# REAL OPTIONS "IN" A MICRO AIR VEHICLE SYSTEM

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# Abstract

The goal of this research is to value Real Options "in" a Micro Air Vehicle (MAV) design system. Real options is defined in the finance literature as the "right, but not the obligation" to take an action (e.g. deferring, expanding, contracting, or abandoning) at a predetermined cost and for a predetermined time. These are called "real options" because they pertain to physical or tangible assets, such as equipment, rather than financial instruments. Real options improve a system's capability of undergoing classes of changes with relative ease. This property is often called "flexibility." Recently, the DoD has emphasized the need to develop flexible system to improve operational, technical, and programmatic effectiveness. The aim of this research is to identify and value real options in the MAV to improve uncertainty management for the system's future.

One of the most significant challenges in applying real options to engineering systems is the problem of identifying sources within the system to create options. To identify the points of interest, systems engineers require knowledge about the physical and non-physical aspects of the system, insight into sources of change, and the ability to examine the dynamic behavior of the system. This paper presents a three phase process to apply real options "in" the system. The first phase is data collection, where designers should identify and model uncertainties and externalities that impact the valuation of designs. The second phase is to determine the alternative designs applicable to the problem. The final phase is modeling and assessing the value, where the real options are valued using decision trees and lattice method to value both the fixed and flexible designs. This work utilizes preliminary results which have demonstrated that by modifying the design of the wing and the empennage components, flexibility can be designed into the MAV to provide better programmatic performance for extended requirements.

Note to the Reader:

This study was generated for academic purposes to demonstrate understanding of the real options analysis tools and applications. Please make careful note of all assumptions and documented sources of data. Many assumptions have been made to simplify the analysis due to the confined scope of this assessment.

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# Background

The US Air Force (USAF), as well as other Department of Defense (DoD) organizations, has validated the need for small unmanned air vehicles (SUAVs) and Micro Air Vehicles (MAVs) to provide situational awareness for ground troops in the battlespace. Demand for all UAVs has grown exponentially over the past two decades as technology has increasingly matured, providing capabilities to satisfy mission deficiencies. While these deficiencies are clearly documented, the requirements for system acquisition are vaguely defined and specify a wide range of performance attributes. Missions applicable to the use of UAV assets are often customized by each service/organization. Because of this uniqueness, prioritizing of performance attributes and design constraints can vary according to the mission, creating a lack of consensus among operators on the ideal design.

Several organizations within DoD services have begun to pursue customized platforms to fulfill individual mission deficiencies. For example, the Marine Corps developed and acquired the Dragon Eye small UAV produced by Aerovironment, while the Army and Air Force both depend on the Raven UAV, also produced by Aerovironment. Furthermore, requirements documents for Rucksack Portable UAV (RPUAV) and Battlefield Air-Targeting Camera Autonomous Micro air vehicle (BATCAM have been approved to address the need for a single man-packable UAV platform, but each have different performance goals. Some missions require longer endurance and range, while other missions require stealthy, short-range missions. This independent approach to satisfy mission needs has caused significant interoperability challenges as operators begin to stove-pipe the process of acquisition.[1]

The lack of consensus has caused struggle within DoD, especially for SUAVs and MAVs where the missions are very customized. A study produced by the US Government Accountability Office (GAO)[2] suggested improvements in planning and coordination could vastly improve emerging interoperability challenges and duplication of Research and Development (R&D) efforts across services. In response, the Office of the Secretary of Defense (OSD) published the *Unmanned Air Systems (UAS) Roadmap*[3] released in 2005, and Air Force Special Operations Command (AFSOC) was pronounced the official Major Command (MAJCOM) for all Small UAVS. AFSOC has organized the deficiencies and recommends a Family of Systems (FoS) approach to the UAS challenge (see Figure 1).

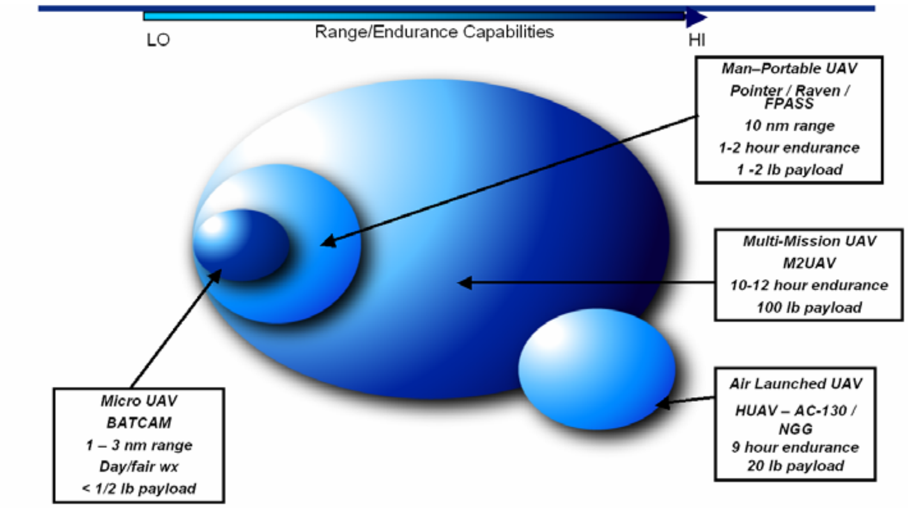


**Figure 1. Air Force Special Operations Family of UAVs Definition[4]**

## Small vs. Micro UAVs

From Figure 1, AFSOC has distinguished between SUAVs and MAVs by range and endurance capability. This approach is less conventional since technology developments may change the classification of platforms. However, for the purposes of this analysis, this classification proves useful, as will be discussed in a later section. More conventionally accepted, the definition of MAVs first employed by Defense Advanced Research Projects Agency (DARPA) programs limits these platforms to a size less than 15-cm (about 6-inches) in length, width or height.[5] However, this definition has morphed to include air vehicles with dimensions up to 24-inches in length, width, or height, as is the case with the BATCAM. Small UAVs are typically interpreted to be less than 10-feet in any dimension, but this too is subject to context. Figure 2 shows both a small and micro UAV to provide a qualitative illustration.

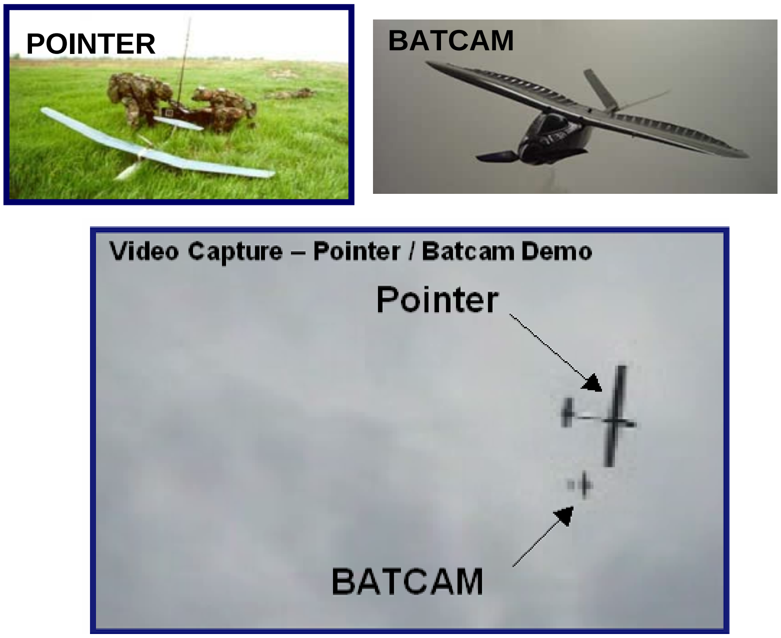


**Figure 2. Small and Micro UAVs (The Aerovironment Pointer SUAV has a wingspan dimension of approximately 8-feet, while the BATCAM MAV has a wingspan dimension of approximately 2-feet.)**

### *Challenge to Industry*

UAV manufacturers desiring to maximize profits by penetrating the market demand for UAVs must consider two approaches: 1) develop customized platforms to satisfy the independent requirements for specific missions or 2) develop a single platform with flexibility to accommodate many, if not all, specific missions. Historically, manufacturers have elected to produce customized platforms, which require independent R&D efforts and ultimately separate manufacturing lines. This customization may lead to significant capital investments if the manufacturer attempts to penetrate both markets.

If manufacturers could value the potential to produce the single flexible option that satisfies requirements for many classes, one platform may fulfill the requirements for both Small and Micro UAVs. This deviation from the current procurement strategy may reduce the diversity of platforms, thereby reducing the number of deployed systems and interoperability challenges.

## Real Options Analysis for MAV Design

Real Options Analysis can be applied "on" a system or "in" a system. When analyzing options "on" a system, flexibility is external to the physical design. Alternatively, real options analysis "in" a system requires the flexible option be internal to the physical design. This paper specifically addresses the value of flexibility "in" a system.

## *The Engineering System*

MAVs contain three major components: the air vehicle, the ground station, and the operator control unit, which is in most cases a software application providing a graphical user interface. However, the complexity of the interactions between the three components is beyond the scope of this analysis, and thus, the system analyzed in this paper will be restricted to considering the air vehicle only for simplicity. The air vehicle will include all components within the physical airframe, including the airframe itself. While encompassing the transceiver hardware and autopilot hardware which possess software components, this analysis will not consider the extensive software interactions of these components with the respective ground station counterparts. Furthermore, the flexibility will be limited to hardware alternatives, rather than modifications to the software algorithms, to improve performance.

## Physical Design Model

The airframe can be decomposed into a series of objects, which can be described in terms of geometric and mass properties. Figure 3 shows the various components of the MAV airframe.

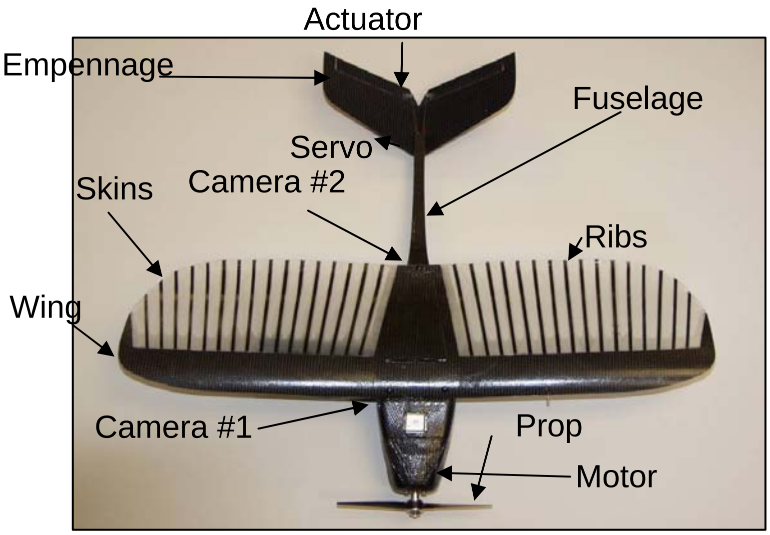
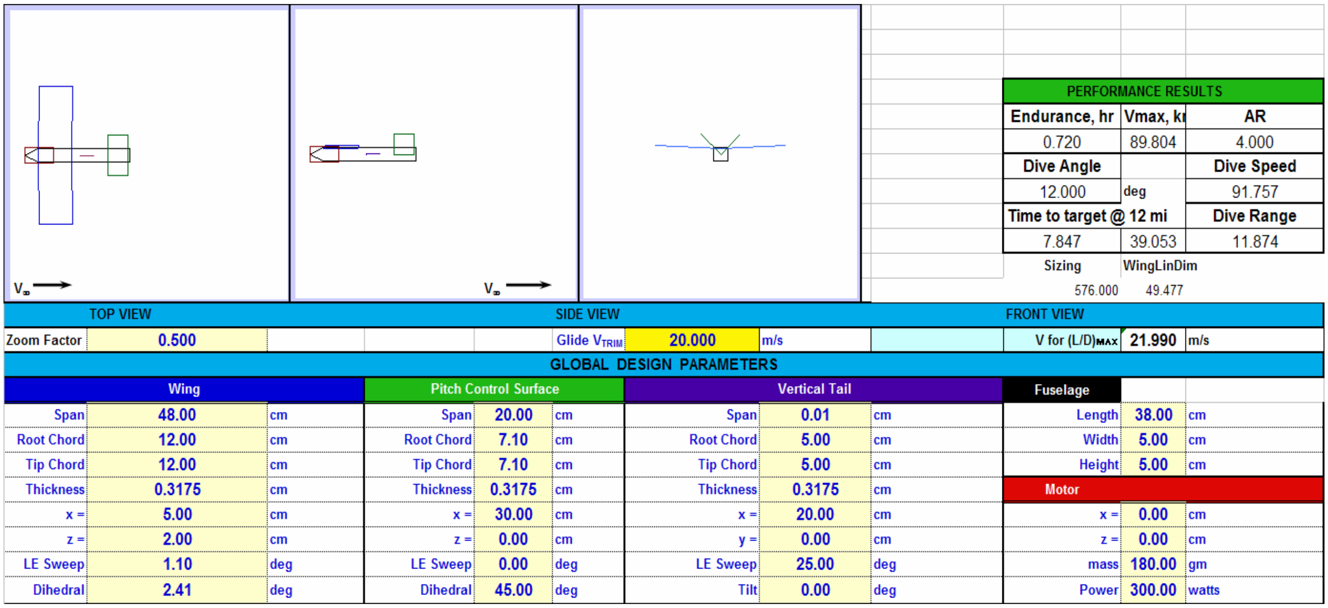


**Figure 3. Objects of MAV Airframe**

A physical model of the air vehicle design was developed using MS Excel© by the USAF Academy[6] and validated by AFRL, Munitions Directorate for a series of MAV platforms. The model accepts geometric and mass property inputs for components of the MAV to return performance objectives, such as endurance, range, and airspeed solutions. Figure 4 is a depiction of the physical model tool. The model will enable designers to quickly compute impacts to performance resulting from changes to the physical design.



**PERFORMANCE RESULTS**

| Endurance, hr | Vmax, kr | AR |
|---|---|---|
| 0.720 | 89.804 | 4.000 |
| Dive Angle | | Dive Speed |
| 12.000 | deg | 91.757 |
| Time to target @ 12 mi | | Dive Range |
| 7.847 | 39.053 | 11.874 |
| Sizing | WingLinDim | |
| 576.000 | 49.477 | |

Zoom Factor 0.500
Glide $V_{TRIM}$ 20.000 m/s
V for $(L/D)_{MAX}$ 21.990 m/s

**GLOBAL DESIGN PARAMETERS**

| Wing | | | Pitch Control Surface | | | Vertical Tail | | | Fuselage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Span | 48.00 | cm | Span | 20.00 | cm | Span | 0.01 | cm | Length | 38.00 | cm |
| Root Chord | 12.00 | cm | Root Chord | 7.10 | cm | Root Chord | 5.00 | cm | Width | 5.00 | cm |
| Tip Chord | 12.00 | cm | Tip Chord | 7.10 | cm | Tip Chord | 5.00 | cm | Height | 5.00 | cm |
| Thickness | 0.3175 | cm | Thickness | 0.3175 | cm | Thickness | 0.3175 | cm | Motor | | |
| x = | 5.00 | cm | x = | 30.00 | cm | x = | 20.00 | cm | x = | 0.00 | cm |
| z = | 2.00 | cm | z = | 0.00 | cm | y = | 0.00 | cm | z = | 0.00 | cm |
| LE Sweep | 1.10 | deg | LE Sweep | 0.00 | deg | LE Sweep | 25.00 | deg | mass | 180.00 | gm |
| Dihedral | 2.41 | deg | Dihedral | 45.00 | deg | Tilt | 0.00 | deg | Power | 300.00 | watts |

**Figure 4. MAV Physical Design Model**

## Identifying Sources of Flexibility

To identify options for flexibility, manufacturers seek areas in the design that can be easily manipulated and contribute to significant performance impacts. Modularity of the airframe allows objects to be easily manipulated. Then, designers should assess the objects that are strongly related to the objectives and functions to select those that are able to significantly influence the system performance. For example, physical connections can be designed at the empennage-fuselage and wing-fuselage interactions, thereby providing the capability to attach different wing-empennage combinations. By changing the geometry of the wing, designers can significantly affect the endurance performance. Realizing this relationship between the physical designs and resulting capability early in the development process provides the manufacturer the option to exploit the flexibility later. However, the system must be initially designed to accommodate the flexibility.

## *Application of ROA*

To illustrate the application of ROA to MAV design, this study establishes a scenario from the perspective of a UAV manufacturer responding to a single customer with a demand for MAVs and SUAVs. The customer has indicated an urgent need and preference for MAVs. When designing the system, the manufacturer must decide whether to target the MAV market or both the SUAV and MAV markets. This paper uses Real Options Analysis to value flexibility in the design, such that a single platform may achieve performance requirements for both MAV and SUAV missions, and therefore penetrate both markets.

## Assumptions

To emphasize the process rather than intensive computations, the following assumptions will be considered to simplify the calculations.

- The manufacturer can only produce one air vehicle design. The manufacturer cannot produce a vehicle for the MAV demand and a separate vehicle for the SUAV demand. Therefore, a single design will be selected for the production cycle.
- The distinction between the demand for SUAVs and MAVs is distinguished by only one performance parameter, endurance. This assumption can be validated by the AFSOC classification structure previously presented.
- The manufacturer will only respond to the single customer demand during the production cycle of six years (2007-2012).
- The manufacturer uses a constant discount rate for all UAV projects: r = 12%

- The manufacturer is not limited by ability to produce (ie capacity).
- It is physically possible to achieve the SUAV requirements utilizing a MAV with an alternate wing and empennage. This assumption was validated by MDO accomplished by Bartolomei[7], which concluded that a 29-inch wingspan could effectively perform 1.1-hours of flight. Figure 5 presents Bartolomei's Pareto frontier for the results of single objective optimization for endurance performance considering longest linear dimension—wingspan in this case—generated using the USAFA physical model.

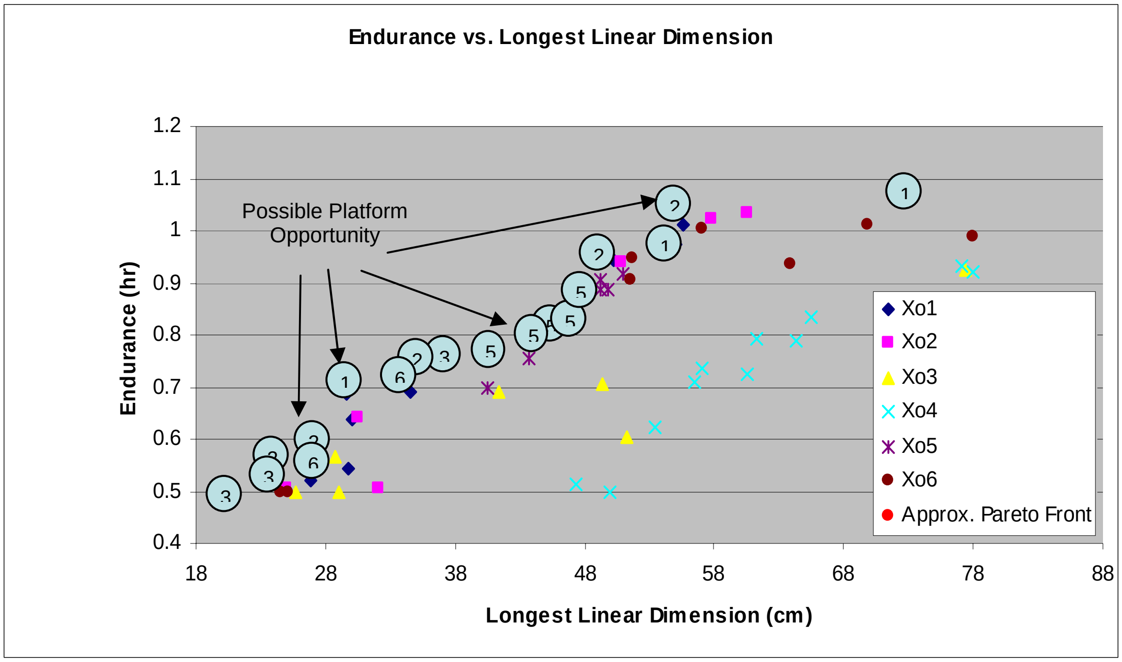


**Figure 5. Estimated Pareto Front for Single Objective Optimization[8]**

Additionally, the manufacturer was presented with the information regarding customer demand shown in Table 1 and Figure 6.[9]

**Table 1. SUAV and MAV Demand Predictions for FY 2005-2012**

| **SYSTEMS** | **FY05** | **FY06** | **FY07** | **FY08** | **FY09** | **FY10** | **FY11** | **FY12** |
|---|---|---|---|---|---|---|---|---|
| **Small & Micro UAVs** | **120** | **153** | **281** | **398** | **486** | **596** | **726** | **726** |
| Micro UAVs | 30 | 30 | 125 | 225 | 325 | 435 | 565 | 565 |
| Small UAVs | 90 | 123 | 156 | 173 | 161 | 161 | 161 | 161 |

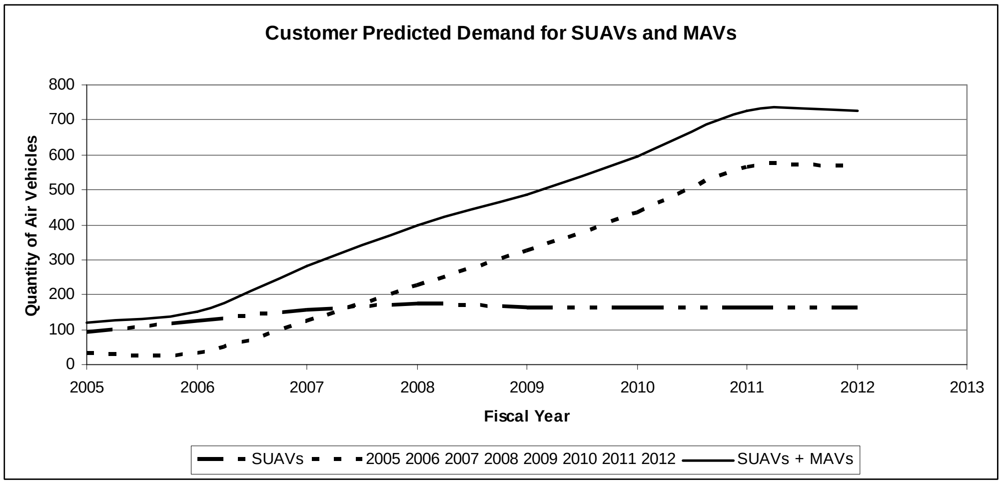


**Figure 6. SUAV and MAV Demand Predictions for FY 2005-2012**

## Possible Designs

Reminder, the intent of this analysis is not to optimize the air vehicle design, but rather implement ROA to select from various designs. Therefore, results of Multi-Design Optimization (MDO) analysis completed by Bartolomei[10] will be referenced for design possibilities. Furthermore, while realistically representative of the industry, all costs and prices are generated only to illustrate the ROA process and should not be referenced beyond the context of this paper. This project will consider two air vehicle design possibilities: fixed and flexible.

### *Fixed Design*

The goal of the fixed design is to satisfy the requirements for the MAV class only. Recall that MAV class vehicles provide endurance capabilities of less than one hour. For this example, the customer has specified an endurance objective less than 30-minutes. Thus, from Figure 5 the wingspan corresponding to 30-minute capability is approximately 8-inches.

For the purpose of this analysis assume capital investment costs of $1.5M are invested initially, and the manufacturer is able to produce the first unit in 2007. Marginal costs for the fixed design will be $2000 per MAV, and the manufacturer plans to sell the product at $7000 per MAV. Table 2 summarizes the financial commitments for the fixed design.[1]

**Table 2. Fixed Design Cost Summary**

| | |
|---|---|
| Target Market | MAVs (2007-2012) |
| Fixed Cost | $1.5M |
| Marginal Cost | $2000 per MAV |
| Price | $7000 per MAV |
| Discount Rate | 12% |

### *Flexible Design*

The goal of the flexible design is to satisfy the requirements for the MAV class only in the first year of production. However, the manufacturer would like to capture the SUAV market in the second year by providing a different wing and empennage that allows the air vehicle to achieve the SUAV requirement. Therefore, the flexible design is the same as the fixed design, except the fuselage is designed with interfaces for interchangeable wings and empennage sections. The interface design must be sufficient to accommodate the air vehicle weight and flight forces (ie, lift and

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[1] NOTE: While realistically representative of industry, all costs and prices are generated only to illustrate the ROA process and should not be referenced beyond the context of this paper.

maneuvering g-forces). Finally, additional wing and empennage designs will then be available for specific customer requirements.

Capital investment cost of the flexible design is $1.75M, including additional research and development for the interface design and additional production line tooling requirements. Marginal cost per MAV is increased to $2500 due to the interface fabrication. The price charged to the customer is not constant for this design, but is instead time dependent. In 2007, the manufacturer produces a single wing for the flexible MAV design capable of meeting the MAV requirement only, and thus the price is the same as the fixed design ($7000 per MAV). However, in 2008 the manufacturer can choose to exploit the flexibility and produce various wings for the flexible MAV design to extend the endurance performance to meet the SUAV requirement as well. The manufacturer could then charge a price for the increased capability compatible with current SUAV pricing, approximately $10,000 per MAV.

**Table 3. Flexible Design Cost Summary**

| | |
|---|---|
| Target Market | MAVs (2007)<br>MAVs + SUAVs (2008-2012) |
| Fixed Cost | $1.75M |
| Marginal Cost | $2500 per MAV |
| Price | $7000 per MAV without flexible option<br>$10000 per MAV with flexible option |
| Discount Rate | 12% |

## Uncertainties

Research and development trends over the past five to ten years have shown dramatic improvements in technology and integration efforts relevant to MAVs. For example, lithium-polymer battery technology has become commercially available and affordable to the radio controlled model industry. This availability in turn has encouraged the development of a variety of electric motors, propellers, and electronic speed controllers for integration into MAVs. Additionally, the regulations for airspace and frequency allocation are being modified to include Unmanned Systems, including MAVs, as seen by the recent Office of the Secretary of Defense (OSD) Unmanned Systems Roadmap drafted in 2005. Uncertainties also exist in economical/financial aspects. DoD is expending increasing funds on the development and procurement of MAVs. While several uncertainties exist, the analysis will focus on two important factors: the demand for MAVs and SUAVs and the ratio of MAVs to SUAVs, which relates to the ability to penetrate the combined market.

### *Uncertainty of Demand*

To model the uncertainty of demand for MAVs and SUAVs, a random number generator was utilized to create a solution set of values for six year period (ie a randomized demand for year 1, year 2, year 3, etc). Then, a simulation generated 1000 sample solution sets to provide a cumulative distribution function CDF. The results are presented in Figure 7.

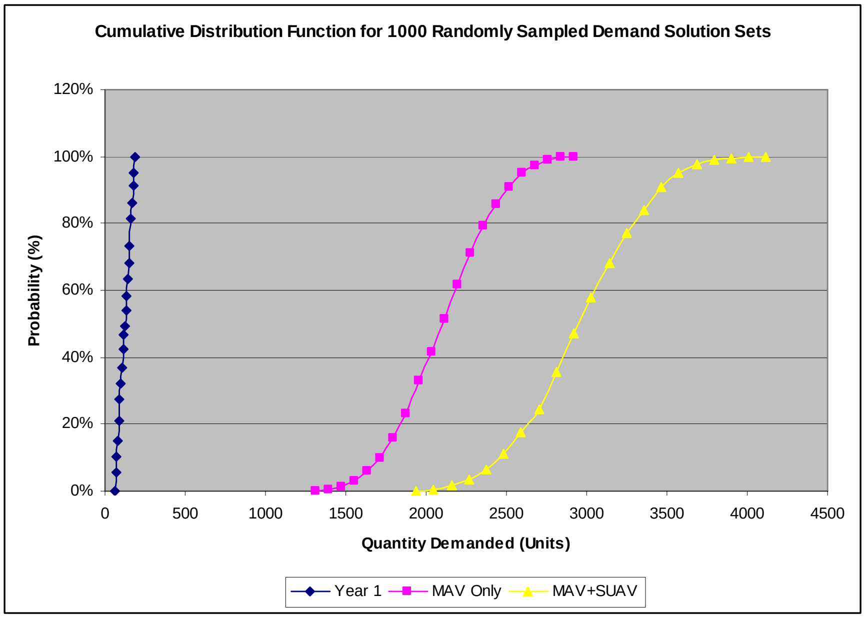

**Figure 7. Cumulative Distribution Function for Demand Uncertainty**

In Figure 7, the "Year 1" curve represents the quantity of MAVs demanded by the customer. However, the "MAV Only" and "MAV + SUAV" curves represent the cumulative demand for Year 2-Year 6. This assumption was made for simplification of the Decision Analysis in the next section.

## *Uncertainty of Predicted Ratio of MAVs to SUAVs*

To simplify for this analysis, this ratio will be held constant as defined in the customer predictions. Therefore, the manufacturer producing a design only capable of performing to the MAV requirement will only penetrate the respective percentage of the demand shown in Table 4, which was interpreted from the customer-given data in Table 1. For example, in 2007 the manufacturer only captures the MAV market demand for both fixed and flexible designs, and thus is only able to penetrate 44% of the total demand for MAVs and SUAVs.

**Table 4. Predicted Ratio of MAVs to SUAVs for FY 05-FY12**

| SYSTEMS | FY05 | FY06 | FY07 | FY08 | FY09 | FY10 | FY11 | FY12 |
|---|---|---|---|---|---|---|---|---|
| Micro Percentage | 0.25 | 0.20 | 0.44 | 0.57 | 0.67 | 0.73 | 0.78 | 0.78 |
| Small Percentage | 0.75 | 0.80 | 0.56 | 0.43 | 0.33 | 0.27 | 0.22 | 0.22 |

## Net Present Value

The Net Present Value (NPV) is the total yearly profits discounted to present value. Using the manufacturer's constant discount rate (r=12%, see Assumptions) and the customer's predicted demand quantities and MAV to SUAV ratio, the NPV is easily calculated for both the fixed and flexible design. However, this calculation does not account for uncertainty in the demand. A random number generator, which returns a uniformly distributed random demand for each year around the predicted value varying by the 50% uncertainty, can be used to value the projects for one particular demand solution set, d = [354,247,580,701,665,834]. Results for both NPV calculations are presented in Table 5.

**Table 5. NPV Analysis for Fixed and Flexible Designs**

| | Predicted Demand | Demand w/ Uncertainty |
|---|---:|---:|
| Fixed | $5.53M | $6.46M |
| Flexible | $12.75M | $14.80M |

## Decision Analysis of Alternative Designs

This section will use a two-stage decision analysis to evaluate both the fixed and flexible designs. Figure 8 displays the two-stage decision tree for the manufacturer.

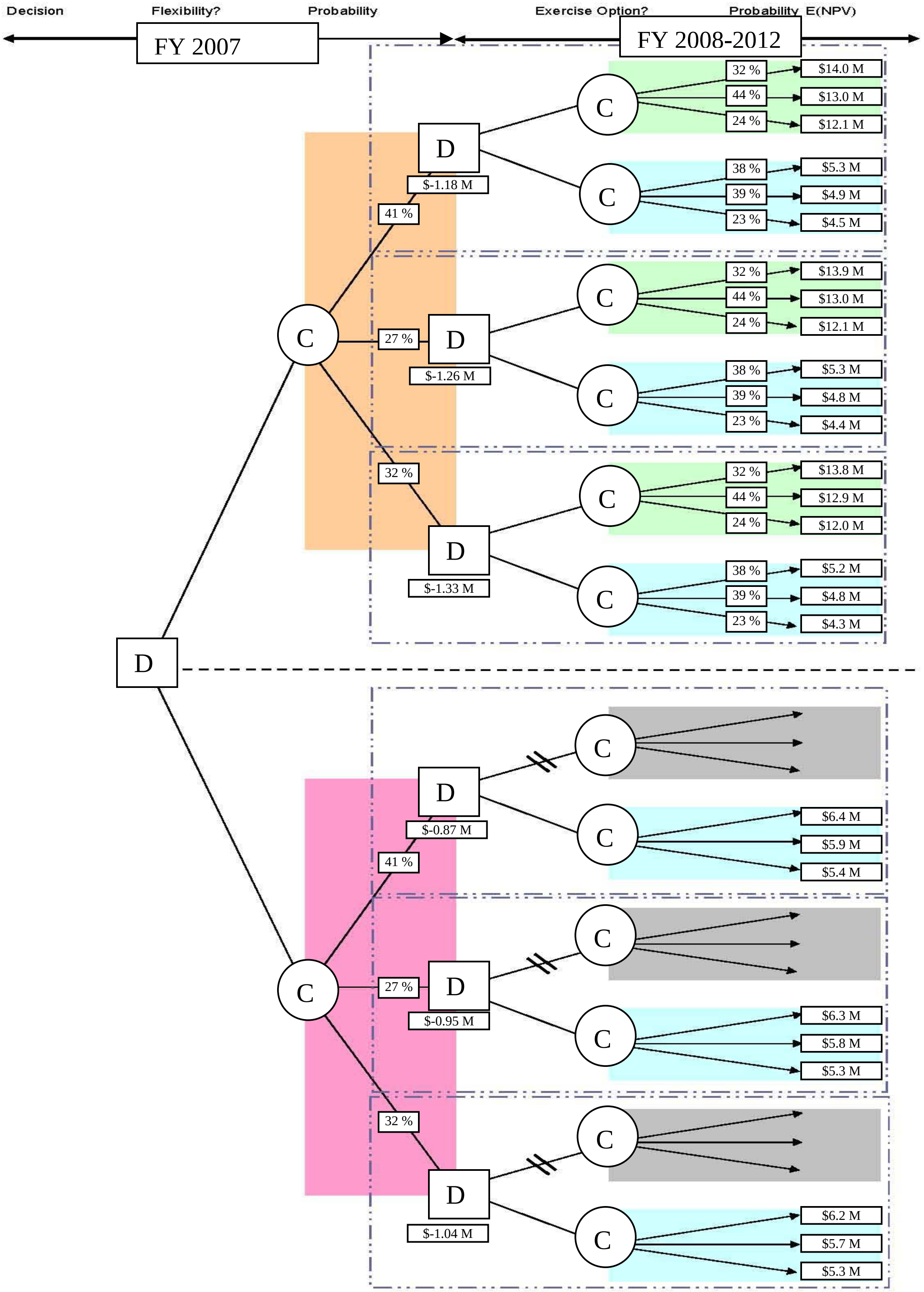

**Figure 8. Two-Stage Decision Tree for Decision Analysis**

The first decision is to either a) build the flexible design or b) build the fixed design. This is followed by a chance of the demand being i) higher than forecasted, ii) equal to the forecasted, or iii) lower than forecasted. The probability of the chance outcomes is determined from the CDF of the 1000 sample solution sets. The demand solution sets were categorized as high, forecasted (expected), or low based on the mean and standard deviation of the CDF. Then, the probabilities associated with the demand categories can be extrapolated from the CDF. A summary of the probabilities is presented in Table 6.

**Table 6. Probabilities of Chance Events**

| | | Demand | Chance Event | Probability (%) |
|---|---|---|---|---|
| Year 1 | MAVs Only | N > 141 | High | 41% |
| | | 104 < N < 141 | Forecasted | 27% |
| | | N < 104 | Low | 32% |
| Year 2 – Year 6 | MAVs Only | N > 2252 | High | 38% |
| | | 1955 < N < 2552 | Forecasted | 39% |
| | | N < 1955 | Low | 23% |
| | MAVs + SUAVs | N > 3142 | High | 32% |
| | | 2765 < N < 3142 | Forecasted | 44% |
| | | N < 2765 | Low | 24% |

The second decision occurs after Year 1 and determines whether the manufacturer will exploit the flexible option of meeting the requirements for both MAVs and SUAVs, thereby capturing the entire market for SUAVs and MAVs. Notice that the fixed design does not have the opportunity to further penetrate the demand, and thus continues to produce MAVs only at the constant MAV to SUAV ratio. This decision is followed by the chance outcome of the demand, and since the manufacturer is not limited by capacity to produce (see Assumptions) the demand correlates to production (revenue). To simplify the decision tree, assume that the demand for Year 2-Year 6 will be fulfilled by a bulk contract, in which the manufacturer will deliver an equal quantities over the five years. For example, if the expected cumulative demand is 1500, then the company will produce 300 units each year for the five year period. As in the first stage, the categories and respective probabilities are calculated from the 1000 sample solution sets. A summary of the stage-two probabilities is provided in Table 6.

The probability of occurrence and expected value of demand can be used to calculate the Net Present Value of each particular event. As previously stated, the manufacturer uses a constant discount rate ($r = 12\%$) for all UAV projects. The expected Net Present Values for each chance for Stage 1 and Stage 2 are summarized in Table x and Table X, respectively. Notice that the NPVs for both the fixed and flexible designs are different than the NPVs calculated previously. This difference is due to the assumption of averaging the production in Year 2-Year 6, and thus the discounting is not comparable for the two methods (this deficiency is discussed later in Conclusions). Using the Value at Risk curve maximizes the upside potential and minimizing the downside results. In this case, the upside of the flexible case increased by meeting the requirements of both MAVs and SUAVs. The manufacturer can thus fulfill 100% of the total MAV + SUAV demand.

**Table 7. Expected NPV for Fixed and Flexible Designs for Stage-One of Decision Analysis**

| | Demand | Chance Event | NPV |
|---|---|---|---|
| Flexible Design | N > 141 | High | $-1.18 M |
| | 104 < N < 141 | Forecasted | $-1.26 M |
| | N < 104 | Low | $-1.33 M |
| Fixed Design | N > 141 | High | $-0.87 M |
| | 104 < N < 141 | Forecasted | $-0.95 M |
| | N < 104 | Low | $-1.04 M |

**Table 8. Expected NPV for Fixed and Flexible Designs for Stage-Two of Decision Analysis**

| | Demand | Chance Event | NPV |
|---|---|---|---|
| MAVs Only | N > 141 | High | $-1.18 M |
| | 104 < N < 141 | Forecasted | $-1.26 M |
| | N < 104 | Low | $-1.33 M |
| MAVs Only | N > 2252 | High | $-0.87 M |
| | 1955 < N < 2552 | Forecasted | $-0.95 M |
| | N < 1955 | Low | $-1.04 M |
| MAVs Only | N > 141 | High | $-1.18 M |
| | 104 < N < 141 | Forecasted | $-1.26 M |
| | N < 104 | Low | $-1.33 M |
| MAVs Only | N > 2252 | High | $-0.87 M |
| | 1955 < N < 2552 | Forecasted | $-0.95 M |
| | N < 1955 | Low | $-1.04 M |
| MAVs Only | N > 141 | High | $-1.18 M |
| | 104 < N < 141 | Forecasted | $-1.26 M |
| | N < 104 | Low | $-1.33 M |
| MAVs Only | N > 2252 | High | $-0.87 M |
| | 1955 < N < 2552 | Forecasted | $-0.95 M |
| | N < 1955 | Low | $-1.04 M |
| | | | |

As seen in Table 8, the manufacturer can maximize the upside potential in Stage-two by building flexible in stage-one although first year returns will seem worse than the fixed design. The expected NPV for the flexible design is $13.07M and only $5.90M for the fixed design. Therefore, the manufacturer should choose to build flexible and exploit the flexibility in Year 2. This result shows the importance of the Decision Analysis approach. If only the first year is considered, the manufacturer may choose to stop production after the first year without realizing the benefits of flexibility in the future years. This solution assumes no externalities leading the manufacturer to believe demand would terminate after only one year. Only if such information was available would the manufacturer consider building the fixed design.

## Lattice Analysis of Evolution of Demand Uncertainty

Lattice Method can be used to model the demand uncertainty also. Calibration of the lattice requires historical data relevant to the system to estimate key parameters. However, this information is not available for new and emerging technologies due to the absence of historical data. For MAVs, where the technology is very new and rapidly changing, this is most certainly the case. The next section will suggest possible assumptions to calibrate the lattice.

### *Assumptions of Method*

The lattice method requires knowledge of the volatility of the demand uncertainty. To proceed with the lattice method analysis in the absence of past data, the volatility is approximated using a related metric: the historical growth in DoD expenditures for all UAVs. Because large UAVs typically cost substantially more than small and micro UAVs, this assumption is somewhat troubling. However, the objective here is to provide uncertainty in the generally growing demand. The assumed volatility for the demand growth for MAVs and SUAVs is calculated Table 9.

**Table 9. Calculation of Volatility Based on 10-Year Budget Data**

| Year | Budget | Growth Rate | LN (Growth Rate) | X-E(X) | (X-E(X))^2 |
|---|---|---|---|---|---|
| 2000 | 284 | | | | |
| 2001 | 363 | 1.28 | 0.25 | 0.08 | 0.01 |
| 2002 | 763 | 2.10 | 0.74 | 0.42 | 0.18 |
| 2003 | 1448 | 1.90 | 0.64 | 0.32 | 0.10 |
| 2004 | 1631 | 1.13 | 0.12 | 0.20 | 0.04 |
| 2005 | 2166 | 1.33 | 0.28 | 0.04 | 0.00 |
| 2006 | 1946 | 0.90 | 0.11 | 0.43 | 0.18 |
| | | Mean | 32% | | |
| | | Variance | 10% | | |
| | | Volatility | 32% | | |

The lattice method also requires knowledge about the predicted growth rate of the demand. Predictions for future DoD UAV budgets are available in the UAS Roadmap[11] (see Table 10). Annual expenditures are not expected to grow at a linear rate, but rather exponentially over the next five years. However, the lattice method assumes a constant expected growth rate, and thus this analysis will use an average of the predicted growth rates as calculated in Table 10.

**Table 10. Expected Constant Growth Calculated from Predicted Budget**

| Index | Year | Predicted Value | Growth | Growth Rate | Expected Value for Constant Growth |
|---|---|---|---|---|---|
| 0 | 2006 | 1946 | | | 1946 |
| 1 | 2007 | 2074 | 128 | 1.07 | 2143 |
| 2 | 2008 | 2249 | 175 | 1.08 | 2361 |
| 3 | 2009 | 2845 | 596 | 1.27 | 2600 |
| 4 | 2010 | 2952 | 107 | 1.04 | 2864 |
| 5 | 2011 | 3113 | 161 | 1.05 | 3155 |
| 6 | 2012 | | | | 3475 |
| | | | Mean | 1.10 | |
| | | Adjusted Mean $\nu$ | | 1.06 | |

As previously mentioned, large UAV assets cost considerably more than SUAVs or MAVs, and thus the number of systems demanded is not a true reflection of the funds expended. For example, several thousand smaller assets may be procured for the same cost as one large UAV asset. Fortunately, the customer also provides data for the number of systems anticipated for future procurements (see Table 1). From this information, manufacturers can predict annual increase in demand for MAVs and SUAVs. Recall that the fixed case will only allow the manufacturer to sell to operators desiring MAVs. However, the flexible system can accommodate various wings to achieve both MAV and SUAV objectives, allowing greater market penetration by selling both classes.

The expected annual growth rate for the cumulative demand for MAVs and SUAVs can be determined from the data presented in Table 11. The demand is expected to grow approximately 40% annually.

**Table 11. Expected Constant Growth Calculated from Predicted Procurements**

| Year | Predicted Value | Growth | Growth Rate | Expected Demand for Constant Growth |
|---|---|---|---|---|
| 2006 | 153 | | | 153 |
| 2007 | 281 | 128 | 1.84 | 213 |
| 2008 | 398 | 117 | 1.42 | 297 |
| 2009 | 486 | 88 | 1.22 | 414 |
| 2010 | 726 | 240 | 1.49 | 577 |
| 2011 | 726 | 0 | 1 | 804 |
| 2012 | 726 | 0 | 1 | 1121 |
| | | Mean ν | 1.40 | |

Because the volatility is near the same magnitude as the expected growth rate, the calibration will require a smaller time step. Here, the time step has been reduced to 0.5 years, yielding a expected growth rate of 20% and volatility of only 16%. The number of terms will then be doubled to twelve, rather than six, to accommodate the smaller time step. Equation 1, Equation 2, and Equation 3 are used to calibrate the probability, upside potential and downside potential, respectively.

$$p = 0.5 + 0.5\left(\frac{\nu}{\sigma}\right)(\Delta t)^{0.5}$$ **Equation 1**

$$u = e^{\sigma \cdot \Delta t^{0.5}}$$ **Equation 2**

$$d = \frac{1}{u}$$ **Equation 3**

A summary of the calibration terms for the lattice is presented in Table 12.

**Table 12. Calibration Parameters for Lattice Method**

| Parameter | | Value |
|---|---|---|
| Initial Demand | $D_o$ | 281 units |
| Time Step | Δt | 0.5 years |
| Expected Growth | ν | 20% |
| Volatility | σ | ±16% |
| Probability Up | p | 94% |
| Upside Factor | u | 1.12 |
| Downside Factor | d | 0.89 |

## *Expected Demand Lattice*

Given the expected volatility and the predicted constant growth rate, the uncertainty of demand can be adequately modeled for use in the lattice method. The outcome lattice for demand is presented in Table 13.

**Table 13. Outcome Lattice for Expected Demand**

| **2006** | | **2007** | | **2008** | | **2009** | | **2010** | | **2011** | | **2012** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year 0** | | **Year 1** | | **Year 2** | | **Year 3** | | **Year 4** | | **Year 5** | | **Year 6** | |
| t = 0 | t = 1 | t = 2 | t = 3 | t = 4 | t = 5 | t = 6 | t = 7 | t = 8 | t = 9 | t = 10 | t =11 | t=12 | |
| 153 | 171 | 192 | 215 | **240** | 269 | 302 | 338 | 378 | 423 | 474 | 531 | 594 | 665 |
| | 137 | 153 | 171 | 192 | 215 | 240 | 269 | 302 | 338 | 378 | 423 | 474 | 531 |
| | | 122 | 137 | 153 | 171 | 192 | 215 | 240 | 269 | 302 | 338 | 378 | 423 |
| | | | 109 | 122 | 137 | 153 | 171 | 192 | 215 | 240 | 269 | 302 | 338 |
| | | | | 97 | 109 | 122 | 137 | 153 | 171 | 192 | 215 | 240 | 269 |
| | | | | | 87 | 97 | 109 | 122 | 137 | 153 | 171 | 192 | 215 |
| | | | | | | 78 | 87 | 97 | 109 | 122 | 137 | 153 | 171 |
| | | | | | | | 69 | 78 | 87 | 97 | 109 | 122 | 137 |
| | | | | | | | | 62 | 69 | 78 | 87 | 97 | 109 |
| | | | | | | | | | 55 | 62 | 69 | 78 | 87 |
| | | | | | | | | | | 49 | 55 | 62 | 69 |
| | | | | | | | | | | | 44 | 49 | 55 |
| | | | | | | | | | | | | 39 | 44 |
| | | | | | | | | | | | | | 35 |

## *Probability Lattice*

The probability lattice presents the probabilities corresponding to the likelihood of the outcome lattice (Table 14). Figure 9 shows the probability distribution function for the final time period.

**Table 14. Probability Lattice**

| **2006** | | **2007** | | **2008** | | **2009** | | **2010** | | **2011** | | **2012** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year 0** | | **Year 1** | | **Year 2** | | **Year 3** | | **Year 4** | | **Year 5** | | **Year 6** | |
| t = 0 | t = 1 | t = 2 | t = 3 | t = 4 | t = 5 | t = 6 | t = 7 | t = 8 | t = 9 | t = 10 | t =11 | t=12 | |
| 1.00 | 0.94 | 0.87 | 0.82 | 0.76 | 0.72 | 0.67 | 0.63 | 0.58 | 0.55 | 0.51 | 0.48 | 0.45 | 0.42 |
| | 0.06 | 0.12 | 0.17 | 0.21 | 0.25 | 0.28 | 0.30 | 0.32 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 |
| | | 0.00 | 0.01 | 0.02 | 0.03 | 0.05 | 0.06 | 0.08 | 0.09 | 0.11 | 0.13 | 0.14 | 0.16 |
| | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 |
| | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | 0.00 | 0.00 |
| | | | | | | | | | | | | | 0.00 |

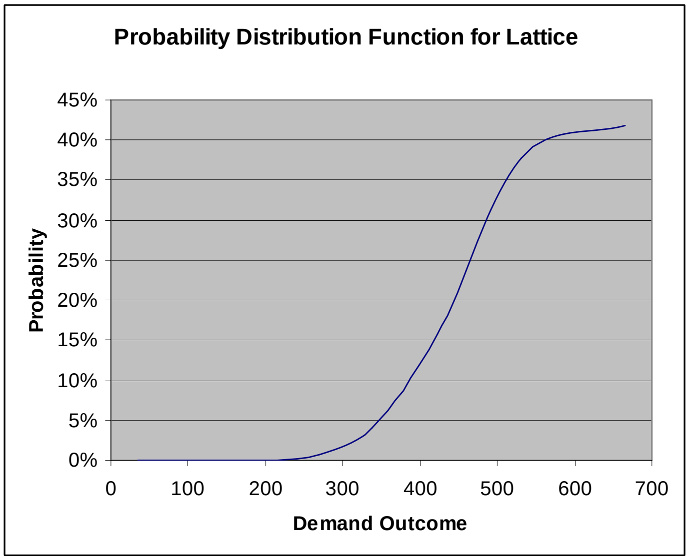

**Figure 9. Probability Distribution Function for Lattice Method (Year 6)**

## *Net Present Value Lattice*

Using the costs and price assumptions previously stated (see Fixed Design and Flexible Design in Assumptions), the expected revenue for each event can be determined and then weighted by the corresponding probability. The expected revenues for the fixed design will differ from the flexible design since the fixed design can only meet the MAV requirement, and thus penetrate only a percentage of the demand predicted by the lattice method. The expected revenues for the fixed and flexible designs are displayed in Table 15 and Table 16, respectively.

**Table 15. Weighted Expected Revenue in $M for Fixed Design (Not Discounted)**

| 2006 | | 2007 | | 2008 | | 2009 | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year 0 | | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | | Year 6 | |
| t = 0 | t = 1 | t = 2 | t = 3 | t = 4 | t = 5 | t = 6 | t = 7 | t = 8 | t = 9 | t = 10 | t =11 | t=12 | |
| 1.500 | 0.000 | 0.373 | 0.391 | 0.520 | 0.544 | 0.674 | 0.706 | 0.807 | 0.845 | 0.943 | 0.987 | 1.034 | 1.083 |
| | 0.000 | 0.041 | 0.065 | 0.115 | 0.151 | 0.224 | 0.273 | 0.357 | 0.421 | 0.522 | 0.601 | 0.686 | 0.779 |
| | | 0.001 | 0.004 | 0.010 | 0.017 | 0.031 | 0.045 | 0.069 | 0.093 | 0.130 | 0.166 | 0.209 | 0.258 |
| | | | 0.000 | 0.000 | 0.001 | 0.002 | 0.004 | 0.008 | 0.012 | 0.019 | 0.028 | 0.039 | 0.052 |
| | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.003 | 0.005 | 0.007 |
| | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 |
| | | | | | | | | | | | | | 0.000 |

**Table 16. Weighted Expected Revenue in $M for Flexible Design (Not Discounted)**

| 2006 | | 2007 | | 2008 | | 2009 | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year 0** | | **Year 1** | | **Year 2** | | **Year 3** | | **Year 4** | | **Year 5** | | **Year 6** | |
| t = 0 | t = 1 | t = 2 | t = 3 | t = 4 | t = 5 | t = 6 | t = 7 | t = 8 | t = 9 | t = 10 | t =11 | t=12 | |
| 1.750 | 0.000 | 0.336 | 0.352 | 1.379 | 1.444 | 1.512 | 1.583 | 1.658 | 1.736 | 1.818 | 1.903 | 1.993 | 2.087 |
| | 0.000 | 0.037 | 0.058 | 0.305 | 0.400 | 0.502 | 0.613 | 0.734 | 0.864 | 1.006 | 1.158 | 1.323 | 1.501 |
| | | 0.001 | 0.003 | 0.025 | 0.044 | 0.069 | 0.102 | 0.142 | 0.191 | 0.250 | 0.320 | 0.403 | 0.498 |
| | | | 0.000 | 0.001 | 0.002 | 0.005 | 0.009 | 0.016 | 0.025 | 0.037 | 0.053 | 0.074 | 0.101 |
| | | | | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.004 | 0.006 | 0.009 | 0.014 |
| | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 |
| | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 |
| | | | | | | | | | | | | | 0.000 |

One caution to note is that because the lattice method uses a time step less than one to accommodate the volatility and expected annual growth rate assumptions, the lattice predicts the demand at two periods within the year. The manufacturer only produces the yearly amount, not the sum of the mid-year and year prediction.

## *Decision Analysis Using Lattice Method*

By comparing the expected revenues of the both designs, the manufacturer would choose whether or not to exploit the flexible option. However, in this case the added investment for the flexibility is all upfront since the only added costs are included in the initial investment and cost of producing the design. Therefore, the manufacturer must decide up front whether to invest. However, the manufacturer has the option with the flexible design to exploit the flexibility by producing additional wings that can meet the SUAV requirements as well as the MAV requirements. Thus, the decision in the lattice is the manufacturer's choice to fully penetrate the market. If the expected revenue for the flexible case is greater than the expected revenue for the fixed case, the manufacturer will exercise the option to fulfill the demand for MAVs and SUAVs. Otherwise, the manufacturer will only choose to produce the quantity demanded for MAVs only. Table 17 shows the results of logical analysis of the expected revenues. True means that the manufacturer would select the desire to exercise the option. Notice that in Year 0 the manufacturer does not produce and sell and thus the greater initial investment for the flexible design causes the decision to favor the fixed design. Furthermore, the manufacturer is limited to only producing MAVs in the first year, and the added cost per unit of the flexible design again leads to favoring the fixed design. However, by carrying out the analysis it is obvious that the best long-term benefit for the manufacturer is realized by selecting the flexible design, which can then be exploited to further penetrate the market.

**Table 17. Decision to Exercise the Option for Lattice Method**

| 2006 | | 2007 | | 2008 | | 2009 | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year 0 | | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | | Year 6 | |
| t = 0 | t = 1 | t = 2 | t = 3 | t = 4 | t = 5 | t = 6 | t = 7 | t = 8 | t = 9 | t = 10 | t =11 | t=12 | |
| FALSE | FALSE | FALSE | FALSE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | FALSE | FALSE | FALSE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | FALSE | FALSE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | FALSE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | | | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | | | | | TRUE | TRUE | TRUE | TRUE | TRUE |
| | | | | | | | | | | TRUE | TRUE | TRUE | TRUE |
| | | | | | | | | | | | TRUE | TRUE | TRUE |
| | | | | | | | | | | | | TRUE | TRUE |
| | | | | | | | | | | | | | TRUE |

By summing the revenues for each period and discounting at the constant rate (r=12%), the NPV for each design can be calculated. The flexible design will consider the decision presented in Table 17. The results for the NPV analysis using the lattice method are presented in Table 18.

**Table 18. Results of Lattice Method**

| | NPV |
|---|---|
| Fixed Design | $4.22M |
| Flexible Design | $9.70M |

## *Discussion of Lattice Method*

For this analysis, the assumptions for the lattice method do not accurately model the expected demand. Figure 10 charts the customer predicted demand and the lattice method predictions. Note that the customer prediction is not within the upper and lower bounds of the lattice prediction. This is because the lattice method assumes a gradual linear growth rate, which is not the case for the MAV and SUAV demand. Thus, the lattice method predictions are flawed.

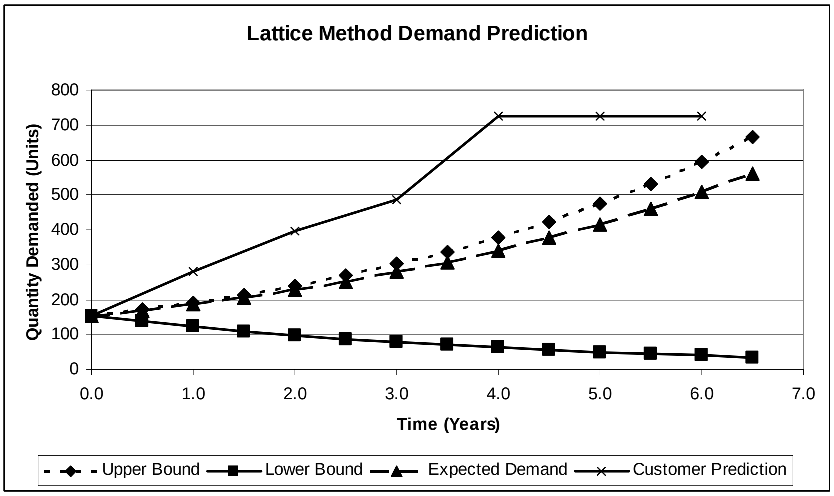

**Figure 10. Lattice Method Predictions vs. Customer Prediction**

## *Summary of Results*

The results of all three methods of analysis presented in this paper are summarized in Table 19. All methods conclude that the flexible design is more valuable for the duration of the project. However, accounting for uncertainty (all except NPV without Uncertainty) allows the manufacturer to recognize the greater upside potential value of the design. Recall that the assumptions required in the Lattice Method Analysis do not accurately model the demand, and thus the results are misleading and not valid.

Furthermore, this example illustrates the value of assessing the entire project to value the designs, rather than looking at individual time instantiations. For instance, because the feasible region (i.e., the area between the upper and lower bounds in Figure 10) is non-convex, decision makers can be deceived if only assessing one time instantiation and may choose the wrong design.

**Table 19. Summary of Results for All Analysis Methods**

| | NPV w/o Uncertainty | NPV w/ Uncertainty | Decision Tree Analysis | Lattice Method Analysis |
|---|---|---|---|---|
| Fixed Design | $5.53 M | $6.46 M | $5.90 M | $4.22 M |
| Flexible Design | $12.75 M | $14.80M | $13.07 M | $9.70 M |

# Conclusions

The analysis presented in this paper has provided an example of how to apply Real Options "in" a design. This application is different from Real Options "on" a design in that it gives the system designers the flexibility to change the design of the MAV to increase the value rather than relying on additional demand quantities to increase production.

ROA tools can be used by system designers, manufacturers, and consumers alike to make informed decisions about the value of adding flexibility to the system at various stages of development. This is most useful early in the development process when opportunities for flexibility are more available to developers. However, it is important to recognize all assumptions and terms of application to carefully select the best method of analysis.

The assumptions made in this analysis should be further assessed and refined to provide a better understanding of the value of the flexible design. Future work should focus on the following areas.

1. Assess the sensitivities to assumptions and uncertainties—Sensitivity studies will allow system designers to identify key areas that are intolerant of error or may be exploited to generate additional benefits.

2. Vary both demand and the penetration ratio—Here the penetration ratio was held constant while demand was uncertain to simplify the analysis. However, it is more realistic to think that the ratio of MAV to SUAV demand will be uncertain also due to the changing mission requirements. Assessing the uncertainty in both demand and ratio should prove additional upside potential and allow the manufacturer to reduce the downside by wisely choosing whether or not to exercise the option.
3. Integrate the physical model and Multi-Design Optimization simulation into the ROA tool—Connecting the MDO tool to the ROA tool will allow the manufacturer to better identify areas for flexibility. Here, the analysis utilized MDO results concluded by Bartolomei[12] that had already identified the wing/endurance relationship. Alternate relationships might have greater impact and be less costly to implement, thereby making the flexible design even more valuable than a fixed design.

# Note from the Author

The Application Portfolio included in this paper was intended to be a teaching tool for the Engineering Systems Analysis for Design (ESD.71) offered by Prof. Richard de Neufville at Massachusetts Institute of Technology. The assignment allowed me to exercise the Real Options Analysis methods to a specific example to better understand how the theoretical concepts can be applied to a unique example. I have gained a better understanding of the tools available to value options, as well as the importance of considering uncertainty within the context of the problem identification. Additionally, after completing the lattice method analysis, I realized the importance of assumptions and accurately modeling the uncertainties, which may lead to different selections of analysis methods (as in this case where the lattice did not appropriately model the non-linear demand prediction).

Finally, I found discussions with colleagues in the class very interesting and insightful since the diversity of the projects provided an opportunity to learn how real options can be applied to numerous cases. I would encourage presentation of the portfolios in a classroom setting to allow all students to experience the process as applied by colleagues to many project selections.

This study was generated for academic purposes to demonstrate understanding of the real options analysis tools and applications. Please make careful note of all assumptions and documented sources of data. Many assumptions have been made to simplify the analysis due to the confined scope of this assessment.

# References

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[1] Pickup, Sharon and Sullivan, Michael J., "Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges," Government Accountability Office Report (GAO-05-395T), 09 March, 2005.

[2] Pickup, Sharon and Sullivan, Michael J., "Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges," Government Accountability Office Report (GAO-05-395T), 09 March, 2005.

[3] "Unmanned Aerial Systems Roadmap, 2005-2030," Office of the Secretary of Defense, The Pentagon, Aug. 2005.

[4] "Air Force Small UAV (SUAV) Flight Plan", Lt. Col. Mike Senseney, AFSOC/XPTJ, 20 April 2004.

[5] James M. McMichael and Col. Michael S. Francis, USAF (Ret.), "Micro Air Vehicles - Toward a New Dimension in Flight," Defense Advanced Research Projects Agency, 07 August, 1997.

[6] EPLANE_MAV.xls developed by USAF Academy for research performed by Capt. Jason Bartolomei, MIT.

[7] Bartolomei, Jason. Multi-Design Optimization Analysis for Endurance vs. Longest Linear Dimension, MIT, 2005.

[8] Bartolomei, Jason. Multi-Design Optimization Analysis for Endurance vs. Longest Linear Dimension, MIT, 2005.

[9] "Air Force Small UAV (SUAV) Flight Plan", Lt. Col. Mike Senseney, AFSOC/XPTJ, 20 April 2004.

[10] Bartolomei, Jason. Multi-Design Optimization Analysis for Endurance vs. Longest Linear Dimension, MIT, 2005.

[11] "Unmanned Aerial Systems Roadmap, 2005-2030," Office of the Secretary of Defense, The Pentagon, Aug. 2005.

[12] Bartolomei, Jason. Multi-Design Optimization Analysis for Endurance vs. Longest Linear Dimension, MIT, 2005.