Integrating Adaptive Smart Technology for 40mm Weapon Platforms

Mitchell T. Cucinotta, James G. Degen, Corey J. McCrury, Donald K. Van Velzer

Abstract— The introduction of UAVs (Unmanned Aerial Vehicles) into US Army inventories is rapidly changing how US forces dominate the battlefield. The vast array of information and lethality gained from UAVs is extremely beneficial to friendly forces operating on the ground. Similar in many respects to UAVs, “smart” munitions have become prominent technological force multipliers. With these munitions, US military forces increasingly have the capability to engage smaller profile targets at extreme distances with pinpoint precision. Due to known advantages of these systems, these capabilities are desired at the lowest unit level possible- such as an Army squad. A squad equipped with munitions that combine UAV and “smart” technology would provide unprecedented intelligence and accurate fire. In light of the Army’s stated desire for these munitions, ARDEC (Armament Research, Development Engineer Center) has undertaken efforts to produce an increasing array of “smart” munitions. In support of these efforts our project team is providing a unique system engineering perspective and course of alternative analysis. Specifically our team is assisting in the airframe development of a 40mm “smart” munition. The United States Military Academy Department of Systems Engineering’s Systems Decision Process serves as the framework for our analysis. Additionally, the Infantry Warrior System (IWARS) simulation platform is utilized to further test defined alternatives. Our analysis and simulations will directly influence the airframe design of the projectile, as well as other capabilities. This paper reports on the progress of these efforts, as well as future developments in the project.

I. INTRODUCTION

A. Background:

THE contents of this technical report are intended to highlight our contribution to the guided projectile project taken on by our team. Each section will chronologically analyze the work done over the course of this project. A chronological analysis will allow the reader to further understand our conclusions and the path which led us to those conclusions.

Mitchell T. Cucinotta is with the Department of Systems Engineering,, United States Military Academy, West Point, NY 10997 (phone: 845-515-1580; e-mail mitchell.cucinotta@usma.edu).

James G. Degen is with the Department of Systems Engineering,, United States Military Academy, West Point, NY 10997 (phone: 845-515-1633; e-mail james.degen@usma.edu).

Corey J. McCrury is with the Department of Systems Engineering,, United States Military Academy, West Point, NY 10997 (phone: 845-515-2766; e-mail corey.mccrury@usma.edu).

Donald K. Van Velzer is with the Department of Systems Engineering,, United States Military Academy, West Point, NY 10997 (phone: 845-515-3851; e-mail donald.vanvelzer@usma.edu).

The concept of a guided projectile is not revolutionary. In fact, ARDEC has developed them before. The development of the Excalibur round for large artillery pieces validated the concept of a guided round. What makes this project different from other guided projectile endeavors is the ability of the war fighter to maneuver the round while in flight and receive real-time video feedback. Controlled flight with video feedback provides the capability to conduct aerial reconnaissance. Aerial reconnaissance is an invaluable combat multiplier in modern warfare. As conflicts, for example in Afghanistan, continue to be fought primarily at the platoon level (and below), the ability for small maneuver units to gain aerial reconnaissance is extremely valuable.

Typically such aerial reconnaissance can only be gained from larger unit resources (Brigade, Division, etc.). Successful production of a round with the ability to provide intelligence to squad level units would be an immediate combat multiplier at the lowest level of combat formations.

Being a multi-year endeavor, this project is still in its initial phases. Currently, the focus is on airframe design. After our team created an over-arching design for the entire system, we honed in on development of the airframe. Working on the airframe allowed us to move through the Solution Design and Decision Making stages of the Systems Design Process. Our model provides our client with the ability to quantitatively compare different airframe design alternatives effectively. Currently, the designs that are being looked at for the airframe are the Warlock A, Warlock B, and Warlock C. Our efforts also provide processes which could be used to further develop the other subsystems of the guided projectile.

II. PROBLEM DEFINITION

A. Problem Statement

Airframe

- I. Facilitate the integration of multidisciplinary engineering teams in the development of an airframe for the 40mm guided projectile that deploys from existing weapons systems, enhances flight time, and has the correct carrying capacity.

Development of the Problem Statement

- II. For the first phase of this project, ARDEC wanted our team to focus on a general Systems overview of the 40mm round as a

whole. We focused on every function and capability that ARDEC envisioned incorporating into the munition. This included an improved airframe, video feedback, stabilized flight, increased range, and guidance navigation control capabilities. For the second phase, both project teams decided to narrow our focus on a Systems approach for the airframe design. We focused on finding a projectile that would enable us to develop the most effective 40mm in accordance with our overall Systems analysis.

B. Stakeholder Identification and Analysis

Stakeholders comprise the set of individuals and organizations that have a vested interest in the problem and its solution.¹ The two major stakeholders that were identified for this project were ARDEC and the Army. This project carries significance for ARDEC because systems engineering support would facilitate optimization of the total system and capabilities of guided projectile while balancing adverse trade-offs. This will help them produce a guided projectile capable of increased range and accuracy. The Army has the need for a new projectile that will enable units to conduct aerial reconnaissance at the squad level, while maintaining or improving the round's lethality.

C. Research

Our research was conducted prior to significant interaction with our client. It was mostly done in the USMA Library or from online journals. We attempted to find articles independent of our client's previous effort which dealt with the subject of "hybrid" or "guided" projectiles. What follows are the documents we discovered and a short explanation of their importance.

1) *The Projectile GRAM (GPS Receiver Application Module) SAASM (Selective Availability/Anti Spoof Module) for ERGM (Extended Range Guided Munition) and Excalibur*²

This article discussed the GPS (Global Position System) engineered into a guided projectile that the Navy and Army are working on developing. The article mentioned that one of the concerns for the GPS in the projectiles is its resistance to the shock of gunfire. Jammer tolerance and tracking accuracy have also been issues. The article also discussed how one of the problems for the projectile has been the high muzzle velocity as the round exits the barrel. High muzzle velocities tend to limit flight durations which subsequently decrease initially important glide time.

2) *Lean (And Agile) Systems Simulation of Guided Projectiles in the Early Development Stage*³

This article provided information regarding several aspects of Guidance, Navigation, and Control (GNC) for

guided projectiles. It mentioned options that would help control the projectile's trajectory. The two main options provided were Canards and Squibs. Canards provide more range and offer tremendous control while squibs minimize the lateral movement of the projectile.

3) *Addressing the Challenges of a Thruster-Based Precision Guided Mortar Munition with the Use of Embedded Telemetry Instrumentation*⁴

This article discusses optimizing a design for a laser guided projectile that contains a telemetry module. During 2006, the XM395, the world's first gun-launched, laser-guided mortar, was demonstrated. A Telemetry module was installed on a mortar to measure flight information such as thrust, acceleration, range, etc. Building Snowmobiles: Air-Dropped Guided Mortar⁵

This article discusses the military using an air delivered 60 or 80 millimeter mortar. Application of Roll Controlled Fixed Canard (RCFC) technology to the 81mm air-dropped guided mortar has been developed in conjunction with ARDEC in Picatinny Arsenal. The company's patented RCFC guidance kit, with an innovative flight-control and GPS-based guidance and navigational system, adds precision strike capability to existing mortars. The nose-mounted guidance kit replaces existing mortar fuses.

D. IDEF0 Modeling

IDEF0 modeling is a way to represent the functions of a system and what goes into performing said functions. The IDEF0 model consists of an activity with inputs, controls, mechanisms, and outputs. The box represents a core activity or function which must be performed in order for the fundamental objective to be achieved. The inputs are to the left of the box and represent what goes into the activity and is used to generate the outputs. Controls are any guidelines or standards that influence the workings of the activity. They enter the top of the box in IDEF0 models. Mechanisms represent the physical aspects that cause the activity to operate. Outputs are the results of the activity. IDEF0 models are provided for this project in the Appendix. Level 0 is the fundamental objective of the system, while Level 1 breaks the activity in Level 0 into three more specific activities. Level 2 then breaks each Level 1 activity into three more activities. This breakdown provides a more in-depth look at how the system performs critical functions to accomplish necessary objectives. IDEF0 modeling allowed us to build the Functional Hierarchy for our system of interest.

E. Functional Hierarchy

The functional hierarchy for the Airframe can be found in Figure 1 of the Appendix. The purpose of a functional hierarchy is to identify the system functions and sub functions. The top tier of the functional hierarchy is the fundamental objective- the desired function of the system.

The second tier consists of the primary functions of the systems, and the two lower tiers are the secondary and tertiary functions. In order to get an overarching idea of how the round functions, we first built a functional hierarchy that tied together all functions and capabilities of the round. However, the Hierarchy in Figure 1 is for the functions of the airframe specifically. This does not take into account things such as video feedback and the guidance control system. In the future, separate Functional Hierarchies will need to be developed for these aspects of the munition.

III. VALUE FOCUSED THINKING

A. Value Hierarchy

The Value Hierarchy for the airframe can be found in the Appendix, represented by Figure 2. The individual boxes of the Value Hierarchy are defined for the reader below. The Value Hierarchy is used to take the knowledge that is gained from the Functional Hierarchy and turn it into qualitative value measures that can be used to evaluate alternatives

Value Hierarchy Definitions- Airframe

1. **Function:** Launching Munitions - the process of launching guided projectile.
 - 1.1. *Objective:* Maximizing the Launch Capacity - allows ARDEC to use all the empty space in a projectile to assist in the rounds delivery
 - 1.2. *Objective:* Maximizing Structural Integrity - is key to the round since we are trying to fire the projectile at its maximum velocity to achieve maximum distance. A side effect is that the electronics inside the projectile can be rendered useless or the body cracks and will break up in the air. Both of these effects render the projectile useless.
2. **Function:** Ensure Guidance Flight Profile - the time from the projectile leaving the tube to the projectile landing at its final destination. During this the user is gaining situational awareness through the use of video feedback and then identifying a target and accurately guiding the projectile to the target.
 - 2.1. *Objective:* Minimizing time to Deploy Lift Surfaces - is key for the projectile to ensure guided flight because if the lift surfaces deploy to slow then they could throw the round so far off course that it will render the round useless.
 - 2.2. *Objective:* Maximize Operator Decision Time (sec) - is the time where we want to maximize the most so we can give the operator the most time to gain eyes on the target, be able to choose between targets, or just scout to see what other treats are around the unit.
 - 2.3. *Objective:* Optimize the Maneuver Mechanism - is the science of finding out what kind of lift surfaces to use, the amount to use, and where they should be placed. These are important because all these factors

influence everything with maximizing the operator decision time.

B. Value Functions

Value functions are used because the data obtained from value measures typically are expressed using a diverse set of measurements (i.e. Hertz, grams, kilometers, etc.). In order to make it possible to compare different value measures, it is necessary to convert all of the data to the same unit. Value functions are used for this purpose. Value functions take the range of data for each value measure and convert it into the unit 'value'. This is done by scoring the data on a scale of 0 value to 100 value, with 0 being the least desirable and 100 being the most desirable. An example value measure can be found in the Appendix (Figure 3).⁶

C. Swing Weight Matrix

The swing weight matrix allows the decision maker to score the different values obtained from the value hierarchy and value functions. The matrix enables the decision maker to identify which value measures are the most critical and conversely which have little impact on the eventual decision. Each value measure is ranked based on the level of importance and the variation in the measuring range. The level of importance is a cognitive or subjective decision by the stakeholder on what they consider important. The variation in the measuring range is an objective component that is drawn from the range of values for each value measure. Using these two considerations, each value measure is given a swing weight between 0 and 100, with 100 being the most heavily weighted measure. Each swing weight is then divided by the summation of all the swing weights in order of its respective global weight. The global weights across all value measures must add up to one. The measure weights are multiplied by the value obtained for each measure from their value functions known as the additive value model. This gives the decision maker the value relative to the other value measures.

D. Solution Scoring and Value Focused Thinking

After obtaining the test data for each alternative, the value functions and swing weights can be used in conjunction to assign value scores. This process makes it very easy to see how various alternatives stack up with one another and what categories are strengths or weaknesses for each one. Although a complete set of test data is not available from ARDEC prior to this publication, a solution scoring model was set up using data obtained from historical analysis or expert opinion as well as preliminary swing weights and value functions derived from stakeholders' feedback. Raw data was based on the expertise of our clients at ARDEC and historical test data from previous 40mm projectiles. Value functions utilize this raw data to obtain a raw value score between 0 and 100. Each value score is then multiplied by its respective swing weight. This will yield an adjusted value score, based on how important the stakeholders deemed the

particular value measure in question. Each measure's adjusted value score is added together to find the total value score for an alternative. This is known as the additive value model. All three alternatives have a total value between about 50 and 56. The entire process described above can also be expressed in the equation for the additive value model (N =number of value measures, w_n =weight assigned to value measure n , and $V(x)$ =value obtained from value functions):

$$Total\ Value = \sum_{n=1}^N w_n V(x)$$

Once the total values for each alternative have been calculated, we then utilize Value Focused Thinking (VFT). VFT examines each alternative in terms of the value for each individual measure as well as the total value score. A stacked bar chart is used as the primary visual tool for VFT. This chart models the score for each value measure in addition to showing how each adjusted value score adds up to the total value. This is an extremely useful tool to compare what advantages and disadvantages an alternative may have. For example, in our stacked bar chart (Appendix-Figure 4), battery life is an obvious strength for Warlock B, while Warlock C leaves a great deal to be desired in that area.

E. Sensitivity Analysis

Although a lot of time was spent on stakeholder analysis to create an acceptable swing weight matrix, it is still very important to conduct an analysis on the sensitivity of the model to derived swing weights. Due to the subjective nature of these weights, it is important to conduct a sensitivity analysis. The sensitivity analyses are completed in Microsoft Excel using a "What-If" data table. The results of a sensitivity analysis for three different swing weights can be seen in the Appendix, Figure 5. The analysis finds what the total alternative score would be if the swing weight in question was 0, 25, 50, or 100. Each analysis is then graphed in order to find whether the value measure is actually sensitive (Appendix- Figure 6). The measure is sensitive if there is a "crossover" point where a different alternative becomes the highest value solution. For example, in Figure 6, there is a crossover point where the swing weight value is about 60. From 0 to 60, Warlock A has the highest value. However, if the swing weight value is higher than 60, Warlock C becomes the best alternative.

F. Conclusion

Our team began the project focused on the problem at large. Our over-arching system analysis provided the client with an eagle's eye view of the different tasks which will contribute to the project. Currently ARDEC's focus is on airframe design.

Moving through the Solution Design and Decision Making stages of the Systems Design Process enabled our client to

see their project from a broad perspective. Our model helped our client weigh different airframe design alternatives effectively. It also gave them artifacts which could be used to further develop the other subsystems of the guided projectile. Using Solution Scoring and Value Focused Thinking allowed us to make further recommendations on the priority of each design parameter. This information enables the client to understand which parameters are going to most affect the value of the airframe.

G. Recommendations

At this time we do not have the necessary test data to provide any concrete recommendations regarding which alternative to adopt. However, when the testing data becomes available, our products can be used to evaluate and determine which airframe best fits the needs of the stakeholders. As the project matures we would recommend that the client continues to take a systems approach in developing the smart munition. Our approach is easy to update which will enable the client to account for unforeseen complications and changes that will arise within the project in the future. The work that we have done should allow ARDEC to identify and develop the most effective 40mm projectile possible.

REFERENCES

- [1] Gergory S. Parnell, Patrick J. Driscoll, and Dale L. Henderson, *Decision Making in Systems Engineering and Management* (Hoboken, NJ: Wiley-Interscience, 2008), pg. 3.
- [2] L. L. Wells, "The Projectile GRAM SAASM for ERGM and Excalibur," *Position Location and Navigation Symposium, IEEE 2000*, accessed September 12, 2011, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=838290&isnumber=18057>.
- [3] ¹ Bradford Davis, "Addressing the Challenges of a Thruster-Based Precision Guided Mortar Munition with the Use of Embedded Telemetry Instrumentation," , accessed September 2011, <http://www.itea.org/files/2009/2009%20Journal%20Files/March%202009/jite-30-01-117.pdf>.
- [4] ^{1m}ARMY PREPS SMART MORTARS | Defense Tech," Defense Tech | The Future of the Military, Law Enforcement and National Security, accessed September 9, 2011, <http://defensetech.org/2003/03/17/army-preps-smart-mortars/>.
- [5] "Building Snowmobiles: Air-Dropped Guided Mortar," Feral Jundi, accessed September 12, 2011, <http://feraljundi.com/2854/building-snowmobiles-air-dropped-guided-mortar/>.
- [6] Posted On (Asc.), "Opportunities - Federal Business Opportunities: Opportunities," Home - Federal Business Opportunities: Home, accessed September/October, 2011, <https://www.fbo.gov/index?s=opportunity>.

APPENDIX

Figure 1: Functional Hierarchy for the Airframe

Figure 2: Value Hierarchy for the Airframe

Figure 3: Distance Traveled Value Measure

Figure 4: Stacked Bar Chart

	Distance Traveled		
Value	Warlock A	Warlock B	Warlock C
	52.28	50.64	56.52
0	59.36	51.31	51.31
25	57.33	51.12	52.81
50	55.48	50.94	54.17
75	53.81	50.79	55.40
100	52.28	50.64	56.52

Figure 5: Sensitivity Analysis Tables

Figure 6: Distance Traveled Sensitivity Analysis