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ASSESSING THE SIMULTANEOUS IMPACT OF REQUIREMENTS, VEHICLE CHARACTERISTICS, AND TECHNOLOGIES DURING AIRCRAFT DESIGN

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ABSTRACT

It is clear that the most fundamental issue for the aircraft designer in the early definition phases of the design process is the effect that requirements have on the system. Requirements drive initial design studies, procurement decisions, and ultimately operational effectiveness and cost. However, it is often the case that the impact of changes and/or ambiguity in requirements is usually not well understood since the relationships between requirements, technologies, and the design space is not adequately quantified. Increasingly, the decisions made early in the design time line involve the choice of new technologies or combinations of new technologies that will ensure the system meets customer requirements. Providing the designer /decision-maker with knowledge of these relationships enhances the viable, robust solution for the customer. In this paper, the authors will present a method which yields a tradeoff environment that allows the simultaneous assessment of technologies, requirements and vehicle characteristics referred to here as the Unified Tradeoff Environment (UTE). The creation of this environment is described along with the tools for its implementation. In addition, a more detailed explanation of the mission requirement space is presented including anticipated uses beyond those associated with the UTE. This environment is illustrated using the Future Transport Rotorcraft as a baseline vehicle. This vehicle epitomizes the new designs, which will rely on technology insertion to meet ambiguous continually evolving requirements.

INTRODUCTION

A great deal of attention recently has been paid to the role of requirements in the design and acquisition of complex systems in both the commercial and military sectors. In the commercial sector, the term “requirements engineering” is coined to explain the process of requirements’ elicitation, analysis, negotiation, validation, documentation and tracing.[1] . On the military side, the design sequence is mandated by Department of Defense Regulation 5000.1 to include a systems engineering process (extensively used by commercial sector) for the design and acquisition of complex systems. Thus, requirements are handled through the requirements analysis and allocation processes inherent in the systems engineering approach.[2,3]

Unfortunately, this emphasis on requirements does not ameliorate the real issue facing designers, namely, the impact requirements have on the system design and the need to ensure realistic requirements are set. For complex system design and acquisition there exists a requirements loop in addition to the design loop or iteration process. This requirements loop occurs, in practice, between Milestone 0 (Mission Needs Statement) and Milestone 1 (Operational Requirements Document) of the military acquisition sequence. The ORD is not constructed in isolation from the designers but in concert with them to ensure adequacy. This process allows the requirements to be captured in unison with the design process and provides some assurance that requirements will not be set that are beyond technical capabilities.

It is clear that the most fundamental issue for the aircraft designer in the early definition phases of the design process is the effect that requirements have on the system. Requirements drive initial design studies,

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procurement decisions, and ultimately operational effectiveness and cost. However, it is often the case that the impact of changes and/or ambiguity in requirements is usually not well understood since the relationships between requirements, technologies, and the design space is not adequately quantified. Increasingly, the decisions made early in the design time line involve the choice of new technologies or combinations of new technologies that will ensure the system meets customer requirements. Providing the designer /decision-maker with knowledge of these relationships enhances the viable, robust solution for the customer.

Many of the user requirements are related specifically to mission requirements. For instance, the environmental requirements are encapsulated in ambient conditions such as temperature and altitude as well as gust loads etc. The obvious performance requirements including payload, range, speed, internal/external loading, mission equipment packages etc. are all elements of a given mission profile which describe how the system is to operate. Based on this set of requirements, the vehicle is subsequently subjected through a sizing and synthesis iterative process. In traditional conceptual design formulations, such mission requirements are prescribed and the analysis results in a limited design space tradeoff environment, if not a single design, early in the design timeline. This traditional environment does not anticipate the variability of mission requirements nor can it easily assess the impact on the system in real-time. The environment proposed here treats the mission requirements as inputs to the analysis instead of responses. Mission requirements are put on equal footing with technology metrics and vehicle characteristics in order to reach the best compromise design.

The research presented in this paper draws from the needs and guidance described above. The need to provide an environment that justifies decisions and documents their effect on the product is borrowed from the commercial acquisition community. The broad guidelines expressed in the defense acquisition community point to the need for an environment that keeps the design space open and allows for tradeoffs as well as establishing key metrics with appropriate targets to aid in the decision making process. Finally, the design community, which is most closely associated with the product of this research, emphasizes the need for a modern design environment that incorporates the ability to address unclear requirements, minimizes the rework of previous design studies and provides guidance for setting requirements.

In this paper, the authors will present a method which yields a tradeoff environment that allows the simultaneous assessment of technologies, requirements and vehicle characteristics referred to here as the Unified Tradeoff Environment (UTE). The creation of this environment is described along with the tools for its implementation. In addition, a more detailed explanation of the mission requirement space is presented including anticipated uses beyond those associated with the UTE. This environment is illustrated using the Future Transport Rotorcraft as a baseline vehicle.

TECHNICAL APPROACH

The discussion above indicates the need for an environment that can accurately capture the various factors that influence the decisions made early in the design time line. As indicated these factors include vehicle characteristics, technology metrics and mission requirements. What is required is the ability to capture the complex design space with a mathematical model that equates the system level attributes of the complex system to the various factors mentioned above. Even at the system level, the inclusion of these three distinct influences can require a complex model. In order to create a more tractable design space model, the environment is partitioned according to influences into the concept space, technology space and mission requirement space. This allows the designer to use the three design spaces individually when needed or in concert to create the UET.

Creation of Unified Tradeoff Environment

In this research, Response Surface Methodology (RSM)[4] is used as an enabler to mathematically represent the combined configuration-requirements-technology space or Unified Tradeoff Environment (UTE). RSM is a process that allows one to model the behavior of a complex system using a simplified equation. RSM includes:

1. Selection of variables and ranges
2. Screening test; Analysis of Variance; 2 level Design of Experiment (DOE)[5]

3. Design of Experiments for determining the appropriate number and combination of simulation cases;
4. Running prescribed analysis cases and collecting appropriate response data
5. Performing multivariate regression analysis to build the response surface equations (RSEs)
6. Model validation; confirmation test; random sample of cases

Generally, the exact deterministic relationships that govern the behavior of the measured responses to the set of design variables are either too complex or unknown. Therefore, an empirical model is constructed which captures the system response as a function of the design variables. The empirical model used in this methodology is assumed to be second order with *k* number of design variables. This second-degree model is assumed to exist and can be expressed in the following form.

$$R = b_o + \sum_{i=1}^{k} b_i k_i + \sum_{i=1}^{k} b_{ii} k_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} k_i k_j \qquad (1)$$

where:

b_i = regression coefficients for linear terms

b_{ii} = coefficients for pure quadratic terms

b_{ij} = coefficients for cross product terms

x_i, x_j = design variables

The coefficients of this regression curve (surface) are determined by applying a least squares analysis to the responses generated by the set of simulations identified through a Design of Experiment. When this model fails to accurately predict the behavior of the complex analysis code, other methods found through independent or dependent variable transformations or artificial neural networks can be used.

As mentioned above, the coefficients of the RSE are determined utilizing a carefully planned design of experiments or simulations. This approach ensures that the resulting RSE will be applicable in a sufficiently large design space without requiring an unrealistic number of simulation runs (or cases) to provide the response data for the regression analysis. The DOE chosen will dictate the number of simulation runs required based on the number of levels considered, the number of interactions modeled and the number of variables prescribed. By employing a fractional factorial DOE the required cases are manageable with higher order effects neglected. Fractional factorial designs neglect third or higher order interactions and, in the case of RSE generation, account for linear and all second order interactions including the quadratic effects (see Equation 1).

The three levels of inputs are mission requirements including payload, range, etc.; design / economic variables which control vehicle geometry /economics and technology dials or k-factors which provide a change in disciplinary metrics to simulate the step change in a response associated with technology insertion. Thus, the problem is broken down into snapshots of the system (Figure 1). The snapshots shown in Figure 1 are visual representations of the response surface equations that mathematically relate the system level attributes to the appropriate variables for each individual snapshot. These snapshots provide “deltas” in responses with respect to baseline values. This approach allows for the combination of the effects of mission requirements and applied technologies along with the geometry of the vehicle on the decision making space. The assumption for this environment is that interactions between k-factors, design variables and requirements do not occur across design spaces. As mentioned earlier, interactions within one of the three design spaces is captured through the RSE model and the appropriate DOE. The effect on the system is then represented as:

Response (i.e. ΔGW) = function (Requirements,
Vehicle Characteristics, Technology k-factors)

Snapshot 1 de-emphasizes the geometry of an aircraft, and instead focuses on the mission requirements. However, it does require a baseline vehicle configuration. Baseline geometry and a baseline technology level set are fixed**,** while top level requirements (*req*) are allowed to vary. Each vector of top level requirements maps to a specific mission. Thus, the effect of primary mission requirement changes on alternate missions can also be tracked. For example, the primary mission range (which sizes the vehicle) can be included as an input variable with the secondary mission range as a fallout response.

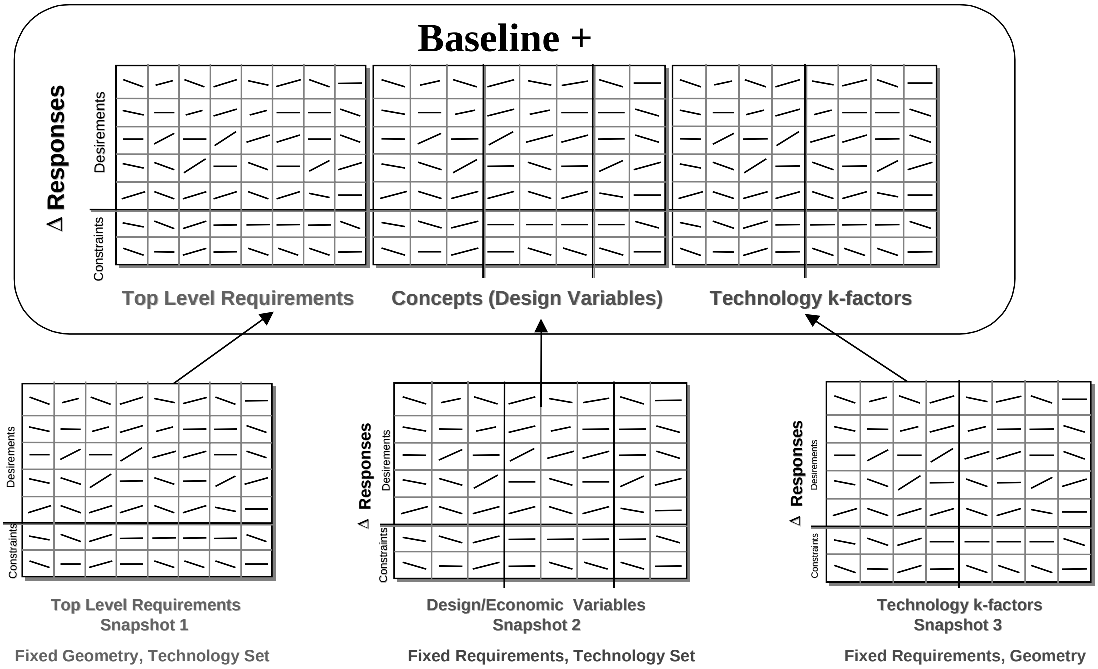


Figure 1: Additive Creation of Unified Tradeoff Environment[6]

In Snapshot 2, the baseline vehicle is once again fixed with regards to mission requirements and applied technologies, but the vehicle characteristics are allowed to vary. Each vector of design variables (*DV*) and economic variables (*EV)* maps to a specific geometry of a configuration.

In Snapshot 3, the requirements and the vehicle are fixed, but the technologies are allowed to vary. The technology k-factors, both product technologies (k_{Tprod}) and manufacturing technologies (k_{TManuf}), used during the creation of this space act as techno-dials allowing the manipulation of various disciplinary metrics to simulate the insertion of individual technologies or combinations of technologies. Each vector of technology k-factors maps to a specific combination of applied technologies. More detailed information on the creation and use of Snapshot 2 and 3 can be found in References 7 and 8.

The overall effect on the system is the summation of these three snapshots and can be written (for example):

$$\mathrm{Re}\,sponse = \left(b_0\right)_{overall} + \Delta\sum(req_1, req_2, req_3, \ldots) + \\ \Delta\sum(DV_1, DV_2, \ldots, EV_1, EV_2, \ldots,) + \\ \Delta\sum(k_{TP1}, k_{TP2}, \ldots, k_{TM1}, k_{TM2}, \ldots)$$

The intercept is thus the combination of the baseline vehicle plus the "delta" contributions from the changes made to requirements, vehicle attributes and technology k-factors. By representing the three design spaces with response surface equations, the designer/decision-maker has created explicit relations between the responses and the various inputs. These surfaces represent a powerful tool for probing the decision space. These response surface equations represent a non-linear set of equations that can be manipulated to:

1. search for alternatives (configuration changes plus technology infusion) that satisfy requirements and constraints
2. simultaneously, optimize on desirements within this feasible space (continuous) or set (discrete) then, perform sensitivity studies to show the perturbation of the solution due to possible changes in requirements and design variables.

Thus the customer / decision-maker has information with regards to the choice between a relaxation in requirements or accepting achievable performance levels. The graphs shown in Figure 1 are called prediction profiles and are interactive visualizations created from the response surface equations with the aid of a commercial software package named JMP[9].

Mission Space Model

The technology space model is created as described above to allow the greatest flexibility in mapping technologies and determining their impact. It provides the decision-maker with real-time information on the impact of a change in technology metrics when used in conjunction with the UTE. Individually, the technology space has found many applications including technology impact forecasting, technology selection and resource allocation as described in References 8 and 10. Likewise, due consideration is required to construct a requirements space model which is generic enough to provide a viable analysis tool both in the UTE and individually. The easiest way to construct this space would be to use relevant inputs such as payload, speed, range, etc. However the proposed design environment requires a more robust solution. The design of new systems for joint missions or the redesign of systems to replace multiple aircraft calls for the ability to simulate the impact of multiple missions in this one environment. This is accomplished by constructing a master mission structure that captures all the mission profiles prescribed.

Through a master mission structure the designer is able to create a continuous requirements/mission space which contains the finite set of specific missions or perturbations usually used to size a vehicle. When created in this manner, the environment is called the Mission Space Model. This model has the advantage of allowing the UTE a multi-mission impact capability. Since this model is a continuous response surface, the designer is not limited by a handful of mission profiles and can explore the impact of altering prescribed mission profiles on system level attributes in unison with technology insertion.

The master mission structure for the Future Transport Rotorcraft is constructed loosely from three missions (Navy, Marine Corps and Army) described as Joint Common Lift (JCL) Heavy Lift-Assault by the Operational Requirements Commonality Assessment (ORCA). These missions are representative of the types of missions anticipated for the FTR. The master mission structure is illustrated in Figure 2.

Although a simplified version of the ORCA missions, this set serves well to illustrate the ability to map various mission profiles. The Mission Space Model constructed using this structure will allow the designer to simulate various ambient conditions and a wide range of payloads including how much payload is dropped. There are three separate cruise range inputs as well the ability to fly the last cruise segment at altitudes up to 8000 feet. The ranges used to create the Mission Space Model for the FTR are given in Table 1 and further give an indication of the wide array of mission profiles that can be mapped.

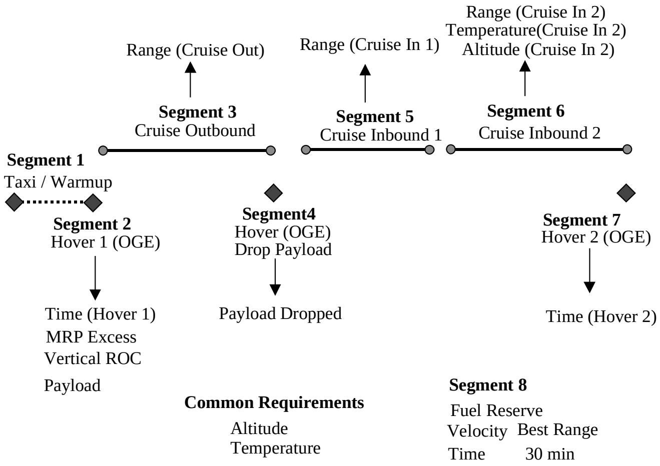


Figure 2: Master Mission Structure

Table 1: Ranges for Mission Space Model

Mission Requirement	Minimum	Maximum
Payload (lbs)	20000	40000
Altitude (feet)	0	4000
Temperature (F)	90	95
Time (Hover 1)(min)	1	5
Range (Cruise Out)(nm)	150	300
Payload Dropped (%)	50	100
Range (Cruise In 1) (nm)	150	290
Altitude (Cruise In 2) (feet)	0	8000
Temperature(Cruise In 2) (F)	30	95
Range (Cruise In 2) (nm)	0	10
Time (Hover 2) (min)	2	5
Vertical ROC (ft/min)	0	200
MRP Excess (%)	0	5

APPLICATION

One of the best examples of a new system that contemplates multiple concepts, relies heavily on assessing technology impacts and has ambiguous or ill-defined requirements is the Future Transport Rotorcraft (FTR). This concept has been the subject of much discussion lately in the rotorcraft community. It is envisioned to carry 10 to 20 tons of payload for 300-1000 kilometers at speeds ranging from 175 to 350 knots. A Unified Tradeoff Environment is constructed for the FTR around a single main rotor/tail rotor configuration. The anchoring point for this configuration is a vehicle similar in size and performance to the CH-53E, thus providing proper trends and scaling laws for this class vehicle. The baseline used to construct the UTE includes modified 2005 Rotary Wing Vehicle Technology Development Approach (RW-TDA) goals as well as IHPTET (Stage II) estimates for the engines. The TDA is a structured government/industry/academia technology approach aimed at addressing technological challenges. It quantifies improvements in the state-of-the-art through measurable goals for system and component level characteristics with respect to established baselines and proposed achievement dates. These assumptions provide a realistic baseline that is not reached by simply scaling the CH-53E-like vehicle to meet FTR requirements. All analysis work is conducted using a proprietary industry synthesis and sizing code. This robust synthesis and sizing code allows the designer to manipulate vehicle characteristics, technology coefficients and mission requirements without internal optimization routines which facilitates the use of Response Surface Methodology and Design of Experiments.

The variables and the ranges used to create the mission requirement space are illustrated above. The variables and their ranges for the concept space are shown in Table 2. The economic variables are included in this space. The technology space is constructed using various technology metrics associated with component weights as well as engine technology. The metric ranges shown in Table 3 encompass the modified 2005 RW-TDA goals used to form the baseline vehicle while allowing further investigation of the impact of technologies. Thus the assumptions made for the RW-TDA goals are easily manipulated to see sensitivities and investigate the vertical integration of these effects on the system level attributes. Notice the ranges include the ability to map the primary benefit derived from a technology as well as penalize a secondary effect.

Table 2: Ranges for Concept Space

Vehicle Characteristics	Minimum (%)	Maximum (%)
Blade Loading	-11	11
Disk Loading	-11	7
Fuselage Wetted Area	-16	12
Flat Plate Drag Area	0	13
Number of Blades	-14	14
Production Run	-50	20
AF Learning Curve	-6	6
Utilization Rate	-38	46

Each of the spaces used to construct the UTE extracts the baseline value from the responses and models the change or “delta” of a response associated with changing an input. Figure 3 provides a detailed look at the environment for the FTR. A sampling of three responses for each space is presented for clarity.

Table 3: Ranges for Technology Space

Technology Factor	Minimum (%)	Maximum (%)
Blade Weight	-25	5
Hub Weight	-25	5
Horiz Tail Weight	-25	5
Vertical Tail Weight	-25	5
Tail Rotor Weight	-25	5
Body Weight	-25	5
Landing Gear Weight	-25	5
Engine Weight	-25	5
Engine Related Weight	-25	5
Drive System Weight	-40	5
Rotor Controls Weight	-25	5
Dir Mech Cntrls Weight	-25	5
Avionics Weight	-25	100
SFC	-40	5
Vertical Drag	-15	5
Flat Plate Drag Area	-15	5

As mentioned earlier, the mathematical models (RSEs) describing the overall design space are visualized in the form of prediction profiles. These screens are an interactive representation of the design space as captured by the design space RSEs. When the hairlines (light gray vertical lines) are moved to indicate the changing of an input variable value, the responses are automatically updated through the RSE. Thus, one can investigate the overall design space by manipulation of the design variables to determine if an objective can be met.

The slopes indicate the relative effect each variable has on the responses and are updated in real time when any input is manipulated. It must be noted, however, that the slopes may be deceivingly flat when one variable has a very strong effect. This is the case with the mission requirement space. The payload variable has a very large range and as expected, will greatly affect gross weight, installed horsepower and acquisition cost as indicated by the highly sensitive slopes. Intuitively, the vertical rate of climb requirement and the excess power requirement at hover should show a positive correlation with each response and installed horsepower in particular. The prediction profile shows a deceptively flat interaction due to the overwhelming effect of payload and other mission requirements. When these requirements are changed they do indicate significant changes in the responses.

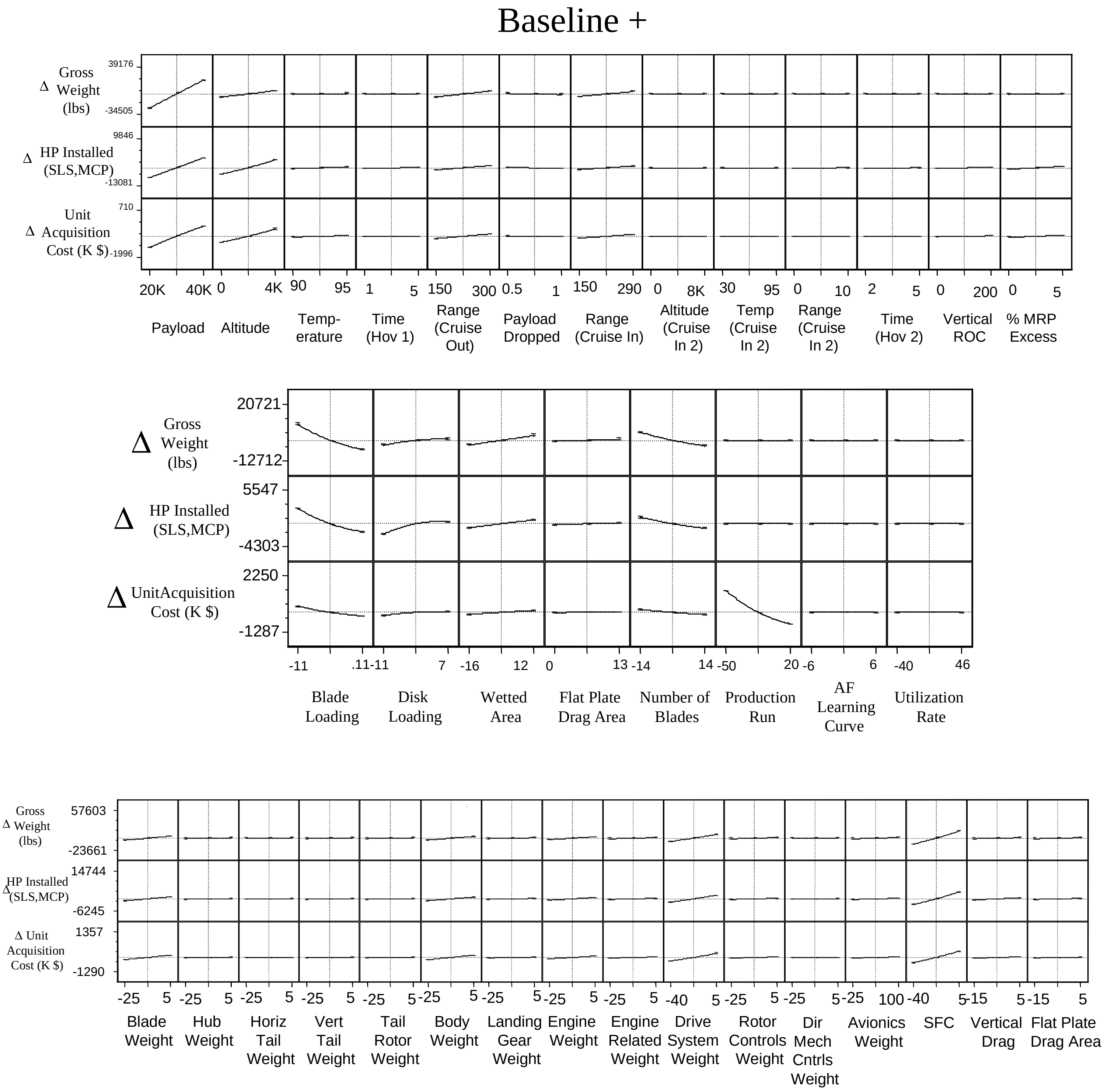


Figure 3: Unified Tradeoff Environment for FTR – Single Main Rotor Departure Point

Potential Uses of the Mission Space Model

In the references sited earlier, the concept space and the technology space have been used in isolation from the UTE to provide the designer with additional analysis capability. In this section the authors will comment on the potential use of the Mission Space Model in a stand-alone form and illustrate these uses by application to the FTR.

When used in a stand-alone form the need to extract the baseline is lost and new response surface equations are constructed which relate the full responses to the mission requirements. Since the response data is already extracted for the UTE, creating new RSEs is a quick post-processing procedure requiring no further analysis runs. This environment allows the designer to map an infinite number of mission profiles and provides the designer with the impact on system level responses. By creating the requirements space up front, the designer is able to view the design process in a new light.

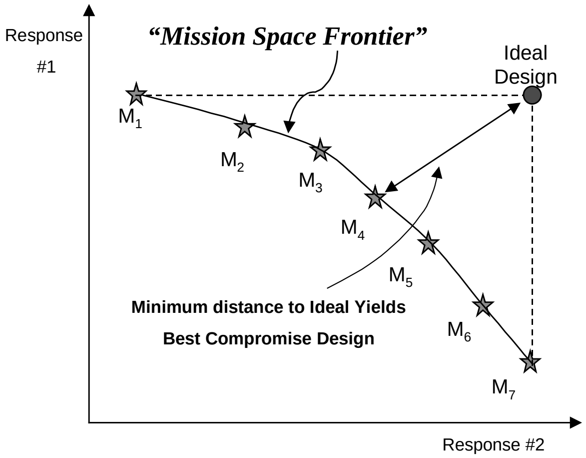


Figure 4: Determining a Compromise Design

The traditional design method uses the given mission profiles as a series of snapshots for vehicle synthesis and sizing. When targets are placed on the responses they become desirements or constraints and allow the designer to identify the mission for sizing. Figure 4 illustrates the traditional design approach in a compact form. Two responses are compared in which the higher value of each is desirable. Seven mission profiles (M1 – M7) are used to size the vehicle and the fallout responses are plotted using stars. As indicated, the ideal solution for these particular responses is not an attainable design, based on the given sized vehicles. However, this ideal design can be used to identify the best compromise design. By employing a multi-attribute decision-making method such as the Technique for Ordered Preference by Similarity to Ideal Solution[11] or simply determining the minimum distance to the ideal design, the best compromise design can be identified.

These seven mission profiles represent distinct points along a "mission space frontier" which could be viewed as analogous to a pareto optimality front. Any point along this front could represent the best compromise design, not just the select few mission profiles provided. The mission space model allows the designer to search the mission frontier for the best compromise design. Creating an algorithm, which will conduct this search represents a future research goal.

Another use for the mission space model relies on the use of probabilistic sampling techniques such as Monte Carlo Simulation. The model can be used to bound the requirements space, identify active constraints and indicate the need for technology insertion. In a deterministic approach, multiple input values are changed and the model is used to determine the impact on the system resulting in a point design. In the probabilistic approach, shape functions or distributions are associated with mission input and a Monte Carlo Simulation randomly samples the distribution. The outcome is a cumulative distribution function (CDF), which illustrates the probability of success (POS) versus the specified response. The shape functions for the inputs can be altered to propagate preferences through the design. For instance, the payload input has a range from 20000 to 40000 lbs. This range is left broad to account for any contingency, however, there are values within this range that are more likely to encompass the greatest need. Skewing the shape function to these values can assist the designer in determining the change in the probability of attaining a response target.

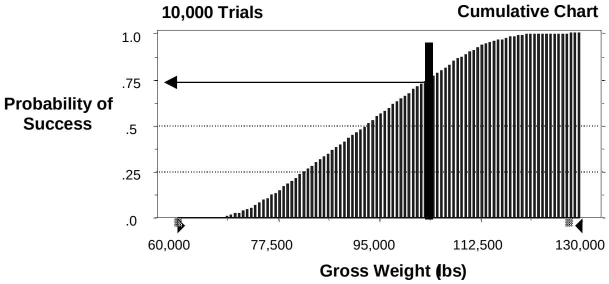
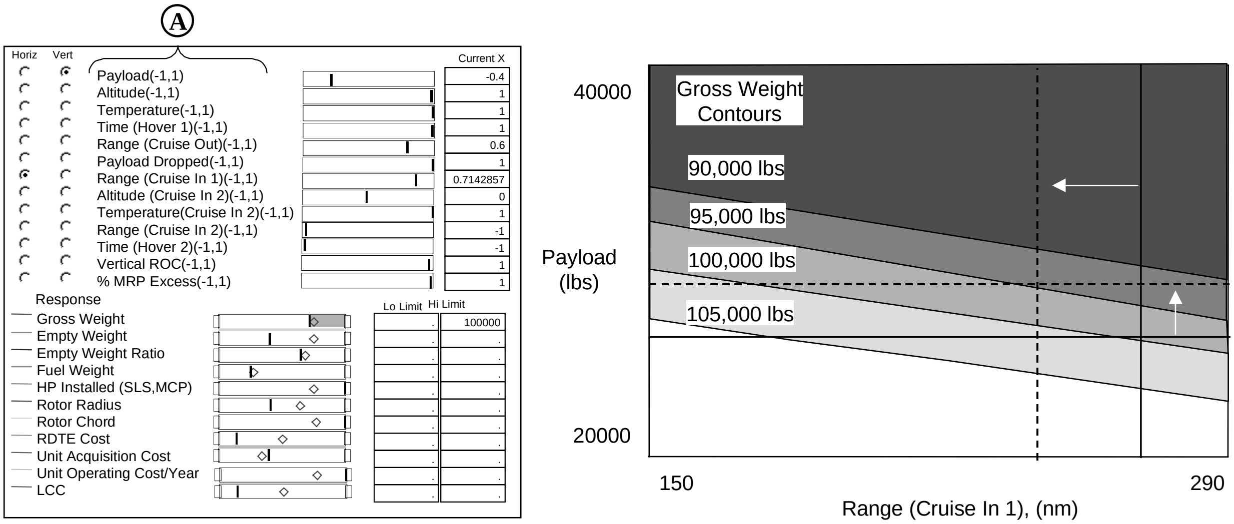


Figure 5: Bounding the Problem

When a shape function is prescribed as a uniform distribution, any value in the range is equally likely and the resulting CDF reflects the bounds of the requirement space. Figure 5 illustrates a bounding CDF for the FTR mission space. By placing targets on this chart, the probability of finding feasible solutions in the requirements space is indicated. For this example, if the designer places an upper limit of 100000 pounds on the vehicle's gross weight, there is a 75% probability of success. The designer must then decide the threshold for POS that is acceptable. If a 70000-pound limit is imposed (possible shipboard compatibility issue for carrier elevators) on the gross weight, this results in a very low POS. This low POS indicates the need to relax constraints or insert technologies in order to provide a feasible solution.



Horiz	Vert		Current X
○	●	Payload(-1,1)	-0.4
○	○	Altitude(-1,1)	1
○	○	Temperature(-1,1)	1
○	○	Time (Hover 1)(-1,1)	1
○	○	Range (Cruise Out)(-1,1)	0.6
○	○	Payload Dropped(-1,1)	1
●	○	Range (Cruise In 1)(-1,1)	0.7142857
○	○	Altitude (Cruise In 2)(-1,1)	0
○	○	Temperature(Cruise In 2)(-1,1)	1
○	○	Range (Cruise In 2)(-1,1)	-1
○	○	Time (Hover 2)(-1,1)	-1
○	○	Vertical ROC(-1,1)	1
○	○	% MRP Excess(-1,1)	1

Response	Lo Limit	Hi Limit
Gross Weight	.	100000
Empty Weight	.	.
Empty Weight Ratio	.	.
Fuel Weight	.	.
HP Installed (SLS,MCP)	.	.
Rotor Radius	.	.
Rotor Chord	.	.
RDTE Cost	.	.
Unit Acquisition Cost	.	.
Unit Operating Cost/Year	.	.
LCC	.	.

Figure 6: Dynamic Contour Plots & Mission Space Frontier

Another way to visualize the requirement space is through carpet plots in the form of dynamic contour plots provided in JMP. To further study the requirement space so as to understand its behavior and impact, such a dynamic contour environment has been constructed for the FTR and is presented in Figure 6. This screen is interactive and has the power of the response surface equations behind it. The left-hand portion of Figure 6 illustrates the control panel used to manipulate the dynamic contour plot. The top of this control panel shows the mission requirements that can be manipulated within the specified ranges (see Table 1). Any combination of these requirements (labeled A) can be used to view the space. This display is set to show payload versus the range for cruise-in segment 1. Notice that the ranges for the mission requirements are shown here on a –1 to +1 scale. This scale is used during the creation of the RSEs in order to preserve the orthogonality upon which the DOE is based. The limits of this range (-1, 1) simply correspond to the minimum and maximum values shown in Table 1. The bottom of the control panel indicates the responses which are available to track (each is color-coded) as well as the ability to place limits on the responses.

Normally, the display is shaded with the appropriate color for the response that is being violated. For example, any violations of gross weight would be shaded red and any violations of installed horsepower would be shaded green. The display in Figure 6 has been converted to grayscale for better viewing. Feasible space in the contour plots is indicated by white (or unshaded) space. The placement of the contour lines is controlled by the designer and aids in performing sensitivity studies. In addition, dots accompanying the contour lines indicate the direction of increasing response value (not visible in this rendering). In Figure 6, the dynamic contours have been set to show various gross weight contours. In this way the sensitivity of the system to changing gross weight limits is seen. By using the slide bars shown in the control panel for the requirement variables, the design space can be searched, in real time, to determine if the gross weight constraints can be satisfied as requirements are changed. The hairlines shown in Figure 6 correspond to the current setting of mission requirements as set in the upper part of the control panel (under Current). This setting violates the 100,000 pound gross weight limit. By moving these crosshairs, the current setting of payload and range is changed and the ability of the system to meet gross weight limits is seen in a highly visual manner. The slide bars for the responses are useful in depicting the magnitude of the violation. When the diamond falls within the shaded region the objective is violated and the distance to the unshaded region indicates the magnitude of the violation. In this case, the current requirement setting violates the gross weight limit only slightly, which is supported by the placement of the diamond close to the feasible boundary.

CONCLUSIONS

In this research, the authors have attempted to provide the design community with new tools and ideas, which will facilitate the design and acquisition process. The Unified Tradeoff Environment brings the influences of vehicle characteristics, technologies and mission requirements to bear in a real-time decision making environment. The Mission Space Model concept has been introduced along with some of its potential uses outside the UTE. Finally, as a proof-of-concept the approach discussed has been implemented to yield a tradeoff environment for the Future Transport Rotorcraft. This research has provided a highly visual, interactive environment for the study of the FTR. The reality of the modern design environment is the increasingly interactive nature of requirement and technology tradeoffs. This research provides a means to facilitate this tradeoff process.

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