APPLICATION OF RISK WITHIN NET PRESENT VALUE CALCULATIONS FOR GOVERNMENT PROJECTS

ABSTRACT

In January 2004, President Bush announced a new vision for space exploration. This included retirement of the current Space Shuttle fleet by 2010 and the development of new set of launch vehicles. The President's vision did not include significant increases in the NASA budget, so these development programs need to be cost conscious. Current trade study procedures address factors such as performance, reliability, safety, manufacturing, maintainability, operations, and costs. It would be desirable, however, to have increased insight into the cost factors behind each of the proposed system architectures. This paper reports on a set of component trade studies completed on the upper stage engine for the new launch vehicles. Increased insight into architecture costs was developed by including a Net Present Value (NPV) method and applying a set of associated risks to the base parametric cost data. The use of the NPV method along with the risks was found to add fidelity to the trade study and provide additional information to support the selection of a more robust design architecture.

INTRODUCTION

NPV is a technique that is used to assess the viability of projects based on the projected receipts and disbursements over the projects planning horizon. It can, however, become difficult to arrive at credible single point estimates for some of these projects. Increases in project complexity, increases in planning horizons, and the need to engage multiple subcontractors are all factors that increase the risk in developing an accurate NPV. One possible approach to address this problem is to incorporate the risks associated with each of these factors into the process to arrive at a project NPV.

This paper explores a methodology to address the risk in developing NPVs for complex aerospace projects. First, a test project, the need for and the current development status of a J-2X to support the new ARES I and ARES V launch systems is discussed. Next, two approaches to modifying NPV, those by Davis [1] and Riddlehoover [6], are presented. Finally, a modified approach based on the work by Davis and Riddlehoover is presented and applied to the J-2X engine nozzle trade study. The paper concludes with a summary of the conclusions drawn from this effort and the identification of further work should be pursued.

BACKGROUND

The 2004 announcement from the President to retire the Space Shuttle fleet also included the development of a new class of launch vehicles to maintain the U.S. presence in space. The first to be developed is the Crew Launch Vehicle (CLV), known as ARES I. This vehicle uses an inline configuration architecture with a Reusable Solid Rocket Motor (RSRM) as the booster propulsion system. This motor will propel the vehicle into the low atmosphere where an additional upper stage engine will then place the vehicle into low earth orbit. The engine selected for the upper stage propulsion is a modified J-2, known as J-2X. The crew capsule will sit atop the entire vehicle.

An additional launch vehicle is also being developed to carry supplies and large payloads required for the International Space Station (ISS) and lunar missions. This vehicle, ARES V, has a significantly larger architecture than the ARES I due to the requirement to carry the larger payloads. ARES V is configured with two Reusable Solid Rocket Motors (RSRM) and five RS-68 engines as the core stage booster engines. The propellants for the RS-68 engines are also stored in a large external tank. This vehicle also requires an upper stage propulsion system and a similar J-2X engine was selected for this stage as well. The ARES V upper stage engine will require slightly different performance than the ARES I upper stage engine.

The J-2X (the modified J-2) engines for the upper stages on both vehicles will be based on heritage Apollo hardware, but modified to meet performance and safety requirements (man rating). The propellants selected for the J-2X engine are liquid hydrogen (LH2) and liquid oxygen (LOX) for their high performance characteristics. Due to the differences in the thrust requirements of both vehicles, the engine is being designed for the larger thrust since it can be throttled back to a lower thrust. There are several requirements given to the engine based upon mission and vehicle requirements for thrust, specific impulse, weight, maintenance, and volume. Each of these requirements is driven down to the subsystems and components of the engine.

There are four major subsystems of the engine including: turbomachinery, combustion devices, avionics and instrumentation, and valves, lines and ducts. For combustion devices, there are five major components. These components are the main injector, main combustion chamber, gas generator, regeneratively-cooled nozzle, and nozzle extension. The focus of this paper will discuss the trade studies being developed for the regeneratively-cooled nozzle. The project drilldown from mission requirements through selection of the nozzle for this project is shown in Figure 1.

Preliminary trade studies have looked at alternative nozzle designs to select the appropriate conceptual architecture to meet mission, vehicle and engine system requirements. There are several decisions that have already been made regarding the nozzle from the engine systems team and lessons learned from past liquid rocket engines. Some of these decisions include overall envelope, contour configuration, and cooling requirements. The vehicle had previously designated the overall envelope in which in the engine will be present. Due to standards in liquid engine design, this overall engine envelope defines the general envelope of the nozzle.
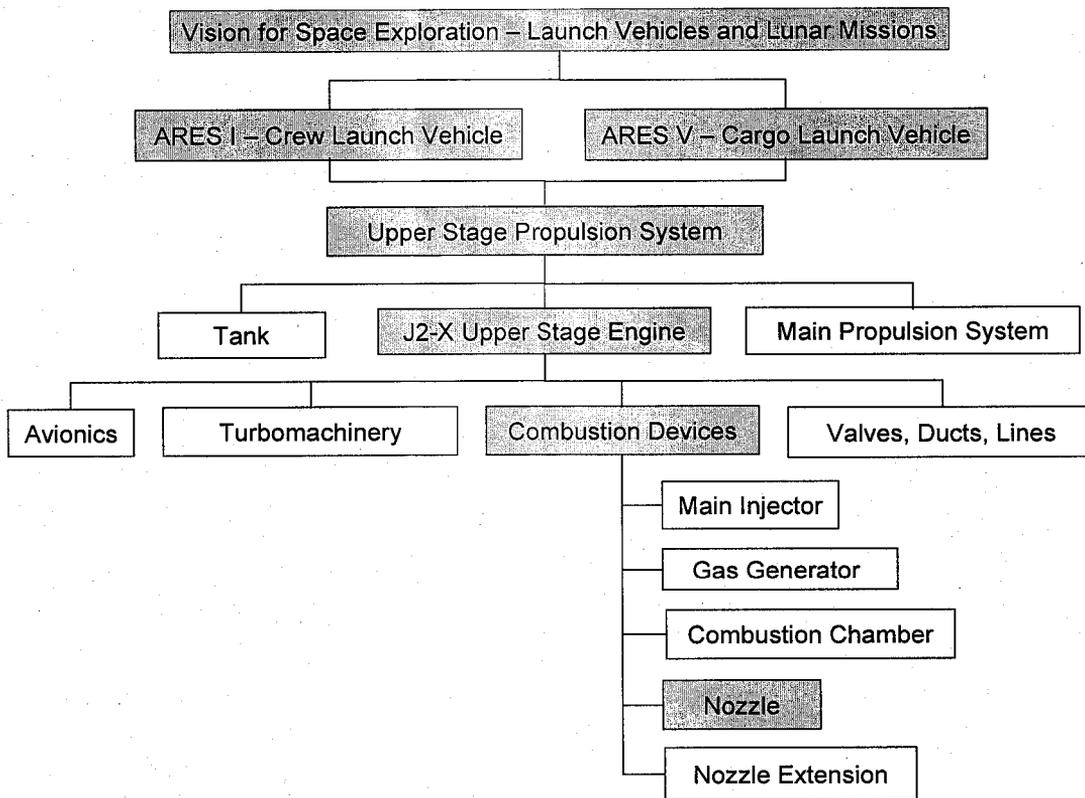
FIGURE 1. Project Drilldown to the J2 Upper Stage Engine.

The purpose of this trade study was to down select between a channel wall nozzle (CWN) and a tube wall nozzle (TWN), of which there are two configurations for each. The major decisions to be made were the configuration of the coolant pass scheme and manifold locations. There are several types of cooling schemes that could have been selected for each configuration of nozzles. A one-pass coolant scheme is a single pass from the aft end of the nozzle to the forward end of the nozzle. The second type of cooling scheme is a 2-pass. This is where the coolant inlet is toward the forward end of the nozzle, makes a downpass, turns around, and does an up-pass to collect in the forward end of the nozzle. Another type of coolant scheme is a 1.X coolant pass. This is where the inlet is located somewhere between the forward end and aft end of the nozzle. The coolant makes a downpass, turns around and makes an up-pass and collects in the forward end. The X designates the location on the nozzle. For example, if the inlet manifold were located half-way down the nozzle, it would be designated as a 1.5 coolant pass.

This study had significant emphasis on the costs for each architecture. There are four nozzle configurations that were evaluated. The 1.6 Pass TWN was selected as the baseline based on a team decision for performance and application of new technologies. Option 2 is the 2.0 Pass TWN. Option 3 is the 1.0 Pass CWN and Option 4 is the 2.0 Pass CWN. Each of these options has unique technical and programmatic differences, thus affecting the cost structure for each.

It is difficult for organizations to evaluate costs for large complex aerospace projects due to the high technological and programmatic risks. The difficulties will increase when the project has an extended planning horizon. The risks that lie in future years add to the difficulties in making a decision of which architecture to pursue in the present. A common method for firms to evaluate a project's cost is using Net Present Value (NPV). Salvatore [10] describes that NPV is "equal to the present value of the expected stream of net cash flows from the project, discounted at the firm's cost of capital, minus the initial cost of the project." This evaluates all the positive and negative cash flows and brings them all to a common period of time for all options. Using the NPV method a firm can include their cost of capital, or minimum attractive rate of return (MARR), which they require to make the project worth pursuing. If the NPV of the project is greater than zero, the firm could invest knowing that the MARR is met and it should not be losing money by investing in the project. This method also works when evaluating multiple mutually exclusive projects. If a firm were to evaluate multiple projects and calculate a NPV for each, the best project would be that of the highest NPV. This method is relatively simple and straightforward which aids in explaining the analysis to senior management. There are multiple sources that illustrate applications of NPV, such as Park [8], Blank and Tarquin [1] and Eschenbach [3.]

Large NASA projects can be a bit more challenging since the government does not operate using profitability. Public sector projects still require financial analysis to determine how capital will be allocated and which option(s) best benefits the agency and society. Methods such as cost-benefit analysis and modified cost-benefit analysis have been developed to evaluate such government projects. These projects can also be evaluated using the traditional techniques such as NPV. The methods for calculating NPV for public and private sector projects are similar; variations occur because of the nature of public sector projects. The primary differences lie within the final evaluation of the final NPVs. As often seen in government contracts the lowest bidder or lowest cost project will receive the funding to complete the proposed work. The government will then typically select the lowest NPV to invest in as opposed to the largest NPV for corporate firms.

There are some potential problems with using NPV to evaluate projects. NPV is strictly a financial tool. There are often other factors such as technical, political, environment, or programmatic that are not included in the NPV calculation. An entity, whether it is the government or a corporate firm, must carefully consider all factors and their associated risks when evaluating a project or a set of options. This is of particular importance when the project spans over several years or decades. The further out in future years that a project is evaluated the higher the risks of that project. The evaluating entity cannot predict what events may happen in future years that could influence the initial calculated costs of the project or options. External risk factors can influence the financial data and subsequently the NPV for evaluating options.

Previous Work

Several authors have researched the topic of applying risk in financial evaluations of a project. Davis [2] presented a method called "Net Present Value Risk-Adjusted (NPVR)". The technique

was used to address critical risk factors within the existing NPV model, and reported that NPVR exposed risks within critical areas that allows for better predictions than the original NPV model. Davis develops a specific model that evaluates six key areas of new product development: value chain, market segment, innovation, capabilities, and interaction and specification assessments. Each of these areas is rated on a scale of $1 - 5$, with 5 being a high chance of success and 1 being a low chance of success. A weighting system is then applied to each of the key areas. The risk weighting includes market, technical and user. The calculation is shown in Equation 1.

$$NPVR = \frac{aM + bM + cT + dT + eU + fU}{10} \times NPV \qquad (1)$$

where,

NPVR = Net Present Value Risk-Adjusted

a, b, c, d, e, f = Value chain, market segment, innovation, capabilities, and interaction and specification assessments, respectively

M = Market Risk

T = Technical Risk

U = User Risk

NPV = Net Present Value

It can be seen from the model above that risk is applied to the NPV calculation using a subjective expert rating system and applying weights to each of the risk factors. This model demonstrated that the application of risk to the NPV calculation helps illustrate how risks may affect the success or failure of a project by highlighting variability in the NPV results.

Riddlehoover [9] proposed a similar approach. The author looked at several locations to open a new facility. In this study, Monte Carlo simulations were run on the new facility locations using the following factors: initial investment, annual cost, annual benefit, and interest rates. Annual Worth (AW) was used in the study rather than NPV. The author found that there was an observed difference between the annual worth for each of the projects, however it did not accurately reflect the risks for each of the projects. The author further developed his annual worth model using a Certainty Equivalent Value (CEV) model which included a risk factor for the project selection. The inputs into the CEV model included three factors: Labor, Transportation, and Real Estate. For input into the model, Riddlehoover applied a weighting factor to each of the location factors similar to what Davis did. He then applied a risk factor for each of the final locations being considered based on an expert rating system. This risk factor presented in the paper used a decimal form between [0, 1], however it was discussed that a scale of $1 - 5$ could be used to achieve similar results. The weighting factor and risk factor are then rolled into a combined risk factor (single number) for each of the options. This combined risk factor in conjunction with the expected value and standard deviation is used in the CEV model as shown in equation 2.

$$CEV = E[x] - R \times \sigma[x] \qquad (2)$$

where,

CEV = Certainty Equivalent Value (Adjusted Annual Worth in this article)

E[x] = Expected value from Monte Carlo simulation

R = Combined Risk factor

$\sigma[x]$ = Standard Deviation from Monte Carlo simulation

In his work Riddlehoover found that the highest Annual Worth (AW) was now down the list for project selection based on a high risk. This model was very simple, but the model had a much higher fidelity compared to the previous Monte Carlo simulations of AW. Higher fidelity means that there were distinctive differences as compared with the previous AW calculations.

Both the CEV and NPVR models applied a factor weighting system to each of the risk factors being considered in the model. This data was then applied in conjunction with the existing NPV data to obtain a new value, reflecting financial and risk data. Each author saw interesting results and in some cases a reversal of the initial decision for project investment. It was shown that sometimes a project with the strongest financial benefit according to NPV calculations is not always the best choice when corresponding risks are applied. These models were applied to both general and specific situations, but certainly show promise for new applications such as government project evaluation.

Method and Scope of Work

This paper applies a NPV-Risk method to the trade study being completed on the J-2X regeneratively-cooled nozzle. This NPV-Risk method is derived from the previous work of Davis and Riddlehoover. The method being used will include a Monte Carlo simulation of the costing data for a selected time period. The input data for this Monte Carlo simulation will be based on required labor for component design and production, required materials, and appropriate rate increases for the time period. Using the NPV and statistical data derived from the Monte Carlo simulation, a NPV-Risk or CEV model will be developed to adjust each of the options. This adjustment will include the application of risks for the nozzle options being considered. There will be some differences discussed in the CEV model for specific application to government projects.

Initial Cost Estimating

In order to develop the required input data into the CEV or NPV-Risk model, it was decided to run a Monte Carlo simulation to obtain these values. The primary output that is required for the CEV model is an expected value and standard deviation for the net present value. A NPV could be calculated for each of the options, but this would not supply an appropriate standard deviation. A calculated NPV does not provide any information about the range of values that are input into the model. Each of these values could have a possible affect on the final outcome. There were five variables of interest for the simulation: Government Labor Rate Increase (%), Government Inflation-Interest Rate (%), Contractor Labor Rate Increase (%), Material Cost Increases (%), and Contractor MARR Value (%).

The first assumption for estimating the associated costs was the time period to study. A period of 15 years was selected in one year increments. This time period will cover the major milestones and a few years beyond to allow for the manufacturing to stabilize. Component testing and full engine testing is scheduled to begin in 2010. A completed nozzle will be required at this time with design and manufacturing leading up to this point. The first ARES I flight is scheduled for

2013 with a major increase in production and flight support leading to this peaking. Another major milestone is 2018 in which the lunar mission will begin. A time period of 3 years beyond this was used for the analysis.

The cost model is broken down into the government side and the contractor side for completeness within the model. To develop the government costing, the activities were broken down into categories. These categories included: trade study development, support from all engineering disciplines (computational fluid dynamics, structural, thermal, and design), design reviews, sub-scale and full scale testing, general insight, manufacturing support, and flight support. Each group was calculated per the year based on the number of required Full-time equivalents (FTE's) to support that task for that year.

After the FTE's were developed for each year, a rate needed to be applied to put these hours into dollar equivalents. For years 2006 through 2010, there were rates previously developed by a NASA business office. In order to develop rates for years beyond 2010, the previous percentage increase in years was averaged and applied to the future years. A Monte Carlo simulation was applied to the NASA FTE labor rates to further understand how these affect the present and future values within the cost development.

An interest rate was selected to be applied to the labor dollars for the government work since a MARR value is not applicable. This is on average the annual cost of living increase per year (inflation rate). Since the government does not need to make a profit, I feel that this rate is appropriate to apply in the analysis. The total cost for each year was calculated and the net present value of the entire government support was determined with the appropriate rates applied.

To determine which system architecture is considered optimum, the manufacturing and contractor design costs must be understood. This data is developed based on estimated costs from the prime contractors costing department. These costs are fully developed from a historical experience base of hours for design, machining, and fabrication based on previous engines. Material and tooling costs are estimated based on vendor pricing and historical records. It is assumed that the costs will be spread out over multiple years during first article manufacturing. For the manufacturing costs for each of the nozzles, it is assumed that the materials will be long lead items and must be purchased 1-2 years in advance. It is common to stock pile certain raw materials to minimize foundry operations. The touch labor and fabrication time is also assumed to be multiple years. It is assumed that the touch labor, materials, and manufacturing engineering support will be the only reoccurring costs to produce nozzles. Design and tooling will be the only non-recurring costs associated with the first article and regular manufacturing activities.

The reoccurring costs expanded over the entire time period is based on the number of nozzles required to support missions for the year. The ongoing support activities are generally assumed to be the same regardless of the nozzle selected and the number manufactured. This is offset to year 2009 since this is when testing starts and design activities should be wrapping up. This number is based on the mission requirements to support space station and lunar flights. There were several rates applied to the contractor's costs to account for increases in materials and labor. The first rate applied to the contractor costs was a percent increase in labor rates. It is

assumed that the labor rate increase is less than the government rates since the contractor does not have as much overhead as the government. This assumption is that several of the facilities and machinery being used are government furnished. The second rate applied was a percent increase in material costs. Since several of the materials are exotic and purchased in lower quantities, it is difficult to get vendor's support in supplying materials. These rates were only applied from 2010 out since several of the long lead items are being ordered in the near term and labor costs are generally known for the next 4 years.

The Minimum Attractive Rate of Return (MARR) applied to the analysis is assumed to be fairly low since there is generally not a high profit margin in the aerospace sector. There are already some markups associated with the material and manufacturing costs given by the vendor. The assumed MARR value is based on discussions with the NASA business office.

As previously discussed, five factors were applied to the Monte Carlo Simulation: Government Labor Rate Increase (%), Government Inflation-Interest Rate (%), Contractor Labor Rate Increase (%), Material Cost Increases (%), and Contractor MARR Value (%). The following is rationale for why each of the minimum and maximum values were chosen for the simulation:

- *Government Labor Rate Increase* – The baseline was 3.76% based on an average increase in labor rates through 2010. These rates were estimated by the authors based on experience. The minimum increase per year was 2.0% and the maximum was 6.9%.
- *Inflation (Interest) Rate Applied* – The average inflation rate was 2.30%. This was based the average increase of living increases applied to government salaries on a yearly basis. The maximum increase based on historical data was determined to be 3.83% and the minimum rate was 1.55%. These are based on rates from 1996 through 2006 (Financial Trend Forecaster, 2007).
- *Rate Increase for Contractor* – The rate increases for the contractor are generally less than the government due to less uncertainty in overhead. The baseline rate used was 2.5%. A minimum value chosen for the analysis was 0.9% and a maximum value was 3.7%. This is at the lower range for the government rates. These rate increases are often tied to inflation since the profit is built into the contractor MARR value. However, the contractor can still request rate increases yearly.
- *Material Cost Increases Per Year* – The base rate chosen for the analysis was 5.5%. A minimum value for the simulation of 4% was selected. A maximum value of 11% was chosen. It is expected that the material costs could be higher than 5.5% rather than lower because of the exotic and low quantity of materials required. This data is based upon casual conversations with a vendor.
- *Contractor MARR Value* – The contractor has already included some of their overhead in the rates applied to support and manufacturing, so a lower MARR value was chosen as a baseline (12%). To run the simulation, a lower value of 10% was selected and 20% selected as a high value since this is more in line with other industries.

A Monte Carlo simulation was completed using @Risk Monte Carlo software package from The Palisade Corporation [7]. The input variables were discussed above and the output variable was NPV. The distribution for each of the input variables was defined as a triangular distribution. This type of distribution was defined since minimum, most likely, and maximum values could

easily be defined for each of the variables. This type of rough simulation method is used for input variables that are lacking a fully defined dataset. The triangularly distributed input variables have been used commonly in other Monte Carlo simulations [5]. For completeness 5 simulations were completed for each option and 1,000 iterations were completed for each simulation. A different random generator seed value was selected for each simulation completed. It was observed that each simulation for each option demonstrated convergence at less than 1.5% level. For each option, the value obtained from the simulations was averaged to obtain one NPV. These values can be seen in Table 1. All dollar values are shown in thousands ($1k).

Table 1. NPV Obtained for Each Trade Study Alternative.

Alternative	NPV
Option 1 – 1.6 TWN	$ 226,162
Option 2 – 2.0 TWN	$ 228,048
Option 3 – 1.0 CWN	$ 240,379
Option 4 – 1.9 CWN	$ 239,743

Since this decision is being made from the government side, it would be based on the lowest net present value of the options. Based on the NPV, the government would select option 1, since this has the lowest NPV of all four. This only considers cost for the trade studies though. It can be seen that there is not a significant difference in costs between the four options based on relative differences. The maximum difference between the highest and lowest NPV's is 5.9%. This analysis did not elect to include learning curves since experience with similar development projects has tended to make the researchers concerned about the accuracy of the learning curve results. The government will pay a fixed amount for a certain number of nozzles per year, so the learning curve is not actually applicable in this situation. Also, there is an aging workforce at the contractor that are eligible to retire in the next several years, so any learning curve may go back to square one with a new workforce. Due to these reasons the learning curve was excluded, but it may be an area for further investigation.

Changes to Applied Model

The Monte Carlo simulation did not show significant relative differences between each of the options. Since this is a long term project and the wrong option selection could have long term effects, it was decided to further develop the cost model. Based on previous work, it has been shown that risk factors can be applied to the net present value in an attempt to bring out more fidelity in the cost data.

There are four primary steps as presented by Riddlehoover to apply the CEV Model. The first step is to develop appropriate weights for each of the factors selected for the risk model. These weights should be normalized and in decimal format. The next step is to develop and apply a rating system to each of the risk factors for each of the options. This will provide a matrix of values for each factor an option. The third step is to develop an overall risk factor. Riddlehoover presented a summation method to develop a combined risk factor for each option. The modified method for this trade study can be seen in Equation 3.

$$\sum_{i=1}^{k} W_i R_i \tag{3}$$

where,

W = Decimal Equivalent of Factor Weight
R = Risk Factor, based on scaling 1 – 5
i = Factor (Government Labor Rate Increase, Government Inflation-Interest Rate, Contractor Labor Rate Increase, Material Cost Increases, and Contractor MARR Value)
k = Total Number of Factors

Once the combined risk factors are calculated for each of the options, the CEV can be determined for each of the options and compared. This CEV value now includes the application of risk applied to the model based on the selected risk factors. The CEV required a slight modification since the previous literature only covered commercial firm projects. Since commercial firm projects are generally for profit, when risk is applied to the model it creates a lower value as seen in Equation 2. If the project has a higher risk, the NPV is then lowered and would not be as attractive to the firm. However, government projects select an option based upon the lowest NPV, so the combined risk factor and standard deviation must be added. This nomenclature properly applies the risk to the model. Now, if one project has more risk, the NPV will be higher and NASA would not be as likely to select that project. The modified CEV can be seen in Equation 4.

$$CEV = E[x] + R \times \sigma[x] \tag{4}$$

where,

CEV = Certainty Equivalent Value (Adjusted NPV)
$E[x]$ = Expected value from Monte Carlo simulation
R = Combined Risk factor
$\sigma[x]$ = Standard Deviation from Monte Carlo simulation

Application of Model to Nozzle Trade Study

Before any steps are completed for the applied CEV model, the appropriate factors to study must be decided upon. It was shown in the previous models that different variables than the NPV variables could be applied within the risk model. However, it was decided that the most appropriate values to include in this model are the same factors as used to run the Monte Carlo simulation. These factors were Government Labor Rate Increase, Government Inflation-Interest Rate, Contractor Labor Rate Increase, Material Cost Increases, and Contractor MARR value. Now, the methodical steps can be completed as discussed in the previous section.

The first step in the model is to develop the factor weights. The factor weights were based on expert rating. The higher values equate to a higher risk for that particular factor. Subsequently, a lower value equates to a lower risk for that factor. The factor weights can be seen in Table 2.

Table 2. Factor Weights for the Trade Study.

Factor	Weight
Government Labor Rates	0.05
Inflation (Interest) Rates	0.1
Rate Increase for Contractor	0.35
Material Cost Increase	0.45
Contractor MARR Value	0.05

It can be seen from the table that the values range from lower risk (0.05) to a higher risk (0.45). The government labor rates were weighted low because these are generally tied to the inflation rates. These rates have not seen any drastic increases over the last few decades are fairly predictable. The overhead is generally constant for these and fluctuations are stable and within expected values. This value was rated at 0.05 because of these reasons. The next factor, Inflation (Interest) Rates, was weighted fairly low as well. Plenty of historical data is available for inflation rates broken down by years and even months. This data does not fluctuate significantly, although there are some increases that are higher than others. Because of these reasons, this was rated 0.10.

The rate increase for the contractor was rated higher amongst the factors. The contractor can increase rates in the future years for no apparent reason. These clauses are within the contract to give the contractor authority to do this. If the contractor has foresight that profitability is not to the level required of management, they may request a rate increase. Although these increases are spelled out in the contract, they are not always accounted for in the NASA budget. This was rated at 0.35. The contractor may not increase the rates drastically in one year, but then the following year may raise it. Although the rates are low, it is considered a risk since several of the costs are developed by the contractor.

Another high risk factor is the material cost increase which was rated at 0.45. Material costs are outside of the government's control and it was determined to be a serious threat to the project. Since materials are purchased in relatively small quantities as compared with other industries, no economies of scale or political power can be asserted. Also, several of the exotic aerospace materials are being purchased by multiple customers, so the future costs of the material can be unpredictable. This was determined to be the highest risk amongst all the factors.

The final risk weighting is the MARR value. MARR values are generally controlled by contractual means within the government. Thus, a contractor is limited on the amount of profit it can make off of certain projects. The government understands that the company must make a profit, so once all costs are figured, a MARR is applied. These values generally do not fluctuate much, so it was determined that a low risk value of 0.05 was appropriate.

The next step for application of the model is to determine a value for each of the risk factors for each of the options. A matrix was developed to aid in the assessment. A scale from 1 to 5 was used with 5 having the highest risk and 1 having the least risk associated. The descriptions for each of the rating scales and factors can be found in Table 3.

Table 3. Scaling Factors and Descriptions for Each Factor

Risk Level	Government Labor Rates	Inflation Rates	Rate Increase for Contractor	Material Cost Increase	Contractor MARR
1	NASA has little involvement in project other than procurement activities. This is an iteration of a previous design.	Economy is stable. The dollar is highly valued in foreign markets, unemployment is extremely low and Employment Cost Index is on the rise.	Contractor does not increase rates. The product is somewhat profitable and there is no need for additional rate increases.	Material costs have decreased; Increase supply in the market allows prices to drop. Lead times are only a few weeks. Special orders are accommodated.	Contractor MARR value is significantly lower compared to other NASA projects.
2	NASA has minimal involvement in the project, limited to design reviews, Technical Interchange Meetings, and risk closures.	Intermediate Level	Contractor increases rates slightly to adjust for minor project risks. This rate increase should not affect NASA.	Intermediate Level	Intermediate Level
3	NASA has daily to weekly involvement in project, including data reviews and discussions with contractor to close issues.	Inflation has increased slightly but not at significant risk of fluctuations. Fluctuations have averaged out to be at a low to medium level.	Rates have increase due to unforeseen risks in design or production. Rate increase is agreed upon by both parties without any major issues.	Material costs have remained fairly stable. There may be a slight increase, but not greater than expected to adjust for inflation.	Contractor MARR is of an average value when compared with other NASA projects.
4	NASA does reviews of data, including independent modeling of selected analyses. Verification plan reviews and concurrence of all closure rationale.	Intermediate Level	Rates have increased due to fairly significant risks. This rate increase is slightly higher than anticipated by NASA.	Materials have increased significantly. Some materials are difficult to obtain, but most can be obtained for a premium price. Lead times are in excess of 6-12 months.	Intermediate Level
5	NASA performs complete and independent analyses of each task. Review of verification plan and witness to certification testing.	Significant increase in prices of consumer goods. The dollar is unstable and purchasing power has decreased significantly.	Significant contractor rates increases to support profitability. Product costs in design or production have increased. NASA does not support these rate increases.	Materials are extremely difficult to purchase and have increased significantly in cost. Lead times are in excess of 24 months and some alloys are rare.	Contractor MARR is significantly higher than most other NASA projects.

This methodical rating approach based on the matrix in Table 3 was used for each of the options. For Option 1, the values can be seen in the table below for the five risk factors. The Government Labor rates were scored at a 2 since NASA would have some involvement in the development of this design. A similar design of this configuration has been completed before, so some review of the concept would be required, but not significant modeling or analysis. The interchanges with the contractor would be limited to design reviews and technical interchange meetings. There would not be a need to hold daily or weekly meetings to review the design with NASA and the contractor.

Inflation rates were scored at 1 due to the fairly stable economy. It can be seen that Inflation Rates did not change for any of the options above and they are all on a level playing field for this

risk factor. This factor could potentially be eliminated since all values were the same, but was kept in the model for comparisons. The dollar is still holding its value and there have not been any significant increases or decreases in inflation/deflation in the past several months. The third factor, Rate Increase for the Contactor, was scored at 4. It is assumed that the new changes to the configuration may not be entirely understood when the detailed design is completed and in order to maintain profitability, the contractor would increase the labor rates. This increase may be higher than anticipated by NASA, thus a higher risk is applied. Option 1 and Option 2 are both of TWN configurations, however since Option 1 is applying some new technologies some of the profit could be decreased if any failures were to occur. Thus when compared with option 1, it is rated slightly higher than option 2 for contractor rate increase. The materials for Option 1, 3 and 4 are more exotic and the team may experience some procurement difficulties. The lead times could potentially be in excess of 6 – 12 months since they may be difficult to obtain. Due to the potential difficulties in acquiring the materials, Option 1 was scored at 4.

The MARR value for Option 1 was scored at 2. This MARR value is not as low as other projects and somewhat average when compared to other NASA projects. Due to this reason, I ranked it at an intermediate value. It can be seen that most of the values for all the alternatives/options are very close. Option 4 is scored slightly higher since this is the furthest from the current experience of nozzles and potentially carries the most risk and deserves higher profitability if successful. The results of the risk assessments can be found in Table 4.

Table 4. Risk Factors and Ratings for Each Option.

| | | Alternatives | | | |
		Option 1	*Option 2*	*Option 3*	*Option 4*
Risk Factor	Government Labor Rates	2	2	3	4
	Inflation (Interest) Rates	1	1	1	1
	Rate Increase for Contractor	4	3	4	5
	Material Cost Increase	4	3	4	4
	Contractor MARR Value	2	2	2	3

A combined risk factor must be calculated for each of the options. This is completed using Equation 3. An example is shown below for Option 1. This calculation was completed for each of the options and the values are provided in Table 5.

$$\sum_{i=1}^{k} W_i R_i = 0.05(1) + 0.10(1) + 0.35(3) + 0.45(4) + 0.05(2) = 3.5$$

where,

W = Decimal Equivalent of Factor Weight

R = Risk Factor, based on scaling 1 – 5

i = Factor (Government Labor Rate Increase, Government Inflation-Interest Rate, Contractor Labor Rate Increase, Material Cost Increases, and Contractor MARR Value)

k = Total Number of Factors

Table 5. Combined Risk Factors for Each Option.

Option 1	3.5
Option 2	2.7
Option 3	3.6
Option 4	4.0

RESULTS

The expected NPV and also the standard deviation were obtained from the original Monte Carlo simulation. The values for each of the options can be found in Table 6 and is identical to the original NPV shown in Table 2.

Table 6. Expected Values and Standard Deviation for Each Alternative.

Alternative	NPV	St. Dev.
Option 1 - 1.6 TWN	$ 226,162	$ 24,331
Option 2 - 2.0 TWN	$ 228,048	$ 23,812
Option 3 - 1.0 CWN	$ 240,379	$ 24,275
Option 4 - 1.9 CWN	$ 239,743	$ 25,628

Each of these values was used to calculate a CEV for each of the options. The CEV was calculated using the modified CEV in Equation 4. An example calculation for Option 1 is shown below:

$$CEV = E[x] + R \times \sigma[x] = \$226,162 + 3.5 \times \$24,331 = \$311,321$$

where,

    CEV = Certainty Equivalent Value (Adjusted NPV)
    $E[x]$ = Expected value from Monte Carlo simulation
    R = Combined Risk factor
    $\sigma[x]$ = Standard Deviation from Monte Carlo simulation

Using Equation 4, a CEV value was calculated for each option. These values can be seen in Table 7.

Table 7. Calculated CEV for each Alternative.

Alternative	CEV
Option 1 - 1.6 TWN	$ 311,321
Option 2 - 2.0 TWN	$ 292,340
Option 3 - 1.0 CWN	$ 326,555
Option 4 - 1.9 CWN	$ 342,254

With the application of risk to the NPV calculation, it can be seen from Table 7 that there are distinct differences between each of the options and these are different from the value originally

calculated and shown in Table 1. There would actually be a reversal in the decision with the application of risk to the model. The government would select Option 2 since this has the lowest NPV including the application of risk. Option 1, which was originally selected before application of the model, has been moved to the second selection. There is actually a reversal if a selection had to be made between the two CWN options. Option 4, which had a lower NPV than Option 3 in the original calculations, is now higher than Option 3 with the application of risk.

It is worth noting that in both analyses, NPV and CEV, Options 1 & 2 appear to be preferential to Options 3 & 4. Although the rank ordering of the options has some reversal when switching analysis methods, these still allow for the decision maker to down select the list of alternatives from 4 options to 2, thus a smaller solution space.

CONCLUSIONS AND FUTURE RESEARCH

The methodology applied is consistent with previous work applying risks to financial calculations such as net present value. It was shown that minor adjustments can be made to apply a commercial firm application to a government project. A CEV model was developed that considered that the government selects projects based on the lowest NPV as opposed to the highest NPV for commercial firms. The CEV model considers risk within the financial calculation so a more-informed decision can be made considering more factors than the typical NPV financial model. Since the risks applied to the model are replicated throughout the calculation, the CEV model was observed to have higher fidelity than a typical NPV calculation.

The application of risk to the NPV financial calculation was a simple method that provided more insight to decision makers. This calculation was applied to a specific trade study for regeneratively-cooled nozzles, but could be applied to any long term project. It has been shown that the application of risks within NPV calculations can be used for both commercial and government projects using slight modifications. The model allows for a balance of the agency risk factors and perceived project risks combined into one model.

This effort noted several areas that could require further research. The first is the impact of using alternative techniques to develop the weighting for both the risk weighting and the risk factors. A different method aside from the 1 – 5 scale could be used to complete these matrices. Another area of further research would be the application of risk factors different from the one used in initial NPV calculations. There is further work that can be completed on the Monte Carlo simulation as well. The CEV can be incorporated within the Monte Carlo simulation to allow the decision maker to quantify the statistical error associated with the cost estimates. The triangular distribution was used for simplicity and the input variables selected. If different variables were selected other than those used for the original NPV calculation, different distributions would need to be investigated.

Decisions between alternatives cannot be made based solely on financial criteria, even if that model incorporates risk. An aggregate decision model must also include non-financial criteria, which are often subjective. The next step in more fully evaluating the selected alternatives

would be the development of a decision model that incorporates multiple decision criteria and weights the criteria based on relative importance.

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