Technology Infusion and Resource Allocation for a Civil Tiltrotor*

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Abstract

The methodology presented in this paper is concerned with the ability to make informed decisions early in the design time line in order to provide a feasible, viable and robust system to the customer. Increasingly, the issues of affordability, uncertainty in design and technology impact assessment are shaping the modern design environment. Current methodologies and techniques are not able to properly handle these issues. The research presented here builds on the authors' previous work which described an appropriate probabilistic design environment that allows for design in the presence of uncertainty as well as the infusion and assessment of new technologies. This environment is an essential part of a design methodology referred to as the Technology Identification, Evaluation and Selection (TIES) method. The objective of this research is to provide a comprehensive, structured, and robust methodology for decision making in the early phases of rotorcraft design. In this paper the authors will describe in detail the steps that encompass the TIES methodology. Illustrative examples of techniques, methods and tools used during the methodology will be presented as applied to NASA's Short Haul Civil Tiltrotor.

Introduction

The successful design of a complex system, such as a rotorcraft, has increasingly become an exercise in forecasting during the early design stages. Forecasting, with a high probability of success, the technical feasibility and economic viability of the system in the early design stages now appears to be the key driving indicator of success. This issue of forecasting in design is directly linked to the ability of the designer to make informed decisions in the early design stages. Yet, the decisions made in the modern design environment increasingly involve choosing new technologies or combinations of new technologies that will ensure system success as well as the decisions to allocate resources to develop needed technologies.

Traditional rotorcraft multidisciplinary design and analysis approaches are based on current engineering standards and practices as well as historical databases that limit the evaluation of non-evolutionary designs. Therefore, assessing the system attributes of a rotorcraft due to the infusion of an innovative technology and/or radical change in capability is difficult. The improvement or degradation caused by a new technology is often posed in the form of changes to appropriate discipline metrics. Rarely does the effect of a new technology uniquely link elementary design variables to system responses especially at the conceptual design level. Furthermore, the exact technology is often unknown and the only information provided is the constraint or objective that is being violated. Therefore, any new approach must provide a means to link discipline metrics to system responses to enable proper generic modeling of new technologies. What is needed is the ability to infuse new "breakthrough" technologies into the design process and evaluate their impact in terms of benefit, cost, and risk even before the time and expense of developing and maturing the technology is complete.

In References 1and 2, the authors described in detail the need and notion for an appropriate probabilistic design environment that allows for design in the presence of uncertainty as well as the infusion and assessment of new technologies. This environment is an essential part of a design methodology referred to as the Technology Identification, Evaluation and Selection (TIES) method developed at Georgia Tech.

In this paper the authors will present the steps that encompass the TIES methodology. Various probabilistic techniques will be discussed as well as the techniques and formulations which allow for technology infusion and resource allocation. NASA's

* Presented at the Vertical Lift Aircraft Design Specialist's Meeting, Holiday Inn, Fisherman's Wharf, San Francisco, CA, January 19-21, 2000.

Short Haul Civil Tiltrotor (SHCT) will be used to illustrate the application of the techniques and methods used in the TIES methodology. The failure or success of this vehicle will depend heavily on its affordability and represents an ideal platform for forecasting the impact of infused technologies.

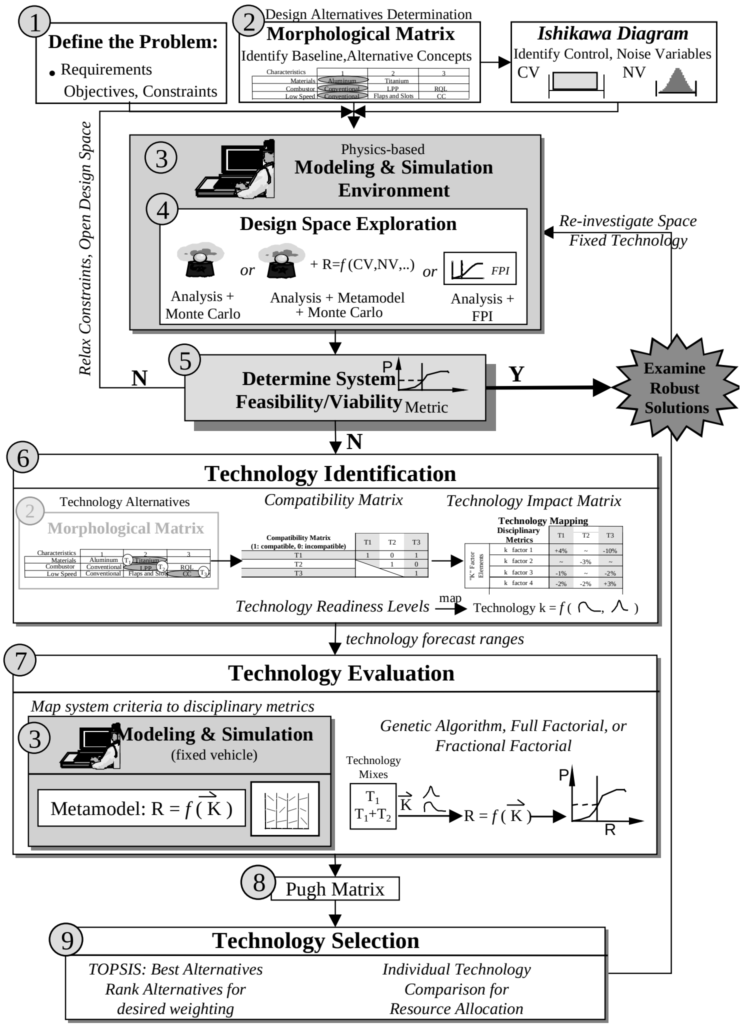

Figure 1: Technology Identification, Evaluation and Selection (TIES)[3]

The nine step process known as TIES provides the decision maker/designer with the ability to easily assess and balance the impact of various technologies in the absence of sophisticated, time-consuming mathematical formulations. This goal is achieved through the use of various probabilistic methods, such as Response Surface Methodology, Monte Carlo Simulations and Fast Probability Integration (FPI)[4]. Formalized techniques, borrowed from other scientific and engineering fields, are utilized to identify alternative concepts and aid in the decision making process. These techniques include Morphological Matrices[5], Pugh Evaluation Matrices[6], and Multi-Attribute Decision Making[7] methods. Through the implementation of each step, the best alternative for a given evaluation metric/criterion can be identified and assessed subjectively or objectively.

The TIES method contains nine steps for implementation[8]. Figure 1 illustrates the overall flow and coordination of the various techniques in order to provide identification, evaluation and selection of individual technologies or combinations of technologies. Details for each step and application to the NASA SHCT follow.

1. <u>Problem Definition</u>: Once the need for a new product is established, the designer must translate the qualitative needs and requirements of the customer into system product and process parameters. This process is facilitated through brainstorming techniques such as the Quality Function Deployment (QFD)[9] method. These techniques assist in defining the problem in terms of objectives, constraints and evaluation criteria. These system level metrics are used in subsequent steps to formalize the decision making process (Figure 1).

The baseline vehicle for this study is NASA's Short Haul Civil Tiltrotor (4/95 Baseline). The design mission consists of a 600 nm design range at a cruise speed of 350 knots with a 50 nm and 45 minute reserve mission[10] (1962 U.S. STA ATM Cond - Zero). After a screening test is conducted the design variables shown in Table 1 are retained as most influential while Table 2 indicates the objectives/constraints tracked. Note that all results presented are normalized with respect to the baseline values except where specifically mentioned.

Table 1 : Design Variables & Ranges (Normalized)

	Minimum	Baseline	Maximum
Wing Aspect Ratio	0.78	1.00	1.04
Wing Loading (lb/sq ft)	0.92	1.00	1.08
Tip speed (fps)	0.93	1.00	1.07
Propeller Diameter (ft)	0.93	1.00	1.10
Thrust coefficient /solidity	0.87	1.00	1.05
Economic range (nm)	1.00	1.00	3.00
Eng Scale Factor (MCP,Deg F)	0.99	1.00	1.07
Production quantity	0.80	1.00	1.20
Utilization (hrs/yr)	0.80	1.00	1.40
Manufacturer ROI (%)	0.67	1.00	1.33
Airline ROI (%)	0.50	1.00	1.50
Fuel cost ($/gal)	0.77	1.00	1.41
Load factor	0.92	1.00	1.46
Hull Insurance Rate (%)	0.20	1.00	2.00
Learning curve	0.98	1.00	1.10

Table 2: Objectives Tracked

Gross Weight
Empty Weight
Installed Power
L/D*Propulsive Efficiency
Disk Loading
Wing Area
500 Ft Sideline Noise
Direct Operating Cost (DOC)
Direct Operating Cost+Interest (DOC+I)
Required Average Yield Per Revenue Passenger Mile ($ / RPM)
Price / Installed Power

2. Baseline and Alternative Concepts Identification: The identification of alternative concepts is facilitated through the use of the Morphological Matrix. This matrix provides an orderly decomposition of the system into subsystems or attributes that are subsequently combined to create alternative concepts. In this way, no combination of subsystems or attributes is overlooked in providing the best solution to a customer's requirements. The feasibility investigation commences with the identification of a baseline vehicle that most often identifies the present-day technology level. An example Morphological Matrix for the SHCT is shown in Table 3. The shaded circles indicate the baseline vehicle for this research with baseline technologies applied. When any shaded oval is moved, this represents another alternative concept and may reflect the infusion of new technologies. These alternative concepts would populate the Pugh Matrix in Step 8.

Table 3: Morphological Matrix

Characteristics \ Alternatives	1	2	3	4
Configuration				
Wing	High Mount	Mid Mount		
Tail	T-Tail	Fuselage-Mounted	H-Tail	
Fuselage	Circular	Non-Circular		
Pilot Visibilty	Synthetic Vision	Conventional		
Seating	3-Abreast	4-Abreast		
Mission				
Range (nm)	400	500	600	
Passengers	30	35	40	
Cruise Speed	300	325	350	375
Rotor				
Configuration	Conventional	VDTR		
Blades/Rotor	3	4	5	
Hub	Articulated	Bearingless	Hingeless	
Propulsion				
Engine	Tilting	Non-Tilting		
Speed	Fixed	Variable		
Power	Normal	Derated		
Structural				
Materials	Aluminum	Composites	Combination	

3. Modeling and Simulation: A modeling and simulation environment is needed to quantitatively assess the metrics being tracked for the concepts identified in the Morphological Matrix. To facilitate the evaluation of many design alternatives and support sensitivity studies, conceptual design is most often performed with the use of monolithic or legacy synthesis/sizing codes. The method described in this paper does not abandon the accumulated knowledge represented by these codes but modifies their use to incorporate them into a probabilistic design environment and facilitate the assessment of new technologies.. The synthesis/sizing codes are, by nature, multi-disciplinary tools. Only the level of fidelity remains an issue. When the chosen synthesis/sizing code is deficient, the appropriate analysis capability is introduced in the form of higher fidelity tools, physics-based analytical models, simulation capabilities, etc. These capabilities are provided by directly linking the analysis or more preferably, by introducing the analysis capability in the form of metamodels.

In order to create the environment needed to analyze the various concepts for the SHCT, the synthesis/sizing code VASCOMP II[11] was enhanced. This enhancement provided the ability to properly model the baseline vehicle. In order to address economic concerns, the Tiltrotor Aircraft Life-Cycle Cost Analysis (TRALCCA) code was developed using NASA Ames' ALCCA as a framework. Newly developed modules for research, development, testing and evaluation (RDT&E) and production cost were incorporated and this analysis capability was integrated into VASCOMP II including the passing of all relevant outputs (weights, block speed, block time). This combined code allows economic analysis for the design mission and/or subsequent economic missions. Capabilities include manufacturer and airline cash flows, operating costs (DOC, DOC+I), required average yield per revenue passenger mile($/RPM), acquisition cost, internal rate of return, break-even units, etc. The tracking of all objectives and constraints is done using this combined analysis code.

4. Design Space Exploration: This step provides for the establishment of the probabilistic design environment and the creation of the design space. The design space is created based on the design variables (and their ranges) defined in Step 1. In probabilistic design, the outcome sought is either a cumulative distribution function (CDF) or a probability density function (PDF) for each design objective or constraint. These distributions represent the outcomes of every possible combination of synthesized designs and are a representation of the feasible design space. The decision maker can now compare the CDF or PDF to a target value or required confidence level. The generation of these distributions entails the linking of the analysis codes with statistical techniques. Fox[12] lists three methods that incorporate such complex computer programs in a probabilistic systems design approach:

- Link a sophisticated design code directly to a random number generator such as a Monte Carlo Simulation to obtain the PDF or CDF of all desired code outcomes
- Approximate the sophisticated analysis code with a metamodel (e.g. Response Surface) and link it with a Monte Carlo Simulation
- Link the sophisticated analysis code with an approximation of the Monte Carlo Simulation

In this study, the results shown are created using the Response Surface Methodology (RSM) and Monte Carlo Simulation option. Since this technique is used during several steps in the methodology, it is appropriate to provide an overview. RSM provides for the construction of Response Surface Equations (RSEs) that relate a response to chosen design variables. These RSEs approximate the results that would be obtained from the synthesis/sizing code. 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 a set of experiments or simulations. This is facilitated through the use of a Design of Experiments (DoE)[13] that provides a statistically efficient combination of experiments (simulations) necessary to collect the needed response data (Objective and Constraint values).

RSEs are created for all objectives/constraints as a function of the design variables for the feasibility assessment. The examination of the design space takes on a very graphical format in this methodology which gives the designer / decision maker a powerful tool for playing "what if" games with the design space. As previously mentioned, the design space is represented by the CDF generated for each system metric. Through the use of inexpensive commercial-off-the-shelf software, including the statistical computer package, JMP[14] and the Monte Carlo Simulator, Crystal Ball[15.]; the CDFs are easily created. The JMP package also provides interactive visualizations of the design space in the form of prediction profiles and contour plots. These various visualization techniques will be introduced during various steps for illustrative purposes.

5. Determination of System Feasibility: Once the target value for a specific metric is identified, concept feasibility is evaluated via the appropriate CDF by overlaying the target value. The CDF provides a plot of the metric value versus the probability of feasibility (success). The intersection of this target value with the CDF identifies the probability of success or confidence one has in achieving the imposed target. The decision maker can then impose a confidence level which must be met in order to consider the metric effectively satisfied. This process facilitates the identification of active constraints (i.e. metrics which do not meet the imposed confidence level). If no constraints (either technical or economic) are active then the system is feasible and viable and the designer can proceed to examining robust solutions. Relieving active constraints can be accomplished by relaxing the target value, relaxing the required confidence level or manipulating design variables within their ranges. When these techniques are ineffective, the infusion of new technologies is the only recourse.

The cumulative distribution functions representing the SHCT design space are shown in Figure 2 with the baseline values indicted as 1.0 on the abscissa. Target values can be applied to these plots to identify the constraint that provides the most difficulty. For example, say the designer wanted to limit the gross weight to 95% of the baseline value or the installed power to 80% of the baseline value. Figure 2a and Figure 2b indicate there is less than a 10% probability of success of attaining these targets with current technology. Thus, technologies that affect weight and engine power would become possible areas for technology infusion. Considering the influence of affordability on a civil tiltrotor, one might look at an economic metric such as DOC+I. This metric includes direct operating costs such as fuel cost, crew cost and maintenance cost as well as the cost of ownership (depreciation, hull insurance, financing). Figure 2d indicates that the probability of feasibility for the baseline is less then 50%. Thus, any decrease in DOC+I, which is likely needed for system viability, is improbable in the current design space and requires the infusion of new technologies interactive and has the power of the response surface equations behind it. It allows manipulation of design variables within the specified ranges and the placement of limits on design objectives. Although difficult to see in grayscale, the display is shaded with the appropriate color for the objective/ constraint that is being violated.

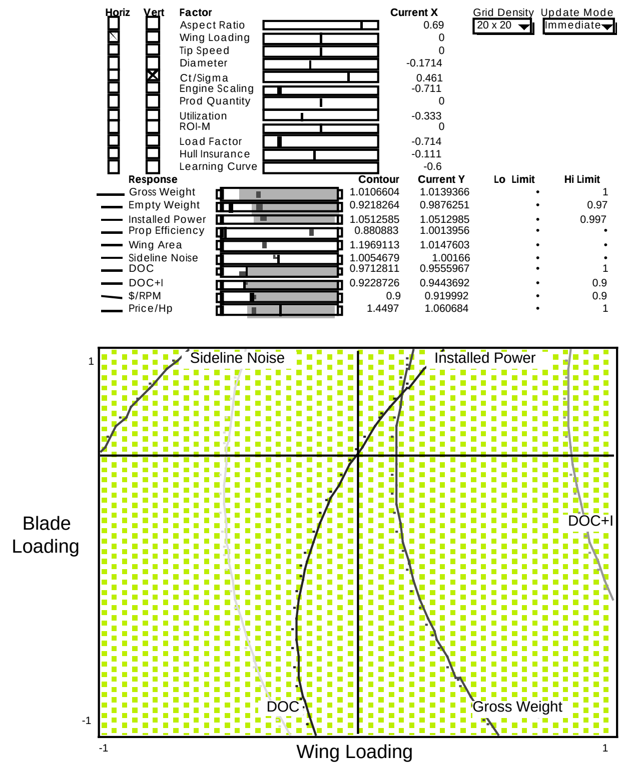

Figure 3: Visualization of Design Space

By using the slide bars for the design variables, the design space can be searched, in real time, to determine if the constraints can be satisfied by manipulation of the design variables. Feasible space in the contour plots is indicated by white (or unshaded) space. The slide bars for the objectives / constraints are useful in depicting the magnitude of the violation. When the dots fall within the shaded region the objective is violated and the distance to the unshaded region indicates the magnitude of the violation. The contour lines shown in Figure 3 are for illustrative purposes only. The placement of the contour lines is controlled by the designer and aids in performing sensitivity studies. Likewise, the dots accompanying the contour lines indicate the direction of increasing metric value. The design variables in this plot are presented on a scale from –1 to 1 which correspond to the low and high limits, respectively, of the range assigned to that variable.

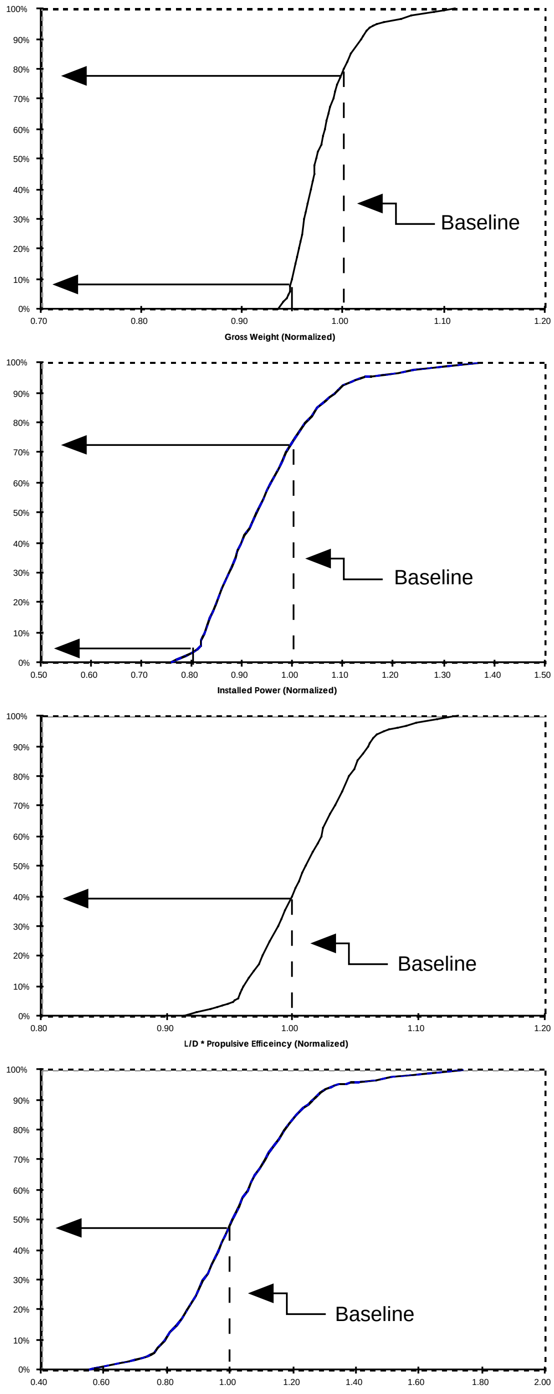

Figure 2 : Design Space Representation With Baseline Technologies Applied

Another way to visualize the design space is through carpet plots in the form of contour plots provided in JMP. An example of this presentation is given in Figure 3 for the SHCT. This screen is

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If the design space exploration indicates the need for technology infusion then Steps 6-9 are executed. As mentioned earlier, formulation of new technologies in terms of elementary variables does not lend itself to disciplinary or multidisciplinary technology assessment. Hence, the assessment of new technologies must be addressed through the metrics they affect. The solution is to model and define technology metrics for the new technologies as a delta with respect to current technology based on expert opinion. In practical terms, technology metric "k" factors are introduced into the analysis or sizing tool to infuse a hypothetical enhancement or degradation associated with the new technology. In effect, the "k" factors simulate the discontinuity in benefits or penalties associated with the addition of a new technology.

This formulation is known as the Technology Impact Forecasting (TIF) environment and provides the means to assess technologies or combinations of technologies needed to overcome technical and economic barriers in the system design. This is accomplished by creating relationships (i.e. RSEs) which relate system level objectives and constraints not to design variables but to the metric "k" factors themselves. This generality allows for the implementation of individual technologies, combinations of technologies (assuming additive property of technology "k" vectors) or simply the identification of metric improvements that will provide the best solution. These metric improvements are then used to identify potential technologies or combinations of technologies. For more details on this topic, the reader is referred to Reference 2.

For the purposes of this study, the assumption is that this generic environment will be used to assess the impact of preconceived technologies. Most likely, these technologies will be part of an S & T (R & D) program within the government (industry). Providing the decision maker/designer with the ability to forecast the impact of technologies on system level metrics and make informed decisions for resource allocation purposes is accomplished through application of Steps 6-9.

6. <u>Technology Identification:</u> Once the specific technologies are identified, the designer/decision maker must establish compatibility rules between technologies as well as the impact each technology will have on technical metrics (i.e. to allow proper modeling of the technology). The technologies used for this study include IHPTET II engines, contingency power, advanced drive system, download reduction, active twist rotor and composite fuselage. Compatibility rules are formalized in the Compatibility Matrix, which identifies the number of technology combinations that are physically realizable. This matrix is best prepared by a multi-disciplinary team (IPT perhaps) that understands the potential benefits and downfalls of the prescribed technologies. The Compatibility Matrix for the technologies mentioned above is shown in Figure 4.

Compatibility Matrix **(1: compatible, 0: incompatible)**	IHPTET II Engine T1	Contingency Power T2	Advanced Drive System T3	Download Reduction T4	Active Twist Rotor T5	Composite Fuselage T6
IHPTET II Engine	1	1	1	1	1	1
Contingency Power		1	1	1	1	1
Advanced Drive System			1	1	1	1
Download Reduction				1	1	1
Active Twist Rotor					1	1
Composite Fuselage						1

Figure 4: Compatibility Matrix

Notice that all technologies are considered physically compatible (denoted by 1). Incompatible technologies can arise from conflicts in integration, manufacturing or in simple function. Placing an active twist rotor system and a dynamically slotted rotor on the same aircraft would not be appropriate and would be considered incompatible technologies in this context. Even the technologies identified for this study could lead to incompatibilities since they have purposely been generalized. If the different methods for achieving contingency power or download reduction are compared individually then incompatible technology combinations would arise since two technologies would be serving the same function.

Once the Compatibility Matrix is created, the impact of each technology is modeled by creating a technical metric "k" vector that accounts for the primary benefits as well as the secondary penalties associated with the infused technology. These "k" vectors are then combined in the Technology Impact

Matrix (TIM). The TIM for the six prescribed technologies is shown in Figure 5. This TIM is constructed based on a literature review of applied research and expert opinion. It reflects the impact the technologies would have when matured to the point of full-scale application. Each technology “k” vector consists of 16 elements and is unique to the technology. The “k “ vector includes primary benefits and secondary penalties. For example, the active twist rotor increases the hover and propulsive efficiency by 5%. However, the rotor weight is increased by 8% due to structural and electrical components needed while the electrical system weight requires a 30% increase. In addition to these weight penalties, the costs associated with manufacturing and maintaining this rotor system is simulated by decreased utilization hours and increased Research, Development, Testing and Evaluation (RDT&E), production and Operation and Support (O & S) costs.

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Technical K_Factor Vector	IHPTET II Engine T1	Contingency Power T2	Advanced Drive System T3	Download Reduction T4	Active Twist Rotor T5	Composite Fuselage T6
Fuel Flow	-20%					
Hover Efficiency					5%	
Propulsive Efficincy					5%	
Download				-50%		
Contingency Power		30%				
Fuselage Drag				2%		-2%
Wing Weight				2%		
Fuselage Weight						-3%
Rotor Weight					8%	
Drive System Weight			-10%			
Engine Weight	-4%	10%				
Electrical System Weight	3%				30%	
Utilization	5%		3%		-2%	-2%
RDT&E	4%	2%	0.50%	+2%	1.89%	10%
Production costs	-3%	1%	1%	+2%	2%	5%
O & S costs	-3%	-2%	+3%	+5%	2%	2%

Figure 5: Technology Impact Matrix

7. __Technology Evaluation:__ The technologies identified in Step 6 are applied to a baseline vehicle and evaluated. The designer is looking for the combination of technologies that will satisfy the customer requirements. When a significant number of technologies are assessed simultaneously and all technologies are compatible, the combinatorial problem can become computationally expensive. For n technologies and assuming only an “on” or “off’ setting for each technology, then 2^n combinations exist. However, the technique used in this method

Table 4: "k" Factor Bounds

Technical Metric "k" Factors	Minimum (%)	Maximum (%)
Fuel Flow	-40%	+10%
Hover Efficiency	-5%	+10%
Propulsive Efficincy	-5%	+10%
Download	-50%	+5%
Contingency Power	11.9%	31%
Fuselage Drag	-20%	+5%
Wing Weight	-20%	+10%
Fuselage Weight	-30%	+5%
Rotor Weight	-20%	+10%
Drive System Weight	-10%	+10%
Engine Weight	-50%	+10%
Electrical System Weight	-10%	+50%
Utilization	-20%	+20%
RDT&E	-20%	+20%
Production costs	-20%	+20%
O & S costs	-20%	+20%

helps mitigate this problem. A metamodel (second-order RSE) is created for each objective/constraint as a function of the 16 elements, which comprise the technical “k” vector. Thus, each of the technology combinations can be assessed rapidly by providing the aggregate technical “k” vector for use in a simple second order polynomial of the form described in Equation 1. The RSEs are created by placing bounds on the elements contained in the TIM and executing a Design of Experiments. The bounds placed on the ”k” vector elements for the six technologies used in this study are shown in Table 4. The bounds are set large enough to accommodate multiple technologies and varying impacts (benefit or penalty).

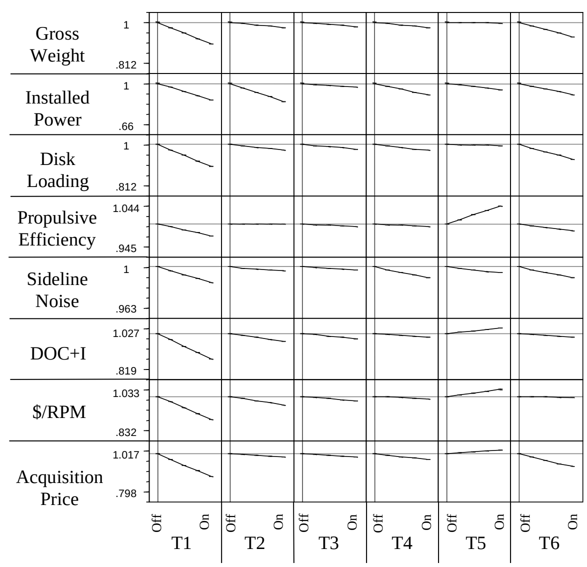

Figure 6 : Full-Factorial Technology Investigation

As a visual aid to the decision maker, a full factorial investigation was conducted and is shown in Figure 6 in the form of prediction profiles. This is a fully interactive environment that allows the designer to apply technologies individually or in combination. This environment is created using metamodels that relate the system metrics to the technologies themselves (i.e. the technology "k" vector). This environment is interactive and allows real time updates of the system metrics as well as the sensitivities (i.e. slopes) as technologies are applied. The decision maker is able to identify which technology has the most impact on a given system metric.

8. <u>Population of the Pugh Evaluation Matrix</u>: The Pugh Evaluation Matrix provides an organized technique for gathering the data required to choose a best alternative. It is populated with numerical values for the evaluation criteria identified in Step 1 (rows). This data is provided for each of the technology combinations (columns). This data is derived from the feasibility assessment previously described with a fixed confidence level imposed by the decision maker. This process is repeated for each metric and concept. It should be noted that the Pugh Evaluation Matrix, as originally conceived, is aimed at decision making under subjective terms when numerical data was unavailable. The matrix is populated based on a subjective scale determined by experts in the system (e.g. Integrated Product Team). The same nomenclature is used in this research although its use is not strictly correct.

9. <u>Technology Selection</u>: The creation of the Pugh Matrix illustrates the complex multi-criteria decision making environment in which the best alternative is chosen. For the purpose of the TIES methodology, a Multiple Attribute Decision Making (MADM) technique known as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is utilized. TOPSIS provides an indisputable preference order of the solutions obtained in the Pugh Matrix resulting in the best alternative concept. This best alternative is established as described below:

- Nondimensionalize each criterion for a given alternative by the norm of the total outcome vector
- Establish relative importance for each criterion through subjective weightings
- Classify each criterion as a benefit or cost to the system
- Establish positive and negative ideal solution vector
- Determine Euclidean distance of each alternative relative to both the positive and negative ideal solution
- Rank alternative concepts based on closeness to positive ideal solution and distance from negative ideal solution

In this way, the TOPSIS method is used to identify the best mix of technologies for a given weighting scenario. For presentation purposes, an Overall Evaluation Criteria (OEC) is used to compare the technology mixes to the baseline vehicle. The OEC is shown below.

$$OEC = w_1 \frac{Weight}{Weight_{BL}} + w_2 \frac{Power}{Power_{BL}} + w_3 \frac{Loading}{Loading_{BL}} + w_4 \frac{\Pr opEff_{BL}}{\Pr opEff} +$$

$$w_5 \frac{Noise}{Noise_{BL}} + w_6 \frac{DOC + I}{DOC + I_{BL}} + w_7 \frac{\$/RPM}{\$/RPM_{BL}} + w_8 \frac{Acq\$}{Acq\$_{BL}}$$

The TOPSIS method and the TIES formulation allows the decision maker to simultaneously assess the impact of technologies for both performance and cost metrics. Different weighting scenarios can be used to vary the emphasis from performance driven to economic driven or anywhere in between.

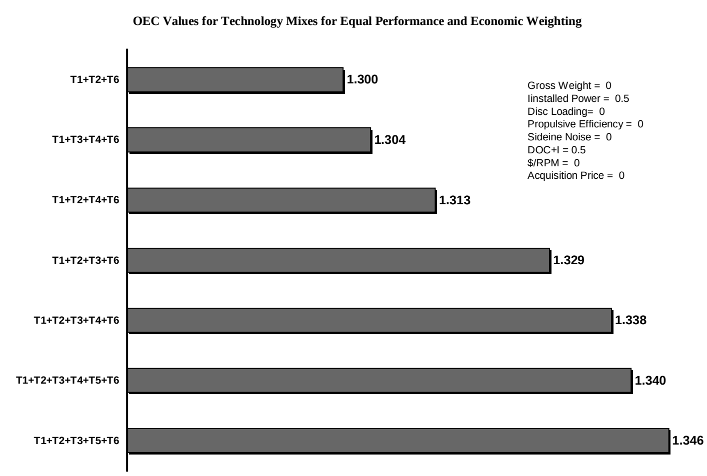

Figure 7 : Technology Evaluation - Equal Performance and Economic Weighting

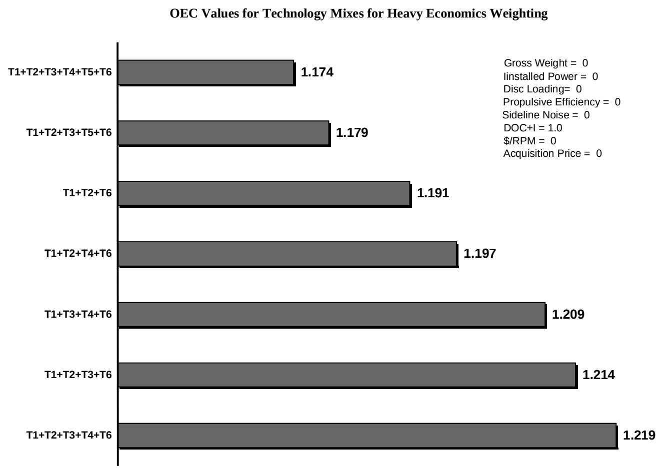

Figure 8: Technology Evaluation: Heavy Economic Weighting

Figure 7 and Figure 8 illustrate the results for the TOPSIS/ OEC evaluation. This format provides the decision maker with the ability to compare technology mixes. For each weighting scenario the same technologies are prevalent. The IHPTET II engines, contingency power and composite fuselage are among the best mixes irrespective of the weighting scenario.

The TOPSIS method provides the best technology mix, however, the resources may not be present to invest in all the technologies needed. Hence, a decision maker is interested in the technology which is most influential for overcoming constraints or meeting goals for resource allocation purposes.

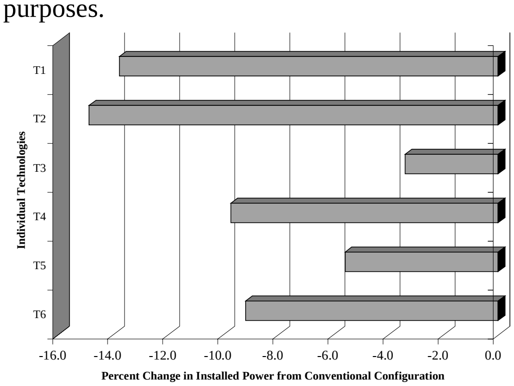

Figure 9: Resource Allocation - Installed Power

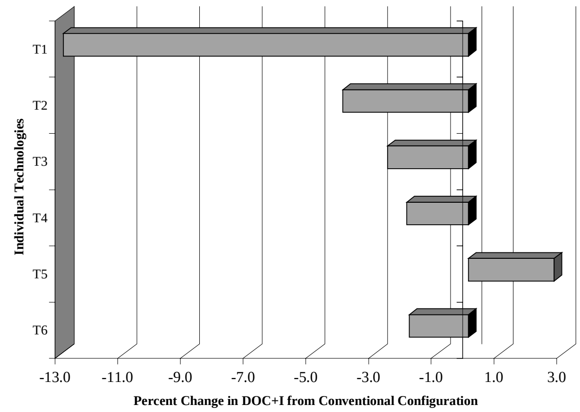

Figure 10: Resource Allocation -DOC+I

A resource allocation investigation is performed by infusing individual technologies into the baseline vehicle and evaluating the changes in system metrics. Figures 9 and 10 illustrate the comparisons made for installed power and DOC+I respectively. If resource allocation is based on installed power, either of the engine technologies provide at least a 14% reduction with contingency power providing the most influence. Since the SHCT's success will be driven by economic viability, it is prudent to look at economic metrics such as DOC+I. This metric overwhelmingly favors the IHPTET II engine technology. When all metrics are examined, the decision maker can make an informed decision for allocating resources to develop technologies.

Concluding Remarks

The Technology Identification, Evaluation and Selection methodology is a nine step process which facilitates the making of informed decisions in the early design stages. The application of this method to NASA's Short Haul Civil Tiltrotor has demonstrated the unique capability to assess the impact of new technologies. Through the use of inexpensive commercial statistical packages, the methodologies created and implemented under this research have provided the decision maker with tools beyond the state-of-the-art. The graphical nature of this method allows the conceptual designer and/or decision maker to analyze the feasibility and viability of a complex system as well the impact of new technologies from a benefit/cost point of view. The ability to assess technology mixes is demonstrated and a means for resource allocation introduced.

Acknowledgments

The work presented in this paper is supported partially under Task 9.2.1 for the National Rotorcraft Technology Center (Contract No. NCC-2-945) and partially under a grant for the Office of Naval Research (Contract No. N00014-97-1-0783) to support the Affordability Measurement and Prediction Initiative. The authors would like to thank the Systems Analysis Branch at NASA Ames as well as Ms. Michelle Kirby for their assistance.

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