted as they are implemented.

Chapter 4: Case Study - Requirement Analysis and Design

To support the iterative and incremental waterfall system of systems approach, a case study was designed using the US Army UAV Roadmap and the analysis of the current UAS landscape. Using this case study, not only can a design for immediate fielding be developed and tested, but the readiness of technologies in this area can be assessed to see if there is an economic impact of this method of fielding, and also the analysis of the user environment compared to the current capabilities.

The initial UAV system requirements were taken from a DOD sponsored class in AY 2011 looking for an open source UAV alternative.

Table 1 - Operational Requirements



Flight	
Operating Altitude(AGL)	>= 300ft
Flight Time	>=15min
Operating Range	<=2,500 feet
Operating Environment	
Temperature	40-120F
Humidity	5-95% humid
Atmosphere	clear to light smoke
Wind	0-5 mph
Ground Level	<=5,000ft
Physical	
Manportable	1 person
Single operator	1 person
Rapid Deployment	<=10min
Operational Up Time	95%
Training Time	<30 min

Communication	
Transmit Health/Status	<=1 min
Transmit Video	Yes
Store Video	Yes
Data Delete at 30 min lost	Yes
Downward facing Video	1 camera
Zoom	Yes
Image location	Yes
Fly by wire	Yes
Return if link broken	Yes
Map Navigation	Yes
Service Life	5 years
Technology	Open Source
Optional	
Forward Facing Camera	
10 oz payload	
Multiple UAV capable ground station	

Survey

To validate the requirements, a survey was distributed to soldiers at the company level and below in a combined arms battalion (CAB). This not only verified the requirements from key stakeholders, but helps refine which capabilities are most urgent, what users think is acceptable, and the feasibility of immediate system alternatives.

The benefit of using a CAB for the survey is that these combat focused units have the soldiers that would employ the proposed systems in training and combat, and are composed of a broad variety of MOS, rank, combat experience, and age. This representative population of users has the most practical knowledge of the current operating environment at the tactical level, where a small UAV would be fielded. Out of the unit population of 750 soldiers, 170 completed the survey.

Survey results indicate that there was a uniform perspective on flight time and range requirements for a system, as well as the amount of time that the system would need to be in the air. These results supported the idea that a "good enough" alternative is feasible with current technologies and that a less robust and technologically advanced tactical UAS with VTOL capability and hover would aid in:

-Target acquisition in buildings or around dead space

-Inter-visibility (IV) Line clearing (See Figure 7)

- Horizontal perspective change for line of sight of dead space (See Figure 8)

-Roof observation (See Figure 8)

-Investigation of suspicious objects (See Figure 9)

Figure 7 - IV Line

Figure 8 - Roof Top Perch

Figure 9 - Tire w/ IED

Another result from the survey was the acceptance of soldiers to operate a low altitude UAV close to the ground that would still be useful given flight time of less than 15 minutes. So while stakeholder's specified much higher altitudes and longer flight endurance, these objectives should not hinder the advancement and fielding of a capability because users do not believe they are required to have additional capability on the ground.

System Architecture

The functional flow for the alternatives should generally follow the functional flow block diagram (FFBD) below, allowing a solider to carry and deploy the platform quickly and individually. Also noted in the results was a preference of soldiers for vehicle carried platforms which is largely the result of the most recent experiences from a unit surveyed in Iraq where they were normally vehicle mounted and always within operating range of vehicle support.

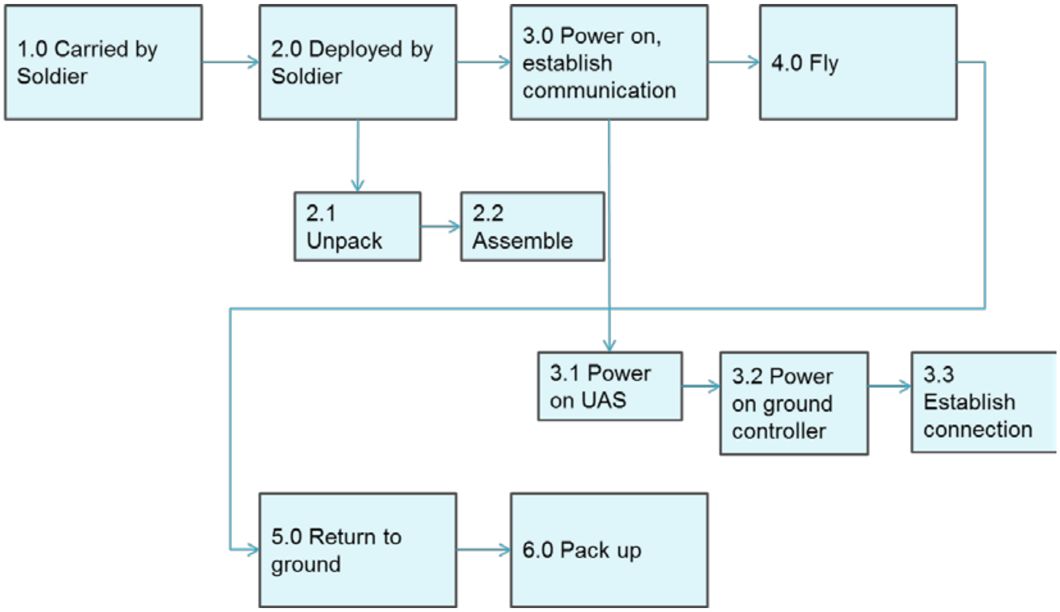
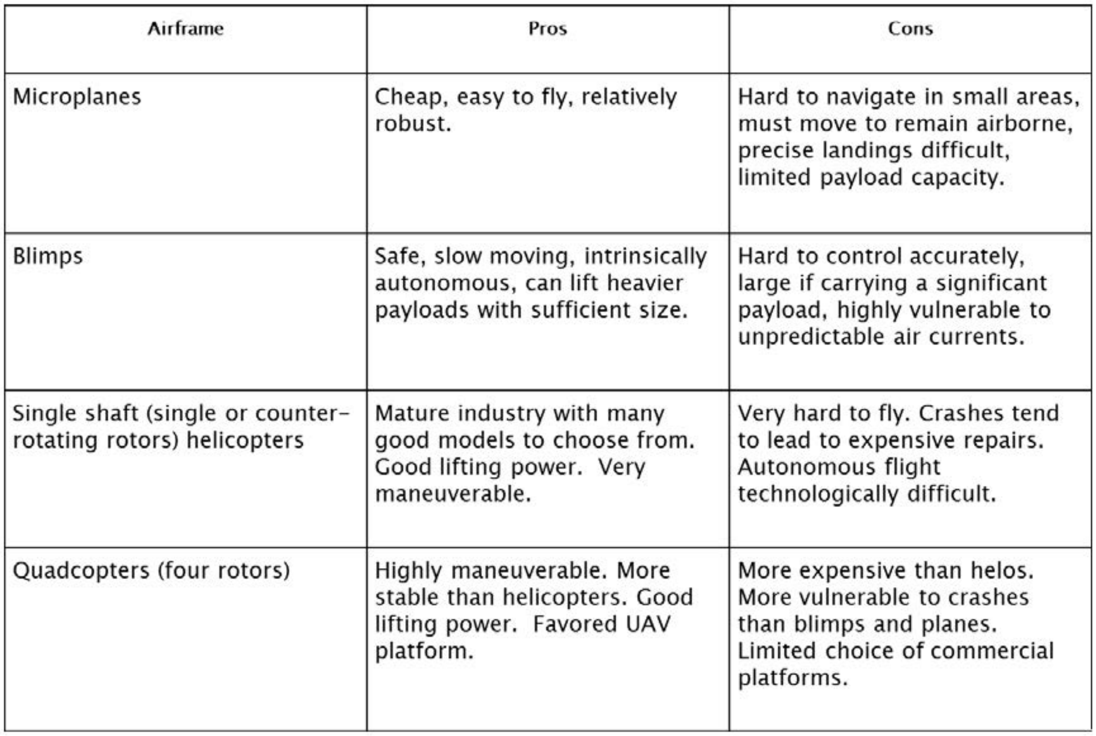


Figure 10 - Functional Flow Block Diagram

Based on the FFBD above and operational specifications, the following four alternatives were evaluated for suitability as a tactical UAV. The quadcopter architecture was selected to proceed forward due to its ability to provide a new capability, ease of flight training, stability of flight, and lifting power.

Table 2 - Tradeoff Analysis



Airframe	Pros	Cons
Microplanes	Cheap, easy to fly, relatively robust.	Hard to navigate in small areas, must move to remain airborne, precise landings difficult, limited payload capacity.
Blimps	Safe, slow moving, intrinsically autonomous, can lift heavier payloads with sufficient size.	Hard to control accurately, large if carrying a significant payload, highly vulnerable to unpredictable air currents.
Single shaft (single or counter-rotating rotors) helicopters	Mature industry with many good models to choose from. Good lifting power. Very maneuverable.	Very hard to fly. Crashes tend to lead to expensive repairs. Autonomous flight technologically difficult.
Quadcopters (four rotors)	Highly maneuverable. More stable than helicopters. Good lifting power. Favored UAV platform.	More expensive than helos. More vulnerable to crashes than blimps and planes. Limited choice of commercial platforms.

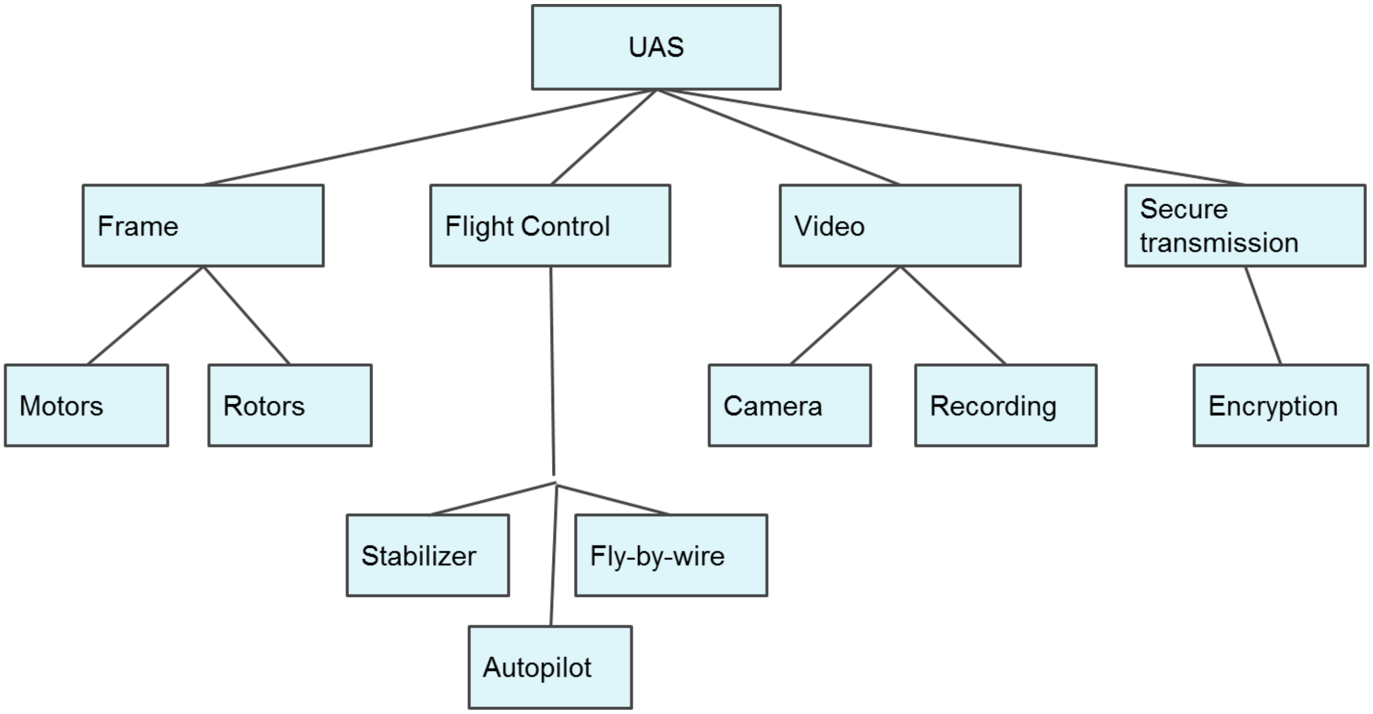


Figure 11 - System Architecture

Chapter 5: Case Study – Data Application

Waterfall I:

Immediate alternative- Parrot AR Drone 2.0

-Easily upgradable in range, ground control station, and multiple platform control the Parrot AR Drone is an open source alternative that can meet all of the necessary functional requirements. It displaces one square foot of space, comes equipped with two cameras, and has an intuitive interface that is almost amazingly fast to learn. The price point for each complete system, as proposed to field, is less than $1,000 to start, including transportation case and spare parts. Training time is reduced due to an intuitive interface and soldier familiarity with the presented video game type controls. Pilots can be trained and have the platform in the air in less than 30 minutes. After the initial training, it takes the pilot less than 2 minutes to get the platform into operation. During the case study, 20 people were trained to use the Parrot AR Drone 2.0 in a ten minute block of instruction. Of the trained population, 10 were soldiers, 10 were civilian. All 20 of the trained personnel were able to successfully perform all functions outlined in the FFBD within 30 minutes of the 10 minute block of instruction.

This open source alternative can be operated by touch on iOS or Android based tablets and phones, via gamepad on the same devices, or via computer. The range can be easily increased from the stock range of 200 ft to several hundred meters with the addition of an external wifi antenna.

Camera: 720p 30fps HD

Lens: 92 degree diagonal wide angle

Processor: 1 GHz 32-bit ARM Cortex A8

Weight: 380 grams with outdoor hull; 420 grams with indoor hull

Motors: 4 brushless 14.5 watt, 28,500 RPM inrunner motors

Battery: 3 element, 1,000 mA/hour rechargeable LiPo

Sensors: 3 axis gyroscope, 3 axis accelerometer, 3 axis magnetometer, ultrasound altimeter

Figure 12 – Parrot AR Drone 2.0 with Case [35]

Waterfall II:

Intermediate alternative – DIY Drones Quad Copter with Ardupilot 2.0

- This alternative is superior to the Parrot AR Drone in most metrics, however the platform is not currently mass produced and each platform must be independently setup, tuned, and operational. More time is needed to prepare this technology to yield reproducible results. The time gained by fielding the AR Drone will aid in the refinement of this alternative so the performance measures achieved are more consistent and the controls more intuitive. Additionally, the user requirements will become more honed as users will have a similar capability in their hands, developing tactics, techniques, and procedures for use. Users will have more constructive feedback that can be used to guide further development of this platform. Initial development and progression should focus on standardization of motor production. Motors that are more responsive and have a consistent output are needed. The current alternatives are poorly manufactured with a wide variance in performance. The autopilot functionality of Ardupilot is advanced and allows users to navigate in a fly by wire fashion with a controller as well as using a map to select waypoints to navigate the platform. This system could be ready for fielding in the near term with a dedicated team to take the current technology and advance it to a reproducible and consistent form.

Waterfall III:

Long Term – Micro UAV, palm size quad with camera and swarm ability

- There has been a lot of development in useable technologies in this arena with a platform that can be used as a starting point that is expected to be available in mid-2013, 12 years sooner that the Army's UAV Roadmap anticipates this capability. The incremental cycle will allow the developers of this system to use feedback from other platforms used in the approach to get this into hands of users and work on keeping prices down as technology develops and as savings are realized in total from the system approach. The vignette below from the US Army UAV roadmap exhibits the capabilities it plans to have in place by 2025 with a micro UAV that can navigate through a structure and recharge using nearby power lines. This may be an achievable goal, but this platform is based on technology that has not been integrated and the system has yet to be developed.

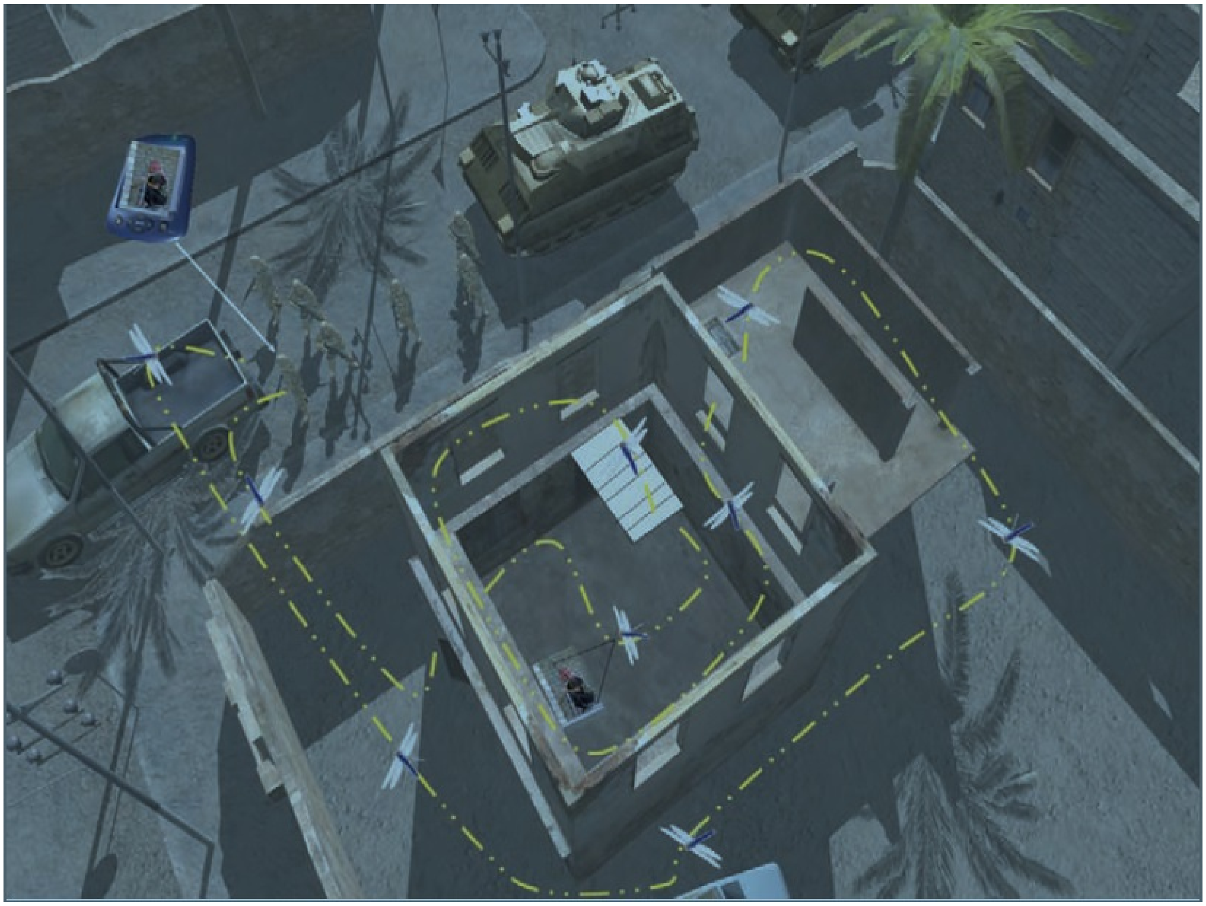


Figure 13 - Micro UAV Vignette

Chapter 6- Benefit Analysis

Earlier systems can save lives by providing stop gap capabilities, a “band aid” so to speak, while future alternatives are prepared. This will save the government millions of dollars than can be used to continue system funding. This earlier capability fielding also allows users more time to develop TTPs that can be applied to the system of systems.

Costs benefit analysis

An incremental systems approach would allow the combination of several processes into one lifecycle, synchronizing efforts and saving funds. By combining processes together, overhead is cut by consolidating facilities and personnel needed to identify, acquire, develop, and field new systems.

Process Streamlining

The Rapid Fielding Initiative (RFI) takes commercial off-the-shelf items and other rapidly fieldable technologies, and gets them into the hands of warfighters’ immediately. While useful, the program’s existence is proof that a more responsive acquisition system is necessary. The RFI cycle bypasses other development processes that are in place and fills gaps that may already be addressed in other planning cycles, or should have been addressed. This system can be replaced by the first waterfall in the incremental commitment model. Then one focused acquisition staff could develop the entire plan to develop a capability, from immediate fielding alternatives, to long term technology development and fielding. The increased number of craft fielded will aid in the long-term distribution of this capability to National Guard and Reserve units. Another cost savings from the shorter service life of initial alternatives is reduced price due to lower maintenance cost long-term and a lower durability requirement on components used(e.g., systems may be replaced with superior alternatives prior to mechanical failure).

Human capital

The cost savings as applied to personnel can be hard to quantify. There are many costs associated with killed and wounded soldiers. To make calculations more concrete, we will use conservative, fixed costs associated with human loss using death gratuity only. This is not intended to devalue the worth of human life, but simply to provide a conservative minimum cost associated with the loss of a life. This number alone is convincing, even without taking into account the cost of training soldiers, treating injuries, medical retirement benefits, and other metrics that could be added and the cost to society for injured or lost soldiers.

Table 3 – Global War on Terror US Military Casualties

U.S. Military Casualties
GWOT Casualty Summary by Casualty
(As of March 8, 2013)
Source: DMDC's Defense Casualty

Operation / Casualty Type	Weaponry	Other	Transportation	Pending	Unknown	Medical	Total
OEF Hostile Death	465	986	28	20	217	2	1718
OEF Non-Hostile Death	120	150	88	17	27	48	450
OEF Wounded in Action	3437	9548	16	21	5258	36	18316
OIF Hostile Death	2078	1062	92	64	170	14	3480
OIF Non-Hostile Death	273	256	255	25	27	93	929
OIF Wounded in Action	19319	8937	129	25	3499	17	31926
OND Hostile Death	12	26	0	0	0	0	38
OND Non-Hostile Death	16	4	0	0	2	6	28
OND Wounded in Action	77	207	0	0	11	0	295
Total	25797	21176	608	172	9211	216	57180

Using data collected from Operation Iraqi Freedom (OIF), there were 3480 hostile fire deaths in Iraq. Additionally, in OIF and Operation Enduring Freedom (OEF) [Afghanistan] combined, there were 2,483 deaths due to improvised explosive devices (IEDs). If just one percent of deaths caused by hostile fire could have been prevented from an earlier fielding of a tactical UAV, the cost savings would provide for approximately 3,500 of the proposed Parrot systems. Extrapolated against IED deaths, the cost savings would provide for approximately

2,500 of the proposed Parrot systems. In either case, given the high ratio of support troops to troops “outside the wire” on a regular basis, that is a system for each squad-sized element.

Table 4 - Cost Benefit Analysis

Death Gratuity	$100,000	Death Gratuity	$100,000
OIF Hostile Deaths	3480	Deaths in Iraq and Afghanistan from IED	2483
Death Costs for OIF in gratuity	$348,000,000	Death Costs from IED in gratuity	$248,300,000
1% Savings	$3,480,000	1% Savings	$2,483,000
Parrot System Cost	$1,000	Parrot System Cost	$1,000
# of systems fielded by Cost benefit	3,480	# of systems fielded by Cost benefit	2483
Square miles in Iraq	169200	Square miles in Iraq	169200
Square miles in Afghanistan	250000	Square miles in Afghanistan	250000
Total square miles	419200	Total square miles	419200
Systems every X miles	120.46	Systems every X miles	168.83
Most troops in Iraq 10/1/2007	166300	Most troops in Iraq 10/1/2007	166300
Parrot per X Troops	47.79	Parrot per X Troops	66.98

Equipment Savings

A more tangible example of cost savings from the faster implementation and fielding of an alternative through the iterative method is to calculate potential savings on equipment that was lost over the time period in which the capability was absent from use. In Operation Iraqi Freedom the following equipment is estimated to have been destroyed according to the General Accounting Office:

Table 5 - Equipment Cost Analysis

Vehicle	Price*	# Destroyed**	Cost
M1A1/2	$4,400,000	80	$352,000,000
M2/3	$3,166,000	55	$174,130,000
M113	$405,815	20	$8,116,300
HMMWV	$61,042	250	$15,260,500

Sources: * FEDLOG
** GAO

TTP Development and Adoption

This progressive approach to development also gives users the ability to develop TTPs, which helps users across the forces incorporate systems into the activities of their respective units. This increases adoption of the technology as well as the volume of feedback to refine future development and implementation. The system can then become more advanced and possibly more robust, as the potential of the system is maximized due to the incremental adoption of the platform and the improved rapport that develops with the users over time. As the system is adopted and TTPs spread throughout the organization the technology will either prove the system is complete, or changes will be identified to make the system more useful.

Chapter 7- Conclusions

The iterative and incremental system lifecycle approach is an effects based process that borrows the best practices from several system development concepts. The result is systems development which is flexible and serves as a compromise between top-down and bottom-up design philosophies. The benefit is a concentrated effort towards a common goal, synchronizing the development of technologies in one direction, under one architecture. As displayed by the case study, the ability to rapidly identify feasible alternatives that meet a minimum threshold required by users, while adhering to the stakeholder's description of system requirements is possible. This not only saves time and resources, but can provide critical capabilities to users that pay for themselves when put into use earlier in the lifecycle due to increased savings in future change management thanks to early user feedback and subsequent refinement early on, and savings in human capital from the early fielding of critical capabilities.

Using the iterative and incremental approach would also allow for the combination of design and implementation methods from multiple fields. An example from the case study would be ending the Army's Rapid Fielding Initiative Program and putting those functions into the normal program managers offices, providing oversight in one location, reducing overhead costs of the system and nesting efforts together instead of creating isolated, islands of development.

This research does not address issues in bureaucracy that currently slow acquisition and development in the federal government. Instead, this design provides defensible alternatives for project management within the constraints of the bureaucratic framework. If nothing else, the iterative and incremental approach provides for fewer separate programs that require oversight, and highlights tangible milestones for project offices as they would produce fieldable systems with real and more frequent concrete results.

Future Works

While the case study was performed with COTS alternatives that were feasible, a more complete analysis of the initial alternative fielding would be useful to gain user feedback and incorporate that into the process. Additionally, the surveys conducted were performed in a combined arms battalion to provide a representative sample for user feedback. By increasing the sample size and using more than one military installation, more data could be extracted from the results. For example, the deployment experience of individuals within a unit tends to be similar, but from unit to unit they can vary widely, reflecting in different user experiences and feedback. Also, separating the data by rank and specialty in more statistically significant numbers could help identify trends in the willingness of different areas of the military to incorporate new technologies.

Lastly, I found it interesting that the number of survey respondents who felt that even if a useable alternative was fielded, they would not be able to use it if higher ranking leaders could not view the video feed from their UAV [Appendix 6]. This is interesting for several reasons:

1) This capability would have little tactical value for a “tactical” asset
2) Long range video transmission would drive up price and weight
3) Long range video transmission would decrease flight endurance
4) This would increase the price and development time for such craft

Combined, these factors point to the specification creep that is rampant in the DOD and go back to stakeholder’s adding requirements that are not necessary for mission accomplishment.

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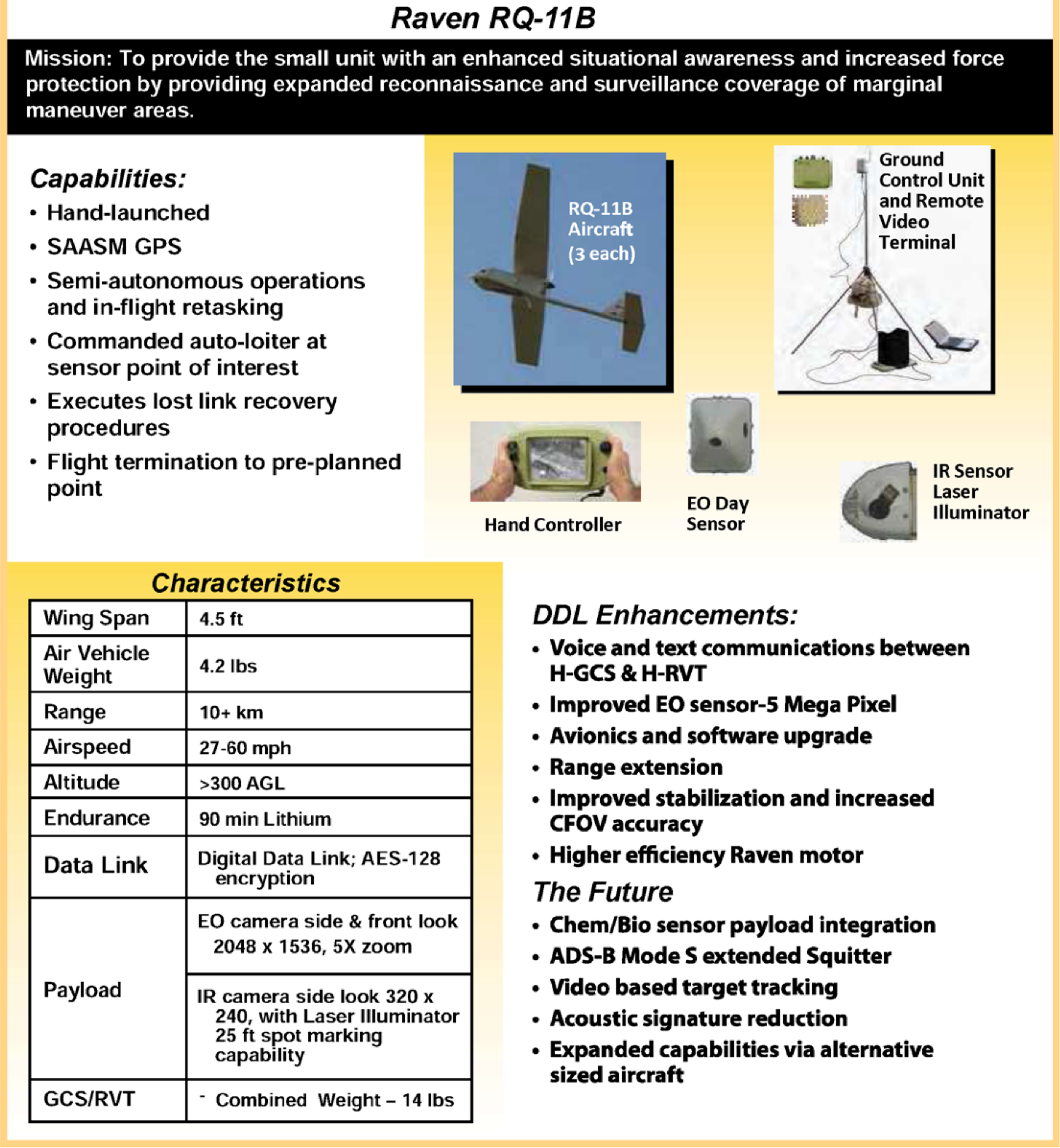
Appendix 1 – Raven RQ-11B Data Sheet [31]



Raven RQ-11B

Mission: To provide the small unit with an enhanced situational awareness and increased force protection by providing expanded reconnaissance and surveillance coverage of marginal maneuver areas.

Capabilities:

- Hand-launched
- SAASM GPS
- Semi-autonomous operations and in-flight retasking
- Commanded auto-loiter at sensor point of interest
- Executes lost link recovery procedures
- Flight termination to pre-planned point

RQ-11B Aircraft (3 each)

Ground Control Unit and Remote Video Terminal

Hand Controller

EO Day Sensor

IR Sensor Laser Illuminator

Characteristics

Wing Span	4.5 ft
Air Vehicle Weight	4.2 lbs
Range	10+ km
Airspeed	27-60 mph
Altitude	>300 AGL
Endurance	90 min Lithium
Data Link	Digital Data Link; AES-128 encryption
Payload	EO camera side & front look 2048 x 1536, 5X zoom
	IR camera side look 320 x 240, with Laser Illuminator 25 ft spot marking capability
GCS/RVT	- Combined Weight – 14 lbs

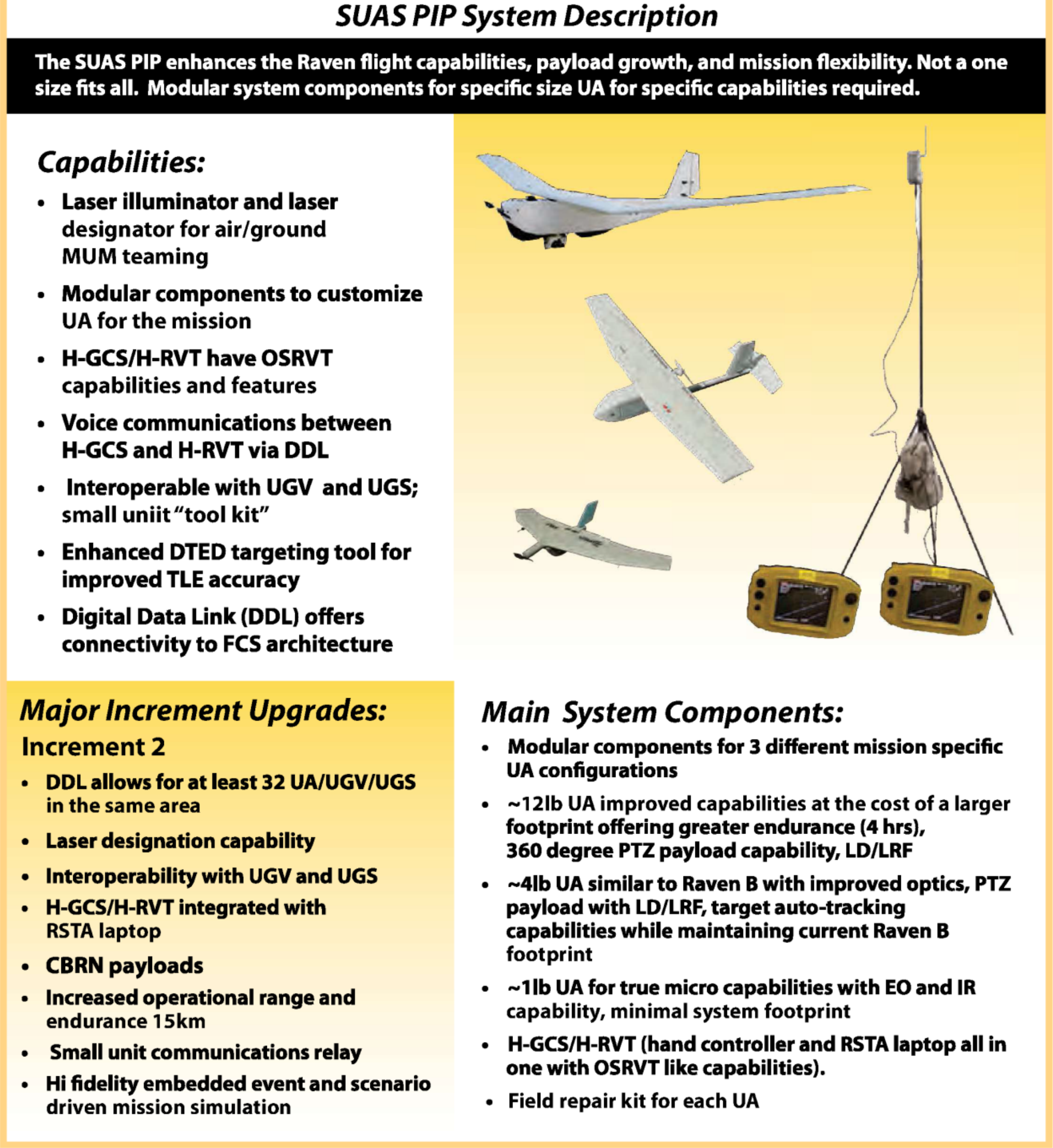
DDL Enhancements:

- **Voice and text communications between H-GCS & H-RVT**
- **Improved EO sensor-5 Mega Pixel**
- **Avionics and software upgrade**
- **Range extension**
- **Improved stabilization and increased CFOV accuracy**
- **Higher efficiency Raven motor**

The Future

- **Chem/Bio sensor payload integration**
- **ADS-B Mode S extended Squitter**
- **Video based target tracking**
- **Acoustic signature reduction**
- **Expanded capabilities via alternative sized aircraft**

Appendix 2 – SUAS Data Sheet [31]



SUAS PIP System Description

The SUAS PIP enhances the Raven flight capabilities, payload growth, and mission flexibility. Not a one size fits all. Modular system components for specific size UA for specific capabilities required.

Capabilities:

- Laser illuminator and laser designator for air/ground MUM teaming
- Modular components to customize UA for the mission
- H-GCS/H-RVT have OSRVT capabilities and features
- Voice communications between H-GCS and H-RVT via DDL
- Interoperable with UGV and UGS; small uniit "tool kit"
- Enhanced DTED targeting tool for improved TLE accuracy
- Digital Data Link (DDL) offers connectivity to FCS architecture

Major Increment Upgrades:

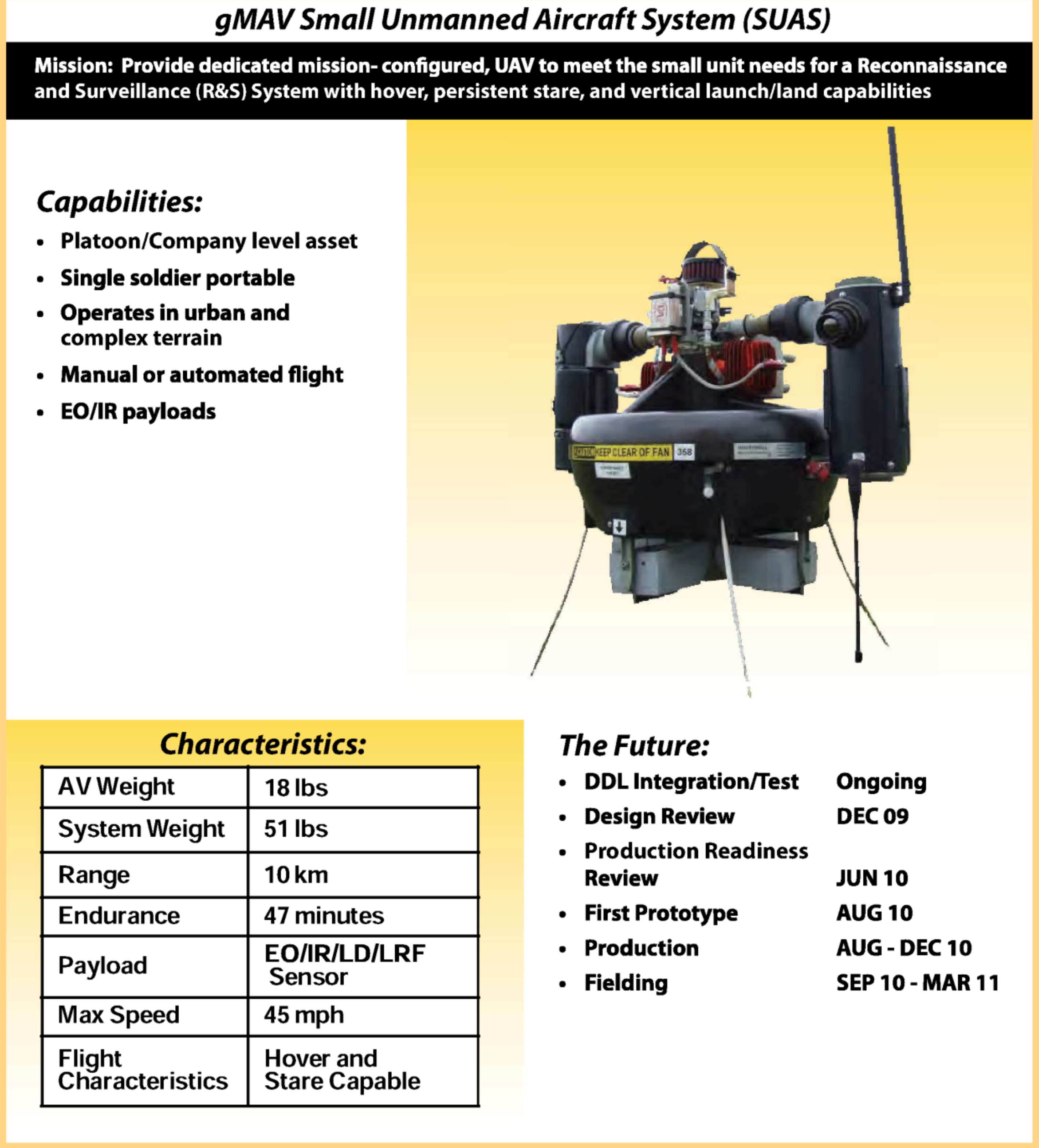
Increment 2

- DDL allows for at least 32 UA/UGV/UGS in the same area
- Laser designation capability
- Interoperability with UGV and UGS
- H-GCS/H-RVT integrated with RSTA laptop
- CBRN payloads
- Increased operational range and endurance 15km
- Small unit communications relay
- Hi fidelity embedded event and scenario driven mission simulation

Main System Components:

- Modular components for 3 different mission specific UA configurations
- ~12lb UA improved capabilities at the cost of a larger footprint offering greater endurance (4 hrs), 360 degree PTZ payload capability, LD/LRF
- ~4lb UA similar to Raven B with improved optics, PTZ payload with LD/LRF, target auto-tracking capabilities while maintaining current Raven B footprint
- ~1lb UA for true micro capabilities with EO and IR capability, minimal system footprint
- H-GCS/H-RVT (hand controller and RSTA laptop all in one with OSRVT like capabilities).
- Field repair kit for each UA

Appendix 3 – gMAV VTOL Data Sheet [31]



gMAV Small Unmanned Aircraft System (SUAS)

Mission: Provide dedicated mission- configured, UAV to meet the small unit needs for a Reconnaissance and Surveillance (R&S) System with hover, persistent stare, and vertical launch/land capabilities

Capabilities:

- **Platoon/Company level asset**
- **Single soldier portable**
- **Operates in urban and complex terrain**
- **Manual or automated flight**
- **EO/IR payloads**

Characteristics:

AV Weight	18 lbs
System Weight	51 lbs
Range	10 km
Endurance	47 minutes
Payload	EO/IR/LD/LRF Sensor
Max Speed	45 mph
Flight Characteristics	Hover and Stare Capable

The Future:

DDL Integration/Test	**Ongoing**
Design Review	**DEC 09**
Production Readiness Review	**JUN 10**
First Prototype	**AUG 10**
Production	**AUG - DEC 10**
Fielding	**SEP 10 - MAR 11**

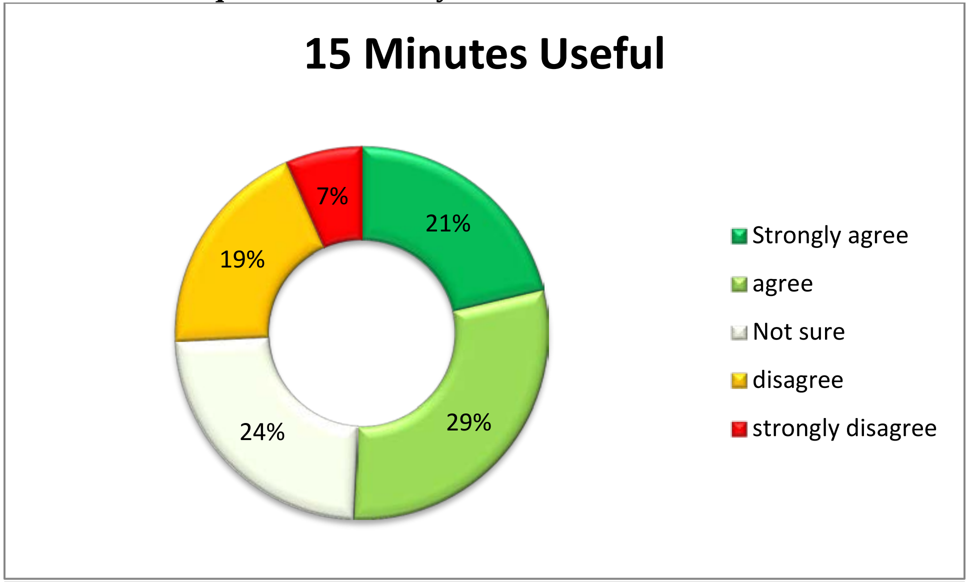
Appendix 4 – Parrot AR Drone Proposed System Cost

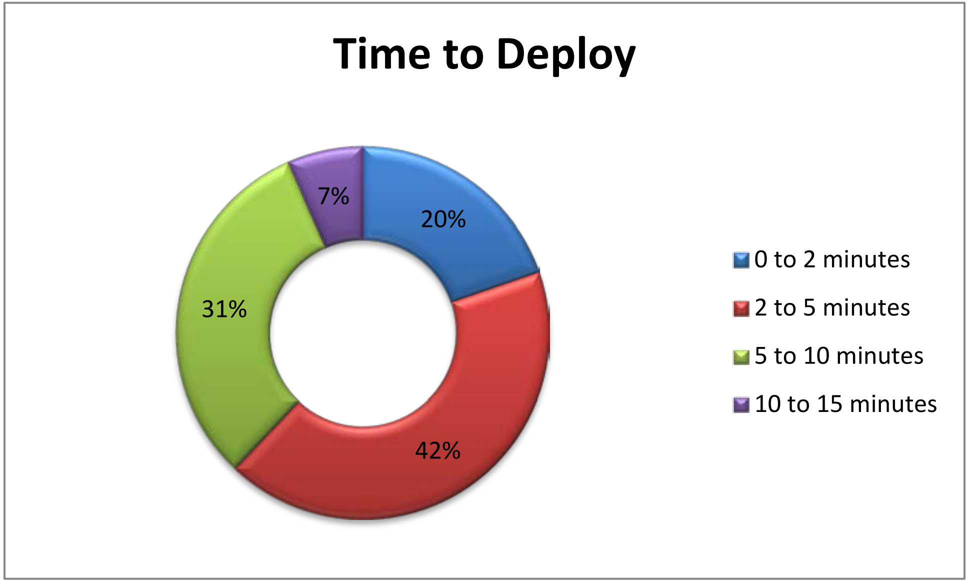
	Unit	Price	QTY	Cost
Parrot AR Drone	1	$300	1	$300
Google Nexus Tablet	1	$200	1	$200
Spare Gears	4	$15	2	$30
Spare Hull	1	$46	1	$46
Spare Battery	1	$40	4	$160
Spare Propellers	4	$12	2	$24
Carry Case	1	$100	1	$100
Tool Kit	1	$20	1	$20
Motor	1	$50	2	$100

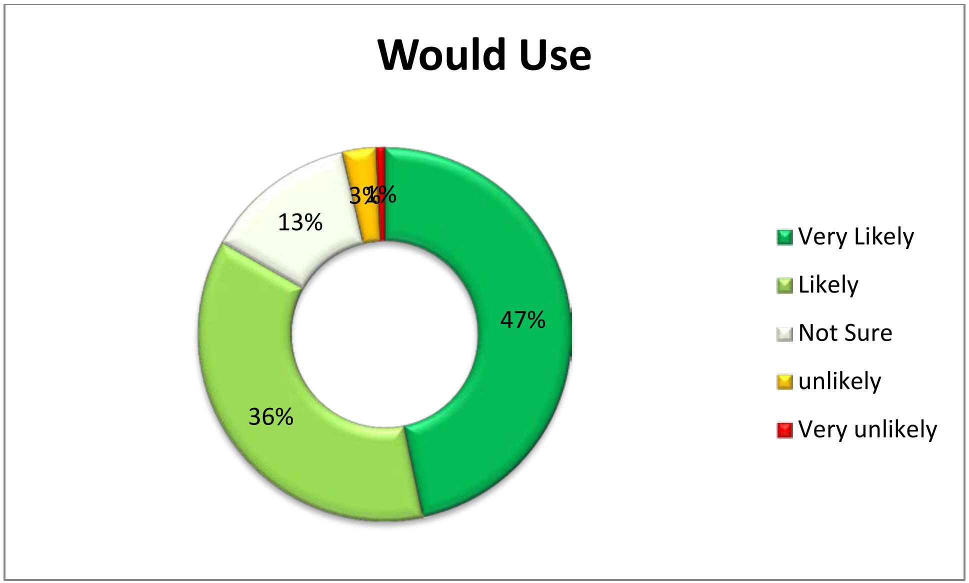
Total	$980

Appendix 5 – Parrott AR Drone System with Case [35]

Appendix 6 – User Requirement Survey Results



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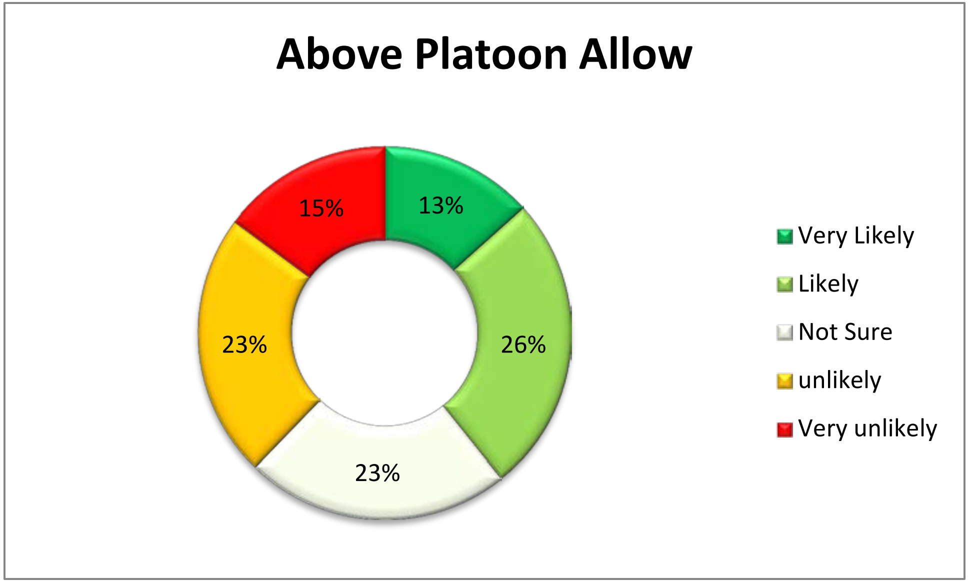
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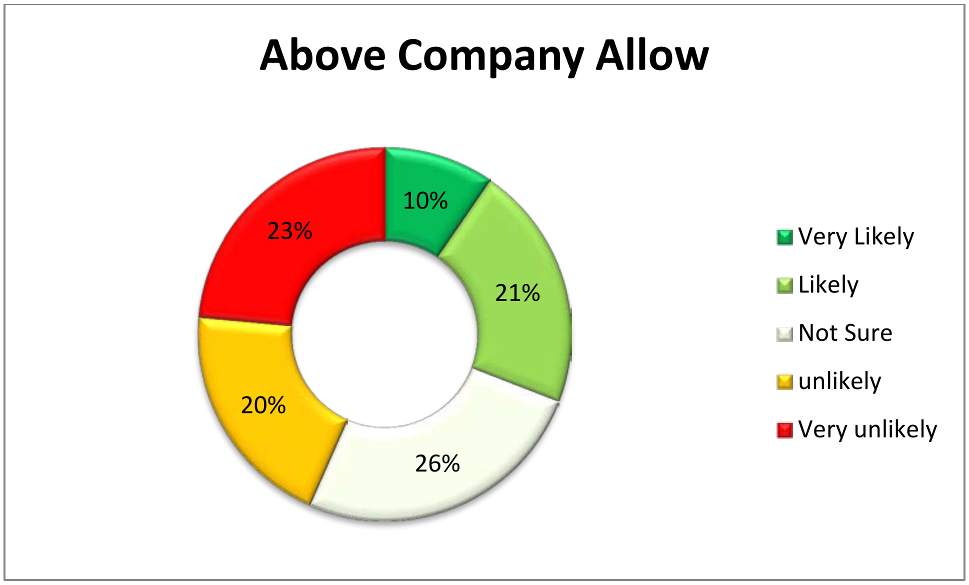
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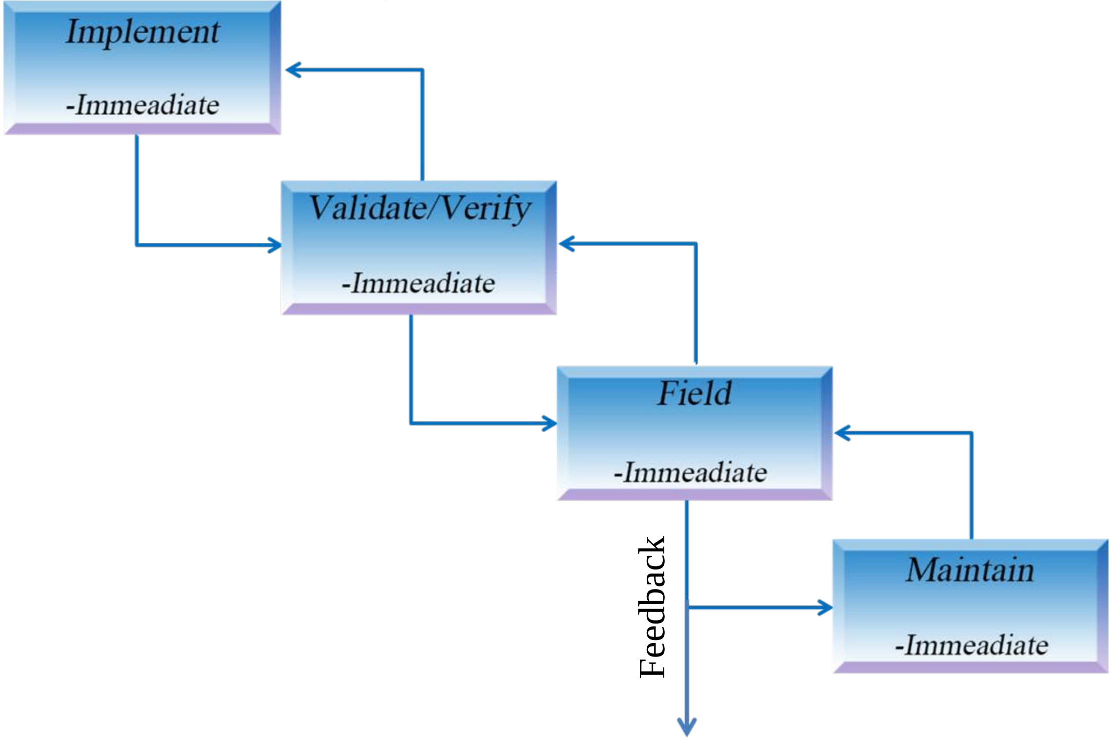
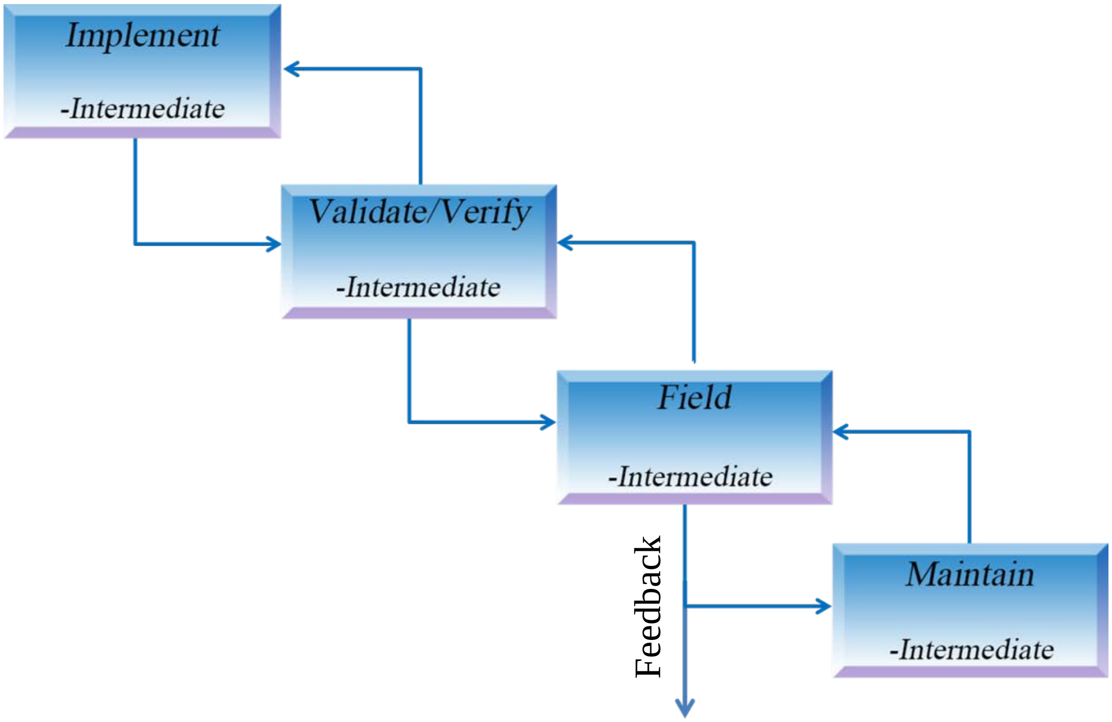
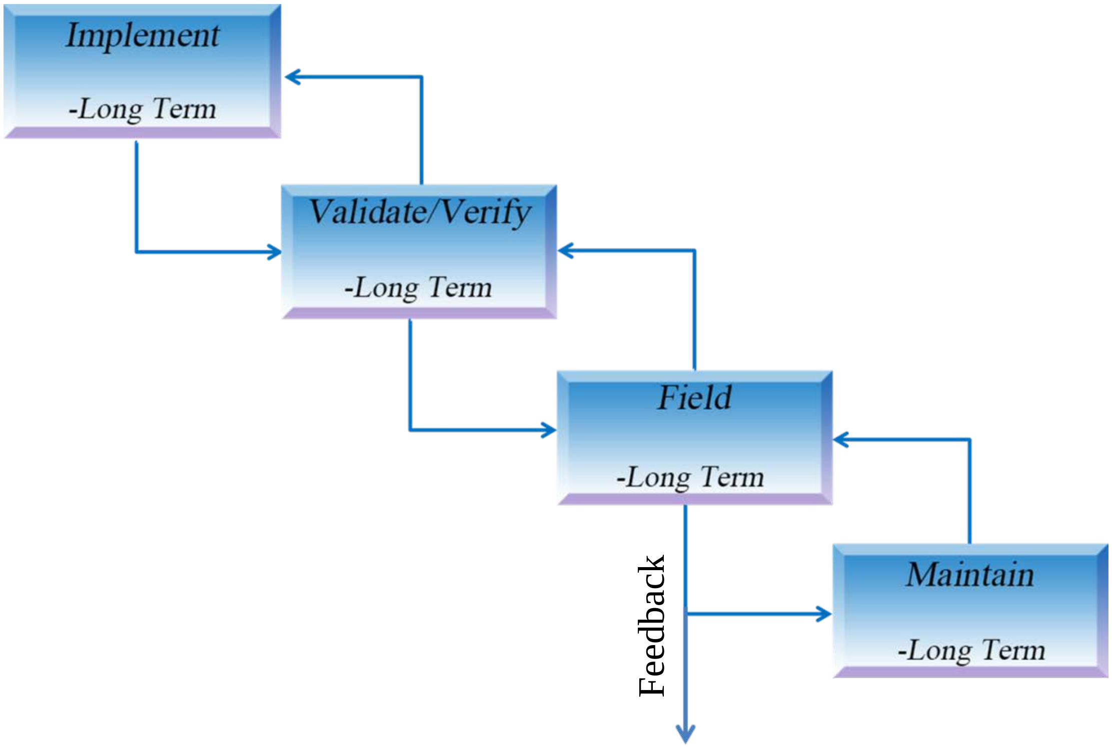
Appendix 7 – Waterfall Diagrams



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Maintain
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