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Unmanned Aerial Vehicle Flight Test Approval Process and its Implications: A Methodological Approach to Capture and Evaluate Hidden Costs and Value in the Overall Process

Tuan U. Tran

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**UNMANNED AERIAL VEHICLE FLIGHT TEST APPROVAL PROCESS AND
ITS IMPLICATIONS: A METHODOLOGICAL APPROACH TO CAPTURE AND
EVALUATE HIDDEN COSTS AND VALUE IN THE OVERALL PROCESS**

THESIS

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AFIT/GRD/ENV/12-M04

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THESIS

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In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Research and Development Management

Tuan U. Tran, BS

Captain, USAF

March 2012

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Abstract

The advancement in small unmanned aerial vehicle (SUAV) technology has brought a new revolution in the military domain. Their uses have become more synonymous with intelligence, surveillance, and reconnaissance missions. Concerns over their flight test safety and accountability have been addressed in multiple policies to mitigate mishaps and increase proper accountability. However, current DoD and FAA mandated regulations and policies concerning UAV flight tests are sometimes considered slow and time-consuming, which may lead to delays in UAV research and development.

This study explores the quantitative and qualitative measure of benefits associated with an abbreviated flight test process for SUAVs. Specifically, it examines the current agreement between two major USAF research centers regarding the SUAV flight test approval process. This research utilized high-level multidisciplinary approaches and techniques including qualitative cost-benefit analysis, interviews, value stream mapping (VSM) analysis, and heuristic risk analysis to evaluate the current-state process. The findings conclude that there is a slight economic cost and schedule savings in an abbreviated process. Additionally, this research finds no correlation between SUAV flight mishaps and system maturity. This research proposes using a streamlined process for additional safety reviews to eliminate non-value added process steps considered unnecessary due to the nature of the SUAV complexity. Furthermore, this study recommends using a decision rule matrix based on the total cost of the SUAV and its weight and energy at impact for choosing an abbreviated flight test safety review process.

*To my Lord and Savior, for His Honor and Glory
have given me the strength to carry on.*

To my parents and my wife for their unwavering support.

*To my mentors whose leadership and mentorship
have set the examples for which I have tried to follow.*

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Table of Contents

	Page
Abstract.....	iv
Acknowledgments.....	vi
Table of Contents.....	vii
List of Figures.....	ix
List of Tables.....	x
I. Introduction.....	1
1.1 USAF Flight Test Process.....	2
1.2 Problem Statement.....	4
1.3 Research Objectives.....	5
1.4 Assumptions and Limitations.....	5
1.5 Thesis Overview.....	6
II. Literature Review.....	7
2.1 MOA between AFRL and AFFTC.....	7
2.1.1 Risk Assessment and Test Approval Authority.....	10
2.1.2 Performance Gaps.....	11
2.1.3 Improvement Initiatives.....	14
2.2 The Importance of Flight Tests.....	15
2.3 Factors in Flight Testing.....	17
2.3.1 Safety.....	17
2.3.2 Cost.....	19
2.3.3 Schedule.....	20
2.4 The Military Market.....	21
2.5 Regulatory Requirements for SUAVs.....	23
2.5.1 Issues with Traditional Flight Test Methods for SUAVs.....	24
2.5.2 UAV Standards and Regulations in the National Air Space.....	26
2.6 Possible Airworthiness and Certification.....	27
2.6.1 Current Initiatives.....	28
2.6.2 DoD Initiatives.....	31
2.7 Summary.....	32
III. Methodology.....	34

3.1 Research Design.....	34
3.2 Qualitative Cost-Benefit Analysis.....	35
3.2.1 <i>Criteria Development and Assumptions for Cost-Benefit Analysis</i>	36
3.2.2 <i>Notional Balance Statement</i>	37
3.2.3 <i>Interviews</i>	39
3.2.4 <i>Cost Sensitivity</i>	40
3.3 Data Variability Analysis.....	40
3.4 Managing Acceptable Cost and Optimal Risk	42
3.5 Summary	46
IV. Results and Analysis.....	48
4.1 Cost Measurement Analysis.....	48
4.1.1 <i>Estimated Cost Balance Statement</i>	49
4.1.2 <i>Initial Cost Results</i>	52
4.1.3 <i>Cost Sensitivity Results</i>	54
4.2 Value Stream Mapping Analysis	56
4.2.1 <i>Data Variability</i>	57
4.2.2 <i>Value Stream Mapping Results</i>	62
4.3 Acceptable Cost and Optimal Risk	62
4.3.1 <i>Perceptual Factors in Assessing Risk</i>	63
4.3.2 <i>Heuristics and Biases in Risk Assessment</i>	65
4.3.3 <i>Notional Optimal Level of Risk</i>	66
4.3.4 <i>A What-if Scenario</i>	68
4.3.5 <i>Managing Risk Results</i>	69
4.4 AFFTC Threshold and Decision Rule	70
4.4.1 <i>Notional Threshold</i>	71
4.4.2 <i>Notional Decision Rule Matrix and Outcome</i>	73
4.4.3 <i>Meta-language and Heuristics</i>	74
4.5 Application of Notional Threshold and Decision Rule Matrix.....	76
4.6 Summary	79
V. Discussions and Conclusions	81
5.1 Capturing Research Objectives	81
5.2 Leadership Risk Management and Buy-in.....	84
5.3 Conclusions	85
5.4 Limitations and Future Research	86
Appendix A: Memorandum of Agreement between AFRL and AFFTC	89
Appendix B: Current Flight Test Process VSM	94
Appendix C: Small UAV Costs and Mishap Data.....	96
Bibliography	98

List of Figures

	Page
Figure 2.1: AFRL and AFFTC Flight Test Approval Process.....	10
Figure 2.2: AFRL and AFFTC Flight Approval Performance Analysis	13
Figure 2.3: Worldwide UAV Forecast.....	21
Figure 2.4: DoD Annual Funding Profiles for UAVs.....	23
Figure 3.1: Research Methodology Overview	35
Figure 3.2: U.S. Military Aircraft and UAV Class A Mishap Rates	43
Figure 3.3: Managing Cost and Level of Risk.....	44
Figure 3.4: Notional Optimal Level of Risk	46
Figure 4.1: System Maturity vs. Cost	54
Figure 4.2: Variation at Program Management	59
Figure 4.3: Bottleneck at AFFTC	61
Figure 4.4: Acceptable and Optimal Risk.....	63
Figure 4.5: Notional Optimal Level of Risk (without AFFTC involvement).....	67
Figure 4.6: Notional Threshold.....	72
Figure 4.7: Notional Decision Rule Matrix and Outcome	74
Figure 4.8: 2011 SUAV Flight Tests	77
Figure 4.9: AFRL Mishaps by Fiscal Year.....	78

List of Tables

	Page
Table 2.1: AFFTC Signature Authority	11
Table 2.2: Example Risk Assessment Matrix	18
Table 3.1: Notional SUAV Flight Test Balance Statement	38
Table 4.1: Estimated Time for AFRL/AFFTC Approval Review	51
Table 4.2: Notional SUAV Cost Balance Statement	51
Table 4.3: Meta-Language and Decision Rule	75

UNMANNED AERIAL VEHICLE FLIGHT TEST APPROVAL PROCESS AND ITS IMPLICATIONS: A METHODOLOGICAL APPROACH TO CAPTURE AND EVALUATE HIDDEN COSTS AND VALUE IN THE OVERALL PROCESS

I. Introduction

“For once you have tasted flight, you will walk the earth with your eyes tuned skywards, for there you have been and there you will long to return.” – Leonardo da Vinci

Historically, humans have approached flight test process and evaluation with scientific methods since the early days of aviation. Mankind has always been fascinated with flight and the ability to control the sky. Examples range from early attempts such as Greek mythology’s Icarus’ wings to real scientific approaches like Leonardo da Vinci’s ornithopter. By the late 19th century, the race was on to build the world’s first powered and controlled flying machine. Numerous flight designs and tests were done by scientists, engineers, and flight enthusiasts competing for the title of the first to sustain heavier-than-air human flight; and in the process, all of them took some form of risks, including those to their own safety. In 1903, brothers Orville and Wilbur Wright took their first successful human-controlled airplane to the air in that historic twelve-second flight and created a new chapter in human innovation. There is no doubt that the Wright brothers had tested various methods for their conceptual flight and preliminary designs before they could control the craft with three-axis control and the correct airfoil design. These pioneers of aviation who experimented with gliders and biplanes laid the groundwork for later generations to build more sophisticated advancements in aerodynamics and engine technology that will power them to new frontiers.

Fast forward a hundred years later, human ingenuity and breakthroughs in machinery have enabled mankind to travel to space and control the air from the ground a thousand miles away. The risks and safety involved in experimenting with new technology have always been a challenge to those who flight tested them; those who tried to experiment with aerial control will often find themselves confronted with failures that may result in putting their lives in harm's way. Despite the risks associated with flight tests, many organizations and government centers continue to set improvement targets with different purposes to control the sky using various methods including the newest marvel of unmanned aerial vehicles (UAV).

1.1 USAF Flight Test Process

Different sources and organizations reference their UAVs in different ways. The nomenclature for an unmanned aerial vehicle is not standard across the industry; some have termed these vehicles as remotely piloted vehicles (RPV), or remotely operated aircraft (ROA), or unmanned aerial systems (UAS). For the purpose of this paper, the term unmanned aerial vehicle (UAV) will be used to indicate any aircraft capable of flight without a human operator on board. Small UAVs (SUAV) specify vehicles that are measured a few feet across in length and wingspan, and these are typically found in surveillance, urban terrain operation, communications relay, and reconnaissance.

Recent development and the ease of access to global positioning systems (GPS) and remote controlled instruments have led to an increase in SUAV research and development (R&D) in the United States (U.S.) and the world in general. It is now possible for a radio-controlled aircraft builder to manufacture SUAVs based on user

requirements and needs. The acceptable low risk and low cost in SUAV systems to operate in the battlefield have gained the attention of the military, causing it to engage in more R&D. Acceptable low risks and low costs are generally defined as the likelihood of an event whose probability of occurrence is subjected to an acceptable risk at a minimal loss but perceived as having greater benefits. The rapid pace of SUAV manufacturing processes has enabled many organizations and the military to conduct a different means of research that may prove critical to national defense and security by utilizing SUAVs to perform various missions, such as border patrol; intelligence, surveillance, and reconnaissance (ISR); and autonomous surveillance and patrol tasks on the battlefield. Presently, flight approval processes for SUAVs in the U.S. national airspace are mandatory in order to satisfy flight requirements as regulated by the Federal Aviation Administration (FAA). Routinely, this process can sometimes take a few weeks to a few months (FAA, 2011).

There is an abundance of literature that describes the flight test approval process for larger and manned aircraft, including those from the U.S. Air Force, U.S. Navy, FAA, and other national test ranges (Ward, 2006; Ingham, 2006; De Garmo, 2004). Similar to manned aircraft, the need to increase safety, reliability, and accountability on UAV performance necessitates flight test approval processes, as these SUAVs are becoming more autonomous. The purpose of a flight test approval process is to bring in multiple experts from different disciplines to strengthen the shared safety and technical responsibility between the approving authority and the operators. It is aimed at improving standards in aviation safety and technical feasibility of the vehicle. Normally, a flight test or ground test approval process accomplishes two main objectives: (1) finding and fixing

any identified aircraft design problems in the test plan and safety plan and (2) addressing, verifying, and documenting the flight test authority and the responsibility of the people involved in the process according to applicable standards and regulations (Ward et al., 2006). These two main objectives bring the flight test process to a minimal level of acceptable risk, which is the lowest risk possible after all hazards have been eliminated or mitigated (Ward et al., 2006).

1.2 Problem Statement

Currently, numerous safety requirements as well as lessons learned from previous tests have resulted in improved UAV design, engineering, and maintenance. Most flight test techniques and procedures for SUAVs are rather simple due to their designs and low cost and maintenance. However, regardless of how simple or complex these SUAVs can be, they are normally treated the same as manned aircraft when it comes to the flight test approval process in the USAF, and also by the FAA. There are also challenges created by flight mishaps that require additional time and resources to approve the “return to flight” of the mishap UAV. A return to flight approval is required once a vehicle is involved in a crash or mishap that results in property damage or injuries. The current UAV flight test approval process assumes the same resources and manpower are available that the majority of manned and larger aircraft projects have. Given the design and developmental scope of SUAVs and their lack of sophisticated hardware, it is hypothesized that the predominant flight test approval process for manned and larger aircraft may not be suitable for SUAVs.

To improve the process for SUAV flight tests, a recommendation is needed to determine the overarching applicable standards and regulations for a SUAV flight approval process. This new recommendation should sufficiently increase the planning and development process for SUAVs that may be targeted for rapid product development for the warfighters, while adhering to safety and flight test regulations and risk management.

1.3 Research Objectives

In narrowing the scope of this study, the main objectives are to establish quantitative and qualitative measures of benefit for an abbreviated flight test process for SUAVs relative to its resource and schedule costs versus using the flight test process used primarily for manned and larger aircraft. In particular, the research will focus on the sizes and costs of the UAV as a way to determine the appropriate recommendation for a formal flight approval process. Additionally, this research will also determine whether or not SUAV flight tests should adhere to current standards and regulations based on their simplicity, cost, and urgency. Finally, this research will explore the benefits and risks involved when not using the current process as set out by the USAF.

1.4 Assumptions and Limitations

Several significant assumptions were required for the comparison of the flight test approval process between SUAVs and larger manned aircraft to be feasible and practical. One primary assumption is the work value in resources and manpower added to each program will be different from each other; particularly, SUAV programs do not require as many resources and manpower as those of larger manned aircraft programs. Another

assumption is the system complexity and safety guidelines of both types of vehicles are assumed to be different due to the nature of manned versus unmanned aircraft (i.e., manned vehicles are more complex and require a higher standard of safety guidelines than unmanned SUAVs). Lastly, the risk assessment and management from both classes of vehicles are also assumed to be different, that is, SUAVs are sometimes expendable because of their low manufacturing and operating costs.

There are more than a few flight test processes nationwide (Ward et al., 2006), each with different approving authority and policies to make flight tests happen. Since this is exploratory research, this research will use the flight test process being utilized at Edwards Air Force Base (AFB) to make assessments and recommendations on the flight test approval process and its implications associated with SUAVs. It is recommended that future follow-on research should seek to validate and generalize this approach and methodology.

1.5 Thesis Overview

Chapter 2: Literature Review, will examine the background in flight test approval process and its implementation, as well as the literature on the current flight test process and issues with traditional flight test methods for SUAVs. Chapter 3: Methodology, will discuss the methodology in collecting data and how each step in the process will be analyzed, as well as the scope of the projects involved. Chapter 4: Results and Analysis, provides analysis and results of this research. And finally, Chapter 5: Discussions and Conclusions, will summarize this research and present findings and recommendations for the flight testing SUAVs, along with recommendations for future research.

II. Literature Review

The purpose of this chapter is to understand the current literature on the small unmanned aerial vehicle (SUAV) flight test approval processes. This chapter starts with the history of flight test requirements and reviews the Memorandum of Agreement (MOA) between the Air Force Research Laboratory (AFRL) and the Air Force Flight Test Center (AFFTC) covering flight operations oversight of AFRL flight test programs and the authority and responsibilities from both organizations. The importance of flight tests will be discussed with factors affecting flight test methods. A short overview of the large potential military market for SUAVs will be presented. Lastly, a brief description of various popular known flight certification processes, including those from the FAA and other international agencies, will be discussed.

2.1 MOA between AFRL and AFFTC

Before AFFTC involvement in AFRL's flight test process, AFRL had been conducting a series of manned and unmanned flight tests ranging in various sizes from desk-sized UAVs to larger manned cargo aircraft. However, after a series mishaps and accidents (AFRL T&E Office, 2011), the Air Force Materiel Command (AFMC) directed that a rated Operations Group Commander provide oversight for all flying activities involving military, government civilian, or contractor flight operations (AFMC/A3, 2006). By AFMC direction, the 412th Operations Group (OG) was identified as the Flight Operation Authority (FOA) for all AFRL flight test programs, except for the AFRL Munitions Directorate (AFRL/RW) for which the 46th OG (Eglin AFB) provides this

oversight. Edwards AFB is the home of AFFTC, including the 412th OG, and is one of the major flight test centers in the U.S. with the expertise to support and provide guidance to program managers (PM) at AFRL before approving any flight operations. The requirement for the 412th OG involvement in AFRL Test and Evaluation (T&E) is formalized in the MOA that was established in May of 2006 (2006-06-06MA). The MOA states:

“The AFFTC has responsibility for the safe and effective conduct of flight operations for AFRL research programs requiring flight activities. The AFMC/A3 defers OPCON to the 412th Operations Group Commander (OG/CC) for AFRL research programs involving military, government civilian or contractor flight operations. To avoid duplicate reviews, inspections or evaluations, an integrated team approach for conducting program flight operation oversight will be used.”

Deferring operational control (OPCON) to AFFTC for all AFRL flight operations includes a variety of programs ranging from small remote controlled (RC) aircraft, such as micro sensor test-beds, to full-scaled aircraft with advanced composite structures. The intent of the MOA is to have experienced flight testers review AFRL programs by providing insight and involvement on flight test programs by test pilots and flight test engineers. The personnel who review AFRL test plans are usually those who have experience with flight operations and also those who have graduated from the USAF Test Pilot School, which is also at Edwards AFB.

There are certain requirements and procedures that AFRL and AFFTC must collaborate together on to have a flight test program approved for flight status. These responsibilities include AFRL providing monthly summaries for flight activities and notes, as well as UAV airworthiness from their safety review boards (SRB). Furthermore,

AFRL conducts technical review boards (TRB) and SRB in addition to documenting all flight authorizations from AFRL and AFFTC. AFFTC responsibilities include reviewing and approving test plans and safety plans in accordance with Federal Aviation Regulations (FAR), Air Force Instructions (AFI), and AFMC and AFFTC supplements. In the case of a flight mishap, AFFTC may provide assistance to the return to flight board and assist in technical and safety reviews (AFMC/A3, 2006). More information on the MOA between AFRL and AFFTC can be found in Appendix A.

Normally, a flight test process begins at the AFRL T&E Office, as shown in Figure 2.1. The AFRL T&E Office accepts a flight test program from one of its directorates and begins coordinating within AFRL. Following AFRL SRBs and TRBs, the test package is submitted to the 412th OG for review. In almost all cases, the 412th OG provides comments and questions concerning flight safety and operational responsibilities and policies back to AFRL T&E Office for action. The review package can include a test plan, safety plan, crew qualifications, results from AFRL SBR, and flight authorizations. Comments and review procedures are usually handled over the phone or through email due to the two geographically separated locations. This overall process may take from three to six weeks for coordination to complete. Flight programs that are assessed as medium to high risks may take longer due to higher safety and technical requirements addressed by FAR, AFI, and AFFTC regulations.

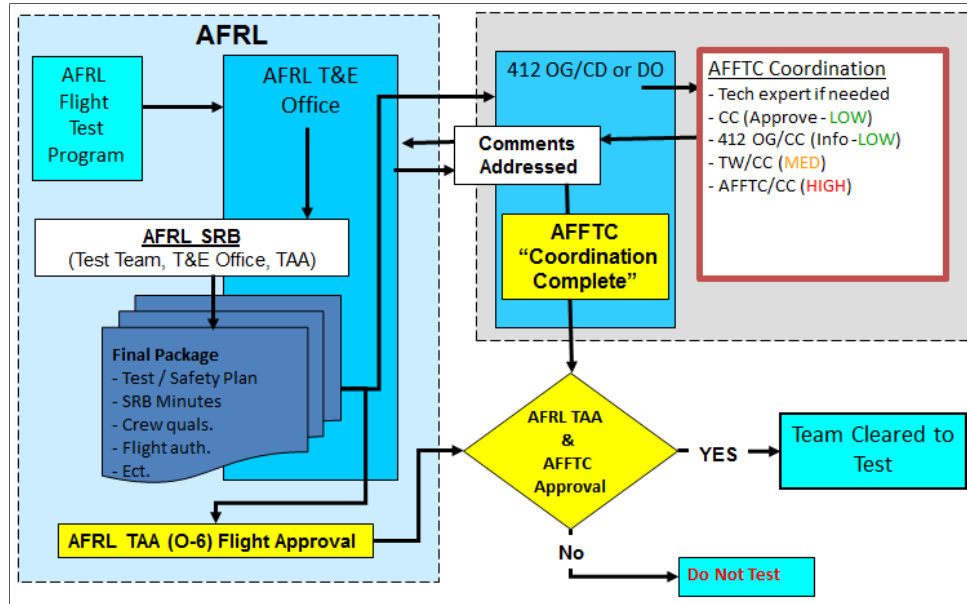


Figure 2.1: AFRL and AFFTC Flight Test Approval Process
(445th Flight Test Squadron, 2008)

In addition to safety reviews from both AFRL and AFFTC, the PM is required to submit a vehicle airworthiness application for flight operations in accordance with AFI 62-6 if the vehicle is to be flown outside restricted airspace. The airworthiness determination is independent from the PM’s chain of execution. The Technical Airworthiness Authority (TAA) is the authority to make these determinations for safe flight operations and approve all certification basis documents and issue Military Type Certificates (MTC) that prove the aircraft system type is in full compliance with the FAR.

2.1.1 Risk Assessment and Test Approval Authority

As determined by the MOA presented earlier, the Test Approving Authority (TAA) from AFRL approves AFRL flight test programs while AFFTC approves the AFRL programs through the FOA. The AFI and Air Force Flight Test Center Instructions (AFFTCI) for flight tests mandate a higher authority review and approval for any

increase in risks. Per AFFTCI 91-5 and AFI 99-103, the signature authorities for low, medium, and high risk test plans are detailed in Table 2.1.

Table 2.1: AFFTC Signature Authority
(AFFTCI 91-5 AFFTC Test Safety Review Process)

ORGANIZATIONAL LEVEL	LOW RISK	MEDIUM RISK	HIGH RISK
Operations Group Commander (OG/CC) or equivalent	Approve	Coordinate	Coordinate
Test Wing Commander (TW/CC) or equivalent	Information	Approve	Coordinate
AFFTC Commander (AFFTC/CC)	Information	Information	Approve

Low risk test plans are approved by the 412th OG Commander (412 OG/CC) and the owning AFRL Division Chief or their deputies before the start of any flight operations. Medium risk test plans are jointly approved by the 412th Test Wing Commander (412 TW/CC) and the owning AFRL Technical Directorate Director. High risk test plans are jointly approved by the AFFTC Commander (AFFTC/CC) and the AFRL Commander (AFRL/CC). All coordination comments between AFFTC and AFRL must be resolved before a final approval for test execution. To avoid any duplicate reviews, inspections, or evaluations by both organizations, an integrated test team approach is used for conducting flight operations oversight.

2.1.2 Performance Gaps

Although instructions were provided by the AFRL T&E Office PMs on procedural methods to conduct flight tests and flight approval process, most of the test plans and safety plans are deemed inadequate by the AFRL T&E Office, which can be

traced to the lack of flight test experience and details in the preparation of test plans. Additional problems are caused because the majority of the PMs never sent initial notifications of pending tests to the AFRL T&E office. In 2010, over 40 test plans were submitted from different directorates to the AFRL T&E office, 90% of which were deemed low risk status, but over 50% of the test plans submitted for coordination were only given a three-week notice in a process that normally requires six months of lead time (AFRL T&E Office, 2011).

Previous research efforts conducted by Homan, Parker, Wirthlin, and Pignatiello (2011) found that the number of test plans submitted to AFFTC creates a potential major work bottleneck at the FOA at Edwards AFB, who is also responsible for nine other local test organizations. Moreover, these local flight tests are the FOA's main duties at Edwards AFB, and they do usually take precedence over approving AFRL flight test programs. Another major problem is the workload and how it flows through the AFRL approval process, thus further delaying the flow of the test plans. As seen in Figure 2.2, members at the AFRL T&E Office handle numerous test plans per year submitted from dozens of PMs from different AFRL directorates. These test plans are sometimes written in non-standardized formats and are usually submitted late. This tardiness in most of the test plans delays the AFRL T&E Office reviewing the test plans and hampers coordinating with the members at AFFTC.

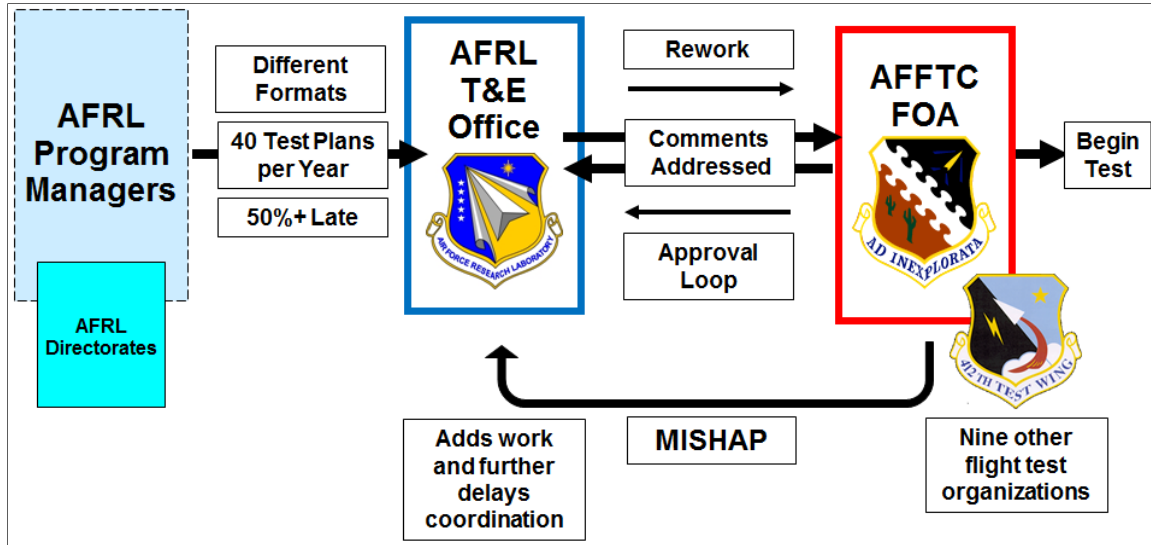


Figure 2.2: AFRL and AFFTC Flight Approval Performance Analysis
(Modified from Homan et al., 2011)

In the case of a mishap, the return-to-flight process also uses the same test approval process and is usually handled by the same members approving the original test plans. Upon learning of a mishap, the AFRL T&E Office and the test team are required to notify AFFTC of the mishap. To mitigate further risks, the test team is required to stop all tests and file a report on the mishap, which takes more time and effort away from any other on-going coordination with the AFRL T&E Office and AFFTC. The reporting process begins when the mishap investigation is initiated by an integrated test team from both AFRL and the test team. AFRL holds all accountability and investigation responsibilities during the mishap. The 412th OG is the ground and return-to-fly approval authority for mishaps that are considered Class A or Class B, which include permanent, partial or total disability or property damage of \$500,000 or more (AFMC/A3, 2006, AFRLM 99-103).

2.1.3 Improvement Initiatives

The performance gaps and issues presented earlier reveal a need for change in the process, manpower, and resources for management and improvement. Collectively, there is room for improvement on both sides of the process. Any new PM to the AFRL flight test process would notice the work burden carried by the AFRL T&E Office; yet, there is still another side to the issue, which is the work of approval authority at AFFTC. The FOA at AFFTC is often times regarded as the single chokepoint and sometimes blamed for the failure to deliver on-time approval of flight dates (Homan et al., 2011). Although AFFTC's main concern for AFRL flight test programs is the safe conduct of flight tests in accordance with applicable AFFTC, FAA, and USAF instructions and their supplements, their main duty lies with nine other local flight test organizations or squadrons (Homan et al., 2011). Therefore, any quick reviews from AFFTC may jeopardize the safety of the program.

Many discussions for improvements and exchange initiatives have been raised by both sides to speed up the process, but few have come to full fruition (AFRL T&E Office, 2011). One of the initiatives that started from both sides of the process was an agreement to draft an amendment to the original MOA to eliminate AFFTC oversight on low risk programs and allow AFRL the authority to approve its own flight test programs without full AFFTC involvement (AFMC/A3, 2006). This initiative was funneled up to AFMC/A3 asking for AFRL to assume full approval authority and responsibility for all low risk programs, with the 412th OG continuing to provide oversight for medium and high risk programs as defined in the MOA. However, the initiative was quickly rejected

at AFMC/A3 after weighing the risks and benefits of having no Operations Group Commander oversight of an AFRL flight test program (HQ AFMC/A3F).

2.2 The Importance of Flight Tests

Flight testing in both piloted and unmanned aerospace vehicles is an ongoing activity that pushes the limits of aeronautical and aerospace knowledge. The primary purpose of flight testing, according to the AGARD Flight Test Manual (Perkins et al., 1959), lists three fundamental reasons for flight testing:

1. *To determine the actual characteristics of the machine.*
2. *To provide developmental information.*
3. *To obtain research information.*

Although the reasons listed above do not specifically indicate that modern aerospace vehicles require teams of engineers and scientists, whether piloted or unmanned; they do, however, provide the classical reasons for conducting flight tests. From this perspective, the true purpose of flight testing is to reduce future uncertainties in the design and test processes before going to the operational stages and airworthiness certifications. Flight testing also provides practical experiences to the operators and involves interaction with other systems that increases interoperability (Williams & Harris, 2002).

Recent advances in technologies and new procedures may have been successfully integrated into the stages of aerospace development, but basic flight tests are required to provide credibility, and these must be proven in the flight test environment including piloted aircraft and UAVs. Additionally, the involvement of humans in UAV missions in

flight tests ensures that the total UAV system functions correctly. Flight tests and evaluations must also determine the suitability of the UAV system for use by the end users, especially the operators and maintainers (Williams & Harris, 2002).

Historically, military systems have relied heavily on prototypes of airplanes to provide valuable predictions for development efforts. Since the early 1970s, the YF-22 and YF-23, the YF-16 and YF-17, the YA-9 and YA-10, and the X-32 and X-35 efforts were all head-to-head flight test comparisons of competing prototypes (Ward et al., 2006). Prototyping does not always lead to production, but may instead lead to further development of an existing design. Subsystems technology must also be proven in the harsh flight environment (Ward et al., 2006). These subsystems include radar, navigational systems, flight management systems, integrated displays, flight control system, communication systems, etc.

According to the UAV Task Force Final Report (2004), unlike manned aircraft which are integrated by a network communication with air traffic control (ATC), flight management, and flight operation from various flight control operators, UAVs are dependent on a network of remote systems and subsystems to make flight operations possible. It is for this reason that testing and evaluation needs to be executed on the entire system of the UAV and not on the vehicle alone. This could raise the magnitude of testing a relatively uncomplicated SUAV to that of testing a highly complex integrated system (Williams & Harris, 2002).

2.3 Factors in Flight Testing

It takes thousands of man-hours and resources to build a new aircraft, but to get certification to be airworthy for flights, every part of an aircraft has to meet standards set out by the military and certifications required from the FAA. Testing a flight vehicle is a complex process. It requires careful planning and measures of completeness and accuracy in the data to be safe, within budget, and on time. In any form of tests, the most significant cost for any program is the cost of safety. Therefore, almost all policies or redundancies address safety concerns throughout the planning and conduct of any series of flight tests. Ward, et al. (2006) discuss the three primary factors in the test planning process as the dominant concerns for all PMs and testers alike.

2.3.1 Safety

Every test carries some element of risk, whether it is a low, medium, or high risk of a new prototype or determining the performance of a new piece of software on an aircraft system. Risk elimination is a responsibility carried by all who are involved in flight testing. Almost all flight test centers endorse a checklist approach toward safety concerns based on the culmination of past experience and what seems to be the best methodology in risk management. There is no single way to manage risk in engineering processes; however, many flight test organizations (both government and industry) use a standard set of procedures common to flight tests to manage risks. The following summary is based on the AFFTC and NASA Procedures and Guidelines on T&E control and conduct of risk assessment and risk mitigation (Ward et al., 2006). Most of the risk management process includes the following steps:

1. Hazard definition
2. Cause identification / Risk assessment
3. Risk mitigation
4. Emergency response

Test specific hazards are those that arise as a direct consequence of the test activity. This step explores some of the “what if” questions that might increase the probability of the hazard event occurring (Ward et al., 2006). Cause identification lists the likelihood of occurrence ranging from improbable to frequent that the cause should occur at least once. The severity of consequence of the cause ranges from negligible to catastrophic, which includes injury and death. Table 2.2 shows an example of a matrix of the hazard probability and its severity category.

Table 2.2: Example Risk Assessment Matrix
(AFFTCI 91-5 AFFTC Test Safety Review Process)

	HAZARD SEVERITY CATEGORY			
	<i>Catastrophic</i>	<i>Critical</i>	<i>Marginal</i>	<i>Negligible</i>
HAZARD PROBABILITY	May cause death, system loss	May cause severe injury, severe occupational illness, or major system/facility damage	May cause minor injury, minor occupational illness, or minor system/facility damage	May cause less than minor injury occupational illness or system/facility damage
FREQUENT Likely to occur frequently during the test	1	3	7	13
PROBABLE Will occur several times during the test	2	5	9	16
OCCASIONAL Likely to occur sometime during the test	4	6	11	18
REMOTE Unlikely, but possible to occur during the test	8	10	14	19
IMPROBABLE Highly unlikely to occur during the test	12	15	17	20

Risk mitigation is the process by which risks are reduced, moving them down and to the right in the risk assessment matrix (Ward et al., 2006). According to Ward et al. (2006), reduction in the severity level usually requires specific hardware mitigations, which are modifications to hardware to enhance the test safety; other reductions in the severity level are procedural mitigations, which are intended to decrease the risk and the likelihood of occurrence. Finally, every hazard analysis should include a procedural response or corrective actions and some planning to address a mishap should it occur.

2.3.2 Cost

The cost of flight testing can range from tens of thousands to millions of dollars depending on the scale and scope of each test. It is therefore up to the engineers and PMs to consider the cost of each test to be conducted and analyzed whether the test is manageable, and most importantly, why the test should be done. While this research does not specifically focus on the factors of cost and the efficiencies of cost control and visibility, it does, however, weigh the cost benefit and risk of not having SUAVs go through the formal flight test approval process that larger manned aircraft do in the USAF.

Support for flight tests should be kept as simple as possible and consistent with the risk and complexity of the test. Sometimes, flight test support can be as simple as a flight mechanic on the ground servicing the aircraft and as complex as linked telemetry and continuous radio communication with all aircraft (Ward et al., 2006). Ignoring the technical expertise on instrumentation can lead to incorrect data and retest, which would add more cost to future tests. Finally, every second spent in the air must be used

productively. PMs should keep a focus on combining series of tests together as often as possible to reduce fuel costs. Productive flying time should be used wisely but also provide sufficient time to check for adequate data collection and test parameters (Ward et al., 2006).

Costs may increase if advanced instrumentation is involved. A SUAV may have low manufacturing cost and is replaceable if damaged, but the sensor payload attached to the SUAV may cost even greater than the SUAV itself. This huge gap in the costs between the carrier and the payload is one of the challenges in the flight test community, and SUAV regulators have yet to define a definite risk analysis to the payload should the UAV experience a flight mishap.

2.3.3 Schedule

Time is money. Naturally, nearly all flight test programs have time and costs among their prime targets or objectives. One of the biggest challenges PMs must face is meeting the scheduled deadline. Flight certification and approvals usually take a while to get approved (DoD OSD, 2009), so it is wise to plan ahead and schedule many months in advance before any actual test is being done. A schedule slip can force an entire program to be up for review or face cancellation. When time and costs are measured, performance may be lost due to constraints in the cost and schedule. However, for other projects such as life critical systems, quality in the performance would be the overriding criteria for determining the value of the project (Ward et al., 2006). A major factor in meeting the test schedule is how many test vehicles are allocated to the flight test program. Increasing

the number of flights or the number of test vehicles may alleviate a schedule problem, but it may not be the answer when costs are at a limit.

2.4 The Military Market

Recently, a market study released by Teal Group Corporation, an aerospace and defense market analysis company, estimates that UAV spending will almost double over the next decade from current worldwide UAV expenditures of \$5.9 billion annually to \$12 billion, of which the U.S. will account for 77% of the worldwide R&D and T&E spending on technology and about 69% on procurement (Teal Group Corporation, 2009). Figure 2.3 shows that the U.S. will dwarf the rest of the world in UAV R&D technology and procurement in the years ahead, followed by European and Asian-Pacific countries.

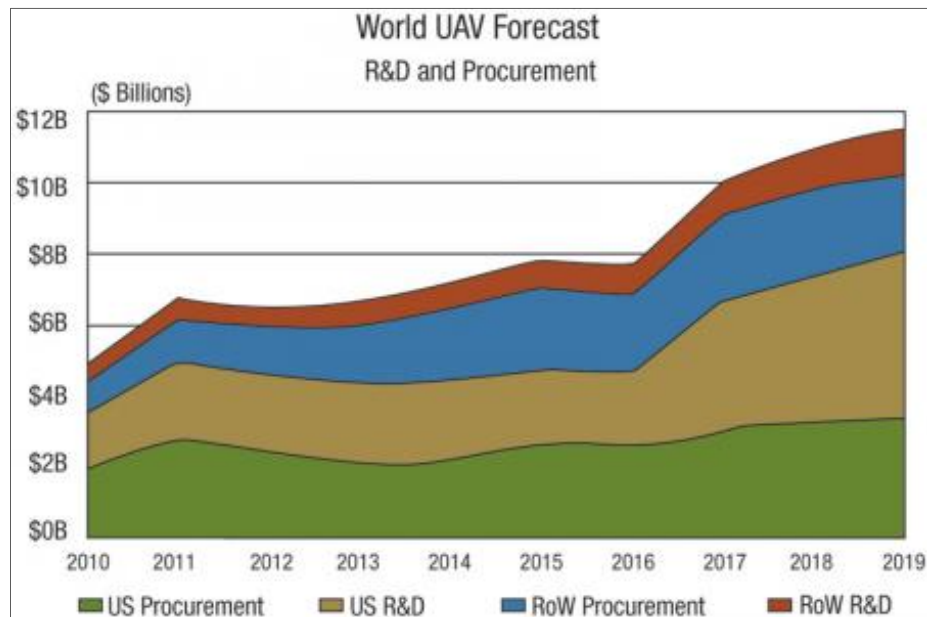


Figure 2.3: Worldwide UAV Forecast
(Teal Group Corporation, COTS Journal Online, 2011)

Today, over 30 countries are investing and developing sophisticated UAVs for multiple purposes, including border patrol, global navigation, agricultural spraying, and planting operations (De Garmo, 2004). The most significant part of the U.S. R&D and procurement spending will be for the interests of the U.S. military. According to the Center for Advanced Aviation System Development (CAASD), since the 1950s, the U.S. military has spent more than \$25 billion on UAV development. However, it has had difficulty in setting priorities, determining missions, and developing UAV standards, which has led to a number of programs being repeatedly modified, replaced, or cancelled (De Garmo, 2004). Despite the difficulty in setting UAV standards, the U.S. DoD is committed to setting the pace for UAV funding, research, and applications. In the last ten years alone, the U.S. military has increased over ten-fold the annual funding for UAVs, as shown in Figure 2.4. This figure is expected to keep rising, eclipsing robotic systems among the DoD's top procurement priorities (Sully, 2004).

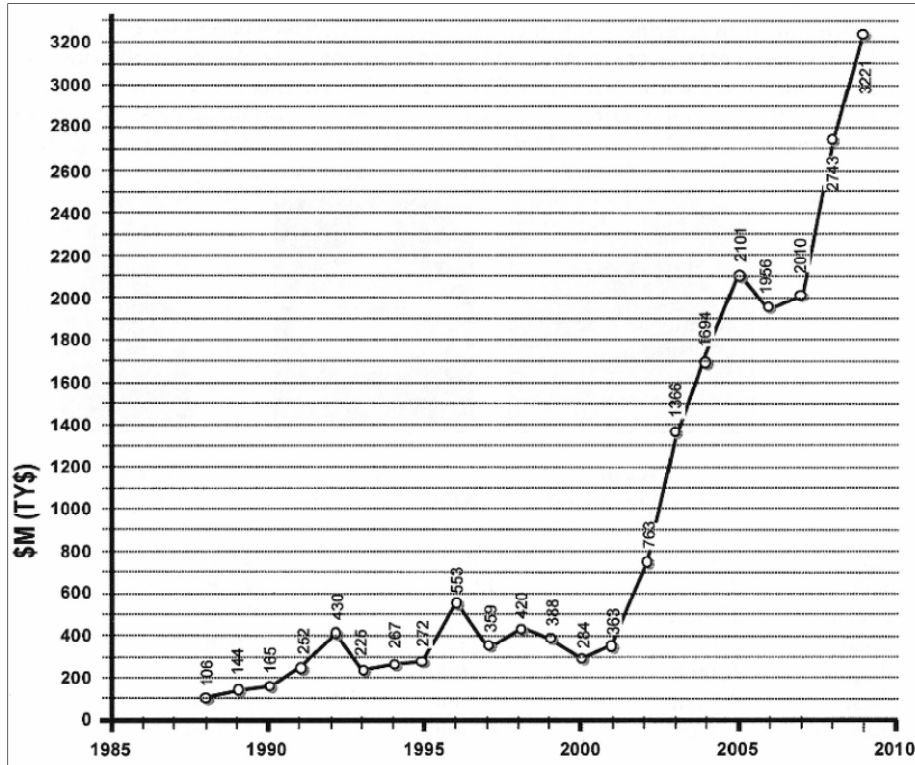


Figure 2.4: DoD Annual Funding Profiles for UAVs (De Garmo, 2004)

2.5 Regulatory Requirements for SUAVs

With a handheld GPS and a keen interest in aerodynamics, hobbyists and infantry alike are becoming attracted to SUAVs. SUAVs, normally powered by small electric or gas turbine engines, are often considered a subclass of UAVs. These SUAVs are becoming increasingly popular due to their sizes and simplicity in data fielding and operation. Traditionally, UAVs are primarily used by the military, but demands for UAV use have expanded to commercial and other governmental uses, which drives a considerable need for UAV flight regulations and operational requirements. However, because of the lack of airspace regulations and airworthiness and safety requirements,

access to UAV applications still present a major barrier and challenges to other markets other than the military (De Garmo, 2004).

An airworthiness certificate is an FAA document which grants authorization to operate an aircraft in flight in compliance with the approved certification basis (FAA Website, 2011). According to AFI 62-601, airworthiness is defined as the “*verified and documented capability of air system configuration to safely attain, sustain, and terminate flight in accordance with approved usage and limits.*” A generic airworthiness defines whether an aircraft has been certified as suitable for safe flight without significant hazard to aircrew, ground crew, passengers (if relevant), or to the general public over which such airborne systems are flown.

2.5.1 Issues with Traditional Flight Test Methods for SUAVs

Not all R&D technology and procurement come without risks and mishaps. According to the DoD’s Airspace Integration Plan for Unmanned Aviation (2004), SUAVs have higher reported loss rates than manned aircraft, especially during takeoff and landing. Because of the nature of UAVs being unmanned, their loss could sometimes be regarded as acceptable in exchange for continuous data gathering and research efforts.

Due to the nature of UAVs and their systems, safety aspects have yet to be defined and this leads to issues not normally considered for manned systems (EASA, 2004). According to Ostler (2006), traditional flight testing methods may not be suitable for SUAVs for a number of reasons. First, in-flight engine power cannot be determined by measuring fuel flow (i.e., electric engines). Second, SUAVs that are electrically

powered do not decrease in weight over time as do conventional aircraft. Finally, data acquisition systems in SUAVs are limited in size and weight.

Another area usually not considered in traditional flight test methods and the T&E of SUAVs is wind tunnel testing and aerodynamic analysis support. Although wind tunnel testing can provide data to predict and develop control surface designs, few SUAV operators opt to utilize wind tunnel testing, as it is generally accepted that flight testing out in the flight range is adequate enough and remains the most reliable method for SUAVs (Williams & Harris, 2002). In addition to SUAV hardware and autonomous system reliability, other flight test challenges include categorical flying qualities, flight performance, and avionics evaluations. Provisions for these SUAV flight tests may not completely follow conventional manned aircraft flight test techniques due to the nature of UAV flight cues and their sensitivities due to of their small physical sizes and weights (Williams & Harris, 2002).

Another area of concern is the required region of airspace possessing the appropriate vertical and lateral limits to conduct flight testing of UAV systems (Williams & Harris, 2002). This region of airspace should have few obstructions, such as power-lines, tall structures, and trees, and it should be located outside civil controlled airspace. Some SUAVs are now able to execute tasks autonomously, such as takeoff and landing. Unfortunately, the lack of UAV regulations has prevented these SUAVs from operating in unrestricted airspace alongside manned aircraft (Ingham et al., 2006). Furthermore, this restriction has more complications due to an unproven technical safety record where the data cannot be collected until more UAVs can operate alongside manned aircraft,

which results in a “chicken and egg” situation (Ingham, 2006; Kuke, 2004; De Garmo, 2004).

2.5.2 UAV Standards and Regulations in the National Air Space

Standards and regulations are part of the flight test process and requirements for airworthiness. By definition, a standard is an accepted minimum requirement in which compliance must be shown to achieve certification or qualification status (Ingham, 2008). UAV standards are currently under development from the FAA for airworthiness certifications. A regulation, such as the FAR, is a set of legislative prescriptions that must be complied with prior to, as well as during, the operation of a UAV in the national airspace (Ingham, 2008). Such regulations are also under development for civil UAV flights in commercial airspace.

Although UAV markets for military and civil applications have been steadily growing, the lack of regulatory framework in creating standards and regulations has been evident. With new UAV technology, major flight test organizations including the FAA must first determine the risks of any associated system failures before the new technology is considered safe to be put into the National Airspace Systems (NAS) (Ingham, 2008). Any unforeseen developments, technological improvements, and human factors play a role in whether the new technology is safe enough to be permitted into the NAS. Once the risks are addressed, flight safety and integration into the NAS are taken in stages, similar to the developmental testing and operational testing and evaluation (DT&E, OT&E) established by the DoD. The FAA is also using the same DT&E and OT&E

methodology to manage the integration of the UAV technology into the NAS (Kalinowki, 2010).

Current recreational use of the NAS limits UAV operations to below 400 feet above ground level and away from airports and air traffic (FAA Website, 2011). The FAA's main concern is not only that UAVs might interfere with commercial and general aviation operations, but that they could also pose a safety problem for other airborne vehicles and persons or property on the ground. Developing and implementing new UAV standards and regulations is a long-term effort for the FAA, especially when there is little data available to integrate UAVs safely and efficiently into the NAS. The FAA also indicates that more safety data is needed before it can establish a decision to fully integrate UAVs into the NAS, where the general aviation public travels each day (FAA Factsheet, 2011).

2.6 Possible Airworthiness and Certification

The objective of UAV certification in an unrestricted airspace is to achieve “file and fly” operations, but in order to achieve flight operations, flight tests will have to be executed in order to prove compliance with relevant regulations and prove its airworthiness (Ingham, 2008). Flight testing for airworthiness in SUAVs is sometimes conducted to observe the usefulness of the latest developments for conventional aircraft. For example, a new control law or a novel wing structure was tested using SUAVs in aerial flight (Brinker, 2001; Murray, 2002). One of the major challenges in operating an SUAV is the capability to detect and avoid aircraft and other objects while airborne. Collision avoidance has become the most pressing concern, and is also the focus for

many studies and research institutions worldwide, including AFRL with its Auto Avoidance Collision System (De Garmo, 2004).

To avoid collisions with other aircraft, UAVs must have a “sense and avoid” capability, which allows them to detect and safely stay clear of other aircraft and obstructions midair (De Garmo, 2004). This development of “sense and avoid” capability in UAVs has also provided significant benefits for both manned and unmanned operators (Ingham et al., 2006). While UAV proponents view this new technology as promising, the limited safety and operational data available does not support the full integration of UAVs into the NAS (FAA Website, 2011).

2.6.1 Current Initiatives

All UAVs and manned aircraft in the NAS are regulated by the FAA under jurisdiction granted by law (FAA, 2011). While it is unarguable that large and heavy UAV airframes require an airworthiness certification, the question yet remains for SUAVs that have wingspans measuring less than a few feet across and weighing less than a hundred pounds. Do these SUAVs need the same airworthiness certification as those of larger sized UAVs? Some UAV enthusiasts argue that if such regulations are mandated on SUAVs to meet the same requirements for airworthiness certification, it would negatively affect airframe vendors and the SUAV manufacturing industry (UAV MarketSpace). A recent safety study for UAV operation in the NAS from MIT’s International Center for Air Transportation (ICAT) (2005) concludes that *“the results of the safety analysis indicate that it may be possible to operate small UAVs with few operational and size restrictions over the majority of the United States.”*

In response to the influx of SUAV airworthiness applications, the FAA has developed a memorandum titled “*Unmanned Aircraft Systems Operations in the U.S. National Airspace System – Interim Operational Approval Guidance*” for guidance of UAVs in the NAS. The FAA is also moving forward with UAV regulations and guidelines to minimize accidents and failures. Furthermore, the FAA is working with the Radio Technical Commission for Aeronautics (RTCA) to develop technical UAV standards. Mainly, RTCA will address two key questions on UAVs regarding their handling of communication, command, and control, and how UAVs will “sense and avoid” other aircraft. According to a statement by Kalinowski before the Committee on Homeland Security (2010), these activities are targeted for completion before 2015.

Other countries are also publishing or have already published regulations for SUAVs. The French Ministry of Defense has drafted UAV regulations which are being used by other organizations as a guideline (Ingham, 2008). The Joint JAA/EUROCONTROL Initiative on UAVs final report (2004) proposes fairness, equivalence, accountability, and responsibility as guiding principles for integrating UAVs operating in civil airspace. The report emphasizes the use of existing manned regulations while recognizing the need to tailor and complement them when considering the specific characteristic of UAV operations.

Other national and international agencies are also proposing standards to bring UAV flight operations within the manned operational environment in conjunction with the military and civil airspace. Some of these various government and industry initiatives include: *The Technical Analysis and Applications Center (TAAC)*, *Joint Planning and Development Office (JPDO) UAV National Task Force (UNTF)*, *UAV National Industry*

Team (UNITE), American Society for Testing and Materials (ASTM) UAV Committee, and many other agencies worldwide with the objective of developing and introducing UAVs regulations in national and international airspace (De Garmo, 2004).

In response to the growth and development of SUAVs, most organizations have already accepted a short cut by adopting manned aircraft regulations that are suitable for UAV flight operations (Ingham, 2008; DoD OSD, 2004; Williams & Harris, 2002). Different agencies or flight test organizations have different regulatory bodies that govern their policies regarding SUAVs. Some agencies have proposed relaxed regulations accordingly for academic institutions, research organizations, and UAV developmental organizations that design and test UAVs provided that these UAVs do not pose a threat to people and property on the ground (Ingham et al., 2006). For example, light UAVs weighing less than 150 kg with a kinetic energy of less than 95 kJ might not be required to be certified, provided that they will operate as radio controlled aircraft within the operator's visual range in unrestricted airspace for missions such as telemetry and aerial photography. However, larger UAVs weighing more than 150 kg with a kinetic energy of more than 95 kJ and light UAVs flying in unrestricted airspace or outside the visual range of the operator will be required to be flight tested and approved in a similar manner to that of manned aircraft (CASR 1998, 2001).

Other approaches to airworthiness and certification of SUAVs include the adaptation of a "safety target" from the European Aviation Safety Agency (EASA). Under this approach, the overall objective of the UAV is within the context of a defined mission and operating environment (EASA, 2004). The Safety Target approach is utilized when UAV operators are under the direct control of a single authority, which has

complete responsibility for safety, and is also the sole “customer.” EASA argues that *“this direct control of operations is a significant advantage when accepting a safety case which relies upon the restriction of operations to compensate for uncertainties over airworthiness”* (EASA, 2004).

2.6.2 DoD Initiatives

As more UAV flight tests are being conducted by the USAF, military standards have become restrictive regarding the safety and responsibility of the UAV programs, resulting in excessive costs in manpower and delays in schedule (Ingham et al., 2006). According to Ingham, et al. (2006), these same restrictions have often excluded suitable suppliers because of their non-compliance with such specifications, regardless of the rapid growth in the number of companies with high interests in the UAV business (Teal Group Corporation, 2011).

In 1999, the DoD, working with the FAA, developed a flight approval process known as a Certificate of Authorization (COA) contained in FAA Order 7610.4, Military Operations, that permitted UAVs to operate in the National Airspace Systems (NAS) (De Garmo, 2004). According to the FAA Factsheet (2011), the FAA issues a COA based on the following principles:

1. *The COA authorizes an operator to use defined airspace and includes special provisions unique to each operation. For instance, a COA may include a requirement to operate only under Visual Flight Rules (VFR) and/or during daylight hours. Most COAs are issued for a specified time period (up to one year, in most cases).*
2. *Most, if not all, COAs require coordination with an appropriate air traffic control facility and may require the UAS to have a transponder to operate in certain types of airspace.*

3. *Due to the UASs inability to comply with "sense and avoid" rules, a ground observer or an accompanying "chase" aircraft must maintain visual contact with the UAS and serve as its "eyes" when operating outside of airspace that is restricted from other users.*

According to De Garmo (2004) and FAA regulations, this process requires a case-by-case safety evaluation of each flight, which results in a lengthy process that can take up to three months to approve depending on the FAA region or regions where the UAV will be flown. Part of the approval process requires the FAA to issue a time and route of the UAV flight to avoid risks to other aircraft and persons in the area, which further limits the utility and missions of UAVs. The process is incapable of sustaining the high volume of UAV flight requests (De Garmo, 2004). The FAA recognizes that the processes is lengthy and has taken steps to streamline the process by standardizing the review process and increasing communication and transparency between the agency and the applicants (Kalinowski, 2010). Normally, COAs are worked on a first-come, first-served basis, with the exception of emergency and disaster situations where the use of UAVs warrants humanitarian needs.

2.7 Summary

This chapter detailed the importance of flight tests and the critical factors in flight testing. There is an abundance of literature on proposals for UAV regulations and safety standards, and this chapter briefly discussed the current initiatives carried out by the FAA and other agencies in promoting UAV technology in the common airspace. However, additional UAV data and flight requirements are needed to reach a decision for UAVs to fly in the commercial airspace. With an understanding of the complications of SUAV

flight test requirements and the background in the MOA between AFRL and AFFTC, it is clear that additional studies are necessary to evaluate the process and determine the benefits of additional safety reviews and the costs associated with it. The literature is silent on this subject and forms the basis of this research.

III. Methodology

This chapter reviews the methodology used in this research. The primary purpose of the methodology is to establish a quantitative and qualitative measure of benefit for an abbreviated flight test process for SUAVs based on the MOA between AFRL and AFFTC. This research's methodology uses interviews, cost sensitivity analysis, and variability analysis using value stream mapping (VSM) techniques in the SUAV flight testing processes for the development of a notional decision rule matrix. This chapter also discusses the development of acceptable cost and optimal risk and the boundaries drawn from analysis to construct a decision rule.

3.1 Research Design

This research is exploratory in nature using multidisciplinary approaches and techniques, both quantitative and qualitative. Quantitative research describes phenomena in numbers and measures instead of words; the focus of the research is usually predetermined and deducted from prior research (Krathwohl, 1998). Qualitative research, on the other hand, describes phenomena in words instead of numbers or measures and usually uses induction to ascertain what is important in the phenomena (Krathwohl, 1998).

By leveraging these multidisciplinary techniques (qualitative cost-benefit analysis, interviews, cost sensitivity, variability analysis, and heuristic risk analysis), this research will evaluate and quantify the current process used in the AFFTC review process

and create a decision rule for future test flights. Figure 3.1 shows an outline of this research's methodology, which will be discussed in detail.

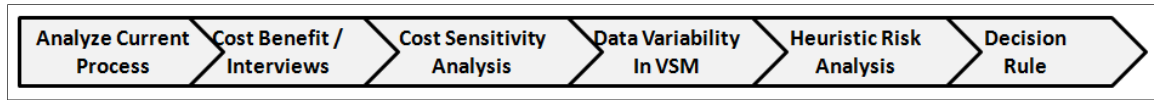


Figure 3.1: Research Methodology Overview

The use of these techniques, both quantitative and qualitative, offers a decision-driven instead of hypothesis-driven methodology. A decision-driven methodology is intended to facilitate making a decision about the applicability or worth of the process in a given situation (Krathwohl, 1998). Such applicability to this situation may include the total cost of the SUAV, its total impact energy, and weight of the vehicle. This overall heuristic evaluation should offer the desired consensus or accepted basis for decision making. For example, if the cost of the SUAV is less than that of the total cost the test, then it may be necessary to reevaluate the total cost of the joint AFRL/AFFTC approval process. Adversely, if the cost of the UAV is greater than that of the total cost of the flight test process and execution, then the approval process is likely justified for greater accountability and safety reviews. This approach may prove to be useful when comparing the current UAV flight approval process to an abbreviated process.

3.2 Qualitative Cost-Benefit Analysis

A qualitative cost-benefit analysis is defined as the determination of the costs of achieving certain benefits (Krathwohl, 1998). Cost-benefit analysis methodologies have been used for multiple purposes in many different studies; its outcomes must be

translated into monetary or other measure of value so their relation to costs may be determined (Krathwohl, 1998). For a cost-benefit analysis conducted in this research, the benefit may be in the form of cost and time savings from an abbreviated flight test process.

According to Krathwohl (1998), cost-benefit analyses are often greatly affected by the assumptions of difficult-to-estimate indirect costs and outcomes, such as the personnel costs of individuals with different levels of qualifications. By measuring outcomes across different programs according to the magnitude of their effects relative to their costs in comparable terms, cost-effectiveness analysis allows a comparison of choices of achieving certain benefits in relation to other methods of obtaining the same benefits (Krathwohl, 1998; Rossi & Freeman, 1985).

3.2.1 Criteria Development and Assumptions for Cost-Benefit Analysis

In order to quantify the current process used by the USAF per the MOA between AFRL and AFFTC, a VSM of the flight test approval process is reused from a lean process improvement study conducted by Homan and colleagues (2011), as shown in Appendix B. To ensure this research quantifies the standard USAF flight test process and any abbreviated flight test process for SUAVs, a comprehensive holistic assumption was required for the comparison of both processes. It is assumed that all work has a value-added and a non-valued-added component to it. First, any value-added (VA) work identified in resources and manpower is assumed to be valid—that an average hourly rate and time per person reviewing the flight test program was standard across all organizations. Second, any non-value-added (NVA) work time and resources consists of

waste and necessary waste, which include policy, regulations, and standard processing time. Non-value-added “pure waste” consists of the “cost of delays,” in which man-hours were considered “lost” due to queuing effects in the approval process and doing “no work” while waiting.

Furthermore, other assumptions in the data gathering of this study include the value-added work in terms of resources and manpower for SUAV programs and those of larger manned aircraft are likely to be different from each other. It was assumed that SUAV programs do not require as much resources and manpower as those of larger manned aircraft programs. Another assumption is that system complexity and safety guidelines of both types of vehicles are assumed to be different due to the nature of manned versus unmanned aircraft (i.e., manned vehicles are more complex and require a higher standard of safety guidelines than SUAVs). Lastly, the risk assessment and management of both classes of vehicles are also assumed to be different—that SUAVs are sometimes expendable because of their low manufacturing and operating costs when compared to larger conventional aircraft.

3.2.2 Notional Balance Statement

By using the criteria for qualitative cost-benefit analysis and the comprehensive assumptions, a notional overall breakdown of the total cost of flight testing a SUAV is proposed in Table 3.1. The total cost of a SUAV flight test includes the costs of approving flight status from both organizations (AFRL and AFFTC) and the cost of test execution.

Table 3.1: Notional SUAV Flight Test Balance Statement

SUAV Program Asset Cost	
Test Execution Cost	
AFRL Review Cost	
AFRL Risk Abatement Cost	
Value Added Work	
Non-value Added Work	
Waste	
Necessary Waste	
AFFTC Review Cost	
AFFTC Risk Abatement Cost	
Value Added Work	
Non-value Added Work	
Waste	
Necessary Waste	
Total SUAV Asset and Liabilities	

This flight test approval process can be summarized in its most basic and simple balance statement equation based on the assumptions and criteria discussed earlier:

$$Test_{Total\ Cost} = AFRL_{Review\ Cost} + AFFTC_{Review\ Cost} + TE_{cost}, \text{ where,}$$

$$AFRL_{Review\ Cost} = AFRL_{RAC} + VA + NVA$$

$$AFFTC_{Review\ Cost} = AFFTC_{RAC} + VA + NVA$$

The $Test_{Total\ Cost}$ is the total cost of the test. The *Review Costs* at AFRL and AFFTC include the *Risk Abatement Cost (RAC)* and the *value-added (VA)* and *non-value-added (NVA)* costs. The *Risk Abatement Cost (RAC)* represents the safety and technical reviews performed by the approving authority at AFRL and AFFTC prior to test execution. The respective *VA* and *NVA* costs at AFRL and AFFTC are directly and indirectly incurred from both organizations as part of approving process per regulations and policy, based on

their respective resources and manpower. Next, TE_{cost} is the cost of test execution, which is the operating cost to fly the SUAV. Finally, the *SUAV Asset Cost* consists of the vehicle platform cost and the payload cost. However, for cost simplicity, this research will not differentiate between these two costs but assumes they are a single asset cost.

The basic notional balance statement sheet presented may be elementary, as it only shows a very generic cost to the total SUAV flight test operation. Additionally, when comparing the two balance statements, one with AFFTC risk abatement cost and the other without AFFTC risk abatement cost, the PM would choose the lesser of the two for cost and schedule savings. However, further analysis in risk assessment, data variability, and cost sensibility may call into question this simple approach.

3.2.3 Interviews

The qualitative cost-benefit analysis for this study will be coupled with insights from qualitative interviews in order to elicit the processing costs of an abbreviated process. It is assumed that the cost-benefit analysis requires personal interviews for data validation and strengthening the results. Interviews are one qualitative research methodology that allows the interviewer to gain a depth of responses from individuals in the process, yet it has its own disadvantages. Interview responses are often reflected by individual biases, and may also be in a form of confidentiality unbeknownst to the interviewer (Kratwohl, 1998). These responses may be difficult to analyze due to the sensitivity of the subject and the predisposition of individuals to respond a certain way.

3.2.4 Cost Sensitivity

Cost sensitivity measures how variations in the overall [SUAV] configuration affect the resource requirements and costs (Tenzer, 1965). As discussed earlier, there are always some forms of uncertainties and risks involve in flight testing, especially to SUAVs when its total cost is sensitive to its payload. One way to measure cost sensitivity is the design and operational parameters of the SUAV. The total flight test costs may greatly increase if an advanced sensor payload is attached to the SUAV, which may also significantly increase the risk factor and the costs associated with the whole program. Another way to look at cost sensitivity is the question of necessity in redundant reviews for SUAVs. SUAV flight parameters and their associated costs may be the driving factor in adding the flight approval review times, as these reviews may cause delays to the programs. To an extent, any changes in the associated costs of the program are sensitive to the decision rule used.

3.3 Data Variability Analysis

In addition to the qualitative cost-benefit analysis, personal interviews, and cost sensitivity analysis, data variability obtained using the VSM will be analyzed. A VSM is one the first products created when attempting a process improvement as described by Womack and Jones (2003). McManus (2005) states that a VSM is a tool for achieving an efficient process, and that its sole purpose is for process improvement by evaluating the process holistically. The goal of the VSM is to depict material and information flows across and throughout all the value-adding and non-value adding (waste) processes required to produce the product (i.e., approval status) and deliver it to the customer (i.e.,

the program manager and test team) (McManus & Millard, 2003). Therefore, the VSM is an appropriate approach due to its “all-in-one” top-level picture of all the processes that occur in the flight approval process, from the time a test plan is submitted to the time it is approved for flight status.

In a perfect process, every link in the approval chain should be synchronized, making the approval system as lean as possible. However, achieving a high level of synchronization requires a “smooth flow” process (Murman, 2002). The current flight test approval process involves moderate to high variability in the value flow streams, as organizations have variable flight test demands at different times and resources to approve flight tests. According to Oehmen and Rebentisch (2010), variability in process execution leads to widely varying process times and thus a low degree of synchronization. Oehmen and Rebentisch (2010) also argue that over utilized capacities (e.g., engineers) can also be a cause for such variations, as these disturbances cannot be buffered and immediately lead to delays.

One of the purposes of VSM is to identify and predict locations of process variability. If variability cannot be controlled due to budget or schedule constraints in the program, then there should be enough takt time in the individual process steps so the end step in the process will not have high variability. Takt time is the number of units of work demanded by the customer divided by the available time (McManus, 2005); for this research effort, it is the number of days needed for a completed test plan review to get approved for flight test. According to McManus (2005), the single most important concept of lean product development is achieving a takt time, and that all tasks or steps in the process must then proceed at this pace.

For example, if the FOA's average rate for approving a test plan is three days, then the takt time at the FOA step is three even if the actual data varies with the workload. The FOA must be able to support this average takt time of three days per test plan review, or the overall demand for work cannot be met, which would trigger bottlenecks and delays in the downstream processes. In summary, in an uncontrolled process with variations of any sort, queuing effects will tend to build delays between process steps and pile up work at bottlenecks (McManus, 2005).

3.4 Managing Acceptable Cost and Optimal Risk

Many in the T&E community know the risk hazards present in the operation of any complex system, manned and unmanned systems included. This concern is probably one of the major reasons why UAV standards and regulations are being worked throughout many organizations in the development of UAV safety and airworthiness certification. Based on data from the T&E community, especially those coming from the military, UAVs have a poor safety record (De Garmo, 2004). According to an April 2003 Congressional Research Service report, the UAV accident rate is 100 times that of manned aircraft (Bone & Bolkcom, 2003). Another study conducted by the USAF in 2002 concluded that the accident rate for UAVs is 50 times greater than that of an F-16 fighter jet (De Garmo, 2004).

A more recent 2009 DoD Unmanned Systems Integrated Roadmap determined that UAVs have suffered mishaps at one to two orders of magnitude greater than the rate (per 100,000 hours) incurred by manned military aircraft. Figure 3.2 shows the mishap rates per 100,000 flight hours between manned and unmanned vehicles between 1986 to

2006. Notice that SUAVs such as the Hunter, Shadow, and Pioneer, whose wingspans and body lengths have an average from 10 feet to 20 feet, have higher mishap rates compared to those of other types of vehicles. Also noted is the decrease in mishaps as these SUAVs accumulate more flight hours. The decrease in SUAV mishaps shown in Figure 3.2 represents a steep learning curve from SUAVs as the technology matures.

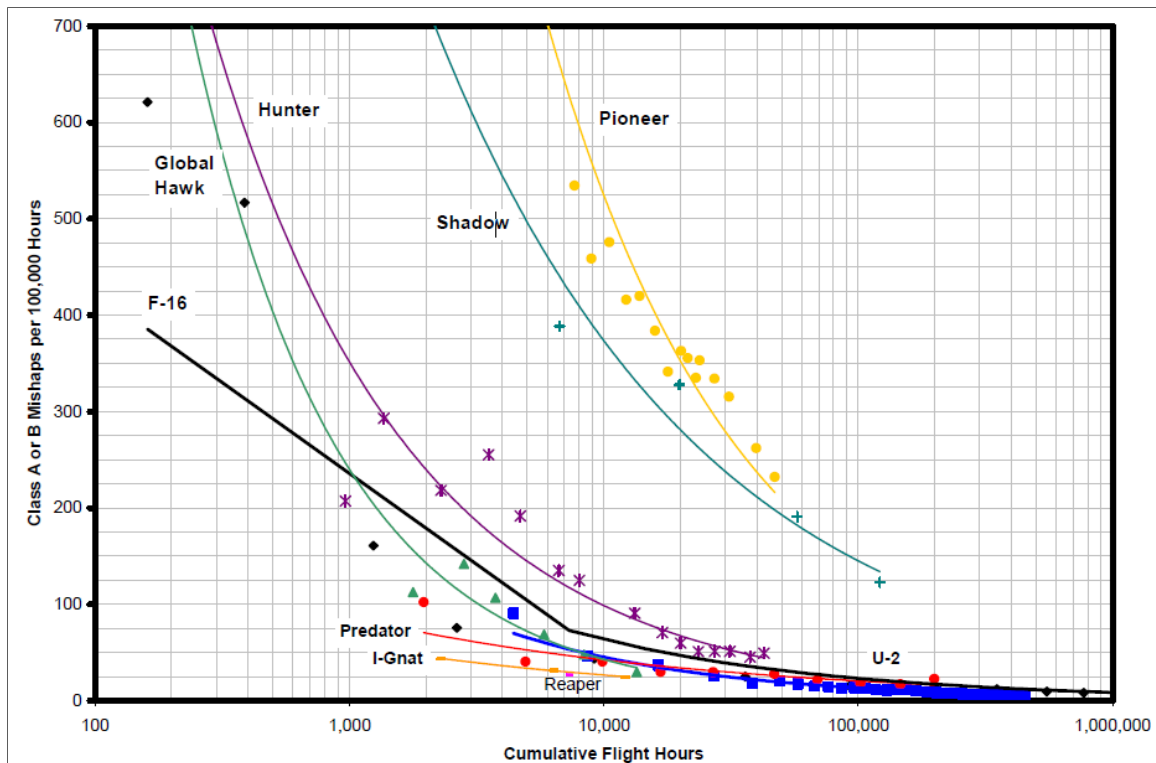


Figure 3.2: U.S. Military Aircraft and UAV Class A Mishap Rates (DoD FY2009-2034 Unmanned Systems Integrated Roadmap, 2009)

It is for this very reason of UAV mishap rates that PMs and UAV operators should carefully manage the cost of these SUAVs and reduce the risk to an optimal level necessary for the continuation of flight tests in the program. As clearly stated in the previous chapter (Chapter 2: Literature Review), the primary goal of any flight approval process for airworthiness and flight certification is to reduce risks and increase safety

standards among SUAVs and other airborne vehicles, including those who flight test them. While it has always been the PM’s goal to reduce the costs in UAV flight operations and any overhead costs incurred while waiting for the flight approval process, the cost of risk abatement in time and resources is almost always never explicitly managed. However, with limited resources and time, the question becomes, “*How much risk abatement is enough as part of the flight test approval process?*” Figure 3.3 shows a classical answer from economics where the optimal level of risk is where the sum of the cost of risk abatement and the expected losses from risk is at a minimum (Morgan, 1981).

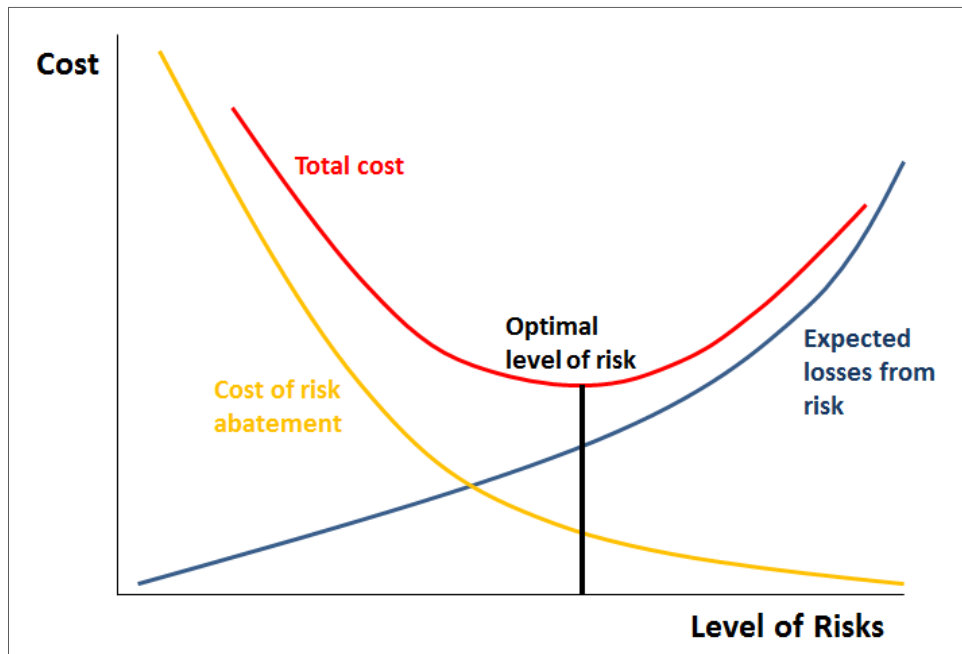


Figure 3.3: Managing Cost and Level of Risk (Morgan, 1981)

Two of the most common forms of risks are “acceptable risk” and “optimal risk.” (Morgan, 1981). Acceptable risk implies a predetermined criterion or standard for a maximum risk threshold level below which risk will be tolerated, and thereby permits the

evaluation of cost, national priority interests, and number of tests to be conducted (U.S. Army White Sands Missile Range, Morgan). Optimal risk implies a trade-off that minimizes the sum of all undesirable consequences (Morgan, 1981). It is this optimality that justifies careful attention, thus the basis of this research in terms of an abbreviated approval process for SUAVs where redundancy in the cost of risk abatement may be unnecessary.

One way to reduce the cost of risk abatement is to actually reduce its cost by shortening some of the safety review times. However, reducing the cost of risk abatement in this way would likely increase the level of risks and the expected losses from risk, resulting in an increase to the total cost of the program because of the accompanying reduction in scrutiny of the safety review. Therefore, the primary method used in this study is to determine the cost benefit of an abbreviated flight test to achieve an optimal level of risk. This optimal level of risk should demonstrate an appropriate reduction in the cost of risk abatement while maintaining or decreasing the expected losses from risk, thus minimizing the total costs incurred from the flight approval process and UAV operation. In investigating the notional optimal level of risk, this study proposes shifting the total cost curve and the cost of risk abatement curve to the left, as seen in Figure 3.4.

If a reduction in the cost of risk abatement is attainable, either through eliminating AFFTC reviews or decreasing the complexity of the vehicle, the abbreviated approval process may reveal that it can be condensed and shortened with probable cost savings to the total cost and expected losses from risk. Various features in the flight test approval process can be factored in when deciding how much risk abatement, or for the purposes

of this research, the degree to which safety reviews are modulated in the process to save time and money.

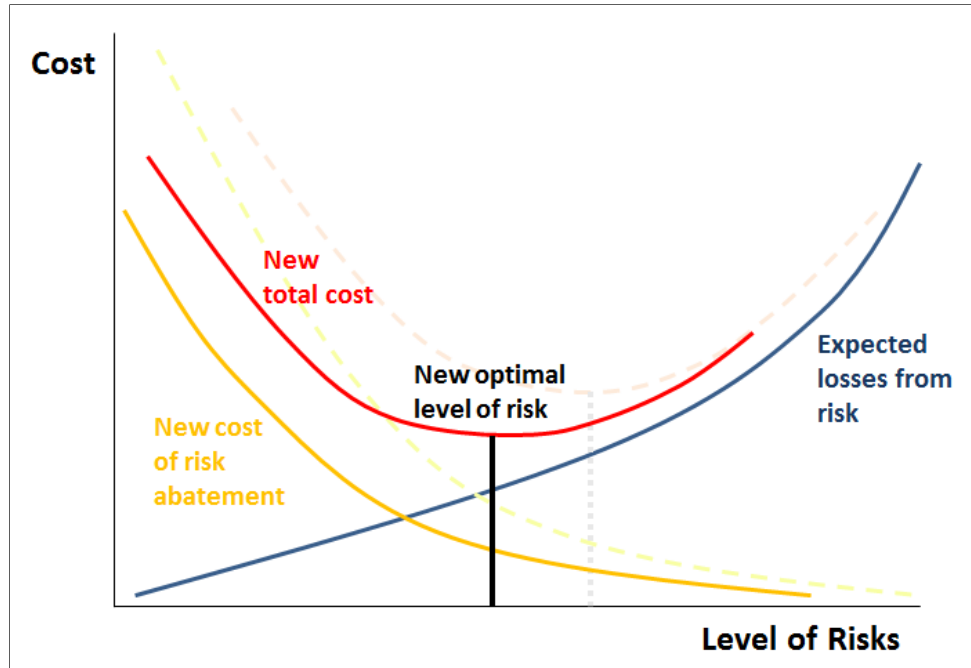


Figure 3.4: Notional Optimal Level of Risk

3.5 Summary

This chapter has detailed the methodology used in this study. The notional flight test balance sheet with proposed assumptions tailored by interviews and cost sensitivity analysis establish the conditions needed to create a better understanding of the costs associated with the flight test approval process. Furthermore, data variability analysis will be used to present a thorough overview of the current process depicted in the VSM and the issues that arise from it. Additionally, by combining the balance sheet and the analyses, this methodology seeks to expose the advantages and disadvantages of flight test process steps in the overall chain of reviews and approvals. Finally, this chapter

notionally identified the costs of risk abatement and the expected losses due to SUAV flight tests. The results and analysis using this methodology are presented in Chapter 4.

IV. Results and Analysis

This chapter describes the results and analysis of the data gathered from the flight test offices. The first section details the flight test balance statement with relevant assumptions in operational and personnel costs to determine the cost-benefit of the review process at AFFTC. The second section focuses on VSM analysis of cost sensitivity and time variability in the chain of approval process through a Variability Simulator. Next, the analysis on risk management with acceptable risk to costs and optimal risk in flight testing are shown. These cost benefits are then measured against the cost of risk abatement and expected losses to the UAV to determine the threshold where it makes sense that the review process at AFFTC adds value.

4.1 Cost Measurement Analysis

Cost measurements are taken from labor hours and costs of operating and maintaining a SUAV. The intention of this analysis is to determine whether the extra reviewing and approval process at AFFTC is needed from the point of view of a simplistic SUAV flight test. These costs were taken from historical data and labor hours were assumed based on the rank and pay grade of the officer in charge of certain processes. Comparisons were made with significant assumptions due to the sensitivity of the SUAV costs and the difficult-to-estimate indirect costs. Nevertheless, the balance statement in the cost measurement analysis shows the financial resources available so that PMs may decide how to use cost information in the assessment of economic alternatives. It may sound elementary that the lower cost in the balance statement will most likely be

chosen, but it may be apparent that there are several other issues and problems that must be dealt with in order to develop further analysis for cost benefits.

4.1.1 Estimated Cost Balance Statement

Historical data from 2011 shows 22 different SUAV tests within the continental United States, averaging \$66,500 in costs per vehicle. Each program had an average of two SUAVs produced and flown during the life of the program, which can be added up to a total of \$133,000 in SUAV program assets. Each SUAV also had an average of 23.8 sorties and 9.9 flight hours (see Appendix C for SUAV costs and mishap data). The test execution cost, estimated at \$30,000, was based off of the average range cost, fuel cost, and any extra burden and overhead costs including personnel involved in the flight test of the SUAV. The following processing days were taken from the current VSM flight test process (Appendix B) developed by Homan et al. (2011) and the AFRL T&E Office (Appendix C) to determine a conservative estimated cost of the review process.

The AFRL technical and safety reviews (TRB & SRB) typically took four to five weeks (25 working days) prior to the actual test execution; therefore, it was possible to estimate the value-added (VA) time and costs of the review process. With a conservative assumption of a four-member team including those at the AFRL T&E Office working 25 working days and one Lieutenant Colonel (O-5) or a GS-15 pay grade technical lead working two (2) days, the total TRB and SRB cost averaged \$20,000. Since AFFTC does not normally take part in the TRB and SBR at AFRL for low risk test plans, this value was low; but nevertheless, an estimate of one (1) working day was added for any comments provided from the FOA to the AFRL TRB and SRB.

Next, the non-value added (*NVA*) work (waste and necessary waste) both at AFRL and AFFTC were greatly assumed as standard processing time with delays. These delays can sometimes be considered as buffer times or variations against uncertainties in the overall process. The assumption on AFRL waste and necessary waste was one (1) and two (2) working days, respectively. AFFTC's non-value added waste work was assumed to be two (2) working days.

Finally, the AFRL risk abatement cost ($AFRL_{RAC}$) was also based on an average O-5 or a GS-15 pay grade combined with the current five (5) working days to approve a flight test at AFRL per the VSM. Likewise with AFFTC risk abatement cost ($AFFTC_{RAC}$), except the current average processing time to approve an AFRL flight test at AFFTC was six (6) working days, which was based off of the data provided by the AFRL T&E Office. When combining all of this data together, the total average SUAV asset and liability has a total cost of \$191,500.

Table 4.1 summarizes the value-added (*VA*) time required at critical steps through the flight approval process. The first step requires the PM to meet with the AFRL T&E Office to conduct TRB and SRB and document mishap reporting procedures in the test plan—all of which happen four to five weeks prior to test execution. The second step requires the AFRL Technical Director Division Chief's (GS-15) review and approval to start test, which normally takes five (5) working days. The third step, which is in conjunction with the second step, requires the FOA at AFFTC to review and approve the test plan in order to start the flight test, which averages six (6) working days. Table 4.2 shows the balance statement of an average typical SUAV flight test.

Table 4.1: Estimated Time for AFRL/AFFTC Approval Review

Process Step	AFRL Processing Time (Work days)	AFFTC Processing Time (Work days)
PM meets with AFRL T&E Office to conduct TRB & SRB and finalizes test plan	4 members take 25 WD 1 O-5/GS-15 take 2 WD	1 O-5/GS-15 take 1 WD
Get AFRL Division Chief (GS-15) to review and approve to start test	1 O-5/GS-15 take 5 WD	n/a
Get AFFTC FOA (O-5) to review and approve to start test	n/a	1 O-5/GS-15 take 6 WD

Table 4.2: Notional SUAV Cost Balance Statement

SUAV Program Asset Cost	\$133,000
Test Execution Cost	\$30,000
AFRL Review Cost	
AFRL Risk Abatement Cost	\$2,100
Value Added Work	\$20,000
Non-value Added Work	
Waste	\$1,200
Necessary Waste	\$1,500
AFFTC Review Cost	
AFRL Risk Abatement Cost	\$2,500
Value Added Work	\$400
Non-value Added Work	
Waste	\$800
Necessary Waste	\$0
Total SUAV Asset and Liabilities	\$191,500

$$Test_{Total\ Cost} = AFRL_{Review\ Cost} + AFFTC_{Review\ Cost} + TE_{cost}$$

4.1.2 Initial Cost Results

As previously emphasized, it is important to recognize that these monetary values are presented with significant assumptions based on empirical observations of only somewhat similar situations befitting an exploratory research such as this. From the data presented, with an average total value of \$191,500 in SUAV asset and liabilities, the total AFFTC review costs (\$3,700) did not represent any substantial impact to the total value of the SUAV. Not only was the AFFTC review cost less than anticipated, the average reviewing time was much shorter than previously expected.

With regards to flight mishap data from the AFRL T&E Office (Appendix C), SUAV flights from 2011 had nine flights mishaps with a total of over \$625,000 in damages, which translated into an average of \$69,400 per flight mishap. Additionally, data from the AFRL T&E Office showed an average of five (5) working days for a return to flight approval from AFFTC upon learning of a mishap. In two mishap instances, the return to flight processing time AFFTC took to approve was three working days and six working days, respectively. By using similar assumptions and estimates on cost, these five working days had an estimated process cost of a little over \$2,000 for a return to flight approval from AFFTC. Again, the average time and cost of a return to flight approval from AFFTC was insignificant compared to the total cost in mishap damages.

In summary, the cost measurement analysis from the data given suggested that the process time and process cost from the AFFTC review was considerably less than previously expected. Moreover, the time to approve a return to flight following a mishap was reasonably less in terms of cost and time. This initial cost analysis shows that the AFFTC involvement in AFRL flight tests may be beneficial and instrumental in

mitigating AFRL flight mishaps, considering SUAV flight tests in 2011 had experienced a mishap with over \$69,000 in damages for each mishap. The extra review at the AFFTC may cause additional time and overhead costs for the test management organization, but in the long run, it may be valuable in providing comments and insights to the PMs and the test teams at AFRL, thereby possibly reducing future flight mishaps. This perceived value of extra small dollars and time to “buy” a decreased chance of failure may be enough to convince the PMs to spend the additional funds to mitigate mishaps. However, given the nature of R&D in UAV test flights, mishaps that cost a few hundred to a few thousand dollars are sometimes considered negligible and acceptable in favor of improved research.

Additional interviews were conducted with the AFRL T&E Office as more details on AFFTC review process were revealed. One of the primary reasons why the approval processing time from AFFTC was cut shorter than what was anticipated at the beginning of this research was the personnel changes that took place in the 412th OG at AFFTC since the Homan et al. (2011) study. Personnel at the AFRL T&E Office noticed the trend in approval review was slashed to almost half that from previous submissions. The AFRL T&E Office also noticed there were no additional re-work or additional value added feedback from the FOA. This decreasing trend in approval time and the lack of in-depth reviews from AFFTC suggested either an absence of interest in SUAV flight test reviews from the new personnel, or that the new FOA has come to fully trust the flight test organizations at AFRL with simple SUAV tests and designs. In addition to the new FOA personnel at AFFTC, the AFRL T&E Office also welcomed in a new Chief, who is a Test Pilot School (TPS) graduate from Edwards AFB. Both organizations have seen an

increase in direct communication on issues relating to SUAV tests. Perhaps the experienced TPS graduate and new Chief at the AFRL T&E Office brings new skills or “value-added” to the process, hence the decreased time in the approval process.

4.1.3 Cost Sensitivity Results

There is difficulty in estimating cost evaluations, especially given sensitivities associated with the programs. These sensitivities include the design and operational parameters of the SUAVs. As shown in Figure 4.1, of the 22 SUAV flight test programs in 2011, nearly half were new and prototypes with variable costs to each program, none of which are dependent on their system maturity.

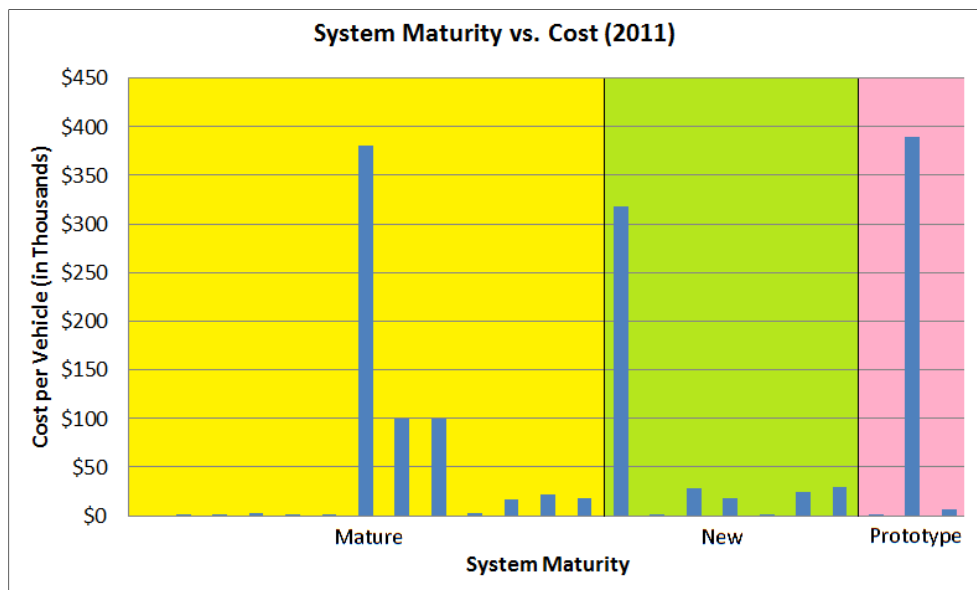


Figure 4.1: System Maturity vs. Cost

Figure 4.1 also shows that costs are not sensitive to system maturity, but rather to the payloads carried by these SUAVs. The cost of some of these SUAVs can be high, mostly due to their expensive payloads such as radar sensors and imaging capabilities.

Since the initial results and mishap data have shown high vulnerability for SUAV mishaps at an average of \$69,400 in losses, PMs and test teams are recommended to have initial estimates on the program's feasibility and categorize test requirements in phases of testing in order to reduce risks to program cost. These phases of testing and development should be separated into a list of "must haves" and "good to haves" with user prioritization that can be used to conduct trade-off at later stages of acquisition development. These phases of testing and development should minimize cost uncertainties, whereas an "all-in-one" package (i.e., one expensive payload on a SUAV) may present a higher risk to cost should a mishap occur. This recommendation is in agreement with the industrial practice of involving customers early in program requirements with clear communication to separate their needs into "must haves" and a "wish list" (CNSTAT et al., 2011). CNSTAT et al. (2011) also recognizes some flexibility that allows for modifications responsive to users' needs and changing environments. However, any changes to program requirements can result in considerable cost increases and schedule delays.

A substantial part of the many levels of safety reviews in the USAF is the structure of accountability in the design and development of the system. A system that has mature technologies will likely experience safer operation than those that have immature systems. With SUAV payload costs that sometimes exceed the cost of the vehicle, it becomes a question of technology maturity of the SUAV itself. Technology immaturity such as those of SUAVs coupled with an expensive payload will certainly cause scrutiny in reviews. According to CNSTAT et al. (2011), technology immaturity is known to be a primary cause of schedule slippage and cost growth in DoD program

acquisition. The success of a system maturity strategy depends on the consistent and continuous definition of requirements and the maturation of technologies. This “evolutionary acquisition” or a spiral acquisition approach to transition new technology to operational capability is reflected in the DoD Instruction 5000.2. The objective of evolutionary acquisition is to balance the needs and available capability with resources, and to put capability into the hands of the user quickly (DoD AT&L).

In summary, system maturity costs were varied with SUAV performance and payload cost. To minimize large mishap costs, a priority list of “must haves” and “good to haves” should be implemented and decided on what and when to test first instead of putting all eggs in one basket and risk it all from system failure.

4.2 Value Stream Mapping Analysis

Value Stream Mapping (VSM) examines the business process and seeks to understand and improve such efforts. While this study does not focus on the efficiency of the process, it does examine the necessity of the extra reviews at AFFTC and the cost benefit of having such reviews. As Homan et al. (2011) described in the present-state VSM, it was apparent that one of the larger areas of waste was the specific loops between the different stakeholders (i.e., program managers) and the AFRL T&E Office. Other problems revealed by Homan et al. (2011) included the lack of initial notifications of pending tests and the absence of standardization in the test plans when submitted for approval. The five main problems identified by Homan (2011) were:

1. *Late notification and/or non-standard work (test plans or safety packages) by PMs*
2. *Firefighting and heroics by AFRL T&E Office*

3. *Bottleneck at FOA (high throughput and low capacity)*
4. *Lack of expected target timeline and non-standard work (mishap report) for return-to-flight process*
5. *Lack of transparency throughout processes for all stakeholders*

In quantifying the present-state VSM and the cost measurements which were discussed in the previous result, initial data suggested that AFFTC involvement in AFRL flight tests may be beneficial in providing feedback and mitigating mishaps given that the costs and time required were miniscule compared to the total cost of the UAV program. However, further analysis was needed to verify and determine the threshold at which AFFTC involvement in low risk test plans adds value and that the extra review is desirable even though it presents a fairly minimal investment in time and cost to the program. Conversely, this threshold will also need to show that AFFTC's involvement in low cost programs are sometimes inapplicable because of SUAV costs and complexity, and any program that falls below this threshold may not require additional reviews at AFFTC.

4.2.1 Data Variability

In this portion of the analysis, a Variation Simulator developed by the Lean Advancement Institute (LAI) at the Massachusetts Institute of Technology (MIT) Lean Academy was used to measure the impacts of variation on cycle time in the approval process. The intention of the variability simulation is to assess the impact that variability has on process performance. Any variability in the simulation value is used for the purpose of predicting relative differences in task execution at a particular step. Such

simulation is not designed to cast judgment or predict performance at AFFTC or AFRL T&E Office.

Reducing process variation is a key component in process improvement methodologies such as lean Six Sigma. In an ideal process flow, where the input rate is equal to or less than that of the output rate at every task, the flow should not experience any delays and the process is deemed fully utilized. However, when variations in the process are considered, the process begins to experience delays and work begins to accumulate at various tasks. For the sake of simplicity, the process flow begins when the PM submits a draft test plan to the AFRL T&E Office, which then begins the safety and technical coordination approval process internally at AFRL and externally at AFFTC. Once the approval process is complete, test execution can begin.

As demonstrated in Figure 4.2, the simulation assumed no output rate variations at the AFRL T&E Office nor the review authority panels; however, the PM station had variations per day in submitting test plans to the AFRL T&E Office. These test plans were varied from one to five per day, which could represent a lack of notifications of pending tests and lack of standardization in the test plans. These variations coming from the PM had the most direct impact on the AFRL T&E Office. Hence, the workload depicted in Figure 4.2 shows the accumulated test plans at the AFRL T&E Office over time when its capacity could only produce three test plans per day.

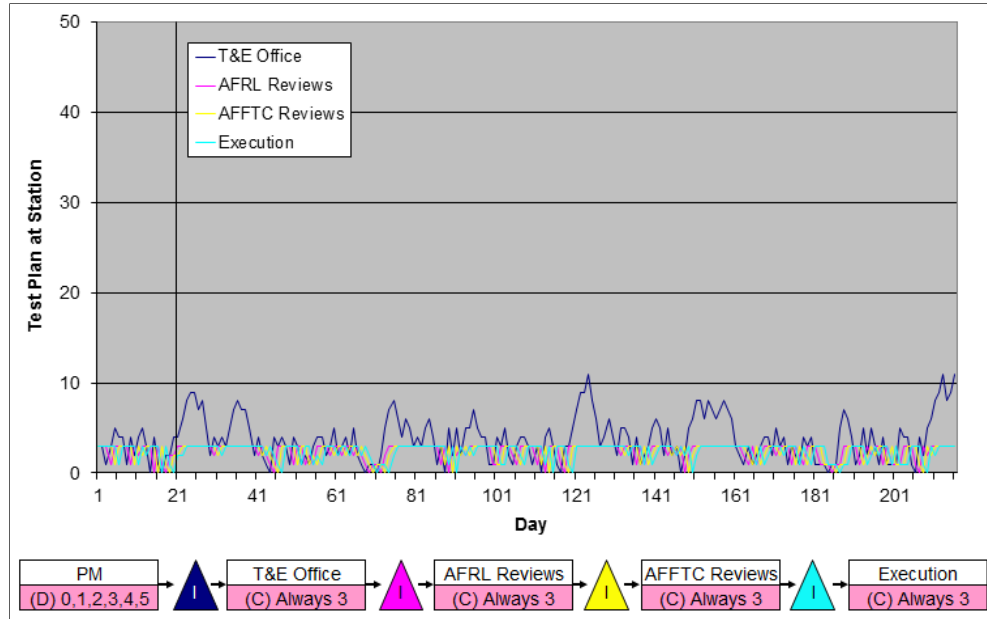


Figure 4.2: Variation at Program Management

Homan et al. (2011) mentioned that the AFRL T&E Office was unable to eliminate the constant late notifications or tardy test packages arriving from the program manager, in addition to the non-standardized test packages. Homan et al. (2011) also discussed the effect of “firefighting” at the AFRL T&E Office where members defer resources to problematic (or late) programs and work harder to meet requirements and push completed programs to the next station. This effect causes the information to get “pushed” instead of “pulled.” According to McManus (2005), information flow should be pulled, not pushed. In other words, information should flow when it is needed by downstream processes, not when upstream processes are done. Repenning et al. (2001) also added that occasional “firefighting” may offer short-term gains, but these temporary gains will come at the expense of the long-run flow of the entire process. Firefighting can

also create bottlenecks for the downstream process, especially when the later process steps have variation, which possibility is discussed in the next simulation.

As shown in Figure 4.3, the FOA at AFFTC had variations in approving SUAV test plans coming from AFRL. One of the main problems identified earlier was the bottleneck at the FOA in the overall process (Homan et al., 2011). This bottleneck was caused by the increasing number of test packages that were pushed to the FOA from the AFRL T&E Office, resulting in variations in approval time. In many instances where programs were deemed low risk, only a single approval authority at the AFFTC handled all of the test packages from AFRL. The problem was even worse when the single FOA at AFFTC was also responsible for nine other local test organizations. These notional results show that the pushed information was not needed by the recipient in the downstream process, and it would certainly not flow “at the right time” for PMs to execute their tests on schedule.

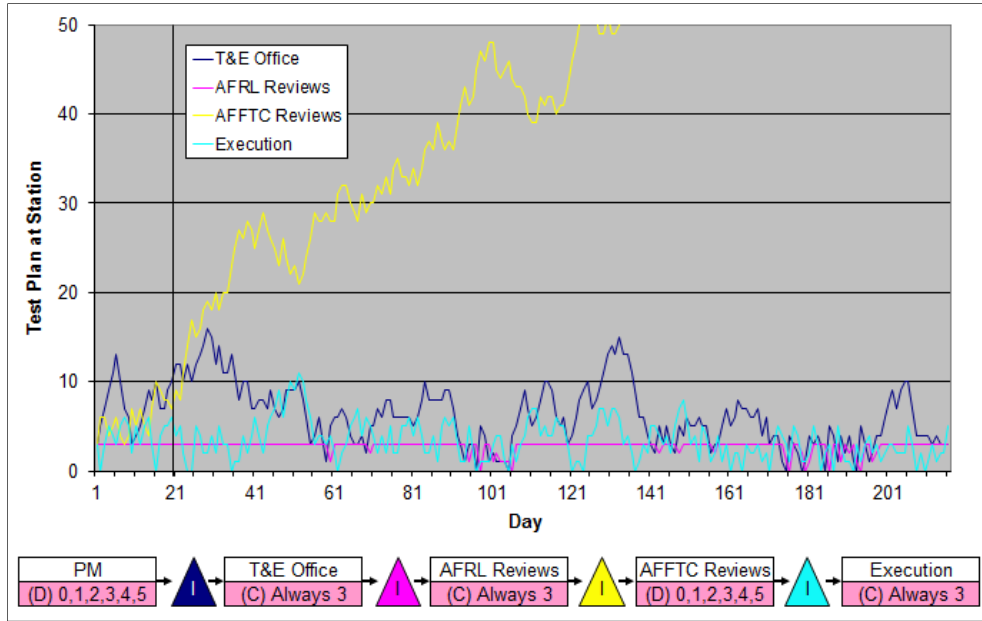


Figure 4.3: Bottleneck at AFFTC

In all simulations conducted with variations of at least one task, the test execution schedule was greatly affected. The simulation could continue with multiple variables at different tasks, but the purpose was to demonstrate the process behavior over a long period of time. With reduced input variability and process variability, the simulation shows improvement in the flow process and allows stations to have excess capacity to pull work. Eliminating variability also allows straight-through flow to meet customer (i.e., program managers) demands.

McManus (2005) specifies that bottlenecks can be caused by effects external to the process, such as the lack of resources, information, or authority to proceed. Such effects coincide with the current-state of the AFRL/AFFTC approval process. That is, if there is a lack of resources, typically the FOA personnel are not available to start a task and the task waits, thus creating a bottleneck. If the externally-provided information is

not available, typically because of the inadequate test plans from the PM, the tasks either wait or proceed with “bad” information (i.e., firefighting) only to be reworked later (after mishaps). Finally, if external approval authority other than from AFFTC is required to proceed, and it is not forthcoming, the task will wait.

4.2.2 Value Stream Mapping Results

In summary, the results from VSM analysis conducted with data variability support the five major problems which were first identified by Homan et al. (2001). Not only does this study support the identified problems, it also postulates that, based on McManus’s VSM manual (2005) and through MIT’s Variation Simulator, bottlenecks are caused by effects external to the process. The variability simulation uncovered the heavy workload and firefighting support that the AFRL T&E Office displayed when PMs failed to follow standardized guidelines. This led to firefighting from the AFRL T&E Office which ultimately led to the bottleneck at AFFTC when more than enough tests plans were compiled at the FOA for approval.

4.3 Acceptable Cost and Optimal Risk

In this portion of the analysis, a notional optimal level of risk is created to evaluate the value of each risk factor before reaching an optimal level of risk and the deciding cost in flight testing them. Risk is usually expressed in terms of probability of occurrence and impact, which leads to dollars and time, and each project will have to control its own destiny through factoring the different indications of risks. SUAV flight mishaps may be all too common for PMs who have flight tested them and those who have the experience to explain why flight mishaps happen. As discussed earlier in the accident

rates of SUAVs, it is all too familiar to the DoD and the FAA. Therefore, they require a thorough review in flight personnel policy, training, and operations for SUAV tests. Figure 4.4 shows the balancing between the level of risks and the costs of a SUAV program to the optimal level of risk, as discussed in Chapter 3.

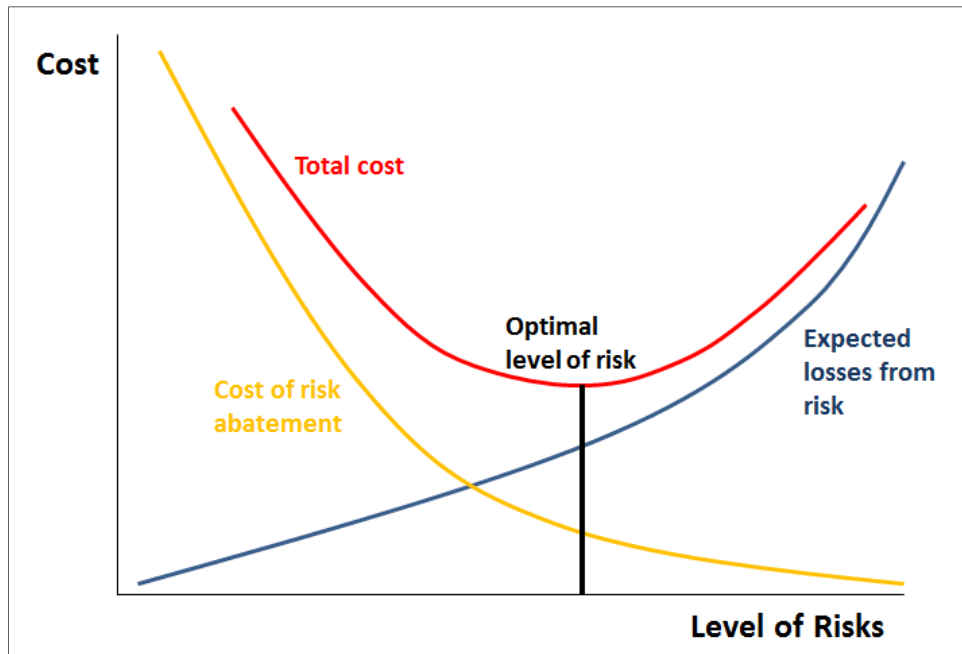


Figure 4.4: Acceptable and Optimal Risk
(Morgan, 1981)

4.3.1 *Perceptual Factors in Assessing Risk*

From the previous analyses in cost measurement and variability, the cost of risk reduction at the AFFTC safety reviews have shown to be minimal compared to the overall costs of the entire program, suggesting that more reviews should be done to quell the increasing number of flight mishaps. Additionally, the time it took for additional reviews at AFFTC was less than anticipated, but that was because of recent personnel changes. Furthermore, personnel at AFFTC were experiencing variations in approving

low risk test plans when too many programs were pushed to the FOA for approval, causing major bottlenecks at AFFTC.

In light of the two previous analyses, why would the PMs and the AFRL T&E Office want to de-scope the level of oversight from AFFTC on low risk programs given that the cost and time required for AFFTC to review them were not as high as originally thought? In other words, what is the reason why people are reluctant to perform risk analysis (i.e., mishap mitigations at AFFTC) for low risk programs when the process time is short and the cost is inexpensive? The key issue is one of perception. Cost measurement results show that the AFFTC processing time is organizational and personality-dependent—that personnel changes in the future may not have the same test plan approval rate, thus adding the uncertainty in the overall process. Additionally, the PMs and the AFRL T&E Office felt that there was no value added at the AFFTC review process.

So why do SUAV programs have to spend a few thousand dollars and an extra week to get the approval from AFFTC when there is no perceived value added from the AFFTC review process? The answer lies in the optimal level of risk that the PM is willing to take. This optimal level of risk taking is non-quantitative and must be based on the perceptual factors that are relevant to the assessment of risk, as identified by Hillson and Hulett (2004).

1. *Familiarity: The extent to which an individual, team, or organization has previously encountered the situation drives whether the risk probability is perceived as high or low. Where there is little or no previous relevant experience, skill or knowledge, the degree of uncertainty is perceived as higher than that case when it is assessed by individuals or groups who have come across the situation before.*

2. *Manageability. The degree of control or choice that can be exercised in a given situation drives the assessment of uncertainty, even if the perception is illusory. Where a risk is seen as susceptible to control, risk probability is assessed as lower than in situations where controllability or choice are absent (or perceived to be so).*
3. *Proximity. If the possible occurrence of a risk is close in time or space to those assessing its probability, it will be seen as more likely than risks which might occur later in time or further away in space.*
4. *Propinquity. This term is used to describe the perceived potential for the consequences of a risk to affect the individual or group directly. The closer the impact is to those assessing the risk, the higher its perceived probability is.*

These factors are hard to recognize and address, as they and other perceptual influences operate subconsciously when individuals and teams assess risk probability and category (Hillson & Hulett, 2004). Another critical reason why low risk programs have to go through AFFTC approval review is to hold accountability and responsibility in the program; these “*ways of seeing and understandings*” of risk in organizational settings were seen as methods of deferring blame to any single organization with respect to issues of risk and responsibility (Hutter & Power 2005). After all, organizations’ and individuals’ interests may vary, but they address issues in test flights through considerations of commonalities in risk management.

4.3.2 Heuristics and Biases in Risk Assessment

In assessing risk, other factors that influence the PMs’ decisions in the perception of risk are known as heuristics or rules-of-thumb. Hillson and Hulett (2004) define heuristics as internal frames of reference used by individuals and groups to inform judgment when no firm data are available. Hillson and Hulett (2004) emphasize the influence of introducing two types of heuristic bias into assessments in situations of

uncertainty. The first type of bias is motivational bias, where the assessor seeks to improve the apparent position of the situation by modifying the estimate of risk probability. The second type of bias is cognitive bias, which arises from unconscious attempts to rationalize the lack of certain knowledge (Hillson & Hulett, 2004). Of these two biases, it is observed that motivational bias is perhaps more commonly found in PMs. The author also noticed in the various interviews that PMs were more likely to exhibit motivational bias. This is a purely anecdotal impression from the author and this has no hard data to quantify this effect.

Motivational bias is difficult to identify and manage as the person or organization assessing the risk has an interest in influencing the results of the analysis (Hillson & Hulett, 2004). SUAVs are distinct by their sizes, costs, and complexity. These factors often define the risk of their test flights. The presumption of motivational bias usually makes the probability of the risk of SUAVs seem to be smaller than what it really is, especially in order to reduce the perception of risk among key stakeholders. It is observed that PMs will use the notion of their SUAVs as being small, lightweight, and inexpensive to de-value the purpose of any extra safety reviews that may cause their programs to incur more costs and time. Granted, it is true from the data gathered that most SUAV programs were deemed as low risk, but the cost sensitivity in the payloads carried by SUAVs were often the deciding factor in categorizing risks.

4.3.3 Notional Optimal Level of Risk

From these perceptual and heuristics factors, PMs will argue that the absence and noninvolvement from AFFTC may create a reduction in the cost of risk abatement, which

reduces the total costs and time incurred from the flight approval process and SUAV operation. This reduction will create a new cost of risk abatement and a new optimal level of risk, as shown in Figure 4.5.

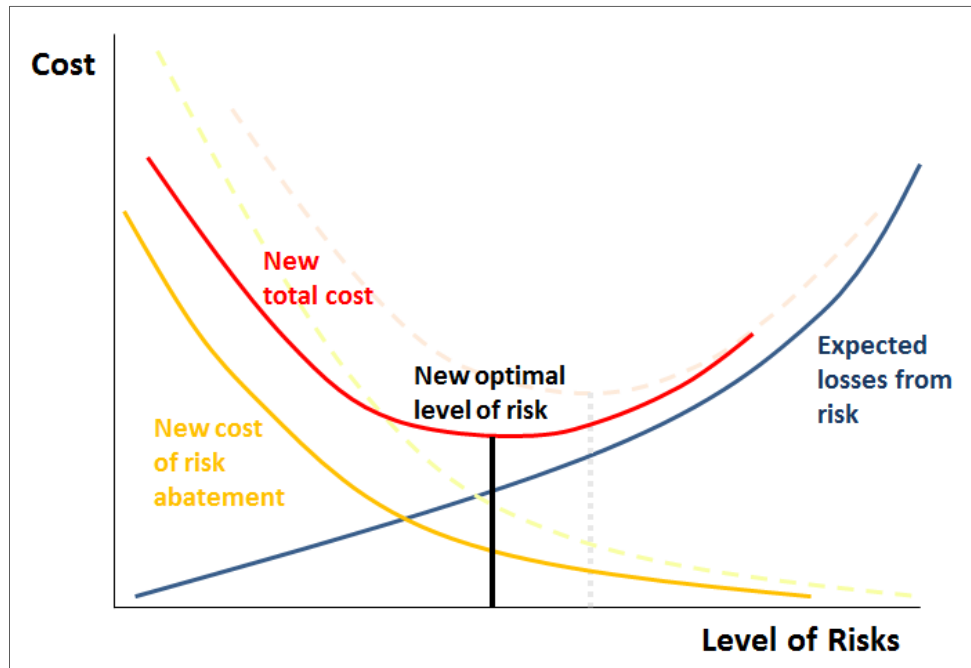


Figure 4.5: Notional Optimal Level of Risk (without AFFTC involvement)

This noninvolvement from AFFTC in low risk programs will be manifested by AFFTC giving full approval authority on low risk tests to the AFRL T&E Office. Not only would this new level of risk abatement reduce the time and costs for the PMs at AFRL, but it would also give the reviewers at AFFTC more time to perform their main duties at AFFTC, given that the FOA’s main duties come from the flight test organizations at AFFTC. Furthermore, since 90% of the tests coming from AFRL are low risk, it would assume that the costs are low and the risks can be negated. Additionally, the data variability analyses have shown a bottleneck at AFFTC when the FOA experiences

variation in approving SUAV test plans coming from AFRL. This new optimal level of risk results in a lesser total cost, and its expected losses from risk is even less due the overall factors from the PM's presumption in the motivational bias and heuristic approaches. This notional optimal level of risk will be carried to the latter section of this chapter to create a notional common threshold and decision rule matrix.

Noninvolvement from AFFTC would certainly increase the number of SUAV programs and increase R&D in SUAVs and their systems. However, risks are still inherently apparent to the PMs and the flight testers. Every project is unique and SUAV projects are no different when it comes to safety. The mishap rate is still high, and the technologies to improve SUAV safety records are still being developed; therefore, it is prudent to approach testing with attentiveness when no AFFTC involvement is granted.

4.3.4 A What-if Scenario

The problems of unintended consequences are high whether the program is categorized as low risk or not. Flight testers are fully aware that most of the accidents happen between test points or on low risk activities (Ward et al., 2006). Rules and regulations are in place for a reason, but in times of budget crunches, there is always pressure to eliminate unnecessary work and waste when results confirm non-added value work. However, when it comes to proper leadership (AFMC/A3, 2006), the thought was not in terms of what the testers in the T&E community characterize as low, medium, or high risk, but the thought stemmed from accountability and responsibility terms—that all flying incurs some level of risk and proper supervision is better to measure and mitigate risks. In an evocative scenario, it would be extremely uncomfortable and an

embarrassment for the test team to explain to leadership about how a low risk mission flown by an AFRL contractor experienced a Class A mishap when the mishap investigation revealed that no rated Operations Group Commander (O-6) oversight was discussed, as dictated by the MOA between AFRL and AFFTC. This thought-vignette was one of the arguments against an improvement initiative from both AFRL and AFFTC to reduce the scope of AFFTC oversight on low risk programs, and was quickly rejected at AFMC/A3. It is the very same reason why the MOA was put in place at the beginning of the joint AFRL/AFFTC flight safety reviews.

4.3.5 Managing Risk Results

One of the challenging outcomes of risk assessment is that it is difficult to objectively quantify risks. Hence, the qualitative results discussed two main objectives. Two questions were answered in the optimal risk analysis section: Why is there a drive to de-scope the AFFTC oversight of low risk programs when AFFTC time and cost to review were short and less expensive than originally thought? And why do SUAV programs have to spend a few thousand dollars and the extra week to get the approval from AFFTC when there is no value added to the program? This research has also included the top level acceptable cost of optimal risk analysis in which the perceptual factors and heuristic factors were taken into account to determine whether or not the extra reviews at AFFTC is necessary. Motivational bias was seen as a tool that most PMs would use to assess risks on their programs based on the notion that their SUAVs were small, inexpensive, and can be replaced with commercial-off-the-shelf parts. The results

from cost measurement analysis, variability analysis, and optimal risk analysis will be tied together to come up with a threshold and reach a decision rule in the next section.

4.4 AFFTC Threshold and Decision Rule

This part of the chapter will sum the previous three analyses and determine a recommendation for an acceptable threshold which would help PMs at test organizations reach a decision rule on a flight test approval process for SUAVs. According to Hillson (2004), an acceptable threshold defines a target against which the effectiveness of responses can be measured. Without such a target, too much effort might be spent on mitigating risk beyond what would be acceptable, or reviews might not go far enough in reducing threats and enhancing opportunities (Hillson, 2004).

Several considerations and assumptions were made when attempting to estimate a notional cost balance statement for SUAVs. From previous estimates, the total SUAV assets and liabilities came to about \$191,500 for a low risk program. This is roughly the same as a Class C mishap definition, which is the total cost of property damage, including all aircraft damage between \$10,000 and \$200,000. In addition to monetary loss, Class C mishaps also involve injuries that result in five or more workdays lost. Because of the approximate SUAV cost assets and liabilities, it is recommended that the decision rule threshold for cost remain at \$200,000. The justification behind this cost threshold is that it holds true to the average cost of the SUAV flight test and anything less than \$200,000 in total assets and liabilities is deemed a Class C mishap should an accident happen. In addition to the cost threshold, there is the size and weight of the SUAV's airframe to consider should it crash to the ground and cause injury and damage

to people and property. A notional threshold in SUAV size and weight will also determine whether the program should go to the extra review at AFFTC.

It is unknown if the DoD or the FAA have rules and regulations for SUAVs based on their size and kinetic energy. However, research from other non-military agencies, such as the JAA and EUROCONTROL (2004), has proposed a cut-off line with respect to SUAV size and kinetic energy at impact. The JAA/EUROCONTROL reviewed the worldwide UAV fleet and judged the capability of existing SUAV models on their workload, masses, kinetic energy, airspeed, and UAV operator's ability. The report proposed a guideline for the regulation of SUAV systems. Generally, most UAVs less than 150 kg are classified as light or SUAV systems (JAA, Weibel & Hansman, 2004). These SUAVs do not have to comply with the same regulations as manned aircraft, yet do not qualify as model aircraft in Europe. However, they are required to operate within restrictions, such as daylight operations and within the visual range of the operator, and in restricted airspace (JAA, 2004). Larger UAVs weighing more than 150 kg, with a kinetic energy at impact of more than 95 kJ flying in unrestricted airspace or outside the visual range of the operator will be required to be flight tested and approved in a similar manner to that of manned aircraft (JAA, 2004).

4.4.1 Notional Threshold

Based off of the notional cost threshold and the proposal from the JAA/EUROCONTROL report, this research proposes using the same standard and regulation based on the size and energy criteria as that of the JAA/EUROCONTROL, and recommends that the DoD and FAA adopt the same technique, or something similar.

Figure 4.6 provides a notional decision rule matrix incorporating size and energy criteria as it pertains to the evaluation of SUAV flight test approval process. The notional decision rule matrix is flexible and can be used given the dependencies of many heuristic factors based on risk assessment and the experience that comes with it. These factors include the environment in which the SUAV is flown, the maturity of the system, and the product weight, size, speed, and complexity. The decision rule matrix assumes that the SUAVs are flown in restricted airspace.

Proposed Mass and Kinetic Energy at Impact < 150 kg & 95 kJ > 150 kg & 95 kJ	1 Extra Review - High cost risk abatement - Low expected losses from risk	3 No Extra Review - Low cost risk abatement - High expected losses from risk
	2 Extra Review - Medium cost risk abatement - Low expected losses from risk	4 No Extra Review - Low cost risk abatement - Medium expected losses from risk
	> \$200K	< \$200K
	Notional Cost Threshold	

Figure 4.6: Notional Threshold

The framework for adoption of this decision matrix is based on the fact that low cost SUAVs with simplistic designs should require less review time. The framework also allows the test team and those at AFFTC and AFRL to assess the risks involved in some of these SUAV programs before a decision is reached. It provides test teams a notional

“tipping point” where AFFTC safety reviewers would essentially add value to the flight approval process. For example, the FOA may spend a greater amount of time on programs that are high cost and/or the systems involved are larger than the average sized UAV that is usually tested.

4.4.2 Notional Decision Rule Matrix and Outcome

Sometimes, decision-making follows a simple rule; people view the problem in a stereotyped way and often determine if the given situation is common or familiar based on their past experiences (Klein, 1998). Likewise, if people decide that the situation is uncommon or unfamiliar, then they follow an alternate safer decision (Klein, 1998). Quadrants 1 and 4 in the decision rule matrix clearly demonstrates Klein’s successful decision making model (1998), that the situation is either common (from past experiences) or uncommon (alternate safe decision). Quadrants 2 and 3 differ in their level of consequences, as the decision is to have either the extra review or no extra review. Quadrant 2 is deemed acceptable in daily operations because of its conservative decision which leads to low consequence (Klein, 1998). Quadrant 3 is not acceptable because it may lead to highly consequential damage or injury (Klein, 1998). Figure 4.7 shows how decisions are made based on the PM’s experience with the program and the given situation.

		What We Think the Situation is		
		Uncommon	Common	
Proposed Mass and Kinetic Energy at Impact	> 150 kg & 95 kJ	<p>1</p> <p>Recognized Uncommon Situation - Success</p> <p><i>AFFTC review is necessary and you should do it</i></p>	<p>3</p> <p>Recognition Trap Error - Failure</p> <p><i>AFFTC review is unnecessary but you should do it</i></p>	Uncommon
	< 150 kg & 95 kJ	<p>2</p> <p>Conservative Error - Failure</p> <p><i>AFFTC review is necessary even when you feel you shouldn't</i></p>	<p>4</p> <p>Recognized Common Situation - Success</p> <p><i>AFFTC review is unnecessary and you shouldn't do it</i></p>	Common
		> \$200K	< \$200K	
		Notional Cost Threshold		

Figure 4.7: Notional Decision Rule Matrix and Outcome (Modified from Klein, 1998)

4.4.3 Meta-language and Heuristics

In order to better define the notional decision rule quadrant as shown in Figure 4.6 and Figure 4.7, one may be inclined to describe risk using meta-language. Risk meta-language is a structured description of a risk which separates cause, risk, and effect. Meta-language allows risk analysis to provide a three part structured risk statement that should ensure risk identification through a heuristic approach (Hillson, 2008). The risk meta-language format can be written like this: “Because of [cause(s)], [risk] might occur, which would lead to [effect(s)].”

Causes are present facts or conditions which can give rise to risks (Hillson, 2008). Once the cause is identified, one can determine the risk by asking “so what?” which would lead to a decision on the uncertainties about the cause. The effects stem from the

conditional future state that the risk decision produces. With respect to the notional decision rule quadrant, the risk meta-language can be written in four separate formats for each quadrant, as shown in Table 4.3.

Table 4.3: Meta-Language and Decision Rule

1. <i>“Because my UAV program is expensive and its impact energy is high [cause], I should increase my time and resources in risk reduction [risk decision], which should lead to low mishap probability and no losses [effect].”</i> This meta-language implies the UAV program is expensive and heavy at impact, to which the PM would make the decision to have the extra review at AFFTC in order to mitigate future risks.
2. <i>“Because my UAV program is expensive and its impact energy is low [cause], I should make some effort in risk reduction [risk decision], which should lead to low mishap probability and expect low losses [effect].”</i> This meta-language implies that the UAV, although lightweight, is still expensive, which would lead the PM to invest a conservative amount in risk reduction at AFFTC in order to reduce future mishaps, which would otherwise cause the expensive UAV to crash and incur greater losses. The effect is a lower expected loss due to the initial risk reduction effort.
3. <i>“Because my UAV program is inexpensive but its impact energy is high [cause], I should not invest too much time and effort in risk reduction [risk decision], which may yield high mishap probability from risk [effect].”</i> This meta-language suggests that the UAV, although heavy, is inexpensive and probably simple to build. The risk decision is to forgo with the extra review due to its inexpensiveness; however, the PM should expect the risk of failure (mishaps) to be high since it does not go through the extra review.
4. <i>“Because my UAV program is inexpensive and its impact energy is low [cause], I should not invest too much time and effort in risk reduction [risk decision], which could lead to medium or low probability of a mishap [effect].”</i> This meta-language suggests that the UAV is inexpensive and lightweight, therefore, the PM should not need the extra review before flying, however, the probability of a mishap is minimum or low due to the lack of reviews.

An area of concern in the decision rule is where SUAVs exceed the proposed mass and kinetic energy at impact criteria but they are under the \$200,000 threshold (decision quadrant 3). The big mass and high kinetic energy at impact may present a hazardous flying experience should a mishap occur on the ground with injury to

personnel involved. This would create a cautious choice for all personnel involved in deciding whether or not AFFTC is needed and if it would add any significant safety comments in the safety review process. Therefore, this framework and decision rule is based on an experienced judgment and heuristic ability of the UAV operator and the test team to control the vehicle.

In summary, risk meta-language is a useful tool for clarifying risk descriptions. The simple three-part framework and decision rule offer general guidelines and rule-of-thumb principles that an experienced PM may be able to find risk, uncertainties, and the effects of risk decisions. There is no best approach in making a decision in whether or not to add the extra review from AFFTC. The best approach may be answered with “it depends.” It depends on the cost of the UAV, the level of sophisticated hardware involved in the UAV, the level of details and complexity of the risk process, and any external factors that play in UAV test flights.

4.5 Application of Notional Threshold and Decision Rule Matrix

After collecting SUAV data with total cost, mass, and impact energy (see Appendix C), this research plots 16 AFRL SUAV programs using the notional threshold and decision rule matrix for further analysis, as shown in Figure 4.8. Notice that the majority of the SUAV programs from 2011 were lightweight (less than 150 kg) and less than \$200,000. As seen in Figure 4.8, one SUAV program had cost, weight, and kinetic energy which exceeded the notional threshold. This program experienced a flight mishap, which was probably caused by the vehicle’s immaturity as data showed that the vehicle had less than one hour of total flying time. Another SUAV (quadrant 2) cost more than

\$200,000, but its mass and kinetic energy were less than the notional threshold; it also experienced a mishap. However, unlike the SUAV mishap in quadrant 1, this vehicle had more flying time and was considered mature. The third SUAV mishap (quadrant 4) was under the cost threshold and proposed mass and kinetic energy. This particular vehicle was considered mature with four sorties and over nine hours of total flying time.

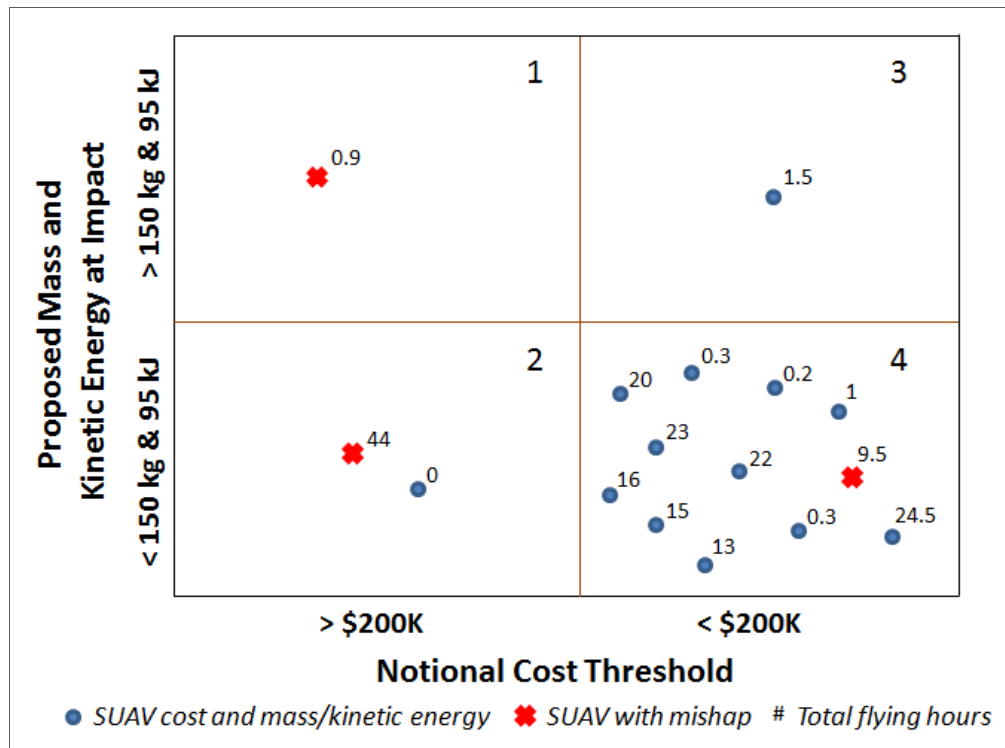


Figure 4.8: 2011 SUAV Flight Tests

Based on the limited data and the three mishaps given, the above figure shows that there is no correlation between flight mishaps and an SUAV's cost and their physical sizes and energy. Nor there is any correlation between system maturity (total flying times) and flight failures. Figure 4.8 also shows that the majority of SUAVs submitted for flight testing are less than \$200,000 and below that of the proposed mass and kinetic

energy threshold. Furthermore, AFRL mishap data from previous years shown in Figure 4.9 reveals that the majority of mishaps were deemed as Class E events, which are occurrences that do not meet reportable mishap classification criteria, but are important to investigate and report for mishap prevention. A total of 46 mishaps were Class E events, eight were considered as Class C mishaps, and only one resulted in a Class B mishap from 2007 to 2012.

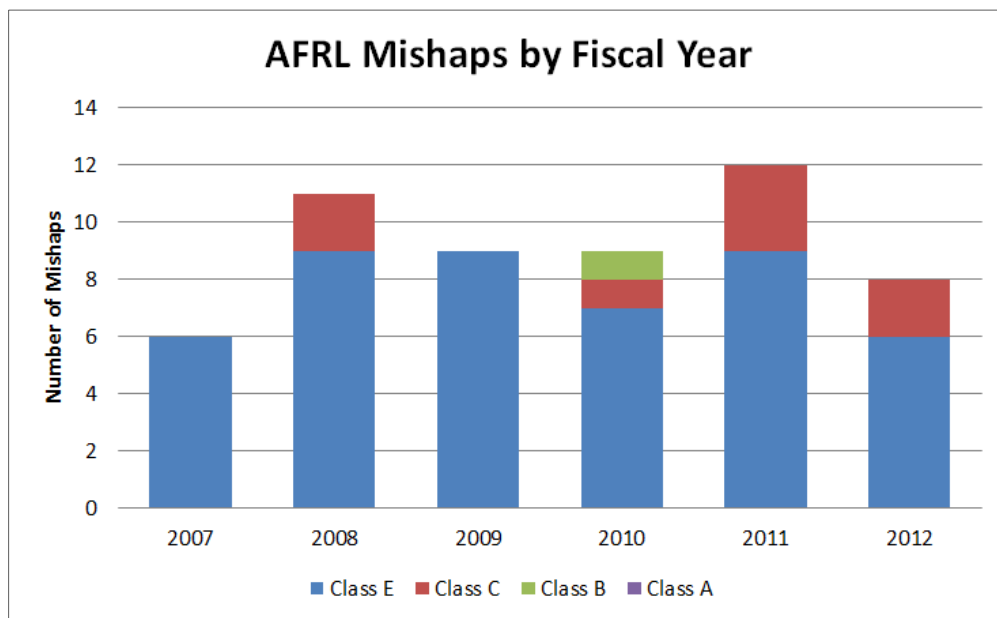


Figure 4.9: AFRL Mishaps by Fiscal Year

Essentially, SUAVs are sometimes prone to system failure; therefore, the flight approval process for SUAVs should be based on the judgmental cost and the proposed mass and impact energy. After all, SUAVs are still a relatively new platform with many opportunities for research and development. An appealing aspect of SUAV development is the fact that the majority of AFRL SUAVs are inexpensive, simple, and tiny to build and assemble versus larger UAVs or manned aircraft.

With a total cost less than or equal to \$200,000 and a small and light weight airframe, an experienced SUAV operator could fly the SUAV without experiencing a mishap or cause extensive damage to people and property. Therefore, in consideration of an SUAV program, it should not necessarily adhere to the extra scrutiny that takes extra time and spends additional resources of the flight test team. Innovations and breakthrough technologies should not be hampered by policy for the sake of a \$200,000 or less mishap. However, for programs that are well over \$200,000, its size and complexity make them a primary target for safety reviews. Therefore, it is within reason to have the extra reviews and operational authority to approve the flying machine.

4.6 Summary

This chapter has presented the results and analysis from data gathered from the flight test offices. Starting with the cost measurement analysis and the notional cost balance statement for an average SUAV program, the initial results revealed that the total time and cost in AFFTC review did not present a significant investment in time and money from the test team at AFRL. Although the cost and time were minimal, having the additional feedback from the FOA at AFFTC may also add some risk mitigations to the test plan. However, further interviews with the AFRL T&E Office revealed that the feedback coming from AFFTC often lacks interest and value to the test plan.

Additionally, cost sensitivity analysis results confirmed that SUAV program costs are not sensitive to system maturity, but rather to the payloads carried by the SUAVs. Data from the variability analysis confirmed that there was heavy workload and firefighting support at the AFRL T&E Office when PMs and test teams failed to submit standardized test

plans on time with adequate notifications of upcoming tests. Variability simulation showed a bottleneck at the AFFTC support due to the push effect caused by accumulated tests and late notifications from the AFRL T&E Office. Lastly, a top level risk analysis was conducted using perceptual factors and heuristic factors to determine whether or not the extra reviews at AFFTC were necessary. A notional optimal level of risk, including the noninvolvement from AFFTC, which decreased the total costs and time incurred in the flight approval process and SUAV operation was developed, but includes a cautious warning.

Finally, in combining all three earlier analyses, this study creates a top-level AFFTC threshold and decision rule recommendation, which was determined from the average \$200,000 SUAV program cost and the weight and impact energy of the SUAV. The decision rule quadrant and the successful decision model should allow the test team and those at AFFTC and AFRL to assess the risks involved in SUAV programs before a decision is reached. It also allows test teams to determine a “tipping point” where AFFTC safety reviewers would essentially add value to the overall flight approval process.

V. Discussions and Conclusions

This chapter provides discussions and conclusions based on results and analysis of this research. Recommendations are provided with a threshold and decision rule approach in the critical chain of SUAV flight approval process. Meta-language and heuristics are used to identify and describe risks by separating the causes from uncertain events. The following section summarizes recommendations for SUAVs' flight approval process and their typical characteristic attributes which include being inexpensive, simple, and often fast to acquire. Next, this chapter wraps up with the research objectives and answers the questions that were asked in the introductory chapter. Additional observations are made on risk management by leadership and the lack of buy-in from leadership to allow AFRL to have full authority on low risk programs. Lastly, this chapter summarizes its conclusions with limitations for this study and suggestions for future research.

5.1 Capturing Research Objectives

This study provided an overarching analysis of the SUAV flight test process currently used by AFRL with oversight from AFFTC. The objective was to establish a measure of benefit for an abbreviated flight test process. While the objective has been met with the notional decision rule matrix, along with ranges for the cut-off cost and SUAV size and impact energy. However, it also revealed a management approach that is difficult to quantitatively measure, and requires years of program management and flight test experience in determining the risk of forgoing AFFTC involvement.

In approaching transparency and improving safety reviews of the flight test program, multiple layers of safety reviews add benefits to mishap mitigation and accountability, yet they may be time consuming for PMs who want to accelerate their tests. Therefore, is it necessary for SUAVs to have the same criteria applied as that of a larger, manned aircraft in flight test approval process? The short answer is yes and no. Safety and accountability are two critical issues in flight testing; however, they should not create an environment in which innovation and development are held back because of a simple mishap from a low risk test plan. This leads to another question which was raised at the beginning of this study: Do SUAVs have to go through the same mishap investigation and reporting process? Evidence from AFRL T&E Office has suggested that these mishaps were minimal, and sometimes they were expected. There is no doubt that flight safety and mishap mitigations are applied at every step of the flight approval process, as instructed in numerous AFIs concerning flight testing. Some of these mishaps can be as simple as a crash landing on an unpaved runway that caused damage to the propeller of the SUAV, but it still resulted in weeks of mishap investigation and going through the return to flight approval process. Nevertheless, not all mishaps are minute; a program at threshold price of \$200,000 with expensive payload would certainly raise concerns if there was no oversight on safety reviews from an appropriate authority.

In contrast to the traditional military standards on SUAV flight tests, the DoD ought to look into research from non-military specifications. This study has developed a notional decision rule based on the proposed JAA/EUROCONTROL (2004) technique on SUAV weight and kinetic energy at impact. The consequences of using such a technique would simplify the SUAV flight test approval process and could save money in the long

run. With a simplified approval process, R&D organizations might be able to increase and expedite the weapons development needed for the warfighters. This coincides with the current DoD policy of supporting intelligence, surveillance, and reconnaissance missions globally. Moreover, an abbreviated approval process for an SUAV is greatly needed for rapid reaction and rapid deployment to the theatre of operation to support the warfighters, as opposed to the generic flight test approval process.

Additionally, data from cost sensitivity and variability analyses showed that system maturity costs were varied with SUAV payload costs. Program managers are always fighting system instability and the risk of uncertainties in the program. These uncertainties may be caused by outside influences such as technology, environment, and political and financial situations. By prioritizing a list of “must haves” and “good to haves,” test teams may be able to minimize the cost of the program and also make it more manageable in determining risks and use the decision rule to determine whether to include reviews by the AFFTC authority. The variability analysis showed a bottleneck occurring at the FOA due to variability in the process caused by the constant flooding of test packages coming from AFRL to the FOA.

In summary, a generic standardized regulation for SUAVs may help the separation of risk assessment and risk management. Differentiating between the two may prove helpful in determining risk analysis when weighing the benefits of an abbreviated flight test process and the costs associated with going through the entire flight approval process. Using a current generic standardized regulation in flight test approval process may have the advantage of consistency, predictability, and administrative efficiency. However, there are also disadvantages in having SUAVs going through the same

standardized flight test approval process as those of larger manned aircraft. These disadvantages can include overgeneralizing SUAVs as having a complex integrated system like those of larger manned aircraft. Another disadvantage is the misallocation of resources and schedule; unlike larger manned aircraft, SUAVs are generally operated by a small team of engineers and observers. Lastly, by putting SUAVs through the same flight test approval process required of larger manned aircraft, there will be some delays which may eventually cause research and development to stop. This mixture of an overly unwieldy risk assessment policy and the potential for interrupted scientific research would probably cause delays and frustration for the PM and the test team.

5.2 Impact of Leadership Risk Management Style

One of the major surprises from this study was the unexpected perspective from AFRL on the lack of value and attention provided by AFFTC reviews. It should be noted that this study does not suggest that the FOA at AFFTC lacks the expertise to provide adequate reviews to the safety of the test missions. This study, however, advocates the notion of a “tipping point” where AFFTC safety reviewers would essentially add value to the overall flight approval process, as discussed in the previous chapter. This tipping point is determined using the notional decision rule matrix. With manning levels in the Air Force already strained, and the fact that 90% of AFRL’s flight test programs are considered by the AFRL and AFFTC as low risk, the level of authority and empowerment in low risk programs should be delegated to those personnel in the field. This delegation would greatly benefit both parties if low risk programs were approved at AFRL instead of AFFTC. It would also reduce the bottleneck problem at the FOA while

increasing opportunities for further flight testing by AFRL. Homan et al. (2011) also identified these issues and the potential opportunities to improve the flight test process.

A problem here lies in the risk adverse mismanagement style of leadership. Stulz (2009) and Taleb et al. (2009) discuss ways that organizations mismanage risk; one of them is the mistake of relying on historical data and becoming convinced that studying the past will help better manage risk in the future. In essence, leadership relies on these historical events (i.e., past mishaps from AFRL test flights) to control risk by predicting extreme events. However, low-probability, high-impact events are almost impossible to forecast, and “*because of socioeconomic randomness, there is no such thing as a ‘typical’ failure or a ‘typical success’*” (Taleb et al., 2009). Numerous joint AFFTC/AFRL proposals have been funneled up to leadership for the delegation of low risk programs to AFRL, yet their status is unknown or leadership refuses to consider them. This overly conservative risk management approach of leadership creates a non-empowered environment for those who want to test their programs and for those who review them.

5.3 Conclusions

This research effort sought to establish top-level quantitative and qualitative measures of benefit for an abbreviated flight test process for SUAVs. Issues such as cost sensitivity, process improvement, and risk management were discussed in this study. The literature review exposed performance gaps, cost and data variability, as well as buy-in from AFRL and AFFTC leadership to delegate low risk programs to AFRL; however, this was rejected due to the lack of accountability in small, low-risk AFRL programs. The literature also reviewed the importance of flight test and the factors that affect the

effectiveness of the flight testing. The increasing trends in SUAV technology development combined with the ever increasing DoD investment for SUAVs in the military has allowed greater R&D effort, yet it is sometimes limited and scaled back because of outdated policy and regulations on SUAV operations in the NAS and restricted airspace. The methodology section explained the research design for this study based on cost and time criteria, combined with data variability simulation and a heuristic approach to risk management.

Research and development in new or un-tested technology often times is susceptible to additional risks, such as flight mishaps while airborne and during takeoff and landing. Often times, some form of risks in new R&D technologies may be acceptable in the pursuit of knowledge. For some risks, such as SUAV flight testing, it produces benefits to flyers and operators in the form of greater understanding of the vehicle's flight characteristics and technological improvements. The findings from this research conclude with a SUAV threshold and decision rule matrix that will empower leadership to make decisions based on relevant data appropriate for SUAVs.

5.4 Limitations and Future Research

There is no doubt that the findings from this research are limited due to the assumptions that it has made. These limitations stem from the lack of adequate data in manpower and resources necessary to capture the entire SUAV business. A larger and broader examination of each SUAV program may give rise to improved assumptions. Another limitation is the data quality in this study, as such data are often limited in distribution due to the sensitivity of these programs. There are definitely more concerning

issues than what is captured in cost and SUAV weights and sizes in the flight test approval process. Approving routine and safe flight tests for SUAVs involve several issues that touch on nearly every aspect of the aviation field, including safety, security, air traffic, regulatory, and socio-economic. These categories should be addressed and assessed in future research to present a grander view of the factors and their impacts associated with SUAV flight tests.

Although this study addresses some of the problems and shortcomings from both AFFTC and AFRL organizations and also provided a decision rule recommendation based on its methodology, there are still areas that can be improved and expanded upon. With better cost data from all previous years' of AFRL flight test programs, future research would be improved on SUAV management costs and their estimates for further cost-benefit analysis. Another area of research that would greatly benefit the flight approval process for SUAVs is to study the variation of UAV sizes and costs and determine if there is variability in the processing time based on their sizes and manufacturing and operating costs.

This research had difficulty determining the optimal level of risk when approaching the approval process in the critical chain. So the optimal level of risk and the new total cost presented in this study is merely an empirical experiment based on available data. Future research should utilize the notional optimal level of risk and determine the appropriate cost of risk abatement in order to find a more quantitative overall total cost and optimal level of risk. Future research should also conduct more appropriate interviews with the FOA at AFFTC, program leaders, and SUAV operators in the overall process. This is an area that would greatly benefit from further discussion and

could be broadened in future research that includes SUAV operators' workload, situational awareness, and human effectiveness issues in SUAV operating environments. Lastly, since this research only focused on one flight test approval process being done per the MOA between AFFTC and AFRL, it is strongly recommended that future follow-on research should seek to generalize and validate this approach and methodology.

Appendix A: Memorandum of Agreement between AFRL and AFFTC

2006-06-06MA

MEMORANDUM OF AGREEMENT
BETWEEN
AIR FORCE RESEARCH LABORATORY
AND
AIR FORCE FLIGHT TEST CENTER

1. **PURPOSE.** This memorandum of agreement is to establish a working relationship and processes to support the Air Force Flight Test Center (AFFTC), 412th Test Wing, 412th Operations Group operational control (OPCON) for all flight activities conducted by the Air Force Research Laboratory (AFRL). The AFRL has overall responsibility for program management and administrative support for its research programs. The AFFTC has responsibility for the safe and effective conduct of flight operations for AFRL research programs requiring flight activities. The AFMC/A3 defers OPCON to the 412th Operations Group Commander (OG/CC) for AFRL research programs involving military, government civilian or contractor flight operations. To avoid duplicate reviews, inspections or evaluations, an integrated team approach for conducting program flight operation oversight will be used.

2. **REFERENCES.** The responsibilities of flying operations under the supervision of the AFFTC and the 412th Operations Group are detailed in Air Force Instructions. Ground and flight activities will comply with applicable regulatory guidance. Modifications of and exceptions to AFI guidance must be coordinated through the 412th OG/CC, in writing, to the designated Office of Primary Responsibility for the specific instruction. Below is a list of the primary Instructions applicable to flight operations.

- AFI 91-206(I)
- AFI 91-204 and AFMC Sup 1
- AFI 91-202 and AFMC Sup 1
- AFFTCI 91-5
- AFI 99-103 and AFMC, AFRL supplements
- AFI 11-401 and AFMC Sup 1
- AFI 11-202 volumes 1, 2, and 3; AFMC supplements
- AFI 11-2FT volumes 1, 2, and 3
- AFJI 10-220 and AFMC Sup 1
- AFI 10-206

3. **SCOPE.** This agreement shall apply to military, government civilian and contractor flight operations regardless of program size or location of actual flight operations.

4. **RESPONSIBILITIES.** AFRL will continue to use processes in place for managing its test programs as outlined in AFI 99-103 and its supplements. The AFFTC and 412th

Operations Group will provide effective flight operations oversight of all AFRL test planning and flight execution. As clarification, the following specifics apply:

4.1 AFRL RESPONSIBILITIES.

a. Provide the 412th OG with program procedures and documentation to meet the intent of AFI 11-401 and its AFMC and AFFTC supplements.

1) Monthly, prior to the last day of any month, the AFRL will provide the 412th OG with an electronic summary of all program flight activity accomplished by each program over the last month, and the scheduled flight activity expected for the next month.

2) As a minimum, each program will be required to document individual flight authorizations using Aeronautical Orders, IMT Form 81 or IMT Form 5416 through the 412th OG. This will be accomplished even if the aircraft to be flown is not USAF owned.

3) Daily flight authorization will be accomplished locally using the procedures detailed in AFI 11-401 and its AFMC and AFFTC supplements. The owning AFRL Division Chief will act as the flying squadron commander and authorize the daily flying schedule, with copies faxed to the 412th OG before flight.

b. Provide the 412th OG with appropriate and sufficient evidence of aircrew and operator qualifications, training and currencies required to perform in-flight duties as detailed in the program test plan and to meet the intent of AFI 11-202V1, V2, V3 and their AFMC and AFFTC supplements.

1) The specific approval for in-flight duties will be given by the 412th OG. It is the AFRL program manager's responsibility for ensuring individuals performing any in-flight duties are certified as qualified and current. Modifications of and exceptions to AFI guidance must be coordinated through the 412th OG/CC, in writing, to the designated Office of Primary Responsibility for the specific instruction.

2) AFRL programs that fly with airborne and/or ground station assets valued at over \$200,000, is assessed as MEDIUM or HIGH risk or fly under an FAA approved Certificate of Authorization (COA) as outlined in FAA regulation 7610.4 will comply with all AFI 10 and 11 series instructions.

c. Provide a rated billet at AFRL for the AFFTC to fill with a Major or Lieutenant Colonel acting as a local Test Representative representing the 412th Operations Group. Test Representative responsibilities will be detailed in the position job description. Duties will be determined collaboratively with AFRL and the 412th OG.

d. Coordinate the technical and safety review information obtained through standard AFRL Configuration Control, Technical Review and Safety Review Board (CCB/TRB/SRB) processes with AFFTC organizations.

1) For all AFRL research programs involving flight operations, copies of CCB/TRB/SRB packages and test plans will be provided to the 412th OG/CC at least fourteen days prior to the first planned test activity. More time may be required for review and coordination if the program is assessed by AFRL safety as MEDIUM or HIGH risk.

2) AFFTCI 91-5 details the signature authority for LOW, MEDIUM and HIGH risk test plans for AFFTC programs and is modified below to support this MOA.

ORGANIZATIONAL LEVEL	LOW RISK	MEDIUM RISK	HIGH RISK
Ops Group CC or equivalent	Approve	Info	Info
Test Wing CC or equivalent	Coord	Approve	Info
AFFTC CC	Coord	Coord	Approve

LOW risk test plans will be approved by the owning AFRL Division Chief or their Deputy and coordinated through 412th OG before the start of any flight operations. MEDIUM risk test plans will be jointly approved by the owning AFRL Technical Directorate Director and the 412th TW/CC. HIGH risk test plans will be jointly approved by the AFFTC/CC and the AFRL/CC. A formal approval briefing may be requested by the approval authority for any test plan, but is required for all HIGH risk test plans. All coordination comments will be resolved before final approval of test execution and made available to both AFFTC and AFRL leadership.

3) AFFTCI 91-5 details the signature authority for LOW, MEDIUM and HIGH risk test cards for AFFTC programs and is modified to support this MOA as follows:

The test cards must be approved before each mission but no earlier than one week before the mission. For LOW RISK tests, the AFRL Division Chief (or equivalent) will approve the cards. For MEDIUM RISK tests, the AFRL Technical Directorate Director and the 412th Operations Group Commander (or equivalent), will approve the cards. For HIGH RISK tests, the AFRL/CC and the 412th Test Wing Commander (or equivalent) will approve the cards.

Once a mission is briefed and the mission slips due to a non-safety related reason, but otherwise remains unchanged, the appropriate approving official may elect to grant approval by telephone or on an "until-flown" basis for up to one week after original approval. If more than one week has passed since the original approval, the approval authority must be contacted and the date on the signature updated.

- 4) Test conduct will otherwise comply with AFFTCI 91-5 procedures unless modified or equivalent procedures are approved through AFFTC/SET and the 412th OG/CC.
- e. Provide a Government Flight Representative (GFR) for all AFRL programs that fall under this MOA and require GFR oversight. The assigned GFR will coordinate with both the AFRL and 412th OG when performing their duties.
- f. Act as the lead agent and liaison with the 412th OG in all cases where configuration control and aircraft modifications affect the research program's test plan approved baseline configuration.

4.2 AFFTC RESPONSIBILITIES.

- a. Provide the AFRL with a flight authority review and approval of all flight activities to ensure AFRL test plans are conducted in accordance with applicable Federal Aviation Regulations and/or Air Force 10 and 11 series instructions and their AFMC and AFFTC Supplements. This responsibility may be delegated to a Government Flight Representative (GFR) when required by contract.
 - 1) Process all waivers to governing regulations concerning flight test operations.
 - 2) Assist AFRL with establishing and approving pilot and operator qualification, training and currency standards for AFRL research programs involving flight activities to meet the intent of AFI 11-202V1, V2, V3, AFI 11-2FTV1, V2, V3 and their AFMC and AFFTC supplements.
 - 3) Assist AFRL with establishing and approving flight authorization requirements for AFRL research programs involving flight activities to meet the intent of AFI 11-401 and its AFMC and AFFTC Supplements.
 - 4) Assist AFRL with establishing and executing an Operational Risk Management processes associated with AFRL research programs.
 - 5) Establish processes to provide AFRL research programs involving flight activities with the Flight Crew Information File (FCIF).
- b. 412th OG will provide AFRL aircraft mishap reporting and accountability assistance as the flight authority for all flight operations. Reporting and accountability will be in accordance with AFI 91-202, 91-204 and 91-206(I) and AFMC and AFFTC supplements.

1) 412th OG will be the grounding and return-to-fly approval authority for individuals involved in a Class A or Class B mishap.

2) AFRL will retain mishap accountability and investigation responsibilities unless transferred IAW AFI guidance.

c. Coordinate and approve the technical and safety review information obtained through AFRL Configuration Control, Technical Review and Safety Review Board (CCB/TRB/SRB) processes with AFFTC organizations to support AFRL research programs while complying with the intent of Air Force 91 and 99 series Instructions and their AFMC and AFFTC supplements.

1) Provide safety and technical assistance for AFRL research programs that are outside the expertise of AFRL. This may include, but is not limited to, providing a representative from within the 412th OG to attend program planning meetings, assist with the preparation of safety and/or technical documentation or attend TRB and/or SRB boards.

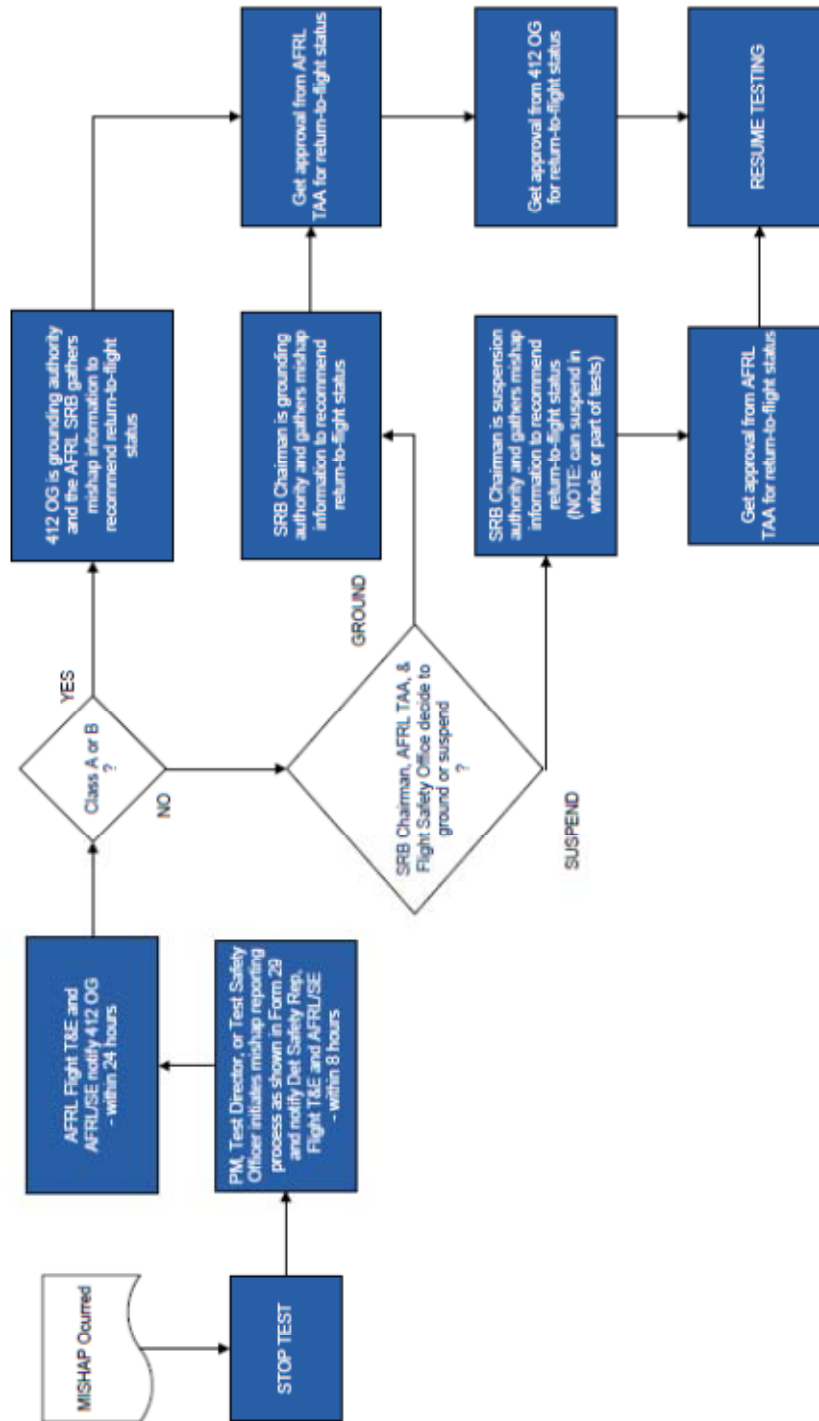
2) For all MEDIUM and HIGH risk assessed test plans, a 412th OG member will be assigned to support the AFRL research program with test planning and integration with AFFTC technical, safety and flight test execution processes.

5. **TERM OF AGREEMENT AND RIGHT TO TERMINATE.** This memorandum becomes effective on the date signed by both organizations and remains in effect indefinitely. Termination of this agreement is only valid if both the AFRL/CC and the 412th OG/CC agree in writing to terminate the agreement. Amendments to this agreement may be made with at least 90-days notification by either party, in writing, detailing the procedures and processes to be amended. This agreement shall be reviewed annually.


TED F. BOWLDS, Maj Gen
Commander, AFRL


CURTIS M. BEDKE, Maj Gen
Commander, AFFTC


LARRY D. NEW, Maj Gen
Director of Operations



Appendix C: Small UAV Costs and Mishap Data

SUAV	Cost Per Vehicle	Vehicles Flown	Total Amount	System Maturity	Sorties	Hours	Weight (kg)	Speed (m/s)	KE (KJ)	Mishaps	Quadrant
Alpha 60	\$ 800.00	7	\$ 5,600.00	Mature	78	20.33	7.7	24.7	2.3		4
Alpha 60	\$ 400.00	1	\$ 400.00	Mature	-	-	-	-	-		-
Arrow MAV Glider	\$ 1,200.00	1	\$ 1,200.00	Prototype	6	0.3	0.9	8.7	0.0		4
Basset	\$ 390,000.00	1	\$ 390,000.00	Prototype	3	0.9	317.5	61.7	604.3	Yes	1
Bat-3	\$ 318,000.00	1	\$ 318,000.00	New	18	44	14.5	30.9	6.9	Yes	2
Big Stik	\$ 1,100.00	5	\$ 5,500.00	New	80	23.3	9	31.4	4.4		4
Blacktip	\$ 6,200.00	2	\$ 12,400.00	Prototype	73	14.85	5.4	49.9	6.7		4
BVM HiVast	\$ 28,000.00	1	\$ 28,000.00	New	12	1.5	31.7	102.9	167.8		3
DG303	\$ 17,800.00	2	\$ 35,600.00	New	23	20.8	-	-	-		-
Intimidator	\$ 1,100.00	5	\$ 5,500.00	New	35	12.9	9	44.8	9.0		4
MOP MAV BDI	\$ 24,000.00	1	\$ 24,000.00	New	2	0.2	4.5	49.9	5.6		4
Osprey (UAV)	\$ 2,333.00	7	\$ 16,331.00	Mature	40	22.15	27.2	33.4	15.2		4
Radian RC	\$ 250.00	1	\$ 250.00	Mature	7	0.3	0.9	8.7	0.0		4
Rascal	\$ 549.00	1	\$ 549.00	Mature	31	4.5	-	25.7	-		-
RMAX	\$ 380,000.00	2	\$ 760,000.00	Mature	0	0	93	11.3	5.9		2
ScanEagle	\$ 100,000.00	1	\$ 100,000.00	Mature	1	1	20	41.2	17.0		4
Silver Fox	\$ 100,000.00	1	\$ 100,000.00	Mature	4	9.5	16.3	28.3	6.5	Yes	4
Skate	\$ 30,000.00	4	\$ 120,000.00	New	64	24.5	0.9	25.7	0.3		4
Tandem Wing	\$ 3,000.00	2	\$ 6,000.00	Mature	7	0.6	-	14	-	Yes	-
Unicorn	\$ 17,000.00	1	\$ 17,000.00	Mature	39	15.9	4.5	24.7	1.4		4
Unicorn	\$ 22,400.00	1	\$ 22,400.00	Mature	-	-	-	-	-		-
Unicorn	\$ 18,700.00	3	\$ 56,100.00	Mature	-	-	-	-	-		-
	\$ 1,462,832.00		\$ 2,024,830.00		523	218					

SUAV Program Asset Cost	\$133,000.00	\$ 133,000.00	<i>\$66,500 x 2 SUAVs</i>
Test Execution Cost	\$ 30,000.00	\$ 30,000.00	<i>Estimated range cost</i>
AFRL Review Cost			
AFRL Risk Abatement Cost	\$ 2,054.79	\$ 2,100.00	<i>1 GS-15 with 5 working days (\$150K salary)</i>
Value Added Work	\$ 20,000.00	\$ 20,000.00	<i>1 GS-15 (\$150K salary) with 2 working days + 4 junior member (\$70K salary) with 25 working days</i>
Non-value Added Work			
Waste	\$ 1,178.08	\$ 1,200.00	<i>1 GS-15 (\$150K salary) with 1 working day + 4 junior members (\$70K salary) with 1 working day</i>
Necessary Waste	\$ 1,534.25	\$ 1,500.00	<i>4 junior members (\$70K salary) with 2 working days</i>
AFFTC Review Cost			
AFRL Risk Abatement Cost	\$ 2,465.75	\$ 2,500.00	<i>1 O-5 (\$150K salary) with 6 working days</i>
Value Added Work	\$ 410.96	\$ 400.00	<i>1 O-5 (\$150K salary) with 1 working day</i>
Non-value Added Work			
Waste	\$ 821.92	\$ 800.00	<i>1 O-5 (\$150K salary) with 2 working days</i>
Necessary Waste	\$ -	\$ -	
Total UAV Asset and Liabilities	\$ 191,465.75	\$ 191,500.00	

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14. ABSTRACT The advancement in small unmanned aerial vehicle (SUAV) technology has brought a new revolution in the military domain. Their uses have become more synonymous with intelligence, surveillance, and reconnaissance missions. Concerns over their flight test safety and accountability have been addressed in multiple policies to mitigate mishaps and increase proper accountability. However, current DoD and FAA mandated regulations and policies concerning UAV flight tests are sometimes considered slow and time-consuming, which may lead to delays in UAV research and development. This study explores the quantitative and qualitative measure of benefits associated with an abbreviated flight test process for SUAVs. Specifically, it examines the current agreement between two major USAF research centers regarding the SUAV flight test approval process. This research utilized high-level multidisciplinary approaches and techniques including qualitative cost-benefit analysis, interviews, value stream mapping (VSM) analysis, and heuristic risk analysis to evaluate the current-state process. The findings conclude that there is a slight economic cost and schedule savings in an abbreviated process. Additionally, this research finds no correlation between SUAV flight mishaps and system maturity. This research proposes using a streamlined process for additional safety reviews to eliminate non-value added process steps considered unnecessary due to the nature of the SUAV complexity. Furthermore, this study recommends using a decision rule matrix based on the total cost of the SUAV and its weight and energy at impact for choosing an abbreviated flight test safety review process.					
15. SUBJECT TERMS Small Unmanned Aerial Vehicle (SUAV), Flight Test Approval Process, Value Stream Mapping, Decision Rule Matrix					
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