VALUE-DRIVEN ROTORCRAFT DESIGN THROUGH INTEGRATED PRODUCT/PROCESS DEVELOPMENT AND ROBUST DESIGN SIMULATION

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ABSTRACT

In his 1999 AHS Nikolsky Lecture: *Technology for Rotorcraft Affordability through Integrated Product/Process Development (IPPD)*[1] the author described the cultural change taking place in industry and government due to the Quality Revolution which identified the need for concurrent engineering education and training[2],as well as new systems approach methodologies that captured the essence of IPPD and Product/Process Simulation. Something like a modern approach to the systems engineering methodology that was developed in the late 1950's and early 1960's for designing and building large scale complex systems, such as ballistic missiles and manned space flight systems, was needed. A generic IPPD methodology was developed by the primary author and his colleagues and taught to industry and government through short courses and professional education. This generic IPPD methodology also became the foundation for the development of the Georgia Tech graduate program in Aerospace Systems Design education and research and led to a large, unique laboratory, the Aerospace Systems Design Laboratory (ASDL), established in 1992, which is now believed to be the largest graduate university complex system design laboratory in the world. With research grants from government and industry the generic IPPD methodology was expanded to include Robust Design Simulation (RDS), Fast Probability Integration (FPI) and Technology Identification Evaluation & Selection (TIES).[1] A summary of this evolution to RDS and some of the PhD research that led to this evolution has been documented in *Value-Driven Design* (VDD)[3]. VDD has been at the heart of the IPPD through RDS methodology. This paper will describe how VDD has been applied for numerous rotorcraft designs through the AHS and rotorcraft industry student design competitions. It will also describe planned research efforts to expand VDD to Value Based Acquisition (VBA) to help make Future Vertical Lift (FVL) more capable, available, dependable and affordable.

1. INTRODUCTION

The biggest impact on the quality of product and process development in the commercial sector in the past 30 years has been the Quality Revolution that started in the late 1980s and progressed rapidly in the 1990s. The end result has been more capable, reliable, affordable and maintainable complex commercial products, such as automobiles and electro-mechanical systems. From this quality revolution new processes, such as Just-In-Time (JIT) and Lean Manufacturing, along with the emphasis on Concurrent Engineering became the norm. While efforts were made to incorporate these new processes into the aerospace community, they have met with limited success. Cost and schedule overruns for aircraft and spacecraft, both in the civil and military sectors, are just as common, or more severe, than they were before the Quality Revolution. This is not to say that efforts were not undertaken in the early 1990s to try and make this paradigm shift applicable in Aerospace and Defense; however, they mostly have come and gone with relatively minor impact. Two undertakings that the primary author participated in was the Lean Aircraft Initiative (LAI) undertaken by the U.S. Air Force with MIT [4] and the Integrated Product and Process Development (IPPD) through Integrated Product Team (IPT) initiative emphasized, and even required, by the Secretary of Defense [5]. While IPTs are now the norm in the Defense community, the idea of using IPPD for IPT implementation seems to have been forgotten.

Following the development of a generic IPPD methodology with industry and teaching it in short courses with the military services and industry [6], the generic IPPD methodology, illustrated in Figure 1, became the foundation for the Georgia Tech graduate program in Aerospace Systems Design.

As illustrated, the generic IPPD Methodology provides for the integration of Systems Engineering (SE) and Quality Engineering (QE) Methods through a Top-Down Design Decision (TDDD) Support Process augmented for implementation in a Computer Integrated Environment (CIE). It should be noted that the third step in the TDDD Support Process is *Establish Value*. While establishing value is called for as the centerpiece in Lean Manufacturing and its name is included for implementation in Value Engineering, there have not been universal calls for Value-Driven Design (VDD) and Value Based Acquisition (VBA). There has been a VDD initiative in the academic and AIAA communities [7] for the past decade and the call for a VBA approach in *Keeping the Edge - Managing Future Defense Systems* [8] has been made by the current U.S. Secretary of Defense.

At Georgia Tech the IPPD methodology foundation has led to a strong research and education program to expand its usage for a number of complex systems and system of systems applications. The research program has led to completing the Robust Design Simulation (RDS) iteration loop in IPPD, as illustrated by the gray boxes in Figure 1. A summary of the research leading to RDS, as well as Technology Identification, Evaluation and Selection (TIES) is illustrated in Figure 2. [1]

Pioneering research in applying Design of Experiment (DOE) and Response Surface Modeling (RSM) opened up the door to hybrid optimization techniques combing gradient-based and experimental approaches. The RDS iteration loop provided a framework for additional methods and techniques for technology insertion with customer satisfaction being the end result, as illustrated in Figure 3.[9] A five step process for implementing IPPD through RDS[9] , as illustrated in Figure 4,was developed and exercised on a number of high visible projects for government and industry.[10,11,12, 13]

In the early 2000's the IPPD through RDS was extended to provide a Unified Tradeoff Environment (UTE) and to include Joint Probabilistic Decision Making (JPDM), as illustrated in Figure 5.[14]

This research provided a probabilistic design environment for the propagation of design uncertainty to the system level to assist in making more educated decisions in the early stages of design. This design uncertainty is associated with the key elements that are addressed in system design and which are captured in the appropriate design environment, namely mission requirements, vehicle attributes and technologies. The proposed environments are constructed using a metamodeling technique called Response Surface Methodology (RSM) and provide a model relating system-level responses to the mission requirements, vehicle attributes and technologies. The Mission Space Model is concerned with mission requirements exclusively and provides the ability to model an infinite set of missions. The Unified Tradeoff Environment (UTE) integrates the mission requirements, vehicle attributes and technologies in a single environment while allowing both deterministic and probabilistic analyses. The design environments and design methods in this research were demonstrated for a rotorcraft of interest then, namely the Future Transport Rotorcraft, with probabilistic applications presented. Both Fast Probability Integration (FPI) and Monte Carlo (MC) are illustrated as options depending on whether fidelity is required in the analyses or the probability functions.[11]

As can be seen in Figure 5, the results of the UTEs result in plots identifying two varying requirements distributions, thus identifying the need for Joint Probabilistic Decision Making (JPDM).[14] This provides the situation illustrated in Figure 6, where the value space is represented as an aspiration space. Also, illustrated are threshold values for each of the requirements; thus the objective values for the requirements would be required to be achieved to reach the value/aspiration space. This sets the stage for Value Based Acquisition (VBA) which is a potential approach that should be considered for the Future Vertical Lift (FVL) to overcome many of the cost and schedule overruns experienced in the past and on today's aerospace and defense programs.[3] The benefits of applying JPDM[14] are:

- ❖ JPDM combines advantages of probabilistic treatment of uncertain information **with multi criteria decision making**
- ❖ Determines the **probability of satisfying all (specified) customer needs**/criteria values as an objective function
- ❖ Facilitates **visual trade-offs** for two requirements at a time, numerical trade-offs > 2 dimensions

2. IPPD AND VDD APPLIED IN GT DESIGNS

Value-drivendesign isa systems engineering strategybasedon microeconomics whi ch enables multidisciplinary design optimization. Value-driven design is being developed by the American Institute of Aeronautics and Astronautics, through a program committee of government, industry and academic representatives. In parallel, the US Defense Advanced Research Projects Agency has promulgated an identical strategy, calling it **Value centric design**, on the F6 Program. At this point, the terms *value-driven design* and *value centric design* are interchangeable. The essence of these strategies is that design choices are made to maximize system value rather than to meet performance requirements.[15]

This is also similar to the *value-driven* approach of *agile software development* where a project's stakeholders prioritise their high-level needs (or system features) based on the perceived business value each would deliver. Value-driven design is controversial because performance requirements are a central element of systems engineering. However, value-driven design supporters claim that it can improve the development of large aerospace systems by reducing or eliminating cost overruns[3] which are a major problem, according to independent auditors.[15]

Another value centric activity was the MIT Led Lean Aircraft Initiative (LAI). [4] The MIT Lean Advancement Initiative (LAI) was a research consortium that was founded in 1993 and active through 2012. LAI's purpose was to enable enterprises to effectively, efficiently, and reliably create value in complex and rapidly changing environments. Over the course of nearly two decades, LAI's collaborative partnerships with industry, government, and academic partners fostered the development of institutional principles, processes, behaviors, and tools for enterprise excellence.[4]

As mentioned in Section 1 the generic IPPD Methodology illustrated in Figure 1 served as the foundation for the Georgia Tech graduate program in education, as well as research. The practice-oriented Master's program developed for its implementation is illustrated in Figure 7.

The rotorcraft systems design courses have used the AHS student design competition (SDC) as its focus since 1984, the first year that the AHS SDC was offered. To say that Georgia Tech dominated these competitions in their first ten years would be an understatement, as illustrated in Figure 8.
These successes helped provide credibility for other capstone graduate programs in fixed wing aircraft design, starting in 1992, and in spacecraft design, starting in 1995. These additional graduate programs led to the establishment of the Aerospace Systems Design Laboratory (ASDL) in 1992 and the Space Systems Design Laboratory (SSDL) in 1995, as illustrated in Figure 9. More importantly, these laboratories established the credibility with faculty that a graduate program in Aerospace Systems Design was not only viable for research, but had large industry and government support. Like the rotorcraft design education approach, the fixed wing and spacecraft programs used national student design competitions, such as sponsored by the AIAA, ASME, and NASA. Today, Georgia Tech has by far the largest aerospace graduate program in the world with ~600 students, half of which are enrolled in Aerospace Systems Design.

While the Georgia Tech AHS graduate rotorcraft design teams have not been nearly as successful over the past ten years, a neck to neck competition with the University of Maryland has proven to be very productive in raising not only the quality of the AHS proposals, but also to initiate multidisciplinary design, analysis and optimization (MDAO) research into the Vertical Lift Research Center of Excellence (VLRCOE), as illustrated by the disciplinary breakdowns in Figure 10. In addition, over the past five years, Georgia Tech has included rotorcraft design as an undergraduate capstone option which also focuses on the AHS SDC. Georgia Tech is now the only university that has both graduate and undergraduate team entries in the AHS SDC.

In summary, the establishment of a strong, robust graduate program in Aerospace Systems Design based on the generic IPPD methodology and its value basis has set the stage for a further expansion to address Value Based Acquisition (VBA) along with the incorporation of a Development Assurance (DA) approach, which has become the best practice in the commercial Aerospace Sector.

3. VALUE BASED ACQUISITION

Value Based Acquisition (VBA) can be considered as an alternative acquisition strategy. In fact, it was proposed in the 2000 Book, "Keeping the Edge – Managing Defense for the Future", edited by two authors, one of which, Ashton Carter, is the current Secretary of Defense.[8] The current Defense Acquisition Strategy is primarily based on a Cost Plus Based Acquisition Strategy, where a single large defense contractor (OEM), is awarded a sole source contractor after DoD Acquisition Milestone B (entry into Engineering and Manufacturing Development). Thus, significant cost increases can, and almost always occur, as much of the technology is not at the appropriate maturity level, whether it be product or process, e.g. manufacturability.

The key to VBA at the program level is the *development of a value model that embodies key system design features*, such as weight, manufacturing cost, reliability, and the like, as well as key acquisition concerns, such as cost and schedule. Once a quantitative value model has been defined, it can become the basis for contracting. A program officer can offer a contract in which price is a function of value. The contract would specify the price that the government would be willing to pay for different levels of performance. Under a value-based contract, a contractor maximizes profit by including only those features whose value to the government exceeds their cost. When a firm accepts a contract under which their profit is directly tied to the value of their current design, per the value model, they will naturally adopt the value model to guide the design, since this is the route to maximizing profits. The firm will also want their subcontractors to adopt Value-Driven Design, so as to enhance profitability and to offload risk onto the subcontractors. The prime contractor will be driven to build incentives into its subcontracts that directly parallel the incentives in the government's prime contract. However, these incentives may be intractable unless the value model is kept simple. It is believed that a realistic application of Value-Based Acquisition *would limit the system value model to less than twenty attributes and less than one hundred equations*. Furthermore, every subcontractor will work toward a flowed-down objective function, which, by distributed optimization theory, is always a single linear equation.[3] Several DoD references reflect mechanisms on how VBA could be implemented. They are:

1. <u>DoD Warranty Guide, Version 1.0, 2009</u>
Incentive warranties provide motivation for the Contractor *to improve upon the minimum acceptable specification requirement*. The levels of performance that the Contractor is incentivized to reach are normally stated as goals in the system or item specification (as well as in the incentive warranty itself). Incentive warranties may take on certain aspects of assurance warranties by *requiring the Contractor to guarantee certain minimum acceptable requirements while, at the same time, incentivizing the Contractor to achieve the incentive goals*. Incentive warranties are typically used when increased performance is desired.

2. <u>DoD Incentive Strategies for Defense Acquistions, 2001</u>.
Suppliers should be rewarded for adopting business processes and principles designed to reduce costs and cycle time while maintaining schedule, achieving performance expectations and maximizing efficiency.

3. <u>U.S. Army Cost Benefits Analysis Guide, 3rd Edition, 24 April 2013</u>.
The final CBA presented to the decision maker must provide a recommendation that meets the objective of the CBA, as well as a value proposition that supports the recommendation. A value proposition is a clear statement that the benefits more than justify the costs, risks, and tradeoffs/billpayers. In other words, **a value proposition is a short statement that describes the tangible results/value a decision maker can expect from implementing the recommended course of action and its benefit to the Army**. A value proposition should tell the decision maker exactly what can be achieved by implementing the recommended course of action.

3.1 Weapon System Effectiveness

Blanchard and Fabrycky [16] define *system effectiveness* as the probability that a system may successfully meet an overall operational demand within a given time and when operated under specified conditions. In short, system effectiveness is the ability of a system to do a job for which it was intended. Blanchard and Fabrycky hold that, in themselves, measures such as Probability of Survival, *PS,* are not sufficient by itself as measures of effectiveness. They hold that system effectiveness is a function of the system's availability, dependability, performance and other defined measures. Weapon system performance can be an equivalent concept to weapon system capability.

The Weapons System Effectiveness Industry Advisory Committee, hereinafter called the WSEIAC, first defined effectiveness during the 1960's in a state-space environment.[17] By a *state-space* is meant the state in which a weapon system is, that is, the weapon system is either functioning properly or it is not functioning properly. Thus the WSEIAC nomenclature determines that a system's state is defined by its condition at a given time. Their work became the established basis for evaluating effectiveness in the US Army. They define system effectiveness as follows:

Systems Effectiveness is a measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a function of the system's availability, dependability and capability. [17]

Availability, Dependability and Capability can be defined as follows [17]:

Availability is a measure of the system condition at the start of a mission. It is a function of the relationships among hardware, personnel and procedures.

Dependability is a measure of the system condition at one or more points during the mission, given the system condition at the start of the mission.

Capability is a measure of the system's ability to achieve the mission objectives, given the system condition during the mission. Capability specifically accounts for the performance spectrum of the system.

3.2 Life Cycle Cost (LCC) Models

The main purpose of a Life Cycle Cost (LCC) model is to estimate the total costs associated with developing, acquiring, operating, supporting, and, at the end of its useful life, disposing of a system. A significant part of the LCC associated with any military system is the costs for initial logistics elements, which are procured with acquisition dollars and the annual and total Operating and Support (O&S) costs. In order for a complete LCC report to be produced, the LCC model must have the capability to capture R&D costs as inputs. Although the elements of LCC can be categorized in different ways, Figure 10 depicts a typical categorization of LCC elements.[18]

3.3 Value Based Acquisition (VBA) Model and Notional Example for Future Vertical Lift (FVL)

The VBA Model is a function of top level Weapon System Key Performance Parameters (KPPs) and Key System Attributes (KSAs) formulated to address the correlation between system effectiveness and life cycle cost. As such, the VBA Model forms a standardized basis for the objective comparison of Aircraft design alternatives or upgrades. The overarching goal of the VBA Model is to provide a quantitative measure of *how well a design is meeting the System Requirements at an Affordable Cost*. For military systems the VBA Model is a function of Capability, Availability and Dependability divided by Life Cycle Cost:

$$\text{(1)} \quad VBA = OEC = \frac{\alpha(\text{Capability}) + \beta(\text{Availability}) + \gamma\,(\text{Dependability})}{\phi\,(\text{Life Cycle Cost})}$$

This model can serve as a Benefits to Cost Ratio (BCR), as well as a means to capture the "Voice of the Customer" through the α, β, γ weighting functions. The BCR is usually an indicator, used in the formal discipline of cost-benefit analysis, which attempts to summarize the overall value for money of a project or proposal. A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. All benefits and costs should be expressed in discounted present values. Benefit cost ratio (BCR) takes into account the amount of monetary gain realized by performing a project versus the amount it costs to execute the project. The higher the BCR the better the investment. General rule of thumb is that if the benefit is higher than the cost the project is a good investment. [19]

However, in the extensive research and development that has been accomplished and demonstrated for Aerospace and other complex systems with the IPPD through RDS and beyond approach, the BCR is represented as an Overall Evaluation Criterion (OEC), where the system effectiveness criteria and their decomposed extensive attributes are kept in engineering and physical terms. Thus, they can relate directly to Key Performance Parameters (KPPs) and Key System Attributes (KSA). The OEC can usually be normalized around a baseline system. This often means that the VBA for the baseline system would be equal to 1.0 with improvements being greater than 1.0. A notional example of how the OEC/VBA could be postulated for Future Vertical Lift (FVL) aircraft is shown in Figure 11, along with the sources of uncertainty that need to be addressed. Research is underway to apply the VBA Approach to address these uncertainties.

An illustrative example from previous Georgia Tech graduate AHS SDC designs was used to show the sensitivity to FVL customer priorities and their impact on Systems Effectiveness as well.[20]

From the FVL Capability Based Assessment (CBA) the platform technology gaps in Figure 12 were identified. Note that only the top level functions of Sustain, Safe, and Survive were addressed. The prioritized gaps were converted into customer requirements and inserted into the Quality Function Deployment (QFD) matrix to obtain the notional key FVL Product and Process Characteristics. This is the first step in the IPPD methods and tools flow illustrated in Figure 13.

These notional key FVL Product and Process Characteristics where then incorporated into the initial OEC with the weightings determined from the QFD matrix as follows:

$$\text{(2)} \quad OEC = (0.361{*}\text{Capability} + 0.274{*}\text{Dependability} + 0.365{*}\text{Availability}) \;/\; LCC$$

Previous Georgia Tech AHS SDC concepts were used to identify viable alternatives from the Morphological Matrix as illustrated in Figure 14. After applying subjective evaluation using a Pugh matrix, a quantitative Multi-Attribute Decision Making (MADM), TOPSIS, was used. It accounted for the weightings from the QFD and resulted in an Advanced Helicopter being selected as the Best Alternative, as illustrated in Figure 15A. Since the impact of mobility or the “Move” Function was not included in the Platform Technology Gaps in Figure 12, the Capability Criterion in the OEC was changed to include a Mobility Capability Index (MCI) defined as:

$$(3)\ MCI = \frac{Payload_{(HOGE4k95)} \ X\ Block\ Speed_{Miission}}{Empty\ Weight\ +\ Fuel\ Weight}$$

New OEC=0.552∗Capability + 0.134∗Dependability+0.314∗Availability/ LCC

As illustrated in Figure 15B with this incorporation of the MCI the MADM results determined the Tilt Rotor Aircraft was the Best Alternative. A third iteration with a Life Cycle Cost (LCC) estimate for each of the three alternatives resulted in MADM results, Figure 15C, which determined the Coaxial Compound as the Best Alternative. While this analysis is notional and deterministic in nature, it illustrates a methodology that can be used with appropriate probabilistic and stochastic techniques. This is the objective illustrated in Figure 11.

4. SUMMARY AND CONCLUSIONS

While the quality revolution of the late 1980s and early 1990s have had a major impact on the quality improvement in commercial systems, such as cars and electro-mechanical systems, their payoff for aerospace and defense systems has been much less. The DoD required Integrated Product/Process Development (IPPD) and the use of Integrated Product Teams (IPTs) was partly successful, as the use of IPTs is now the norm throughout DoD and industry. However, there is less evidence that IPPD is being applied throughout industry and government.

Over the past twenty-five years Georgia Tech in its Aerospace Systems Design Program has continued to develop IPPD through RDS methods and tools for complex civil and military systems and system of systems. These methods and tools can provide a necessary environment for developing future systems, such as the Future Vertical Lift (FVL) Aircraft Program.

5. REFERENCES

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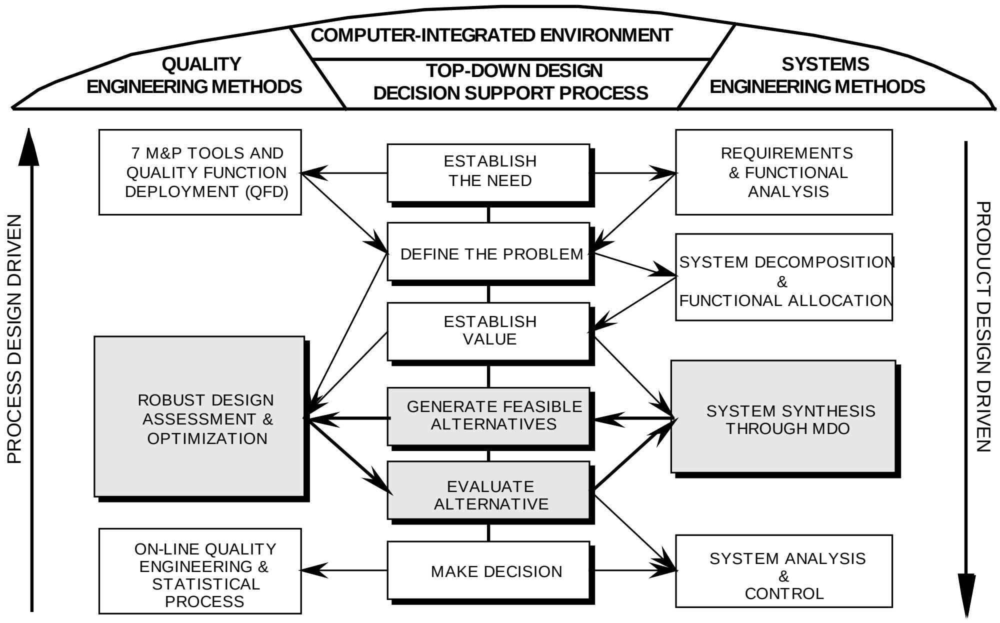

Figure 1. Georgia Tech Generic IPPD Methodology

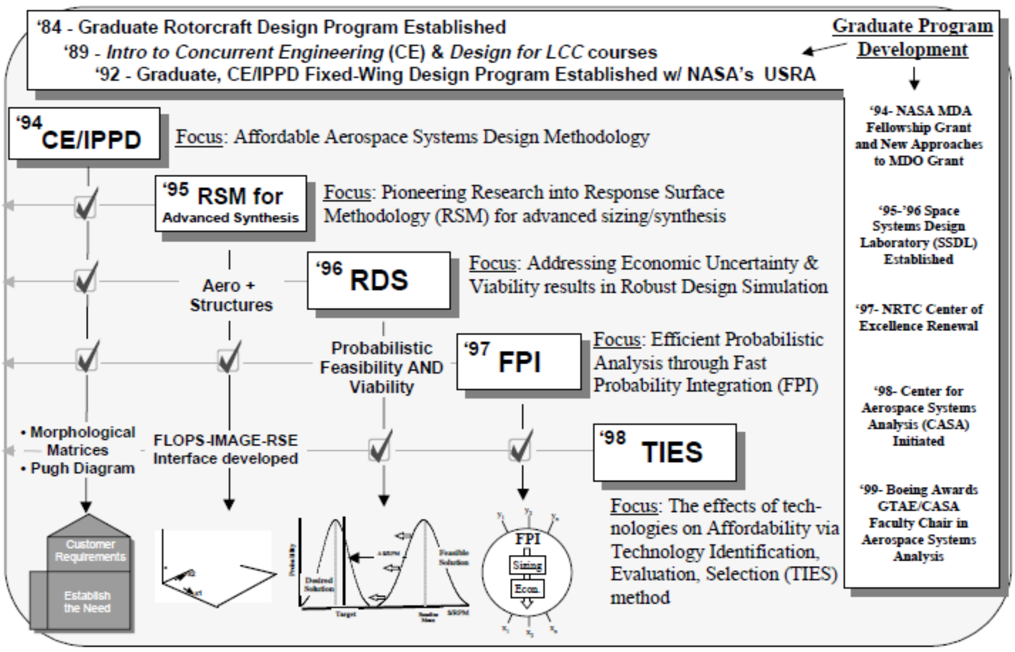

Figure 2. Evolution of Georgia Tech IPPD Methodology to RDS[1]

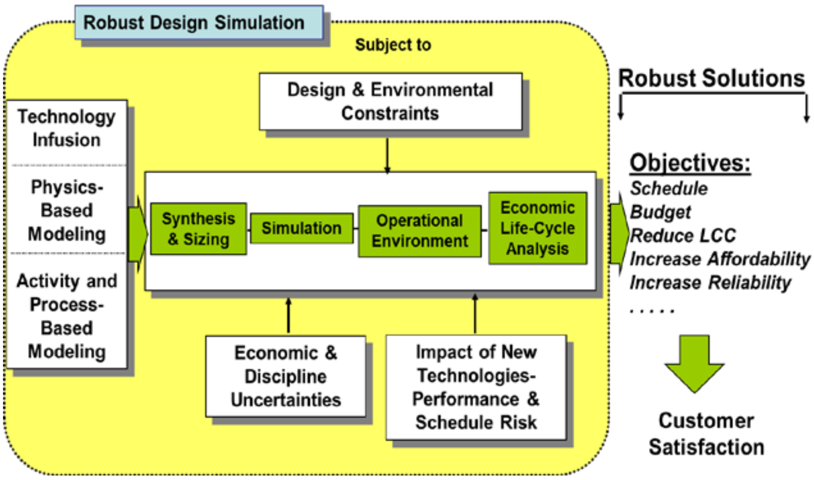

Figure 3. RDS Iteration Loop Illustrated by Gray Boxes in Figure 1[9]

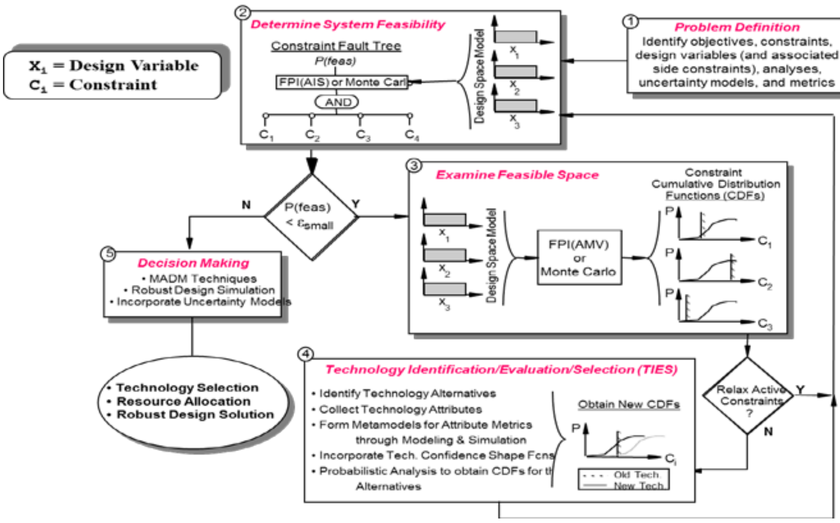

Figure 4. Five Step Process for Implementing IPPD through RDS[9]

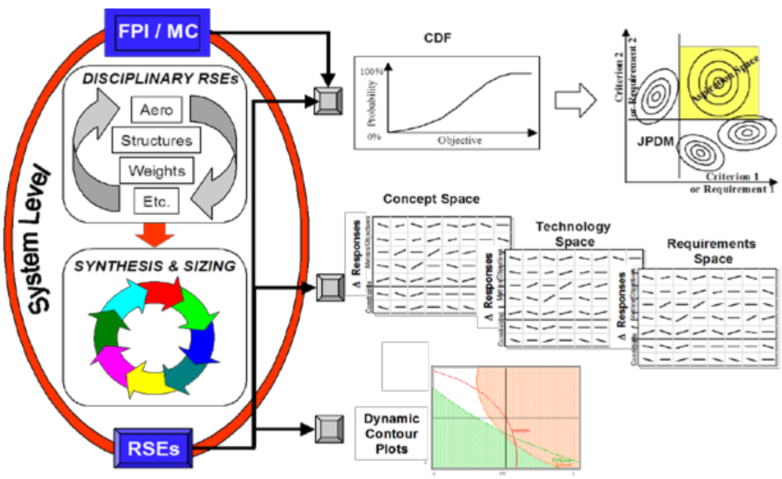

Figure 5. Probabilistic Unified Tradeoff Environment[14]

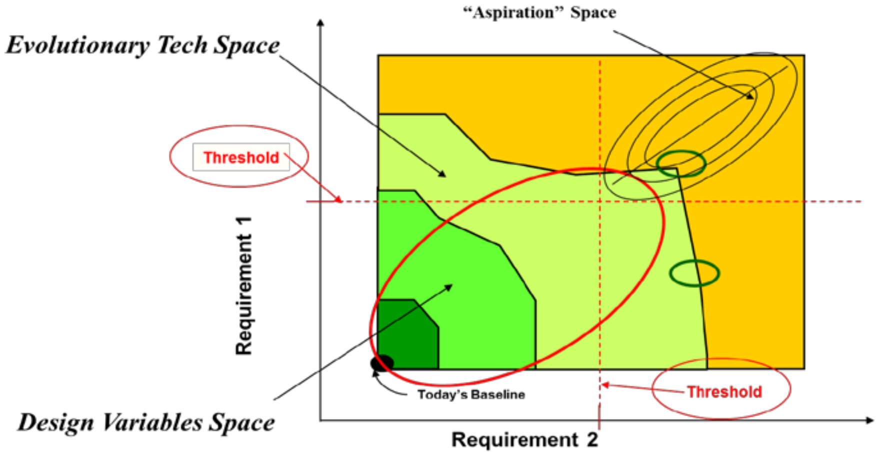

Figure 6. JPDM Illustrated for the Value/Aspiration Space

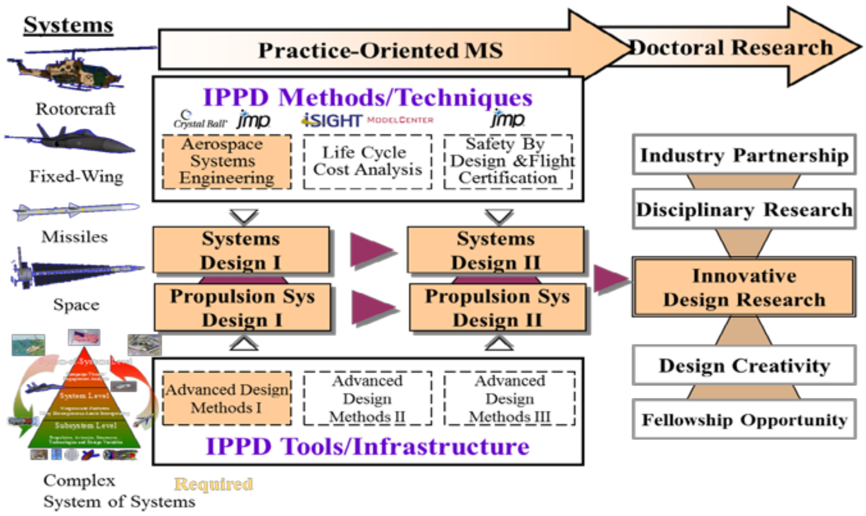

Figure 7. Georgia Tech Masters Degree Program in Aerospace Systems Design

Year	Sponsor	Project	Winners
1984	Boeing	Combat Search & Rescue	RPI and GIT
1985	Boeing	Sport Helo for Home Construction	GIT 1st& 2nd; PSU 3rd
1986	Boeing	One Man RW Racer	GIT all categories
1987	Bell	Low Cost TR Commuter Opns	GIT 1st& 2nd; RPI 3rd
1988	Sikorsky	Heavy Lift Helicopter	GIT 1st& 2nd; UMD3rd
1989	MDHS	Light Utility Helicopter	GIT all categories
1990	Boeing	Remotely Piloted Surv Vehicle	GIT all categories
1991	Bell	High Speed VTOL	GIT all categories
1992	Sikorsky	VTOL Package Express AC	GIT 1st; RPI 2nd
1993	MDHS	Scout Reconnaissance	NPGS 1st& ASU 2nd
1994	Boeing	Dual Use VTOL	GIT 1st& NPGS 2nd

Figure 7. AHS SDC Award Winners First Ten Years

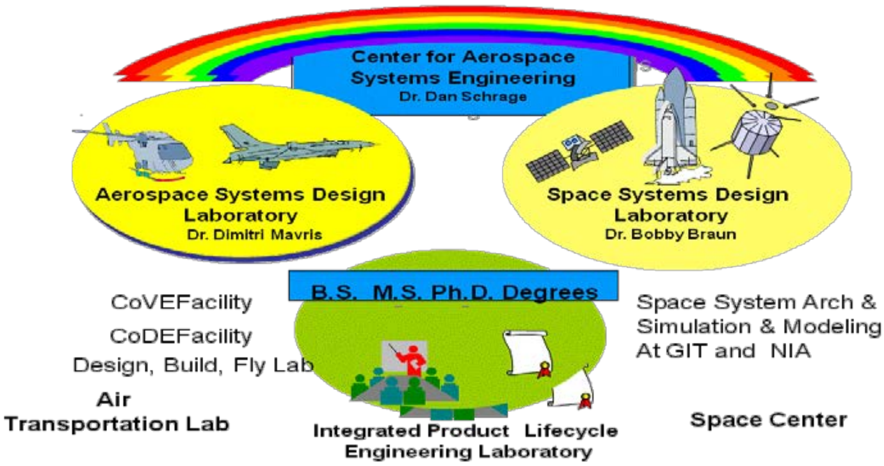

Figure 8. Georgia Tech Aerospace Systems Design Laboratories

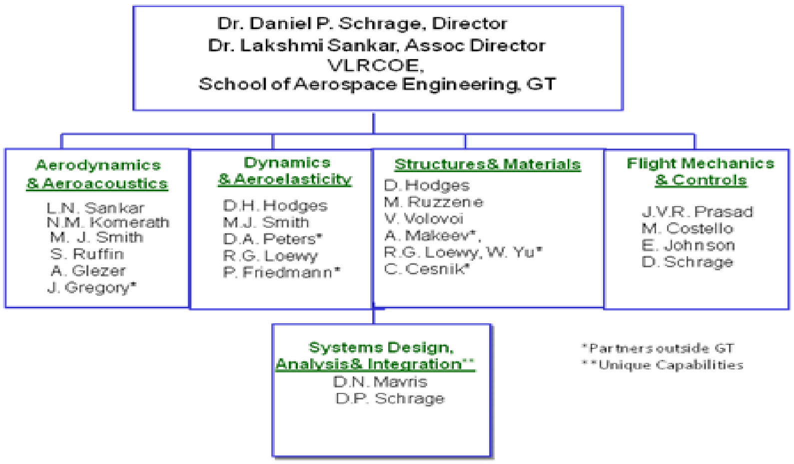

Figure 9. Georgia Tech VLRCOE Disciplinary Breakdown

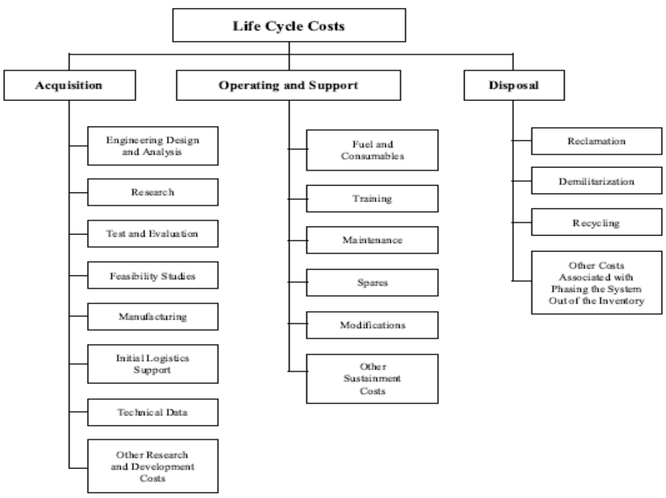

Figure 10. Typical Categorization of LCC Elements for a Weapon System [17]

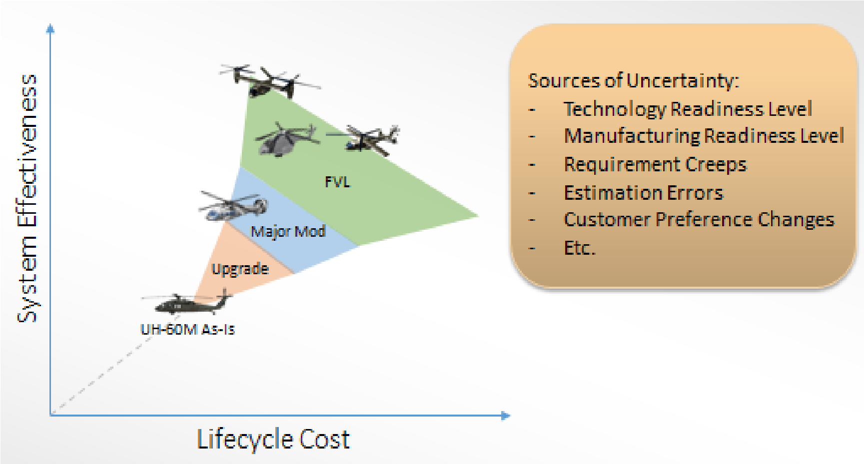

Figure 11. Notional OEC/VBA Approach for FVL

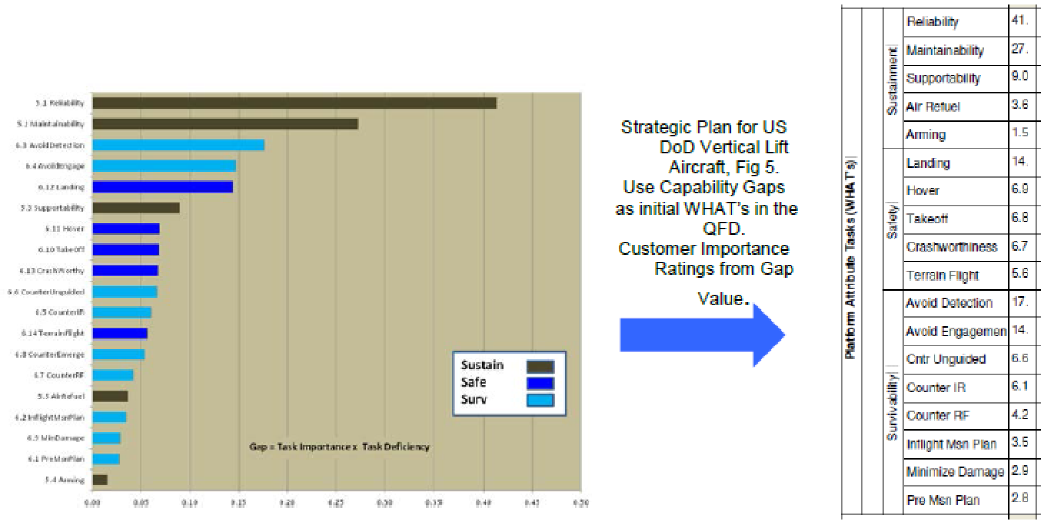

Figure 12. FVL Platform Technology Gaps for Sustain, Safe and Survive Mission Functions

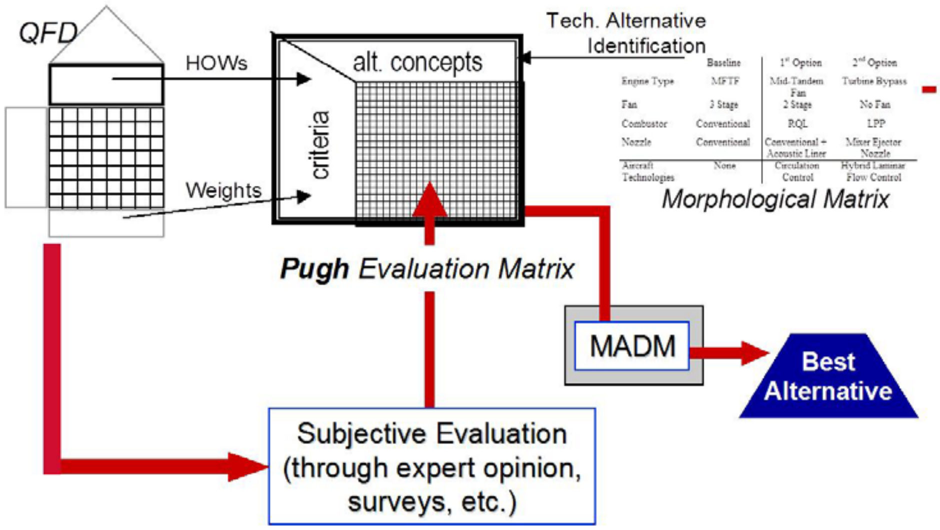

Figure 13. IPPD Methods and Tools for Initial Best Alternative Selection

	UH-60	Reasons (Baseline)	Adv Helo	Reasons	Coaxial	Reasons	Tilt Rotor	Reasons
Cruise Speed	1	Low airspeed	2	150 - 200 kts	3	200 - 250 kts	4	250 - 300 kts
Combat Radius	1	Lower range than target	3	500 nm range	3	est. 640 nm range	3	700 nm range
6k/95 Perf	2	6k95 at some	2	low HOGE ~5k ft	3	demonstrator	3	low HOGE ~5k ft
Internal Payload	2	Higher payload	3	4000 lbs useful load	2	4000 lbs	3	5000 lbs useful load
Unmanned Ops	2	Some integration	3	Designed to rqmts	3	Design to rqmts	3	None
Networked C2	2	Some integration	3	Designed to rqmts	3	Design to rqmts	3	None
Passengers	4	Capable area	2	Designed to rqmts	3	Design to rqmts	3	large passenger cap
Shipboard Comp	3	Variants comp	2	Est., Not evaluated	3	Est., Not evaluated	1	Estimated
Transportability	3	Transportable	2	Large Rotor Helo	2	Large (Tall) Coaxial	5	Self Deploy
FMC Rate	3	Known maint	4	maintenance	2	Dual rotor compound	2	higher maintenance
Sensors	3	Some sensors	3	Some sensors	2	Limited sensors	3	Some sensors
Sit. Awareness	3	Average SA	3	Estimated	3	Estimated	3	Estimated
Survivability	4	High Survive	4	Composite Airframe	3	Crashworthiness Eval	3	FAR Structural Eval

Figure 14. Notional FVL Concepts from previous GT AHS SDCs

Relative closeness to the ideal solution: Ci = Si-/(Si*+Si-)		
C_A	0.4237	UH-60
C_B	0.6143	Adv Helo
C_C	0.3138	Coaxial
C_D	0.4548	Tilt Rotor

Original TOPSIS Results

Relative closeness to the ideal solution: Ci = Si-/(Si*+Si-)		
C_A	0.3292	UH-60
C_B	0.4408	Adv Helo
C_C	0.5644	Coaxial
C_D	0.6664	Tilt Rotor

Updated TOPSIS Results

Relative closeness to the ideal solution: Ci = Si-/(Si*+Si-)		
C_A	0.5156	UH-60
C_B	0.5327	Adv Helo
C_C	0.5988	Coax
C_D	0.5915	Tilt Rotor

Updated TOPSIS with Cost

Figure 15A,B, C . Results from Three Iterations of Figure 13.