METHODOLOGY FOR EXAMINING THE SIMULTANEOUS IMPACT OF REQUIREMENTS, VEHICLE CHARACTERISTICS, AND TECHNOLOGIES ON MILITARY AIRCRAFT DESIGN

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Abstract

The process of systems engineering has always emphasized the definition of requirements as the first step toward product development. Typically, however, these requirements were examined in isolation from the potential systems and technologies they would likely impact. Further, requirements were treated deterministically during design, which sometimes led actual systems that were non-robust when different requirements were encountered. Thus, there is a need to examine requirements early on and in a new way. This "new way" must include an environment for the simultaneous examination of requirements, design variables, and technologies. Further, this environment must be built in a probabilistic fashion since the requirements may be ambiguous and/or uncertain, the eventual cost and performance of critical technologies are highly uncertain, and the possibility of system "growth" must be accounted. The ultimate goal of the probabilistic approach is finding solutions robust to these uncertainties. A methodology for the creation of just such an environment is described in this paper. Subsequently, the implementation of the methodology is demonstrated through an example study of a notional, multi-role fighter aircraft. Important visualization and probabilistic analysis techniques are highlighted. The approach is found to be extremely valuable, especially in light of the recent initiation of several major programs in the aerospace sector which exhibit the challenges of joint service requirements, the need for advanced technologies, and an increasing emphasis on affordability.

1 Introduction and Background

Increasing attention is being placed on improving aerospace system design and acquisition processes in order that they better achieve *affordable* products. In general terms, affordability is a measure of value, typically involving the combination of operational effectiveness, cost, and schedule considerations. Thus, research oriented toward affordability improvement often begins with the definition of a set of measures and targets for the affordability components (effectiveness, cost, schedule) and subsequently "optimizing" the product (e.g. wing shape), the process (e.g. wing production procedure) or technology set (e.g. wing flow control). At the 1996 ICAS, Mavris and DeLaurentis (Ref. [1]) addressed an important new technique in aircraft synthesis by demonstrating the usefulness of response surface methodology (RSM) for design space modeling and aircraft optimization. At the 1998 ICAS (Ref. [2]), the same authors extended this idea to modeling the need for and predicted impact of critical technologies for systems that were not feasible or viable with current technology. This was accomplished through the introduction of a five-step probabilistic process

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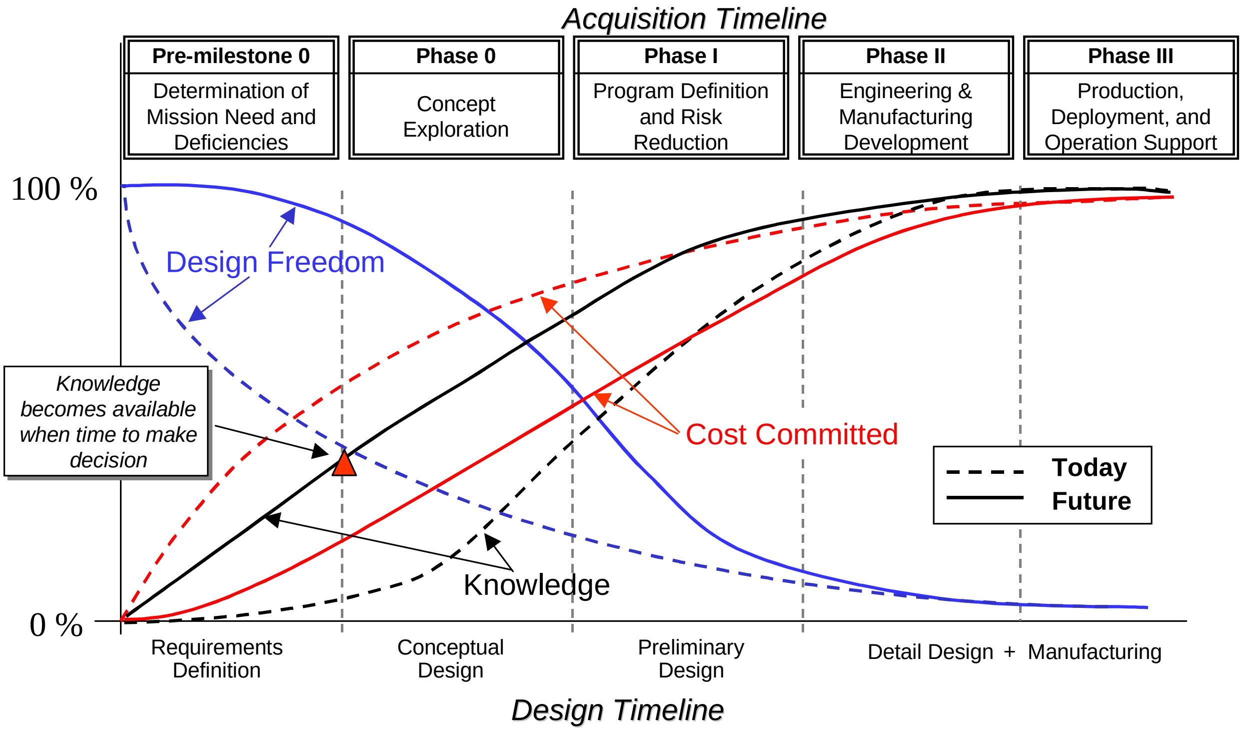


Figure 1: The relationship of design freedom, knowledge, and cost committed

for examining system feasibility and viability. However, the definition of the affordability component measures and targets that drove these studies are dependent on the subjective opinion of the customer/user, i.e. the requirements. These requirements are often ambiguous and typically change over time. *Therefore, understanding the simultaneous impact of requirements, product design variables, and emerging technologies during the concept formulation and development stages is critically important, and until now elusive.*

The creation of such an understanding would significantly facilitate the trade-off determination process and the early design activities, as illustrated in Figure 1. When one begins to consider requirements, it is natural to think both about the acquisition timeline and the design timeline since they are similar in several respects. As depicted in Figure 1, in traditional practice employed today, the establishment of fixed, firm, or arbitrary requirements immediately reduces the options for design (design freedom) while at the same time committing a significant portion of the eventual cost for the program. This is often done with minimal knowledge (especially quantitatively) of the interplay between the requirements, possible concepts (normally studied later in conceptual design), and technologies. The capture of this interplay represents valuable *new knowledge*, which can in turn allow for more design freedom to be maintained and better decision-making during acquisition. A newly developed approach for creating this understanding is the subject of the research reported in this paper.

There appears to be an urgent need for such methods in the aerospace sector, especially since many future systems are envisioned to have “joint” service requirements and a heavy emphasis on affordability. Joint requirements are always a challenge since there is a risk that compromises for “the many” result in a vehicle useful or affordable to nobody. On the other hand, joint requirements can spur the examination of technologies or concepts not otherwise considered. Several current or impending programs are prime examples. At NASA, planning is underway for a 2nd (and 3rd) Generation Reusable Launch Vehicle (RLV), envisioned to be designed, built, and operated commercially but able to satisfy unique NASA requirements. Such a scenario is a clear challenge indeed, when one considers the typical uncertainty in government spending profiles and the industry's increasing aversion to risk. The current international Joint Strike Fighter (JSF) program and the proposed U.S. Army/Navy Joint Transport Rotorcraft (JTR) program are examples from the military realm of problems with aggressive joint requirements and affordability goals. Further, these programs are proposed in the midst of the formation of new acquisition guidelines in the U.S. Department of Defense (DoD) 5000 Series Acquisition guide updates. These updates call for a new role for systems engineering, with emphasis on open systems and robustness.

1.1 Reachability

In Ref. [2], a comprehensive method for achieving system feasibility and economic viability was established. The underlying theme of that approach is "how do we get 'there' from 'here'?". This idea is termed *reachability*. In general, one can reach program goals (or create a "fit system", or "reach the aspiration space") by affecting one or more of three sets of items: design variables, evolutionary technologies, and revolutionary concepts. This idea of reachability is shown in Figure 2, with two requirements representing the measures of fitness and their associated thresholds defining an "aspiration space". In most cases, the easiest and most efficient means to achieve modest improvements is through incremental changes of existing design variables. This amounts to fine-tuning of an existing concept through optimization or growth (simple scaling) and is represented by the dark green shaded area in the lower, left portion of Figure 2. More aggressive improvements, however, demand the additional assistance of evolutionary technologies. The term evolutionary implies that the fundamental system concept is unchanged, but new and better technologies for subsystems are employed. An improved reach toward the thresholds results from this process, depicted in Figure 2 by the lighter green shaded region. The boundaries of each of these first two regions can be thought of as "Pareto fronts", or the locus of non-dominated solutions in each case.

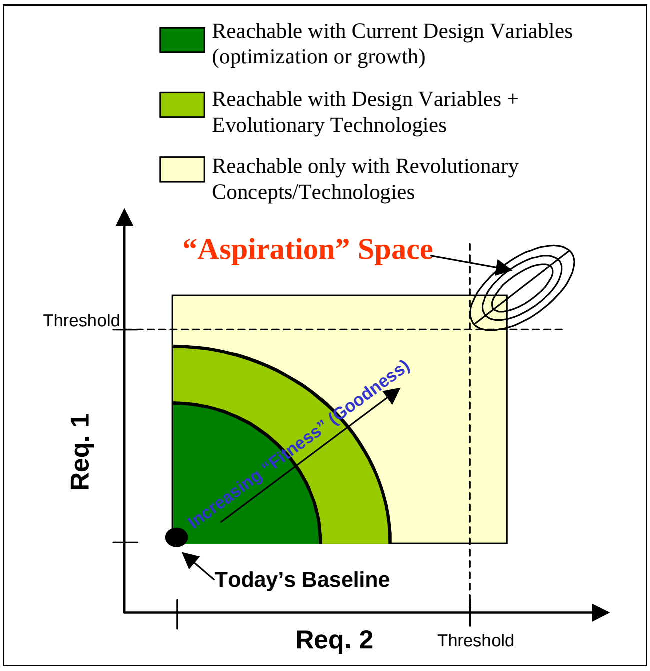


Figure 2: Notion of reachability

If yet further improvements in the "desirement space" are necessary, revolutionary concepts are required. Here, the concept itself is fundamentally changed. This is represented by the lightly shaded, outer region in Figure 2. For example, the transition from propeller driven aircraft to jet for high-speed flight was a revolutionary concept. The invention of the airplane itself as a mode of transportation is an even more striking example. Design variable changes and evolutionary technologies represent a form of local search, while these revolutionary concept changes represent large "jumps" on the landscape of a system's fitness. Of course, when one of the elements of the fitness measure is the actual research and development cost to reach a certain point in the landscape, the level of difficulty of the problem is increased. As a final thought, a fourth option, re-examining the requirement targets themselves, should not be overlooked. Solutions lying just outside the "border" of viability may switch rapidly to the viable region with a small relaxation of a single requirement.

The feasibility/viability method presented in Ref. [2] was the first step towards tackling these challenges, while the results of this paper can be viewed as only a second step. Clearly, much more research is required to fully understand the dynamics of reachability, but the potential benefits certainly merit the work.

2 Method Description

2.1 Mathematical Modeling

Key parameters in the method are divided into responses (those values typically associated with measures of effectiveness) and inputs (those values that typically drive the search). Responses include requirements, desirements, and constraints. *Requirements* are thresholds on performance or cost metrics that *must* be satisfied (e.g. Mission Radius must be 500 nm). *Desirements* are metrics that are desired to be maximized or minimized to delineate between competing alternatives which satisfy the requirements (e.g. minimize O&S fleet costs). *Constraints* are limits imposed either by nature, operational environment, government regulations, communities, market, etc. (e.g. a carrier-based aircraft must have a resultant speed below an upper limit for safe operations). Inputs include concept design variables, requirements, and technology k-factors. *Concept design variables* are configuration parameters that define a concept (including economic inputs). *Requirements*, defined above, can also be treated as inputs in this method, depending on the problem at hand. *Technology k-factors* are parameters that simulate the affect of technologies through a change in a disciplinary metric that produces a step change in responses.

The method is founded fundamentally on the assumption that a parametric mathematical model that relates changes in requirements, design variables, and technology k-factors of a system to overall desirements (measures of goodness) can be constructed. Normally, such relationships are computed through sizing/synthesis codes that combine vehicle characteristics, a prescribed mission, and a technology-level assumption (usually in the form of entry-to-service date) to produce vehicle size, weight, and performance estimates. The parametric mapping is constructed through the use of metamodels, specifically through the formation of Response Surface Equations (RSEs) based on the actual aircraft sizing and synthesis codes

The process begins by having an appropriate team of designers, analysts, and technologists construct a set of desirements (***D***), a set of possible requirements (***RQ***), design and economic variables (***DV***) that characterize a concept, and technology k-factors ($\boldsymbol{k_T}$). A baseline concept within this combined space is also chosen as a datum. Next, the Design of Experiments (DOE) technique is used to define three separate sets of simulations that need to be conducted in order to generate data for regression of the three sets of RSEs. These response equations capture the change in a desirement, ΔD_i, with respect to changes in either requirements, design/economic variables, or technologies, respectively. The typical, generic functional form for each is displayed in Eqs. (1-3). When varying the requirements, the design/economic variables and technologies are held fixed at baseline values. Likewise, when forming the technology equations, the requirements and vehicle characteristics are fixed. Finally, the requirements and technologies are fixed for the vehicle equations. The b_o term is the intercept, which is the value of the response with all inputs at their nominal values.

$$\begin{aligned}\Delta D_{Req} &= (b_0)_{Req} + \sum_{i=1}^{k} b_i RQ_i + \sum_{i=1}^{k} b_{ii} RQ_i^2 \\ &\quad + \sum_{i=1}^{k-1}\sum_{j=i+1}^{k} b_{ij} RQ_i RQ_j\end{aligned} \tag{1}$$

$$\begin{aligned}\Delta D_{Tech} &= (b_0)_{Tech} + \sum_{i=1}^{k} b_i k_{Ti} + \sum_{i=1}^{k} b_{ii} k_{Ti}^2 \\ &\quad + \sum_{i=1}^{k-1}\sum_{j=i+1}^{k} b_{ij} k_{Ti} k_{Tj}\end{aligned} \tag{2}$$

$$\begin{aligned}\Delta D_{Con} &= (b_0)_{Con} + \sum_{i=1}^{k} b_i DV_i + \sum_{i=1}^{k} b_{ii} DV_i^2 \\ &\quad + \sum_{i=1}^{k-1}\sum_{j=i+1}^{k} b_{ij} DV_i DV_j\end{aligned} \tag{3}$$

The three sets of regression equations are then aggregated into an overall expression for changes in desirements as a function of requirements, design/economic variables, and technology improvements, as shown in Eq. (4). For the purposes of visibility and creation of decision-support tools, it is assumed that the three sets of RSE inputs are independent (and thus un-correlated) from each other. Thus, their contributions are considered to be additive. However, subsequent confirmation testing is employed to check the validity of this assumption. If some variables are dependent, one possible solution is to identify mixes of design variables, requirements, and technology factors that are independent and then create three "mixed" set of RSEs. This route is under current study.

$$D_i = (b_0)_{overall} + \Delta D_{Req} + \Delta D_{Tech} + \Delta D_{Con} \qquad (4)$$

2.2 Representation of Results

RSEs are often examined through prediction profiles. In the prediction profile environment, the sensitivity of each response to each input is displayed as a curve that depends on all other inputs. A change in the value of one input variable affects its own sensitivity on responses, but also that of all other inputs due to the interaction term in the RSEs. A notion of the profile environment for the equation set Eqs. (1-3) is given in Figure 3.

These profiles are viewed in an interactive decision-support tool, which allows a user to adjust each component and immediately see the impact on the desirements, achieving real-time sensitivity analysis. Further, a tool called the contour profiler that is based on the same equations can be used for the real-time exploration in a graphical setting. Snapshots of this powerful graphical tool are provided later in the proof-of-concept implementation.

Within this unified environment, the challenge of analyzing complex aerospace systems with joint requirements and multi-role capabilities is approached in two ways. The first approach, documented in this paper, employs the two-tiered concept of one primary mission and subsidiary alternative missions. In the execution of the multiple analysis runs required to form the RSEs, the primary mission is used to size the vehicle. Subsequently, this sized vehicle solution is analyzed for alternative missions. Fallout performance for these analyses is recorded and tracked as desirement responses. Thus, primary mission requirements are regressed variables and secondary mission requirements are responses (along with the primary goals), forming an environment that allows for requirement trade-off. In fact, this can be done through the use of the contour profiler to trade requirements vs. goals graphically and in real time.

When the variety of missions to be satisfied have sufficient similarity in structure, a more elegant approach is envisioned. In this setting, "mission types" themselves (e.g. for a maritime fighter, air superiority, all-weather attack, close air support) are employed as regressor variables. Thus, a designer can "tune in" a mission in the prediction profile environment and determine the responses in real

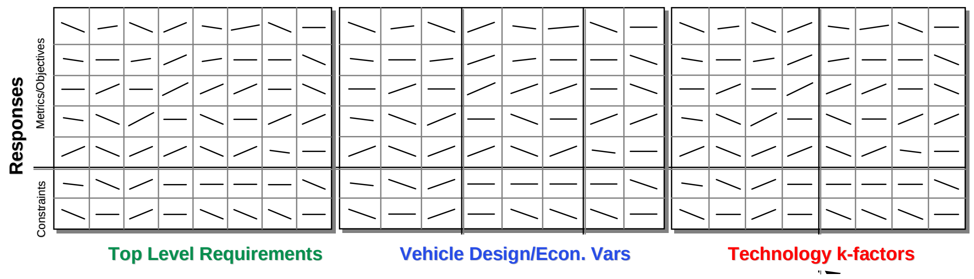
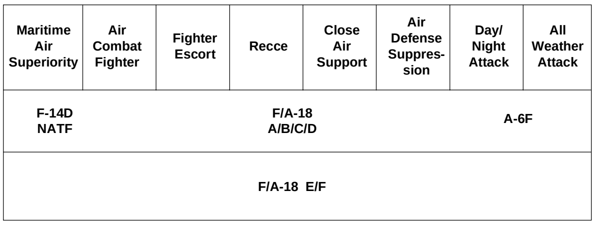


Figure 3: Unified environment for design sensitivities

time. This idea is not taken further in this paper, though it is under current study by the authors.

3 Proof of Concept Implementation

The approach is demonstrated on a notional, multi-role, carrier-based aircraft, similar in several respects to the development of the U.S. Navy's F/A-18E/F. In this application example, the goal is to understand the possible avenues for expanding the mission envelope for an existing aircraft while keeping development cost close at hand. Such a capability expansion drove the F/A-18E/F development as illustrated in Figure 4 from Ref. [3]. In the present example, emphasis is placed on illustrating the underlying modeling principles as well as the several ways in which the resulting set of non-linear RSEs can be used to assess affordability and associated trade-offs in a probabilistic fashion.



Ref. Young, et.al. AIAA-98-4701, 1998.

Figure 4: F/A-18E/F as an example of mission requirements expansion

3.1 Construction and Validation of Baseline Aircraft

Construction of the environment begins with a set of baseline mission requirements and a baseline aircraft configuration. This is the starting point from which the combined environment is constructed, and it is represented by the $(b_o)_{overall}$ term in Eq. (4). In the present case, to illustrate the process of modeling multiple, joint and/or conflicting requirements, a primary mission akin to the all-weather attack extreme of Figure 4 is constructed and shown in Figure 5. A secondary mission akin to the air superiority role (the other extreme in Figure 4) is also constructed and shown in Figure 6.

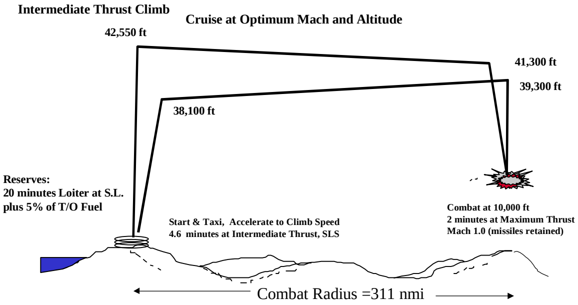


Figure 5: Primary mission- (Attack)

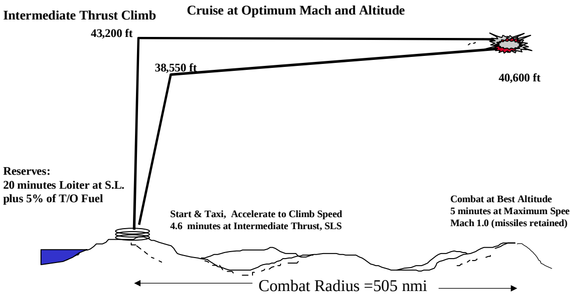


Figure 6: Alternate mission- (Air Superiority)

In the following analysis, the aircraft is sized according to the primary mission and subsequently "flown" on the secondary mission to record the fallout performance. The responses to be tracked include desirements and constraints associated with affordability. These are summarized in Table 1.

Table 1: Responses for multirole, carrier-based system

Desirements	
$RDTE	Research, develop., test, & evaluation cost
$\$1^{st}\ Unit$	The production cost of the first unit
$O&S	Operations & support cost for fleet
TOGW	Take-off Gross Weight
Constraints	
TOWOD *LDWOD*	Min. takeoff and landing wind-over-deck speeds (a function of aircraft weight, high lift aero, & catapult/arresting gear capacities)
Vapp	Approach speed for carrier landing
Ps	Combat specific excess power
AltRng	Achievable radius for the alternate mission)

3.2 Construction of Requirements Space

The first space to be constructed is the requirement space for the notional multi-role fighter. Seven requirements along with a range of variation for each were chosen in an attempt to capture part of the capability expansion represented by Figure 4. In particular, the mission radius, payload, and need for auxiliary tanks can vary widely between the primary and alternate missions. In the current approach, the auxiliary tank variable is set at either zero, one (center fuselage mounted), or two (wing mounted). Depending on the value of this variable, appropriate fuel, weight and drag values are included in the sizing analysis. This information, displayed in Table 2, serves as the input to the RSM process for the generation of requirement RSEs.

The baseline aircraft model in the sizing/synthesis program is used to execute the cases required for the regression data. The RSEs for each of the responses in Table 1 are obtained and displayed through prediction profiles in Figure 7.

Note that actual values for the desirements are displayed in the figure instead of "deltas" as specified in Eqns. (1-4). This is done simply to facilitate practical understanding of the RSE sensitivities.

Table 2: Primary mission requirements and ranges

Requirement	Min	Max
Mission radius (nm)	296	435
Ultimate Load factor	6.5	7.9
Combat Mach number	0.9	1.1
Mission Payload (lbs)	0	1000
Thrust per Engine (lbs)	14500	21000
Ref. Wing Area (ft^2)	380	520
Stealth penalty (lbs)	0	1000
Auxiliary Fuel Tanks	0	2
Specific Fuel Consumption (SFC) k-factor	0.9	1

This screen is interactive and can be viewed as a "sensitivity calculator" that allows designers and managers to together rapidly evaluate "what-if" scenarios. A more graphical depiction of the space is achieved through the contour profiler, shown in Figure 8. The "slide-

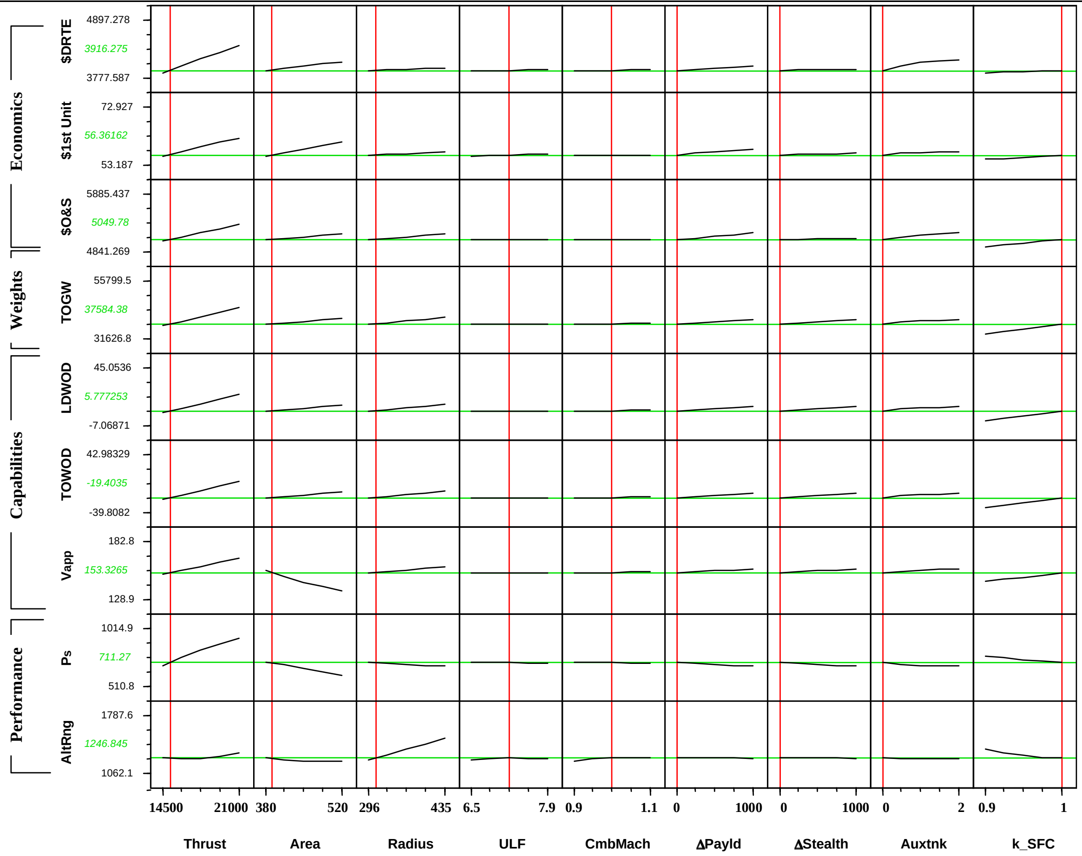
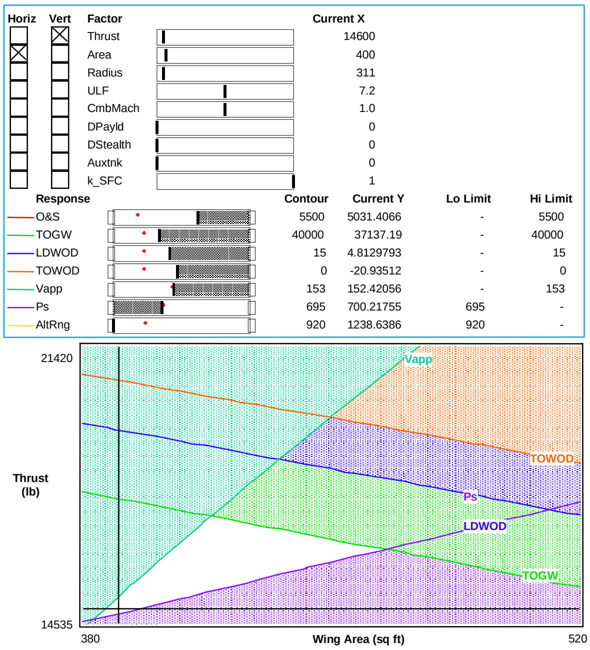


Figure 7 : Response Surface Equations (RSEs) for the requirements space

bars" which constitute the upper portion of the figure allow the designer to adjust the regressor variables. In the present case, these are the mission requirements set at the same baseline levels as in Figure 7. The effect on the responses to an adjustment of the requirements is instantly computed and the design space shapshot is redrawn. Further, constraint values can be assigned to the responses to determine the amount of feasible space available under the given scenario. Shaded regions then indicate the portion of the space in which one or more constraints are being violated. For example, typical constraints on the wind-over-deck, excess power, approach speed, O&S cost, and weight for the multi-role maritime fighter are imposed with the resulting feasible space depicted as un-shaded in Figure 8.



Horiz	Vert	Factor	Current X
☐	☒	Thrust	14600
☒	☐	Area	400
☐	☐	Radius	311
☐	☐	ULF	7.2
☐	☐	CmbMach	1.0
☐	☐	DPayld	0
☐	☐	DStealth	0
☐	☐	Auxtnk	0
☐	☐	k_SFC	1

Response	Contour	Current Y	Lo Limit	Hi Limit
O&S	5500	5031.4066	-	5500
TOGW	40000	37137.19	-	40000
LDWOD	15	4.8129793	-	15
TOWOD	0	-20.93512	-	0
Vapp	153	152.42056	-	153
Ps	695	700.21755	695	-
AltRng	920	1238.6386	920	-

Figure 8: Contour Profiler: Graphical depiction of constrained requirement space

Clearly, one key benefit of this graphical environment is that it allows for the examination of how a change in requirements affects the feasible design space. This is illustrated in the three snapshot series contained in Figure 9, where a continual increase in mission radius (through movement of its "slide bar") causes the feasible space to "disappear", all else held constant. An analyst could then pursue two avenues: 1) relax other requirements or constraints in order to regain a portion of the feasible space, or 2) look to evolutionary technologies for improved performance. An example of combining both avenues is displayed in Figure 10. Here, the "expanding mission" scenario is modeled by an increased in the radius requirement to 430 nm, a slight increase in the load factor requirement, and more aggressive constraints on the `Vapp`, `Ps`, and `AltRng` over the baseline aircraft. To recover the feasible space, the introduction of a propulsion technology that improves the SFC by about 3.5% (captured through the `k_SFC` factor) is simulated. The result is that a small area of feasibility opens in the high thrust, high wing area region of the design space as shown in Figure 10. Here, one k-factor was included n the requirements space to illustrate this trade. A more detailed discussion of the full technology k-factor space is discussed next.

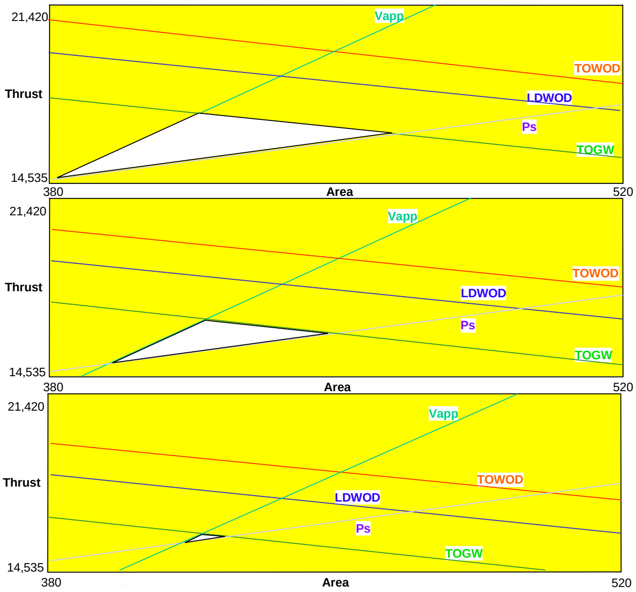
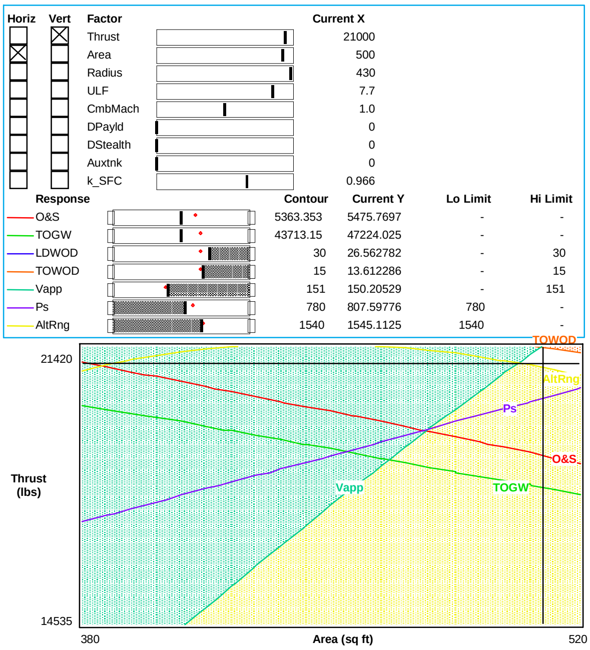


Figure 9: Shrinking feasible space- The effect of increasing mission radius requirement:



Horiz	Vert	Factor	Current X
☐	☒	Thrust	21000
☒	☐	Area	500
☐	☐	Radius	430
☐	☐	ULF	7.7
☐	☐	CmbMach	1.0
☐	☐	DPayld	0
☐	☐	DStealth	0
☐	☐	Auxtnk	0
☐	☐	k_SFC	0.966

Response	Contour	Current Y	Lo Limit	Hi Limit
O&S	5363.353	5475.7697	-	-
TOGW	43713.15	47224.025	-	-
LDWOD	30	26.562782	-	30
TOWOD	15	13.612286	-	15
Vapp	151	150.20529	-	151
Ps	780	807.59776	780	-
AltRng	1540	1545.1125	1540	-

Figure 10: Modified scenario- A new snapshot

3.3 Construction of the Technology k-factor Space

The purpose of the technology k-factor space is to allow the examination of "reachability" through evolutionary technology insertion. Actual technologies are modeled in this setting by adjusting the vector of disciplinary metric technology k-factors. For the current study, nine technology k-factors and associated ranges were chosen and are displayed in Table 3. These factors were chosen so that two of the most typical generic technology classes that affect performance, i.e. aerodynamic and structural improvements, could be captured in the sizing code. The k-factor for propulsion improvements, in the form of specific fuel consumption (`k_sfc`), was included in the requirement space construction instead of here as an example of how mixing can be used for specific trade studies. Additionally, three cost-related k-factors are employed. The k-factors for Research, Design, Test & Evaluation (RDT&E), 1^{st} unit production, and operations and support (O&S) cost are needed to assess the potential cost associated with technology development as well as technology's that are targeted toward cost (instead of performance) improvements. The variables and ranges for the technology k-factor space are used to create an appropriate experimental design and subsequent regression analysis gives the technology k-factor RSEs. These are presented in Figure 11. Again, actual values for the desirements are displayed in the figure instead of "deltas" as specified in Eqns. (1-4) for ease of understanding by the designers.

Table 3: Technology k-factors and ranges

Technology k-factor	Range
Induced drag (k_C_{Di})	-10% to 0%
Zero-lift drag (k_C_{Do})	-10% to 0%
Wing weight (k_Ww)	-15% to +15%
Fuselage weight (k_Fw)	-15% to +15%
Vert. tail weight (k_VTw)	-15% to +15%
Horiz. tail weight (k_HTw)	-15% to +15%
RDT&E Cost (k_RDTE)	-20% to +5%
1^{st} unit product. Cost (k_T1)	-20% to +5%
O&S Cost (k_O&S)	-20% to +5%

These RSEs are used to evaluate individual technology scenarios that may be proposed to extend the reachability of a baseline concept. Of course, any future prediction of technology impacts for which the technologies themselves are not fully mature incurs risk. Thus, a probabilistic approach must be taken. A very detailed methodology, called the Technology Identification, Evaluation, & Selection (TIES) process, has been developed using this k-factor approach. Further descriptions and implementations of TIES can be found in Refs.. [2] and [4].

4 Further Exploration of the Combined Space- Probabilistics & Optimization

4.1 Probabilistic Requirement-Technology Tradeoff

Returning to Figure 1, a critical task in the early stages of both the design and procurement process is to use the knowledge available to make decisions about the mix of technologies that may be required for a given concept. However, this knowledge is often imprecise or vague (especially the requirements) as well as uncertain (especially the performance of

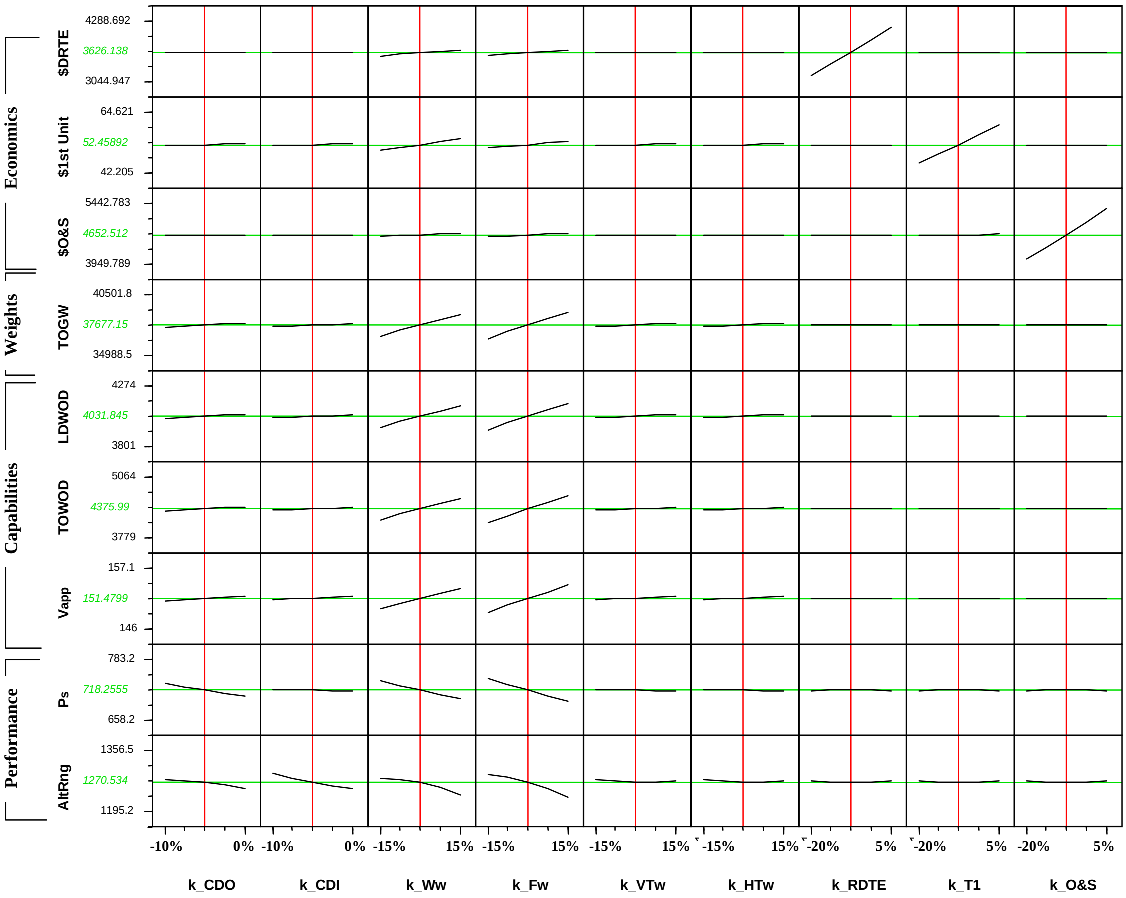


Figure 11: Response Surface Equations (RSEs) for the technology k-factor space

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immature but promising technologies). Thus, the combined space represented by Eq. (4) must be set in a probabilistic environment that allows for such non-deterministic elements. For example, assume that the baseline vehicle concept is fixed and an estimate is desired for the ability of a technology scenario to allow a requirement to be met.

Assume further that this requirement is vague, since the war fighter and doctrine communities may not yet have converged on a fixed target and/or the potential threats cannot be determined exactly. This situation is depicted in Figure 12. The probability density function (PDF) on the left represents the range of possible values of the requirement the system is likely to achieve under a technology scenario with uncertain ultimate performance. The PDF on the right is the range and likelihood of possible values of the requirement that the customer may want. A new random variable is defined as the difference between the anticipated and required, as shown in Eq. (5). It is this new random variable, the probability of meeting the requirement, that must be determined in order to make the design and/or acquisition decisions implied in Figure 1.

$$P(\mathbf{Req}_{Ach} - \mathbf{Req}_{Ant} > 0) = P(Z > 0) \qquad (5)$$

4.2 Simultaneous Solver

In addition to the important graphical tools developed, the sets of RSEs can be used to examine reachability in a numerical fashion. The dependent (i.e. Responses) and independent variables in the equation sets can be interchanged and subsequently fed to a non-linear, simultaneous equation solver to determine if solutions exist in the aspiration space (see Figure 2). For example, one could fix the requirements and conduct a search over

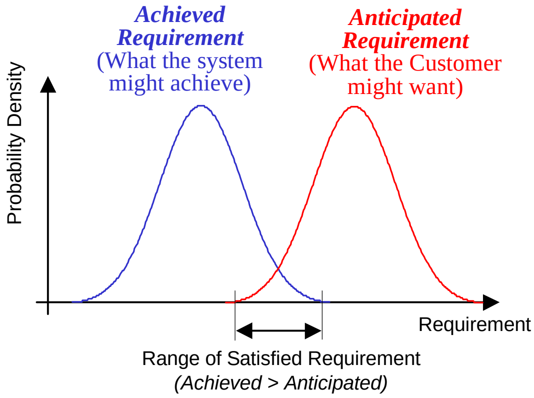

Figure 12: Requirements ambiguity and technology uncertainty

evolutionary technologies and design variables to achieve the goals. Alternatively, the design variables can be fixed while the search is over the requirements and technology levels. Such a tool provides a powerful capability to rapidly study possible tradeoffs and their implications on the process of setting requirements and designing solutions.

An illustration of this technique has been conducted using a non-linear solver from MATLAB®. The requirement (Eq. (1), Figure 7) and technology k-factor (Eq. (2), Figure 11) RSE sets for the notional maritime aircraft are employed in a search for a minimum weight design that has a long range attack radius, stealth characteristics, and improved performance. This sample problem, summarized in Table 4, consists of two firm requirements (treated as equality constraints), five inequality constraints on key responses, and one overall desirement. The free variables in the search include the remaining requirements from Table 2 and the technology k-factors from Table 3.

Table 4: Example problem for simultaneous solver

Objective (Desirement): *Min. -ΔTOGW*	
Equality Constraints	
Primary Mission Radius	= 500 nm
Δweight Stealth	= 500 lbs
Inequality Constraints	
$\Delta AltRng \geq 4\%$	$\Delta Ps \geq 2\%$
$\Delta O\&S \leq -3\%$	$\Delta LDWOD \leq -3$ knots
$\Delta OEW \leq -4\%$	

Solutions obtained by the solver need not be unique and can depend on the initial conditions. However, one typical solution was found and is displayed in Table 5. Note that the desirement and some of the constraints are not necessarily opposed since several some constraints are not at their limit. The delta in *$O&S* is an exception. In any case, the point of this brief example was to emphasize the wide array of studies possible once the "new knowledge" (i.e. the RSEs) is created.

Table 5: Typical simultaneous solver results

Objective (Desirement): *ΔTOGW = -8.8%*	
Equality Constraints	
Primary Mission Radius	= 500 nm
Δweight Stealth	= 500 lbs
Inequality Constraints	
$\Delta AltRng = 6.9\%$	$\Delta Ps = 3.6\%$
$\Delta O\&S = -3\%$	$\Delta LDWOD = -6$ knots
$\Delta OEW = -10.1\%$	

Further, solutions such as these only indicate "what-if" possibilities, especially in the use of the k-factors. Actual technologies must be developed to achieve the k-factor settings, and this is a tremendously complex problem in its own right.

5 Conclusions

The creation of an analysis-based environment that simultaneously examines requirements, design variables, and technology k-factor has been described in this paper. It was found that a decision-maker greatly benefits from this environment due to the real-time visibility it allows, both graphically through such tools as prediction profiles and the contour profiler, and numerically through the solution of the equations with specified targets (scenario simulation). In a larger sense, the concept of reachability was introduced as the overarching task facing the designer or acquisition manager, a task for which these tools can be extensively used.

The ability to actually construct such and environment through the use of response surface equations was demonstrated through example for a notional, carried-based aircraft. Such an aircraft, with expanded mission roles and numerous constraints, is typical of most major aerospace systems currently envisioned.

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