DEVELOPMENT OF A TAILORED FLIGHT TEST APPROACH FOR SMALL UNMANNED
AIRCRAFT SYSTEMS

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Aerospace Engineering

by
Neil Alexander Wolfe

August 2019

© 2019

Neil Alexander Wolfe

ALL RIGHTS RESERVED

COMMITTEE MEMBERSHIP

TITLE: Development of a Tailored Flight Test Approach for
Small Unmanned Aircraft Systems

AUTHOR: Neil Alexander Wolfe

DATE SUBMITTED: August 2019

COMMITTEE CHAIR: Aaron Drake, Ph.D.
Professor of Aerospace Engineering

COMMITTEE MEMBER: Paulo Iscold, Ph.D.
Associate Professor of Aerospace Engineering

COMMITTEE MEMBER: David Marshall, Ph.D.
Professor of Aerospace Engineering

COMMITTEE MEMBER: Kurt Colvin, Ph.D.
Professor of Industrial & Manufacturing
Engineering

ABSTRACT

Development of a Tailored Flight Test Approach for Small Unmanned Aircraft Systems

Neil Alexander Wolfe

This document contains the details of a study conducted to determine an effective performance flight test approach specifically for small Unmanned Aircraft Systems (sUAS). This was done by taking proven procedures and documentation from the FAA and the Air Force for manned aircraft and tailoring them specifically for use with sUAS flight test programs. A 'sUAS Flight Testing Handbook' was created from the proceedings to aid commercial organizations and recreational developers conducting sUAS research without access to flight test experience. A performance flight test program was conducted with the AeroVironment RQ-20 Puma sUAS using the developed approach to verify that the 'sUAS Flight Test Handbook' was effective at guiding the test program safely and effectively. The development of the handbook, the results of the Puma Flight Test Program (PFTP), and the instructional 'sUAS Flight Test Handbook' itself are detailed throughout this report. The handbook includes a set of recommendations developed from experience with the PFTP that apply to both commercial and recreational developers of sUAS. A set of documentation is also provided in the form of instructional templates that plan the test program, report the results, and allow sUAS performance flight testing to be carried out safely and effectively.

Keywords: sUAS, handbook, AeroVironment, instructional, templates, recommendations, flight test, performance, commercial, recreational

ACKNOWLEDGMENTS

This study would not have been possible without the help of the California Polytechnic State University; San Luis Obispo, Autonomous Flight Lab. The Autonomous Flight Lab (AFL) employs students to conduct sUAS research and provided the AeroVironment RQ-20 Puma and supported all flight test operations for the Puma Flight Test Program. Many students dedicated significant amounts of time to aid in developing this thesis study by supporting the flight test operations conducted. Many thanks to the AFL and its team of dedicated students in the Summer of 2019.

TABLE OF CONTENTS

	Page
LIST OF TABLES	ix
LIST OF FIGURES	x
CHAPTER	
1. INTRODUCTION	1
1.1 Statement of Problem	1
1.2 Abbreviations and Acronyms	2
1.3 Purpose of Study	3
1.4 Study Approach	5
1.4.1 The Autonomous Flight Lab	5
1.4.2 The AeroVironment RQ-20 Puma	6
1.4.3 The California Polytechnic State University Educational Flight Range	8
1.4.4 Performance Test Requirements	8
1.4.5 Measures of Effectiveness	10
1.4.6 Approach Documentation	13
2. BACKGROUND	14
2.1 The Civil Aircraft Industry	14
2.2 The Military Aircraft Industry	17
3. DEVELOPMENT OF APPROACH	23
3.1 sUAS Flight Testing Recommendations	24
3.1.1 Flight Range Selection	25
3.1.2 Crew Selection	25
3.1.3 Instrumentation	25
3.1.4 Emergency Plans and Equipment	26
3.1.5 Weather Limitations	26
3.1.6 Current Regulations	27
3.1.7 Pre- and Post-Flight Briefings	27
3.1.8 Assembly and Airworthiness Inspections	27
3.1.9 Pre-Flight Checks/Tests	28
3.1.10 Weight and Balance	28
3.1.11 First Flights	28
3.1.12 Planning Tests for Specific Aircraft	29
3.2 Test Planning Report	29
3.2.1 Executive Summary	31
3.2.2 Introduction	31
3.2.3 Test and Evaluation	32
3.2.4 Appendix	34
3.3 Flight Test Card	35
3.3.1 Test Objectives	37
3.3.2 Test Site	37
3.3.3 Present Personnel	37
3.3.4 Aircraft Description	37
3.3.5 Aircraft Call Sign	37
3.3.6 Relevant Radio Frequencies	38
3.3.7 Weather Limits	38
3.3.8 Operation Limits	38

3.3.9 Applicable NOTAMs	38
3.3.10 Test Sequence	38
3.3.11 Watch Items	39
3.3.12 Personnel Contact Info	39
3.3.13 Directions to Test Site	39
3.4 Quick Look Report	39
3.4.1 Specific Test Day Information	40
3.4.2 Test Objectives	41
3.4.3 Test Sequence	41
3.4.4 Preliminary Test Results/Conclusions	41
3.4.5 Unrelated Performance Issues	41
3.4.6 Testing Incidents	42
3.4.7 Next Test	42
3.5 Final Testing Report	42
3.5.1 Executive Summary	44
3.5.2 Figures	45
3.5.3 Tables	45
3.5.4 Abbreviations and Acronyms	45
3.5.5 Purpose and Background	45
3.5.6 Test Description	46
3.5.7 Operational Effectiveness and Suitability	47
3.5.8 Performance Deficiencies	49
3.5.9 Summary of Conclusions and Recommendations	50
3.5.10 References	50
3.5.11 Appendix	50
4. SUAS PERFORMANCE FLIGHT TEST HANDBOOK	51
4.1 Introduction	51
4.2 sUAS Flight Testing Recommendations	51
4.3 sUAS Test Planning Report	61
4.4 sUAS Flight Test Card	61
4.5 sUAS Quick Look Report	62
4.6 sUAS Final Testing Report	63
5. VERIFICATION OF APPROACH	65
5.1 Puma Flight Test Recommendations	65
5.2 Puma Test Planning Report	65
5.2.1 Executive Summary	66
5.2.2 Introduction	66
5.2.3 Test and Evaluation	66
5.2.4 Appendix	68
5.3 Puma Flight Test Cards	69
5.3.1 Test Objectives	70
5.3.2 Test Site	70
5.3.3 Personnel	70
5.3.4 Aircraft	70
5.3.5 Call Sign	70
5.3.6 Frequencies	71
5.3.7 Weather Limits	71
5.3.8 Operation Limits	71
5.3.9 NOTAMs	71
5.3.10 Test Sequence	71

5.3.11 Watch Items.....	72
5.3.12 Phone Numbers.....	72
5.3.13 Directions	72
5.4 Puma Quick Look Report.....	72
5.4.1 Specific Test Day Information	73
5.4.2 Test Objectives.....	74
5.4.3 Test Sequence	74
5.4.4 Preliminary Test Results	74
5.4.5 Preliminary Conclusions.....	74
5.4.6 Unrelated Performance Issues.....	75
5.4.7 Testing Incidents	75
5.4.8 Next Test.....	75
5.5 Puma Final Testing Report	76
5.5.1 Executive Summary	77
5.5.2 Figures.....	77
5.5.3 Tables.....	77
5.5.4 Abbreviations and Acronyms.....	77
5.5.5 Purpose and Background	78
5.5.6 Test Description.....	78
5.5.7 Operational Effectiveness and Suitability	79
5.5.8 Performance Deficiencies	80
5.5.9 Summary of Conclusions and Recommendations	81
5.5.10 References	81
5.5.11 Appendix	81
6. SIGNIFICANCE OF STUDY	83
6.1 Commercial/Research Development	83
6.2 Recreational Development	84
6.3 Future Development	84
BIBLIOGRAPHY	86
APPENDICES	
A. Generic sUAS Test Planning Report Template	87
B. Generic sUAS Flight Test Card Template	102
C. Generic sUAS Quick Look Report Template	105
D. Generic sUAS Final Testing Report Template.....	108
E. Puma Test Planning Report Example	127
F. Puma Flight Test Card Example.....	141
G. Puma Quick Look Report Example.....	144
H. Puma Final Testing Report Example	147

LIST OF TABLES

Table	Page
1. Abbreviations and Acronyms	2
2. Test Matrix for the Puma Flight Test Program	12

LIST OF FIGURES

Figure	Page
1. The Cal Poly AFL AeroVironment RQ-20 Puma Test Aircraft.....	6
2. Flight profile for the Climb/Glide/Speed Test.....	11
3. Overhead approximate flight plan for the Endurance/Position/Altitude Test	12
4. Resources and chosen key documentation.....	23

Chapter 1

INTRODUCTION

1.1 Statement of Problem

As of 2019, small Unmanned Aircraft Systems (sUAS) are becoming popular and viable tools to solve everyday problems facing humans across the world. They promise a more efficient alternative to existing methods and have become the focus of many different research and product development studies across various industries. However, the success of any system hinges on its ability to perform as required by the end user. In the manned aircraft industry, an intensive flight test program is used to determine performance characteristics and certify an aircraft as safe for flight. Though many users of sUAS are fundamentally different than the users of manned aircraft, the method of determining aircraft performance from a flight test program is very similar. Unfortunately, many of the smaller organizations attempting to research and develop sUAS do not have the flight test experience or personnel required to conduct an informative flight test program. Because of this, important performance metrics go untested, FAA regulations may be overlooked, and safety considerations are ignored. This risks the delivery of an unsatisfactory product, the loss of the test aircraft, and/or safety of the operation which jeopardizes the success of the entire sUAS development. Due to the lack of public documentation available, the sUAS industry is in express need of a generic flight test handbook to mitigate the above risks.

1.2 Abbreviations and Acronyms

Table 1: Abbreviations and Acronyms

Term	Definition
AFL	Autonomous Flight Lab
ALT	Refers to Puma's Altitude Holding Mode.
ATC	Air Traffic Control
AVO	Air Vehicle Operator
Cal Poly	California Polytechnic State University, San Luis Obispo
EFR	Educational Flight Range
FAA	Federal Aviation Administration
GCS	Ground Control Station
GPS	Global Positioning System
KTAS	Knots True Airspeed
Li-Po	Lithium-Polymer
MO	Mission Observer
MOE	Measure of Effectiveness
NAS	National Airspace System
NATO	North Atlantic Treaty Organization
NAV	Refers to Puma's Navigation Mode
NOTAM	Notice to Airmen
Part 107	Refers to the FAA's AC 107-2 [1]
PFTP	Puma Flight Test Program
PIC	Pilot in Command
SBP	San Luis Obispo County Regional Airport
sUAS	small Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
V/STOL	Vertical/Short Takeoff and Landing
VO	Visual Observer
VTOL	Vertical Takeoff and Landing

1.3 Purpose of Study

Advancements in technology such as high capacity Lithium Polymer (Li-Po) batteries and autonomous flight controllers have allowed sUAS the capability to fill niche spots in the commercial industry that cannot be substituted by ground equipment or manned aircraft. Many large companies like AeroVironment, Swift, and Amazon have noticed the potential for growth in this regard and are actively designing systems that can compete in the commercial sUAS industry. Smaller organizations are also active in the industry but often don't have the same amount of resources or experience in aerospace to aid in safely and effectively producing an unmanned system. Whether it be research for a university, or product development for a non-aerospace focused company, it is the tendency of the general population to assume that 'drones' are a much simpler, less expensive, and less complex system to operate than a manned aircraft counterpart. While this is sometimes true, even when flying small 'drones', operational risks much like those posed by manned aircraft become relevant with their use. 'Drone' is a term that is generally used to describe any type of vehicle that can be remotely operated. A term that is better suited to refer specifically to unmanned aircraft is 'UAS' or Unmanned Aircraft Systems. The Federal Aviation Administration (FAA) designates remote aircraft below 55.5 pounds as 'sUAS' (small Unmanned Aircraft Systems). Any system that takes flight makes use of sharing the National Airspace System (NAS) with all other aircraft present which poses a risk to navigation for both manned and unmanned aircraft. Unmanned aircraft also pose similar risks to the environment, to the general public, and to property as do manned aircraft. The manned aircraft industry has proven its ability to maintain an exceptional safety record while facing these risks through mandatory flight test and certification of commercially used aircraft. This suggests that in order to achieve the same level of safety, unmanned aircraft would benefit unconditionally from undergoing the same process before being used commercially and even recreationally. Generally, this sentiment is not realized by organizations unfamiliar with the aerospace industry. The FAA however, has realized the similarity in risk between using manned and unmanned aircraft and published Advisory Circular 107-2 [1] (AC 107-2) in 2016 which permits the use of sUAS commercially under certain operational regulations. However, as of 2019 the FAA has not

published any certification standards or flight test handbooks to aid those entering the sUAS industry. In fact, background detailed in Chapter 2 uncovered a distinct lack of sUAS flight test procedures available from any public source.

Flight test not only determines if an aircraft is safe for use, but it also provides the producing entity with valuable information that determines if the aircraft meets the original requirements it was created to achieve. A product that doesn't meet its original design requirements is likely to fail in any aspect of the commercial industry and this can be disastrous, especially for small businesses and organizations. Many of these smaller organizations attempting to enter the sUAS industry do not have the flight-testing experience required to run an effective and informative flight test program. With no public resources available to address this problem, these organizations are left with no structured flight test method to verify safety and capability specifically for small Unmanned Aircraft Systems. Both the civilian and military manned aircraft industries have followed a standard performance flight test approach that has proven safe and effective for many years. However, much of this approach is focused on characteristics of manned aircraft and certification that are usually irrelevant to the operation of sUAS. Without experience in an sUAS focused test program, it becomes difficult to determine what information from these sources is relevant and useful. A logical course would be to selectively choose relevant features from the manned flight test industry while applying it to a real sUAS test program.

The purpose of this study is to provide small businesses and organizations lacking a flight test background with a standard approach that is tailored for sUAS and allows them to conduct safe and effective flight tests leveraging experience from years of success in the manned industry. With this study, organizations will then be able to verify that their aircraft exhibits safe handling characteristics and has the desired performance characteristics to make it a viable commercial product. In the likely event that the FAA eventually publishes certification standards for commercial sUAS, companies using this approach will then have a practical method for certifying their aircraft. The use of this study can even be extended to recreational remote-control enthusiasts when first flying new aircraft that have been homebuilt or purchased. The result is a multi-purpose flight test 'handbook' tailored specifically for commercial sUAS programs with

caveats for individual recreational flight test that is valid for any aircraft type. The intent is to provide a public resource that aids in pushing the sUAS industry and regulation of it down the same path the manned aircraft industry has followed. This will ideally assist in relaxing operational regulations and reducing risk, therefore giving sUAS a much wider range of utility for the commercial industry.

1.4 Study Approach

As mentioned above, a logical way to create a sUAS performance flight test approach is to take proven documents from the manned aircraft flight test industry and apply them to a real sUAS test program. There are many publicly available documents that describe procedures recommended by both the FAA and the United States Air Force. A detailed review of all the documents considered in this study can be found in Chapter 2. The relevant information provided by the background research of this study was used to develop sUAS specific flight test document templates, the process of which is detailed in Chapter 3. A generic sUAS performance flight test 'Handbook' was constructed to be valid for any aircraft type which can be found in Chapter 4. The Autonomous Flight Lab (AFL) on campus is a great resource for sUAS flight test and possesses a variety of sUAS that it regularly uses as test platforms. The documents described in Chapter 3 will then be verified through the flight test of a sUAS with the AFL, the results of which are described in Chapter 5. The details of how the test program with the AFL proceeded are included below.

1.4.1 The Autonomous Flight Lab

The Autonomous Flight Lab is an organization at Cal Poly that conducts UAS flight test research for a variety of clients. The AFL has a great deal of expertise in this area and employs multiple Student Assistant Flight Test Engineers making it the best fit resource available to aid in developing this study. It possesses a variety of unmanned aircraft including helicopters, conventional fixed wing aircraft, and VTOL (Vertical Takeoff and Landing) fixed wing aircraft that it uses on a regular basis. The aircraft inventory represents some of the most advanced UAS in both the commercial and military industry. The AFL typically operates under the regulations of AC

107-2 depending on the needs of their clients which again falls in-line with the purpose of this study. Due to these factors, the relevant information found in Chapter 2 will be applied to a sUAS test program conducted in close cooperation with the AFL and will feature one of the aircraft in their inventory. The aircraft chosen for this study is the AeroVironment RQ-20 Puma which is described in detail below.

1.4.2 The AeroVironment RQ-20 Puma

The AeroVironment RQ-20 Puma is a 15-pound fixed wing sUAS designed to provide a rapidly deployable aerial surveillance, reconnaissance, and intelligence gathering platform for the United States Army. The Puma, pictured below, is a unique aircraft in many different aspects of its operation.

Figure 1: The Cal Poly AFL AeroVironment RQ-20 Puma Test Aircraft.

It is designed ruggedly to withstand persistent use in battlefield scenarios. It features a single electric motor with collapsing propellers and only rudder and elevator control surfaces. It can be swiftly assembled and hand launched on the battlefield to provide surveillance for up to 2.5 hours. It has a maximum radio control range of 12.4 miles. The Puma can fly at a maximum speed of 45 knots and has a 9.2-foot wingspan. The fuselage, wing, and control surfaces are made of composite materials. When the Puma needs to be recovered, instead of landing like a conventional aircraft, it performs a pitch-up maneuver that puts it into a deep stall. With help from the flight controller, the low wing loading of the Puma allows it to stall in a controlled manner and impact the ground a short distance from where the command to land was initiated. It is designed to survive this impact and continue to be operational. The main wing and elevator frequently detach on impact to absorb the excess energy and protect the elevator control surface from damage. This further facilitates its use on the battlefield where there is typically a lack of long smooth surfaces to land an aircraft conventionally.

The Puma can fly in three different flight modes; Manual, Altitude, and Navigation Mode. In Manual Mode, the input from the handheld transmitter is mixed by the flight controller to provide full flight control from with the rudder and elevator. In Altitude Mode, the Puma uses its on-board sensors to maintain a set altitude while responding to directional changes from the user. In Navigation Mode, up to 4 waypoints may be set via the ground station computer which the Puma will fly autonomously until the flight mode is changed.

The Puma has a large array of on-board sensors that provide vital information to the pilot and the flight controller. The main sensors on-board include a GPS unit that reports coordinate location and altitude, a pitot-static system that reports velocity and the wind vector, and a voltage sensor that determines battery capacity. The information from these sensors can be logged by the on-board data recorder once per minute. This information is also display on the pilot's hand controller, and the computer ground station.

To conduct surveillance, the Puma has a multipurpose camera payload mounted on a gimbal that can be rotated to focus on a target. Video is transmitted to the hand controller for the pilot to

view. To rotate the camera, it first must be deployed from within the fuselage that protects it on landing. The payload bay is modular and can be equipped with various payloads.

The AFL has used the Puma on many occasions and is well trained to provide support of its performance flight test. Because of the Puma's unique operational characteristics and on-board sensor array, it provided a suitable platform for deriving a generic approach for performance sUAS flight testing. Its rugged design makes it an appropriate subject for extensive flight testing and will be the sole aircraft used in this study to determine the relevant information to use from the manned aircraft industry. The AFL granted permission to test the Puma and pledged support of its operation while this study was conducted.

1.4.3 The California Polytechnic State University Educational Flight Range

Choosing a suitable location for testing activities is vital for maintaining the safety of any flight test activity. For the purposes of this study the location must be compatible with AC 107-2 [1] regulation. The Cal Poly Educational Flight Range (EFR) is a parcel of land near Cuesta College that has been built explicitly for the purposes of flying and testing sUAS. It features a weather station, preparation tables, battery charging power, fire extinguishers, first aid, a runway, and helipad. It is located outside of the San Luis County Regional Airport (SBP) Class D airspace which allows remote aircraft to be flown without requesting permission from Air Traffic Control (ATC). ATC is aware of the activity at the EFR and issues warnings to pilots in the airspace surrounding SBP. The airspace of the flight range is above grass fields and hills situated away from any uninvolved persons. Access to the EFR is restricted to those conducting aerospace research at Cal Poly and members of the San Luis Obispo Recreational Flyers Club. University research is given priority over any recreational flying. The combination of these factors makes the EFR the best suited location for the flight test activities to be performed as part of this study. All performance flight test with the RQ-20 Puma will be conducted at the Cal Poly EFR.

1.4.4 Performance Test Requirements

The RQ-20 Puma was likely extensively tested by AeroVironment prior to production because it was intended to meet the requirements of the United States Army. This allowed AeroVironment

to deliver a satisfactory product and list performance specifications in the Puma user manual. However, the manual is missing some aircraft performance characteristics that could be useful to the AFL team as they use the Puma in the future. A range of applicable performance flight tests were determined by considering how the Puma operates during its mission. The tests described below serve to confirm the performance AeroVironment claims for the Puma and to provide additional useful information not included in the user manual.

- **Maximum Climb Rate:** A typical test conducted for manned aircraft to determine the maximum rate of climb achievable. Specification for this performance metric is not listed in the Puma's user manual but is useful if the Puma is used for higher altitude surveillance. Since no specification is given, a relaxed maximum climb rate requirement was created for the test: The Puma shall have a maximum rate of climb greater than 100 feet per minute.
- **Deep Stall Glide Ratio:** This is an sUAS/Puma specific test as it involves a purposeful deep stall of the aircraft that results in a controlled glide/fall and impact with the ground as a landing maneuver. AeroVironment has stated that the ratio is 1:1, which allows the aircraft to land nearby the operator in places without paved surfaces for a standard landing. This is a useful metric because it will allow the AFL to better determine where the Puma will land when the sequence is initiated. A requirement was created from the ratio stated by AeroVironment: The Puma shall have a deep stall glide ratio of 1:1.
- **Maximum Level Speed:** A typical test conducted for manned aircraft to determine the maximum speed achievable while the aircraft is trimmed for level flight. This information is useful if the Puma needs to reach a waypoint within a certain time or needs to track a moving target. The Puma's user manual specifies a maximum speed of 45 KTAS. A requirement was created to emulate what the actual requirement may have been: The Puma shall have a maximum level speed of greater than 40 KTAS.
- **Endurance:** A typical test conducted for manned aircraft to determine the maximum time the aircraft can stay aloft. This information is useful for the Puma because it is intended to provide long range surveillance and reconnaissance capabilities for which a long endurance is vital. The Puma User Manual specifies the general endurance of the aircraft to be 2 to 3

hours. A requirement was created from the specified endurance: The Puma shall have an endurance of 2.5 hours.

- Position Keeping Error: This is a test for unmanned aircraft that rely on GPS for positioning. This is a useful metric because the Puma is capable of following flight plans autonomously via GPS and needs to fly within a certain distance of its planned waypoints to have effective surveillance capabilities. There is no specified requirement for this metric so one was created for the test program: The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.
- Altitude Holding Error: This is a test for both manned and unmanned aircraft with autopilots. This is a useful metric for the Puma because it can follow autonomous flight plans in Navigation (NAV) mode and can hold its altitude in Altitude (ALT) mode. It needs to fly at its commanded altitude to provide effective surveillance capabilities. There is no specified requirement for this metric so one was created for the test program: The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.

1.4.5 Measures of Effectiveness

The requirements above become Measures of Effectiveness (MOEs) for the test program. A MOE, as defined by the 'Air Force Test & Evaluation Guidebook' [5], "is a qualitative or quantitative measure of a system's performance or a characteristic that indicates the degree to which it performs the task or meets a requirement under specified conditions. MOEs should be established to measure the system's capability to produce or accomplish the desired result". These are used to track whether a system is meeting its requirements and will be an effective solution. The MOEs to be quantified in this study come from the above requirements and result in the following six metrics.

- Maximum Climb Rate (feet per minute)
- Deep Stall Glide Ratio (ratio)
- Maximum Level Speed (KTAS)
- Endurance (minutes)

- Position Keeping Error (feet)
- Altitude Keeping Error (feet)

The above MOEs were quantified with two different flight test designs. Each test design allows for the quantification of 3 MOEs per flight to increase the efficiency of the program. Each test was conducted 3 times for repeatability. The first test was named the Climb/Glide/Speed test and the flight profile is included in the figure below. This profile was also run three times per test which resulted in nine total repeats of each MOE. The stabilize portion of the profile returns the aircraft to steady, level flight so that the next MOE could be quantified.

Figure 2: Flight profile for the Climb/Glide/Speed Test.

The other test designed was named the Endurance/Position/Altitude Test. An overhead view of the approximate flight plan used is included in the figure below. Because the aircraft endurance was 2-3 hours, the Endurance MOE could only be quantified once per test with three total repeats. The Puma flew this flight path approximately 50-80 times per flight which allowed for the repeated collection of Position and Altitude data at the Recorded Data Point in orange. The Puma flight planner only allows 4 waypoints to be placed which forms a quadrilateral. This flight plan was chosen to allow the aircraft to fly directly through the Recorded Data Point so that the Position and Altitude MOEs could be accurately quantified.

Figure 3: Overhead approximate flight plan for the Endurance/Position/Altitude Test.

A table representing all the tests completed as part of the Puma Flight Test Program is included below to show the extent of the testing and repeatability completed.

Table 2: Test Matrix for the Puma Flight Test Program.

Test Name	Test #	Date	Runs/Repeats
Climb/Glide/Speed	Test 1	5/17	Run 1, Run 2, Run 3
	Test 2	6/26	Run 4, Run 5, Run 6
	Test 3	7/11	Run 7, Run 8, Run 9
Endurance/Position/Altitude	Test 1	7/17	Position/Altitude Repeats: 20
	Test 2	7/26	Position/Altitude Repeats: 20
	Test 3	8/01	Position/Altitude Repeats: 20

1.4.6 Approach Documentation

The sUAS flight test approach being constructed in this study will primarily consist of a set of documents to help guide an organization in effectively planning, conducting, and reporting flight test activities as part of a flight test program. The documents will be created using templates provided by public military sources and will be tailored for use with sUAS through documentation from the FAA and a sUAS flight test program in conjunction with the AFL. The documents will then be turned into templates with recommendations for sUAS programs and will form the main part of a performance flight test 'handbook'. The handbook will also be supplemented with recommendations tailored from FAA documents and derived from the sUAS test program. This handbook should provide a valuable and effective resource for organizations attempting to research/develop sUAS without flight test experience. A detailed explanation of the chosen documents and their purpose can be found in Chapter 3 of this thesis study.

Chapter 2

BACKGROUND

This study includes a review of literature on unmanned aircraft and flight test doctrine in order to determine the suitability of the topic and establish an approach that can be derived from manned flight testing. Many organizations are attempting to research and develop sUAS solutions to solve commercial problems and increase the efficiency of certain operations. However, many of the organizations showing interest in the industry are not explicitly aerospace focused. Small UAS are aircraft that weigh less than 55.5 pounds and fit under the new FAA Part 107 regulations mentioned later in this chapter. Outside of commercial applications, the homebuilt remote-control industry is also growing and is a common hobby for people across many countries, ages, and genders. Testing an aircraft before it is put to use is one of the most important steps in the process because it determines whether the system is performing as intended, if it is an effective solution to the problem being posed, and if it is safe to operate. Unlike the manned aircraft industry, there is a significant lack of standard, structure, and efficiency in the flight-testing process of sUAS. For remote control hobbyists, this is likely because the aircraft are viewed as inexpensive with a high turnover rate which would make structured flight testing impractical. In the commercial industry, UAS are still a developing concept and an effective flight test doctrine has not yet been established for generic UAS. It can also be difficult to find personnel with sUAS flight test experience. Due to this deficiency, it is envisioned that creating an adaptable sUAS flight test approach for these two industries would be a beneficial and worthwhile thesis topic to pursue.

2.1 The Civil Aircraft Industry

As sUAS become less expensive to buy/develop and more capable, the industry will only increase in size. Currently there is a large push to develop sUAS for commercial use, especially in the agriculture industry. The FAA is rapidly adjusting to this demand and has recently released a set of regulations that apply specifically to remote pilots of small aircraft which allows them to use the NAS and ensure safety across both manned and unmanned platforms. The rules are

detailed in the FAA's 'Advisory Circular 107-2 (AC 107-2)' [1] and referred to as the Small UAS Rule (Part 107). It is the official rating needed for remote pilots to fly commercial sUAS for monetary gain. This is good news for the commercial UAS industry because it means the operation of unmanned aircraft is being considered similar to that of manned aircraft. It has made the process of flying sUAS much easier for businesses and encourages them to explore the possibilities of unmanned flight. Part 107 covers sUAS remote pilot in command certification, responsibilities, aircraft requirements, and defines operational limitations. The certification specified by Part 107 is only pilot specific and does not address the aircraft being flown. A Part 107 certification requires that a pilot pass an initial aeronautical knowledge test and be vetted by the Transportation Safety Administration. This will be mentioned in a section relevant to crew responsibility and management for commercial sUAS flight testing applications. Pilot responsibilities include doing a pre-flight check and the only regulation requirement is that the airworthiness of the platform be maintained. This includes checking propeller integrity, wiring connections, mechanical connections, radio connections, and battery levels. These checks will be vital to complete for both independent and commercial sUAS operator and therefore is of high importance to cover in this study. Part 107 requirements about operational limitations to altitude, speed, airspace, etc. will be used to guide the test process as commercial sUAS must conform to these rules. It would be beneficial for recreational users to follow these rules also. Considering this, sUAS should be treated similar to a manned aircraft that must go through a rigorous flight-testing process before it can be certified and sold for public use or transport. This ensures the safety of the users and verifies that the initial design requirements are being met. These are qualities not just important for manned aircraft but also for sUAS in order to be considered as viable commercial products.

The flight-testing process is usually left to the manufacturer of an aircraft and this is where the sUAS industry is lacking. The manned industry generally follows the same basic procedure for flight testing most aircraft because it has become a safe and well-established process. The FAA has provided the typical procedure for flight testing amateur-built aircraft and ultralights in Advisory Circular 90-89B (AC 90-89B) titled 'Amateur-Built Aircraft and Ultralight Flight Testing

Handbook' [2]. They have not, however, created any such manual or documentation pertaining to the flight testing of unmanned aircraft which explains why there is no industry standard for much smaller aircraft with no pilot. Luckily, the procedure for flight-testing amateur-built and ultralight aircraft can be easily adapted and this document will be used to guide the creation of a flight test approach tailored for commercial and homebuilt sUAS. AC 90-89B is a detailed document that provides suggestions that encompass many important aspects of flight testing. These include sections on selecting a proper airport, emergency plans and equipment, test pilot requirements, assembly and airworthiness inspections, weight and balance, powerplant tests, propeller inspections, as well as procedures for the first and following flights. The airport selection mentioned is specific to manned aircraft but will be tailored to sUAS as it contains pertinent information on observer and bystander safety, airport atmospheric conditions and emergency landing considerations. The emergency plans specified in this document address in-flight or on-ground emergency scenarios such as engine failure, fire, and flight control problems. Ground crew emergency and fire procedures that detail clothing, equipment, and hospital locations are also included and will be modified to apply specifically to typical sUAS emergencies. These emergency plans will be used to aid the planning portion of the flight test approach and will supplement the actual testing procedure so that the crew has a direct resource during testing. The test pilot requirements include that the pilot is "Rated, Competent, and Current" for the system being used and gives examples of test pilot knowledge that is important to consider for both manned and unmanned aircraft. This will aid in the assignment and planning of an sUAS flight test team. This document also goes over general assembly airworthiness inspections that include inspection of joints, wings, landing gear, and propeller blades. These are important steps in risk mitigation for an aircraft of any size and can be easily modified for sUAS. The handbook also covers procedures for conducting the first few flights of a new aircraft that are presented in safe, sequential, and logical manner which will be useful for extending to small unmanned aircraft. A general first flight plan is suggested as well as actuator settings and handling characteristics that should be analyzed. The amateur built handbook takes a much less formal approach than the following Air Force documents, but a combination of the two will be optimal for

creating an approach for both commercial and recreational sUAS. The FAA is a reputable source and this document was built on the foundation of many years of manned flight experience that will help provide a solid baseline for the formulation of the proposed thesis topic.

While these are not the only documents that guide flight test for civilian aircraft, they represent the most relevant applications to sUAS. AC 107-2 [1] addresses the specific regulations placed on commercial use of sUAS which must be followed when conducting flight test activities. AC 90-89B [2] aims to guide the flight testing process for small manned aircraft that are amateur or homebuilt. At the time of this study, there is no FAA document that discusses flight test techniques specifically for sUAS. This makes AC 90-89B the most relevant flight test guide when considering the size and typical development of sUAS.

2.2 The Military Aircraft Industry

Another useful source of information on the topic is the Air Force. Test and Evaluation is a vital part of developing new aircraft for the Air Force and their approach is detailed in series of public documents. The managerial aspects of Air Force Test and Evaluation are outlined in the 'Test and Evaluation Management Guide' [3]. Much of this document pertains to the political and hierarchical process the Air Force must work through and is unnecessary for the proposed study. The important information the Test and Evaluation Management Guidebook provides is a structure for planning and reporting tests that facilitates the efficiency and effectiveness of Air Force Test and Evaluation programs. This document provides descriptions for the Test Plan, Testing Criteria, and Evaluation Plan. Modifying these for use with sUAS should allow the user to create an effective and structured plan for testing small remote aircraft. The document also provides descriptions of System Specification, Test Design, and Quick Look Reports. The System Specification Report in this document lists the technical performance requirements and the steps for verification of them. This is a useful process for those attempting to develop commercial sUAS that must satisfy some customer/user requirements. A truncated version will be created for sUAS that allows the test team to be aware of the requirements that must be satisfied and the process

for testing them. The Test Design report helps convey if the test in question will be efficient and answer the desired questions. It identifies specific Measures of Effectiveness and the data/analysis methods that will be used to complete the test. This is another useful document for commercial sUAS development and should include the number of tests and resources required to help management allocate time and resources for testing activity. This document, along with the System Specification Report will be combined to create a single Test Planning Report that will be more useful to commercial organizations than the recreational developer. During Air Force testing, Quick Look Reports are written to report available data to facilitate management decision making. If a test must span multiple days, a Quick Look Report should be completed for commercial sUAS at the end of the final day to inform management of testing progress made. A template for commercial sUAS Quick Look Reports would be a useful edition to this thesis topic. These reports should help the test crew by documenting their intention and progress. Lastly, the document defines Measures of Effectiveness, Trouble Indicators, and System Life Cycle/Design Limit Testing; all of which are relevant to an sUAS test program on a smaller scale. MOEs are useful metrics for determining whether the system meets requirements. Defining potential MOEs and their importance will aid in creating the previously mentioned reports. Planning and reporting are vital parts of the flight testing process and using parts of the Air Force Management documentation in the sUAS industry will allow the users to be well notified of testing milestones and results as well as keep sUAS testing programs on schedule. This type of documentation will not apply to the individual sUAS developer but should be covered in a section dedicated to commercial developers.

To supplement the planning material found in the previous document, another document by the Air Force was reviewed called 'Air Force Flight Test Center Test Plan Preparation Guide' [4] also from Edwards Air Force Base published in 1994. This provides a complete guideline for formulating an Air Force Test Plan document. Because of the manned aircraft application of this document, the test plan is lengthy and very detailed. This intensity will not be required but when paired with information from the previously mentioned document, will aid in creating a single sUAS focused Test Planning Report which is a vital part of the overall flight test approach. This

document will allow the program manager to have an understanding of all aspects of the test including the resources required, test objectives, expected results, safety requirements, and test reporting so that the scope of the test program may be fully anticipated. It will also be a reference for the test crew while the test phase is active, allowing them to account for all required testing. This document will be used in conjunction with the 'Test and Evaluation Management Guide' to create a format for an sUAS specific test plan that will plan commercial flight test operations.

Another resource reviewed was the 'Air Force Test & Evaluation Guidebook' [5], published by the Air Force in 2004. This is an extensive document similar to the 'Test and Evaluation Management Guide'. This, however, provides a table of contents template for a Final Test Report. Most of the sections specified in the table of contents are relevant to both military systems and sUAS. The template includes sections for a Purpose and Background, Test Description, Operational Effectiveness and Suitability, and Deficiency Reports. Each is further broken into subsections that would be useful in a final test report specifically for sUAS. Based on each subsection's suitability for use with sUAS, it was omitted or combined to create a concise template for a sUAS Final Testing Report. The template can be further refined when it is applied to the Puma test program proposed in this study. This provides an adequate base for deriving an sUAS specific Final Testing Report that comes from a proven Air Force approach.

Another document with useful information is NATO's Flight Test Techniques Series – Volume 14, 'Introduction to Flight Test Engineering' [6] published in 2005. This is a comprehensive document that addresses manned flight test procedure and uses United States manufactured aircraft for examples throughout. It is not as technically detailed as the previous Air Force Test Engineering Handbook but obtains its value from generically describing different test methods. It has chapters pertaining to Flight Test Instrumentation, Data Processing, Flight Test Planning, Pre-Flight Tests, Safety Aspects, Test Operations, Performance, and Post Flight Tasks. This document goes into detail about the importance of planning and specifying the instrumentation and data processing required by the flight test engineer. Small unmanned systems will require slightly different instrumentation, but commercial programs should follow a similar process to ensure all required data will be collected and implemented in the test platform. A section in the

test plan should address the specification of instrumentation to ensure all requirements can be evaluated and summed up in a model test matrix. The document also details how flight test plans should be developed in a similar way to previous documents about test planning. The frequency of this suggestion in the reviewed documents suggests it is an important and useful aspect to ensure efficient flight testing. This document will be used in conjunction with other planning-oriented documents to produce a valid commercial sUAS test plan document. Pre-flight tests are important steps in verifying an aircraft is ready to fly. This document provides an in-depth insight into common ground tests completed for manned aircraft. For example, propulsion/thrust testing, taxi, weight and balance, and calibration tests are a few mentioned that would also be applicable to small unmanned aircraft. Pre-flight testing any type of aircraft is a vital step before making the first flight. As much testing as possible should be done on the ground to reduce cost and risk to the program. Using suggestions from this document, a series of recommendations will be created for unmanned aircraft to derive confidence the system will perform as expected when flown for the first time. This section will be useful to both commercial and individual aircraft developers. The safety aspects in the document cover choosing a test site, ensuring the crew is qualified, monitoring weather, setting operational limitations to the flight envelope. Those involved in developing an sUAS may not be well informed of common safety aspects in flight testing, and like most other aspects of this test approach, should be tailored for use with sUAS and included in a set of safety recommendations. This will allow individual and commercial sUAS developers to consider using effective flight safety procedures derived from the manned industry. Performance testing is a vital part of the overall flight test matrix and provides valuable information about aircraft flight characteristics. Performance tests that are applicable in this article include takeoff/landing, endurance, maneuver, and climb/descent tests. The article focuses on manned fixed wing aircraft so the specific contents may not be as useful as the general test sequence and precautions. These may not apply specifically to all unmanned aircraft but since a general test approach is to be created, the user can pick and choose which tests are relevant to their sUAS. In conjunction with the FAA Homebuilt Flight Test Manual this document will help to derive a set of recommendations and techniques that would be beneficial for use with small unmanned aircraft.

The post-flight contents of this document are focused on reporting and preparing for the next test. Tests cards are filled out and data from the test is collected and disseminated to people responsible for data processing. A post-flight debrief is conducted, the next test is detailed, and test cards created. The document emphasizes that planning should be a continuous process because there is usually inadequate time between tests to start planning the next test. This is a valuable step in the process for commercial sUAS operations to sum up progress made during the test session and will keep the crew prepared for the next test. Since this document was developed by NATO (North Atlantic Treaty Organization) it likely has a wide application to the aircraft of different countries which should extend to aircraft of smaller sizes given careful consideration.

To create a test approach for sUAS, many current techniques for manned aircraft will be derived into relevant techniques for small unmanned aircraft. It will be important for any commercial company or individual creating and testing a new aircraft to follow an efficient test plan, perform relevant tests, and report the results for documentation and analysis. After conducting extensive research, little has been found pertaining directly to the flight testing of sUAS which are rapidly becoming popular and starting to enter the commercial market. Had any reliable documentation been found on these topics it would have been included in this section. Instead, the deficiency of information provides a unique opportunity for this thesis topic to be useful in the future of commercial and amateur sUAS development. To derive recommendations that would be relevant to a generic small UAV, the FAA's 'Amateur-Built Aircraft and Ultralight Flight Testing Handbook' [2] and NATO's 'Introduction to Flight Test Engineering' [6] thoroughly discuss details of manned aircraft performance testing. Information from the manned industry for test planning can be found in multiple sources mentioned above which include the FAA's 'Amateur-Built Aircraft and Ultralight Flight Testing Handbook' [2], the Air Force's 'Test and Evaluation Management Guidebook' [3] and 'Air Force Flight Test Center Test Plan Preparation Guide' [4], as well as NATO's 'Introduction to Flight Test Engineering' [6]. These documents will provide information that can be synthesized into an effective test planning approach for small unmanned aircraft. All testing should be followed by effective reporting practices that provide

valuable information to the developer of the sUAS. Information and templates will be used from the Air Force's 'Test and Evaluation Management Guide' [3] and 'Air Force Test & Evaluation Guidebook' [5]. Following modified versions of Air Force documentation for reporting test results will allow the sUAS test team to document results effectively and succinctly, ensuring the tests are effective at answering all desired questions. The FAA's Part 107 regulations will be used as an overall guideline in this study for it to follow current regulation. Enough information has been found through these documents to provide an adequate base to derive a complete test approach that is efficient and effective for any generic sUAS platform.

Chapter 3

DEVELOPMENT OF APPROACH

The approach being developed will include a set of recommendations for sUAS testing and instructional templates for essential documentation that should be produced for a sUAS test program. The FAA and Air Force provide many recommendations for conducting tests programs and this information in conjunction with findings from the Puma Flight Test Program (PFTP) conducted as part of this study were used to create a set of sUAS Flight Test Recommendations. The military aircraft industry has a standardized approach to flight test that has proven effective across many programs. When entering a flight test program, it is important to produce certain documents that plan, record, and report the findings and results. The 'Test & Evaluation Management Guide' by the Air Force details the documentation that is used to manage flight test programs. The documentation found relevant to sUAS flight test includes the Test Planning Report, Flight Test Card, Quick Look Report, and Final Testing Report. The figure below shows which resources were used to derive the relevant documentation.

Figure 4: Resources and chosen key documentation.

The documents and the templates released by the Air Force were modified specifically to address sUAS flight testing. The documents and the modifications made are explained in the subsections below.

3.1 sUAS Flight Testing Recommendations

A set of recommendations for sUAS flight testing was created to help guide the planning of test activities as the instructional templates detailed in the sections below only include recommendations for filling out the documentation. These recommendations were derived from the FAA's 'Amateur-Built Aircraft and Ultralight Flight Testing Handbook' [2] and 'Advisory Circular 107-2 (AC 107-2)' [1] as well as NATO's 'Introduction to Flight Test Engineering' [6]. Experience with the Puma Flight Test Program was also used to supplement these recommendations. They address important planning factors as listed below.

- Flight range selection
- Crew selection
- Instrumentation
- Emergency plans and equipment
- Weather limitations
- Current Regulations
- Pre- and post-flight briefings
- Assembly and airworthiness inspections
- Pre-flight checks/tests
- Weight and Balance
- First flights
- Planning tests for specific aircraft

The intention of these recommendations is that they will be considered prior to planning a test and will help to create a safe test program that can be applicable to any small remote aircraft.

Caveats will be made for those intending to use this study to guide recreational flight test operations. The development of the recommendations themselves are explained below and will be provided as part of the 'handbook' being created as a part of this study in Chapter 4.

3.1.1 Flight Range Selection

This recommendation was made to aid in choosing an appropriate sUAS testing location. The FAA's 'Amateur-Built Aircraft and Ultralight Flight Testing Handbook' [2] details airport selection pertaining to small manned aircraft. This is significant to sUAS because it helps mitigate the safety risks of the program and helps ensure it remains within Part 107 regulation. Both the FAA Handbook [2] and AC 107-2 [1] were used to create this recommendation in addition to insight gained from completing the Puma Flight Test Program. The use of the EFR as a flight range for the Puma Flight Test Program was optimal as its facilities allowed safe testing of all MOEs. The selection of a flight range well suited for testing sUAS is vital to the success of the program which is stressed by this recommendation.

3.1.2 Crew Selection

This recommendation was made to suggest a flight test team structure that is efficient for sUAS testing operations. The FAA Ultralight Handbook [2] suggests crew selection pertaining to manned aircraft while AC 107-2 [1] and the AFL flight test team structure provide specific positions for multiple crew members that make up a well-rounded team. Suggesting positions for the team from the pilot to traffic observers ensures that no one person is overwhelmed, and all safety aspects are covered during operations. Each crewmember of the AFL had a designated position for the Puma Flight Test Program. This recommendation is based on the effectivity of the roles each member filled.

3.1.3 Instrumentation

This recommendation mainly comes from experience with the Puma Flight Test Program and is mentioned in NATO's 'Introduction to Flight Test Engineering' [6]. This is an important recommendation to make because the instrumentation on sUAS varies widely between aircraft. If

not included in the system design, the test aircraft will need to be fitted with the proper instrumentation to conduct testing. It is important to consider the instrumentation required to quantify the MOEs that give the flight test purpose. The instrumentation on board the Puma was effective at capturing the data required for all MOEs. This recommendation was developed to suggest certain instrumentation that should be incorporated onto the aircraft to collect data for generic sUAS testing. The set of instrumentation on the Puma was highly effective at collecting the required data and allowed the wind vector to be removed from affected data.

3.1.4 Emergency Plans and Equipment

This recommendation was made to suggest the emergency plans and equipment that should be prepared before the initiation of a sUAS flight test program. The FAA Ultralight Handbook [2] makes suggestions on emergency plans and equipment pertaining to small manned aircraft while the Puma Flight Test Program applied sUAS specific guidelines. Combining these sources for use in the recommendation given as part of this study allows an sUAS flight test program to be prepared to mitigate emergencies that might arise during operations. Emergency plans and equipment should be made and brought to any flight test being conducted. This recommendation suggests typical emergency plans and equipment that should be brought to every flight test.

3.1.5 Weather Limitations

This recommendation was made to suggest considering the weather limitations that are regulated by the FAA and that could affect the accuracy of the data collected during a flight test program. AC 107-2 [1] regulates the visibility, ceiling, and cloud proximity of commercial sUAS operations while the Puma Flight Test Program uncovered certain weather conditions that made sUAS data collection less accurate than desired. Combining these sources allows a flight test program to remain within FAA regulation and avoid collecting data that may be inaccurate and skew the perception of the aircraft's nominal performance. The Puma Flight Test Program typically faced eight knot average winds which can have a large affect on the data if the wind vector cannot be accurately measured by the aircraft instrumentation. This recommendation

stresses the importance of conducting tests in optimal weather conditions and uses the experience of the PFTP to suggest types of weather that affect the accuracy of collected data.

3.1.6 Current Regulations

This recommendation was made to ensure that any commercial sUAS operation remain within regulation mandated by the FAA. AC 107-2 [1] provides all the applicable guidelines and is referenced for this specific recommendation. This will allow the user of this study to maintain safe operation within the legal bounds allowed for sUAS use.

3.1.7 Pre- and Post-Flight Briefings

This recommendation was made to suggest the effectivity of conducting both pre-flight and post-flight briefings for sUAS flight test operations. The use of these in the Puma Flight Test Program proved to be an effective way to prepare the team for the tests to occur during the day and to review the results of the flight test afterwards. When used in a sUAS flight test program, the team will be set up for safe and effective flight test operations. The use of pre- and post-flight briefings in the PFTP was used to guide the suggestion of the briefings and their contents. It allowed the test team to review the flight test card and understand their assigned roles, the test sequence, and any important watch items for the test.

3.1.8 Assembly and Airworthiness Inspections

This recommendation was made to suggest that assembly and airworthiness inspections be conducted throughout a flight test program. This suggestion mainly comes from the FAA Ultralight Handbook [2] which pertains specifically to small manned aircraft. However, this also applies to unmanned aircraft that typically feature components that are intended to be unassembled and reassembled upon deployment. This is an important recommendation to make because it allows the assembly and airworthiness of the aircraft to be continuously monitored throughout the program in effort to maintain the safety and effectivity of testing operations. This recommendation suggests the inspection of the aircraft assembly and airworthiness, which was critical for operation of the Puma. The Puma, like many other aircraft, has multiple points where flight

surfaces are attached and detached for transport which should be inspected prior to flight. Minor damage is typical of sUAS operation and airworthiness inspections of propellers and flight surfaces were another critical part of ensuring the success of the PFTP.

3.1.9 Pre-Flight Checks/Tests

This recommendation was made to suggest the typical pre-flight checks that should be conducted prior to launching an sUAS. The FAA Ultralight Handbook [2] details pre-flight checks that pertain to small manned aircraft, but many apply to sUAS at the same time. This is another important recommendation to make because it standardizes the approach to flying a specific aircraft and ensures that it is ready for safe flight. In the Puma Flight Test Program these checks ensured the aircraft was setup correctly for flight.

3.1.10 Weight and Balance

This recommendation was made to call attention to additional pre-flight checks that are of increased importance for the safety of the operation. The FAA Ultralight Handbook [2] covers weight and balance checks as well as locating the CG position. It is much easier to check these on an sUAS as they weight much less and can typically be handled by a single person. These recommendations are important to make because incorrect weights or placements of the CG can detrimentally affect the flight qualities of the aircraft.

3.1.11 First Flights

This recommendation was made to suggest the process for conducting the first flights of a newly designed or modified aircraft. The FAA Ultralight Handbook [2] discusses the processes for the first flights of a new small manned aircraft. Many of these suggestions were applied to the first flights of a generic sUAS so that an unexperienced flight test program may take the appropriate first steps in testing a new aircraft. The process detailed by the FAA was created to minimize the risk to the aircraft, pilot, and uninvolved persons and therefore provides an excellent basis for sUAS specific safety recommendations. The FAA Ultralight procedure was then reduced and modified to cover sUAS specific first flight recommendations with caveats for rotary wing aircraft.

3.1.12 Planning Tests for Specific Aircraft

This recommendation was made to suggest that flight tests should be planned by carefully considering the specific aircraft being tested. This was mainly derived from experience with the Puma Flight Test Program. Not all aircraft are the same and require different considerations when planning the test program. This recommendation stresses the importance of tailoring the approach recommended in this study directly for the aircraft being tested to make it as applicable as possible. This approach was made generally to apply to a wide range of sUAS. To make sure the approach is applicable, this recommendation stresses that the flight test program manager filling out the documentation think critically about the capabilities and characteristics of the specific aircraft.

3.2 Test Planning Report

The Test Planning Report is a report used by the Air Force to fully plan a test program prior to any testing activities. A template for the Air Force version is provided by the 'Air Force Flight Test Center Test Plan Preparation Guide' [4] and is much lengthier than is required for sUAS as the Air force generally works with much more complex systems that require more extensive testing. However, it is a useful document to derive for use with sUAS as it allows management to anticipate the scope of the test program and provide the required resources. The cover page, signature page, and table of contents were recreated from the public Air Force template. The table of contents was then modified to only include sections and subsections pertinent to the flight test of sUAS, shown below.

- Executive Summary
- Introduction
 - Background
 - Test Item Description
 - Test Objectives

- Test and Evaluation
 - Constraints and Limitations
 - Test Resources
 - Safety Requirements
 - Security Requirements
 - Test Project Management
 - Measures of Effectiveness
 - Test Procedures
 - Test Reporting
 - Environmental Protection
- Appendix
 - Test Condition Matrix
 - Safety/Risk Conditions
 - Requirements Traceability
 - Data Analysis Plan
 - Instrumentation Plan
 - List of Abbreviations

The Test Planning Report included in this study was created after choosing the AeroVironment RQ-20 Puma and a range of performance tests as detailed in Chapter 1. The sections and subsections listed in the table of contents were then filled out with the amount of information appropriate for the flight test of the Puma. The completed Test Planning Report for the Puma flight Test Program can be found in Section E of the Appendix and its development is detailed below. Each section of the report was then interpreted to apply generically to sUAS testing as described in the following subsections. The generic template for the sUAS Test Planning Report can be found in Section A of the Appendix.

3.2.1 Executive Summary

The Executive Summary of the sUAS Test Planning Report should be included on the third page after the title and sign-off pages. This provides a summary of the proposed testing activities and the contents of the report. It should mention all involved agencies/organizations and the reasoning for the proposed test program. It should also briefly describe the proposed test aircraft and the intended results of the flight test program. The high-level resources required to complete the test, the planned program start and end dates, as well as an overview of the proposed testing activities should also be included in the Executive Summary.

3.2.2 Introduction

The Introduction section of the Test Planning Report should consist of 3 subsections developed from the 'Air Force Flight Test Center Test Plan Preparation Guide' [4] in conjunction with experience in the Puma Flight Test Program. It should be the first section included after the Table of Contents. The development of the subsections is described in detail below.

Background: The Background should be the first subsection within the Introduction. The Background should again refer to the aircraft and purposes of the testing proposed in more detail. It can also describe the entity conducting the test program, who will be involved, and any teams that must be formed to complete the program. The end of the Background should specify the intention of the document to propose a planned test program and should include the recipients of the report.

Test Item Description: The Test Item Description should be the second subsection within the Introduction and is where the test aircraft should be described in detail. Aircraft characteristics like the typical weights, configurations, flight control methods, applicable payloads, ground control stations, known expected performance metrics, recovery methods, and any other notable aircraft characteristics should be explained.

Test Objectives: The Test Objectives should be the third and final subsection within the Introduction. The primary and secondary objectives of the flight test program should be

specified. The primary objectives of the flight test program are likely to be to quantify the performance metrics of the aircraft to determine whether it meets its original design requirements. The performance metrics should be included by name. The secondary objectives of the test are likely to be to discover any unanticipated performance and system functionality characteristics of the sUAS.

3.2.3 Test and Evaluation

The Test and Evaluation section of the Test Planning Report is the most significant and describes how the tests will be organized and conducted throughout the entire test program. It includes 9 subsections that were developed from the 'Air Force Flight Test Center Test Plan Preparation Guide' [4] in conjunction with experience from the Puma Flight Test Program. The development of the subsections is described in detail below.

Constraints and Limitations: The Constraints and Limitations subsection should detail any regulatory constraints as well as organization and aircraft specific limitations to the scope of the test program. Applicable regulatory constraints for commercial sUAS are specified in AC 107-2 [1] and any organizational/aircraft limitations will be specific to each test program. The type of aircraft, airspace regulations/NOTAMs, and constraints to the Area of Operation should be considered. This ensures the flight test program is kept safe and effective.

Test Resources: The Test Resources subsection should detail all resources required over the entirety of the test program. This includes all required personnel, facilities, hardware, software, and any other funding that will be required to conduct the proposed testing activities. This ensures that all resources will be provided when testing occurs.

Safety Requirements: The Safety Requirements subsection details any specific considerations that should be made to ensure the safety of the flight test program. Federal and local regulations should be considered, as well as any organization specific regulations. Features of the specific aircraft being tested that present a safety hazard should also be

considered (hazardous materials, flight characteristics, etc.). This ensures safety requirements are made known to management as well as those involved in the test program.

Security Requirements: The Security Requirements subsection should detail any security considerations that must be made for the program. This can include protecting classified information, protecting intellectual property, following export regulations, organization specific concerns, and any other applicable security considerations. This ensures the program remains within regulation and avoids a loss of property or revenue.

Test Project Management: The Test Project Management subsection should detail how the flight test team is internally organized and should also address any external relationships that may exist as part of the test program. This ensures the team structure and relationships are acknowledged by those signing off on the Test Planning Report.

Measures of Effectiveness: The Measures of Effectiveness subsection should detail all the MOEs that will be used to gauge whether the sUAS meets its original requirements. MOEs should be derived from the system requirements that the aircraft was designed to meet and should result in metrics that can be quantified from flight testing the aircraft. Quantifying these is the main purpose of the test program and provides insight on the capability of the aircraft to provide its intended function.

Test Procedures: The Test Procedures subsection should detail all specific test procedures required to quantify each MOE previously described in chronological order. This provides insight on what the tests will consist of and the resources required at each stage of the flight test program. Note that more detailed procedures can be found on the Flight Test Card and will be briefed prior to each test. It should include the test titles, planned dates, a description, the relevant MOEs being tested, the crew/resources required, and step by step procedures for each test to take place. This ensures those signing off on the program are informed of the detailed plan for each test.

Test Reporting: The Test Reporting subsection should detail how and when the data will be recorded, distributed, and analyzed throughout the test program. Quick Look Reports should be distributed as soon as possible after each test is completed and the Final Testing Report should follow once all tests are completed. This ensures everyone involved understands when to expect data and results, allowing them to proactively make decisions about the aircraft design if needed.

Environmental Protection: The Environmental Protection subsection should detail any undesirable environmental risks due to the proposed program. This includes emissions, use of hazardous material, risk to the environment, risk to wildlife, etc. Also describe how any significant risks will be mitigated.

3.2.4 Appendix

The Appendix should be the last section of the Test Planning Report and contains six subsections that support the rest of the document. The format was developed from the 'Air Force Flight Test Center Test Plan Preparation Guide' [4] and the contents were developed with experience from the Puma Flight Test Program.

Test Condition Matrix: The Test Condition Matrix is used to plan out each individual flight test in chronological order. It includes the Test Name, Test Date, MOEs being quantified, and any applicable notes. Notes can include deliverables post-test, flight conditions, and/or names of pilots planned to fly the test, etc. It explains the number of tests required, the timeline for the program, and the purpose for each. This allows management to anticipate the resources required and allows the flight test team to anticipate the scope of the program.

Safety/Risk Conditions: The Safety/Risk Conditions subsection of the Appendix describes any possible safety or risk conditions that may exist as a result of conducting the flight test program. It includes a name of the condition, the resulting aircraft behavior, planned response to mitigate the condition, and the probability the condition will occur. This ensures

management and the flight test team are prepared for any condition that may occur and are briefed on a method to mitigate the associated risk.

Requirements Traceability: The Requirements Traceability subsection of the Appendix describes the relationships between the original system requirements and the MOEs derived from them. This should be represented as a table with one column containing the system requirements and with the other column containing the relevant MOE and its units of measurement. It may not always be clear what requirement a MOE is quantifying and this ensures that each MOE has a strict purpose for testing and relates to a specific requirement.

Data Analysis Plan: The Data Analysis Plan subsection of the Appendix should address how the data will be recorded, analyzed, and distributed. It should note the specific resources required to conduct the data analysis and should address the complexity involved in acquiring/reducing the data. This allows management to provide any data analysis resources that may be required and determines the amount of work to be done.

Instrumentation Plan: The Instrumentation Plan subsection of the Appendix should address the instrumentation required to record the data needed to quantify each MOE. Any additional instrumentation that must be acquired should be noted also. This ensures that management can purchase the required instrumentation prior to the start of the test program allowing it to be conducted efficiently.

List of Abbreviations: The List of Abbreviations subsection is the last in the Appendix and should define any abbreviations or acronyms used throughout the document.

3.3 Flight Test Card

The Flight Test Card should be a two sided 8.5"x5.5" sheet of paper that is formatted to provide the flight test team with the most vital information needed to complete the specific flight test being conducted. It is widely used across the flight test industry and its small form factor allows it to be easily handled and recognized. It is distributed to the entire team present at the

pre-flight briefing so that all are informed of the how the test will be conducted, any relevant constraints, watch items, and risk mitigation methods. It is the main document of reference while the test is being conducted.

For this study, the AFL desired to use a test card that has been proven effective for their operations. Because the AFL is an sUAS testing organization, the test card they have created is a relevant and concise template for emulation in this study. The AFL was responsible for providing the test card as it was already filled out with most of the information required. The AFL was then supplied with the test sequence needed to acquire the required data for later analysis. The information included in the AFL test card is listed below.

- Test Objectives
- Test Site
- Present Personnel
- Aircraft Description
- Aircraft Call Sign
- Relevant Radio Frequencies
- Weather Limits
- Operation Limits
- Applicable NOTAMs
- Test Sequence
- Watch Items
- Personnel Contact Info
- Directions to Test Site

One of the Flight Test Cards used in the Puma Flight Test Program and can be found as used in Section F of the Appendix. Each section of the Flight Test Card was then interpreted to apply generically to sUAS testing as described in the following subsections. The generic instructional template for a sUAS specific Flight Test Card derived from the AFL version can be found Section B of the Appendix.

3.3.1 Test Objectives

The Test Objectives section of the Flight Test Card should include a short summary of the specific test objectives to be achieved during the test flight. It should mention the specific MOEs being quantified. This ensures the test team has a common goal when using the Flight Test Card during the test.

3.3.2 Test Site

The Test Site section of the Flight Test Card should include the test site name along with the coordinate location. The elevation of the test site above sea level should be noted as well as any other pertinent test site information. This provides information that is useful for anyone unfamiliar with the test site and when using GPS functions of the system.

3.3.3 Present Personnel

The Present Personnel section of the Flight Test Card should list all present personnel by first and last name and should correspond to a certain position within the flight test team. Suggested positions for the flight test team are described in the recommendations created as part of this study. This allows the team to be briefed on their function prior to the flight test and ensures all required positions are covered for the test flight.

3.3.4 Aircraft Description

The Aircraft Description section of the Flight Test Card should contain the manufacturer, model number, and name of the aircraft being tested. This ensures that the team is briefed on the aircraft being flown prior to the flight and provides a reference during the test.

3.3.5 Aircraft Call Sign

The Aircraft Call Sign section of the Flight Test Card should contain the FAA call sign of the aircraft being tested. This enables the call sign to be referenced during the test if needed and would likely occur if the operation is within ATC controlled airspace.

3.3.6 Relevant Radio Frequencies

The Relevant Radio Frequencies section of the Flight Test Card should include the VHF radio frequencies for the ATC of nearby airports and heliports. This section can also include frequencies used by the flight test team to communicate and guarantees the frequencies are accessible in case contact with ATC must be made.

3.3.7 Weather Limits

The Weather Limits section of the Flight Test Card should include the AC 107-2 [1] regulated weather limits for commercial use of sUAS. If the aircraft has any other weather limits (likely to be wind/gust limits) they should also be specified in this section. This allows the limits to be referenced during the test in the case that the weather deteriorates.

3.3.8 Operation Limits

The Operation Limits section of the Flight Test Card should include any AC 107-2 [1] regulated operational limits for commercial sUAS use. Any other aircraft specific operational limits should be specified in this section, if applicable. This ensures that regulations can be referenced and that the aircraft will not be flown outside its operational limits during the flight test.

3.3.9 Applicable NOTAMs

The NOTAMs section of the Flight Test Card should list any applicable NOTAMs the operation is taking place under. The most likely NOTAM is Part 107 from AC 107-2 [1]. List any other NOTAMs issued in the Area of Operation also. This ensures that no FAA regulations are broken as the NOTAMs may be referenced during the test.

3.3.10 Test Sequence

The Test Sequence section of the Flight Test Card should list the step by step instructions for the test sequence that will achieve the test objectives of quantifying the desired MOEs. This should be a numbered list that allows the pilot to complete each maneuver of the flight as needed

to acquire the desired data. The Test Sequence should begin from takeoff and end at landing. This guarantees the pilot has a reference for the required maneuvers during the flight test.

3.3.11 Watch Items

The Watch Items section of the Flight Test Card should include any applicable watch items for the location and/or the system being tested. These can include battery voltage levels, current levels, signal strength indicators, Center of Gravity location, etc. It should include the specific thresholds and limits for each item listed. This allows important aircraft health indicators to be referenced during the test and that any potential risk is mitigated.

3.3.12 Personnel Contact Info

The Personnel Contact Info section of the Flight Test Card should include the contact info of the personnel present during the test. A telephone number or email is sufficient. Emergency service numbers should be listed in this section also. This provides a reference to all team members during and after the test.

3.3.13 Directions to Test Site

The Direction to Test Site section of the Flight Test Card should include short and concise instructions for reaching the test site. This ensures that a description of the location can be found in case an emergency must be reported or a team member cannot find the location.

3.4 Quick Look Report

The Quick Look Report is a short document used by the Air Force that summarizes the days testing activities. Ideally this document should be provided to the test team and management by the test engineer within two days of the test. A description of the Air Force Quick Look Report can be found in the Air Force's 'Test & Evaluation Management Guide' [3]. It allows the team and management to stay informed on the progress of the test program or of any setbacks and issues with the design as soon as they appear. It is the most detailed record of the testing for that day

and includes a preliminary analysis of the data recorded so that unsatisfactory results may be addressed as soon as possible. This reduces the risk of a delayed program or an unsatisfactory product. A blank template was made from the Air Force description and sUAS relevant sections were kept as below.

- Specific Test Day Information
- Test Objectives
- Test Sequence
- Preliminary Test Results
- Unrelated Performance Issues
- Testing Incidents
- Next Test

After the first Puma test, the template was filled out to provide a blanket summary of the day's testing activities and results. Throughout the Puma Flight Test Program, the Quick Look Report has been modified to ensure all sUAS relevant information was reported. One of the six Quick Look Reports created for the Puma Flight Test Program can be found in Section G of the Appendix. Each part of the Quick Look Report was then interpreted to apply generically for sUAS testing as described in the following subsections. The generic template for a sUAS specific Quick Look Report can be found in Section C of the Appendix.

3.4.1 Specific Test Day Information

The Specific Test Day Information section of the Quick Look Report includes all the smaller font text at the top of the first page. It includes information on the test date, aircraft, location, weather conditions, involved agencies, and present personnel. This should be included in a Quick Look Report because it describes the conditions of the test on that specific day and provides a record for the flight test team that allows the documents to be referenced later.

3.4.2 Test Objectives

The Test Objectives section of the Quick Look Report should address both the primary and secondary objectives for that specific test. The primary objectives of the flight test are likely to be quantifying the MOEs giving purpose to the test. The MOEs should be included by name in this subsection. The secondary objectives of the test are likely to be discovering any unanticipated performance and system functionality characteristics of the sUAS. This gives the Quick Look Report a purpose for the MOE quantification.

3.4.3 Test Sequence

The Test Sequence section of the Quick Look Report is different than that found on the Flight Test Card. The Test Sequence section should specify a name for the test and should specify names for each repeatability run of the test in the order of completion. The pilots name should be listed under the run name as well. This allows a record of the pilots and the tests completed to be referenced as needed later.

3.4.4 Preliminary Test Results/Conclusions

The Preliminary Test Results section of the Quick Look Report should display the preliminary MOE results found by reducing the data of that specific test. The best way to display the data is graphically and should show each run individually as well as the total average for each MOE. Below the graphical representations should be a light analysis of the results displayed. The MOE results should be listed again, and a preliminary conclusion should be made about whether the MOEs meet the original system requirements. This allows management and the flight test team to formulate early opinions about the effectivity and safety of the system.

3.4.5 Unrelated Performance Issues

The Unrelated Performance Issues section of the Quick Look Report should address any performance qualities of the aircraft noticed during the test that are not relevant to the MOEs for the test. Attributes of the entire system should be included here so that they can be reported to

the team. This allows management and the flight test team to be aware of other issues or positive performance attributes the system displays when in operational use.

3.4.6 Testing Incidents

The Testing Incidents section of the Quick Look Report should address any incidents that occurred during the flight test. Incidents that should be recorded include anything that causes damage to the aircraft or that breaks a constraint, limitation, or regulation. The incident should be described as concisely as possible and the result or damage should be reported. At the end, a conclusion about the aircraft's airworthiness for future flight should be made and underlined. This permits management to purchase components or fund repairs for the aircraft. It also provides a record of damage to the aircraft that must be repaired prior to the next flight.

3.4.7 Next Test

The Next Test section of the Quick Look Report should address the next planned test. A short description of the test and the MOEs to be tested should be included and followed by the anticipated test date and location. This informs the flight test team of the next test to occur and allows them to prepare for it.

3.5 Final Testing Report

The Final Testing Report is a document used by the Air Force to synthesize all resulting data and information collected over the entire test program. A template for the Air Force version of the document can be found in the 'Air Force Test & Evaluation Guidebook' [5]. The Final Testing Report is a compliment to the Test Planning Report as it addresses all the planned tests and results. Results and information from each test are displayed individually and comprehensively, considering repeatability. It also includes any other unrelated information discovered during testing pertinent to the use of the aircraft. The Final Testing Report is a standalone document so that the scope and results of the entire test program may be understood solely from reading this resource. The report should be completed after the conclusion of all testing activities planned and

distributed to the test team and to management for archival. The main sections of the Final Testing report are listed below.

- Executive Summary
- Figures
- Tables
- Abbreviations and Acronyms
- Purpose and Background
 - Testing Purpose
 - Testing Background
 - Description of System Tested
 - Test Force, Location, Dates
- Test Description
 - Test Objectives
 - Scope and Method
 - Planning Considerations and Limiting Factors
 - Business Relationships
- Operational Effectiveness and Suitability
 - Summary
 - MOEs
 - Additional Findings
 - Safety Assessment
 - Environmental Impact Assessment
 - Operational Impact Assessment
- Performance Deficiencies
 - Deficiency Reports
 - Impact Summary
- Summary of Conclusions and Recommendations
- References

- Appendix

For this study, the Final Testing Report was completed after all planned testing activities were concluded. The public template provided by the Air Force was used in conjunction with the Test Planning Report to guide the creation of a blank sUAS specific Final Testing Report. Each section was then interpreted to apply generically to sUAS testing as described in the following subsections. The report should be filled out by taking the scope described in the Test Planning Report and by including individual test results from each Quick Look Report. Results from the entire test program should be synthesized to reflect repeatability and were more conclusively analyzed than in the individual Quick Look Reports. Major conclusions should be made for the MOEs and original system-level requirements, as well as unrelated performance and handling characteristics. The Final Testing Report should then be distributed to the flight test team and management so that the performance of the aircraft may be archived for future reference. The completed Final Testing Report for the Puma Flight Test Program can be found in Section H of the Appendix. The generic instructional template for a sUAS specific Final Testing Report can be found in Section D of the Appendix.

3.5.1 Executive Summary

The Executive Summary section of the Final Testing Report should be similar to the Executive Summary of the Test Planning Report but should be more focused on describing the final outcome of the flight test program. It should detail the organization, the aircraft of interest, and a high-level purpose for the test program. It should summarize the testing that occurred and briefly explain the purpose of the document. Dates that the testing occurred, and any business relationships needed to complete the testing should also be mentioned. This provides a high-level overview of the test program and, when read with the Summary of Conclusions and Recommendations section, should provide a high-level description of the entire program and its results.

3.5.2 Figures

The Figures section of the Final Testing Report should include all the figures created from analyzing the data recorded over the entire program. The figures should paint a clear picture about the results and behavior of the aircraft and should address each MOE planned for the test program. Comparisons should be made between individual tests and full averages should be shown with error bars representing the variation in results. As much graphical information about the test results as possible should be included in this section and organized in a condensed and readable fashion. Each figure should include a short description underneath the graph. This allows the reader to browse the display of results which is the main function of the Final Testing Report.

3.5.3 Tables

The Tables section of the Final Testing Report should include the tabulated results for all MOEs quantified. If possible, results should be shown from all tests done for repeatability as well as the total average result. If applicable, also quantify the variation in the data recorded (standard deviation). Tables should have units and the total average should be bolded for emphasis. This lets the reader identify the exact values that correspond to the previous Figures section.

3.5.4 Abbreviations and Acronyms

The Abbreviations and Acronyms section of the Final Testing Report should define any abbreviations or acronyms used throughout the document.

3.5.5 Purpose and Background

The Purpose and Background section of the Final Testing Report is similar to the Introduction section of the Test Planning Report. This, however, was created by referencing the 'Air Force Test & Evaluation Guidebook' [5] which provided the main template for the Final Testing Report. There are four subsections within the Purpose and Background as described below.

Testing Purpose: The Testing Purpose subsection of the Introduction should include a concise purpose for testing the aircraft. The purpose is likely to quantify the performance MOEs that were derived from the original system requirements. The organization conducting the flight test program, aircraft, and location of testing should also be mentioned. This delivers a direct purpose for the document and the test program to achieve.

Testing Background: The Testing Background subsection of the Introduction should include the background behind the Testing Purpose. The reason the tests were required, and the implications of the results should be mentioned in this subsection. A summary of how the program was conducted and the intention of the document should be stated also.

Description of System Tested: The Description of System Tested subsection of the Introduction can be the same as the Test Item Description in the Test Planning Report. The type of aircraft, the configuration, and any important characteristics of the aircraft that should be known to an external viewer of this document should be described.

Test Force, Location, Dates: The Test Force, Location, Dates subsection of the Introduction should describe the test force and any business relationships being utilized throughout the test program. The test location should be described as well as the general dates of the entire test program.

3.5.6 Test Description

The Test Description section of the Final Testing Report was created by referencing 'Air Force Test & Evaluation Guidebook' [5]. The scope and method behind the test program are detailed in the four subsections of the Test Description. Each subsection was interpreted from the Air Force document to apply generically for sUAS testing as follows.

Test Objectives: The Test Objectives subsection of the Test Description should describe the primary and secondary (if applicable) test objectives. The primary objectives are likely to be proving the capability of the aircraft by verifying that it meets the requirements used to guide its design. The MOEs used to do so should be mentioned by name. Secondary objectives are

likely to be discovering any unintended/unknown characteristics of the aircraft and system design. This documents the specific objectives the test program was created to achieve.

Scope and Method: The Scope and Method subsection of the Test Description should explain where the MOEs mentioned in the Test Objectives section came from and their meaning. The sensors being used to record data should be mentioned and the method used to record the data should also be specified. An explanation of how the data was reduced, analyzed, the sequence of testing to be done, and which tests will address which MOEs should be included. It is beneficial to create a bulleted breakdown of each test in addition. This explains the method by which the tests were conducted and how the data was collected.

Planning Considerations and Limiting Factors: The Planning Considerations and Limiting Factors subsection of the Test Description should be similar to that of the Test Planning Report and should describe any operational constraints or limitations that were a factor for the test program. Organization and/or specific flight area rules should be considered. If operating under Part 107 for sUAS, the legal constraints to operation should also be listed in this section as well as weather constraints for the specific aircraft. This serves to document the constraints and limits that could not be broken to acquire data throughout the program.

Business Relationships: The Business Relationships subsection of the Test Description should briefly describe any business relationships utilized during the test program. It should also mention other organizations and their roles if they were included in the test program. This serves to document the relationships between different entities over the course of the test program (if applicable).

3.5.7 Operational Effectiveness and Suitability

The Operational Effectiveness and Suitability section of the Final Testing Report is where the major conclusions and results of the quantified MOEs are discussed. This section was derived from the 'Air Force Test & Evaluation Guidebook' [5]. The effectiveness of the sUAS is discussed

through six subsections. Each subsection was interpreted from the Air Force document to apply generically for sUAS testing as follows.

Summary: The Summary subsection of Operational Effectiveness and Suitability should summarize the high-level results of the test program. It should also explain whether the program was effective at quantifying the metrics it was designed to as well as detail whether the results of the test program have implications for the aircraft's operational performance. This summarizes the purpose of Operational Effectiveness and Suitability.

MOEs: The MOEs subsection of Operational Effectiveness and Suitability should describe each MOE planned for testing and trace it back to a requirement. This subsection should explain how data was recorded for each MOE and how the data was reduced/analyzed. The conclusion of each MOE should include a bulleted breakdown of the results with a concise conclusion on whether the original requirement for the MOE was met. This determines whether the system met its original design requirements.

Additional Findings: The Additional Findings subsection of Operational Effectiveness and Suitability should list any additional discoveries about system operational characteristics that don't fall under specific MOEs. Any other notable performance characteristics of the system should be listed in this subsection and should be briefly noted in a bulleted list. This serves to document any other discoveries about how the system operates during the test program.

Safety Assessment: The Safety Assessment subsection of Operational Effectiveness and Suitability should assess the safety of operating the system. Any conditions that could cause safety issues and how/if they can be mitigated should be listed. A concise conclusion on the perceived safety of the using the system should also be included. This provides a conclusion on whether the system is safe to operate for its intended purpose.

Environmental Impact Assessment: The Environmental Impact Assessment subsection of Operational Effectiveness and Suitability should assess the environmental impact associated with operation of the system. It should consider whether the use of the system will affect an

ecosystem or natural resource. A concise conclusion of the environmental impact of the system should also be included. This provides a conclusion on whether the operation of the system will adversely affect the environment.

Operational Impact Assessment: The Operational Impact Assessment of Operational Effectiveness and Suitability should assess the operational impact the results of the test program have for the system. If requirements were not met, it should address the consequences for the operational capability of the system and any other additional factors that could do the same. This provides a conclusion on whether the aircraft is perceived as operationally capable or if it must be redesigned.

3.5.8 Performance Deficiencies

The Performance Deficiencies section of the Final Testing Report should discuss any negative performance characteristics of the aircraft discovered during testing. This section was derived from the 'Air Force Test & Evaluation Guidebook' [5]. The deficiencies are noted through two subsections. Both subsections were interpreted from the Air Force document to apply generically for sUAS testing as follows.

Deficiency Reports: The Deficiency Reports subsection of Performance Deficiencies should summarize any deficiencies of the system performance. These are generally negative features of the aircraft performance at risk of impacting operational capability. This subsection should include any failed MOEs and other negative characteristics seen during testing. The deficiencies should be numbered and listed in order of priority. The summary should include a description of the deficiency, how it can affect operational capability, and the priority level of the deficiency. This serves to detail what features of the system need to be improved before it can become a viable product.

Impact Summary: The Impact Summary subsection of Performance Deficiencies should Summarize the total impact of all the deficiencies on the operational capability of the system. It should also address whether any of the deficiencies are critical to the system being

successful or safe and provide a concise conclusion on the impact of the listed deficiencies.

This provides a conclusion that details which aircraft deficiencies must be addressed for it to become a finished product.

3.5.9 Summary of Conclusions and Recommendations

The Summary of Conclusions and Recommendations section of the Final Testing Report should summarize the major conclusions of the test program. It should address whether requirements were met and whether the system is effective and safe to operate. Recommendations should be made about addressing any deficiencies mentioned earlier. This provides a concise conclusion on the status of the aircraft design and capability at the time the test program had concluded.

3.5.10 References

The References section of the Final Testing Report should include any references to documents used throughout the test program. This ensures all documentation vital to the test program is mentioned in the Final Testing Report.

3.5.11 Appendix

The Appendix section of the Final Testing Report should include any other figures, tables, and/or records that were used throughout the test program. Items appended in the Test Planning Report should be considered to append to the Final Testing Report such as the Test Condition Matrix and Requirements Traceability Table. This ensures all vital resources are included in the Final Testing Report so that it may be a standalone document.

Chapter 4

SUAS PERFORMANCE FLIGHT TEST HANDBOOK

4.1 Introduction

This Chapter contains an approach that will allow any organization, with or without flight test experience, to safely and effectively conduct a sUAS flight test program for any type of aircraft. It emphasizes an approach that a commercial or research organization should use if a sUAS product is being developed, but when applied with discretion, can apply to the recreational developer also. Whether developing a new system, modifying an existing system, or flying an aircraft for the first time, it is vital that a flight test program be conducted to determine how the aircraft performs. This allows the user to understand how the aircraft will behave when it is used operationally and reduces the risk involved in its use. It also allows the developer to determine whether the aircraft is suitable for the purpose it was designed and whether it will be a successful product. This approach covers a set of recommendations for flight testing sUAS and is accompanied by a set of documentation that should be filled out during the program. For commercial developers, the documentation allows the flight test program to be transparent for management and facilitates communication between the flight test team during the program. At the conclusion of the program, all documentation should be archived so that they can be referred to if needed later. The documentation is listed in the order of its intended use in the following sections.

4.2 sUAS Flight Testing Recommendations

This is a list of recommendations for both commercial and recreational developers created by combining FAA suggestions for manned aircraft development with the experience gained through the Puma Flight Test Program. These recommendations should be reviewed along with the FAA's Advisory Circular 107-2 (AC 107-2) prior to planning or conducting any flight test program. AC 107-2 is the FAA regulations placed on commercial sUAS use and is also the certification

required to fly sUAS for commercial purposes. These recommendations generally apply to all sUAS aircraft and flight test activities, but the user should be careful and use discretion to ensure that the recommendations are applied specifically for the aircraft and tests being conducted.

- **Flight Range Selection:** Selecting an appropriate location to flight test the aircraft is one of the most important considerations to be made when planning the flight test program. The first factor to consider when choosing a location is the legality of operating a sUAS in that area. As a commercial developer, it is necessary to abide by the FAA Part 107 regulations regarding flight for sUAS and these should be fully reviewed and understood before planning a test. Recreational developers would benefit from following the same regulations though are bound by a different set of regulations designated by the FAA as Section 336. When selecting a location, it is important to adhere to the Part 107 regulations on airspace and operation near uninvolved people (AC 107-2; Sections 5.8, 5.11). Priority should be given to finding a location in Class G airspace which is uncontrolled, so that operations may be conducted at the whim of the test team. To operate in any other airspace, authorization must be obtained from ATC which can cause delays in the test program. It is also beneficial to find a location that is sparsely populated, as it is against regulation to directly fly over uninvolved persons that are not under the protection of cover. An easy way to avoid this concern is to fly in a sparsely populated area, which also has the added benefit of avoiding confrontation with people who may not enjoy the presence of UAV nearby. It is beneficial to find an area clear of obstructions that could block the view of the aircraft or interfere with radio communications. Depending on the type of aircraft, select a location that can support takeoff and landing operations. If the sUAS lands like a typical aircraft it will likely need a long and level paved or grass surface to take off and land from. V/STOL (Vertical/Short Takeoff and Landing) aircraft may not need to make this same consideration so it is important to plan for the specific type of aircraft being tested. Typically, the best locations to conduct testing activities are established remote aircraft flight ranges which can be found nearby most populated areas in the US.

- Crew Selection: Selecting a specific crew for the flight test operation is also an important consideration to make. Recreational developers can operate alone if they remain dedicated to controlling the aircraft without distraction. To conduct a commercial flight test in a safe manner, it is recommended to have at least 2 people present, however it is always beneficial to have more. The following positions are required or recommended for sUAS flight test operations.
 - PIC (Pilot in Command) or AVO (Air Vehicle Operator): Required position. The PIC/AVO is responsible for directly controlling the aircraft and/or having the controls within reach at all times. The PIC/AVO is directly responsible for the actions of the aircraft. For commercial operations, this person must be Part 107 certified by the FAA and should have some experience flying remote vehicles (AC 107-2 Section 5.2). If experience is not an option, practicing on remote flight simulators is recommended before attempting to fly a UAV for the first time.
 - VO (Visual observer): Required Position. The VO is responsible for monitoring air and ground traffic and should be briefed on how to do so. This is done by visually scanning the sky and ground near the area of operation and listening for approaching aircraft engines. It is often beneficial to have more than one VO if possible. The VO is an important position because it is vital to ensuring that all Part 107 regulations are heeded such as giving way to manned aircraft and avoiding operation over uninvolved persons.
 - MO (Mission Observer): Recommended Position. If the sUAS utilizes a separate GCS (Ground Control Station) from the main controls, the MO is responsible for monitoring the output. The MO can record parameters by hand and inform the PIC/AVO of aircraft parameters as the test proceeds.
 - Test Director: Recommended Position. The Test Director oversees that the test sequence is performed correctly, and the data is recorded adequately. This is an important because the other positions should be focused on maintaining the safety of the flight operation.

- Instrumentation: Flight testing for specific metrics often requires that the aircraft be fit with the corresponding sensors capable of recording the data needed. Not all aircraft will have the necessary instrumentation as part of their stock sensor suite and additional instrumentation may need to be added. An essential piece of equipment for conducting sUAS flight tests is a GPS module. This can report position, altitude, and groundspeed. Other pieces of equipment that increase the accuracy of recorded data include a pitot static probe, angle of attack sensor, current/voltage sensor, and on-board cameras. Carefully consider what instrumentation is required to quantify the desired metrics and detail it in the Test Planning Report.
- Emergency Plans and Equipment: Whether the purpose is commercial or recreational, it is important to have emergency plans made and safety equipment in possession before planning flight test activities. The most probable emergencies include battery fires, wildfires, damage to property, and injury to people. Having plans to contend with these emergencies is highly recommended. Emergency service contact information and directions to the test location should be placed on the Flight Test Card so that the information is readily available while testing. Bringing the equipment listed below is also highly recommended to mitigate the risk involved if one of these situations occur.
 - Fire Extinguisher: Required equipment. Should be rated for, and large enough to contend with battery chemical fires.
 - First Aid Kit: Required equipment.
 - Cell Phone or Radio: Required equipment.
 - Safety Glasses: Recommended equipment.
 - Protective Gloves: Recommended equipment.
 - Anemometer: Recommended equipment.
 - Camera: Recommended equipment.
- Weather Limitations: Weather tends to be a much larger factor for sUAS as they are smaller and lighter, and usually not waterproof. This is a factor that applies to both commercial and recreational sUAS developers. Flight test activities should ideally take place in the calmest

conditions possible to acquire baseline performance data unless the test specifically requires other conditions. Weather conditions should be monitored repeatedly as the test approaches. Visibility should be as specified in AC 107-2 Section 5.10.3 to comply with regulation. To ensure baseline performance data, it is recommended to organize the flight test to take place in the early morning after sunrise. This is when the wind tends to be more calm and thermal circulation above the ground is less likely to occur. This aims to ensure that the recorded data is not altered by the weather conditions present. It is also important to make sure that the weather conditions are appropriate for the aircraft being flown. Wind speed and density altitude should be monitored, otherwise the aircraft may not be able to fly correctly.

- **Current Regulations:** Commercial sUAS flight test programs must adhere to the regulations specified in the FAA's AC 107-2. These should be thoroughly reviewed and understood before planning any flight test activity. Recreational developers can adhere to the FAA's Section 336 regulations but are recommended to instead adhere to AC 107-2 to increase the safety of the activity.
- **Pre- and Post-Flight Briefings:** For commercial developers operating as a team, a pre-flight briefing should occur before every flight test. This is where the Flight Test Card should be distributed to the team and reviewed together. Each person on the team should understand their role and the sequence of the test activity. A post-flight briefing should also occur after the flight test is complete. The post-flight briefing should address whether the test objectives were met, any incidents that occurred, and the plan for the next test flight if applicable.
- **Assembly and Airworthiness Inspections:** Assembly and Airworthiness inspections should occur before and after every flight for both commercial and recreational sUAS developers. Many sUAS can be disassembled and reassembled to fit a smaller form factor and it is critical that the points of connection are inspected for integrity between each flight. For commercial developers, it is recommended to record any findings of inspections made on the aircraft, the number and length of flights that have been made, and how many times batteries have been charged (if applicable) in a dedicated logbook. Airworthiness inspections should include the following checks.

- Check all propeller surfaces for chips/cracks.
- Check all assembly points for integrity.
- Check wing surfaces and airframe for damage (if applicable).
- Check control surface connection points for integrity (if applicable).
- Check electrical connections for integrity.
- Check landing gear wheels rotate, and brakes are functional (if applicable).
- Pre-Flight Checks/Tests: Pre-flight checks and tests should be completed prior to every flight, ensuring basic function of the onboard systems for both commercial and recreational developers. This can occur at the same time as the Assembly and Airworthiness Inspection. The following checks should be completed prior to every flight as applicable to the aircraft in question.
 - Check that all control surfaces and landing gear are fully functional (if applicable).
 - Check the propeller is secured properly.
 - Check battery charge or fuel level is adequate for test.
 - Check all electrical connections are sound and exposed wires are clear of props.
 - Check the battery/fuel is secured properly.
 - Check the aircraft weight and balance are acceptable.
 - Conduct a motor test run.
 - Check radio communications range and status.
 - Check weather conditions are appropriate.
- Weight and Balance: The Weight and Balance should be confirmed during the Pre-Flight Checks. They have been included in a new recommendation because of their importance to the safety of the aircraft. Electric aircraft typically do not have a varying weight, stability, or centers of gravity during flight as no liquid fuel is consumed. Initial placement of the battery or payload is usually the biggest factor for electric aircraft. If the aircraft utilizes liquid fuel it is important to ensure that the fuel tank/s are placed in a fashion that allows the aircraft to remain balanced throughout the flight. The weight of the aircraft should be checked prior to the first flight so that the maximum takeoff weight is not exceeded. The Center of Gravity

- (CG) should also be checked prior to every flight to ensure that it is located within the designed margin for the aircraft. Positioning of the battery, payload, and/or fuel tank will have a large effect on the CG position. The positioning of the CG will have a large effect on the stability of the aircraft. Typically for fixed wing aircraft the proper CG is located along the centerline of the fuselage somewhere within the first quarter of the wing chord (width). The designer of the aircraft should be referenced for the actual intended position. For helicopters and multirotors, the proper CG location is typically centered between all rotors. Both the aircraft weight and the CG placement will influence the stability qualities of the aircraft. Incorrect placement of the CG could result in dangerous stability characteristics. Depending on the flight test being conducted, it would be beneficial to include the proper CG location and maximum takeoff weight for reference under the Watch Items section of the Flight Test Card.
- First Flights: If the aircraft has never been flown before, the risk associated with the operation is much greater, whether the developer is commercial or recreational. It is recommended that the first flight occur in the early morning under calm conditions. All test flights should be planned out before hand and noted in the Test Planning Report. The risk level can be reduced by adhering to the following recommendations for the first few flights of the aircraft.
 - Complete all Inspections and Pre-Flight Checks/Tests.
 - Remove unnecessary persons from the operational area.
 - Ensure the test team and anyone else present is aware the flight is occurring.
 - Complete multiple taxi tests (if applicable) to understand the ground handling characteristics of the aircraft.
 - Have emergency equipment and plans readily available.
 - Ensure the aircraft weight, balance, and center of gravity are appropriate as described in the section above.
 - First Flight: The first flight of the aircraft should be well rehearsed in the head of the pilot. Control of the aircraft should almost be second nature at the time of the first flight. A good way to prepare for the first flight is to fly remote aircraft simulators with a similar aircraft type following the anticipated flight path of the real flight extensively. Many consumer

remote transmitters can be plugged into a computer to use with the simulator which will give the pilot experience with the actual flight controls. When conducting the takeoff roll or rotor spin up, look for any off nominal behavior from the aircraft (Vibrations, trimming, balance, etc.). If anything is detected, abort the takeoff immediately. If the aircraft has retractable landing gear, leave the gear extended for the first few flights. Climb to an altitude between 200 and 400 feet AGL and trim the aircraft for level flight (if applicable). Climbing to a higher altitude (but below 400 feet AGL) is recommended during the first flight because it gives the pilot time to react to responses from the aircraft. Do not implement any autonomous functions of the aircraft (if applicable). Begin by testing the aircraft response to inputs along the roll, pitch, and yaw axes. Start with small control inputs that gradually increase in magnitude. The aircraft response does not need to be quantified during this test, but the pilot should determine whether the aircraft is stable and maneuvers as desired along all axes. The stall speed test is important for a fixed wing configuration, so the aircraft is not stalled during the first landing. If the aircraft has flaps, start by deploying them in varying degrees to understand how the aircraft behaves and maneuvers when deployed. Begin the stall speed test in level flight with adequate throttle and slowly decrease throttle until the aircraft visibly starts to approach a stall. The aircraft will likely be at a high angle of attack and the wings may start to buffet when approaching the stall. The pilot should make a mental note and if possible, team members should make a physical note of the speed when stall signs begin to show. Avoid fully stalling the aircraft during this maneuver if possible. When this is complete, or if it is not necessary, the aircraft can be set up to land. Approach the landing at a speed safely higher than the recorded stall speed (if applicable) and do not over control the aircraft. If the landing setup does not feel right, it is appropriate to go around and setup again. Keep an eye on the battery/fuel level if this is done multiple times before landing the aircraft.

- Following Flights: Prepare for the second flight the same as the first flight. Correct any discrepancies noted during the first flight and fly the same flight path again with the same purpose of understanding how the aircraft flies. Keep the landing gear extended for this

flight as well (if applicable). During the third flight the pilot can begin to explore other functions of the aircraft, the gear can be retracted, and performance noted. Any other flights following this should begin to quantify important performance metrics for the aircraft. Be sure to maintain a safe altitude buffer during maneuvers that could result in altitude loss like stalls and glides (if applicable). Some examples of typical performance metrics for fixed and rotary wing aircraft are listed by priority below.

- Fixed Wing

Stall Speed: Determine at what speed the aircraft stalls.

Endurance: Determine how long the aircraft can fly before approaching a critical battery/fuel level.

Motor off Glide Ratio/Angle: Determine how the aircraft glides when no power is applied.

Rate of Climb: Determine the rate of climb at different throttle applications.

Max Speed: Determine the maximum speed achievable in steady level flight.

Stability: Determine the stability characteristics of the aircraft along each axis.

Rate of Descent: Determine the safe rate of descent for landing.

Takeoff Speed: Determine the typical takeoff speed of the aircraft.

Weight Testing: Determine performance under different takeoff weights (if necessary).

Autonomous Functions (if applicable): Determine how the aircraft performs when given 'autonomous' flight paths/commands.

- Rotary Wing

Endurance: Determine how long the aircraft can fly before approaching a critical battery/fuel level.

Rate of Climb: Determine the rate of climb at different throttle applications.

Max Speed: Determine the maximum speed achievable in steady level flight.

Rate of Descent: Determine the safe rate of descent for landing.

Weight Testing: Determine performance under different takeoff weights (if necessary).

Autonomous Functions (if applicable): Determine how the aircraft performs when given 'autonomous' flight paths/commands.

These are recommendations for the first flights generic small unmanned aircraft. These tests are meant to quantify performance metrics that should be known to safely operate the aircraft. They may not apply to all aircraft directly and will need to be modified/chosen by the user to fit the specific type of aircraft being tested. Additional tests may be added that apply to specific aircraft and functions, but all must be specified in the test plan and should occur after the applicable tests above. Refer to the below bullet for further explanation.

- Planning Further Tests for Specific Aircraft: The tests mentioned above are generally applicable to both fixed wing and rotary wing aircraft but should be tailored for the specific aircraft being tested if it has unconventional qualities. When planning further tests it is important to deeply consider the function of the aircraft and what metrics are applicable for both commercial and recreational applications. Generally, aircraft are designed to satisfy some user/system requirements. Satisfying these requirements makes the aircraft effective for the purpose it was designed. Flight tests should be planned to determine whether the system requirements are met. The military turns the requirements into metrics called Measures of Effectiveness (MOEs). By quantifying the system MOEs, the design of the aircraft can be verified or modified so that it is able to meet the requirements set for it and be a successful product/aircraft. Quantifying MOEs is an integral part of this sUAS flight testing approach. A complete example of how this was conducted and documented in the Puma Flight Test Program is described in Chapter 5.

4.3 sUAS Test Planning Report

The sUAS Test Planning Report is the first document that should be completed prior to conducting a flight test program for commercial development. For recreational developers, it is suggested to use discretion to determine what sections of the report are relevant for their specific aircraft as it tends to be intensive if the purpose of the aircraft is recreationally based. Despite this, it is always recommended that a plan for recreational performance tests be made and safety considerations be made. The Test Planning Report when filled out completely, fully anticipates the scope of the test program, explains the purpose of testing, and determines what resources will be required. This allows management of resources and test program transparency for the organization conducting it. The tests should be planned with the development team and management during the creation of this document to determine the requirements that must be met for the aircraft to be effective. The requirements should then be turned into metrics that will be quantified by the flight test activities referred to as Measures of Effectiveness by the military industry. It is important to organize the tests in the most efficient manner possible, ideally measuring data samples for more than one MOE per flight if possible. Flight test activities tend to be costly but can be reduced if tests are designed properly. Refer to Section E of the Appendix for the Puma Test Planning Report completed for use in the Puma Flight Test Program. An instructional template for completing the generic sUAS Test Planning Report can be found in Section A of the Appendix. It can be filled out by replacing or removing any text that is red. Any other colored text should be left as is.

4.4 sUAS Flight Test Card

The sUAS Flight Test Card describes test specific information and is the primary document of reference for instructions and information while the test is being conducted. It is an 8.5" x 5.5" piece of paper brought by every member of the team to the test location. It can be an 8.5" x 11" piece of paper that is folded in half. This is a beneficial document to produce for both commercial and recreational developers. One should be created for each individual flight test and should be

distributed during the pre-flight brief to the team conducting the test. The pre-flight brief should consist of a review of the flight test card which contains all the important test information. Team member positions, weather limitations, Air Traffic Control frequencies, the test sequence, watch items, and emergencies service contact info should all be included in the test card so that any resource possibly required for the test can be found. The flight test maneuvers should be conducted as listed on the Flight Test Card. A post-flight debrief should also be conducted that reviews whether the test sequence was performed properly and whether enough data was recorded. Any incidents or additional findings of the flight test should also be mentioned during the post-flight debrief. One of the two completed Puma Flight Test cards as used in the PFTP can be found in Section F of the Appendix. An instructional template for creating a generic sUAS Flight Test Card can be found in Section B of the Appendix. Any text in red should be replaced or removed. Any other text should be left as is.

4.5 sUAS Quick Look Report

The sUAS Quick Look Report is a short report that should be put together after each flight test is completed. It is most useful to a commercial sUAS development team but could be a useful resource for the recreational developer, at their discretion. The Quick Look Report is meant to concisely report test specific information immediately after a test has been completed and should ideally be no more than 2 pages long. It includes the weather during the test, the test objectives, preliminary results of the data analysis, a comparison of MOE results to requirement standards, a record of all other characteristics seen during the test, and details for the next test. Information should be recorded during the test so that the Quick Look report can be filled out afterwards. It requires that a preliminary data analysis be carried out and should include graphical representations of the MOE results including the associated variation/standard deviation. A short analysis of the results should be included, and preliminary conclusions made on whether the quantified MOEs met the standards set by the requirements for the system. The report should then be disseminated to the test team and management within 2-3 days of the test. If tests occur

on consecutive days, it should be delivered before the next test occurs. One of the six Puma Quick Look Reports as completed for the PFTP can be found in Section G of the Appendix. An instructional template for a generic sUAS Quick Look Report can be found in Section C of the Appendix. Any text in red should be replaced or removed. Any other text should be left as is.

4.6 sUAS Final Testing Report

The sUAS Final Testing Report culminates all the findings of the test program and allows for archival of the results. This is useful to commercial sUAS developers and with discretion could be useful to recreational developers as it tends to be intensive for recreational flight test activities. This document is meant to be a complete review of the test program with a much deeper and conclusive analysis of results than is featured in the Quick Look Report. The Final Testing Report should be completed after the conclusion of all required flight tests. It should be a standalone document that when reviewed, provides a complete picture of the flight test program to uninvolved persons. It covers the scope and purpose of testing, details the results of the quantified MOEs, concludes whether the original system requirements were met, and notes any additional characteristics or deficiencies discovered throughout the test program. Each MOE should be specifically addressed, and conclusions made about whether the requirement was met. Graphical and tabulated versions of the results should be included for each MOE in the Figures and Tables sections at the beginning of the document. Any additional notable characteristics of the system discovered during testing should be included as well as any performance deficiencies. Performance deficiencies are failed MOEs and any other negative characteristics of the system that should be addressed to provide an effective system. Conclusions on operational suitability and safety should be made to aid in management decision making. It is important to provide as much relevant information as possible in this report. The Final Testing Report should then be disseminated to the test team and to management for archival. The Puma Final Testing Report as completed for the PFTP is included in Section H of the Appendix. An instructional template for a

generic sUAS Final Testing Report is included in Section D of the Appendix. Any text in red should be replaced or removed. Any other text should be left as is.

Chapter 5

VERIFICATION OF APPROACH

5.1 Puma Flight Testing Recommendations

This is a list of recommendations created by taking information found in the review of relevant literature to this study and tailoring it towards sUAS by applying the experience gained through the Puma Flight Test Program. These recommendations were formed after the completion of the Puma Flight Test Program so that the experience of conducting a full sUAS flight test program could be effectively applied. The Puma Flight Test Program was an effective test program because both the primary and secondary objectives were achieved in the planned amount of time. Therefore, this set of recommendations draws its verification as an effective sUAS flight test resource from its conception through an effective and successful sUAS flight test program. The recommendations have been included in Chapter 4 and were designed to apply to generic aircraft of both commercial and recreational purposes (with discretion).

5.2 Puma Test Planning Report

Prior to beginning the Puma Flight Test Program, six metrics of interest were chosen for the program in collaboration with AFL management. Some were chosen as standard performance metrics while others were chosen as metrics of interest that the AFL felt would be useful to quantify. The template of the Test Planning Report released by the Air Force was used to guide the creation of the Puma Test Planning Report. The Puma Test Planning Report fully plans out the testing of all six metrics and was submitted to the head of the AFL and the Chief Puma Test Pilot at the time for approval. This served to provide management with a full view of how the tests would be conducted and the resources required to do so. This part of the approach derives its verification as an effective sUAS flight test resource from its use in planning the PFTP. The Puma Test Planning Report proved effective at planning the program and resulted in the timely completion of the program taking only the minimum amount of flight tests necessary to quantify

the desired metrics. This suggests that the sUAS Test Planning Report instructional template is an effective resource for sUAS performance flight testing. A detailed analysis of the major sections of the report is included below. The Test Planning Report as completed for the PFTP is included in Section E of the Appendix.

5.2.1 Executive Summary

The Executive Summary section of the Puma Test Planning Report proved an effective method to summarize the purpose and plan for the entire Puma Flight Test Program. Located at the beginning of the document, it was easy to quickly read and understand the scope of the proposed test program. If management didn't care to review the entire report, the executive summary for the Puma Test Planning Report proved detailed enough to provide an understanding of the proposed program.

5.2.2 Introduction

The Introduction section of the Puma Test Planning Report proved an effective method to describe the background behind the required testing, the test aircraft, and the test objectives of the Puma Flight Test Program. The Background subsection of the Introduction concisely described the background and purpose behind testing the RQ-20 Puma for the AFL in a way that made it easy to understand why the test program was needed. The Test Item Description was an important part of the document that detailed characteristics of the Puma aircraft. It proved effective at describing features of the Puma being tested that are not typical of most sUAS, such as the deep stall landing procedure. The Test Objectives subsection of the Introduction was also an effective way to describe the objectives that the test program was proposed to achieve. All three subsections in combination provide a clear and concise overview of the intentions of the test program for management and any other recipients of the report.

5.2.3 Test and Evaluation

The Test and Evaluation section of the Puma Test Planning Report proved an effective method to describe the specifics of the proposed test program. This section consisted of multiple

subsections that each serve to plan and mitigate risk throughout the program. The subsections include Constraints and Limitations, Test Resources, Safety Requirements, Security Requirements, Test Project Management, Measures of Effectiveness, Test Procedures, Test Reporting, and Environmental Protection. The Constraints and Limitations subsection proved effective at making any regulations and aircraft operational constraints known to the recipients of the report and is something that applies heavily to the commercial operation of sUAS. The Test Resources subsection was used to notify AFL management of all resources required to complete the proposed tests. This was effective because the AFL was then able to provide the required resources throughout the program allowing it to take place effectively and efficiently. The Safety Requirements subsection was important for the Puma Flight Test Program because it listed requirements that should be met in order to maintain the safety of the test operation. By following the safety requirements, the PFTP was conducted safely without consequence. The Security Requirements subsection provided an important function by noting the export control on the Puma's flight computer and user manual. By noting this in the Puma Test Planning Report, the PFTP avoided breaking any export regulations. The Test Project Management subsection was effective at detailing the relationship between the AFL and the author of this study who worked in conjunction to conduct the PFTP. It clarified the roles personnel and different organizations would play during the proposed program for the recipients of the report. The Measures of Effectiveness subsection was proficient at detailing the MOEs to be quantified over the course of the PFTP and served to notify the recipients of the report how the MOEs were chosen. The Test Procedures subsection was effective at showing management that the tests had been fully planned and the step by step instructions for the pilot would result in quantified MOEs for the Puma. The Test Reporting subsection was used to explain to AFL management how and when the results of the test would be reported in the form of Quick Look Reports and the Final Testing Report. This informed management of how and when to expect reports from the program to aid in product development decision making. The Environmental Protection subsection was effective at describing the potential environmental consequences of completing the program and described how the effects would be mitigated. In the PFTP this was used to plan protection methods for the

herds of cattle that surrounded the EFR. All these sections in combination provided a complete test plan that would guarantee the success of the PFTP and provide the management structure with a transparent view of how the program would be conducted.

5.2.4 Appendix

The Appendix section of the Puma Test Planning Report was used to append tables and descriptions that supplemented the contents of the test plan. The Appendix included subsections addressing a Test Condition Matrix, Safety/Risk Conditions, Requirements Traceability, a Data Analysis Plan, an Instrumentation Plan, and a List of Abbreviations. The Test Condition Matrix supplemented the Test Procedures by listing each test and its parameters for the entire program in chronological order. This effectively provided management with a timeline for the PFTP that was successfully achieved. The Safety/Risk Conditions supplemented the Safety Requirements subsection by listing any possible risk or safety conditions the Puma might encounter during the program as well as the severity and plans for mitigation. This proved effective for the PFTP even though none of the conditions were seen because the flight test team was prepared for any that may have occurred. The Requirements Traceability subsection showed management the traceability of the specified MOEs from the original system requirements for the Puma and confirmed the need to perform the proposed testing activities. The Data Analysis Plan was created to explain how the data collected during the PFTP would be analyzed and reported and was effective at conveying this to management of the AFL. The Instrumentation Plan was an important subsection of the Appendix for the Puma Test Planning Report because it specified what instrumentation would be required to collect the required data so that management could provide access to it over the course of the program. While the PFTP did not require any external instrumentation for the Puma, this would be effective for any program that needed to acquire additional instrumentation/sensors. The List of Abbreviations was used to define any abbreviations or acronyms used throughout the Puma Test Planning Report so that any recipient of the report could understand the contents.

When all planning considerations were brought together to create the Puma Test Planning Report, the document became a comprehensive and descriptive plan for the entire test program. It provided management with a transparent view of the test program so that approval for the proposed testing could be issued. The report facilitated the completion of the program on schedule and preserved the safety of the Puma as well as the flight test team through the planning of a low risk flight test program. The entire report was an effective method for planning the PFTP and therefore should apply to, and do the same for, any generic sUAS test program it is used to plan.

5.3 Puma Flight Test Cards

The AFL desired to use its own Flight Test Cards that have been developed for use in sUAS test programs. The AFL was given the test sequences required to obtain data for each MOE which were then included in the AFL Flight Test Cards. The AFL supplied the Flight Test Cards to everyone present at the pre-flight briefings where the cards were briefed before the team made its way to the EFR to conduct the test. Each section on the flight test card was addressed during the pre-flight briefings. This served to notify the team of their positions for the day, explain the test sequence, and highlight any important watch items for the test. The Flight Test Card was verified as an effective sUAS flight test approach resource through its history of use with the AFL. The AFL uses the cards every time a sUAS flight test is made and hence have tailored the cards for exactly the purpose this thesis study aims to achieve. The AFL Puma Flight Test Cards proved effective as the operation was conducted without incident and all the required maneuvers were conducted as specified so that data could be recorded. Because two different tests were designed, two different versions of the Puma Flight Test Card were created for the PFTP and one is included in its entirety in Section F of the Appendix. The AFL Flight Test Cards were then used to create generic instructional templates for any sUAS test flight. The success of the AFL Flight Test Cards suggests that the generic sUAS Flight Test Card instructional template is an effective

resource for sUAS performance flight testing and a detailed analysis of the major sections of the Puma Flight Test Card is included below.

5.3.1 Test Objectives

The Test Objectives section of the Puma Flight Test Card proved an effective way to list the test objectives so that the flight test team would be able to reference them during the test.

5.3.2 Test Site

The Test Site section of the Puma Flight Test Card proved an effective and informative way to list the details of the test location so the flight test team could use it as a reference for the testing activities being completed.

5.3.3 Personnel

The Personnel section of the Puma Flight Test Card proved an effective way to specify personnel responsibilities during the test flights and provided a reference for the team as the test was being conducted. It ensured that every vital position was covered and that every member of the team knew what their role was for the day.

5.3.4 Aircraft

The Aircraft section of the Puma Flight Test Card served to inform the team of what aircraft was being tested and allowed a record of the tests performed on the aircraft to be maintained by referencing the test cards.

5.3.5 Call Sign

The Call Sign section of the Puma Flight Test Card served to provide a reference for the aircraft call sign in case contact with ATC or nearby air traffic had to be made to comply with regulation.

5.3.6 Frequencies

The Frequencies section of the Puma Flight Test Card was an effective way to list the relevant air traffic frequencies in the test area and provided a reference for the flight test team in case contact with ATC had to be made to comply with regulation.

5.3.7 Weather Limits

The Weather Limits section of the Puma Flight Test Card was an effective way to list the Part 107 weather restrictions as well as the Puma specific weather limitations. This provided a reference for the team so that the weather could be monitored during the test in case of deterioration.

5.3.8 Operation Limits

The Operation Limits section of the Puma Flight Test Card was an effective way to list the Part 107 operational limits as well as the Puma specific operational limitations. This provided a reference for the flight test team that allowed the test maneuvers to be monitored so that operational limits were not broken.

5.3.9 NOTAMs

The NOTAMs section of the Puma Flight Test Card served to inform the team of NOTAMs issued in the area as well as the current Part 107 NOTAM the aircraft was being flown under. This provided a reference for the team during the test that ensured the test program would comply with FAA regulation.

5.3.10 Test Sequence

The Test Sequence section of the Puma Flight Test Card provided a reference for the team and pilot so that the test maneuvers could be completed as planned in the Puma Test Planning Report. This ensured that the pilot always had a reference for the commands to give to the aircraft so that the required data could be collected.

5.3.11 Watch Items

The Watch Items section of the Puma Flight Test Card provided a reference for the flight test team that listed voltages and settings of the Puma that needed to be monitored to maintain the safety of the operation. This proved effective because the Watch Items were always monitored and never allowed to reach the threshold values.

5.3.12 Phone Numbers

The Phone Numbers section of the Puma Flight Test Card provided a reference for the contact information of both the management of the AFL and of emergency services. This was effective because if management needed to be contacted about the test, or if an emergency arose, the numbers were readily available.

5.3.13 Directions

The Directions section of the Puma Flight Test Card provided a reference for the directions to the test site. This was effective because if the information was needed in an emergency or to direct team members, it was readily available on the card.

When all were combined to form the Puma Flight Test card it proved an asset to have in the field. As the only source of information during the flight tests, it provided vital references that kept the operation safe, effective, and efficient. Because of the use of the Puma Flight Test Cards, all the required data was recorded which resulted in the success of the PFTP. The entire Puma Flight Test Card was an effective resource for conducting the tests in the PFTP and therefore should apply to, and do the same for, any generic sUAS test program it is used in.

5.4 Puma Quick Look Reports

After every test was completed, a Puma Quick Look Report was created to document the preliminary results and test conditions. The description provided by the Air Force was used to create a 2-page document that was filled out with information pertaining to each Puma test. There

were six tests conducted, so six Puma Quick Look Reports were made and distributed to the team a few days after each test was completed. This part of the approach was verified as effective through its use in the PFTP. The reports proved an effective way to disseminate information and allowed the team to draw preliminary conclusions about the system as the testing progressed. In addition to the preliminary results of the test, the documents noted any additional characteristics noticed and any testing incidents that occurred. They featured graphical representations of the MOE results and make a preliminary conclusion on whether the MOEs quantified during the test met the original requirements they were derived from. This allows the development team to start addressing flaws in the design early if it appears a requirement will not be met. The report also detailed the next test to be completed so that the team would be prepared and served as a record of information needed to formulate the Puma Final Testing Report. An example of one of the Quick Look Reports completed for the PFTP can be found in Section G of the Appendix. The Puma Quick Look Reports were created from generic instructional templates derived from the Air Force description. The success of the Puma Quick Look Reports suggests that the generic instructional sUAS Quick Look Report template is an effective resource for sUAS performance flight testing and a detailed analysis of the major sections of the Puma Quick Look Reports is included below.

5.4.1 Specific Test Day Information

The Specific Test Day Information section of the Puma Quick Look reports provided a record of the conditions of the test. This included the date and time, the aircraft, the location, the weather conditions, involved agencies, and present personnel. All factors were recorded for later analysis in the Puma Final Testing Report. This proved important for the PFTP because it was eventually found that the start time and weather tended to have large effects on the consistency of the data recorded. Because the Puma Quick Look Reports were distributed as soon as possible after each test was completed, they provided management with records of the same information which could be useful for reference later.

5.4.2 Test Objectives

The Test Objectives section of the Puma Quick Look Report described the specific objectives for each day's test. This was important to include because the objectives changed when different MOEs were being tested and it provides a measure of success for that specific flight test. When distributed to the AFL team and management, the Test Objectives section provided a clear purpose for the test.

5.4.3 Test Sequence

The Test Sequence section of the Puma Quick Look Report described the sequence that the tests/runs were completed during the test and their associated pilots. This was important for the PFTP because it formed a record of the tests completed and the results between different pilots could either be averaged or analyzed.

5.4.4 Preliminary Test Results

The Preliminary Test Results section of the Puma Quick Look Report graphically represented the preliminary results of the data analysis for that specific test. This was important because the graphical representation tends to paint a better picture of the results than just tabulated results and the differences between individual runs and the total average could be compared for the Puma.

5.4.5 Preliminary Conclusions

The Preliminary Conclusion section of the Puma Quick Look Report served to provided listed versions of the MOE results as well as a conclusion on whether the MOEs met the original system requirements they were derived from. This informed the AFL team and management of the current operational capability of the aircraft as the testing progressed which allowed for early decisions about the capability of the aircraft to be made.

5.4.6 Unrelated Performance Issues

The Unrelated Performance Issues section of the Puma Quick Look Report served to document any other characteristics of the system that were not quantified as MOEs. This is important because as the PFTP progressed, more was learned about the operation of the Puma which needed to be documented. This section was effective at documenting other features of the aircraft that weren't the focus of the tests so they could be reported comprehensively in the Puma Final Testing Report.

5.4.7 Testing Incidents

The Testing Incidents section of the Puma Quick Look Report served to document any incidents that occurred during the test program. This was effective because the rough landings associated with the Puma's deep stall tended to damage the aircraft slightly. By documenting this damage and the repairs made, management could purchase replacement parts as needed and the AFL team could reference what repairs needed to be made before the next flight. This is important for any sUAS and makes it a relevant and useful contribution to the generic sUAS Quick Look Report.

5.4.8 Next Test

The Next Test section of the Puma Quick Look Report served to describe the next planned test so that the test team could be prepared for the general purpose of the test and reference the planned date for it. This is effective because it allows the allocation of personnel to be made according to who is available or the cancellation the test if not enough crew are available.

When all these sections are combined, a comprehensive description of the results of the test day is formed. This is valuable because it provides early insight to the performance capabilities of the aircraft and documents each test day in detail. When distributed to management it provides a transparent picture of accomplishments of the test. It also allows management to make decisions about the product development as early as possible which helps to mitigate some risk involved in the program. The entire Puma Quick Look Report was an effective resource for conducting the

tests in the PFTP and therefore the template should apply to, and do the same for, any generic sUAS test program it is used in.

5.5 Puma Final Testing Report

The Puma Final Testing Report was created by taking an Air Force template for the document and altering it to be relevant to the PFTP. It was delivered to the AFL team for documentation after all planned flight tests were completed. The data analysis in the Final Report is much deeper than is featured in the Quick Look Reports and covers all aspects of the flight test program. This part of the approach draws its verification as an effective sUAS flight test resource from its use in the PFTP. The Puma Final Testing Report was designed to be a standalone document so that the purpose and results could be understood without having to be directly involved in the flight test program itself. It detailed information about how the test program was organized, the MOEs it quantified, and any other information learned while flight testing the Puma. It was an effective resource because it allowed for a detailed analysis of each MOE result which was tied back to whether the original requirements for the system were met or not. This allowed AFL management and the team to make decisions about the operational effectiveness, safety, and deficiencies of the Puma. It also included a breakdown of any additional flight characteristics discovered while testing. If the impact was negative, or if an MOE was failed, it was reported as a deficiency in the design and the impact of the deficiency along with recommendations for resolving it were given. The Puma Final Testing report proved to be an effective way to disseminate all the important information and to conclude the program in a fashion that allows management to make important decisions about the operation of the Puma. The Puma Final Testing Report as it was completed for the PFTP can be found in its entirety in Section H of the Appendix. To format this report, a generic instructional template was created from the template released by the Air Force and was altered to apply specifically to sUAS. The success of the Puma Final Testing Report at concluding the program suggests the generic

instructional sUAS Final Testing Report is an effective resource for sUAS performance flight test and an analysis of the major sections of the report is included below.

5.5.1 Executive Summary

The Executive Summary section of the Puma Final Testing report provided an overview of the test program and a description of the contents of the document. Because the Puma Final Testing Report was designed to be a standalone document, the Executive Summary is vital for describing a high-level overview of the Puma program and noting the intentions of the entire document. This was effective because if the Puma Final Testing Report was the only document read by an external person, the scope and purpose of the test program would be understood.

5.5.2 Figures

The Figures section of the Puma Final Testing Report contained all the graphical representations of data collected over the course of the program that quantified the MOEs of interest. A description was added underneath each graph so that some context would be provided. Placing all the Figures at the beginning of the Puma Final Testing Report allowed AFL management to rapidly locate the data most vital to the product development.

5.5.3 Tables

The Tables section of the Puma Final Testing Report contained all the tabulated representations of data collected over the course of the program that quantified the MOEs of interest. This allows the exact values of the average MOE result and its standard deviation to be reported. This section supplements the Figures section and the two combined provide all the results of the MOEs that were quantified. This was effective because all the MOEs results that were tabulated could be easily located at the beginning of the document.

5.5.4 Abbreviations and Acronyms

The Abbreviation and Acronyms section of the Puma Final Testing Report contained definitions of all the abbreviations and acronyms used throughout the document. The aerospace

industry tends to utilize a lot of acronyms and because this document was designed to be standalone, it is important to include this section for the recipients of the report.

5.5.5 Purpose and Background

The Purpose and Background section of the Puma Final Testing Report contained subsections addressing the Testing Purpose; the Testing Background; a Description of the Tested System; and the Test Force, Location, Dates. The Testing Purpose subsection included the purpose for testing the Puma and was effective at describing it for the purpose of the standalone report. It provided a reference for the purpose of the entire program that would be the focus of the report. The Testing Background subsection provided the background behind the purpose for the test program. This facilitated the standalone nature of the document by providing a complete explanation of why the program needed to be conducted. The Description of Tested System subsection provided the same description of the Puma found in the Test Planning Report which detailed both typical and atypical aspects of the aircraft that should be known to understand the report. The Test Force, Location, Dates subsection addressed the test force conducting the PFTP, the location the testing occurred, and the general dates the program took place between. This provides additional important information for any recipients of the report. All these subsections in combination provide a complete overview of the scope and purpose of the test program that facilitate the standalone intention of this document and made this section of the Puma Final Testing Report a relevant and useful contribution to include in the generic sUAS Final Testing Report.

5.5.6 Test Description

The Test Description section of the Puma Final Testing Report contained subsections addressing the Test Objectives, Scope and Method, Planning Considerations and Limiting Factors, and Business Relationships. The Test Objectives subsection specified the primary and secondary objectives for the PFTP. This is important to include because these are more specific than the Testing Purpose section and address each MOE to be quantified by name. The Scope and Method subsection was a general overview of how the PFTP was conducted and organized.

This subsection was effective at describing how tests were organized to collect data for multiple MOEs in the same flight, as well how the data would be recorded and analyzed. The Planning Considerations and Limiting Factors subsection lists the constraints and limits placed on the test program by regulation and by the perceived capability of the aircraft. This section was effective at noting what factors limited the proposed tests for the PFTP. The only test that could not be conducted was the Radio Range Test because the anticipated range of the Puma was much farther than the VLOS regulation set by the FAA. The Business Relationships section served to detail the relationships between the differing entities participating in the PFTP. It was effective at noting the roles the AFL and the author of this study would play when working in conjunction. This is important because often different organizations may work together on the same flight test program with different objectives. When all these subsections are combined, a comprehensive description of how the tests were conducted is formed.

5.5.7 Operational Effectiveness and Suitability

The Operational Effectiveness and Suitability section of the Puma Final Testing Report contains subsections addressing the Summary, MOEs, Additional Findings, a Safety Assessment, an Environmental Impact Assessment, and an Operational Impact Assessment. The Summary provided an overview of the Operational Effectiveness and Suitability section because it was the most important section within the Puma Final Testing Report. The Summary addressed the high-level results of the test program and whether the program was effective at quantifying the MOEs. The MOEs subsection detailed each individual MOE quantified over the PFTP and its results. This was effective because it referenced the relevant Figures at the beginning of the document and provided an analysis for the results of each MOE. The Additional Findings subsection detailed any additional characteristics of the Puma that were found during the PFTP. This was important because when testing for specific MOEs, other unknown or unanticipated characteristics of the system appeared and needed be documented. This occurred multiple times during the PFTP and this section provided an adequate avenue for documentation. The Safety Assessment subsection assessed the safety of operating the Puma. This was an effective way to

report the perceived safety of operating the Puma to the AFL team because it provided a concise conclusion for the aircraft after being tested extensively. The Environmental Impact Assessment assessed the impact of operating the Puma on the environment. Because the Puma was electric and did not have any hazardous materials on board besides the Lithium-Ion battery, this section was not as significant for the PFTP as it could be for other applications. It was included because it provides an area to document the environmental impact of other aircraft that may use the generic template with differing propulsion systems or payloads. The Operational Impact Assessment assessed the operational capability of the aircraft based on the results of the quantified MOEs and additional findings. This was one of the most important subsections because it provided a conclusion about how effective the Puma was at meeting the requirements set for it. This must be included in the generic template because it provides one of the most important conclusions in the report. When all the subsections are combined a comprehensive analysis of the aircraft performance is formed and conclusions can be made about the capability of the aircraft to fulfill its design.

5.5.8 Performance Deficiencies

The Performance Deficiencies section of the Operational Effectiveness and Suitability contained subsections addressing Deficiency Reports and an Impact Summary. The Deficiency Report subsection was used to report the three MOEs that failed to meet the system requirements for the PFTP as well as any additional findings that were negative characteristics of the aircraft. This was an effective way to report the deficiencies of the Puma as they were listed by priority and included possible ways to fix the deficiencies. The Impact Summary subsection addresses the impact the deficiencies have on the operational capability of the aircraft. For the Puma, even though it had multiple deficiency reports, the operational capability was not severely affected by them. This was an effective way to note that while the aircraft did not perform as desired, the intended capability of the aircraft is still intact which bodes well for the system. When these subsections are combined, the Performance Deficiencies section provides an adequate way to report features of the aircraft that need to be addressed and their impact on the capability

of the aircraft. This allowed the AFL team to form conclusions and be aware of the deficiencies that come with operating the Puma.

5.5.9 Summary of Conclusions and Recommendations

The Summary of Conclusions and Recommendations section of the Puma Final Testing Report provided a comprehensive conclusion about the findings of the entire PFTP. This finished the report by reiterating whether the MOEs were met and detailed any additional findings that affected the performance of the aircraft. It included recommendations about the operational use of the Puma learned through the extensive PFTP. This was effective because the conclusions and recommendations provided the AFL with quantified performance metrics and knowledge of previously unknown characteristics of the Puma.

5.5.10 References

The References section of the Puma Final Testing Report contained any references made to other documents or organizations made throughout the PFTP. This is important because as a standalone document, the Final Testing Report should include references to any relevant documents needed to understand the program.

5.5.11 Appendix

The Appendix section of the Puma Final Testing Report contained any figures, tables, and/or quotes that provide supplemental information for the report. The Puma Final Testing Report Appendix section included the Requirements Traceability table made as part of the Puma Test Planning Report so it could be referenced to facilitate the standalone nature of the document.

When all these sections are combined, a comprehensive standalone document is formed that reported the findings of the entire PFTP. If the AFL chooses to archive this document for their records, the Puma will never have to be flight tested for these metrics again in the same configuration. As university research organizations are made of student employees, the turnover rate for personnel is typically high. When the current AFL personnel move on, this information would otherwise be lost if not archived. With this document, any new personnel in the future

should be able to read it and understand how the test program was conducted and what the performance results were. The success of this report to document the entire PFTP suggests that the generic instructional sUAS Final Testing Report template it was created from should apply to, and do the same for, any generic sUAS flight test program.

Chapter 6

SIGNIFICANCE OF STUDY

6.1 Commercial/Research Development

This study is significant for commercial and research-based developers of sUAS that do not have access to or experience with aircraft flight test experience. This study has combined experience from years of manned flight test with experience in a sUAS flight test program with the RQ-20 Puma to provide a tailored approach for any generic sUAS development. Universities conducting research and small companies now have access to a resource that wasn't available before and should aid in making sUAS development safer and more effective for them. This has the added benefit of spreading standard flight test knowledge throughout the sUAS development industry which could speed up technological advancement of sUAS related products.

Conducting flight test activities often comes with increased risk as the system is not yet proven and if not conducted properly can risk damage to property, people, and/or loss of the aircraft. This can be detrimental to small research and commercial development organizations that do not have the funding to support the loss of a test aircraft and continue the program. This approach should give organizations confidence in their programs by providing a base for testing that emphasizes safety and efficiency. The documentation facilitates communication within an organization as it did with the Puma Flight Test Program which is beneficial for a team-based activity.

Producing documentation while conducting flight tests allows the proceedings to be archived and referenced if needed later. Many research-based organizations at Universities and small businesses have high employee turnover rates and the information from the flight test activities will disappear with them if not properly documented. This ensures the flight tests will only have to occur once and the information discovered during the program will be preserved.

The approach has been distilled to only include the most relevant information from the manned flight test industry while maintaining its utility for sUAS. The level of work required to

produce the documentation and conduct the flight tests is appropriate for an sUAS flight test program and can be completed by a single dedicated employee, making it a good fit for small teams to use.

The long-term goal of this study is to produce an approach to flight testing that could be a standard across the sUAS industry while remaining customizable for any type of aircraft or test required. The study succeeded in producing a set of instructional templates for documents and recommendations that are well formulated to achieve this goal. If it is adopted by organizations without flight test experience, it has the potential to be a very useful resource for creating safe and effective flight test programs.

6.2 Recreational Development

This study was prominently focused on providing an approach for small companies and organizations conducting sUAS research and product development, but still can be useful for recreational developers. This approach includes caveats that might apply to the recreational developer of sUAS. If reviewed with careful discretion, parts of this approach can be valuable to recreational developers without flight test experience. Often, loss of a test aircraft or damage to property is detrimental for the recreational developer also. This approach aims to recommend certain processes that help mitigate the risk that these may occur. With the absence of any other resource available for sUAS flight test procedures and recommendations, this study is the best fit resource for guiding sUAS flight test activities for any aircraft in a safe and effective fashion.

6.3 Future Development

This study was successful at developing the preliminary framework for a standard sUAS flight test approach. It was further developed through the Puma Flight Test Program with the AFL. However, the AFL is a dedicated sUAS flight test organization with significant experience that contributed to the success of the approach and the program itself. In the future, the approach

should be tested through use in flight test programs with the target audience of the approach (small companies or organizations without flight test experience and recreational developers).

PolyGAIT, an organization on the Cal Poly campus that specializes in RFID product development, has plans to use the process to guide their flight test programs in the near future. PAAC, an agriculture automation research club also at Cal Poly, has sUAS aircraft they plan to develop for agricultural purposes. The use of the approach through organizations such as these should be analyzed for effectivity and modified to better provide its target audience with the instruction required to conduct their research safely and effectively.

The application of this approach to recreational developers should also be further proven by applied testing. The San Luis Obispo Flyers Club is a private organization that also makes use of the EFR. It consists of several members that fly various types of purchased and homebuilt sUAS that could provide suitable test subjects for use of the approach recreationally.

Another suggestion is to turn the developed documentation into semi-automated forms that can be filled out more rapidly and effectively than they currently can be. Instead of leaving the creation of the documentation completely up to the user, these forms would allow the user to have more limited options possibly in the way of drop-down lists, checkboxes, and/or free-fill areas. An improvement on this would include a database of conditions or test results that makes the forms more automated.

A final suggestion is to expand the flight test applicability of this approach to apply additionally to systems/payload and flight/handling qualities. The scope of this study was limited to performance testing because it provides critical information about the operation of the aircraft and somewhat applies to the other two categories of flight test previously mentioned. The expansion of testing applicability will emulate how the Air Force typically tests aircraft and reduces it from its current widely generic form.

BIBLIOGRAPHY

- [1] "Advisory Circular 107-02." *Federal Aviation Administration Regulatory and Guidance Library*, 21 June 2016, www.faa.gov/uas/resources/policy_library/media/ac_107-2_afs-1_signed.pdf.
- [2] "Amateur-Built Aircraft and Ultralight Flight Testing Handbook Advisory Circular 90-89B." *Federal Aviation Administration Regulatory and Guidance Library*, 24 May 1995, [rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/d08fa9393154b636862569ba006f6d7f/\\$FILE/ATTLMVEO/AC90-89A.pdf](http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/d08fa9393154b636862569ba006f6d7f/$FILE/ATTLMVEO/AC90-89A.pdf).
- [3] "Test & Evaluation Management Guide." *Defense Acquisition University*, Aug. 2016, www.dau.mil/guidebooks/Shared%20Documents/Test_and_Evaluation_Mgmt_Guidebook.pdf.
- [4] "Air Force Flight Test Center Flight Test Preparation Guide." *Defense Acquisition University*, May 1994, myclass.dau.mil/bbcswebdav/institution/Courses/Deployed/TST/TST303/Student_Materials/TST303%20V1.9%20Student%20CD%20Jan17/1%20US%20Air%20Force%20Guidance/AFFTC%20Test%20Plan%20Guide.pdf.
- [5] United States, Congress, Air Force. "Air Force Test and Evaluation Guidebook." *Air Force Test and Evaluation Guidebook*, 1.0 ed., USAF, 2004.
- [6] Stoliker, F.N. "DTIC ADA444990: Introduction to Flight Test Engineering." *Archive.org*, London : F. Warne ; New York : Scribner, Welford, and Armstrong, July 2005, archive.org/stream/DTIC_ADA444990/DTIC_ADA444990_djvu.txt.

APPENDICES

A. Generic sUAS Test Planning Report Template

A template for a generic sUAS Test Planning Report is included on the following page of this section. This is an example of the suggested formatting for a Test Planning Report in practical use. The following template is a series of images that can be used to formulate the Test Planning Report for any generic sUAS test program. Any text in red should be removed upon completing the final version. Any other text should be left as is for effectivity of the template.

Company/Agency Logo

Descriptive Title of Proposed Test Program

Test Program Engineer Name
Test Program Engineer

Month and Year Proposed

TEST PLANNING REPORT

Company/Agency Name Here – Logo in top right or left of document

1

The following test plan and related activities have been approved by the following governing persons.

Prepared by:

John/Jane Doe
Test Program Engineer

This Test Plan has been reviewed and approved for implementation:

John/Jane Doe
Manager or Chief Pilot

EXECUTIVE SUMMARY

- Describe involved agencies and reasoning for proposed test program.
- Describe the test aircraft proposed for use and the intended results of the test program.
- Describe Test Planning Report contents, resources required, program start and end dates, and proposed testing activities.
- ****EXAMPLE BELOW****

EXAMPLE: This document details the proposed Test and Evaluation activities to be carried out for the Cal Poly San Luis Obispo AFL (Autonomous Flight Lab). The AFL is an entity that conducts UAS (Unmanned Aircraft System) research and development. This testing occurs as part of a thesis topic developed by Neil Wolfe at California Polytechnic State University, San Luis Obispo. The thesis topic aims to derive complete performance flight testing procedures for general sUAS (Small Unmanned Aircraft Systems). Small companies with the desire to create an unmanned platform to showcase a product will find this especially useful as they usually do not have any tested procedures in place.

The aircraft to be tested is the AFL's AeroVironment Puma fixed wing UAS. Performance testing of the Puma is proposed to verify the validity of the procedures developed to flight test generic sUAS. This proposed tests in this document will cover a broad spectrum of relevant aircraft performance evaluations that provide valuable information about the flight characteristics of a new, modified, or existing system.

This document aims to detail the necessary flight test activities, crew, resources, safety, requirements and MOE's (Measures of Effectiveness) involved in testing the Puma aircraft. Resources from the AFL will be required which include the Puma aircraft and current pilots. The testing activities are proposed to occur Friday mornings between March and August of 2019 and will require both ground and flight testing.

Table of Contents

EXECUTIVE SUMMARY	3
INTRODUCTION	5
BACKGROUND	5
TEST ITEM DESCRIPTION.....	5
TEST OBJECTIVES	5
TEST AND EVALUATION.....	6
CONSTRAINTS AND LIMITATIONS	6
TEST RESOURCES	6
SAFETY REQUIREMENTS.....	6
SECURITY REQUIREMENTS.....	7
TEST PROJECT MANAGEMENT	7
MEASURES OF EFFECTIVENESS	7
TEST PROCEDURES	8
TEST REPORTING	10
ENVIRONMENTAL PROTECTION	10
APPENDIX	11
TEST CONDITION MATRIX	11
SAFETY/RISK CONDITIONS.....	12
REQUIREMENTS TRACEABILITY	12
DATA ANALYSIS PLAN.....	13
INSTRUMENTATION PLAN.....	13
LIST OF ABBREVIATIONS	14

****RECOMMENDED TABLE OF CONTENTS STRUCTURE****

INTRODUCTION

BACKGROUND

- In detail, describe background of the proposed test program. Describe purpose of tests and name the aircraft being tested. Specify the intended recipients of the Test Planning Report. See Example below.

EXAMPLE: When a new aircraft is created or an existing aircraft is modified, the first flight tests that must be done to understand the flight characteristics of an aircraft are performance tests. These tests allow the developing entity to understand if the aircraft design meets the original requirements set for the project. The original requirements of the Puma aircraft are unknown, but performance specifications are listed in the user manual. These specifications will be used as requirements to judge if the Cal Poly AFL Puma meets the original Puma specifications. The purpose of these tests is to help verify the process being developed for sUAS flight test while also determining the actual performance characteristics of the Puma given to the Cal Poly AFL. A series of tests will be done to evaluate overall Puma performance and will be detailed in this document. This document will be given to the head of the AFL and Chief Puma Pilot as a proposal/plan for testing activities.

TEST ITEM DESCRIPTION

- In detail, describe the test aircraft. Specify the type of aircraft, typical weight, flight control methods, payload, ground-station, expected endurance, recovery methods, etc. See example below.

EXAMPLE: The aircraft being tested is the AeroVironment RQ-20 Puma. It is a 15 lb. hand launched, fixed wing sUAS originally designed to conduct surveillance, reconnaissance, and intelligence gathering for the United States Military. The Puma is one of few unmanned aircraft also certified to fly in US airspace for commercial purposes. Puma features one electric motor and 2 control surfaces (Rudder, Elevator). The Puma has a camera suite and gimbal payload supported by a 9.2 ft wingspan. It is operated from a tablet-like controller that supports manual and autonomous flight for roughly 2.5 hours. The Puma lands by performing a controlled stall just above the ground with wings that separate from the fuselage upon impact. The Puma is a simple platform but very durable, making it suitable for vigorous flight tests associated with procedural development.

TEST OBJECTIVES

- In detail, describe the primary and secondary test objectives. Specify any requirements or characteristics the tests are intended to quantify. See example below.

EXAMPLE: The primary objectives of these tests are to verify that the thesis-based documentation and procedures for conducting generic sUAS flight test are effective and efficient. Secondary objectives are to determine the actual performance characteristics of the Puma used by the AFL. The performance characteristics to measure will be the Puma's endurance, climb, maximum level speed, deep stall glide ratio, GPS accuracy, and altitude holding capabilities.

TEST AND EVALUATION

CONSTRAINTS AND LIMITATIONS

- Describe and list any applicable constraints or limitations to the testing activities proposed. Consider the type of aircraft, airspace regulations, and constraints to the Area of Operation. See example below.

EXAMPLE: Conducting tests in commercial airspace requires that the testing entities heed to commercial sUAS regulations. For aircraft under 55 pounds, these regulations are referred to as the FAA Part 107 Small Unmanned Aircraft rules. Any flight in US airspace for commercial purposes must operate under these restrictions. Restrictions relevant to the proposed testing are detailed below:

- Maintain flight at or below 400 feet AGL (Above Ground Level).
- Flight only in Class G airspace.
- Maintain flight over EFR (Educational Flight Range) property.
- Maintain flight within VLOS (Visual Line of Sight).
- Minimum visibility of 3 miles from GCS (Ground Control Station).
- Pilot must have current FAA sUAS Certification.

TEST RESOURCES

- Describe any resources (personnel, hardware, funding, etc.) that will be required to conduct the proposed testing activities. See example below.

EXAMPLE: To conduct these tests, resources from the Cal Poly AFL will be required. These resources include the AeroVironment Puma aircraft as well as current pilots to fly the aircraft. This includes all required hardware, software, and supplies required to operate the Puma aircraft. Conducting the tests will also require an area where remote flight testing is permitted. The Cal Poly EFR fits requirements for a testing location and access to the field is necessary.

SAFETY REQUIREMENTS

- Describe and list any applicable safety requirements for the proposed testing activities. Consider aircraft type, federal and local regulations, and involved agency procedures. See example below.

EXAMPLE: Reference the Safety Risk Matrix in the Appendix. To maintain safe testing practices, the following safety requirements must be met while testing the Puma aircraft. The following are derived from Part 107 Rules, EFR Rules, and from AFL procedures.

- Keep flight below 400 feet AGL.
- Fly only in Class G airspace.
- Fly aircraft within VLOS.
- Minimum weather visibility of 3 miles from GCS.
- No flight over uninvolved persons.
- Limit flight to EFR property.
- PIC (Pilot in Command) must be FAA sUAS certified.
- PIC must be current with Puma aircraft.

- Aircraft hand-launcher must utilize PPE (Personal Protective Equipment).
- Fire extinguisher must be present during flight operations.
- Emergency Service numbers should be easily accessed.
- Emergency Plans should be developed and briefed.
- Additional crew should be present to monitor air and ground traffic.

Reference Appendix Section B for Flight Safety/Risk Conditions.

SECURITY REQUIREMENTS

- Describe any applicable security requirements for the proposed testing activities. Consider federal regulations, export control, IP concerns, and involved agency requirements. See example below.

EXAMPLE: The Puma aircraft was originally designed for military purposes and payloads. The flight computer, accompanying software, and User Manual are export controlled and therefore distribution of related material must be monitored.

TEST PROGRAM MANAGEMENT

- Describe the management relationship between involved personnel and agencies. See example below.

EXAMPLE: The program manager for the Puma Flight Test Program is Neil Wolfe, the thesis developer. The program manager shall work in conjunction with AFL Manager Dr. Aaron Drake, and Olivia Lockhart the Puma Chief Pilot.

MEASURES OF EFFECTIVENESS

- Describe and list the Measures of Effectiveness that will be used to gauge whether the test aircraft performance meets the original program requirements. Relevant MOEs can be derived from requirements the aircraft was designed to meet. The end result should be a metric that can be quantified by flight testing the aircraft. See example below.

EXAMPLE: Measures of Effectiveness (MOEs) are characteristics used to determine if a system meets the original requirements for the system. As noted earlier, the original requirements for the Puma aircraft are not explicitly known. However, the specifications provided in the Puma User Manual and Datasheet will be used to backtrack logical requirements for the aircraft that will have associated MOEs. This will not be the typical method for testing sUAS, but is done to achieve the primary testing objective to determine an efficient documentation and testing process for generic sUAS. The requirement traceability for the MOEs are included in Appendix Section C. MOEs to be monitored during testing are as below.

- Endurance: Hours
- Maximum Level Speed: Knots
- Glide Path Ratio: N/A
- Climb Rate: Feet Per Minute
- Data Link Range*: Miles
- GPS Longitudinal/Latitudinal Flight Path Accuracy: Coordinates
- Altitude Accuracy: Feet

*Range of the Puma is prone to rapid change due to ground geography. Also, as noted in Appendix C, the requirement traceability suggests the range of the Puma aircraft shall be approximately 20 km, which is out of VLOS and breaks Part 107 Rules and the Safety requirements for this test project. Therefore range, a valid MOE, should not be tested on this platform for this project.

TEST PROCEDURES

The following are high level procedures for each flight test to be completed during the project. This section is intended to give an idea of what the tests will consist of and the resources needed for each in chronological order. Detailed test procedures will be distributed by means of flight test card to the pilot and crew prior to testing. The test will be given a name, description, date (subject to change), and crew will be specified here.

- Test Name: **Test Title and # of runs planned**

Test Date (Subject to change on availability/weather): Date and time of day

Description: In detail, describe the specific test planned. Describe how the test will be conducted, how the data will be recorded, and equipment to be prepared prior to testing. Describe the aircraft flight plan and configuration. Note required personnel and their positions needed to conduct the test. Describe how data will be reduced to provide test results, how test repeatability will be conducted, and how many runs of the test are required.

MOEs to be measured:

List all MOEs and associated units being measured during the test here

Crew required:

List all required crew by name and position here, summarize responsibilities.

Required Resources:

List all required resources here (location, hardware, personnel, etc.)

Test Procedures:

1. List all test procedures here.
2. Should be step-by-step instructions on how the pilot and test engineer will conduct the test from takeoff to landing.
3. Add more procedures here.

****EXAMPLE TEST PROCEDURE INCLUDED BELOW****

- **Test Name: Puma Climb Rate Test, 3 runs**

Test Date (Subject to change on availability/weather): 5/17/2019 – Morning

Description: Another vital test to complete during the initial flight test phase is the maximum climb rate test. This will provide the pilot information on the maximum safe climb rate possible from the aircraft. The Puma batteries should be fully charged before this flight. The main purpose of this flight is to determine the maximum climb rate of the Puma. This test will need to be done with the Puma under manual control of the PIC. This will require multiple climbs to 300 feet AGL and allows for the testing of multiple other MOEs in the same test. The Puma can then perform a deep stall, where glide path data will be recorded. The deep stall will be initiated at 300 feet AGL and recovered before the aircraft reaches 100 feet AGL. Once the data is recorded from the glide, a max level speed test can be conducted at 100 feet AGL. This data will then be averaged to come to a sensible conclusion. This test will require multiple runs to obtain sufficient data to analyze.

MOEs to be measured:

Maximum Climb Rate (Feet Per Second)
Maximum Level Speed (KTAS)
Deep Stall Glide Ratio (N/A)

Crew required:

Dr. Aaron Drake, Head of AFL, acting as pilot and aircraft operations manager.
Olivia Lockhart, AFL Pilot, Puma current, acting as pilot and monitor.
Neil Wolfe, Thesis developer, acting as test manager and engineer.
Additional AFL Crew as needed, acting as safety monitors and operational aid.

Required Resources:

AFL AeroVironment Puma and associated hardware, software, and supplies.
AFL Operational Managers, Pilots, and Crew.
Access to Cal Poly EFR.

Test Procedures:

1. Full Crew to arrive at EFR with all required resources including fully charged Puma batteries.
2. Pilot and hand launcher will launch Puma.
3. Timer will start and altitude will be recorded every 10 seconds.
4. End recording climb rate data at 300 feet AGL. 100-foot buffer in case the altitude fluctuates greatly which is a known Puma attribute.
5. Allow aircraft to stabilize and initialize deep stall for recovery at 300 feet AGL. Record starting coordinates and altitude.
6. Allow aircraft to glide from 300 feet AGL and recover before reaching 100 feet AGL. Record coordinates and altitude just prior to recovery.
7. Start Maximum Level Speed test, adjust altitude to 100 feet AGL.
8. Accelerate aircraft from cruise speed to full power.

9. Adjust aircraft trim to maintain level flight.
10. Allow airspeed to stabilize.
11. Record Max Level Speed in knots every 10 seconds when steady, level flight is achieved. Record 3-10 data points.
12. End Max Level Speed Test.
13. Repeat 3-5 times to acquire sufficient data.
14. Analyze data.

TEST REPORTING

- Describe how and when the data will be recorded, analyzed and distributed after every test is completed. Describe how and when the results of the entire test program will be distributed. See example below.

EXAMPLE: Data from test flights should be analyzed immediately after the flight. This will come in two forms, hand recorded data and data from the flight log recorded by the Puma during flight. It is important to do this in case unexpected results occur in either set. In the case of this test program, Quick Look Reports should be constructed by the test program manager after each test session and will be distributed to all involved in the testing program once complete. The Quick Look Report should include a review of the day's test activities and a synopsis of the data collected. It will reference any accidents or off-nominal events that occurred during the day. It will also review the next day/sessions testing to occur. Since testing is planned to occur on a weekly basis, expect Quick Look Reports to be distributed 1-2 days after the test is completed.

At the end of the test project a final report will be distributed to all involved. This report will encompass all testing activities and their results. It will explain the purpose of the testing and the method by which the testing was completed. It will confirm or deny whether the test objectives and all MOEs have been measured and provide results. It will also detail the future of the flight test program and what the next phase should include.

ENVIRONMENTAL PROTECTION

- Describe any undesirable environmental risks due to the proposed test. This includes emissions, risk to the environment, risk to wildlife, etc. Describe how environmental risks will be mitigated. See example below.

EXAMPLE: The Puma utilizes electric propulsion, so emission concerns are minimal. The larger concern is that of a crash resulting in a Lithium Ion battery fire that could potentially turn into a wildfire depending on the climate in the testing location. The test location is in central California, but recent rains have reduced the wildfire risk during the intended testing times. Nonetheless, a fire extinguisher will be present during testing and emergency service numbers will be obviously displayed to the team on the Flight Test Card. Emergency services should be contacted in the case of any moderately sized fire.

The test location is also home to wildlife and herds of cattle so the pilot must be mindful of flying over any living thing not involved in the test itself. Tests are planned at altitude to reduce the effect of noise on the wildlife and allow adequate distance to recover from stalls during the stall tests.

APPENDIX

A. TEST CONDITION MATRIX

Create a test matrix that with specific details of every individual test planned in the program. Include the Test Name, Test Date, MOEs being quantified, and any applicable notes. Notes can include any applicable deliverables post-test, flight conditions, and/or names of pilots planned to fly the test. See example below.

Test Name	Test Date-Variable	MOEs	Notes
Puma Endurance Test #1	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 1
Puma Endurance Test #2	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 2
Puma Endurance Test #3	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 1,2, or 3
Puma Climb Rate Test #1	5/17/2019	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 1
Puma Climb Rate Test #2	TBD	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 2
Puma Climb Rate Test #3	TBD	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 1,2, or 3

B. SAFETY/RISK CONDITIONS

- Describe any relevant safety or risk conditions that could occur during the planned testing activities. Include a name of the condition, the resulting aircraft behavior, planned response to mitigate the condition, and the probability the condition will occur. See example below.

Possible Risk Conditions

- **Loss of Link**
 - Aircraft Behavior: Land Immediately, Go To Rally, Finish Flight.
 - Response: Attempt to regain control of aircraft. Do not attempt to regain control below 100 feet AGL.
 - Probability: Low
- **Loss of power**
 - Aircraft Behavior: Stall, Altitude Decrease, Crash
 - Response: Maintain control over aircraft. If possible, bring Puma back to launch point. If area appears safe initiate deep stall for recovery. Respond to stall or crash site.
 - Probability: Low
- **Loss of control**
 - Aircraft Behavior: Stall, Altitude Variation, Crash
 - Response: Attempt to regain control of aircraft. If possible, bring Puma back to launch point. If area appears safe initiate deep stall for recovery. Respond to crash site.
 - Probability: Low
- **Battery fire**
 - Aircraft Behavior: Stall, Altitude Variation, Crash
 - Response: Maintain control over aircraft. If possible, bring Puma back to launch point. If area appears safe initiate deep stall for recovery. Respond to crash site with fire extinguisher. Call Emergency Services, inform of location and emergency status.
 - Probability: Low

C. REQUIREMENTS TRACEABILITY

- Describe how the MOEs for the entire program are chosen from system level and derived requirements. Show a table of the MOEs being measured and the corresponding requirement from which it was derived. See example below.

EXAMPLE: Typically, system level and derived requirements would come from specific user needs for a system, but for the AeroVironment Puma these are unavailable. For this test project, the specifications of the Puma system will be used as requirements from which the MOEs for the intended tests are derived. These are likely not the original requirements for the system but are typical of unmanned aircraft and therefore will help achieve the primary objective of thesis development by specifying some arbitrary requirements for the Puma.

System Requirement Statement	Derived MOE
The Puma shall have an endurance of 2.5 hours.	Endurance (Hours)
The Puma shall have a maximum level speed greater than 40 knots.	Maximum Level Speed (Knots)
The Puma shall have a deep stall glide ratio of 1:1.	Deep Stall Glide Ratio (N/A)
The Puma shall have a maximum climb rate greater than 100 feet per minute.	Maximum Climb Rate (Feet Per Minute)
The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.	Longitudinal/Latitudinal GPS Accuracy (Feet)
The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.	Altitude Accuracy (Feet)
The Puma shall have a range of greater than or equal to 9.32 miles (15 km).	Range (Miles)

D. DATA ANALYSIS PLAN

- Describe how the data will be recorded, analyzed, and distributed. Note the specific resources required to conduct data analysis, and the complexity involved in acquiring/reducing the required data. See example below.

EXAMPLE: Data will be recorded onto flight test cards by hand directly from the GCS during testing. The data will then be averaged and compared over all tests and the results will be displayed using Excel or Matlab graphing tools. Electronic versions of the raw recorded data will be distributed to those involved upon request from the flight test program manager. The data to be acquired from these tests is relatively simple and requires minor reduction for calculating end results.

E. INSTRUMENTATION PLAN

- Describe and list the instrumentation required to record relevant data for the planned testing activities. Note instrumentation that must be acquired to conduct the test. See example below.

EXAMPLE: The Puma has a closed circuit set of sensors which will be used to measure the required MOEs. No additional sensors are needed for this testing phase. The data is displayed onto the GCS screen which allows it to be recorded by hand at specific locations and times. An accurate timer will be required for the flight test engineer. The sensors to be utilized to measure MOEs on the Puma are listed below.

- GPS Coordinate Output
- Pitot-Static Velocity Output
- GPS Altitude Output
- Wind Velocity
- Flight computer data recorder.

Ground Instrumentation

- Timer

- Anemometer

F. LIST OF ABBREVIATIONS

- Create a table of the abbreviations used throughout the Test Planning report. Include the definition and units, if applicable. See example below.

Abbreviation	Definition	Units
AFL	Autonomous Flight Lab	N/A
AGL	Above Ground Level	N/A
FAA	Federal Aviation Administration	N/A
GCS	Ground Control Station	N/A
GPS	Global Positioning System	N/A
MOE	Measure of Effectiveness	Varies
PIC	Pilot in Command	N/A
PPE	Personal Protective Equipment	N/A
sUAS	Small Unmanned Aircraft System	N/A
UAS	Unmanned Aircraft System	N/A
VLOS	Visual Line of Sight	N/A

A completed example of a Test Planning Report can be found in the Appendix of this thesis.

B. Generic sUAS Flight Test Card Template

A template for a generic sUAS Flight Test Card is included on the following page of this section. This is an example of the suggested formatting for a Flight Test Card in practical use. The following template is a series of images that can be used to formulate the Flight Test Card for any generic sUAS test program. The Flight Test Card should only occupy a single 8.5" x 11" sheet of printing paper and should have both pages printed on one side with room to fold in half in the middle. Any text in red should be removed upon completing the final version. Any other text should be left as is for effectivity of the template.

Flight Test Card			Organization Logo here										
Aircraft Model	Call Sign	Date	1/2										
<u>Test Objective</u> Short description of test objectives here													
<u>Test Site</u> Location Name (Coordinate location here) Elevation: Test site elevation from sea level here Additional test site information here as required													
<u>Personnel</u> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%;">Test Director:</td> <td>Test Director name here</td> </tr> <tr> <td>AVO:</td> <td>Air Vehicle Operator name here</td> </tr> <tr> <td>MO:</td> <td>Mission Observer name here</td> </tr> <tr> <td>VO:</td> <td>Visual Observer name here</td> </tr> <tr> <td>Other positions as required:</td> <td>Other names here as required</td> </tr> </table>				Test Director:	Test Director name here	AVO:	Air Vehicle Operator name here	MO:	Mission Observer name here	VO:	Visual Observer name here	Other positions as required:	Other names here as required
Test Director:	Test Director name here												
AVO:	Air Vehicle Operator name here												
MO:	Mission Observer name here												
VO:	Visual Observer name here												
Other positions as required:	Other names here as required												
<u>Aircraft</u> Full aircraft name and model number here													
<u>Call Sign</u> Full FAA aircraft call sign here													
<u>Frequencies</u> Nearby ATC radio frequencies here Ex: San Luis Tower 124.0													
<u>Weather Limits</u> Area of operation and aircraft specific weather limits here Ex: VMC, 1000-ft ceiling, 3-nm visibility													
<u>Operation Limits</u> Operational limits here Ex: Max altitude of 400 ft AGL within .8 nm of AVO													
<u>NOTAM</u> Operational Notice to Airmen here Ex: Part 107													

Flight Test Card			Organization Logo here
Aircraft Model	Call Sign	Date	2/2
<p><u>Test Sequence</u></p> <p>Flight test sequence here.</p> <p>Ex: Endurance and Position/Altitude Keeping Test</p> <ol style="list-style-type: none"> 1. Launch Aircraft 2. Start tracking GCS and aircraft battery endurance 3. Enter 'Long Endurance' NAV mode at 300 feet AGL (500 MSL) and fly standard pattern 3-4 times 4. Adjust waypoints to satisfy data collection requirements 5. Continue in NAV mode with new waypoints to collect test Lat/Lon/Alt data 6. When data collection is complete adjust waypoint setup to allow improved monitoring near AVO as battery is depleted 7. Wait for 15 minutes remaining battery warning to appear 2 times (21.5V) 8. Land <p><u>Watch Items</u></p> <p>List test watch items here</p> <p>Ex:</p> <ol style="list-style-type: none"> 1. Air vehicle battery voltages <ol style="list-style-type: none"> a. 15-minute flight time remaining warning: 21.5V b. 1-minute flight time remaining warning: 19V 2. GCS battery voltages <ol style="list-style-type: none"> a. BB-2590 GCS battery: 26V b. Flight battery: 21.5V <p><u>Phone Numbers</u></p> <p>List personnel, emergency service, nearby flight operation names and phone numbers here</p> <p>Ex:</p> <p>Neil Wolfe: 555-555-5555</p> <p>San Luis Tower: 555-555-5555</p> <p>Police: 555-555-5555</p> <p>Fire Department: 555-555-5555</p> <p><u>Directions</u></p> <p>Short description of test location directions here for emergency services</p>			

C. Generic sUAS Quick Look Report Template

A template for a generic sUAS Quick Look Report is included on the following page of this section. This is an example of the suggested formatting for a Quick Look Report in practical use. The following template is a series of images that can be used to formulate the Quick Look Report for any generic sUAS test program. Any text in red should be removed upon completing the final version. Any other text should be left as is for effectivity of the template.

Descriptive Test Title and Test Number

Quick-Look Report Template

Test Date: mm/dd/yyyy – Brief XXXX (Time) XXX (Timezone)

Test Aircraft: Producer and aircraft model number

Test Location: Location of testing activities

General Conditions: Describe weather conditions here (thermals, wind, temperature, visibility)

Involved Agencies: Companies/Agencies involved

Personnel present: First and last name of personnel present, can include position

Test Objectives: Describe the main objectives of the test here. Should address the Measures of Effectiveness (MOEs) that the test aims to quantify. Describe the purpose and reason for testing.

Test Sequence/Configuration:

- **Configuration:** Describe the aircraft configuration during testing (payload, fuel, landing gear, etc.).
- Describe the sequence of testing (Test Name and Run #)
Pilot: Include pilot name if applicable.
- Climb/Glide/Speed Run 1 ****EXAMPLE****
Pilot: John Doe
- Test Title Run X
Pilot: Name of pilot

Preliminary Test Results: Graphically display MOE results below to allow preliminary conclusions.

*Error bars represent +/- one standard deviation of the averaged data points.

Other MOE Results here

Company/Agency Name Here – Logo in top right or left of document

Other MOE Results here

Preliminary Conclusions: Summarize the results of testing activities here. Address any prominent trends in the data, any outlying data points, and possible reasons for results that aren't as expected. Display the MOE results below and compare to desired performance specification.

- Average Maximum Climb Rate: 696 feet per minute (Meets requirement: > 100 fpm) ****EXAMPLE****
- Compare MOE #2
- Compare MOE #3

If deeper analysis is required to understand results, include that here. Compare results of this specific test to results of previous tests of the same MOEs. Address if all MOEs tested meet or do not meet the original requirement specified in the Test Planning Report.

Unrelated Performance Issues:

- Discuss any performance issues unrelated to the MOEs tested here.
- Difficulty maintaining consistent altitude in the Altitude Hold flight mode. ****EXAMPLE****

Testing Incidents:

- Discuss any incidents that occurred during testing here. Specify sequence when incident occurred.
Result/Damage: Discuss the result or specific damage caused by the incident here.
- Prior to Run 2 aircraft impacted runway on hand launch, took no significant damage. ****EXAMPLE****
- During Run 2 aircraft flew above 400 feet AGL for a limited amount of time. ****EXAMPLE****
Result: Violation of Area of Operations constraint to 400 feet AGL ceiling, no effect.
- During Run 3 aircraft impacted runway as intended on recovery landing. ****EXAMPLE****
Damage: One snap-screw broken and replaced, ready for future use.

Conclusion: Summarize the incident report by stating the aircraft operational status and required repairs.
Aircraft took minimal damage and fit for continued use. Antenna stand leg must be repaired or replaced.
****EXAMPLE****

Next Test: Describe the next test to be completed below (Test Title and Run #, MOEs, Date, and Location).
The next planned test is Endurance/Flight Path Accuracy Test #1 and will follow a new test sequence. This is the first test measuring the total endurance of the Puma flying autonomously in Navigation Mode (expected to be 2-3 hours). The accuracy of Puma's altitude, latitude, and longitude keeping abilities will be measured at the same time. The test date is tentatively scheduled for July 17th, 2019 based on personnel availability and weather conditions. It will be located at the Cal Poly EFR. ****EXAMPLE****

A further Quick Look Report example can be found in the Appendix of this thesis.

Company/Agency Name Here – Logo in top right or left of document

D. Generic sUAS Final Testing Report Template

A template for a generic sUAS Final Testing Report is included on the following page of this section. This is an example of the suggested formatting for a Final Testing Report in practical use. The following template is a series of images that can be used to formulate the Final Testing Report for any generic sUAS test program. Any text in red should be removed upon completing the final version. Any other text should be left as is for effectivity of the template.

Organization Logo
Here

ORGANIZATION AND AIRCRAFT FINAL TEST REPORT

AUTHOR
Test Project Engineer

MONTH AND YEAR

FINAL TEST REPORT

ADDITIONAL COMPANY INFO HERE (LOCATION, DIVISION, ETC.)

EXECUTIVE SUMMARY

Write an executive summary of the testing activities that occurred here. Should detail the organization, the aircraft of interest, and a high-level purpose for the test program. Summarize the testing that occurred and briefly explain the purpose of the document. Dates that the testing occurred, and any business relationships needed to complete the testing should also be mentioned here. See example below.

EXAMPLE: This document details results of the proposed Test and Evaluation activities carried out for the Cal Poly San Luis Obispo AFL (Autonomous Flight Lab). The AFL is an entity that conducts UAS (Unmanned Aircraft System) research and development. This testing occurred as part of a thesis topic developed by Neil Wolfe at California Polytechnic State University, San Luis Obispo. The thesis topic aims to derive complete performance flight testing procedures for general sUAS (Small Unmanned Aircraft Systems). Small companies with the desire to create an unmanned platform to showcase a product will find this especially useful as they usually do not have any tested procedures in place.

The aircraft tested was the AFL's AeroVironment RQ-20 Puma fixed wing UAS. Performance testing of the Puma was proposed to verify the validity of the procedures developed to flight test generic sUAS. The proposed tests covered a broad spectrum of relevant aircraft performance evaluations that provide valuable information about the flight characteristics of a new, modified, or existing system.

This document details the results of a series of flight tests designed to determine if the Puma's Measures of Effectiveness (MOE's) satisfied the original system requirements. Because the Puma is already a finished product, the AFL will use this information to guide their operations with the aircraft. The testing activities occurred on weekday mornings between March and August of 2019.

Table of Contents

Follow the template for the table of contents below. This has been taken from the Air Force Test and Evaluation Management Guidebook. Replace the page numbers and add additional MOEs as necessary.

EXECUTIVE SUMMARY	2
FIGURES	4
TABLES	7
ABBREVIATIONS AND ACRONYMS	8
PURPOSE AND BACKGROUND	9
TESTING PURPOSE.....	9
TESTING BACKGROUND	9
DESCRIPTION OF SYSTEM TESTED	9
TEST FORCE, LOCATION, DATES.....	10
TEST DESCRIPTION.....	11
TEST OBJECTIVES	11
SCOPE AND METHOD	11
PLANNING CONSIDERATIONS AND LIMITING FACTORS.....	12
BUSINESS RELATIONSHIPS.....	12
OPERATIONAL EFFECTIVENESS AND SUITABILITY	13
SUMMARY.....	13
MOE #1: MAXIMUM CLIMB RATE	13
MOE #2: DEEP STALL GLIDE RATIO	14
MOE #X: MOE TITLE HERE	14
ADDITIONAL FINDINGS.....	14
SAFETY ASSESSMENT.....	15
ENVIRONMENTAL IMPACT ASSESSMENT	15
OPERATIONAL IMPACT ASSESSMENT	15
PERFORMANCE DEFICIENCIES	16
DEFICIENCY REPORTS.....	16
IMPACT SUMMARY	16
SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS	17
REFERENCES	18
APPENDIX	18

FIGURES

Include all Figures created as part of data analysis here. The figures should paint a clear picture about the results and behavior of the aircraft and should address each MOE planned for the test program. Comparisons should be made between individual tests and full averages should be shown with error bars representing the variation in results. Provide as much graphical information about the test results as possible organized in a condensed and readable fashion. See examples below.

A. EXAMPLE: Maximum Climb Rate Test Averaged Results

Figure 1: Average maximum climb rate from each test and overall total result.

Figure 2: Average maximum climb rate results for Test 1.

Figure 3: Average maximum climb rate results for Test 2.

Figure 4: Average maximum climb rate results for Test 3.

B. EXAMPLE: Maximum Climb Rate Profile Samples

Figure 5: Maximum climb rate at every second of the maneuver for Test 3, Run 2. Shows the large variation in climb rate that occurred throughout the test. Only one run is shown as this is typical throughout all runs.

C. Further Figures Here

Figure Here

Figure XX: Brief description of the figure contents here. Add concise points of interest if desired.

TABLES

Include tabulated results for all MOEs here. If possible, show results from all tests done for repeatability and show the total average result. If applicable, also quantify the variation in the data recorded (standard deviation). Tables should have units and the total average should be bolded for emphasis. See examples below.

A. EXAMPLE: Maximum Climb Rate Test Averaged Data Table

Tabulated Maximum Climb Rate Results		
	Average (feet per minute)	Standard Deviation ($\pm$ feet per minute)
Test 1	668	128
Test 2	606	84
Test 3	696	86
All Tests Avg.	656	99

B. EXAMPLE: Deep Stall Glide Ratio Test Averaged Data Table

Tabulated Deep Stall Glide Ratio Results		
	Average Ratio	Standard Deviation ($\pm$ ratio)
Test 1	1.29	0.04
Test 2	1.46	0.28
Test 3	1.36	0.24
All Tests Avg.	1.37	0.19

ABBREVIATIONS AND ACRONYMS

List all abbreviations and acronyms used throughout the document here alphabetically. Include the abbreviation and/or acronym, and the definition next to it. See example below.

EXAMPLE:

AFL	Autonomous Flight Lab
AGL	Above Ground Level
ALT	Refers to Puma Altitude Mode
Cal Poly	California Polytechnic State University, San Luis Obispo
EFR	Educational Flight Range
FAA	Federal Aviation Administration
fpm	feet per minute
GCS	Ground Control Station
KTAS	Knots True Airspeed
MOE	Measure of Effectiveness
NAV	Refers to Puma Navigation Mode
sUAS	small Unmanned Aircraft Systems
UAS	Unmanned Aircraft Systems
VLOS	Visual Line Of Sight

PURPOSE AND BACKGROUND

TESTING PURPOSE

Concisely explain the purpose for testing here. Mention the conducting organization, the aircraft used, and the location of the test program. See example below.

EXAMPLE: The purpose of the proposed testing activities was to determine important performance characteristics of the AeroVironment RQ-20 Puma sUAS operated by the Autonomous Flight Lab (AFL) at California Polytechnic State University, San Luis Obispo (Cal Poly). This information will be used to aid in the development of a thesis study by Neil Wolfe and will provide the AFL with quantified information about how the aircraft performs in flight.

TESTING BACKGROUND

Explain the background for the test program here. Mention the reason the tests were required and what the implication of the results may be. Summarize how the program was conducted and the intention of this document. See example below.

EXAMPLE: The AFL uses the Puma for various testing purposes to aid clients in product development or research. It is known by the AFL that because of the Puma's design, the aircraft tends to have radically varying performance characteristics that are not mentioned in the Puma User Manual. The Puma User Manual contains a few performance specifications but is missing many that could be useful to the AFL. The variation in performance and the lack of a full performance profile makes operation of the Puma susceptible to some increased risk. The performance of the Puma will be evaluated to aid in decreasing operational risk and safety concerns. The performance of the Puma was judged against its documented performance specifications which, to aid the thesis study, were used as system level requirements. For performance specifications not detailed in the user manual, logical system level requirements were created to allow an evaluation of performance. A series of flight tests were performed to evaluate overall Puma performance and will be detailed in this document. This document will be given to the AFL as a final report of the findings of this flight test program.

DESCRIPTION OF SYSTEM TESTED

Describe the system being tested here. Describe the type of aircraft, the configuration, and important characteristics of the aircraft that should be known to an outside viewer of this document. See example below.

EXAMPLE: The aircraft being tested is the AeroVironment RQ-20 Puma. It is a 15 lb. hand launched, fixed wing sUAS originally designed to conduct surveillance, reconnaissance, and intelligence gathering for the United States Military. The Puma is one of few unmanned aircraft also certified to fly in US airspace for commercial purposes. Puma features one electric motor and 2 control surfaces (Rudder, Elevator). The Puma has a camera suite and gimbal payload supported by a 9.2 ft wingspan. It is operated from a tablet-like controller that supports manual and autonomous flight for roughly 2.5 hours. The Puma lands by performing a controlled stall just above the ground with wings that separate from the fuselage upon impact. The Puma is a

simple platform but very durable, making it a suitable aircraft from the AFL inventory for vigorous flight testing.

TEST FORCE, LOCATION, DATES

Describe the test force conducting the program here. Mention any business relationships being utilized to complete the test. Describe the test location and the general dates the tests took place between. See example below.

EXAMPLE: As detailed in the Puma Test Planning Report, the main test force consisted of AFL personnel in addition to Neil Wolfe, a graduate student at Cal Poly developing a thesis study. The AFL personnel provided full support of all required flight operations while Neil Wolfe analyzed the recorded data and documented the results of the flight test program. The testing location was the Cal Poly Educational Flight Range (EFR). The EFR is located near Cuesta College outside of controlled airspace and is a designated sUAS area of operation. Priority and liability coverage are given to Cal Poly students and organizations operating out of the EFR. All testing activities occurred on weekday mornings between March and August of 2019.

TEST DESCRIPTION

TEST OBJECTIVES

Describe the primary and secondary (if applicable) test objectives here. The primary objectives are likely to be proving the capability of the aircraft by verifying that it meets the requirements used to guide its design. The MOEs used to do so should be mentioned by name here. Secondary objectives are likely to be discovering any unintended/unknown characteristics of the aircraft and system design. See example below.

EXAMPLE: The primary objective of these tests was to aid in development of the thesis study being conducted by Neil Wolfe. Secondary objectives were to determine the actual performance characteristics of the Puma used by the AFL. The performance characteristics quantified were the Puma's maximum climb rate, deep stall glide ratio, maximum level speed, endurance, position keeping error, and altitude holding error.

SCOPE AND METHOD

Describe the scope and method of the test program here. This should explain where the MOEs mentioned in the Test Objectives section came from and their meaning. The sensors being used to record data should be mentioned here and the method used to record the data should also be specified. Explain how the data was reduced and analyzed. Explain the sequence of testing to be done and which tests will address which MOEs. It is beneficial to create a bulleted breakdown of each test in addition. See example below.

EXAMPLE: As mentioned earlier, the performance characteristics above and specified in the Puma Test Planning Report were turned into MOEs so that the Puma's performance could be evaluated against its system level requirements. The Requirements Traceability Matrix can be found in the Appendix of this document. A series of flight tests were designed allowing data to be collected from the Puma's on-board sensors to quantify the MOEs. Each flight test had an associated Flight Test Card that included specific maneuvers needed to acquire the data. Repeatability was designed into each flight test for data reliability. The data was recorded by capturing the screen of the Puma's Ground Control Station (GCS) which displayed all the required data. The data was then input to Microsoft Office Excel for analysis. The result was a series of six flight tests, each quantifying three different MOEs. The first three tests consisted of the same test sequence which allowed the collection of data for the maximum climb rate, deep stall glide ratio, and maximum level speed. The final three tests consisted again of a similar test sequence and measured the endurance, position keeping error, and altitude holding error. These are listed below for conciseness.

- Flight Test Sequence 1
 - Title: Puma Max Climb/Deep Stall Glide/Max Speed Test
 - MOEs
 - Maximum Climb Rate
 - Deep Stall Glide Ratio
 - Maximum Level Speed
 - Conducted 3 times
- Flight Test Sequence 2

- Title: Puma Endurance/Position Keeping/Altitude Holding Test
- MOEs
 - Endurance
 - Position Keeping Error
 - Altitude Holding Error
- Conducted 3 times

PLANNING CONSIDERATIONS AND LIMITING FACTORS

Describe any operational constraints or limitations that were a factor for the test program here. Consider organization and/or specific flight area rules. Ensure if operating under Part 107 for sUAS the legal constraints to operation are specified here. Also include weather constraints for the specific aircraft. See example below.

EXAMPLE: Conducting tests in commercial airspace requires that the testing entities heed to commercial sUAS regulations. For aircraft under 55 pounds, these regulations are referred to as the FAA Part 107 Small Unmanned Aircraft rules. Any flight in US airspace for commercial purposes must operate under these restrictions. Restrictions relevant to the proposed testing are detailed below:

- Maintain flight at or below 400 feet AGL (Above Ground Level).
- Flight only in Class G airspace.
- Maintain flight over EFR (Educational Flight Range) property.
- Maintain flight within VLOS (Visual Line of Sight).
- Minimum visibility of 3 miles from GCS (Ground Control Station).
- Pilot must have current FAA sUAS Certification.

BUSINESS RELATIONSHIPS

Briefly describe any business relationships utilized during the test program here. Mention if people from other organizations were included in the test program and their roles. See example below.

EXAMPLE: The testing activities proposed by Neil Wolfe were completed in close cooperation with the Cal Poly AFL which owns the Puma and possesses the personnel needed to support flight operations.

OPERATIONAL EFFECTIVENESS AND SUITABILITY

SUMMARY

Summarize the high-level results of the test program here. Explain whether the program was effective at quantifying the metrics it was designed to. Detail whether the results of the test program have implications for the aircraft's operational performance. See example below.

EXAMPLE: Flight testing the Puma was successful in determining the six desired MOEs as well as other unanticipated flight characteristics which are detailed below. Three of the six MOEs met the original system level requirements and the other three did not. If these requirements were vital to a system development the system design would need to be to be addressed. In reality, the AFL Puma cannot be redesigned and these MOEs represent important performance characteristics that could aid AFL operation of the Puma. The flight test activities were used to provide proficiency training for AFL personnel as well to discover unknown characteristics about how the Puma operates. Utilizing the information found in this flight test program, the operation of the Puma for the AFL should be much safer and effective than it previously was.

EXAMPLE: MOE #1: MAXIMUM CLIMB RATE

The MOE section should describe each MOE planned for testing and trace it back to a requirement. This section should explain how data was recorded for each MOE and how the data was reduced/analyzed. The conclusion of each MOE section should include a bulleted breakdown of the results with a concise conclusion on whether the original requirement for the MOE was met. See examples below.

Example: The Puma's maximum climb rate was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a maximum climb rate greater than 100 feet per minute.*

The maximum climb rate was recorded 3 times per flight test to obtain an average for the day. It was calculated by recording and averaging the altitude for every second of the max climb maneuver. This result was then averaged over the 3 tests allocated for the MOE. The maximum climb rate was susceptible to large variation as is shown in *Figures 5 and 6* which can be found in the Figures section at the beginning of this document. These show the climb profile and climb rate over the course of one run from each test and support the conclusion that the Puma's maximum climb rate is susceptible to large variation. During testing it was found that wind speed and thermal circulation appeared to have a large effect on the climb performance. *Figures 1-4* show the results for each individual test in comparison to the total average. The final result for the maximum climb rate MOE is as below.

- Puma Maximum Climb Rate
 - Average: 656 feet per minute
 - Standard Deviation: ± 99 feet per minute
 - Conclusion: Exceedingly meets the original system level requirement

EXAMPLE: MOE #2: DEEP STALL GLIDE RATIO

The Puma's deep stall glide ratio was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a deep stall glide ratio of 1:1.*

The deep stall glide ratio was recorded three times per flight test to obtain an average for the day. It was calculated by recording the altitude and groundspeed of the Puma every second during its descent. Windspeed recorded by the Puma was removed from the groundspeed to obtain the true airspeed which was used to determine the horizontal distance traveled. This result was then averaged over the three tests allocated for the MOE. This MOE was relatively consistent but still showed some large variation through all the test runs and can be seen in the glide profile of Test 3, Run 2 in *Figure 11* in the Figures section at the beginning of this document. This could be due to a variety of factors but is most likely because of wind gusts and the speed at which the stall was approached. *Figures 7-10* show the results for each individual test in comparison to the total average. The final result for the deep stall glide ratio MOE is as below.

- Puma Deep Stall Glide Ratio
 - Average: 1.37:1
 - Standard Deviation: $\pm .19:1$
 - Conclusion: Does not meet the original system level requirement

MOE #X: MOE TITLE HERE

...

ADDITIONAL FINDINGS

The findings listed below are a short summary of additional performance characteristics discovered while performing the planned flight tests.

List any additional discoveries about system operational characteristics that don't fall under MOEs here. Anything can be listed here, and any notable characteristics should be briefly noted in a bulleted list. See example below.

- Difficulty maintaining altitude in Altitude Hold mode.
- Difficulty descending in high wind conditions.
- At ¼ transmitting power, the large GCS battery last over 2.5 hours.
- Can manually navigate Puma manual when in NAV mode.
- The Puma flight battery also works to power the GCS with an adapter.
- Loop timeout must be set longer than expected flight time.
- Etc.

SAFETY ASSESSMENT

Summarize the safety of operating the system here. List any conditions that could cause safety issues and how/if they can be mitigated. Provide a concise conclusion on the perceived safety of the using the system. See example below.

EXAMPLE: Throughout testing the Puma proved itself able to safely and effectively follow all commands given. As mentioned above, the Puma deviated from its plan only one time because of a setup error with the loop timeout. It proceeded to land at its designated safe landing point proving the function of this feature. With the loop timeout set correctly for the application, this will not be a problem. The Puma does have a rather large altitude holding error and variation, so extended operations within 50 feet of the ground are not recommended. When applying full throttle in Altitude mode the Puma tends to bank right and lose altitude, so it is important to be aware of this behavior when performing this maneuver. Changing from NAV mode to ALT mode also produces an extreme banking and altitude loss behavior and is not recommended within 50-100 feet of the ground. Hand launch with little to no wind is difficult to do but if properly organized does not pose a safety risk to those in the vicinity. Video, Telemetry, and Radio links were never lost during operation proving the robustness of the communications systems. If these warnings are heeded when operating the Puma, it becomes an exceptionally safe aircraft to fly and is fit for commercial use.

ENVIRONMENTAL IMPACT ASSESSMENT

Summarize the environmental impact associated with operation of the system. Consider whether the use of the system will affect an ecosystem or natural resource. Provide a concise conclusion of the environmental impact of the system. See example below.

EXAMPLE: Operation of the Puma poses little threat to the environment as it emits no carbon dioxide. Any threat it does pose comes from unintended emergency situations such as a crash or battery fire. If proper precautions are made, there should be no environmental impact from use of the Puma system.

OPERATIONAL IMPACT ASSESSMENT

Summarize the operational impact the results of the test program have for the system. If requirements were not met, address the consequences for the operational capability of the system. Mention any other factors that could affect the operational capability of the system. See example below.

EXAMPLE: Operationally, the Puma proved suitable performance for its main applications of surveillance and reconnaissance. It met the requirements for max climb rate, max level speed, and endurance making it effective when considering these characteristics. While the Puma did not meet the requirements for the deep stall glide ratio, position keeping error, and altitude holding error, the margins are small enough that it should have minimal impact on its primary applications. When planning a mission, if these characteristics are acknowledged then there will generally be little operational impact. The Puma's susceptibility to performance degradation due to wind gusts and thermals has a slightly larger impact as its dynamics become more unpredictable. It also becomes difficult to effectively hand launch with little to no wind. This can be worked around by launching from a raised area or developing/utilizing a mechanical launcher. During testing the Puma proved suitable performance in winds up to 15 knots. The Puma's capability to achieve its primary applications should only be slightly hindered by these characteristics and is therefore operationally capable.

PERFORMANCE DEFICIENCIES

DEFICIENCY REPORTS

Summarize any deficiencies of the system performance here. These are generally negative features of the aircraft performance at risk of impacting operational capability that should be fixed. This should include any failed MOEs and other characteristics seen during testing. The deficiencies should be numbered and listed in order of priority to address. The summary should include a description of the deficiency, how it can affect operational capability, and the priority level of the deficiency. See example below.

EXAMPLE: The following list details any operational deficiencies found while operating the Puma. These are negative features of the aircraft that could potentially affect the operational use. These reports are prioritized in the order of importance for operational capability. When attempting to address aircraft deficiencies it is most valuable to start at the beginning of the list.

1. The altitude holding error of ± 29 feet in both NAV and ALT mode does not meet the original system level requirement. The aircraft tends to fly much higher than it is commanded to. This can affect any use under Part 107 and can affect the quality of the surveillance capability the Puma provides. This is the top priority deficiency because it can affect safety and effectivity and was an original system level requirement. This could potentially be fixed with software modifications to the flight controller.
2. When full throttle is applied, the Puma's attitude keeping abilities are compromised and it tends to drift to the right and lose altitude rapidly. This doesn't allow for straight and level flight which could compromise the surveillance capabilities of the Puma. This is of medium priority as full throttle is not often applied during use. This could potentially be fixed by modifying the flight control software or by checking the control surfaces for deviations from the optimal configuration.
3. Etc.

IMPACT SUMMARY

Summarize the total impact of all the deficiencies on the operational capability of the system. Address whether any of the deficiencies are critical to the system being successful or safe and provide a concise conclusion on the impact of the listed deficiencies. See example below.

EXAMPLE: The impact of these deficiencies slightly detracts from the operational capability of the Puma. However, none of these deficiencies pose major or crucial risks on the Puma's ability to safely and effectively provide surveillance and reconnaissance capability. These should be addressed to provide a better product that meets the system requirements. The flight control software seems to be the major contributor to these deficiencies and is only something that AeroVironment can address. In the case of the Puma's use with the AFL, the best way to mitigate these deficiencies is to be aware of their presence during operation.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Summarize the major conclusions of the test program here. Address whether requirements were met and whether the system is effective and safe to operate. Make recommendations about addressing any deficiencies mentioned earlier. Provide a concise conclusion on the status of the aircraft design and capability at the time the test program had concluded. See example below.

EXAMPLE: In conclusion, the Puma has proven to be a reliable, safe, and effective platform capable of providing the desired surveillance and reconnaissance performance. It met 3 of the six requirements created for it and only slightly failed to meet the other three which should have little affect on the Puma's operational capability. During the test program many unknown qualities of the Puma were discovered and documented, making it a safer and more effective system. Some of these were undesirable performance issues which can be mitigated if the AFL team operating the Puma is aware of them. Almost all the deficiencies found during testing, including the 3 failed MOEs, are only able to be fixed by an aircraft redesign or flight controller update. The Puma was made by AeroVironment, so there is not much the AFL can do about addressing the deficiencies of the aircraft. The best course of action is to brief any users of the AFL Puma on the findings of this report so the operation can be conducted safely and effectively.

REFERENCES

List any references utilized during the test program here. See example below.

EXAMPLE: United States, Congress, Air Force. "Air Force Test and Evaluation Guidebook."
Air Force Test and Evaluation Guidebook, 1.0 ed., USAF, 2004.

APPENDIX

List any documents, figures, tables, etc. to be appended here. See example below.

A. EXAMPLE: Requirement Traceability Matrix

System Requirement Statement	Derived MOE
The Puma shall have an endurance of 2.5 hours.	Endurance (Hours)
The Puma shall have a maximum level speed greater than 40 knots.	Maximum Level Speed (Knots)
The Puma shall have a deep stall glide ratio of 1:1.	Deep Stall Glide Ratio (N/A)
The Puma shall have a maximum climb rate greater than 100 feet per minute.	Maximum Climb Rate (Feet Per Minute)
The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.	Longitudinal/Latitudinal GPS Accuracy (Feet)
The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.	Altitude Accuracy (Feet)
The Puma shall have a range of greater than or equal to 9.32 miles (15 km).	Range (Miles)

E. Puma Test Planning Report Example

The series of images beginning on the following page represent the Test Planning Report as completed for the Puma Flight Test Program. This report can serve as a functional example of the Test Planning Report and can be used to guide the creation of the document for any generic sUAS test program.

CAL POLY AFL AEROVIRONMENT PUMA PERFORMANCE TEST PLANNING REPORT

NEIL A. WOLFE
Test Project Engineer

APRIL 2019

TEST PLANNING REPORT

CALIFORNIA POLYTECHNIC STATE UNIVERSITY SAN LUIS OBISPO, CALIFORNIA - PART OF A THESIS BY NEIL WOLFE

1

The following test plan and related activities have been approved by the following governing persons.

Prepared by:

Neil A. Wolfe
Project Engineer

This Test Plan has been reviewed and
approved for implementation:

Olivia S. Lockhart
Puma Chief Pilot

EXECUTIVE SUMMARY

This document details the proposed Test and Evaluation activities to be carried out for the Cal Poly San Luis Obispo AFL (Autonomous Flight Lab). The AFL is an entity that conducts UAS (Unmanned Aircraft System) research and development. This testing occurs as part of a thesis topic developed by Neil Wolfe at California Polytechnic State University, San Luis Obispo. The thesis topic aims to derive complete performance flight testing procedures for general sUAS (Small Unmanned Aircraft Systems). Small companies with the desire to create an unmanned platform to showcase a product will find this especially useful as they usually do not have any tested procedures in place.

The aircraft to be tested is the AFL's AeroVironment Puma fixed wing UAS. Performance testing of the Puma is proposed to verify the validity of the procedures developed to flight test generic sUAS. The proposed tests in this document will cover a broad spectrum of relevant aircraft performance evaluations that provide valuable information about the flight characteristics of a new, modified, or existing system.

This document aims to detail the necessary flight test activities, crew, resources, safety, requirements and MOE's (Measures of Effectiveness) involved in testing the Puma aircraft. Resources from the AFL will be required which include the Puma aircraft and current pilots. The testing activities are proposed to occur Friday mornings between March and August of 2019.

Table of Contents

EXECUTIVE SUMMARY	3
INTRODUCTION	5
BACKGROUND	5
TEST ITEM DESCRIPTION	5
TEST OBJECTIVES	5
TEST AND EVALUATION	6
CONSTRAINTS AND LIMITATIONS	6
TEST RESOURCES	6
SAFETY REQUIREMENTS	6
SECURITY REQUIREMENTS	7
TEST PROJECT MANAGEMENT	7
MEASURES OF EFFECTIVENESS	7
TEST PROCEDURES	7
TEST REPORTING	10
ENVIRONMENTAL PROTECTION	10
APPENDIX	11
TEST CONDITION MATRIX	11
SAFETY RISK MATRIX	12
REQUIREMENTS TRACEABILITY	12
DATA ANALYSIS PLAN	13
INSTRUMENTATION PLAN	13
LIST OF ABBREVIATIONS	13

INTRODUCTION

BACKGROUND

When a new aircraft is created or an existing aircraft is modified, the first flight tests that must be done to understand the flight characteristics are performance tests. These tests allow the developing entity to understand if the aircraft design meets the original requirements set for the project. The original requirements of the Puma aircraft are unknown, but performance specifications are listed in the user manual. These specifications will be used as requirements to judge if the Cal Poly AFL Puma meets the original Puma specifications. The purpose of these tests is to help verify the process being developed for sUAS flight test while also determining the actual performance characteristics of the Puma derivative given to the Cal Poly AFL. A series of tests will be done to evaluate overall Puma performance and will be detailed in this document. This document will be given to the head of the AFL and Chief Puma Pilot as a proposal/plan for testing activities.

TEST ITEM DESCRIPTION

The aircraft being tested is the AeroVironment RQ-20 Puma. It is a 15 lb. hand launched, fixed wing sUAS originally designed to conduct surveillance, reconnaissance, and intelligence gathering for the United States Military. The Puma is one of few unmanned aircraft also certified to fly in US airspace for commercial purposes. Puma features one electric motor and 2 control surfaces (Rudder, Elevator). The Puma has a camera suite and gimbal payload supported by a 9.2 ft wingspan. It is operated from a tablet-like controller that supports manual and autonomous flight for roughly 2.5 hours. The Puma lands by performing a controlled stall just above the ground with wings that separate from the fuselage upon impact. The Puma is a simple platform but very durable, making it suitable for vigorous flight tests associated with procedural development.

TEST OBJECTIVES

The primary objectives of these tests are to verify that the thesis-based documentation and procedures for conducting generic sUAS flight test are effective and efficient. Secondary objectives are to determine the actual performance characteristics of the Puma used by the AFL. The performance characteristics to measure will be the Puma's endurance, climb, maximum level speed, deep stall glide ratio, GPS accuracy, and altitude holding capabilities.

TEST AND EVALUATION

CONSTRAINTS AND LIMITATIONS

Conducting tests in commercial airspace requires that the testing entities heed to commercial sUAS regulations. For aircraft under 55 pounds, these regulations are referred to as the FAA Part 107 Small Unmanned Aircraft rules. Any flight in US airspace for commercial purposes must operate under these restrictions. Restrictions relevant to the proposed testing are detailed below:

- Maintain flight at or below 400 feet AGL (Above Ground Level).
- Flight only in Class G airspace.
- Maintain flight over EFR (Educational Flight Range) property.
- Maintain flight within VLOS (Visual Line of Sight).
- Minimum visibility of 3 miles from GCS (Ground Control Station).
- Pilot must have current FAA sUAS Certification.

TEST RESOURCES

To conduct these tests, resources from the Cal Poly AFL will be required. These resources include the AeroVironment Puma aircraft as well as current pilots to fly the aircraft. This includes all required hardware, software, and supplies required to operate the Puma aircraft. Conducting the tests will also require an area where remote flight testing is permitted. The Cal Poly EFR fits requirements for a testing location and access to the field is necessary.

SAFETY REQUIREMENTS

Reference the Safety Risk Matrix in the Appendix. To maintain safe testing practices, the following safety requirements must be met while testing the Puma aircraft. The following are derived from Part 107 Rules, EFR Rules, and from AFL procedures.

- Keep flight below 400 feet AGL.
- Fly only in Class G airspace.
- Fly aircraft within VLOS.
- Minimum weather visibility of 3 miles from GCS.
- No flight over uninvolved persons.
- Limit flight to EFR property.
- PIC (Pilot in Command) must be FAA sUAS certified.
- PIC must be current with Puma aircraft.
- Aircraft hand-launcher must utilize PPE (Personal Protective Equipment).
- Fire extinguisher must be present during flight operations.
- Emergency Service numbers should be easily accessed.
- Emergency Plans should be developed and briefed.
- Additional crew should be present to monitor air and ground traffic.

Reference Appendix Section B for Flight Safety Risk Matrix.

SECURITY REQUIREMENTS

The Puma aircraft was originally designed for military purposes and payloads. The flight computer, accompanying software, and User Manual are export controlled and therefore distribution of related material must be monitored.

TEST PROJECT MANAGEMENT

The project manager for the Puma Flight Test Program is Neil Wolfe, the thesis developer. The project manager shall work in conjunction with AFL Manager Dr. Aaron Drake, and Olivia Lockhart the Puma Chief Pilot.

MEASURES OF EFFECTIVENESS

Measures of Effectiveness (MOEs) are characteristics used to determine if a system meets the original requirements for the system. As noted earlier, the original requirements for the Puma aircraft are not explicitly known. However, the specifications provided in the Puma User Manual and Datasheet will be used to backtrack logical requirements for the aircraft that will have associated MOEs. This will not be the typical method for testing sUAS but is done to achieve the primary testing objective to determine an efficient documentation and testing process for generic sUAS. The requirement traceability for the MOEs are included in Appendix Section C. MOEs to be monitored during testing are as below.

- Endurance: Hours
- Maximum Level Speed: Knots
- Glide Path Ratio: N/A
- Climb Rate: Feet Per Minute
- Data Link Range*: Miles
- GPS Longitudinal/Latitudinal Flight Path Accuracy: Coordinates
- Altitude Accuracy: Feet

*Range of the Puma is prone to rapid change due to ground geography. Also, as noted in Appendix C, the requirement traceability suggests the range of the Puma aircraft shall be approximately 20 km, which is out of VLOS and breaks Part 107 Rules and the Safety requirements for this test project. Therefore range, a valid MOE, should not be tested on this platform for this project.

TEST PROCEDURES

The following are high level procedures for each flight test to be completed during the project. This section is intended to give an idea of what the tests will consist of and the resources needed for each in chronological order. Detailed test procedures will be distributed by means of flight test card to the pilot and crew prior to testing. The test will be given a name, description, date (subject to change), and crew will be specified here.

- Test Name: **Puma Endurance Test, 3 runs**

Test Date (Subject to change on availability/weather): TBD – Morning

Description: A vital test that can be completed during the first flight of an aircraft is an endurance test. Knowing how long an unmanned aircraft can fly before a low power or

fuel warning is displayed is extremely important because it will provide information that reduces the risk of a mishap during testing that could result in a loss of the test platform. The Puma batteries will be fully charged prior to the flight. Due to the 2.5 hour anticipated endurance of the aircraft, the Puma will be using a pre-programmed flight plan that it can maintain with autonomy for the duration of the test within VLOS. Because the use of the autonomous flight control of the Puma is confirmed, it is possible to use this capability on the first test flight on this program. A PIC shall be present at the controls for the duration of the test. Due to the length and steady state nature of the endurance test it is also possible to record and evaluate other MOEs to increase the efficiency of test matrix completion. Since the aircraft will be using GPS to guide it through the flight plan, testing the ability of the aircraft to follow the intended path is possible whilst measuring the endurance of the aircraft. This will be done by comparing the current coordinates of the aircraft to the intended location of the waypoint created in the autonomous flight plan. The aircraft will be running the same route repeatedly to satisfy the endurance test, making this a valid opportunity to gather repeatable data on the flight path/altitude accuracy which is an important parameter for surveillance aircraft.

MOEs to be measured:

- Endurance (hours/minutes)
- Longitudinal/Latitudinal Keeping Error (feet)
- Altitude Holding Error (feet).

Crew required:

- Dr. Aaron Drake, Head of AFL, acting as pilot and aircraft operations manager.
- Olivia Lockhart, AFL Pilot, Puma current, acting as pilot and monitor.
- Neil Wolfe, Thesis developer, acting as test manager and engineer.
- Additional AFL Crew as needed, acting as safety monitors and operational aid.

Required Resources:

- AFL AeroVironment Puma and associated hardware, software, and supplies.
- AFL Operational Managers, Pilots, and Crew.
- Access to Cal Poly EFR.

Test Procedures:

1. Full crew to arrive at EFR with all required resources including fully charged Puma batteries.
2. Upload a repeatable flight plan to Puma that satisfies Safety Requirements.
3. Hand launch Puma and set to follow autonomous flight plan. Start Endurance measurement.
4. Verify Puma is flying flight plan as expected.
5. Record coordinates as Puma flies through specified waypoints.
6. Record altitude at a constant interval (every 30-60 seconds/waypoints).
7. Allow Puma to fly path until low battery warning.
8. Recover Puma.
9. Analyze data.

- **Test Name: Puma Climb Rate Test, 3 runs**

Test Date (Subject to change on availability/weather): 5/17/2019 – Morning

Description: Another vital test to complete during the initial flight test phase is the maximum climb rate test. This will provide the pilot information on the maximum safe climb rate possible from the aircraft. The Puma batteries should be fully charged before this flight. The main purpose of this flight is to determine the maximum climb rate of the Puma. This test will need to be done with the Puma under manual control of the PIC. This will require multiple climbs to 300 feet AGL and allows for the testing of multiple other MOEs in the same test. The Puma can then perform a deep stall, where glide path data will be recorded. The deep stall will be initiated at 300 feet AGL and recovered before the aircraft reaches 100 feet AGL. Once the data is recorded from the glide, a max level speed test can be conducted at 100 feet AGL. This data will then be averaged to come to a sensible conclusion. This test will require multiple runs to obtain sufficient data to analyze.

MOEs to be measured:

Maximum Climb Rate (Feet Per Second)
Maximum Level Speed (KTAS)
Deep Stall Glide Ratio (N/A)

Crew required:

Dr. Aaron Drake, Head of AFL, acting as pilot and aircraft operations manager.
Olivia Lockhart, AFL Pilot, Puma current, acting as pilot and monitor.
Neil Wolfe, Thesis developer, acting as test manager and engineer.
Additional AFL Crew as needed, acting as safety monitors and operational aid.

Required Resources:

AFL AeroVironment Puma and associated hardware, software, and supplies.
AFL Operational Managers, Pilots, and Crew.
Access to Cal Poly EFR.

Test Procedures:

1. Full Crew to arrive at EFR with all required resources including fully charged Puma batteries.
2. Pilot and hand launcher will launch Puma.
3. Timer will start and altitude will be recorded every 10 seconds.
4. End recording climb rate data at 300 feet AGL. 100-foot buffer in case the altitude fluctuates greatly which is a known Puma attribute.
5. Allow aircraft to stabilize and initialize deep stall for recovery at 300 feet AGL. Record starting coordinates and altitude.
6. Allow aircraft to glide from 300 feet AGL and recover before reaching 100 feet AGL. Record coordinates and altitude just prior to recovery.
7. Start Maximum Level Speed test, adjust altitude to 100 feet AGL.

8. Accelerate aircraft from cruise speed to full power.
9. Adjust aircraft trim to maintain level flight.
10. Allow airspeed to stabilize.
11. Record Max Level Speed in knots every 10 seconds when steady, level flight is achieved. Record 3-10 data points.
12. End Max Level Speed Test.
13. Repeat 3-5 times to acquire sufficient data.
14. Analyze data.

TEST REPORTING

Data from test flights should be analyzed immediately after the flight. This will come in two forms, hand recorded data and data recorded from the Puma GCS during flight. It is important to do this in case unexpected results occur in either set. In the case of this test program, Quick Look Reports should be constructed by the flight test engineer after each test session and will be distributed to all involved in the testing program once complete. The Quick Look Report should include a review of the day's test activities and a synopsis of the data collected. It will reference any accidents or off-nominal events that occurred during the day. It will also review the next day/sessions testing to occur. Since testing is planned to occur on a weekly basis, expect Quick Look Reports to be distributed 1-2 days after the test is completed.

At the end of the test project a final report will be distributed to all involved. This report will encompass all testing activities and their results. It will explain the purpose of the testing and the method by which the testing was completed. It will confirm or deny whether the test objectives and all MOEs have been measured and provide results. It will also detail the future of the flight test program and what the next phase should include.

ENVIRONMENTAL PROTECTION

The Puma utilizes electric propulsion, so emission concerns are minimal. The larger concern is that of a crash resulting in a Lithium Ion battery fire that could potentially turn into a wildfire depending on the climate at the testing location. The test location is in central California, but recent rains have reduced the wildfire risk during the intended testing times. Nonetheless, a fire extinguisher will be present during testing and emergency service numbers will be obviously displayed to the team on the Flight Test Card. Emergency services should be contacted in the case of any moderately sized fire.

The test location is also home to wildlife and herds of cattle so the pilot must be mindful of flying over any living thing not involved in the test itself. Tests are planned at altitude to reduce the effect of noise on the wildlife and allow adequate distance to recover from stalls during the stall tests.

APPENDIX

A. TEST CONDITION MATRIX

Test Name	Test Date-Variable	MOEs	Notes
Puma Endurance Test #1	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 1
Puma Endurance Test #2	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 2
Puma Endurance Test #3	TBD	Endurance GPS Accuracy Altitude Accuracy	Deliverables: -Quick Look Report 200' Altitude Cruise Speed Pilot 1,2, or 3
Puma Climb Rate Test #1	5/17/2019	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 1
Puma Climb Rate Test #2	TBD	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 2
Puma Climb Rate Test #3	TBD	Climb Rate Max Level Speed Stall Speed	Deliverables: -Quick Look Report 300' Ceiling Varying Speed Pilot 1,2, or 3

B. SAFETY/RISK CONDITIONS

Possible Risk Conditions

- **Loss of Link**
 - Aircraft Behavior: Land Immediately, Go To Rally, Finish Flight.
 - Response: Attempt to regain control of aircraft. Do not attempt to regain control below 100 feet AGL.
 - Probability: Low
- **Loss of power**
 - Aircraft Behavior: Stall, Altitude Decrease, Crash
 - Response: Maintain control over aircraft. If possible, bring Puma back to launch point. If area is clear, initiate deep stall for recovery. Respond to stall or crash site.
 - Probability: Low
- **Loss of control**
 - Aircraft Behavior: Stall, Altitude Variation, Crash
 - Response: Attempt to regain control of aircraft. If possible, bring Puma back to launch point. If area is clear, initiate deep stall for recovery. Respond to crash site.
 - Probability: Low
- **Battery fire**
 - Aircraft Behavior: Stall, Altitude Variation, Crash
 - Response: Maintain control over aircraft. If possible, bring Puma back to launch point. If area is clear, initiate deep stall for recovery. Respond to crash site with fire extinguisher. Call Emergency Services, inform of location and emergency status.
 - Probability: Low

C. REQUIREMENTS TRACEABILITY

Typically, system level and derived requirements would come from specific user needs for a system, but for the AeroVironment Puma these are unavailable. For this test project, the specifications of the Puma system will be used as requirements from which the MOEs for the intended tests are derived from. These are likely not the original requirements for the system but are typical of unmanned aircraft and therefore will help achieve the primary objective of thesis development by specifying some arbitrary requirements for the Puma.

System Requirement Statement	Derived MOE
The Puma shall have an endurance of 2.5 hours.	Endurance (Hours)
The Puma shall have a maximum level speed greater than 40 KTAS.	Maximum Level Speed (KTAS)
The Puma shall have a deep stall glide ratio of 1:1.	Deep Stall Glide Ratio (N/A)
The Puma shall have a maximum climb rate greater than 100 feet per minute.	Maximum Climb Rate (Feet Per Minute)
The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.	Longitudinal/Latitudinal Keeping Error (Feet)

The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.	Altitude Holding Error (Feet)
The Puma shall have a range of greater than or equal to 9.32 miles (15 km).	Range (Miles)

D. DATA ANALYSIS PLAN

Data will be recorded onto flight test cards by hand directly from the GCS during testing. The data will then be averaged and compared over all tests and the results will be displayed using Excel or Matlab graphing tools. Electronic versions of the raw recorded data will be distributed to those involved upon request from the flight test program manager. The data to be acquired from these tests is relatively simple and requires minor reduction for calculating end results.

E. INSTRUMENTATION PLAN

The Puma has a closed circuit set of sensors which will be used to measure the required MOEs. No additional sensors are needed for this testing phase. The data is displayed onto the GCS screen which allows it to be recorded by hand at specific locations and times. An accurate timer will be required for the flight test engineer. The sensors to be utilized to measure MOEs on the Puma are listed below.

- GPS Coordinate Output
- Pitot-Static Velocity Output
- GPS Altitude Output
- Wind Velocity
- Flight computer data recorder.

Ground Instrumentation

- Timer
- Anemometer

F. LIST OF ABBREVIATIONS

Abbreviation	Definition	Units
AFL	Autonomous Flight Lab	N/A
AGL	Above Ground Level	N/A
FAA	Federal Aviation Administration	N/A
GCS	Ground Control Station	N/A
GPS	Global Positioning System	N/A
KTAS	Knots True Airspeed	Knots
MOE	Measure of Effectiveness	Varies
PIC	Pilot in Command	N/A
PPE	Personal Protective Equipment	N/A
sUAS	Small Unmanned Aircraft System	N/A
UAS	Unmanned Aircraft System	N/A

F. Puma Flight Test Card Example

The series of images beginning on the following page represent the Flight Test Card as completed for the Puma Flight Test Program. Each image represents one half of the full page allocated for the Flight Test Card. It was then folded in half along the seam of the two pages. This report can serve as a functional example of the Flight Test Card and can be used to guide the creation of the document for any generic sUAS test program.

FLIGHT TEST CARD

RQ-20

N618CP

8/1/19

1/2

TEST OBJECTIVE

Puma flight proficiency and Neil Wolfe's endurance tests

TEST SITE

Educational Flight Range (35°19'42.4"N 120°45'08.7"W)

Elevation: 210 ft

Gate Code: 2021

PERSONNEL

Test Director: Eric Ashley

AVO: Will Bergman, Luke Bodkin, Wyll Soll

MO: Luke Bodkin, Wyll Soll, Will Bergman

Shadow MO: Arielle Sampson, Runjia Chen

VO: Eric Ashley, Luke Bodkin, Will Bergman

Launch: Wyll Soll

AIRCRAFT

AeroVironment Puma AE

CALL SIGN

Unmanned Aircraft N618CP

FREQUENCIES

San Luis Tower: 124.0

Santa Barbara Approach: 127.725

WEATHER LIMITS

VMC, 1000-ft ceiling, 3 nm visibility

Winds below 25 kts

OP LIMITS

Max altitude of 400 ft AGL within 0.8 nm of AVO

NOTAM

Part 107

FLIGHT TEST CARD

RQ-20

N618CP

8/1/19

2/2

TEST SEQUENCE

1. Launch (don't forget Falcon Tracker)
2. Start tracking Flight/GCS battery voltages every 15 minutes
3. Enter standard NAV mode at 300 ft AGL (500 MSL) for a few cycles
4. Adjust the waypoints to collect data crossing through a single waypoint
5. Continue in NAV mode with new waypoint setup to allow Neil to collect Lat/Long/Alt data each pass
6. Adjust NAV setup for continued endurance near the AVO and wait for the 15 minute flight time warning (21.5 V)
7. Land

WATCH ITEMS

1. Air vehicle battery voltages
 - a. 15 minute flight time warning: 21.5 V
 - b. 1 minute flight time warning: 19 V
2. GCS battery voltages
 - a. BB-2590 GCS battery: 26V
 - b. Flight battery: 21.5 V
3. Loop Timeout - If the Loop Timeout is reached in NAV mode the current loop is completed, then the E-to-L landing procedure is initiated automatically

PHONE NUMBERS

Aaron Drake:

Eric Ashley:

Camp SLO:

San Luis Tower:

University Police:

Fire Department:

DIRECTIONS

Cal Poly Education Flight Range- adjacent to Cuesta College on northwest side

G. Puma Quick Look Report Example

The series of images beginning on the following page represent the Quick Look Report as completed for the Puma Flight Test Program. This report can serve as a functional example of the Quick Look Report and can be used to guide the creation of the document for any generic sUAS test program.

RQ-20 Puma Max Climb/Deep Stall Glide/Max Speed Test #1

Quick-Look Report

Test Date: 05/17/2019 – Brief 0900 PST

Test Aircraft: AeroVironment RQ-20 Puma

Test Location: Cal Poly Educational Flight Range (EFR)

General Conditions: Sunny, thermal potential, 12 kt avg. westerly wind w/ light gusts.

Involved Agencies: Cal Poly AFL

Personnel present: Dr. Aaron Drake, Olivia Lockhart, Luke Bodkin, Neil Wolfe

Test Objectives: Determine the maximum climb rate, deep-stall glide ratio, and maximum level speed of the AeroVironment RQ-20 UAS. Determine if system requirements are met by design solution. Provide valuable performance information to pilots of the Puma.

Test Sequence:

- Climb/Glide/Speed Test Run 1
Pilot: Olivia Lockhart
- Climb/Glide/Speed Test Run 2
Pilot: Dr. Aaron Drake
- Climb/Glide/Speed Test Run 3
Pilot: Olivia Lockhart

Preliminary Test Results:

*Error bars represent +/- one standard deviation of the averaged data points.

CALIFORNIA POLYTECHNIC STATE UNIVERSITY SAN LUIS OBISPO, CALIFORNIA - PART OF A THESIS BY NEIL WOLFE

Preliminary Conclusions: Consistent results were achieved between all runs. There is one outlying data point for the third Max Climb run. For Puma Climb/Glide/Speed Test #2 the average Measure of Effectiveness (MOE) results are as follows:

- Average Maximum Climb Rate: 668 feet per minute (Meets requirement: > 100 fpm)
- Average Deep-Stall Glide Ratio: 1.29:1 (Does not meet requirement: 1:1)
- Average Maximum Level Speed: 41.09 KTAS (Meets requirement: > 40 KTAS)

All results are on the same order as expected from the aircraft. The results between runs were largely consistent which suggests they are reliable. The one outlying Max climb run also has a large variation and suggests the climb may have been affected by a thermal or gust. The only MOE that did not meet the original system level requirement was the Glide Ratio which was slightly greater than 1:1. Two more tests of these MOEs are planned and should aid in determining the validity of these results.

Unrelated Performance Issues:

- Difficulty maintaining consistent altitude in the Altitude Hold flight mode.
- Difficulty descending in high wind conditions.
- Difficulty maintaining attitude at full throttle; drifts sharply to the right.

Testing Incidents:

- After Run 3 aircraft landed on barbed wire fence during recovery deep-stall landing.
Damage: New wing punctured in multiple places. Rudder composite material split and needs repair.

Conclusion: Aircraft took minimal damage and fit for continued use. Puncture holes in wing should be taped over and rudder must be repaired.

Next Test: The next test is Climb/Glide/Speed Test #3 and will follow the same sequence. This is the second test measuring maximum climb rate, deep-stall glide ratio, and maximum level speed. The date of test is tentatively planned for June 26th, 2019 based on personnel availability and weather conditions. It will be located at the Cal Poly EFR.

H. Puma Final Testing Report Example

The series of images beginning on the following page represent the Final Testing Report as completed for the Puma Flight Test Program. This report can serve as a functional example of the Final Testing Report and can be used to guide the creation of the document for any generic sUAS test program.

CAL POLY

CAL POLY AFL AEROVIRONMENT PUMA FINAL TEST REPORT

NEIL A. WOLFE
Test Project Engineer

AUGUST 2019

FINAL TEST REPORT

CALIFORNIA POLYTECHNIC STATE UNIVERSITY SAN LUIS OBISPO, CALIFORNIA - PART OF A THESIS BY NEIL WOLFE

EXECUTIVE SUMMARY

This document details results of the proposed Test and Evaluation activities carried out for the Cal Poly San Luis Obispo AFL (Autonomous Flight Lab). The AFL is an entity that conducts UAS (Unmanned Aircraft System) research and development. This testing occurred as part of a thesis topic developed by Neil Wolfe at California Polytechnic State University, San Luis Obispo. The thesis topic aims to derive complete performance flight testing procedures for general sUAS (Small Unmanned Aircraft Systems). Small companies with the desire to create an unmanned platform to showcase a product will find this especially useful as they usually do not have any tested procedures in place.

The aircraft tested was the AFL's AeroVironment RQ-20 Puma fixed wing UAS. Performance testing of the Puma was proposed to verify the validity of the procedures developed to flight test generic sUAS. The proposed tests covered a broad spectrum of relevant aircraft performance evaluations that provide valuable information about the flight characteristics of a new, modified, or existing system.

This document details the results of a series of flight tests designed to determine if the Puma's Measures of Effectiveness (MOE's) satisfied the original system requirements. Because the Puma is already a finished product, the AFL will use this information to guide their operations with the aircraft. The testing activities occurred on weekday mornings between March and August of 2019.

Table of Contents

EXECUTIVE SUMMARY	2
FIGURES	4
TABLES	11
ABBREVIATIONS AND ACRONYMS	13
PURPOSE AND BACKGROUND	14
TESTING PURPOSE.....	14
TESTING BACKGROUND	14
DESCRIPTION OF SYSTEM TESTED	14
TEST FORCE, LOCATION, DATES.....	14
TEST DESCRIPTION.....	15
TEST OBJECTIVES	15
SCOPE AND METHOD	15
PLANNING CONSIDERATIONS AND LIMITING FACTORS.....	15
BUSINESS RELATIONSHIPS.....	16
OPERATIONAL EFFECTIVENESS AND SUITABILITY	17
SUMMARY.....	17
MOE #1: MAXIMUM CLIMB RATE	17
MOE #2: DEEP STALL GLIDE RATIO	17
MOE #3: MAXIMUM LEVEL SPEED	18
MOE #4: ENDURANCE.....	18
MOE #5: POSITION KEEPING ERROR	19
MOE #6: ALTITUDE KEEPING ERROR.....	19
ADDITIONAL FINDINGS.....	20
SAFETY ASSESSMENT.....	20
ENVIRONMENTAL IMPACT ASSESSMENT	20
OPERATIONAL IMPACT ASSESSMENT	21
PERFORMANCE DEFICIENCIES	22
DEFICIENCY REPORTS.....	22
IMPACT SUMMARY	23
SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.....	24
REFERENCES	25
APPENDIX	25

FIGURES

A. Maximum Climb Rate Test Averaged Results

Figure 1: Average maximum climb rate from each test and overall total result.

Figure 2: Average maximum climb rate results for Test 1.

Figure 3: Average maximum climb rate results for Test 2.

Figure 4: Average maximum climb rate results for Test 3.

B. Maximum Climb Rate Profile Samples

Figure 5: Maximum climb rate at every second of the maneuver for Test 3, Run 2. Shows the large variation in climb rate that occurred throughout the test. Only one run is shown as this is typical throughout all runs.

Figure 6: Maximum climb profile at every second of the maneuver for Test 3, Run 2. Slight fluctuation is shown in the climb profile but overall it is relatively linear. Only one run is shown as this is typical throughout all runs.

C. Deep Stall Glide Ratio Test Averaged Results

Figure 7: Average deep stall glide ratio results from each test and overall total result.

Figure 8: Average deep stall glide ratio results from Test 1.

Figure 9: Average deep stall glide ratio results from Test 2.

Figure 10: Average deep stall glide ratio results from Test 3.

D. Deep Stall Glide Ratio Profile Sample

Figure 11: Profile of the deep stall maneuver for Test 3, Run 2. The glide slope tends vary slightly which elongates the metric. Only one run is shown as this is typical throughout all runs.

E. Maximum Level Speed Test Averaged Results

Figure 12: Average maximum level speed results for each test and overall total result.

Figure 13: Average maximum level speed results for Test 1.

Figure 14: Average maximum level speed results for Test 2.

Figure 15: Average maximum level speed results for Test 3.

F. Endurance Test Averaged Results

Figure 16: Average endurance results for each test and overall total result.

G. Position Keeping Error Test Averaged Results

Figure 17: Average position keeping error results for all tests and overall total result.

H. Position Keeping Error Test Sample

Figure 18: Profile of all the data points collected for position keeping error in Test 1. Shows relatively consistent results with a couple outliers. This is common among all runs.

I. Altitude Holding Error Test Averaged Results

Figure 19: Average attitude holding error results for all tests and overall total result. Notice how all results are a positive average altitude error.

J. Altitude Holding Error Test Sample

Figure 20: Profile of all the data points collected for altitude holding error in Test 1. Notice the large variation in the error and the tendency to be at a higher altitude vs. lower altitude. This is common among all runs.

TABLES

A. Maximum Climb Rate Test Averaged Data Table

Tabulated Maximum Climb Rate Results		
	Average (feet per minute)	Standard Deviation ($\pm$ feet per minute)
Test 1	668	128
Test 2	606	84
Test 3	696	86
All Tests Avg.	656	99

B. Deep Stall Glide Ratio Test Averaged Data Table

Tabulated Deep Stall Glide Ratio Results		
	Average Ratio	Standard Deviation ($\pm$ ratio)
Test 1	1.29	0.04
Test 2	1.46	0.28
Test 3	1.36	0.24
All Tests Avg.	1.37	0.19

C. Maximum Level Speed Test Averaged Data Table

Tabulated Maximum Level Speed Results		
	Average (KTAS)	Standard Deviation ($\pm$ KTAS)
Test 1	41.09	1.42
Test 2	43.36	4.21
Test 3	39.24	2.09
All Tests Avg.	41.23	2.57

D. Endurance Test Averaged Data Table

Endurance Tabulated Results		
	Average (minutes)	Standard Deviation ($\pm$ minutes)
Test 1	163	-
Test 2	201	-
Test 3	163	-
All Tests Avg.	176	18

E. Position Keeping Error Test Averaged Data Table

Position Keeping Error Tabulated Averages			
	Avg. Latitude Error (feet)	Avg. Longitude Error (feet)	Avg. Total Error (feet)
Test 1	31.89	14.38	35.82
Test 2	26.08	19.24	32.97
Test 3	24.42	14.28	28.57
All Tests Avg.	27.46	15.97	32.45

Position Keeping Error Tabulated Standard Deviations			
	Avg. Latitude Standard Deviation ($\pm$ feet)	Avg. Longitude Standard Deviation ($\pm$ feet)	Avg. Total Standard Deviation ($\pm$ feet)
Test 1	34.25	8.58	34.46
Test 2	15.66	13.17	19.54
Test 3	17.38	9.03	19.17
All Tests Avg.	22.43	10.26	24.39

F. Altitude Holding Error Test Averaged Data Table

Altitude Holding Error Tabulated Results		
	Average (feet)	Standard Deviation ($\pm$ feet)
Test 1	29.04	37.69
Test 2	13.6	31.94
Test 3	45.23	36.01
All Tests Avg.	29.29	35.21

ABBREVIATIONS AND ACRONYMS

AFL	Autonomous Flight Lab
AGL	Above Ground Level
ALT	Refers to Puma Altitude Mode
Cal Poly	California Polytechnic State University, San Luis Obispo
EFR	Educational Flight Range
FAA	Federal Aviation Administration
fpn	feet per minute
GCS	Ground Control Station
KTAS	Knots True Airspeed
MOE	Measure of Effectiveness
NAV	Refers to Puma Navigation Mode
sUAS	small Unmanned Aircraft Systems
UAS	Unmanned Aircraft Systems
VLOS	Visual Line Of Sight

PURPOSE AND BACKGROUND

TESTING PURPOSE

The purpose of the proposed testing activities was to determine important performance characteristics of the AeroVironment RQ-20 Puma sUAS operated by the Autonomous Flight Lab (AFL) at California Polytechnic State University, San Luis Obispo (Cal Poly). This information will be used to aid in the development of a thesis study by Neil Wolfe and will provide the AFL with quantified information about how the aircraft performs in flight.

TESTING BACKGROUND

The AFL uses the Puma for various testing purposes to aid clients in product development or research. It is known by the AFL that because of the Puma's design, the aircraft tends to have radically varying performance characteristics that are not mentioned in the Puma User Manual. The Puma User Manual contains a few performance specifications but is missing many that could be useful to the AFL. The variation in performance and the lack of a full performance profile makes operation of the Puma susceptible to some increased risk. The performance of the Puma will be evaluated to aid in decreasing operational risk and safety concerns. The performance of the Puma was judged against its documented performance specifications which, to aid the thesis study, were used as system level requirements. For performance specifications not detailed in the user manual, logical system level requirements were created to allow an evaluation of performance. A series of flight tests were performed to evaluate overall Puma performance and will be detailed in this document. This document will be given to the AFL as a final report of the findings of this flight test program.

DESCRIPTION OF SYSTEM TESTED

The aircraft being tested is the AeroVironment Puma RQ-20. It is a 15 lb. hand launched, fixed wing sUAS originally designed to conduct surveillance, reconnaissance, and intelligence gathering for the United States Military. The Puma is one of few unmanned aircraft also certified to fly in US airspace for commercial purposes. Puma features one electric motor and 2 control surfaces (Rudder, Elevator). The Puma has a camera suite and gimbal payload supported by a 9.2 ft wingspan. It is operated from a tablet-like controller that supports manual and autonomous flight for roughly 2.5 hours. The Puma lands by performing a controlled stall just above the ground with wings that separate from the fuselage upon impact. The Puma is a simple platform but very durable, making it a suitable aircraft from the AFL inventory for vigorous flight testing.

TEST FORCE, LOCATION, DATES

As detailed in the Puma Test Planning Report, the main test force consisted of AFL personnel in addition to Neil Wolfe, a graduate student at Cal Poly developing a thesis study. The AFL personnel provided full support of all required flight operations while Neil Wolfe analyzed the recorded data and documented the results of the flight test program. The testing location was the Cal Poly Educational Flight Range (EFR). The EFR is located near Cuesta College outside of controlled airspace and is a designated sUAS area of operation. Priority and liability coverage are given to Cal Poly students and organizations operating out of the EFR. All testing activities occurred on weekday mornings between March and August of 2019.

TEST DESCRIPTION

TEST OBJECTIVES

The primary objective of these tests was to aid in development of the thesis study being conducted by Neil Wolfe. Secondary objectives were to determine the actual performance characteristics of the Puma used by the AFL. The performance characteristics quantified were the Puma's maximum climb rate, deep stall glide ratio, maximum level speed, endurance, position keeping error, and altitude holding error.

SCOPE AND METHOD

As mentioned earlier, the performance characteristics above and specified in the Puma Test Planning Report were turned into MOEs so that the Puma's performance could be evaluated against its system level requirements. The Requirements Traceability Matrix can be found in the Appendix of this document. A series of flight tests were designed allowing data to be collected from the Puma's on-board sensors to quantify the MOEs. Each flight test had an associated Flight Test Card that included specific maneuvers needed to acquire the data. Repeatability was designed into each flight test for data reliability. The data was recorded by capturing the screen of the Puma's Ground Control Station (GCS) which displayed everything required. The data was then input to Microsoft Office Excel for analysis. The result was a series of six flight tests, each quantifying three different MOEs. The first three tests consisted of the same test sequence which allowed the collection of data for the maximum climb rate, deep stall glide ratio, and maximum level speed. The final three tests consisted again of a similar test sequence and measured the endurance, position keeping error, and altitude holding error. These are listed below for conciseness.

- Flight Test Sequence 1
 - Title: Puma Max Climb/Deep Stall Glide/Max Speed Test
 - MOEs
 - Maximum Climb Rate
 - Deep Stall Glide Ratio
 - Maximum Level Speed
 - Conducted 3 times
- Flight Test Sequence 2
 - Title: Puma Endurance/Position Keeping/Altitude Holding Test
 - MOEs
 - Endurance
 - Position Keeping Error
 - Altitude Holding Error
 - Conducted 3 times

PLANNING CONSIDERATIONS AND LIMITING FACTORS

Conducting tests in commercial airspace requires that the testing entities heed to commercial sUAS regulations. For aircraft under 55 pounds, these regulations are referred to as the FAA Part 107 Small Unmanned Aircraft rules. Any flight in US airspace for commercial purposes must operate under these restrictions. Restrictions relevant to the proposed testing are detailed below:

- Maintain flight at or below 400 feet AGL (Above Ground Level).
- Flight only in Class G airspace.
- Maintain flight over EFR (Educational Flight Range) property.
- Maintain flight within VLOS (Visual Line of Sight).
- Minimum visibility of 3 miles from GCS (Ground Control Station).
- Pilot must have current FAA sUAS Certification.

BUSINESS RELATIONSHIPS

The testing activities proposed by Neil Wolfe were completed in close cooperation with the Cal Poly AFL which owns the Puma and possesses the personnel needed to support flight operations.

OPERATIONAL EFFECTIVENESS AND SUITABILITY

SUMMARY

Flight testing the Puma was successful in determining the six desired MOEs as well as other unanticipated flight characteristics which are detailed below. Three of the six MOEs met the original system level requirements and the other three did not. If these requirements were vital to the product development, the system design would need to be addressed. In reality, the AFL Puma cannot be redesigned and these MOEs represent important performance characteristics that could aid AFL operation of the Puma. The flight test activities were used to provide proficiency training for AFL personnel as well to discover unknown characteristics about how the Puma operates. Utilizing the information found in this flight test program, the operation of the Puma for the AFL should be much safer and more effective than it previously was.

MOE #1: MAXIMUM CLIMB RATE

The Puma's maximum climb rate was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a maximum climb rate greater than 100 feet per minute.*

The maximum climb rate was recorded 3 times per flight test to obtain an average for the day. It was calculated by recording and averaging the altitude for every second of the max climb maneuver. This result was then averaged over the 3 tests allocated for the MOE. The maximum climb rate was susceptible to large variation as is shown in *Figures 5 and 6* which can be found in the Figures section at the beginning of this document. These show the climb profile and climb rate over the course of one run from each test and support the conclusion that the Puma's maximum climb rate is susceptible to large variation. During testing it was found that wind speed and thermal circulation appeared to have a large effect on the climb performance. *Figures 1-4* show the results for each individual test in comparison to the total average. The final result for the maximum climb rate MOE is as below.

- Puma Maximum Climb Rate
 - Average: 656 feet per minute
 - Standard Deviation: ± 99 feet per minute
 - Conclusion: Exceedingly meets the original system level requirement

MOE #2: DEEP STALL GLIDE RATIO

The Puma's deep stall glide ratio was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a deep stall glide ratio of 1:1.*

The deep stall glide ratio was recorded three times per flight test to obtain an average for the day. It was calculated by recording the altitude and groundspeed of the Puma every second during its descent. Windspeed recorded by the Puma was removed from the groundspeed to

obtain the true airspeed which was used to determine the horizontal distance traveled. This result was then averaged over the three tests allocated for the MOE. This MOE was relatively consistent but still showed some large variation through all the test runs and can be seen in the glide profile of Test 3, Run 2 in *Figure 11* in the Figures section at the beginning of this document. This could be due to a variety of factors but is most likely because of wind gusts and the speed at which the stall was approached. *Figures 7-10* show the results for each individual test in comparison to the total average. The final result for the deep stall glide ratio MOE is as below.

- Puma Deep Stall Glide Ratio
 - Average: 1.37:1
 - Standard Deviation: $\pm .19:1$
 - Conclusion: Does not meet the original system level requirement

MOE #3: MAXIMUM LEVEL SPEED

The Puma's maximum level speed was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a maximum level speed greater than 40 knots.*

The maximum level speed was recorded three times per flight test to obtain an average for the day. It was calculated by recording the groundspeed of the Puma once for each second of the maneuver. The true airspeed was then calculated by removing the wind vector which was also recorded by the Puma's sensors. This result was then averaged over the three tests allocated for the MOE. This MOE was largely consistent over all its runs as shown in *Figures 12-15* which show the results for each individual test in comparison to the total average. However, the aircraft tended to turn right sharply and lose altitude when completing this maneuver which is detailed in the deficiency section of this document. The final result for the maximum level speed MOE is as below.

- Puma Maximum Level Speed
 - Average: 41.23 KTAS
 - Standard Deviation: ± 2.57 KTAS
 - Conclusion: Meets the original system level requirement

MOE #4: ENDURANCE

The Puma's flight endurance was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have an endurance of 2.5 hours (150 minutes).*

The endurance was recorded once per flight test due to its extended nature. It was calculated by the Puma's flight controller and was displayed on the GCS screen. This result was then averaged over the three tests allocated for the MOE. Two different flight batteries of similar usage levels were used for the test. One battery was run twice and produced extremely consistent results. The other battery was used one time and produced an outlying result, but this test day

was unusually calm compared to the other tests and likely allowed the Puma to conserve energy better. *Figure 16* in the Figures section at the beginning of this document show the results for each test flight where the outlying result is clearly visible. The final result for the Puma's endurance MOE is as below.

- Puma Endurance
 - Average: 176 minutes
 - Standard Deviation: ± 18 minutes
 - Conclusion: Meets the original system level requirements

MOE #5: POSITION KEEPING ERROR

The Puma's autonomous position keeping error was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.*

The position keeping error was recorded 15-20 times over the course of each endurance test which was then used to create an average for the day. It was calculated by finding the difference between the coordinates of closest point in the Puma's autonomous planned flight path and the commanded waypoint of interest. The coordinate difference was then converted to a distance in feet. The results were relatively consistent across all tests which are shown in *Figure 17* in the Figures section at the beginning of this document in comparison with the total average. *Figure 18* shows the error for each data point in Test 1. The variation in the error was relatively large and is likely due to the Puma's flight dynamics and susceptibility to wind gusts. The final result for the Puma's position keeping error MOE is as below.

- Puma Position Keeping Error
 - Average: ± 32 feet
 - Standard Deviation: ± 24 feet
 - Conclusion: Does not meet the original system level requirement

MOE #6: ALTITUDE HOLDING ERROR

The Puma's autonomous altitude holding error was a proposed MOE as it traces back to the following system level requirement.

- *The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.*

The autonomous altitude holding error was recorded 30-40 times over the course of each endurance test which was then used to create an average for the day. It was calculated by finding the difference between the aircraft altitude and the commanded altitude of the waypoint of interest. The average altitude holding error varied greatly between tests while the standard deviation was relatively consistent. This can be seen in *Figure 19* in the Figures section at the beginning of this document which shows the average altitude error for each test in comparison to the total average. The differences in the average error is likely due to the varying wind conditions seen between tests. The Puma was also much more likely to be at a higher altitude

than commanded rather than lower which is shown in *Figure 20*. The final result for the Puma's altitude holding error is as below.

- Puma Altitude Holding Error
 - Average: ± 29 feet
 - Standard Deviation ± 35 feet
 - Conclusion: Does not meet the original system level requirement

ADDITIONAL FINDINGS

The findings listed below are a short summary of additional performance characteristics discovered while performing the planned flight tests.

- Difficulty maintaining altitude in Altitude Hold mode.
- Difficulty descending in high wind conditions.
- Difficulty maintaining attitude when full throttle is applied in Altitude Hold mode.
- Difficulty launching with little to no wind.
- Switching from NAV mode to ALT mode causes unsafe handling near the ground.
- Periodically erratic flight control in NAV mode when set to 'Long Endurance'.
- AFL 120V power adapter does not work.
- At $\frac{1}{4}$ transmitting power, the large GCS battery last over 2.5 hours.
- Can manually navigate Puma manual when in NAV mode.
- The Puma flight battery also works to power the GCS with an adapter.
- Loop timeout must be set longer than expected flight time.
- The Puma can be set to 4 different flight control modes when in NAV mode.

SAFETY ASSESSMENT

Throughout testing the Puma proved itself able to safely and effectively follow all commands given. As mentioned above, the Puma deviated from its plan only one time because of a setup error with the loop timeout. It proceeded to land at its designated safe landing point proving the function of this feature. With the loop timeout set correctly for the application, this will not be a problem. The Puma does have a rather large altitude holding error and variation, so extended operations within 50 feet of the ground are not recommended. When applying full throttle in Altitude mode the Puma tends to bank right and lose altitude, so it is important to be aware of this behavior when performing this maneuver. Changing from NAV mode to ALT mode also produces an extreme banking and altitude loss behavior and is not recommended within 50-100 feet of the ground. Hand launch with little to no wind is difficult to do but if properly organized does not pose a safety risk to those in the vicinity. Video, Telemetry, and Radio links were never lost during operation proving the robustness of the communications systems. If these warnings are heeded when operating the Puma, it becomes an exceptionally safe aircraft to fly and is fit for commercial use.

ENVIRONMENTAL IMPACT ASSESSMENT

Operation of the Puma poses little threat to the environment as it emits no carbon dioxide. Any threat it does pose comes from unintended emergency situations such as a crash or battery fire. If proper precautions are made, there should be no environmental impact from use of the Puma system.

OPERATIONAL IMPACT ASSESSMENT

Operationally, the Puma proved suitable performance for its main applications of surveillance and reconnaissance. It met the requirements for max climb rate, max level speed, and endurance making it effective when considering these characteristics. While the Puma did not meet the requirements for the deep stall glide ratio, position keeping error, and altitude holding error, the margins are small enough that it should have minimal impact on its primary applications. When planning a mission, if these characteristics are acknowledged there will generally be little operational impact. The Puma's susceptibility to performance degradation due to wind gusts and thermals has a slightly larger impact as its dynamics become more unpredictable. It also becomes difficult to effectively hand launch with little to no wind. This can be worked around by launching from a raised area or developing/utilizing a mechanical launcher. During testing the Puma proved suitable performance in winds up to 15 knots. The Puma's capability to achieve its primary applications should only be slightly hindered by these characteristics and is therefore operationally capable.

PERFORMANCE DEFICIENCIES

DEFICIENCY REPORTS

The following list details any operational deficiencies found while operating the Puma. These are negative features of the aircraft that could potentially affect the operational use. These reports are prioritized in the order of importance for operational capability. When attempting to address aircraft deficiencies it is most valuable to start at the beginning of the list.

1. The altitude holding error of ± 29 feet in both NAV and ALT mode does not meet the original system level requirement. The aircraft tends to fly much higher than it is commanded to. This can affect any use under Part 107 and can affect the quality of the surveillance capability the Puma provides. This is the top priority deficiency because it can affect safety and effectivity and was an original system level requirement. This could potentially be fixed with software modifications to the flight controller.
2. It is very difficult to launch the Puma with little or no wind. Because of the size and weight, the successful launch rate with no wind tends to be very low. This typically causes uncontrolled impacts with the ground which can damage the airframe and its components. This is of high priority because the aircraft is expensive and crashing on the hand launch can severely inhibit the Puma's availability for surveillance purposes. This can potentially be fixed by developing or purchasing a mechanical launching system to aid in no wind takeoffs.
3. Switching from NAV mode to ALT mode sometimes causes very sharp banks and an associated loss in altitude. When done near the ground this is a dangerous dynamic because the Puma becomes uncontrollable and unpredictable for 1-3 seconds. This is of high priority because it could cause a crash which could severely inhibit the Puma's availability for surveillance purposes. This could potentially be fixed with software modifications to the flight controller.
4. When full throttle is applied, the Puma's attitude keeping abilities are compromised and it tends to drift to the right and lose altitude rapidly. This doesn't allow for straight and level flight which could compromise the surveillance capabilities of the Puma. This is of medium priority as full throttle is not often applied during use. This could potentially be fixed by modifying the flight control software or by checking the control surfaces for deviations from the optimal configuration.
5. Because of the Puma's design, it is difficult to descend in high wind conditions. This occasionally forces the Puma to fly higher than desired and can compromise the operational effectiveness. This is of low priority because the Puma can descend by entering the deep stall landing mode and then recovering from it. This is not desirable because it can be difficult to do successfully and compromises the intended flight path. This could potentially be fixed by modifying the flight control software.
6. The deep stall glide ratio of 1.37:1 does not meet the original system level requirement. It is larger than the requirement and can cause the Puma to land in an unintended location which could potentially damage the aircraft. This is of low priority because the magnitude of deviation from the requirement is small and on the correct order. This could potentially be fixed by a modification to the flight control software.

7. The position keeping error of ± 32 feet does not meet the original system level requirement. It is larger than the requirement and could compromise the operational capability of the Puma to provide surveillance functions. This is of low priority because the magnitude of deviation from the requirement is small and the camera field of view is usually large enough to negate this error. This could potentially be fixed by modification to the flight control software.

IMPACT SUMMARY

The impact of these deficiencies slightly detracts from the operational capability of the Puma. However, none of these deficiencies pose major or crucial risks to the Puma's ability to safely and effectively provide surveillance and reconnaissance capabilities. These should be addressed to provide a better product that meets the system requirements. The flight control software seems to be the major contributor to these deficiencies and is only something that AeroVironment can address. In the case of the Puma's use with the AFL, the best way to mitigate these deficiencies is to be aware of their presence during operation.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the Puma has proven to be a reliable, safe, and effective platform capable of providing the desired surveillance and reconnaissance performance. It met 3 of the six requirements created for it and only slightly failed to meet the other three, which should have little effect on the Puma's operational capability. During the test program, many unknown qualities of the Puma were discovered and documented, making it a safer and more effective system. Some of these were undesirable performance issues which can be mitigated if the AFL team operating the Puma is aware of them. Almost all the deficiencies found during testing, including the 3 failed MOEs, are only able to be fixed by an aircraft redesign or flight controller update. The Puma was made by AeroVironment, so there is not much the AFL can do about addressing the deficiencies of the aircraft. The best course of action is to brief any users of the AFL Puma on the findings of this report so the operation can be conducted safely and effectively.

REFERENCES

United States, Congress, Air Force. "Air Force Test and Evaluation Guidebook." *Air Force Test and Evaluation Guidebook*, 1.0 ed., USAF, 2004.

APPENDIX

A. Requirement Traceability Matrix

System Requirement Statement	Derived MOE
The Puma shall have an endurance of 2.5 hours.	Endurance (Hours)
The Puma shall have a maximum level speed greater than 40 knots.	Maximum Level Speed (Knots)
The Puma shall have a deep stall glide ratio of 1:1.	Deep Stall Glide Ratio (N/A)
The Puma shall have a maximum climb rate greater than 100 feet per minute.	Maximum Climb Rate (Feet Per Minute)
The Puma shall have a Longitudinal and Latitudinal GPS accuracy +/- 10 feet.	Longitudinal/Latitudinal GPS Accuracy (Feet)
The Puma shall have an altitude keeping accuracy of +/- 20 feet AGL.	Altitude Accuracy (Feet)
The Puma shall have a range of greater than or equal to 9.32 miles (15 km).	Range (Miles)