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The Air Warrior's Value of National Security Space

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THE AIR WARRIOR'S VALUE OF NATIONAL SECURITY SPACE

THESIS

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Table of Contents

Page

Acknowledgements iv

Table of Contents vi

List of Figures x

List of Tables xi

Abstract xii

I. Introduction 1
- What Does National Security Space Bring to the Air War? 1
- Setting the Decision Frame 3
- The Remainder of the Thesis Document 3

II. Literature Review 5
- Literature Review — Methodology 5
  - Value-Focused Thinking 5
  - Eliciting Value Hierarchies 7
  - The Decision Frame 9
  - Comparing VFT With a Space Systems Engineering Approach 10
  - Comparing VFT With a Net Assessment Approach 16
- Literature Review — Applications to Decisions Affecting Space Architectures 17
- Literature Review — Applications of VFT in Space Architectural Element Decisions 25
- New Combat Demands, New Appreciation 26

Page

III. Research Method 28
The Initial Hierarchy 28
The First Tier Defined 29
First Tier Value Decomposition — “Understand” 31
Understand — Vision 32
Understand — Communication 32
First Tier Value Decomposition — “Move” 33
First Tier Value Decomposition — “Fight” 34
Value Elicitation 35
Specifying the Decision Context 35
Determining the Measures and Single Dimensional Value Functions 36
Weighting the Hierarchy 37
Choosing an Overall Value Function 37

IV. Results 38
Description of the Hierarchy 38
Communication 40
Navigation 41
Denial. 42
The Measures and Single-Dimensional Value Functions 44
Weights 46

V. Conclusions 47
Insights Revealed 47
Mission Phase Matters. 47
Data vs. Voice. 48
Value Preservation Thresholds. 48
The Overall Value Function 49

Page

VI. Recommendations 50
Recommendations for the Present Study 50
Classified Value Elicitation 50
Comparing Systems 50
Sensitivity Analysis 51
Cost Analysis 51
Test for Mutual Preferential Independence 51
Elicit Values from All Warfighters 52
Recommendations for VFT Studies in General 52
Standardize Terminology 52
Elicit a Revisit Time from SMEs 53

Appendix A. A Review of VFT Hierarchies. 54

Appendix B. Preliminary Value Hierarchies Derived from Doctrine Using Content Analysis and Affinity Grouping. 66
Problem Statement 67
A New Look at the Value of Space 67
Previous Efforts to Identify Values Using Doctrine 69
Methodology 73
Application of Content Analysis 73
Inductive Category Development Using Affinity Grouping. 83
Summary of Methodology 88
Extracted Hierarchies 88
Space Commission Report 89
Definition of *Space Commission Report* Values 91
JP 3-14 (draft) 92
Definition of JP 3-14 (draft) Values 93
Definition of AFDD 2-2 Values 95
Definition of AFDD 2-2 Values 96
SPACECAST 2020 97
AeroSpace Integrated Investment Study (ASIIS) 99
Conclusions and Recommendations 102
Conclusions 102
Recommendations 104

Page

Appendix C. The Measures and Single-Dimension Value Functions. 113

Bibliography 128

Vita.. 131

List of Figures

Page

Figure 1. The Initial Hierarchy. 31

Figure 2. The "Understand" Value and Its Branches. 31

Figure 3. The "Move" Value and Its Branches. 33

Figure 4. The "Fight" Value and Its Branches. 34

Figure 5. The Value Hierarchy. 39

Figure 6. The Communication Value and Its Branches. 40

Figure 7. The Navigation Value and Its Branches. 42

Figure 8. The Denial Value and Its Branches. 43

Figure 9. A Generic Value Hierarchy. 57

Figure 10. A Hypothetical Increasing Piecewise Linear SDVF. 59

Figure 11. A Hypothetical Decreasing S-curve SDVF. 60

Figure 12. Hierarchical Display of a Single-Tier Additive Value Function With 3 Attributes. 61

Figure 13. Generic Value Hierarchy With Local Weights Added. 63

Figure 14. Illustrative example of affinity grouping using objective phrases from the Space Commission Report. 87

Figure 15. Value Hierarchy Derived from *Space Commission Report Executive Summary* (January 2001). 90

Figure 16. Value Hierarchy Derived from Joint Publication 3-14, *Joint Doctrine for Space Operations* (draft) (April 2001). 93

Figure 17. Value Hierarchy Derived from AFDD 2-2 95

Figure 18. *SPACECAST 2020 Operation Analysis* Value Hierarchy (top two levels changed from table format to hierarchy format). 99

Figure 19. AIM Value Hierarchy (top two levels). 101

List of Tables

Page

Table 1. The Space Mission Design and Analysis Process. 11

Table 2. Focus of Attention at Each Step of the Space Mission Design and Analysis Process. 13

Table 3. Command-Oriented Architecture Priorities. 20

Table 4. Demand-Oriented Architecture Priorities. 20

Table 5. Space Architecture Determinants. 21

Table 6. Constellation Implications, Demand-Oriented Architecture. 23

Table 7. Qualifications of the Air Combat Expert Panel. 35

Table 8. Value Preservation Thresholds for Communication Values.............................. 41

Table 9. Measures at the Base Level of the Hierarchy. 45

Table 10. Assessed Values of Threat Destruction. 46

Table 11. Testing Coding Scheme on a Sample of Text.. 79

Table 12. Values and Weighting for the Force Enhancement Value in the SPACECAST 2020 Operational Analysis Hierarchy. 98

Table 13. Examples of Proxy Attributes from AIM. 100

Table 14. Comparison of Strategic Objectives and First Tier of Values for the Three Extracted Hierarchies and the Two Elicited Hierarchies..................................... 102

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Abstract

The 2001 Report of the Commission to Assess United States National Security Space Management and Organization recommended that U.S. efforts in national security space be elevated to the highest national security priority. With more focused high-level attention on national security space decisions, a measure that captures and quantifies the value of space capabilities to combat operations professionals is desired. This thesis models what the air warriors desire from space assets in combat.

A Value-Focused Thinking (VFT) approach was used to elicit values from air combat experts with operational experience. An initial Gold Standard value model was constructed and validated by air combat experts with recent experience in joint air operations. The strategic objective, "Leverage National Security Space Capabilities to Enhance Air Combat Operations," was decomposed into values which were structured into a hierarchy. Measures and value functions were identified for the bottom-tier values, which were weighted locally to assess their relative importance.

The research identified measures of merit with thresholds beneath which value at higher levels is eliminated, resulting in a multiplicative value function using indicator variables. An additional result is the separation of communication and navigation measures into pre-flight and in-flight components, which has not been documented in previous literature.

THE AIR WARRIOR'S VALUE OF NATIONAL SECURITY SPACE

I. Introduction

What Does National Security Space Bring to the Air War?

The U.S. Government employs a vast array of national and military space capabilities (termed *national security space* in this thesis) that have served, and continue to serve, as a force multiplier in military operations. National security space gives the warfighter engaged in operations the leverage that comes from "global view" (SPACECAST 2020, 1994: Introduction). This leverage, however, comes at a price. The *Report of the Commission to Assess United States National Security Space Management and Organization* (also known as the *Space Commission Report*) cautioned that the U.S. is uniquely dependent on national security space, and that this dependence results in vulnerabilities (*Space Commission Report*, 2001:9). Adding to the price to be paid for space leverage for the warfighter is the monetary burden of putting systems in space, with cost being a "fundamental limitation to nearly all space missions" (Wertz and Larson, 1999:2).

The advantages, vulnerabilities, and high cost of space capabilities represent multiple values that must be considered when making national security space decisions. The focus of this thesis is to uncover and model the values that air combat professionals hold with respect to national security space. The approach involves capturing both the qualitative and quantitative contributions of space to the air war, as assessed by air warriors with experience in executing air combat operations. Throughout the text of this thesis the term *air warrior* will be used to denote the air combat professional, defined as the military service member who directly applies force with air assets.

The senior Air Force leadership has recently stated that three core competencies remain at the heart of the Air Force's mission. Two of these competencies, *technology-to-warfighting* and *integrating operations,* will be nurtured by the analysis done in this thesis (Roche, 2003:1-2; Jumper, 2003:1-2).[1] *Integrating operations* involves translating the Air Force's "air and space power vision into decisive operational capability" (Jumper, 2003:2), which has been and continues to be crucial to "prevailing in conflict and averting technological surprise" (Roche, 2003:2). The goal of *integrating operations* is to "envision, experiment, and ultimately, execute the union of a myriad of platforms and into a greater synergistic whole" in support of maximizing the unique capabilities that air and space power bring to the fight (Roche, 2003:2), resulting in the seamless integration of systems, activities, and expertise (Jumper, 2003:2). The goal of this thesis is to develop the air warrior's yardstick for measuring how well national security space capabilities satisfy these core competencies.

This integration of technology into warfighting requires decision makers to balance multiple objectives. Value-Focused Thinking (VFT), as developed by Ralph Keeney and refined by Craig Kirkwood and others, is a modeling technique that has been frequently used to assist with both military and civilian decisions. In this thesis VFT is used to identify and quantify what the users of national security space value in an analytical, documented, and traceable manner. As will be shown in Chapter II, VFT has been applied in a broad array of military applications, and this thesis is an effort to

[1] The other competency is "Developing Airmen" (Roche, 2003:1; Jumper 2001:1), which falls outside the scope of assessing the value of space from the air warrior's point of view.

extend its advantages to maximize national security support to the air combat professional. The resulting model not only represents the air warrior's point of view for his or her own benefit, but also provides useful insights to decision makers in the Intelligence Community (IC), and analysts in the modeling and simulation communities.

Setting the Decision Frame

Setting the decision frame is a prerequisite to building a value model. The decision frame consists of the fundamental objectives, which are the focus of this study, and the decision context, which is set beforehand by the scope of the activity being contemplated (Keeney, 1992:35). There exist various decision contexts concerning the set of space alternatives that provide value to the air warrior, from the comprehensive case of all activities in space to any narrower set of space activities. The boundary of the analysis of this thesis includes all Department of Defense (DOD) and Intelligence Community space assets, termed national security space by the *Space Commission Report* (2001:ix), but excludes civil and international programs beyond the span of control of the DOD and IC. An additional boundary is set by the need to limit analysis to unclassified concepts and systems, although classified analysis is a possibility for the future.

The Remainder of the Thesis Document

Chapter II of this thesis describes VFT and its previous applications to national security space decisions, as well as examining the roles that values play in other space decision-making methods. Chapter III presents the methodology employed in the study, and Chapter IV presents the resulting model. Chapter V summarizes the results of the research, and Chapter VI presents recommendations for future work in this area.

II. Literature Review

A review of literature pertinent to valuing national security space is important for several reasons. A general overview of Value-Focused Thinking (VFT) sets the stage for explaining the methodology in the study. An examination of values in other forms of decision making with implications for national security space highlights the advantages of a values-first approach. Previous work in VFT – as it has been applied to national security space decisions, both at the space architecture level and at the architectural element level – is then summarized, along with its implications for the topic this thesis addresses.

Literature Review — Methodology

Value-Focused Thinking

Value-Focused Thinking (VFT) has been used over a broad array of applications to develop decision-making preference models that are both qualitative and quantitative. Ralph Keeney, in his text entitled *Value-Focused Thinking* (1992), explains the VFT process by contrasting it with the usual decision-making process, which he terms Alternative-Focused Thinking (AFT). He describes AFT as first defining the problem, then identifying alternatives, and finally specifying the values by which the alternatives will be evaluated. He states that identifying alternatives before evaluation considerations will "stifle creativity and innovation" (Keeney, 1992:48). In essence, putting emphasis on alternatives can act as a restrictive influence on additional alternative generation, without regard to their suitability to the decision situation. AFT may also obscure values not initially apparent to the decision maker (Keeney, 1992:24).

AFT may be likened to the admonishment "don't just stand there, do something." A focus on alternatives may lead to a quick and easy "solution" in the short term, but with a price to be paid in terms of the "solution's" consequences (Keeney, 1992:6). Value-Focused Thinking (VFT), on the other hand, encourages stakeholders to "sit down" and take measure of their values before rushing to "do something" that may or may not be in accord with the true values that are relevant to the decision.

VFT, in contrast to AFT, calls for identifying what is important to the decision-maker *before* alternatives are considered. Paying attention to the decision maker's values first may broaden the scope of solutions beyond those that were specified by the initially apparent alternatives (Keeney, 1992:27), and may uncover the decision maker's or decision making group's hidden values (Keeney, 1992:24).

Keeney further maintains that a focus on values offers several other advantages to decision making. Awareness of values may help a decision maker decide which information will be relevant to the problem, thus avoiding the waste of collecting extraneous information (Keeney, 1992:24-25). Discussion of values brings more stakeholders into the decision process, as values are usually stated in terms that avoid esoteric technical concepts (Keeney, 1992:25). Values identification can help multiple stakeholders resolve conflicts by separating discussions about decision outcomes from discussions about the relative desirability of those outcomes by clarifying the basis for disagreements (Keeney, 1992:25-26). Explicating values can ensure consistency across multiple decisions (Keeney, 1992:26) and thinking about values may assist us in creating new decision opportunities that offer chances for improving performance on the decision maker's own terms (Keeney, 1992:27). Finally, values and their relative importance to the decision maker can be modeled in terms of an objective function that quantifies the consequences of alternatives that may be considered (Keeney, 1992:26). This is the primary advantage this thesis purports to lend the air warrior: a method of quantitatively evaluating national security space decision alternatives according to the values that the air warrior holds.

Kirkwood (1997:12-13) recommends structuring a decision maker's values in a hierarchy, with the decision maker's overall strategic objective at the top, and the fundamental objectives that directly support the strategic objective in the first tier. As value hierarchies have become commonplace in decision analysis literature, this literature review will pass directly to the elicitation methods. For the interested reader a detailed description of value hierarchies can be found in Appendix A.

Eliciting Value Hierarchies

Kirkwood mentions two sources from which value hierarchies can be developed: relevant literature and casual empiricism (Kirkwood, 1997:21-22). A review of the literature relevant to the current problem being studied may lead to information that is useful for developing a hierarchy, or may even uncover hierarchies themselves that yield insight into the current problem.[2] Value hierarchies can also be elicited from the decision's stakeholders themselves. Kirkwood terms this approach *casual empiricism* (emphasis in original), and he recommends that it be done through structured interviews to ensure buy-in from the stakeholders and to ensure that the appropriate measures, value functions, and weights are included in the hierarchy

[2] For a set of preliminary national security space value hierarchies derived from content analysis of doctrine, see Appendix 2.

(Kirkwood, 1997:21-22). The method of this study has utilized both sources of values, as will be explained in Chapter III.

The Gold Standard approach is often used to extract values hierarchies from relevant literature. As used in Burk and Parnell (1997: 66) and described by Parnell, Conley, Jackson, Lehmkuhl, and Andrew (1998:1338), this approach entails identifying an authoritative policy document that describes major objectives within the decision context. An adequate Gold Standard document will directly supply one or more tiers of the value hierarchy from the objectives described within. The remainder of the hierarchy can be developed by individuals who have the expertise necessary to render adequate judgments that concern the decision at hand.

When time available with subject matter experts is limited, analysis of an authoritative Gold Standard document can provide a starting point for a value hierarchy. Extracting objectives from a Gold Standard document (e.g., doctrine) may be done directly as in SPACECAST 2020 (Burk and Parnell, 1997:66), or may be accomplished through a systematic analysis if there is enough lead-time before the casual empiricism process begins. Appendix B describes such an approach that was accomplished in strategic preparation for this thesis in which implicit organizational objectives for national security space were identified in addition to the explicit capability-based objectives.

The Silver Standard approach (Parnell *et al*., 1998:1340) is often used where no Gold Standard document exists. This approach entails structuring a hierarchy from the bottom up by identifying the objectives at the lowest tier. For example, in *Foundations 2025*, the value model developed for the *Air Force 2025* study, bottom-tier objectives were identified using verbs to describe basic tasks that became bottom-level objectives. The verbs were then structured into sub-objectives, objectives, and fundamental objectives by the use of affinity diagrams, with the overarching strategic objective taken from the original charge given to the *Air Force 2025* participants ("achieve air and space dominance") (Parnell *et al*., 1998:1340).

The Platinum Standard, as developed by Parnell, Bennett, Engelbrecht, and Szafranski (2002:82-83) uses information from both Gold Standard documents and structured interviews with senior decision makers and stakeholders whose schedules do not allow the time required to meet and discuss all of the bottom-level objectives needed to form the lowest tier of the hierarchy. In their study of NRO Operational Support Office (OSO) resource allocation, Parnell *et al*. (2002) used information from 23 structured interviews from within the OSO and from other NRO organizations to list the future activities that would provide the most value to the NRO and its customers. They then used affinity diagrams to group the activities into functions, from which the strategic objective[3] and fundamental objectives[4] for the hierarchy were identified, with the help of the Gold Standard documents and the interviews. Weights were elicited beginning with the lowest level and proceeding upward by means of a survey of 23 OSO personnel (Parnell *et al*., 2002:85).

<u>The Decision Frame</u>

Keeney (1992:30) points out that a decision is framed by the decision context and the fundamental objectives. The values of concern in a given decision situation are

[3] Parnell *et al*. (2002) use the term "fundamental objective" to describe what is termed "strategic objective" in the remainder of this thesis. To retain consistency, the term "strategic objective" will be used.
[4] Parnell *et al*. (2002) use the term "objective" to mean what the term "fundamental objective" means in the remainder of this thesis.

made explicit by objectives (Keeney, 1992:55) which are categorized into fundamental objectives and means objectives (Keeney, 1992:34-35). Fundamental objectives "characterize the essential reasons for interest" in a given decision situation, while means objectives are "means to the achievement of the fundamental objectives." Fundamental objectives can be identified by asking, "Why Is This Important?" (Keeney, 1992:66) (also known as the WITI test). Applying the WITI test to an objective will lead to one of two responses: either the objective is important because it supports the achievement of another objective, or it is simply important in its own right (Keeney, 1992:78). The first response indicates that the objective is a means objective that supports another objective (which may or may not be a fundamental objective) while the second response indicates that a fundamental objective has likely been found (Keeney, 1992:66).

Comparing VFT With a Space Systems Engineering Approach

Wertz and Larson address values and objective structuring in their text entitled *Space Mission Analysis and Design* (Wertz and Larson, 1999:12-13). Although they limit their discussion of values to the space mission design framework, an examination of where values enter into the process is instructive. Their process, which has "evolved over the first 40 years of space exploration," (Wertz and Larson, 1999:1) consists of the steps listed in Table 1:

Table 1. The Space Mission Design and Analysis Process.

Define Objectives	Step 1. Step 2.	Define broad objectives and constraints. Estimate quantitative mission needs and constraints.
Characterize the Mission	Step 3. Step 4. Step 5. Step 6.	Define alternative mission concepts. Define alternative mission architectures. Identify system drivers for each. Characterize mission concepts and architectures.
Evaluate the Mission	Step 7. Step 8. Step 9.	Identify critical requirements. Evaluate mission utility. Define mission concept (baseline).
Define Requirements	Step 10. Step 11.	Define system requirements. Allocate system requirements to elements.

Wertz and Larson, 1999:2.

The decision maker in space mission analysis and design (SMAD) can be the sponsor, designer, end user, and/or the developer (Wertz and Larson, 1999:7). The SMAD process starts with the decision maker's values by qualitatively identifying primary and secondary objectives at Step 1. Instead of subdividing the main objective into supporting objectives, however, in Step 2 they focus attention on defining quantitative measures and thresholds that will meet the objectives. Both Steps 1 and 2 require implicit value judgments to be made in determining what the objectives are and what numerical measures of performance are required to meet the objectives. Value judgments are also made when deciding which objective is primary and which ones are secondary.

Generation of alternatives begins early in the process at Steps 3 and 4. System drivers, which are the parameters that have the most impact on system design and cost (Wertz and Larson, 1999:4), are identified at Step 5. These parameters, the independent variables that control overall system performance, cost, and design (Wertz and Larson, 1999:4) are akin to the attributes in a value hierarchy, as they are the inputs into the functions that will be used for evaluation. In Step 5, then, the focus shifts back to values, as identifying the parameters that have the *most* impact on system design and performance requires value judgment (emphasis added). Step 6 embraces both alternatives and values by defining "in detail what the system is" (which corresponds to alternatives) and "does" (which corresponds to values) (Wertz and Larson, 1999:4). Values are the focus at Step 7, with judgments made as to which requirements are critical and which ones are not. Evaluation of alternatives occurs at Step 8, with evaluation of the goodness of the critical performance measures left to the system user or developer (Wertz and Larson, 1999:5). Step 9 is the selection of one or more alternative baseline system designs, and becomes the starting point for the iterative trade process (Wertz and Larson, 1999:5). This returns the focus to alternatives. Step 10 again requires implicit value judgments, as it "translates the broad objectives and constraints of the mission into well-defined system requirements" (Wertz and Larson, 1999:5). Values are key at Step 11, the allocation of requirements to the specific elements of the space mission (Wertz and Larson, 1999:5). A key feature in the entire 11-step process is successive iteration through all 11 steps until the requirements are met (Wertz and Larson, 1999:2). This allows both values and alternatives to be adjusted according to the decision maker's preferences. The oscillating focus between values and alternatives, as assessed by this author, is shown in Table 2.

Table 2. Focus of Attention at Each Step of the Space Mission Design and Analysis Process.

			Focus of Attention
Define Objectives	Step 1.	Define broad objectives and constraints.	Values
	Step 2.	Estimate quantitative mission needs and constraints.	Values
Characterize the Mission	Step 3.	Define alternative mission concepts.	Alternatives
	Step 4.	Define alternative mission architectures.	Alternatives
	Step 5.	Identify system drivers for each.	Values
	Step 6.	Characterize mission concepts and architectures	Alternatives/ Values
Evaluate the Mission	Step 7.	Identify critical requirements.	Values
	Step 8.	Evaluate mission utility.	Values
	Step 9.	Define mission concept (baseline).	Alternatives
Define Requirements	Step 10.	Define system requirements.	Values
	Step 11.	Allocate system requirements to elements.	Values

Modified from Wertz and Larson, 1999:2.

Keeney's approach focuses on values in a different manner. First, the situation should be assessed as a decision problem, which "usually occurs as a result of actions that are not controlled by the decision maker" (Keeney, 1992:48) or a decision opportunity, which is "identified and defined by the decision maker" (Keeney, 1992:50). Although space mission designs have been precipitated by external events in the past (e.g., Sputnik, the Challenger accident), most current national security space missions represent opportunities to improve on existing capabilities (e.g., GPS III follows GPS II, SBIRS improves on DSP). Keeney's framework would thus categorize most space missions as decision opportunities (Keeney, 1992:50).

The process for addressing decision opportunities depends on whether strategic objectives have been specified or not. As the SMAD process calls for defining broad objectives in Step 1, it is assumed that strategic objectives have not been specified. The VFT sequence of activities for decision opportunities where strategic objectives have not been specified are as follows (Keeney, 1992:49):

1. Identify a decision opportunity.
2. Specify values.
3. Create alternatives.
4. Evaluate alternatives.
5. Select an alternative.

Value judgments are apparent in the first two activities, implicitly in the first case and explicitly in the second. From there values set the stage for generation and consideration of alternatives.

Interestingly, Wertz and Larson discount the value of having one overarching strategic objective that subsumes and links a set of fundamental objectives. The following statement deems two of the objectives from their notional FireSat system incompatible:

> …we recommend strongly against numerical formulas that try to "score" how well a mission meets its objectives. We can compute probabilities for achieving some technical objectives, but trying to numerically combine the coverage characteristics of different FireSat constellations with the political impact of launching FireSat is too simplistic for effective decision making. Instead, we must identify objectives separately so we can judge how to balance alternative objectives and mission concepts (Wertz and Larson, 1999:13).

A value-focused analysis would address this apparent incompatibility by using proxy attributes where directly measurable attributes are not apparent. These are measures that indirectly assess the achievement of one objective by directly measuring the achievement of an associated objective (Keeney, 1992:103; Kirkwood, 1997:24). In the FireSat example, the decision maker would be asked to examine his/her/their values to determine how much coverage characteristics are worth in comparison to political impact. Should political impact prove to be unquantifiable or immeasurable, an attribute may be identified that captures the political impact of launching a satellite (for example, this proxy attribute could be the number of diplomatic notes received from a particular government that mention the launch in a positive or negative manner). These values would then be weighted in the hierarchy according to the decision maker's preferences.

Keeney also addresses oscillation between AFT and VFT before strategic objectives have been specified:

> Before specifying strategic objectives, a decision maker may use alternative-focused thinking in one decision situation and use value focused thinking in another decision situation. It is perhaps a bit schizophrenic, but one can jump back and forth from one approach to another on different "problems" (quotes in original). But after the decision maker does the deep thinking necessary to identify and structure strategic objectives and spends the time to understand the guiding significance of these objectives for decision making, the decision maker should naturally use value-focused thinking in all decision situations. The decision maker will now view the world "through value-focused glasses" (quotes in original) (Keeney 1992:51).

Recall that SMAD requires iteration of the whole 11-step process (Wertz and Larson, 1999:2). In his framework Keeney does allow oscillation between alternatives and values in order to specify strategic objectives (Steps 1 and 2 of SMAD), but once they have been specified, he recommends that VFT be used to complete the process. Keeney's contribution to SMAD would be to have the decision maker firmly define objectives at Steps 1 and 2, and relate them to each other in a hierarchical fashion. This should shorten the time spent on values at later points in the 11-step process, especially at Steps 7 and 8 where the meaning of "critical" will have been firmly established, quantified, and documented through value elicitation. With rigorous identification of and definition of values at the outset, Steps 1 and 2 may be omitted in succeeding iterations of the SMAD process.

Another point of contrast between SMAD and VFT is their respective treatment of unstated objectives. Wertz and Larson (1999:12) acknowledge that "nearly all space missions have a *hidden agenda* which consists of secondary, typically nontechnical objectives" (italics in original) that are "equally important to satisfy" (Wertz and Larson 1999:12). Although Wertz and Larson state that secondary and nontechnical objectives must be identified (Wertz and Larson 1999:13), they prescribe no method for uncovering them. In contrast, Keeney (1992:24) holds that the conscious values uncovered by VFT "may also provide many keys to identify previously subconscious values by "specifying attributes and quantifying values" (Keeney, 1992:158).

<u>Comparing VFT With a Net Assessment Approach</u>

Barry D. Watts applies net assessment in his diagnostic approach to valuing the military use of space. Citing his conversation with Andrew Marshall, the Pentagon's Director of Net Assessment, he describes net assessment as "a discipline or art that relies, above all else, on genuine understanding of the enterprise or business involved rather than sophisticated models, complex systems, and abstract theory" (Watts, 2001:5). From his empirical (as opposed to prescriptive) perspective, he states "For the United States, the military value of orbital systems rests almost exclusively in force enhancement rather than force application" (Watts, 2001:12), citing several examples from the Persian Gulf War to support his view.

Watts admits more than once that his approach is not prescriptive, but diagnostic (Watts, 2001:5,107), and herein lies the most striking difference between his net assessment and VFT. Although Watts provides an evaluation of the U.S. military use of space, his approach merely examines current alternatives that have been implemented, and does not prescribe any approach to determine how the U.S. should assess the military value of space. An approach to this problem applying VFT, in contrast, would be prescriptive in nature (Keeney and Raiffa, 1976:vii), as it would postpone consideration of alternatives until the values by which the assessment should be made have been identified and modeled.

Literature Review — Applications to Decisions Affecting Space Architectures

To date there are few models used to assess the value of national security space capabilities with representation of the warfighter's perspective. Perhaps the best-known space value model is SPACECAST 2020, a 1994 study directed by the Chief of Staff of the Air Force (CSAF) to "identify and conceptually develop high-leverage space technologies and systems that will best support the warfighter in the twenty-first century" (*SPACECAST 2020 Operational Analysis*, 1994:1). This study used the judgments of students and faculty from the Air Force Institute of Technology, the School of Advanced Airpower Studies, the Air War College, and the Air Command and Staff College to develop a value model to score space systems in pursuit of the CSAF's directive. While some of the participants were combat experts, *not all* of them had been directly responsible for force application, and this may have had the effect of mitigating the air warrior's direct input into the value model. The scope of the model thus included more than just the air warrior's perspective. Additionally, the

SPACECAST 2020 team was tasked with developing a value model only for ranking and scoring technologies and systems. Excluded from the study were concepts that did not concern non-technical considerations such as organization, policy, and education. The execution of the model was limited to a series of white papers developed in the course of the SPACECAST 2020 study, each presenting a space system and its enabling technology with the promise of a high return on investment to the Air Force.

In 1995-96 the Air Force 2025 study was undertaken in an attempt to "generate ideas and concepts on the capabilities the United States will require to dominate air and space forces in the future" (*AF 2025 Operational Analysis*, 1996:Chapter 1). A value model emerged from the 2025 study that was used to evaluate systems and technology concepts that hold great promise for future Air Force application. As with its predecessor SPACECAST 2020, the participants in the study were students and faculty from the Air War College, the Air Command and Staff College, the Air Force Institute of Technology, and civilian consultants. Although the air warrior's perspective was represented in this group, it was mixed with a broader set of perspectives intended to give the fullest evaluation possible of air and space capabilities. As with SPACECAST 2020, AF 2025 was centered on technology and systems concepts, but it was not intended to measure the value of other concepts. Another limiting factor for this research effort is the breadth of the AF 2025 approach. The intent of AF 2025, as stated above, was to evaluate *all* systems and concepts relevant to the Air Force, and was not solely focused on the value of national security space capabilities. Although valuable general insights emerged from AF 2025, it does not present a pure air warrior perspective, nor does it allow a focused assessment of the value of national security space.

Daehnick (1999:103-181) elaborates on one of the main dichotomies brought forth in SPACECAST 2020 (1994:5): that of command orientation and demand orientation. He notes that the terms have traditionally been used to describe information flow in a system, but that they can be applied to every part of a space architecture (Daehnick, 1999:163n2). He describes the current space architecture as command-oriented: "centralized, driven by specific performance requirements and employing a push approach to providing services" (Daehnick, 1999:104). Daehnick contrasts this description with demand orientation, which "implies a more decentralized organization, a user-pull approach to providing services, and a focus on responsiveness" (Daehnick, 1999:104). To aid in making "value judgments about an architecture and especially to compare alternatives," he lists the following attributes (values) that provide a means for qualitative description: performance, responsiveness, flexibility, robustness, logistics requirements, reliability/availability, ease of operations, environment impact, and cost (Daehnick, 1999:114-115). Although this is clearly an attempt to incorporate VFT into space architecture decision making, formal decision analysis concepts such as mutual exclusivity, collective exhaustiveness, and preferential independence are not mentioned.

Daehnick's characterizations reveal that a proper VFT approach that captures the values of the user (in this thesis, the air warrior) is well-suited in making the transition from a command to a demand orientation, as command-oriented architectures are capital-intensive and lend themselves to incremental change, while the responsiveness and adaptive nature of demand-oriented architectures are more in tune with what the user needs (Daehnick, 1999:104-105). Tables 3 and 4 display Daehnick's comparison of priorities (weights) that command- and demand-oriented architectures reflect.

Table 3. Command-Oriented Architecture Priorities.

H = High M = Medium L = Low	Space Segment			Ground Segment			Launch Segment		
	Payload	Constellation	Craft	TT&C	Facilities	User	C^2	Sites	Vehicle
Performance	H	H	H	H	H	M	H	H	H
Responsiveness	M	M	M	H	M	H	M	L	L
Flexibility	M	M	L	L	M	L	L	M	L
Robustness	H	H	H	M	L	L	M	M	L
Logistics Requirements	L	L	L	L	L	L	L	L	L
Reliability	H	H	H	H	H	H	H	H	H
Ease of Operations	L	L	L	M	M	M	M	L	L
Environmental Impact	L	L	L	L	L	L	L	M	L
Cost	L	L	M	L	L	M	L	L	M

Daehnick, 1999:118.

Table 4. Demand-Oriented Architecture Priorities.

H = High M = Medium L = Low	Space Segment			Ground Segment			Launch Segment		
	Payload	Constellation	Craft	TT&C	Facilities	User	C^2	Sites	Vehicle
Performance	M	H	M	M	M	H	H	H	M
Responsiveness	M	H	M	M	H	H	H	H	H
Flexibility	L	H	H	H	M	M	H	H	H
Robustness	M	H	M	M	L	H	H	H	H
Logistics Requirements	L	M	M	L	L	H	L	H	H
Reliability	M	H	M	M	M	H	H	L	M
Ease of Operations	H	M	H	H	M	H	M	M	H
Environmental Impact	L	L	L	L	L	L	L	M	M
Cost	H	M	H	M	M	M	H	H	H

Daehnick, 1999:119.

These priorities reflect relative, not absolute, priorities in design considerations. For example, a low priority item is not necessarily unimportant, but its priority would compare unfavorably with a high or medium priority item (Daehnick, 1999:118). Consistent definitions of “high,” “medium,” and “low” would strengthen the measurement of the priority each attribute receives in each orientation.

Daehnick identifies other factors that come into play in space architecture decisions as determinants, and he groups them into three categories: requirements, technology, and budget (Daehnick, 1999:122). These factors are largely out of the decision maker’s control. He lists the groupings of determinants shown in Table 5 as follows:

Table 5. Space Architecture Determinants.

Requirements	**Technology**	**Budget**
Global coverage	DOD ability to drive technology	In decline, especially for research, development, and acquisition
Early access	Increased emphasis on dual use	Need to reduce life cycle costs
Pop-up crises	Microprocessor revolution	Can market forces be tapped?
Flexible, expandable capabilities	Command, control, and communications improvements	
Rapid throughout	Miniaturization, structures, material	
	Standardization and modularity, flexible manufacturing	

Daehnick, 1999:131.

Daehnick then raises the question of representing mathematically the value judgments implied in the orientation matrices Tables 3 and 4 and the by cross-multiplying either the command-oriented matrix or the demand-oriented matrix with a matrix of the determinants (Daehnick 1999:130). He suggests, if both the determinants and the elements and attributes (values) could be represented mathematically, their matrices could be cross-multiplied to produce a "complete description of an architecture."[5] Like Wertz and Larson (1999:13), he is skeptical of measuring qualitative value judgments. He instead recommends an approach that better accommodates the subjectivity inherent in dealing with qualities that are difficult to estimate, but that may lend itself to eventual quantification.

Daehnick's approach involves building a table of the attributes (values), one architectural element (e.g. the constellation) and its priority with respect to command- or demand-orientation, and the implications of each of the three determinants on the element. This methodology would then extend to each element of the architecture. Table 6 shows these implications for a demand-oriented architecture with respect to the constellation element:

[5] Although Daehnick's suggestion to build quantitative measures to value judgments by using matrix multiplication has intuitive merit, he misses one of the requirements for matrix multiplication to take place: the number of columns in the first matrix must equal the number of rows in the second.

Table 6. Constellation Implications, Demand-Oriented Architecture.

<table>
<tr><th></th><th>Priority</th><th colspan="3">Implications — Constellation</th></tr>
<tr><th></th><th>Constellation</th><th>Requirements</th><th>Technology</th><th>Budget</th></tr>
<tr><td>Performance</td><td>H</td><td>Emphasis on systemic versus satellite measures</td><td>Distributed architecture, use most recent technology</td><td rowspan="7">Because of the requirement for incorporation of multiple new technologies, need more R,D,&A money’ this is somewhat offset since many of the technologies are being pursued commercially</td></tr>
<tr><td>Responsiveness</td><td>H</td><td>Right product available quickly to all users</td><td>Tailored systems, rapid build and launch</td></tr>
<tr><td>Flexibility</td><td>H</td><td>Adapt to changing situation</td><td>Standardization, modularity,C^3, on-board processing</td></tr>
<tr><td>Robustness</td><td>H</td><td>Proliferate, degrade gracefully</td><td>Autonomy, distribution, C^3, on-board processing</td></tr>
<tr><td>Logistics</td><td>M</td><td>Augment and replenish</td><td>Standardization, modularity</td></tr>
<tr><td>Reliability</td><td>H</td><td>Backup/swing capability vice individual system</td><td>Redundancy, self-healing constellations</td></tr>
<tr><td>Ease of Operations</td><td>M</td><td>More systems>need for standardized operations</td><td>Autonomy, C^3, processing, expert systems</td></tr>
<tr><td>Environment</td><td>L</td><td>Boost or deorbit</td><td>Extra fuel, short-life orbits</td><td>No money for nuclear</td></tr>
<tr><td>Cost</td><td>M</td><td>Trade off some capability for affordability</td><td colspan="2">Technology investment requirements heavy, but dual-use a possibility</td></tr>
</table>

Daehnick, 1999:134.

As mentioned, this approach lacks quantitative measures to gauge how well a specific alternative meets a particular value. While the implications are “derived from observation” (Daehnick, 1999:130), they are not traceable as presented in this form, and the method of observation is not specified. It is unclear whose values have been elicited in Daehnick’s analysis, so it cannot be determined if the opinions of air warriors have been represented.

The reasons Daehnick lists for the current command orientation of national security space architecture include compartmentalization due to security, a dearth of well-documented requirements for expanded capabilities, bureaucratic turf wars, perceptions of technology limitations, cost, national politics, and "an inability to articulate requirements from the side of the war fighter" (Daehnick, 1999:121-122). This thesis addresses his call for a more focused effort at demand orientation for national security space architecture by soliciting the demands (values) from the air warfare experts themselves.

VFT was also used in the source selection for the next generation of imagery satellites for the National Reconnaissance Office (NRO). Burk, Deschappelles, Doty, Gayek, and Gurlitz (2002) applied VFT in the form of multiattribute value decomposition which resulted in 6 values at the first level (assuredness/robustness, design scalability, flexibility, quality, quantity, and timeliness) which were decomposed into 24 values at the second level, which themselves were decomposed into 256 metrics[6] (Burk *et al*., 2002: 49). The second-level attributes and the metrics were unavailable in open sources.

Loftis (2002) extracted preliminary value hierarchies by applying content analysis to national security space doctrine. Using a method similar to the Silver Standard, three space doctrine documents were scanned to collect phrases that direct action toward objectives. These phrases were then affinity-grouped in a manner similar to that of the verbs in the Foundations 2025 study (Parnell, Conley, Jackson, Lehmkuhl, and Andrew, 1998:1340-1344). Value hierarchies consisting of the strategic objective and top two tiers were constructed for each doctrinal document from these groupings to

[6] Burk *et al*. (2002) use different terminology, with "attributes" and "sub-attributes" meaning the highest and second highest levels of the hierarchy, respectively, and "metrics" replacing attribute as previously defined.

provide a doctrinal basis for future value-focused national security space discussions. An extended excerpt from Loftis (2002) can be found in Appendix B.

Literature Review — Applications of VFT in Space Architectural Element Decisions

VFT also has practical applications in space decision making that concerns individual elements of space architecture. Lehmkuhl, Lucia, and Feldman (2001) applied VFT to assist the GPS Joint Program Office in selecting the waveform for the next generation of GPS satellites. In addition to its significance as a practical application of VFT to space decisions, an important result of this VFT model is its result in a waveform decision that was not initially the first choice of the review team.

The NRO's Advanced Systems and Technology Directorate (AS&T) was tasked with providing technology innovations to revolutionize global reconnaissance (Parnell, Gimeno, Westphal, Engelbrecht, and Szafranski, 2001:21-22). A future value model for AS&T's Technology Enterprise was requested to challenge its research and development (R&D) managers and technologists with *audacious* objectives (emphasis in original). The strategic objective was to "provide technology innovations to revolutionize global reconnaissance," and its supporting fundamental objectives were to "provide information superiority to enable NRO customers to revolutionize future capabilities," to "reduce life cycle costs by an order of magnitude," and to "rapidly design and deploy innovative technology solutions" (Parnell *et al*., 2001:22). The value model was then used to compare the value and cost of projects in progress (Parnell *et al*., 2001:25-30). Of particular interest to this study are the attributes used for some of the objectives under "visualize the operational space," a sub-objective of "provide information superiority…,” since they include qualitative values such as “plan in real-time,” (Parnell *et al*., 2001:22) and “resolve political, economic, social, and military conflicts with no loss of life or resources” (Parnell *et al*., 2001:23).

VFT was also applied in an effort to structure the resource allocation process of the NRO’s Operational Support Office (OSO) (Parnell, Bennett, Engelbrecht, and Szafranski, 2002). Whereas the previous OSO process was described as “ad hoc” or “wing it” (Parnell *et al*., 2002:78), a value model was developed to score alternatives under consideration. The Platinum Standard approach was used, with inputs coming from leaders and functional experts from both within the OSO and from other NRO organizations, and additional information supplied from OSO/NRO Gold Standard documents (Parnell *et al*., 2002:82). The interviewees were asked to identify future OSO activities which were then aggregated into functions using affinity diagrams, and objectives were specified for each of these functions to form the qualitative value model. Evaluation measures were developed for each objective by OSO management and technical leaders (Parnell *et al*., 2002:84).

New Combat Demands, New Appreciation

Much has changed in the U.S. defense posture since SPACECAST 2020 and AF 2025 were published — a war on terrorism has commenced, new organizations for the defense of the homeland have been and are being erected, and major shifts in national space policy have taken place. As new warfighting experience is accumulating, new requirements are developing, and new possibilities for space utilization are emerging, a new model of the value of national security space from the perspective of the air warrior at the point of force application is warranted to capture perspectives not previously obtained.

Having reviewed much of the professional literature that covers the interface of values and national security space decisions, attention in this thesis now turns to the research method used in this analysis of the air warrior's value of national security space.

III. Research Method

This chapter outlines the approach taken in the study. An initial hierarchy was constructed from doctrine, and was given an initial face-validation by an operational expert, a graduate of the USAF Weapons School. The initial hierarchy was then revised and presented to a panel of subject matter experts (SMEs) for their input over a series of four facilitated discussions. For difficult topics additional expertise was rendered through electronic discussions with a group of instructors from the USAF Weapons School. The expertise found at the Weapons School is recognized as the highest in the Air Force, with only seven percent of the USAF fighter pilot community ever having attended (Hehs, 1995: paragraph 11). Weapons School instructors are chosen from the best graduates after a tour of operational duty, representing an additional cut above the rest.

After the values were identified, the SMEs then developed measures, single-dimension value functions (SDVFs), and assigned local weights to the hierarchy, which was then modeled in a spreadsheet.

The Initial Hierarchy

The overarching strategic objective by which the value of space support to air combat is measured is **Leverage Space Capabilities to Enhance Air Combat Operations**. This value is at the top of the value hierarchy developed in this study.

As mentioned, the Gold Standard is often used when time with subject matter experts (SMEs) is limited. Following the precedent set in the SPACECAST 2020 study (Burk and Parnell, 1997:66), doctrine provided the starting point for the initial hierarchy. An examination of joint doctrine revealed no document dedicated exclusively to air operations. Air Force Doctrine Document 2-1, *Air Warfare*, was examined and found to provide "initial guidance for conducting air operations as part of aerospace warfare" (AFDD 2-1, 2000:v) which is consistent with the aim of this thesis. AFDD 2-1 touts Asymmetric Force Strategy as a "new American way of war" that requires "sophisticated military capabilities to achieve national objectives and avoid costly force-on-force engagements" (AFDD 2-1, 2000:3), and the five components of Asymmetric Force Strategy were considered for the first tier of values.

The First Tier Defined

The first tier of values is taken from the following five components of Asymmetric Force Strategy (AFDD 2-1, 2000:3-5): the **Commander's Conceptualization of the Battlespace**, **Controlling the Battlespace**, **Decisive Maneuver**, **Precision Employment**, and **Integrated Sustainment**. The consideration of each as a candidate for a fundamental objective in support of the strategic objective, **Leverage Space Capabilities to Enhance Air Warfare Operations** and the rationale for acceptance or rejection is explained below:

The Commander's Conceptualization of the Battlespace "includes collecting and exploiting the information necessary to identify threats and opportunities regarding national interests" (AFDD 2-1, 2000:3). National security space provides considerable leverage in support of these objectives, and thus was included as a candidate for a fundamental objective. As this thesis is focused on the perspective from the cockpit, the qualifier **Commander's** will be omitted. This value is summarized in the hierarchy as "Understand."

Controlling the Battlespace as defined in AFDD 2-1 (2000:4) is the freedom of operation necessary to enable friendly forces to "employ, maneuver, and engage forces while denying the same capability to the adversary," and thus qualifies it as a means objective that supports the objectives of **Decisive Maneuver** and **Precision Employment**. By virtue of using the same verbiage as these two other components, **Controlling the Battlespace**, while still a key concept, violates the independence requirement for a value hierarchy (Kirkwood, 1997:17-18) and was therefore *eliminated* as a direct candidate for a fundamental objective.

Decisive Maneuver involves "positioning forces to gain favorable advantages" (AFDD 2-1, 2000:4). National security space contributes to this objective by augmenting aircraft's navigational capabilities, and is included for consideration as a fundamental objective. This value is summarized in the hierarchy as "Move."

National security space contributes to **Precision Employment** by supplying information to make force application "truly precise" (AFDD 2-1, 2000:5). Airpower assets are needed to "engage the adversary on land, at sea, or in the air," and space capabilities, by virtue of their global view of these media (SPACECAST 2020, 1994: Introduction), can enhance **Precision Employment**. It is thus included as a candidate for a fundamental objective. This value is summarized in the hierarchy as "Fight."

Integrated Sustainment supports deploying and maintaining forces, and includes logistics, readiness, facilities, and modernization (AFDD 2-1, 2000:5). Although **Integrated Sustainment** is crucial to winning the air war, for the purpose of this study it was determined that these qualities fall outside of the context of national security space decisions from the air warrior's cockpit view. **Integrated Sustainment** was thus *eliminated* as a candidate for a fundamental objective for this study.

The strategic objective and the initial hierarchy developed from AFDD 2-1 are shown in Figure 1:

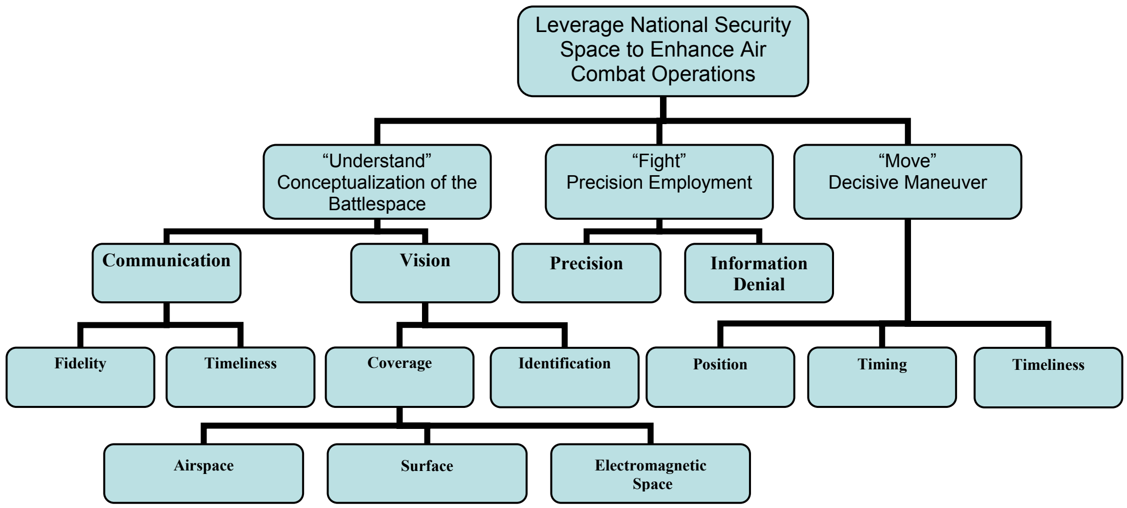


Figure 1. The Initial Hierarchy.

First Tier Value Decomposition — "Understand"

Value definition now proceeds down each first-tier branch. The "Understand" value is shown in Figure 2:

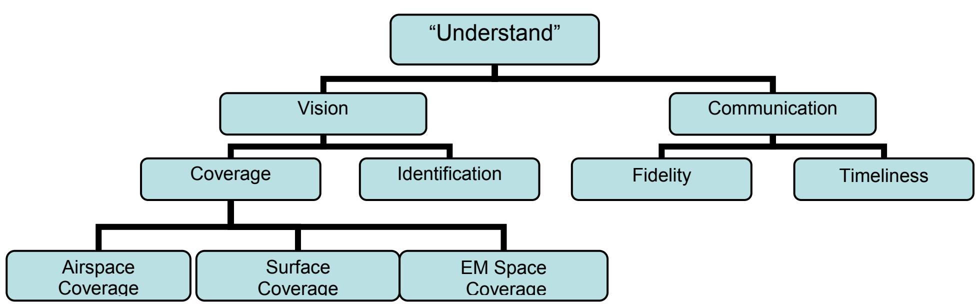


Figure 2. The "Understand" Value and Its Branches.

Supporting the **Conceptualization of the Battlespace** are the values **Vision** and **Communication**. These descend from two of the values that emerged from the SPACECAST 2020 study (Foreword): "unparalleled perspective **(Vision)** and very rapid access to the earth's surface **(Communication)**."

Understand — Vision

According to AFDD 2-1 (2000:3), "collecting and exploiting the information necessary to identify threats and opportunities" is essential to conceptualizing the battlespace. The concepts of collecting/exploiting information and identifying threats/opportunities, translate into **Coverage** and **Identification** from space-based systems. As space offers unparalleled perspective (SPACECAST 2020: Foreword), it follows that that all aspects of earth coverage of events that concern the air warrior must be considered: **Airspace Coverage**, **Surface Coverage**, and coverage of the electromagnetic spectrum **(EM Space Coverage)**. As information is collected using space-based capabilities, its exploitation value is dependent on how well the event can be identified, thus marking **Identification** as a value that falls under **Vision**.

Understand — Communication

Conceptualizing the battlespace is enhanced by the availability of information from elements outside the cockpit. JP 3-51, *Joint Doctrine for Electronic Warfare*, describes the importance of **Communication** to conceptualizing the battlespace:

> The ability to **exchange near real-time data (such as targeting information)** ***enhances situational awareness*** **and combat coordination** between various force elements including EW (electronic warfare) strike and/or execution assets, command-control units, ES (electronic warfare support) collection units, supported units, and others, is a critical combat requirement. (JP 3-51, 2000:III-6, boldface in original, italics added for emphasis)

The emphasis on near real-time data implies that **Timeliness** is a value that specifies the importance of communication. JP 3-51 also specifies that the exchange of data between force elements must be routine (JP 3-51, 2000: III-6). For a routine exchange of data to take place clarity should be the norm; constant querying of transmitted messages would indicate the exchange has not become routine practice. Thus, **Fidelity** is proposed as a value that supports **Communication**.

First Tier Value Decomposition — "Move"

Continuing with the breakdown of the first-tier values, **Decisive Maneuver**, summarized as **"Move,"** is the second first-tier value that national security space capabilities can enhance. The expanded **"Move"** value is shown in Figure 3, and is specified below:

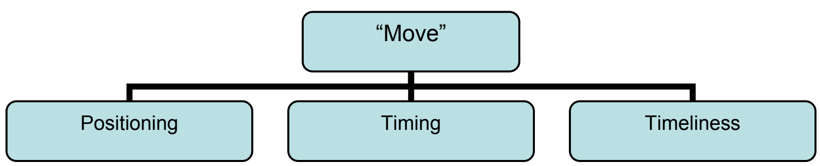


Figure 3. The "Move" Value and Its Branches.

According to AFDD 2-1, **Decisive Maneuver** is "positioning forces to gain favorable advantages over an adversary or event in anticipation of engagement or strike", with an emphasis on transitioning to **Precision Employment** (AFDD 2-1, 2000:4). **Positioning** is thus a value that supports **Decisive Maneuver.** Maneuvers must also be executed at the right time and in the right sequence in accordance with the Master Air Attack Plan (MAAP). According to AFDD 2-1, "the characteristics of targets may also dictate the assignment of timing requirements to their order of attack in the MAAP." This implies that the **"Move"** objective requires a sense of **Timing** in addition to **Positioning**. Finally, as the pace of air combat can be crucial to the outcome, the speed at which **Positioning** and **Timing** can be acquired is added as a value expressed as **Timeliness**. Together, **Positioning**, **Timing**, and **Timeliness** are grouped as **Navigation**.

First Tier Value Decomposition — "Fight"

Precision Employment is the final first-tier value to define. The expanded **"Fight"** value is shown in Figure 4, and its specification follows:

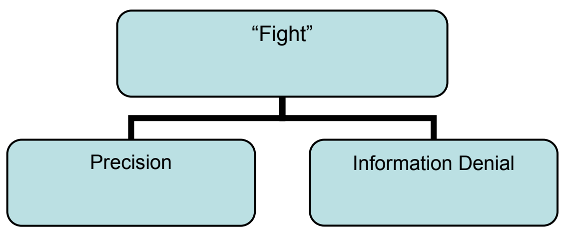


Figure 4. The "Fight" Value and Its Branches.

The **"Fight"** value is derived from **Precision Employment**, found in AFDD 2-1 (2000:5). Taken directly from the title, **Precision** describes a value space capabilities may add to air combat operations. Putting policy considerations aside, national security space may also aid in denying an adversary information which may threaten aircrews, in support of the same objectives as the policy of securing the exclusive rights to imagery over an area of conflict, as was the case over Afghanistan in the fall of 2001. (Morning Edition, 2002). Space-based **Information Denial** thus constitutes a value that may aid the air warrior.

Value Elicitation

The initial hierarchy formed the basis for interactive value elicitation from a panel of air combat experts with the requisite training and experience to offer expert opinion on air combat operations. The qualifications of the members of the panel are outlined in Table 7:

Table 7. Qualifications of the Air Combat Expert Panel.

Combat Role and Platform	Service	Experience
F-14 Pilot	Navy	Recently returned from deployment in East Asia
F-14 Radar Intercept Officer	Navy	Operation Southern Watch
EA-6B ECM* Officer	Navy	Operation Southern Watch, Operation Joint Forge, Operation Enduring Freedom
EA-6B ECM* Officer	Navy	Operation Southern Watch, Operation Northern Watch, Operation Enduring Freedom
F/A-18 Pilot	Navy	Operation Enduring Freedom, recently returned from deployment in East Asia
F-15E Pilot	Air Force	Operation Noble Eagle
F-15C Pilot	Air Force	Operation Northern Watch, Operation Southern Watch
B-52 Pilot	Air Force	Test pilot, previous combat alert duty in support of Middle Eastern Theater air operations
CH-46 Pilot	Marine Corps	Operation Allied Force, Operation Enduring Freedom

* Electronic Countermeasures

Of note is the joint nature of the group, with operational experience from three branches of the U.S. armed services represented.

Specifying the Decision Context

When identifying the values the SMEs were told that two conditions were necessary for a value to qualify. The first was that it had to represent something important to their cockpit mission. The second was that it had to be a quality that national security space capabilities provide or enhance. They were also told to exclude perceived budget and policy limitations and to focus their attention on what *they* value.

Determining the Measures and Single Dimensional Value Functions

Keeney and Raiffa note that "choosing a utility function subject to the given constraints is somewhat of a heuristic process" (Keeney and Raiffa, 1976:198).[7] In the context of choosing a utility function that may be "almost appropriate" versus searching for one that is "more appropriate" (quotes in original), they acknowledge that the decision maker is faced with weighing the disadvantages of each. Due to operational and resource restrictions, casual empiricism with the SMEs for this study was accomplished over a spectrum of distances via facilitated meetings, one-on-one interviews, and e-mail dialogue. To clarify such a complex and abstract subject as values, measures, and value functions across a diffusely located group of experts, this approach was the best fit.

In the facilitated discussions a set of candidate measures was reviewed, and the SMEs were asked to choose the most appropriate, or to improve them as needed. Upper and lower bounds were set, along with a direction of preference. The SMEs were asked if any measures were constrained by thresholds, and what effect failure to meet a threshold would have on the value under consideration.

With measures identified the focus turned to assessing the single dimension value functions (SDVFs). The SMEs were presented with three generic examples of SDVFs for the cases of both increasing and decreasing monotonicity: linear, exponential, and S-curve (later modified to piecewise linear). They were then asked to

[7] In 1976 the term "utility function" meant what we now refer to as "value functions."

assign value on a scale of 0 to 1 for levels of attainment of each measure according to the type of value function. For linear measures only the endpoints were necessary to plot, for exponential functions the endpoints plus the level that corresponds to a value of 0.5 was assessed, and for piecewise linear functions the value at each transition from one rate of value change to another was plotted.

In cases where the value assessed depended on the operational scenario (for example, the degree of acceptable collateral damage), the SMEs were told to assume that the most restrictive conditions applied (e.g., minimal collateral damage).

Weighting the Hierarchy

Per Stillwell, von Winterfelt, and John (1987:443), local weighting is recommended for hierarchies constructed from the top down. This was the method chosen for this hierarchy. To preserve consistent understanding of the definitions of each value, the SMEs themselves were asked to weight each branch of the hierarchy.

Choosing an Overall Value Function

Utility independence conditions may be used to specify the final form of the value function (Keeney and Raiffa, 1976:224). For this analysis mutual preferential independence was assumed, implying that overall value function is additive linear. As will be shown in Chapter IV, the additive linear function was modified by adding indicator variables to account for measures for which failure to meet the threshold eliminated all value.

IV. Results

Description of the Hierarchy

As mentioned in Chapter III, the strategic objective is **Leverage Space Capabilities to Enhance Air Combat Operations**. After reviewing the initial hierarchy presented in Chapter III, the SMEs developed it into a hierarchy that represented their values. In this process they identified three first-tier values that support the strategic objective: **Communication**, **Navigation**, and **Denial**. The SMEs felt that the contributions of **Communication** and **Navigation** to the strategic objective would sufficiently different with respect to the phase of the operation that they should be weighted differently. Each is therefore divided into **Pre-Flight** and **In-Flight** components to allow for different weighting with respect to the combat planning and execution phases of air operations.

The full hierarchy is shown below in Figure 5.

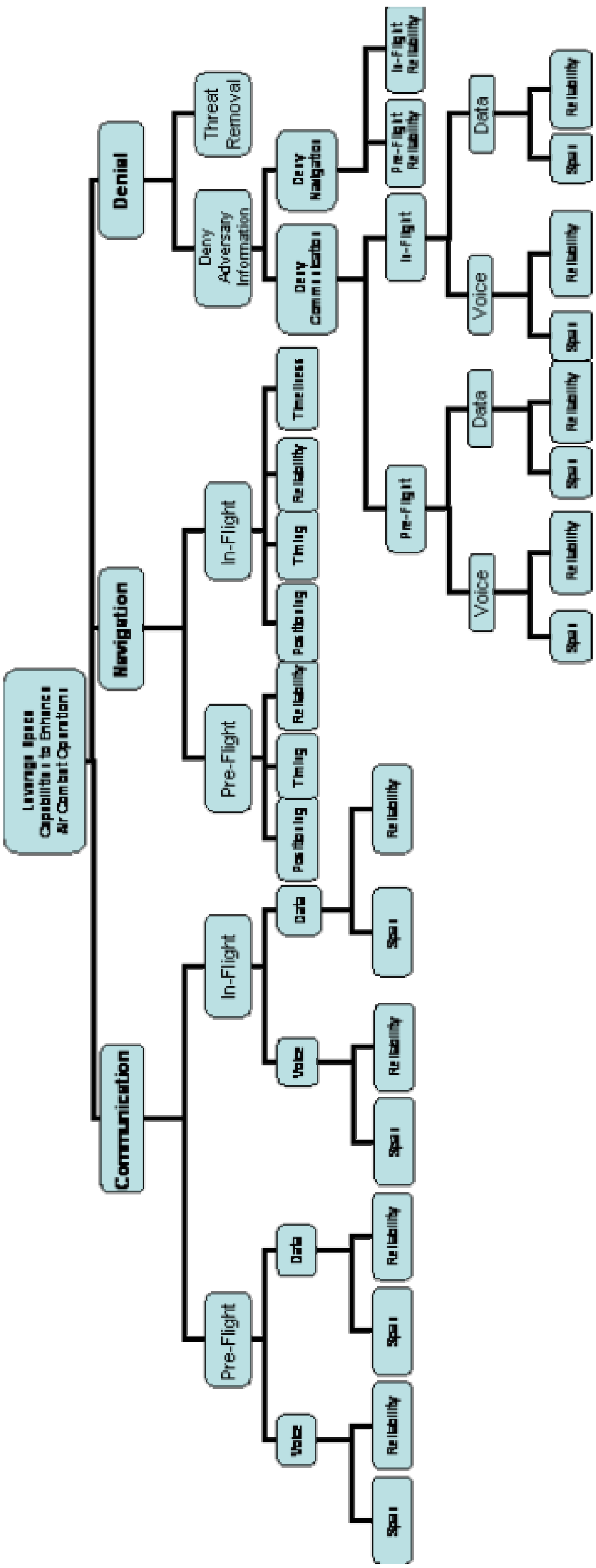
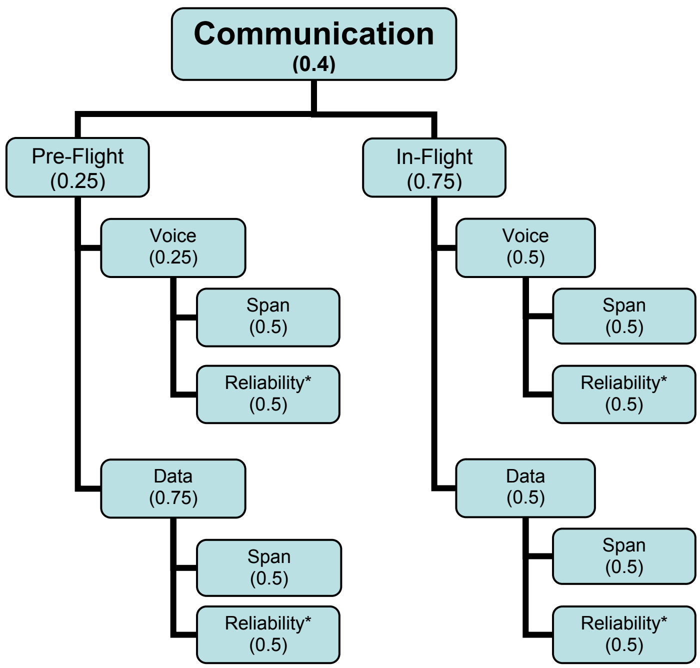


Figure 5. The Value Hierarchy.

A description of each branch follows, and the measures with their SDVFs can be found in Appendix C.

Communication

The complete decomposition of **Communication** is shown in Figure 6. The numbers in parentheses represent the local weights assigned by the SMEs.



*Indicates value preservation threshold beneath which value for all of parent value is eliminated.

Figure 6. The Communication Value and Its Branches.

As mentioned, **Communication** was divided into **Pre-Flight** and **In-Flight** components. These were each divided into **Voice** and **Data** components, which were themselves divided into **Span** and **Reliability**. At this point the SMEs agreed that **Span** and **Reliability** could be broken down no further.

Early in the elicitation process the SMEs recognized that particular thresholds of **Communication** must be met in order for a system to have value at higher levels. To incorporate this characteristic measures were identified that have value preservation thresholds, which only allow nonzero value when the threshold has been exceeded. Precedent for this can be found in Kerchner, Deckro, and Kloeber (2001:51-52), in which thresholds of attainment were identified for certain measures of Psychological Operations (PSYOPS) products. For a PSYOP product to contribute any value toward an objective, it the PSYOPS value model required to meet a threshold value for certain measures. In a similar fashion the measures shown in Table 8 that support the **Communication** value were deemed to have thresholds.

Table 8. Value Preservation Thresholds for Communication Values.

Value	Measure	Threshold	Threshold-Dependent Value
Communication — Pre-Flight — Voice — Reliability	Uptime During Pre-flight Planning	75%	Communication — Pre-Flight — Voice — Span
Communication — Pre-Flight — Data — Reliability	Uptime During Pre-flight Planning	75%	Communication — Pre-Flight — Data — Span
Communication — In-Flight — Voice — Reliability	Uptime During Operation	90%	Communication — In-Flight — Voice — Span
Communication — In-Flight — Data — Reliability	Uptime During Operation	90%	Communication — In-Flight — Data — Span

In reviewing the thresholds elicited, it can be seen that the air warrior requires a high degree of reliability for in-flight voice and data communication. If it is to be valued in the fight, it must be held to be dependable.

<u>Navigation</u>

After dividing **Navigation** into **Pre-flight** and **In-flight** components, the SMEs changed very little from the "Move" value in the initial hierarchy. As one indicator of the difference in **Navigation** value with respect to operational phase, the SMEs considered **Timeliness** to be worthy of inclusion only in the **In-flight** portion of **Navigation**. The remainder of **Navigation** is symmetric, consisting of **Positioning**, **Timing**, and **Reliability**, which then had measures attached.

The complete decomposition of **Navigation** is shown in Figure 7.

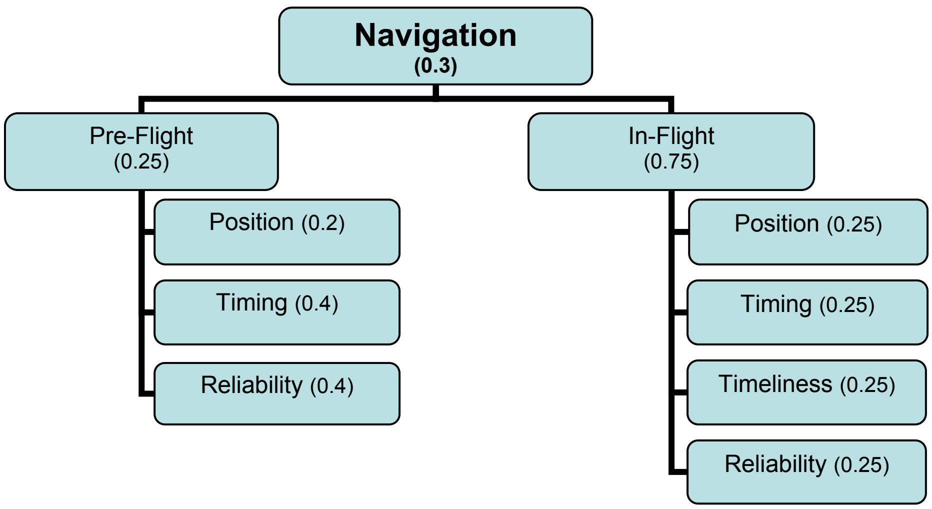


Figure 7. The Navigation Value and Its Branches.

<u>Denial.</u>

The SMEs defined **Denial** as the ability of a space-based system to protect aircrews from threats. The full decomposition of Denial is shown in Figure 8.

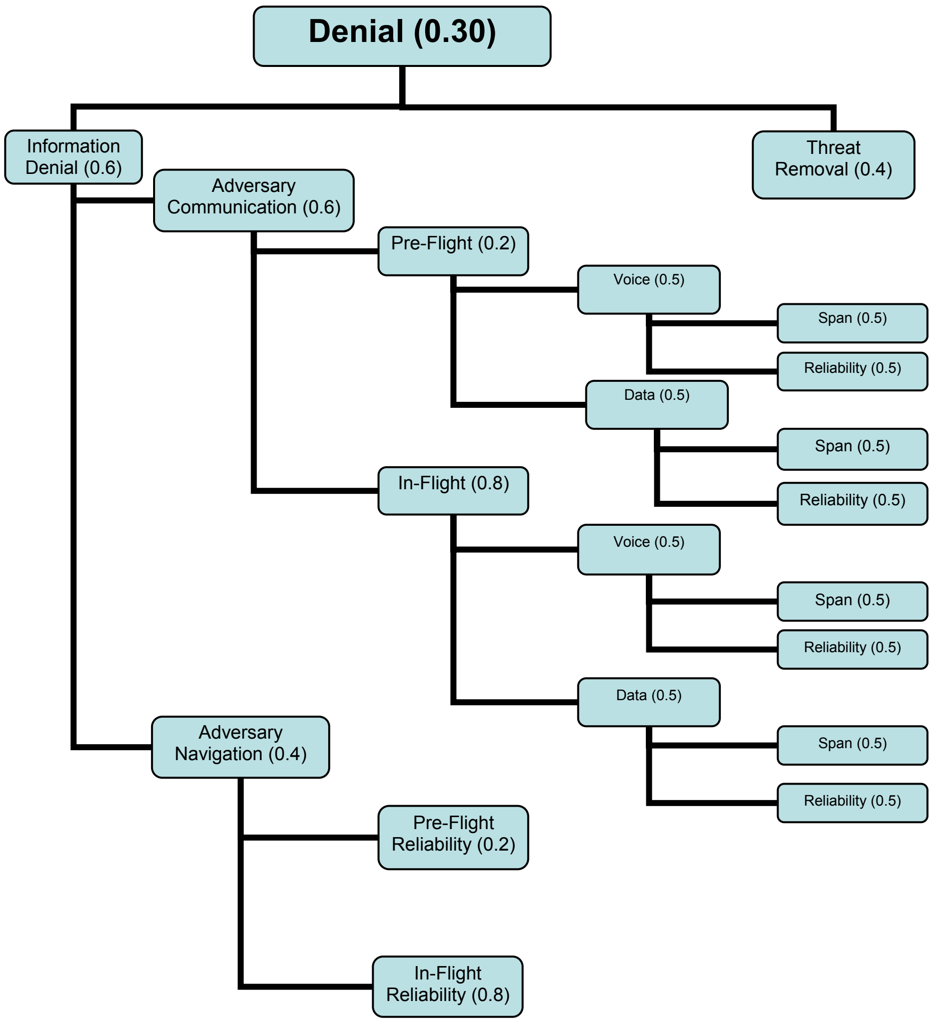


Figure 8. The Denial Value and Its Branches.

The SMEs felt that, should a space-based capability to protect aircrews be developed, it would be important for that capability to deny an adversary information and to destroy threats that the adversary may pose. **Information Denial** was specified to have two components, **Adversary Communication** and **Adversary Navigation**. These values were broken down in the same manner as the **Communication** and **Navigation** values in the first tier of the hierarchy, with the reasoning being that opponents in an armed conflict, both being human, will value **Communication** and **Navigation** in the same way. The SMEs decided, however, that the thresholds identified in **Communication** would not apply to **Adversary Communication**, and that denying an adversary a reliable navigation capability in both phases was the only value that should be included under **Adversary Navigation**

The other value under **Denial** is **Threat Destruction**. This value could not be further decomposed by the SMEs, and its value was determined to be best expressed in qualitative terms. The measuring scale was categorical in the direction of increasing threat.

The Measures and Single-Dimensional Value Functions

The base-level measures identified by the SMEs are listed below in Table 9. All but one of them (**Threat Destruction**) are repeated in the hierarchy due to the division of values by mission phase and the assumed similarity of **Communication** and **Navigation** appreciation on the part of both friendly and adversary forces. Complete descriptions of each measure and its associated SDVF can be found in Appendix C.

Table 9. Measures at the Base Level of the Hierarchy.

Base-Level Value	Measure	Comments
Span	Bandwidth Increase	Bandwidth was identified as a proxy for the volume of information. Although an argument could be made for naming the value **Capacity**, the SMEs retained the term **Span**. The SMEs felt that the value of increased bandwidth could best be expressed as a factor of improvement over current capability.
	Area of Coverage	Fixing a numerical value on the area of coverage proved problematic, so a categorical measure was identified to represent increments of value to the air warrior.
Reliability	Uptime	The % of time the capability is available.
Positioning	Horizontal Error	Error (in ft). The SMEs thought that ft is more commonly used than meters by aircrews.
	Altitude Error	See Horizontal Error comments.
Timing	Timing Error	Difference from true time in sec.
Timeliness	Update Time	Time between request and receipt for a navigational update .
Threat Destruction	Level of Threat	No direct measure for threat level posed by an adversary could be readily identified, so value was assessed according to categories.

It was decided that some values could not be measured on a continuous scale, and could be better expressed categorically. For these measures the value for each category was directly assigned. For the **Threat Destruction** value consensus between the points of view of the B-52 pilot and the fighter pilots was reached in the following manner. All were asked to rank and number the four threat categories (anti-aircraft artillery (AAA), tactical surface-to-air missile (SAM), strategic SAM, and airborne aircraft) in increasing order (1 to 4). The ranks for each threat category were then summed and normalized to find their relative value. The results are presented below in Table 10:

Table 10. Assessed Values of Threat Destruction.

	AAA	Tactical SAM	Strategic SAM	Airborne Aircraft
Bomber	1	3	2	4
Fighter	1	2	4	3
Total	2	5	6	7
Normalized Value = (Fighter + Bomber)/8	2/8	5/8	6/8	7/8

Weights

As mentioned, the hierarchy was weighted locally. The SMEs were asked to examine each value, beginning with the first tier, and determine the relative weights of each with the constraint that they all sum to one.

V. Conclusions

The SPACECAST 2020 study was completed in 1994, nine years prior to this one. Values, objectives, and the technical means to achieve them change over time, and the SMEs were asked to recommend a revisit time for this study. In their judgment five years is an adequate revisit time to determine if changes in objectives and means have caused changes in the air warrior's value structure for space capabilities.

Insights Revealed

This analysis reveals several insights into space support for air operations that have not been documented in previous studies of the value of national security space. The conclusions that can be drawn from this research include

1. The value of space support varies according to the mission phase.
2. The air warrior's demand for data in the cockpit is expected to grow as more is supplied.
3. Thresholds exist for reliability measures that eliminate the entire contribution of the parent value to the overarching strategic objective.

More discussion of these conclusions follows.

<u>Mission Phase Matters</u>

The value the air warrior places on the space-enabled capabilities delivered varies with phase of operation. Weights for both **Communication** and **Navigation** were 0.25 for the pre-flight phase in which mission planning is the focus, but soared to 0.75 for the in-flight portion in which rapid decision-making and intense multi-tasking occupy much of the air warrior's time. This insight has operational implications for synchronizing Space Tasking Orders (STOs) with Air Tasking Orders (ATOs) for a given theater or theaters (AFDD 2-2, 2001:37-39). Space support to the air warrior should be optimized for the time periods when more aircraft are in the in-flight phase, as specified by the ATO for a given operation.[8]

Data vs. Voice

A picture is worth a thousand words, or, in the air warrior's parlance: a heads-up display image is worth a thousand voice transmissions. The air warrior forecasts a burgeoning need for data, as proxied by the measure of bandwidth. Although there is some uncertainty specifying the upper end of the scale for the air warrior's value of data volume, there is no contest in the air warrior's mind between data and voice communication. A set of images gives the air warrior a far better concept of the battlespace than does a set of voice transmissions. The only limitation on the air warrior's value of data mentioned in the discussions was human processing ability.

Value Preservation Thresholds

Another insight not found in previous VFT analyses of national security space is that of reliability thresholds. The expected percentage of operational time, either in-flight or pre-flight, that a communication system is available is an indicator of its overall value for the specific function and phase desired (e.g., pre-flight data communication). If the air warrior cannot expect a system to be available for at least the threshold percentage, it contributes zero value not only to its reliability score but also to its span score. Although SPACECAST 2020 included an availability score for communication value, it was not linked to the other scores subsumed by

[8] No de-emphasis of warriors not fighting in the air medium is intended here. As this analysis only covers space support to the air warrior, inferences cannot be drawn on a broader scope than that of air operations. Further analysis on space support to all warfighters is recommended to determine if phase is a consideration for space support for them.

communication. The air warrior's value of communication as modeled in this thesis, on the other hand, displays a dependency of span on reliability.

The Overall Value Function

To define the overall value function**,** let the overall weight of the *i*th measure, w_i, be defined as the product of each local weight and the weights immediately above it in the hierarchy. Let X_i denote the *i*th measure, and $v_i(X_i)$ denote the SDVF for each measure. To account for the value preservation thresholds in the communication reliability measures, let the indicator variable *I* have a value of one when the threshold is met, and zero otherwise. Let the set *R* contain each value in the model whose contribution is eliminated by threshold non-attainment (communication **Reliability** and **Span**). The overall value function is then

$$v(X) = \sum_{i \notin R} w_i v_i(X_i) + \sum_{i \in R} I_i w_i v_i(X_i) \qquad (1)$$

For this analysis a companion spreadsheet with measures, SDVFs, and overall value function was developed. This spreadsheet accompanies all electronic copies of this thesis.

VI. Recommendations

Recommendations for the Present Study

Classified Value Elicitation

Although the SMEs deemed an unclassified value hierarchy to be sufficient, a value elicitation environment free of classification constraints is desired. This would presumably strengthen the focus on values by encouraging out-of-the-box thinking on the part of the SMEs. The high classification of many national security space activities considerably narrows the breadth of understanding in the warfighting community (Toler and Tindell, 2003). Since no major declassification of national security space looms on the horizon, a study in an environment that allows for classified discussion of values and measures is recommended to augment this one.

Comparing Systems

Two different types of analysis of alternatives are recommended for this model: analysis of different systems and analysis of different versions of the same system. The value model may be used to compare different architectures to assess their contribution to winning the air war in a given scenario, or to aid in source selection for a specific capability. For example, when different contractors are being considered for a communications system, the model can be used to assess the value each delivers to the air warrior.

The value model may also be used to assess the improvement of one version of a system over its predecessor, particularly if new capabilities are added. For example, if a space-based navigation system should happen to have a communications package as a secondary payload, the model can evaluate the value of such a configuration to the air warrior.

Sensitivity Analysis

As is usually done in multiple criteria decision analyses, sensitivity analysis is recommended to determine if an alternative is sensitive to variation in weights.

Cost Analysis

The output of the model is a numerical result between 0 and 1. This value can be divided by a system's cost to derive a benefit/cost ratio for comparing alternatives, following the precedent of Kerchner (2001:49-50). The cost need not be expressed solely in dollars — a value hierarchy that expresses cost in other terms, such as international political costs of space force application or research and development opportunity cost due to diverted national technical resources may be built. It is recommended that a cost hierarchy be elicited from the stewards of the public purse (the Office of Management and Budget, for example), as they represent the key decision makers on whose shoulders the cost of a space capability falls.

Test for Mutual Preferential Independence

Kirkwood (1997:239) specifies that Mutual Preferential Independence (MPI) is necessary to justify the additive value function. Every effort was made to ensure this concept in the development and elicitation stages of this model. The only exceptions, of course, were the reliability thresholds that affect other values in the model. Although the additive value function has been shown to be robust under moderately non-ideal conditions (Stewart, 1996:301-309), further research should be accomplished to ensure that MPI holds at least moderately well for this model.

Elicit Values from All Warfighters

This analysis of the air warrior's value of national security space should be broadened to determine how other warfighters value space. This analysis is a first cut at the larger problem of integrating space capabilities into the entire battlespace.

Recommendations for VFT Studies in General

Standardize Terminology

As Keeney notes in *Value-Focused Thinking: A Path to Creative Decisionmaking*, Alternative-Focused Thinking (AFT) is "the 'natural' way we have all learned to deal with decisions" (Keeney, 1992:6). SMEs are valued for their expertise within a given decision context, which has usually been accrued over time by evaluating and selecting alternatives. They therefore enter into facilitation with an AFT mindset. Communicating the idea of value requires them to think about what lies behind alternatives that makes them valuable or not, and this can be a time-consuming process that requires careful facilitation.

The multiple meanings of the word "value" itself compound this difficulty when used in facilitation. In current VFT parlance "value" can take on different meanings:

1. A quantitative result from an evaluation (the *value* of space to air combat).
2. The evaluation considerations that are distilled by using the WITI test.

Military SMEs are already accustomed to thinking in terms of core "values." Care must be taken during facilitation discussions to establish common understanding of value terminology.

Elicit a Revisit Time from SMEs

Objectives change, alternatives change, lessons are learned. At the time of the present writing, nine years have passed since SPACECAST 2020 was published. As was noted in Chapter I, many changes in national security space organization, policy, and technology have come about since then. To capture possible changes in values as a result of changes in means and ends, the value hierarchy should be updated after a time period specified by the SMEs. When asked when they would expect their values to change sufficiently to revisit the analysis, the SMEs responded that five years would be a good time to conduct this study again. To account for changing values, leadership turnover, and improvements in means of reaching goals, a SME-specified revisit time should be included as part of every VFT analysis.

Appendix A. A Review of VFT Hierarchies.

Value-Focused Thinking

Ralph Keeney, in his text entitled *Value-Focused Thinking*, states "values are what we care about… (and) should be the driving force for our decision-making" (Keeney, 1992:1). Values are what matter to us, the "principles used for evaluation" (Keeney, 1992:6) of alternatives, but, he contends, the usual approach to decision making takes a different form that he terms "Alternative-Focused Thinking (AFT)" (Keeney, 1992:4).

The AFT approach begins with identifying the problem, and then continues with immediate consideration of available alternatives. After identifying the alternatives the next step is to select the best from among them.[9] The visibility of, and familiarity with, available alternatives tends to influence the values which the decision maker thinks are important, thus masking many of the values that are germane to the decision. In this approach, values are made explicit by alternatives. Consideration of alternatives often involves listing their advantages and disadvantages, which in turn determine the values by which the decision maker will judge the alternatives. Sifting through alternatives and then identifying the principles used for their evaluation holds a great deal of intuitive appeal, as alternatives represent the "what to do" part of the decision. Keeney considers it to be "the easy way out of a decision problem," however, with "a price to be paid later when the consequences accrue" (Keeney, 1992:6). The danger in

[9] In addition to Keeney (1992:4), Charles Lindblom in "The Science of Muddling Through" (Lindblom, 1959) asserts that decision-making often begins with alternatives, but uses it to advance a quite different view. Essentially, he holds that most problems are too complex for an exhaustive consideration of all available alternatives and their consequences, and that merely tweaking previously known alternatives offers a sufficient problem-solving paradigm.

this approach is twofold: first, what is important to the decision maker may be outside the span of values originally encompassed by the alternatives considered, and second, much time may be wasted sifting through alternatives before a method of measurement has been identified.

In contrast, Keeney offers Value-Focused Thinking (VFT) as a higher leverage approach to decision making than AFT. Central to the VFT approach is the recognition that decisions need not be considered problems, but opportunities to create alternatives (Keeney, 1992:8) by beginning with what matters: values (Keeney, 1992:8-9). He states that "values of decision makers are made explicit with objectives," (Keeney, 1992:33) and goes on to explain that the decision maker's true values that drive the decision should be identified before examining alternatives (Keeney, 1992:22).

Listing objectives in order to explicate values is a good start toward identifying values; organizing them according to purpose helps structure the decision making process. To link objectives with values, Keeney separates objectives into two types: fundamental and means (Keeney, 1992:34). Fundamental objectives are those that describe why the decision is important to the decision maker; means objectives prescribe a means of attaining a higher objective.

To link means objectives to the fundamental objectives they support, Keeney applies the "Why is this important?" (WITI) test for means objectives, which asks the decision maker why he/she thinks a particular means objective is worth pursuing. This may lead to another means objective, which will also be subject to the WITI test. The WITI test is repeatedly applied in this manner.   Using this process, a candidate for a fundamental objective is identified when the response to WITI test is independent of any other objective. In other words, when an objective is important on its own merit, and not merely because it supports another objective, it may represent a fundamental objective (Keeney, 1992:66).

Keeney goes on to caution that both fundamental *and* strategic objectives satisfy the WITI test for a means objective (emphasis added), and states that a legitimate fundamental objective should only be influenced by alternatives within the decision context. If a candidate fundamental objective can be influenced by alternatives outside the decision context, then a means objective that supports the candidate fundamental objective is the actual fundamental objective (Keeney, 1992:67).

Relating Values to Each Other

Application of the WITI test begs the question "how important is this?" It is not enough to say an objective has value, but a method is needed to determine what objectives have more weight than others. To this end a model called a value hierarchy can be constructed to depict the relationships of the objectives to each other. The hierarchy depicts the strategic objective at the top, with the fundamental objectives that support it in the first tier. Each fundamental objective consists of its own supporting objectives in the second tier. This pattern continues until the base level is reached (Kirkwood, 1997:13). This final level consists of objectives that cannot be broken down further into more basic elements. An example of a generic value hierarchy is shown in Figure 9:

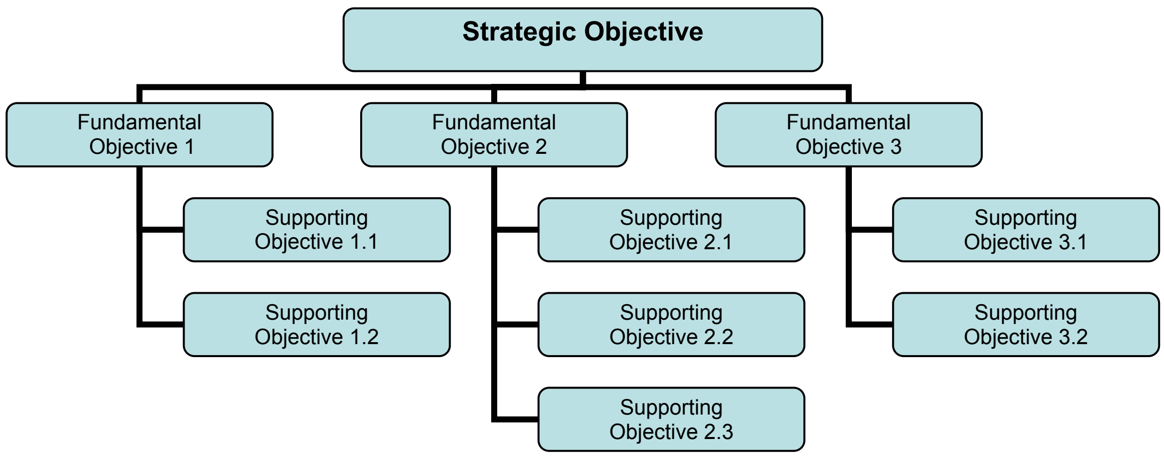


Figure 9. A Generic Value Hierarchy. An illustration of how a strategic objective, fundamental objectives, and supporting objectives are structured.

This model forms the basis for scoring alternatives to determine which contributes the most to satisfy the strategic objective.

When the value hierarchy is completed, attributes (measures) are identified that represent measurement of the base level objectives (Kirkwood, 1997:24-28). Attributes are quantifiable qualities that measure the degree of attainment of the lowest tier objectives. Other terms used include *measure of effectiveness*, *measure of performance*, and *criterion* (Keeney, 1992:100).

Keeney goes on to identify three categories of attributes: natural, constructed, and proxy (Keeney, 1992:101). Natural attributes are those that can directly be interpreted without much specialized knowledge. For example, coverage area directly expresses how much of the earth's surface is accessible to a satellite, without much specialized knowledge needed to understand its meaning. Constructed attributes are those developed specifically for a given decision context (Keeney, 1992:102). An example of a constructed attribute is the G/T ratio (gain-to-noise temperature) used to specify the performance of communications antennas; a more commonly encountered one is the system used to rank universities by national periodicals. Particular measures such as money donated by alumni and SAT scores are developed, weighted, and added together to form a score by which alternatives are ranked. Proxy attributes (proxies, for short) are used when direct measures cannot be easily identified. Proxies substitute for direct measures on the basis of a "perceived relationship" to the achievement of an objective (Keeney, 1992:103). Keeney uses the relationship of pollution to structural damage to illustrate this concept. Where an objective in environmental planning may be to minimize this kind of damage, a direct measure may be difficult to identify. In this case sulfur dioxide concentration could be used as a proxy attribute to indicate damage to structures (Keeney, 1992:103). Kirkwood distinguishes proxies by contrasting them with direct attributes, which offer a direct means of measuring the attainment of an objective, as opposed to associating it with a substitute measure (Kirkwood, 1997:24).

Attributes are the numerical input into single dimensional value functions (SDVFs), which score the value of each level of attainment for each attribute on a common scale. The simplest SDVF is linear in form, where value increases or decreases linearly as the level of attribute attainment increases.

Kirkwood (1997:62-68) recommends two types of SDVFs: piecewise linear and exponential. The piecewise linear SDVF is assessed with the assumption that the value of each attribute will change linearly for one or more increments of increase in measure. The rate of increase need not be the same for the entire scale; the change in value added (or decreased) may indeed vary over various portions of it. A hypothetical example of a piecewise linear SDVF is shown in Figure 10, where value increases at different linear rates over the measurement scale of the attribute.

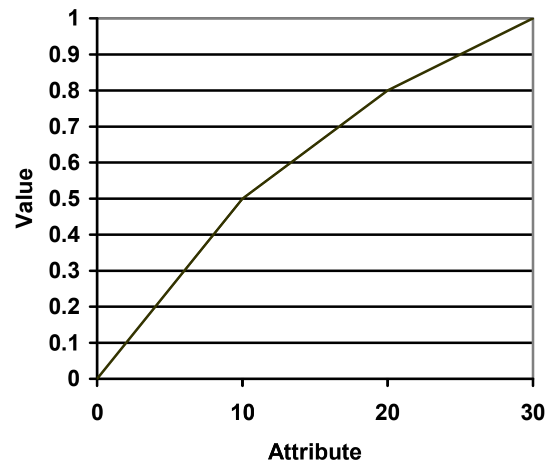


Figure 10. A Hypothetical Increasing Piecewise Linear SDVF.

The exponential SDVF allows for increasing or decreasing returns to scale, as shown in equation (2) for a monotonically increasing value function,

$$v(x) = \begin{cases} \dfrac{1-\exp\left[-\left(x-x_0\right)\big/\rho\right]}{1-\exp\left[-\left(x^*-x_0\right)\big/\rho\right]} & \rho \neq \text{infinity} \\ \dfrac{x-x_0}{x^*-x_0} & \text{otherwise} \end{cases} \tag{2}$$

and in equation (3) for a monotonically decreasing value function:

$$v(x) = \begin{cases} \dfrac{1-\exp\left[-\left(x^*-x\right)/\rho\right]}{1-\exp\left[-\left(x^*-x_0\right)/\rho\right]} & \rho \neq \text{infinity} \\ \dfrac{x^*-x}{x^*-x_0} & \text{otherwise} \end{cases} \qquad (3)$$

where exp [·] denotes the exponential function, x is the attribute under consideration, x^* represents the highest value that x can attain, x_0 is the lowest value for x, and ρ is a term called the exponential constant which determines the shape of the value function. For $\rho>0$ the SDVF will be concave, for $\rho<0$ the SDVF will be convex, and as ρ approaches infinity the SDVF will approach linearity.

When the maximum increase or decrease in value occurs in the middle of the attribute scale the S-curve value function may be most appropriate. This function depicts slow changes in value at the extremes of the attribute scale, but rapid changes near the center. A hypothetical decreasing S-curve function is illustrated in Figure 11.

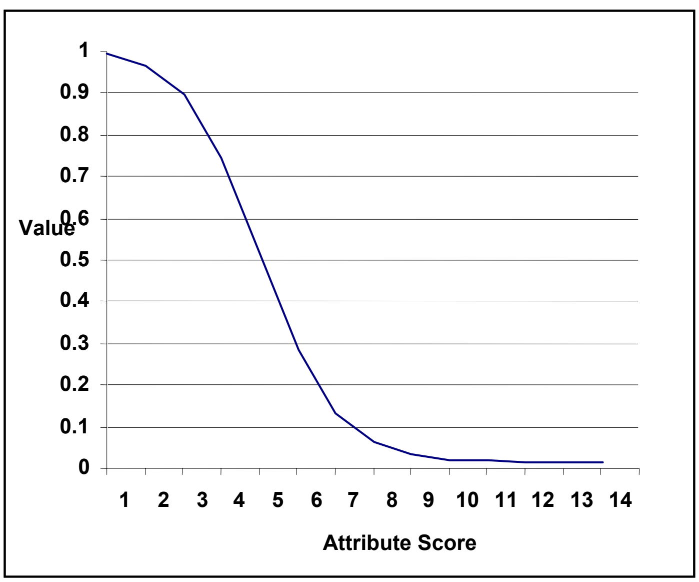


Figure 11. A Hypothetical Decreasing S-curve SDVF.

The exponential SDVF can also be used to express the decision maker's attitude toward risk (Kirkwood 1997:138-139). When applied in this fashion it is called the risk tolerance, with risk aversion expressed by $\rho>0$, risk seeking by $\rho<0$, and risk neutrality by $\rho \rightarrow$ infinity. When the decision maker's attitude toward risk is assessed in this manner, the value function is termed a utility function and is denoted by $u(x)$.

Finally, the additive linear value function is formed by weighting the SDVFs according to the preferences of the decision maker and then summing.[10] The equation for the hierarchy shown in Figure 12 has the following form:

$$v(X_1, X_2, \ldots, X_n) = w_1 v_1(X_1) + w_2 v_2(X_2) + \cdots + w_n v_n(X_n) \qquad (4)$$

where each X_i is the score for each attribute, the v_i's are the SDVFs for each attribute, the w_i's are the global weights for each value elicited from the decision maker, and n is the number of attributes. With all $v_i(X_i)$ bounded by 0 and 1, equation (4) expresses the value of an alternative in such a fashion that the least possible score is 0, and the best possible score is 1.

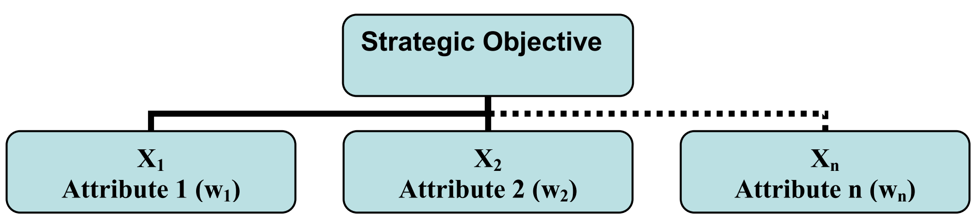


Figure 12. Hierarchical Display of a Single-Tier Additive Value Function With 3 Attributes

[10] Kirkwood (1992:253) also describes a value function form called the multiplicative utility function, which takes the risk preference of the decision maker into account and is usually determined by direct assessment (1992:254).

Equation (4) expresses the value function as a linear combination of the attributes. Many sources in the literature (Keeney and Raiffa, 1976:230), (Keeney, 1992:134), (Kirkwood, 1997:249), (Clemen and Reilly, 2001:652) state that attributes must be *additive independent* for the linear additive value model to hold, and that additive independence requires that all attributes be mutually preferentially independent. This essentially means that the preference ordering of the consequences of any attribute do not depend on the level of attainment of any other attribute or set of attributes.

To this point value hierarchies that contain only a single tier of fundamental objectives below the strategic objective have been addressed. For hierarchies with more than one tier below the strategic objective there exist three schemes of weighting. Non-hierarchical (or global) weighting is used to value each attribute against every other in the hierarchy (Stillwell, von Winterfeldt, and John, 1987:443), thus expressing each attribute's contribution to the strategic objective on a *global* basis. Global weighting takes place entirely at the bottom level, with the weights of all attributes summing to 1. For hierarchies constructed using a bottom-up approach (the Silver Standard) global weighting may be most appropriate, but for hierarchies with large numbers of attributes this scheme requires numerous value judgments to be made. Hierarchical (or local) weighting assesses the weight of each objective according to its contribution to the objective immediately above it (Stillwell *et al.*, 1987:443), with the weights of the values that comprise a single objective summing to 1. As these assessments reflect judgments made regarding contributions to a single objective, this method may be most appropriate for values constructed using a top-down approach (the

Gold Standard) that identifies values by breaking down fundamental objectives into their sub-objectives. Stillwell *et al*. also briefly describe a higher-level value hierarchy, with attributes and weights assessed at the upper-level tiers of the hierarchy (Stillwell *et al*., 1987:443). This thesis will only consider local and global weighting schemes.

Clemen and Reilly (2001:625) address the manner in which an attribute's overall weight within a locally weighted multiple tier hierarchy can be found. The overall weight for a single attribute is calculated by multiplying its local weight by the local weight of each objective directly above it up to and including the first tier. For the hierarchy in Figure 13, global weights for supporting objectives 2.1, 2.2, and 2.3 would be 0.3 X 0.4 = 0.12, 0.3 X 0.4 = 0.12, and 0.3 X 0.2 = 0.06, respectively.

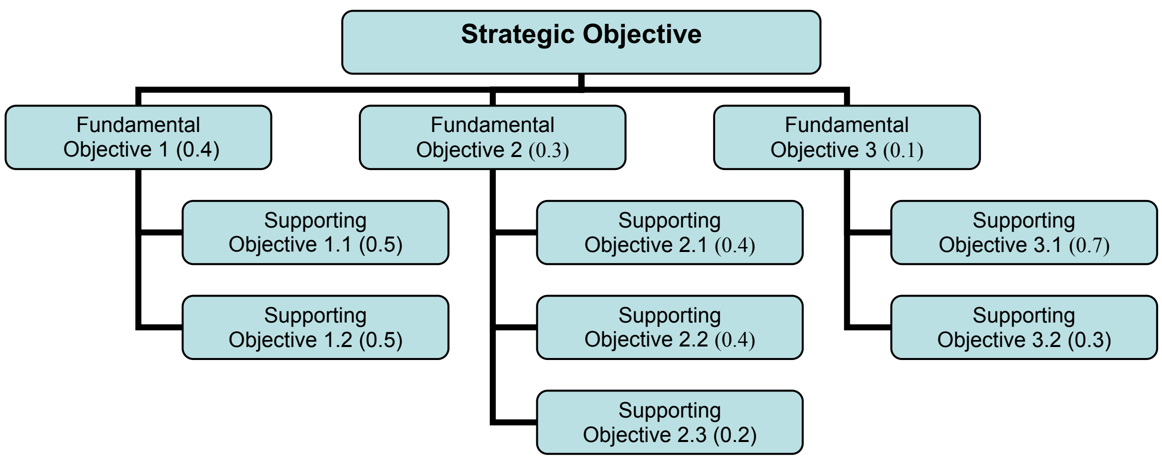


Figure 13. Generic Value Hierarchy With Local Weights Added.

Kirkwood specifies the characteristics a value hierarchy should have: completeness, nonredundancy, decomposability, operability, and small size (Kirkwood, 1997:16). Completeness means that every key value of the decision maker should be included in the model; omitting one or more would not fully evaluate an alternative under consideration. This concept is also called collective exhaustiveness (Keeney, 1992:78). Nonredundancy requires that each value be counted only once in the hierarchy; double counting would give a value disproportionate weight in the model. Related to nonredundancy is mutual exclusivity (Keeney, 1992:78), which specifies that each objective in a hierarchy should be defined in such a manner that its components can be clearly separated into clearly discrete components. This is often combined with the preceding characteristic to form the MECE (mutually exclusive, collectively exhaustive) principle.

Decomposability occurs when the contribution of one measure is independent of the contribution of the others. An example of a value that is not decomposable comes from Kirkwood: in the context of looking for employment, suppose that the value "economic issues" consists of "pension benefits," "salary," and "medical coverage." The value of a good salary may be offset by a bad pension or bad medical plan. In this case "economic issues" is not decomposable, as a change in one of its sub-values affects the others (Kirkwood, 1997:18).

Operability is the usability of the hierarchy to the decision maker. For example, in a large military command a value hierarchy should be constructed in a manner such that the commander can understand and use it, whether he/she is by specialty an operator, a logistician, or acquisitions officer, or a specialist of any other type.

Finally, the value hierarchy should be as small as possible in order to avoid including factors that do not have an impact on the decision. For example, when purchasing an automobile the color may be this kind of factor. If alternatives are available in all acceptable colors, or perhaps in only one color, it may not be necessary to include in the hierarchy (Kirkwood, 1997:19).

Keeney and Raiffa (1976:41-43) advocate keeping value hierarchies as small as possible. When specifying objectives from the strategic objective downward, theoretically the hierarchy could be extended to an “absurd length” by including a sub-hierarchy for every individual affected by the decision (Keeney and Raiffa, 1976:43). In their illustrative example of passenger transportation in the Northeast Corridor, this number could reach 50 million people. Although their example describes an unrealistic size for a hierarchy, it does serve to make the point for keeping the size of an actual hierarchy manageable.

This appendix has reviewed the basic principles of VFT. For more specific details the reader is referred to Kirkwood (1997), Keeney (1992), Clemen and Reilly (2001), and Keeney and Raiffal (1976).

Appendix B. Preliminary Value Hierarchies Derived from Doctrine Using Content Analysis and Affinity Grouping.

To illustrate the values inherent in national security space doctrine, an extended excerpt from a technical report completed by Loftis in October 2002 follows. Within this appendix all references to "this study" or "this analysis" refer to the technical report, and not to the analysis accomplished described in the main body of the thesis.

To obtain the values comparable to those that might have been elicited using a Silver Standard approach with a panel of experts, content analysis using inductive category development was used to collect both explicit and implied objectives from three national security space doctrine documents. Affinity grouping was applied to form the first two tiers of the value hierarchies, which were then compared with two previous value hierarchies, one of which was accomplished using the Gold Standard approach (SPACECAST 2020), with the other using the Silver Standard (ASIIS). The hierarchies extracted from doctrine were intended as preliminary studies, and as such were not weighted and only developed through the top two tiers.

This study led to two conclusions. First, the analysis method used uncovered doctrinal values that retained the capability focus of SPACECAST 2020, such as "reduce vulnerability" and "ensure freedom of action in space," but also values that depict how to organize and manage national security space activities, such as "ensure unity of command" and "focus diverse national security space activities." Further study into constructing proxy attributes is recommended in order to capture the organization and management values. The second conclusion is that doctrine now advocates raising the profile of national security space activities to the level of the highest national security priorities, as evidenced by "elevate space issues to highest levels" and "promulgate space advantages to national security community." This represents a departure from previous assessments of national security space values, which as mentioned previously, have been focused on capabilities.

Problem Statement

A New Look at the Value of Space

In January 2001 the Commission to Assess United States National Security Space Organization Management and Organization issued its final report, recommending sweeping changes in the way the U.S. utilizes space for national security purposes. The scope of the report encompasses all U.S. space activities that contribute to national security (hereafter called *national security space*), including both Department of Defense (DOD) activities and other systems that belong to non-DOD national agencies. As many of the changes recommended in the report (hereafter referenced as the *Space Commission Report*) have been implemented, it represents not only a shift in thinking with respect to national security space, but also a shift in action. The focus of this analysis is to examine systematically the change in national security space values after the release of the *Space Commission Report*, with the result being a doctrine-based value model which will provide a backdrop for more conventional elicitation from subject matter experts.

Doctrine presents fundamental principles for the employment of forces (JP-1, 2000:vi). It continually evolves as lessons learned over time are incorporated into a common frame of reference to give military commanders and their subordinates a common frame of reference for conducting operations. Doctrine "provides the distilled insights and wisdom gained from experience in warfare and other operations requiring the use of the military instrument of national power" (JP-1, 2000:I-8).

With the broad changes recommended by the *Space Commission Report* taking center stage in the space policy arena, a reexamination of what the national leadership values from space is in order. To this end, and to set the stage for further discussion of national security space values, three sources of space doctrine were identified for this analysis: the *Space Commission Report Executive Summary*, *Joint Doctrine for Space Operations* (JP 3-14, draft), and *Space Operations* (AFDD 2-2). These three publications cover space doctrine from the national, joint, and Air Force perspectives, respectively.

Although the *Space Commission Report* is not doctrine, it was selected for the study because of the value implications of the fundamental changes its authors recommend for accomplishing the nation's objectives in space. As its purpose is to assess management and organization of national security space, it does not address the full breadth of issues contained in doctrine. It does, however, specify national-level objectives for national security space, including activities outside the Department of Defense (*Space Commission Report*, 2001:2). The analysis was limited to the executive summary of the report.

Joint Publication 3-14, *Joint Doctrine for Space Operations* (draft) was selected due to its status as the highest level of space doctrine within the DOD. Military operations are almost always conducted jointly, and the joint perspective cannot be ignored in a study of doctrine, especially when such guidance comes from the highest level of military command. At the time of this study JP 3-14 (draft) was only available in draft form.

One of the Space Commission's recommendations was to establish the Air Force as the DOD's executive agent for space, citing the Air Force's budget authority for 85% of national security space assets (*Space Commission Report*, 2001:55). As this recommendation has been implemented, an examination of official Air Force space doctrine was key to this study. The 1998 version of this doctrine was analyzed, and analysis of the recent 2001 version is recommended to complete the picture of national security space values.

The approach of this study is descriptive, not prescriptive. The intent is not to judge the content of doctrine on its merits, but to determine in a systematic manner the full set of values expressed in different doctrinal texts, and to compare them with values asserted by previous doctrinal texts. Critical normative judgments about national security space values are left to the decision makers themselves.

The terms *doctrinal document* and *doctrinal text* are used in this study to include both doctrine stated as such and policy papers from which doctrinal values can be extracted. Additionally, the term *national security space* is preferred in this study over *military space* to account for the non-military space operations concepts covered by the *Space Commission Report*.

Previous Efforts to Identify Values Using Doctrine

Previous approaches to identify values from doctrinal documents include Doyle, Deckro, Jackson, and Kloeber (1997), in which fundamental objectives for information operations are extracted as they are stated in the documents, and then evaluated for suitability for a value hierarchy. Their results indicate that no document that by itself provided a complete basis for identifying information operations values, "indicating that an information warfare value model must be sought outside this context" (Doyle *et al*., 1997:46).

Another example of identifying values from doctrine comes from Kerchner, Deckro, and Kloeber (2001). In this case a value hierarchy was developed to value psychological operations (PSYOPS), with the strategic objective coming from joint psychological operations doctrine, and its supporting objectives coming from definitions in Army Field Manual 33-1 (Kerchner, Deckro, and Kloeber, 2001:46-47). At this point, with the strategic objective and its supporting fundamental objectives determined from doctrine, a team of PSYOPS experts developed the remainder of the hierarchy.[11]

Kloeber (1995) identified values from Army doctrine. Citing Army Field Manual FM 100-5, *Airland Battle Doctrine*, he developed quantitative measures for the five tenets of Army operations: agility, initiative, depth, synchronization, and versatility (Kloeber, 1995:12-14). These tenets (or values) were not necessarily directly measured. For example, one measure of synchronization was "combined arms," in which a variation value was computed in the same fashion as population variance. The data points were the various battlefield operating systems used in an operation. A high variance indicated a "lack of balance among the different combined arms, whereas a low variation indicat(ed) a very balanced effort" (Kloeber, 1995:151).

These studies extract explicitly stated values from doctrine, but no mention of implied values is made. Essentially, the only values identified are the ones that

[11] Value hierarchies are explained in greater detail in Appendix A of the thesis.

doctrine says are values. The present study approaches value identification from doctrinal documents in a different manner. The entire basic content of doctrinal documents is analyzed for objectives, with the premise that all stated objectives must be examined to identify the set of values held by the doctrine's authors. As doctrinal content is analyzed, values are identified when patterns emerge among the objectives extracted. As the same or similar objectives reappear they can be collected using the affinity grouping process, and structured into a hierarchy using value-focused thinking (VFT) concepts. Focusing on objectives directed by doctrine, the analysis excluded supplementary portions of doctrine such as appendices that merely serve to support the main text.

Doyle *et al*. (1997) did not have the advantage of an existing value hierarchy for information warfare with which to compare their results. Such a hierarchy for national security space does exist in the form of the operational analysis for SPACECAST 2020, a 1994 study directed by the chief of staff of the Air Force (CSAF) to "identify and conceptually develop high-leverage space technologies and systems that will best support the warfighter in the twenty-first century" (*SPACECAST 2020 Operational Analysis*, 1994).

Drawing heavily on draft joint doctrine, a team of experts was assembled to develop a quantitative method of assessing new systems concepts and technologies for their value in meeting anticipated requirements of the warfighter. As a starting point values were extracted from the four basic types of space operations listed in JP 3-14 (draft, 1994): force application, force enhancement, space control, and space support. Using this top-down approach the SPACECAST 2020 team then decomposed these four first-tier values into progressively more detailed sub-values until they arrived at qualities that could be measured (*SPACECAST 2020 Operational Analysis*, 1994). Doctrine was used in this case as a launching pad for an effort to identify the attributes that measure the value of national security space activities; however, there was no focus on the doctrine itself.

Without extracting values from doctrine in such a manner that they are established to be mutually exclusive and collectively exhaustive, it is possible that the values will overlap (e.g., Space Support may not be exclusive of Force Enhancement). It is also possible that they may not cover all of the guidance contained in space doctrine (e.g., insights about organization of space forces may be missed). To illustrate this point, the SPACECAST 2020 value model will be presented later in this study as a reference against which the value models extracted from space doctrine will be compared.

The Aerospace Integrated Investment Study (ASIIS) was accomplished in 1999 as a joint effort between Air Combat Command (ACC) and Air Force Space Command (AFSPC) to provide an integrated framework for air and space force modernization analysis, as well as to help each command develop its own internal investment plan (Scitor and ANSER, 1999:35). The value model for this analysis was derived from a draft version of *Air Force Vision 2015* (Lehmkuhl and Tedeschi, 2000), and was tailored from its original ASIIS form to one that specifically captured AFPSC's values by deleting those values not relevant to AFSPC (Lehmkuhl, 1999). The model was used to facilitate trade-off decisions for air and space integration studies (Scitor and ANSER, 1999:34-35), and clarified several measures used in AFSPC's previous model used for mission area assessment (MAA). This value model, called the AeroSpace Investment Model (AIM), will be presented below as a reference for comparison with the space doctrine hierarchies.

The focus of this study is to identify all the values that national security space doctrine. The approach taken borrows from both the Gold Standard and the Silver Standard methods. By using a systematic method that encompasses the entire document, a complete picture of what doctrine says is important is formed that includes not only operational capabilities such as those listed in SPACECAST 2020, but other concepts that have traditionally received less focus, due to the intent of previous studies. For example, some of draft JP 3-14 addresses command relationships of space forces under various conditions (draft JP 3-14, 2001:III-1 to III-2); this aspect was missed with the top-down approach of SPACECAST 2020 that started the value hierarchy with the four types of space operations. A systematic approach that addresses the whole message of space doctrine is needed to ensure both stated and implied values are identified. The systematic approach this study integrates concepts from content analysis to identify objectives, affinity grouping to aggregate them into values, and Value-Focused Thinking to build a value model.

Methodology

Application of Content Analysis

Objectives are often directly stated or implied in organizational directives, policies, and, as this and many other studies have shown, doctrine. These documents provide in written form directions toward accomplishment of objectives. It is the premise of this study that the content of directive documents can be systematically analyzed in order to elicit values from stated objectives. This study is intended to be a preliminary assessment of military space values, and the results herein will be most useful as a springboard to direct elicitation from an actual.

Content analysis dates back at least to eighteenth century Sweden, where it was used to settle a religious controversy over whether a collection of songs carried dangerous and dissentious ideas (Krippendorff, 1980:13). By the twentieth century it had evolved into a discipline and was applied in the fields of psychology, sociology, and political science. The arrival of computerized data processing in the 1950's made it easy to accomplish the repetitive processes of coding and quantifying textual content. Krippendorff has concluded that "content analysis has evolved into a scientific method that promises to yield inferences from essentially verbal, symbolic, or communicative data." (Krippendorff, 1980:20).

According to Weber, content analysis can be used to make inferences from text; he lists among its uses "(to) reveal the focus of individual, group, institutional, or societal attention" (Weber, 1990:9). This study will show that by uncovering the focus of institutional attention of a doctrinal text in a systematic manner by identifying objectives, the doctrine's values can be inferred, and can form the basis of a value hierarchy that can be used as an organizational decision-making tool.

Weber lists the following eight steps for creating a coding scheme for analyzing a text for content (Weber, 1990:21-24):

1. Define the recording units
2. Define the categories
3. Test coding on a sample of text
4. Assess accuracy or reliability
5. Revise the coding rules
6. Return to Step 3 (until the desired reliability has been achieved)
7. Code all the text
8. Assess achieved reliability or accuracy

These steps represent the ideal case where more than one human is available to code text. Due to manpower constraints and the preliminary nature of this study, some of these steps will be limited in their application. Where possible the impact of these limitations on the reliability of the study will be addressed.

1. *Define the recording units.* Weber lists the possible units of a text to be analyzed to include individual words, word senses, sentences, themes, paragraphs, or even the whole text, depending on the objective of the study and reliability required (Weber, 1990:21-23). Coding by individual word was eliminated primarily due to the labor-intensive effort required and its narrow scope with respect to identifying objectives. For example, the words "inception," "is," or "competent" by themselves do not indicate objectives, but require more specificity. The multiplicity of word meanings (the word "have" by itself can mean "possess" or be used to indicate the present perfect tense of a verb) and time limitations also eliminate coding by individual word.[12] Coding by word senses (the same as coding by word, but accounting for multiple meanings) was eliminated for the same reasons. Coding by sentence was eliminated not because of its inadequacy in capturing an objective, but because a sentence may contain more than one objective.

[12] Using computer software designed for content analysis would alleviate this burden, and its use is recommended for further study. Possible implications of this method include limitations on a computer's detection of meaning, much as spellcheckers in word processing software are limited in their ability to gauge word usage.

Krippendorff identifies units of analysis as physical, syntactical, referential, propositional (and kernels), and thematic (Krippendorff, 1980:60-62). Physical units are pages, issues of a newspaper, posters, and in the case of non-textual media, even frames of film and units of broadcast time. No physical unit within doctrinal documents is available as a candidate for identifying objectives. Syntactical units and items are those that are "natural" relative to the grammar of the communications medium, and do not require judgments of meaning. These are excluded from consideration due to the judgment of meaning required to identify objectives. Objectives may not appear "naturally" in doctrinal text; some interpretation may be required to determine if a word or phrase directs action toward an objective or merely sets up the context for an objective mentioned elsewhere. Referential units are used to account for the various ways a particular object, event, person, act, country, or idea may be mentioned (or referenced) in a text (e.g., interpreting Prohibition, the Eighteenth Amendment, and Volstead Act as meaning the same thing). This type of unit would be appropriate if one particular objective were under analysis, but the intent here is to identify different objectives. Propositional units (and kernels) are required to possess a certain structure or set of structures such as

subject/verb/object

Objectives in doctrinal text may have different structures, so restricting the analysis to one specific structure or a set of structures runs the risk of missing those objectives expressed in other forms.

As previously discussed, values are specified by objectives, and as stated above, most coding units are too cumbersome or restrictive to capture objectives. The thematic unit described by Krippendorff, however, does allow for the judgment of meaning required to identify objectives, and it best fits the purposes of this study. Thematic units are

> …identified by their correspondence to a particular structural definition of the content of narratives, explanations, or interpretations. They are distinguished from each other on conceptual grounds and are contrasted with the remaining portion of irrelevant material by their possessing the desired structural properties (Krippendorff, 1980: 62-63).

The conceptual ground on which this study distinguishes thematic units is the question of whether or not a portion of text contains language that directs action toward an objective. If a portion of text directs or recommends action, then it is interpreted as an objective. It is then selected as a data point for analysis. In this manner the objectives are identified for separating into categories as described below.

The objective-oriented language found in this study most often took the form of a phrase containing an action verb, as the following example from the Space Commission report shows:

> Because of space capabilities the US is better able to sustain and extend deterrence to allies and friends in our highly complex international environment. (*Space Commission Report*, 2001:11)

Here the objective stated in the text is "sustain and extend deterrence," and this objective is the data point for analysis. The remainder of the sentence describes the context for sustaining and extending deterrence — the US is the actor sustaining and extending deterrence, it is only to be extended to "allies and friends," the reason is our space capabilities, and the setting is "our highly complex international environment." Decision alternatives aimed at satisfying the objectives of sustaining and extending deterrence must fit within the bounds of the decision context: the US must be the actor, they must use space capabilities, allies and friends must be able to benefit from deterrence, and the alternative must be workable in a highly complex international environment.

2. *Define the categories*. The categories into which qualifying text falls are the values implied by the objectives. Weber describes constructing a set of content categories on the basis of a single concept (Weber, 1990:24), with the advantages being "intensive and detailed analysis of a single theoretical construct," and providing "an explicit rationale not only for what is retained, but also for what is excluded from the analysis." In this study the single theoretical construct is the objective, and the categories are the values implied therein. Affinity grouping was used to delineate the separate values into a mutually exclusive and collectively exhaustive set.

This study identifies categories as the relationships between objective phrases emerge. Mayring (2000) terms this procedure *inductive category development*. He summarizes it as follows:

> The main idea of the procedure is, to formulate a criterion of definition, derived from theoretical background and research question, which determines the aspects of the textual material taken into account. Following this criterion the material is worked through and categories are tentative and step-by-step deduced. Within a feedback loop those categories are revised, eventually reduced to main categories and checked in respect to their reliability. If the research question suggests quantitative aspects (e.g. frequencies of coded categories) can be analyzed (Mayring, 2000: paragraph 12).

In this study the research question defines the criterion of definition as language that directs action toward an objective, and the categories (the particular values) are not determined ahead of time but arise in the course of the analysis of the text. The categories were revised and reduced during the affinity grouping process (described below).

3. *Test coding on a sample of text.* To ensure that the scheme is practical for the purposes of the study, a small sample of the text should be coded before applying the scheme to the entire text. The following sample from the *Space Commission Report* tests the scheme:

> <u>Advance US Tech Leadership</u>
>
> To achieve NS objectives, and compete successfully internationally, US must maintain technological leadership in space. This requires a healthy industrial base, improved S&T resources, an attitude of risk-taking and innovation, and government policies that support international competitiveness. In particular, the government needs to significantly increase investment in breakthrough technologies to fuel revolutionary capabilities. Mastery of space also requires new approaches that reduce significantly the cost of building and launching space systems. Box: The US will not remain world's leading space-faring nation by relying on yesterday's technology to meet today's requirements at tomorrow's prices.
>
> In Table 11 an example of the coding decisions is shown:

Table 11. Testing Coding Scheme on a Sample of Text.

Objective Phrases (data points)	**Context**
achieve NS objectives	
compete successfully internationally	
maintain technological leadership	in space
requires	
a healthy industrial base,	
improved S&T resources,	
an attitude of risk-taking and innovation	
support international competitiveness.	government policies
significantly increase investment	in breakthrough technologies
fuel revolutionary capabilities	
mastery of space	
requires new approaches	
reduce significantly the cost	of building and launching space systems
(In box outside text) remain world's leading space-faring nation	US
not rely on yesterday's technology meet today's requirements	(not) at tomorrow's prices

NS = national security S&T = science and technology

Some questions arise when extracting objectives from this sample. Where do the adverbs fall, with the objective or in the context? Should the second objective be listed as "compete," "compete successfully," "compete internationally," or "compete successfully internationally?" Although the argument can be made that only the verb directs action and the adverbs merely modify the verb, including the adverb in the objective phrase specifies the objective more clearly, and allows for grouping with other verbs that fall into the same context when forming the hierarchy.[13] This places the probability of error on the side of identifying some objectives too narrowly, as opposed to missing them altogether. If an objective is identified too narrowly, the affinity grouping process will aggregate it back into its broader context.

The context for an action can be presented in negative terms, such as in the last sentence in the sample text. In this case the word "not" was added in parentheses to the context, even though it appeared in text coded as an objective. Following the same rationale as when keeping adverbs in order to retain context, the original meaning of the text is retained.

According to the scheme, the recording unit for this analysis was language that directs action toward an objective. The remainder of the text describes a decision context, or scope of appropriateness for potential alternatives in a decision situation. This study focuses on the values implied by the objectives, and, in accordance with the single theoretical construct described above, are excluded from analysis.

4. *Assess accuracy or reliability.* Weber identifies three forms of reliability pertinent to content analysis: stability, reproducibility, and accuracy (Weber, 1990: 17).

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[13] Using the affinity grouping process to categorize objective phrases into values is explained in the section entitled "Inductive Category Development Using Affinity Grouping" on p. 25.

Stability refers to the consistency achieved by the same coder coding the text multiple times. This study did not test for stability due to time constraints. Reproducibility (also called inter-coder reliability) refers to the consistency of results obtained by multiple human coders. As this study only used one coder, reproducibility is assumed, as objective phrases can readily be separated from the rest of the text. Accuracy refers to consistency of coding against a recognized norm or standard. In this case the standard to be used is the objective phrase, identifiable by a verb that directs action accompanied by adverbs and objects that specify the context of the objective.

Deciding whether a portion of text describes an objective or a decision context is, of course, subject to the coder's interpretation. There is no way to avoid differences in human interpretation of words, but using more than one coder, each working independently, would be a way to narrow this bias to within an acceptable tolerance of commonly held meanings. Weber notes this problem in estimating reliability, and recommends that disagreements between coders be resolved only after the reliability of the process has been estimated (Weber, 1990:23). The reliability of this study would be increased by using more than one human coder. Due to the preliminary nature of the study and manpower limitations, however, this was not practical. As the purpose of the study was to identify candidates for space doctrine values to augment elicitation by structured discussion, the effect of the absence of reliability testing is noted, but assumed not to affect the results in a manner inconsistent with this purpose. It is assumed in this study that another analyst coding the same texts using the same unit of analysis (the objective phrase) under the coding scheme defined above would be able to differentiate between portions of text that specify objectives and those that do not.

Another study by a different analyst using the same methodology would verify whether or not an acceptable degree of accuracy has been obtained.

5. *Revise the coding rules.* This step applies when the desired level of reliability is not attained. Readers of this report interested in doing their own analysis of space doctrine are invited to verify the results from this one in order to validate the coding scheme. Additional analyses of the topic and comparison of results with those presented in this report will improve the reliability of this analysis and its methodology.

6. *Return to Step 3.* This step applies until the desired level of reliability is attained.

7. *Code all the text.* Every objective phrase identified by the coding scheme is then extracted for the affinity grouping process described below.

8. *Assess achieved reliability or accuracy.* As mentioned in Step 4, if this study were to be done using multiple human coders, resolution of any disagreements between them would wait until all the text is coded. This prevents human collaboration from masking weaknesses or inconsistencies in the rules themselves. Verification of the reliability of this methodology by other analysts is invited.

Krippendorff acknowledges the subjectivity inherent in content analysis when he notes "how categories are defined…is an art. Little is written about it." (Krippendorff, 1980:76). The subjectivity addressed by Krippendorff does not diminish the results of this study, as its purpose is to use space doctrine values as a springboard for interactive value elicitation from "real-world" decision makers in the national security space community, which itself will have a subjective component. [14]

Inductive Category Development Using Affinity Grouping.

Forming categories as they emerge as the analysis proceeds is the textual analog of the affinity grouping procedure, which gathers and categorizes ideas that emerge during group brainstorming sessions. This method of systematically grouping data into categories was developed by the Japanese anthropologist Jiro Kawakita, who used it to assemble large volumes of detailed notes into categories by observing the patterns that emerged from them (Brassard, 1989:18).

Affinity grouping was used for the Foundations 2025 model in AF 2025 (Parnell, Conley, Jackson, Lehmkuhl, and Andrew, 1998:1340-1344). The strategic objective[15] was taken from the CSAF's original charge to the participants, "achieve air and space dominance." To obtain the objectives for the value hierarchy, the participants were asked to identify tasks that supported the strategic objective and to state them in the form of key action verbs (Parnell *et al*., 1998:1340). Verbs were isolated from nouns to the greatest extent possible to avoid institutional bias. The verbs were then aggregated into tasks by grouping related verbs together, thus encouraging mutual exclusivity (Parnell *et al*., 1998:1341). The tasks, some of which were decomposed into subtasks, formed the base level of the hierarchy. They were then structured into a value hierarchy by applying the affinity grouping process again, resulting in functions (awareness, reach, and power) that supported the strategic

[14] To address the subjectivity of the single human coder (the author of this report), a brief description of this coder's experience is in order. The coder is an engineering graduate with some recent graduate-level public administration study, and has served as a missile launch officer and missile procedures instructor.
[15] Parnell *et al*. (1998) term this the "overarching objective."

objective, "achieve air and space dominance." This analysis of national security space doctrine followed a similar methodology, except that objective phrases containing action verbs were used in place of the tasks identified by the AF 2025 participants.

Brassard defines the Affinity Diagram tool as follows:

> This tool gathers large amounts of language data (ideas, opinions, issues, etc. (*sic*)), and organizes it into groupings based on the natural relationship between each item, and defines groups of items. It is largely a creative rather than a logical process (Brassard, 1989:17).

A group brainstorming setting is an open system in which new ideas enter by harnessing the creativity of more than one participant. In this open system the intent is to generate new alternatives. In this study the system is limited to the text and the coder, whose input is limited to what is observed in the text, in a fashion similar to Jiro Kawakita's original process.

Brassard lists seven steps in creating an affinity diagram (Brassard, 1989:20-33):

1. Assemble the right team
2. Phrase the issue to be considered
3. Generate and record ideas
4. Display the complete cards
5. Arrange the cards into related groupings
6. Create the header cards
7. Draw the "finished" affinity diagram

1. *Assemble the right team*. Brassard states that a team must have the "necessary knowledge to uncover the various dimensions of the issue" (Brassard, 1989: 20). His intent here is to have as many different perspectives as possible in order to spur the creation of many ideas. Although this study is not aimed at generating new ideas, but at identifying those already stated in text, the convergence of results obtained

by multiple coders would more accurately capture values within an acceptable tolerance of commonly held meanings. For reasons mentioned above, this study uses a team of one.

2. *Phrase the issue to be considered*. At this stage in the study the issue to be considered is whether a portion of text contains language that directs action toward an objective.

3. *Generate and record ideas*. Brassard characterizes this as a brainstorming step. Although this is a study of a closed system, the idea of gathering and recording disparate pieces of information still applies. The goal is to dissect the material into movable elements that can be rearranged as logical patterns emerge.

Brassard recommends recording the emergent ideas onto cards for team access and mobility. Although this study does not use cards, the reference to cards in the remainder of the steps is left to retain fidelity to Brassard's explanation.

4. *Display the completed cards.* The cards to which Brassard refers are used so all team members can have access to the ideas generated. In this one-coder study a computer is used, and physical mobility is not an issue. In a multiple-coder study this step would be valuable at Step 8 of Weber's method for creating and testing a coding scheme.

5. *Arrange the cards into related groupings*. This procedure is largely the same as Step 2 in Weber's process and in Mayring's summary of inductive category development. Brassard prefers the term *groupings* to *categories* to encourage flexibility in the team's thinking, but this study will ignore the distinction.

6. *Creating the header cards*. Brassard's header cards "capture(s) the central idea that ties all of the cards together" (Brassard, 1989:31). In this study these are the initial objectives that will be subjected to the WITI test in order to identify values.

7. *Drawing the "finished" affinity diagram*. This step finalizes the affinity process. Brassard mentions "superheaders" that may be necessary to tie together related groupings (Brassard, 1989:33). In this study the analog is the WITI test — if two groupings appear to be related they may support the same value. Mutual exclusivity must be enforced, and if the groupings are not mutually exclusive, then the process should be repeated until mutual exclusivity is attained. An example of a "finished" affinity diagram for the value "Reduce Vulnerability" can be found in Figure 14 below.

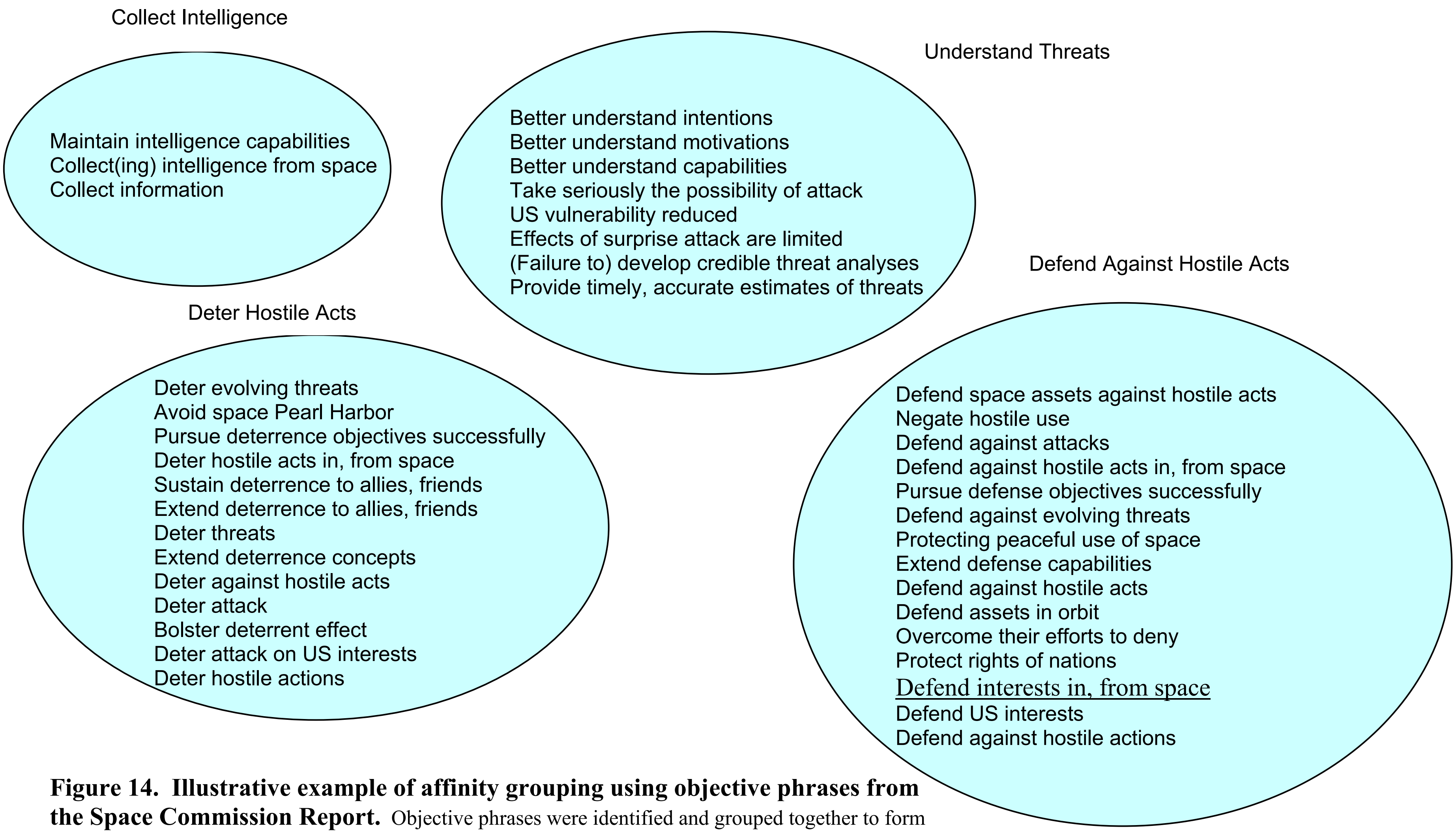


Figure 14. Illustrative example of affinity grouping using objective phrases from the Space Commission Report. Objective phrases were identified and grouped together to form values on the basis of related meanings. These values were then grouped to form the value "Reduce Vulnerability." Some of the groups of values may be decomposed further, e.g., separate "defend interests in space" and "defend interests from space," (underlined in figure).

Summary of Methodology

The content analysis the national security space doctrines analyzed in this report used objective phrases as coding units. These phrases were then affinity-grouped to form the upper levels of a value hierarchy for each. From these values the overarching strategic objective for each doctrine was inferred by applying the WITI test. The hierarchies that were extracted from doctrine were then compared with the existing value hierarchy from SPACECAST 2020 and the ASIIS study to illustrate how the values by which we measure space as a national security asset have changed.

Extracted Hierarchies

The extracted hierarchies for each doctrine are presented below, followed by the hierarchies from the *SPACECAST 2020 Operational Analysis* and ASIIS. The extracted hierarchies identified values two tiers deep, with the overarching strategic objectives inferred from the first tier of values. These values set the stage for identifying more specific values for the lower tiers of the hierarchies and developing quantifiable attributes to support them. The ideal method to accomplish this would be to discuss the meanings of the objective phrases with their authors, thus providing a validation mechanism for the study. Absent this possibility, national security space users and stakeholders are candidates for developing the remainder of the hierarchies. Depending on whether users and stakeholders fall under the aegis of national, joint, or Air Force space, the appropriate hierarchy (*Space Commission*, JP 3-14 (draft), or AFDD 2-2, respectively) should be selected for completion.

Space Commission Report

The decision context of the *Space Commission Report Executive Summary* was the "organization and management of space activities that support U.S. national security interests" (*Space Commission Report*:2). This produced a broader overarching strategic objective than was found in strict military doctrine. The strategic objective supported by the first tier of values is to "realize U.S. interests in space."

The broad national scope and focus on organization suggest great complexity in defining measures of merit at the basic level of the hierarchy. Unlike the *SPACECAST 2020 Operational Analysis* hierarchy, which was constructed over a span of four weeks and required a "a broad selection of students and faculty from the Air Force Institute of Technology, the School of Advanced Airpower Studies, Air War College, and Air Command and Staff College," (SPACECAST 2020, 1994) a fully enumerated value model for all of national security space would require input from the leadership of every national agency with an interest in space. The *Space Commission Report* suggests there are seven Cabinet-level departments, five Senate committees, six House committees, and a multitude of agencies (*Space Commission Report*, 2001:3). The difficulty inherent in assembling such large number of government decision makers for direct value elicitation argues strongly in favor of doctrinal document analysis as a method of extracting national security space values. The model constructed recognizes this difficulty, as illustrated by the value "Execute space development" which contains the sub-value "Focus diverse national security space elements." When the base level of the hierarchy is developed, proxy attributes may bridge across their various perspectives to reconcile the differences arising from the diversity of stakeholders.

The hierarchy and definitions of values derived from analysis of the 386 objective phrases in the report are presented in Figure 15.

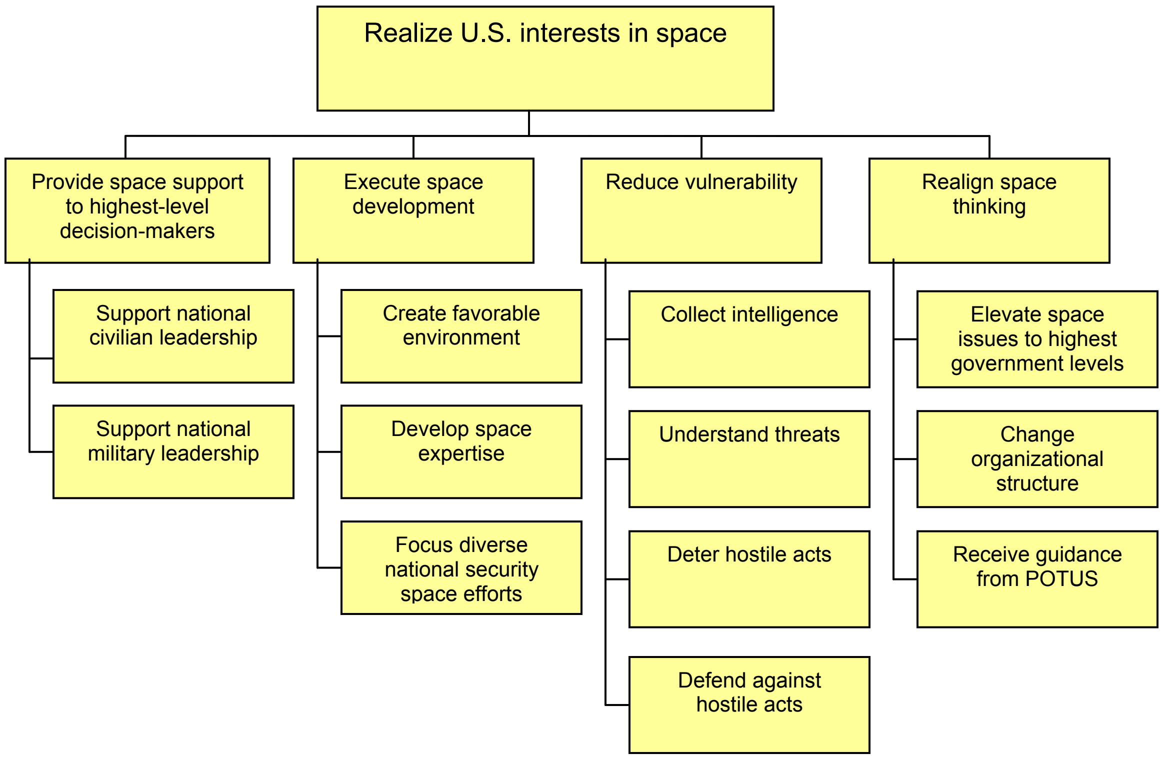


Figure 15. Value Hierarchy Derived from *Space Commission Report Executive Summary* (January 2001).

Definition of *Space Commission Report* Values

Provide Space Support to Highest-Level Decision-Makers:
Support national civilian leadership — Ensure the President has resources required to manage crises and conflicts.
Support national military leadership — Provide space-related services to augment air, land, and sea forces in support of military operations.

Execute Space Development:
Create favorable environment — Encourage a risk-taking culture of innovation and a friendly legal and regulatory environment with friendly "rules of the road" for developing space expertise.
Develop space expertise — Create and sustain a cadre of space professionals, and incorporate their expertise into new doctrine.
Focus diverse national security space efforts — Promptly merge disparate U.S. space activities.

Reduce Vulnerability:
Collect intelligence — Gather information on potential sources of vulnerability.
Understand threats — Analyze information collected to provide a better understanding of vulnerability.
Deter hostile acts — Deter actions hostile to U.S. interests.
Defend against hostile acts — Defend against hostile acts directed against U.S. interests.

Realign Space Thinking:
Elevate Space Issues to Highest Government Levels — Position and fund U.S.space organizations so that space activities are given attention commensurate with their importance.
Change Organizational Structure — Streamline U.S. government offices to improve management and oversight of space programs.
Receive Guidance from the President — Follow Presidential direction and guidance in setting the course for national security space programs.

JP 3-14 (draft)

The value hierarchy extracted from the 604 objective phrases of Joint Publication 3-14, *Joint Doctrine for Space Operations* (draft, 2001) is shown in Figure 16. Two of the values refer to operations in space: "provide responsive support to supported CINC" and "optimize space resource usage." These appear to lend themselves to more measurable decomposition than the other two, "organize for space operations" and "articulate the contribution of space," which are more conceptual in nature. Thus, the model for joint space doctrine shows that the joint doctrine authors emphasize quantification of space values more than the Space Commission did, but did not carry it as far the authors of SPACECAST 2020. The differing decision contexts (technological vs. organizational/managerial) account for the differential emphasis on quantification. As with the hierarchy for the *Space Commission Report*, when the base level of the hierarchy is developed, proxy attributes may be an accurate measure of the conceptual values.

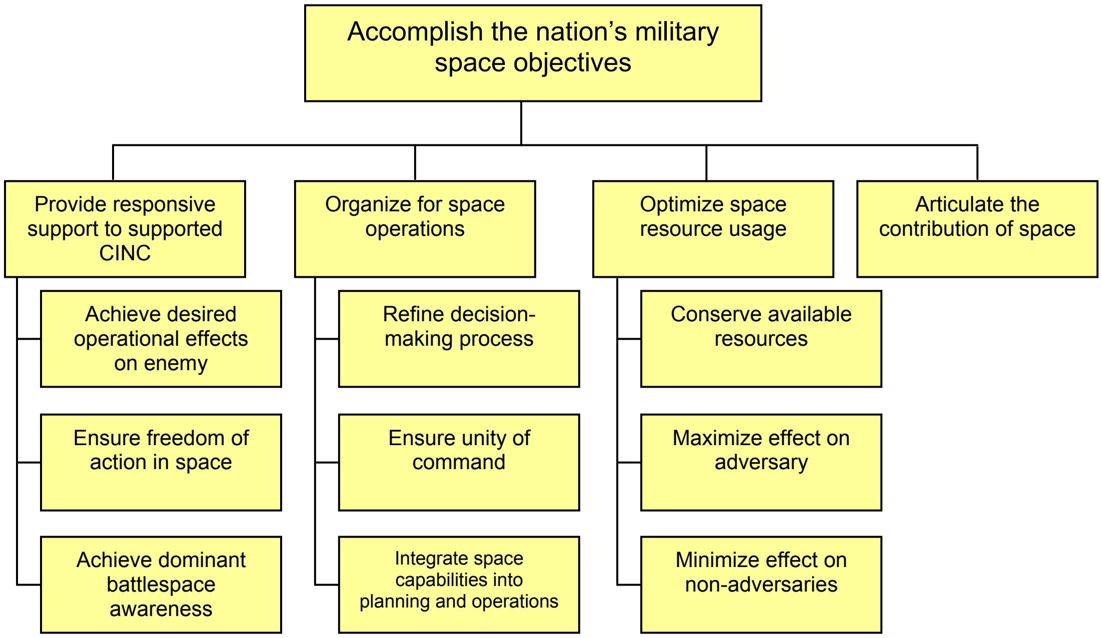


Figure 16. Value Hierarchy Derived from Joint Publication 3-14, *Joint Doctrine for Space Operations* (draft) (April 2001).

Definition of JP 3-14 (draft) Values

Provide Responsive Support to Supported Theater Commander

Achieve desired operational effects on the enemy — Use space capabilities to deceive, disrupt, deny, degrade, and destroy as necessary to remove any enemy advantage from space.

Ensure freedom of action in space — Operate space systems toward the goal of protecting space interests and gaining space superiority.

Achieve dominant battlespace awareness — Collect information, understand the situation, predict hostile actions, and disseminate information throughout the commander's theater.

Organize for Space Operations:

Refine decision-making processes — Establish requirements and priorities, reduce decision time, and codify insights so that decision-making processes are organized for support of space operations.

Ensure unity of command — Ensure clear designation of supported and supporting CINC, along with clear rules for designating command and control authority of space assets

Integrate space capabilities into planning and operations — Integrate all space capabilities (military, national, civil, commercial, and allied), the means for their protection, their supporting industrial base, and National Guard and Reserve space components into all facets of strategy, doctrine, education, training, exercises, operations of US military forces.

Optimize Space Resource Usage:

Conserve available resources — Reduce the number and type of forces needed to achieve military objectives.

Maximize effect on adversary — Maximize the effect of weapons on the adversary throughout the battlespace.

Minimize effect on non-adversaries — Minimize the effect of weapons on non-adversaries throughout the battlespace.

Articulate the Contribution of Space:

Examine and describe the role of space forces in accomplishing military objectives by identifying space as a center of gravity and considering space in development of courses of action.

AFDD 2-2 (1998)

As this analysis continues into Air Force-specific doctrine, it reveals a mix of conceptual and quantifiable values similar to the doctrinal texts examined previously. The more easily quantified values parallel some of those in the SPACECAST 2020 hierarchy, with "surveillance" appearing in each at the sub-value level, and "reduce adversary's benefit from space" in AFDD 2-2 being almost the same as "negation" in SPACECAST 2020. As with the *Space Commission Report* and JP 3-14 (draft), proxy attributes for less directly quantifiable values such as "Reach Out to Joint Force/National Leadership/Civil Sector" may be the best means to measure what they represent. The value hierarchy extracted from the 312 objective phrases of Air Force Doctrine Document 2-2, *Space Operations* is shown below in Figure 17.

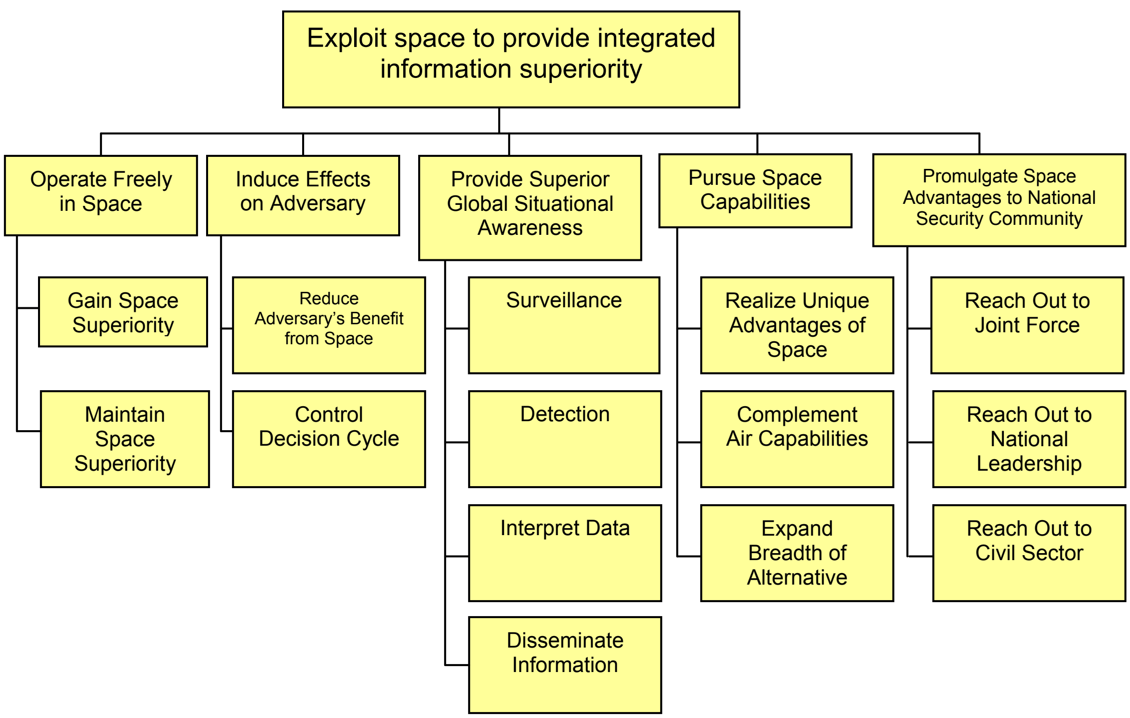


Figure 17. Value Hierarchy Derived from AFDD 2-2. *Space Operations* (August 1998).

Definition of AFDD 2-2 Values

Operate Freely in Space:

Gain Space Superiority — Gain control of activities conducted in and through the space environment.

Maintain Space Superiority — Maintain control of activities conducted in and through the space environment.

Induce Effects on Adversary:

Reduce Adversary's Benefit from Space — Use lethal, nonlethal means to achieve five major effects on adversary: deception, disruption, denial, degradation, and destruction.

Control Decision Cycle — Increase friendly forces' ability to detect, plan, and react faster than adversary.

Provide Superior Global Situational Awareness :

Surveillance — Maintain a continuous, instantaneous presence over enemy territory not available from terrestrial-based forces.

Detection — Detect enemy space and missile forces, and any alterations in the space environment.

Interpret Data — Identify enemy space and missile forces, and characterize the space threat environment.

Disseminate Information — Provide critical information essential to NCA (sic) decision process in determining response to attack

Pursue Space Capabilities

Realize Unique Advantages of Space — Use space systems to full advantage to provide unlimited range, rapid deployability, and unprecedented accuracy to friendly forces.

Complement Air Capabilities — Leverage space and air capabilities to attain air superiority early in the campaign.

Expand Breadth of Alternative Capabilities — Plan for use of civil, commercial, and allied space systems to support multipurpose operations in the space medium.

Promulgate Space Advantages to National Security Community

Reach Out to Joint Force — Augment DOD space sys in order to enhance lethality, precision, and agility of combat forces.

Reach Out to National Leadership — Employ multipurpose space systems as national policy dictates to give our national leaders the presence and war-fighting options needed for power projection.

Reach Out to Civil Sector — provide essential support and expertise to civil sector agencies performing combat, noncombat MOOTW.

At this point, the values identified from space doctrine are candidates to be broken down into quantifiable measures, as was done in the ASIIS study and in Kloeber (1995). To this end, interactive values elicitation with the decision makers and stakeholders through structured interviews would be the ideal method of identifying the quantifiable attributes needed to measure the value of national security space activities.

SPACECAST 2020

The value hierarchy constructed by the participants in SPACECAST 2020 used the types of space operations and their corresponding capabilities from the 1994 version of JP 3-14 (draft) as a starting point (*SPACECAST 2020 Operational Analysis*, 1994). The SPACECAST 2020 participants then decomposed these values into quantifiable attributes. Because of its use of both doctrine and interactive solicitation from experts, this hierarchy was selected as a basis of comparison with the value hierarchies extracted from current space doctrine.

As the decision context for SPACECAST 2020 was "to quantify and compare different systems' contributions to various space capabilities," (*SPACECAST 2020 Operational Analysis*:1), each value was decomposed into its sub-values and sub-sub-values before quantitative measures of merit were identified. For example, within the value Force Enhancement is the sub-value Communications, and it is broken down as follows in Table 12:

Table 12. Values and Weighting for the Force Enhancement Value in the SPACECAST 2020 Operational Analysis Hierarchy.

OVERALL OBJECTIVE: Control and Exploit Space				Line Item No.	Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
Force Enhancement 0.37	Communications 0.22	Crisis availability	0.35	1	Initial # links in theater	about 10	25	100	1000's
		Capacity	0.35	2	Decompressed MB/sec	300 Mbits/sec/link	600	1000	3000
		Interoperability	0.20	3	Common-use systems	Little	All AF systems	All US systems	US, commercial, intl.
		Security	0.10	4	Level of secure links	Corps	Division	Battalion	Platoon

From SPACECAST 2020 Operational Analysis, Appendix 1.

As the study of doctrinal text values only identified the first two tiers under the overarching strategic objective, only the first two tiers of the SPACECAST 2020 model are shown below in Figure 6.

The full hierarchy is displayed in Sub-Appendix 1. In Figure 17 below the top two tiers and the overarching strategic objective of the SPACECAST 2020 value hierarchy are presented.

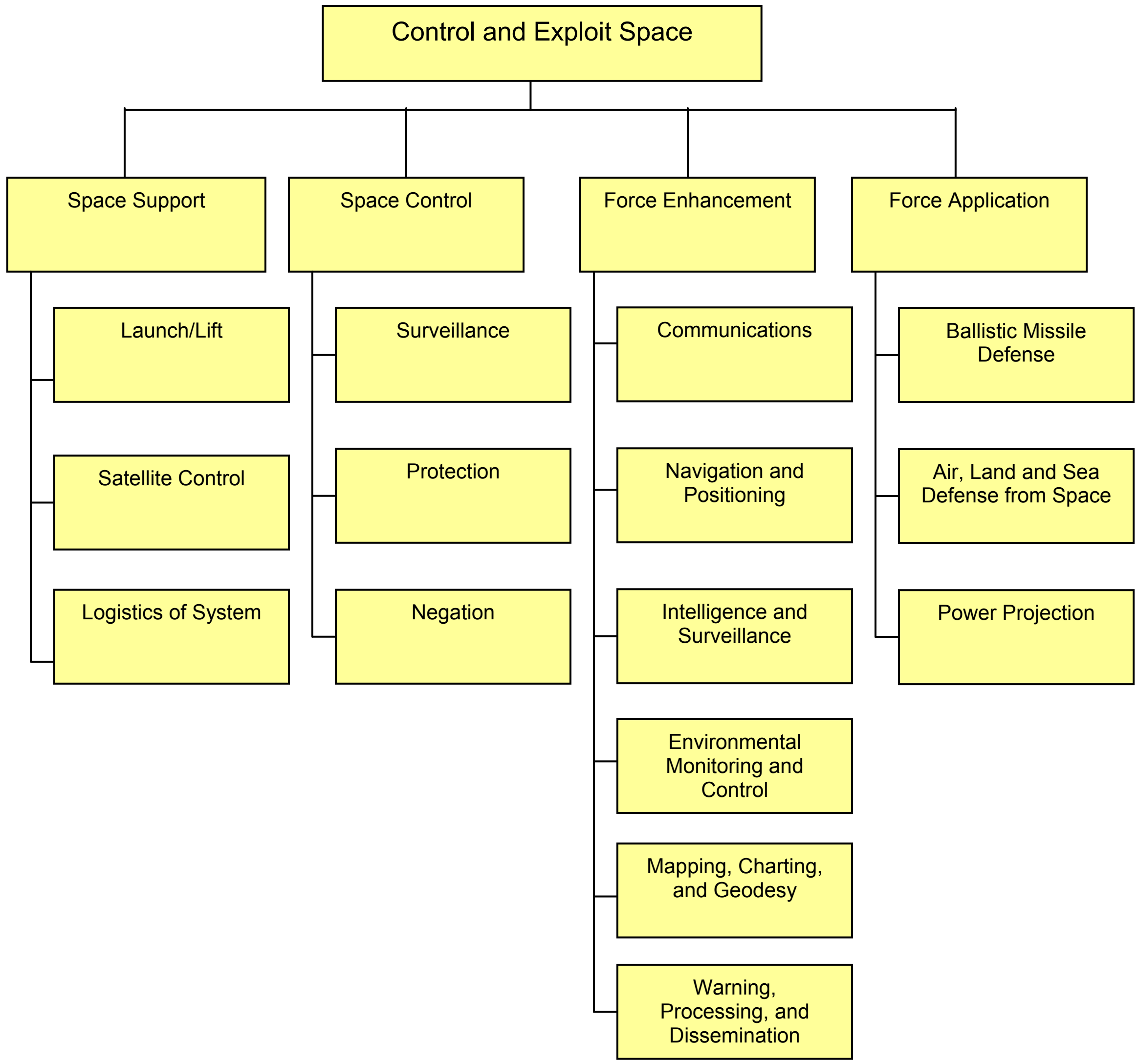


Figure 18. *SPACECAST 2020 Operation Analysis* Value Hierarchy (top two levels changed from table format to hierarchy format).

<u>AeroSpace Integrated Investment Study (ASIIS)</u>

The ASIIS produced the Aerospace Investment Model (AIM) for Fiscal Year 2004. The overarching strategic objective, *Vigilance, Reach, and Power*, was taken from the Air Force Strategic Vision from Fall Corona '99 (Lehmkuhl, 1999), and the first tier of values consisted of the following: Inform, Enable, Act. These and their sub-values touch on some of the less directly quantifiable values such as those shown in Table 13:

Table 13. Examples of Proxy Attributes from AIM.

Bottom-tier Value	**Example of "Soft" Attribute**
Inform — Command and Control — Maintain Common Operational Picture	Adequacy of Command Picture — Rating of completeness of information by key operators in the command and control chain
Inform — Command and Control — Develop Plans	Responsiveness of Plans Developed — Rating by development personnel as to the degree of responsiveness of the products they produce to create accurate command pictures
Inform — Command and Control — Execute Plans	Plan Execution Capacity — Percent plans of interest that can be coordinated at a command level
Enable — Prepare-Train-Space Operations — Missile Operators	Level of Impact of Evaluations on Systems — Level of impacts to missile operators from tests and evaluations
Act — Mission Planning- Missile Operations	Wartime Scenario Support — The percentage of wartime scenarios that can be adequately planned within 3 hours. Adequate planning will address all resources/support needed to make the missile resource positioned appropriately or immediately taskable as applicable

From ASIIS Candidate Measures, 2000 (document accompanying Lehmkuhl, 1999).

Completed in 1999, the space values identified in this study depict the shift toward inclusion of "soft" values, which will need proxy attributes for measurement. The top two levels of AIM, along with the strategic objective, are shown below in Figure 7. The full model is presented in Sub-appendix 3.

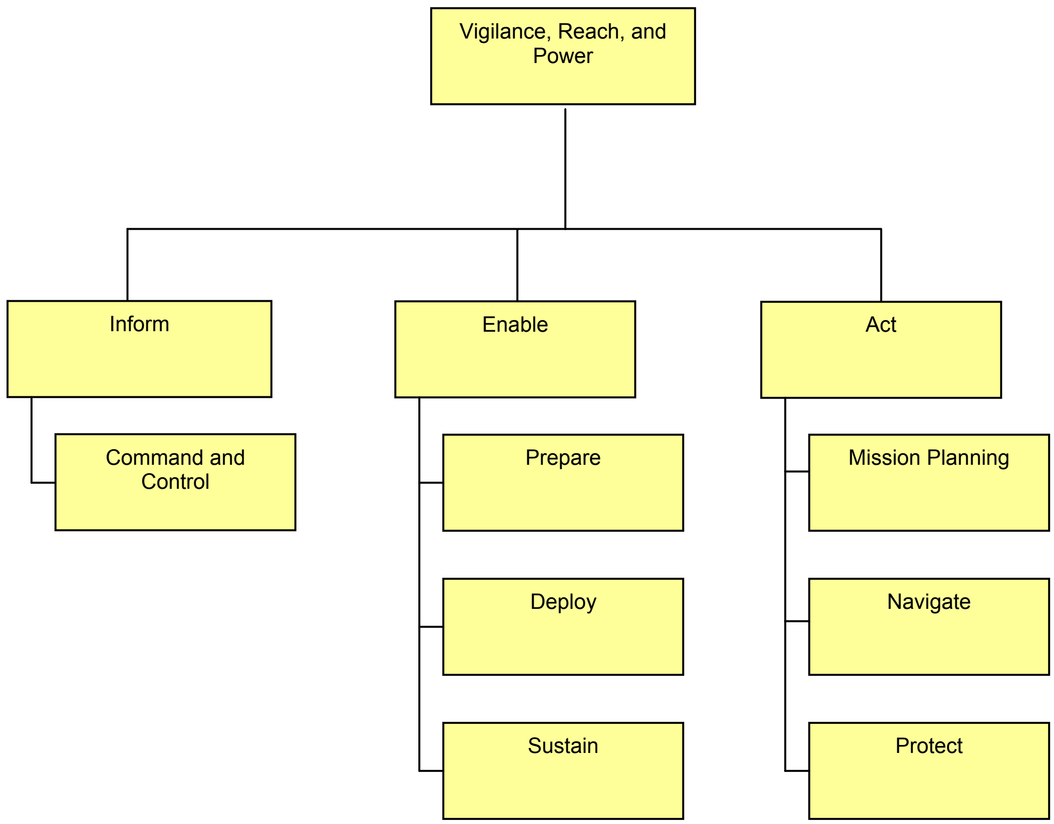


Figure 19. AIM Value Hierarchy (top two levels).

Conclusions and Recommendations

Conclusions

The more recent national security space value hierarchies display a trend toward values that represent qualities such as organization and planning that are not depicted in SPACECAST 2020 (1994). This is somewhat expected, due to the original intent of that study, which was to evaluate systems and technologies. The shift toward organization and planning objectives began with AFDD 2-2 (1998) and continued with the Aerospace Investment Model (1999), JP 3-14 (draft, 2001) and the *Space Commission Report* (2001). Table1 4 depicts a comparison of the strategic objectives and first tier values of each of these studies.

Table 14. Comparison of Strategic Objectives and First Tier of Values for the Three Extracted Hierarchies and the Two Elicited Hierarchies.

<table>
<tr><th></th><th>Strategic Objective</th><th>First Tier of Values</th></tr>
<tr><td rowspan="4">SPACECAST 2020, 1994 (taken directly)</td><td rowspan="4">Control and exploit space</td><td>Space support</td></tr>
<tr><td>Space control</td></tr>
<tr><td>Force enhancement</td></tr>
<tr><td>Force application</td></tr>
<tr><td rowspan="5">AFDD 2-2, 1998 (extracted)</td><td rowspan="5">Exploit space to provide integrated information superiority</td><td>Provide superior global situational awareness</td></tr>
<tr><td>Operate freely in space</td></tr>
<tr><td>Pursue space capabilities</td></tr>
<tr><td>Induce effects on adversary</td></tr>
<tr><td>*Promulgate space advantages to national security community</td></tr>
<tr><td rowspan="3">ASIIS, 1999 (taken directly)</td><td rowspan="3">Vigilance, Reach, and Power</td><td>Inform</td></tr>
<tr><td>Enable</td></tr>
<tr><td>Act</td></tr>
<tr><td rowspan="4">Space Commission Report, 2001 (extracted)</td><td rowspan="4">Realize U.S. interests in space</td><td>Provide space support to highest-level decision makers</td></tr>
<tr><td>*Execute space development</td></tr>
<tr><td>Reduce vulnerability</td></tr>
<tr><td>*Realign space thinking</td></tr>
<tr><td rowspan="4">Draft JP 3-14, 2001 (extracted)</td><td rowspan="4">Accomplish the nation’s military objectives</td><td>Provide responsive support to supported CINC</td></tr>
<tr><td>*Organize for space operations</td></tr>
<tr><td>Optimize space resource usage</td></tr>
<tr><td>*Articulate the contribution of space</td></tr>
</table>

* Values that represent “soft” qualities for which the SPACECAST 2020 value model does not account.

This study finds that a sea change in space thinking has taken place over the last eight years, as measured by the differing values that have emerged from value models. Whereas SPACECAST 2020 using doctrine only as a starting point focused on directly measurable attributes, the value models for the AIM study and from the space doctrinal texts include concepts such as organization, integration, and command relationships. It may be reasoned that this is not an unexpected result, given that the participants of SPACECAST 2020 were charged with producing a model with which to evaluate systems and concepts. This is precisely the point. What has changed is the direction set forth by decision makers, whether it be expressed through doctrine or directed studies such as SPACECAST 2020 and ASIIS. The direction not only encompasses directly measurable operational capabilities, but has expanded to include measurement of organization and planning not as easily measured. These are concepts that will require proxy attributes to be constructed. For example, "Rating of completeness of information by key operators in the command and control chain," (AIM: Inform — Command and Control — Maintain Common Operational Picture) will require a proxy attribute to be constructed to define "key operators" and "completeness of information."

An additional conclusion of this study was reached. In addition to measuring organizational aspects of national security space, doctrine now directs that the profile of space and what it can contribute to national security should be raised. Each current doctrinal source directs the elevation of space and its contribution to national security to a prominent level of discussion within the national security community. With the importance given to articulating the contribution of space, doctrine now seeks to bring space to the high ground of national security planning.

Recommendations

Kloeber (1995) has constructed proxy attributes to measure concepts such as organizational agility (Kloeber, 1995:130-136) and combined arms (Kloeber 1995:147-159), using time to publish orders and variance of the number of different types of battlefield operating systems as primary inputs. An examination of these attributes may lend insight to attributes that measure national security space organizational values. Further study in this area is recommended for filling out the remainder of the hierarchies.

As mentioned above, repeating this analysis by using different human coders is recommended to validate the methodology used in this analysis. A convergence of values from different analysts would indicate that the methodology is sound, while divergence would indicate that the methodology should be revisited. Content analysis software, although less capable than humans of discerning meaning from context, offers a means to ensure the same assumptions are made throughout an analysis such as this one. Further analysis is recommended in these areas.

A consideration that cannot be overlooked is that, although the Air Force has been named the DOD's executive agent for space, the other services have an interest in national security space to support their missions as well. Similar analysis of Army and Navy space doctrine is invited and recommended to determine if they value organizational concepts in a manner similar to the doctrine reviewed in this study.

Finally, doctrine is in a constant state of evolution. The 2001 edition of AFDD 2-2, *Space Operations*, has been recently made available, and a preliminary examination revealed 738 objective phrases in it. Analysis using the method outlined in this study is necessary to provide a complete assessment of the how deep the "sea change" in national security space thinking has been.

Sub-Appendix 1. Value Model from the SPACECAST 2020 Operational Analysis. Presented in tabular form. The first three columns represent the three tiers of the hierarchy, with attributes (measures of merit) for the base level of the hierarchy in the sixth column. The complete study, with alternate future scenarios with varied weights and alternatives scored is available at http://www.au.af.mil/Spacecast/monographs/ops-anal.doc

SPACECAST 2020 VALUE MODEL 27 May 94

Hierarchy with weights (Spacecast 2020 "Standard World"):

OVERALL OBJECTIVE: Control and Exploit Space

Tier 1	Tier 2	Tier 3	Weight	Line Item No.	Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
Force Enhancement 0.37	Communications 0.22	Crisis availability	0.35	1	Initial # links in theater	about 10	25	100	1000's
		Capacity	0.35	2	Decompressed MB/sec	300 Mbits/sec/link	600	1000	3000
		Interoperability	0.20	3	Common-use systems	Little	All AF systems	All US systems	US, commercial, intl.
		Security	0.10	4	Level of secure links	Corps	Division	Battalion	Platoon
	Navigation & Positioning 0.20	Availability	0.10	5	Crisis Availability	Very good	100%	--	--
		Data availability	0.25	6	Receiver size/cost	Handheld/$1000	Handheld/$100	Wristwatch/ $50	On one chip
		Accuracy	0.25	7	Location precision	10 m	1 m	1 cm	--
		Robustness	0.40	8	Resistance to CM	None (common user)	Antijam	Antijam, antispoof	AJ, AS, antivirus
	Intelligence & Surveillance 0.25	Processing Speed	0.36	9	Auto image processing	Some change det.	Search, recognition	Humans for review only	Full auto report to user
				10	(not used)				
		ID Capability	0.21	11	Image interpretability	(classified)	(classified)	(classified)	(classified)
		Coverage	0.14	12	Area per unit time	(classified)	(classified)	(classified)	(classified)
		Day-night, All Weather	0.29	13	% time data available	(classified)	(classified)	(classified)	(classified)
				14	(not used)				
	Environmental Monitoring and Control 0.07	Spectral Bands	0.20	15	Multispectral bands	5	10	100's	1000's
		Weather Prediction	0.20	16	Prediction	24 hrs	3 day	1 week	1 month
		Multispectral Coverage	0.20	17	Multispectral revisit time	7 days	5 days	1 day	Hours
		Weather Detail	0.20	18	Instant WX info	Cloud cover	Clouds+precipitation	Clds+precip+ winds	--
		Weather Control	0.20	19	Amount of control	--	Clear fog	Modify patterns	Weather on demand
	Mapping, Charting, & Geodesy 0.08			20	(not used)				
		Surface Characterizatn	0.31	21	Amount of detail	Surface terrain	Trafficability	All structures	Full resource characteriztn
		Mensuration	0.31	22	Geodetic precision	(classified)	(classified)	(classified)	(classified)
		Data availability	0.38	23	Time to get new map	Months	1 month	1 week	1 day
	Warning, Processing, & Dissemination 0.18	Coverage	0.20	24	Coverage	Ltd global ICBM	Ltd global MRBM	Global MRBM	Global SRBM/cruise
		ID Capability	0.30	25	What and where	(classified)	(classified)	(classified)	Missile type and target
		Timeliness	0.40	26	Time to tactical warning	10 min	5-10 min	1 min	Seconds
		Security	0.10	27	Resistance to CM	None	Antijam	Antijam, antispoof	AJ, AS, antivirus

Sub-Appendix 1 (continued). Value Model from the SPACECAST 2020 Operational Analysis.

SPACECAST 2020 VALUE MODEL (Part 2)

Area	Mission	Task	Subtask	Weight	#	Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
Force Application 0.19	Ballistic Missile Defense 0.37	Acquisition & Tracking 0.25	Coverage	##	28	Covered area	--	Most of Eurasia	Half of globe	World
			Accuracy	##	29	Track accuracy	--	3 m in atmos.	3 m everywhere	1 m everywhere
			Discrimination	##	30	ID/Discrimination	--	Warning of RV/decoy	Limited discrimination	Mid-course discrimination
		Survivability		0.13	31	Qualitative judgment	--	No 1-point failures	Some capacity concerted attack	Full capacity major power attack
		Kill lethality		0.23	32	Pk	--	0.7 endoatmospheric	0.7 endo & boost	> 0.7 all phases
		Timeliness		0.14	33	Required warning time	--	10 days	Hours	Seconds
		Coverage		0.14	34	Defended area	--	--	Regional	Global
		Capacity		0.12	35	RVs handled at a time	--	A few	100	Entire enemy force
	Air, Land, & Sea Defense from Space 0.27	Acquisition & Tracking 0.20	Coverage	##	36	Covered area	--	Most of Eurasia	Half of globe	World
			Accuracy	##	37	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	1 m, ground or air tgt
			Discrimination	##	38	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
		Survivability		0.17	39	Qualitative judgment	--	No 1-point failures	Some capacity concerted attack	Full capacity major power attack
		Kill lethality		0.13	40	Pk	--	0.9, fixed targets	0.5, armored vehicles	0.9, ground/air tgts
		Timeliness		0.23	41	Required warning time	--	Weeks	Days	Minutes
		Coverage		0.27	42	Covered area	--	--	Regional	Global
	Power Projection 0.37	Acquisition & Tracking 0.30	Coverage	##	43	Covered area	--	Most of Eurasia	Half of globe	World
			Accuracy	##	44	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	1 m, ground or air tgt
			Discrimination	##	45	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
		Survivability		0.13	46	Qualitative judgment	--	No 1-point failures	Some capacity concerted attack	Full capacity major power attack
		Kill lethality		0.17	47	Pk	--	0.9, fixed targets	0.5, armored vehicles	0.9, ground/air tgts
		Timeliness		0.22	48	Required warning time	--	10 days	Hours	Seconds
		Coverage		0.18	49	Covered area	--	--	Regional	Global

Sub-Appendix 1 (continued). **Value Model from the SPACECAST 2020 Operational Analysis.**

SPACECAST 2020 VALUE MODEL (Part 3)

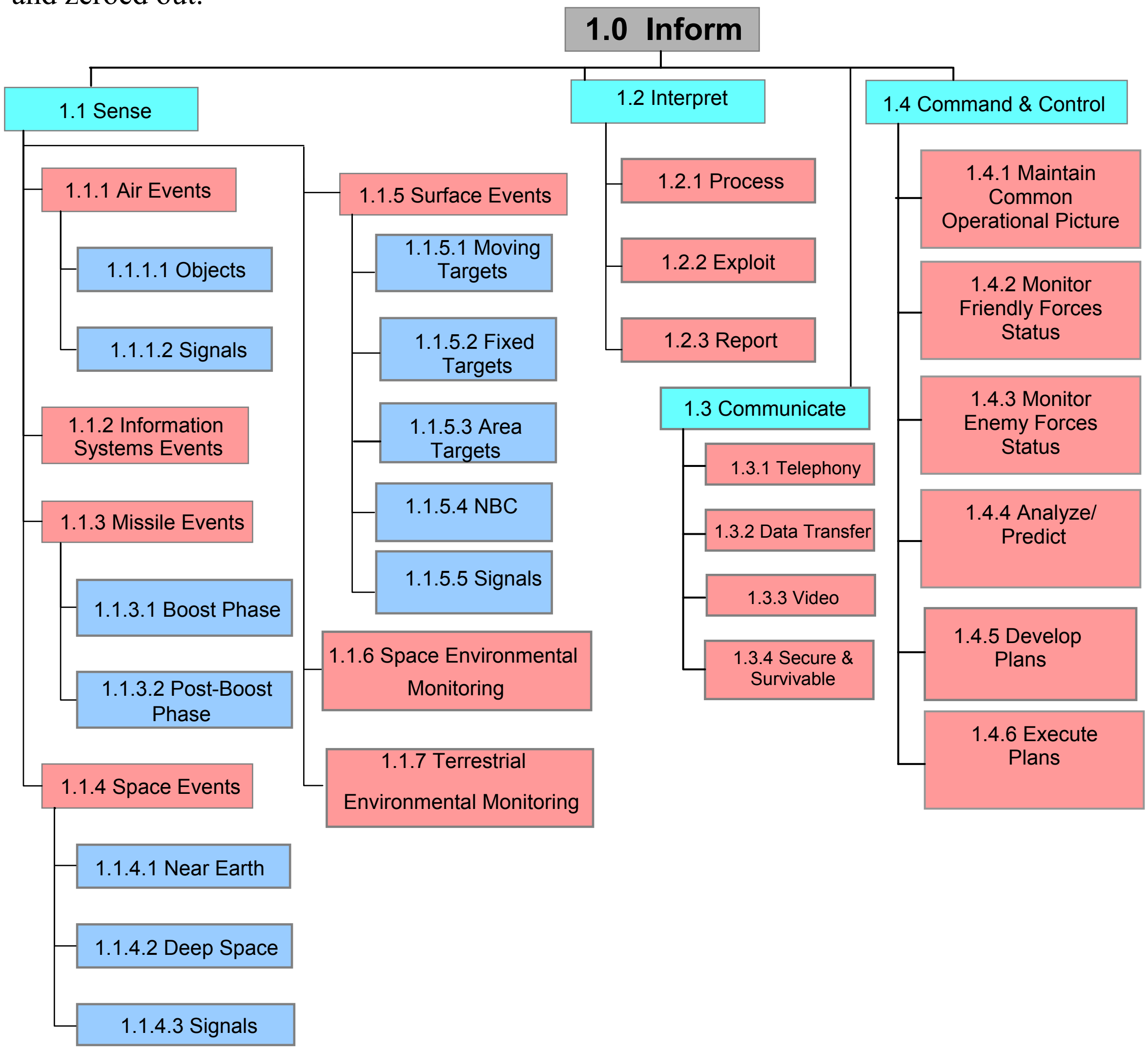
						Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
	Surveillance	Availability	Coverage	##	50	Percent of space	90% Earth orbits	All Earth orbits	Cislunar space	Heliocentric orbits
		0.33	Revisit Time	##	51	Time to view	10s of hrs	1-6 hrs	10-60 min	< 1 min
		Robustness	Survivability	##	52	Qualitative judgment	Single-point failures	No 1-point failures	Some capacity concerted attack	Full capacity major power attack
	0.33	0.33	Maintainability	##	53	Time to restore	Months +	Days	Hours	Seconds
		Accuracy	Resolution	##	54	Target sample distance	(classified)	1 m	10 cm	1cm
Space		0.33	Identification	##	55	Percent objects ID'd	(classified)	(classified)	85%	100%
Control			Track/Predict	##	56	Avg # objects lost	500	100	10	0
0.22	Protection	Active	Maneuver	##	57	Response time	Hours	1 hour	Minutes	Seconds
						Delta Velocity	m/sec	10 m/sec	100 m/sec	km/sec
		0.40	Jamming	##	58	Spectral range	Selected bands	Double # bands	All major bands	All RFs
			Decoys	##	59	Avg decoys / S/C	0	0.5	1	10
						Range of effectiveness	--	VIS	VIS+IR	VIS+IR+Radar
	0.33		Defensive Fire	0.10	60	Pk	--	0.1	0.2	0.7
		Passive	Redundancy	##	61	Qualitative judgment	Single-point failures	No 1-point failures	Some capacity concerted attack	Full capacity major power attack
		0.60	CC&D	##	62	Pd	1	0.8	0.5	0.2
			Hardening	##	63	Sure safe W on target	1 W	10 W	100 W	1 MW
			Crypto Security	0.10	64	Percent S/C with crypto	90%	100%	--	--
	Negation	Target Acq 0.20			65	Time to produce state vector after launch	Hours-days	2 hours	90 min	Minutes
		Destructive	Coverage	##	66	Percent of S/C	--	10%	20%	70%
	0.33	ASAT	Weapon Capacity	##	67	Avg # shots / target	--	0.1	1	10
		0.20	Effectiveness	##	68	Pk / shot	--	0.1	0.2	0.7
		Incapacitating	Coverage	##	69	Percent of systems	--	10%	20%	70%
		Systems 0.60	Effectiveness	##	70	Pr{incapacitate}	--	0.1	0.2	0.7

Sub-Appendix 1 (continued). Value Model from the SPACECAST 2020 Operational Analysis.

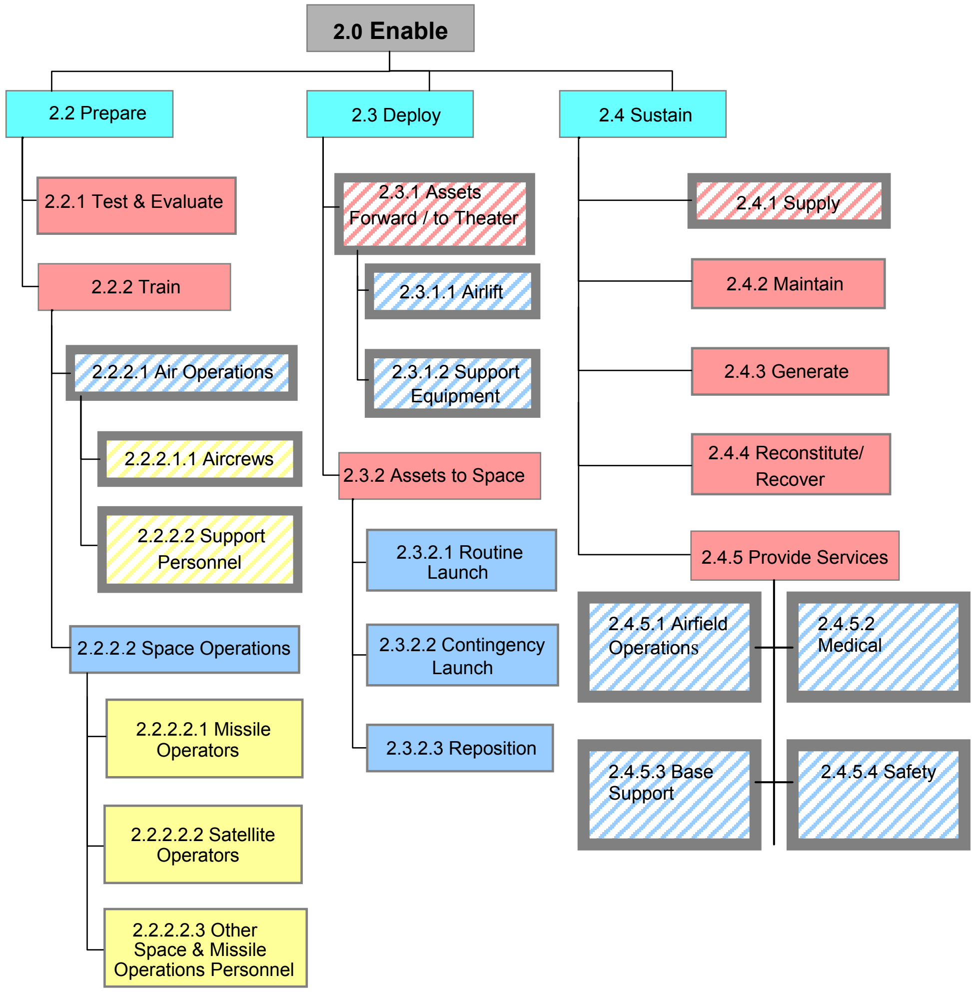
SPACECAST 2020 VALUE MODEL (Part 4)

						Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
Space Support 0.22	Launch/ Lift 0.62	Cost 0.25	Recurring	##	71	Cost/lb to orbit	$6,500	$5,000	$2,000/lb	$200/lb
			Non-recurring	##	72	Develop/procure cost	$10B	$5B	$2B	$300M
		Responsiveness 0.20	Timeliness	0.17	73	Required warning time	Months	Weeks	Days	Hours
			Orbit range	0.17	74	Inclinations achievable	30%	40%	70%	90%
			Surge capability	0.17	75	Increase in rate	1 x	2 x	5 x	10 x
			Mission range	0.17	76	Missions supported	1	2	Several	All current
			Non-destruct abort	0.17	77	Pr{soft abort|abort}	0	0.1	0.5	0.9
			Post-abort restart	0.17	78	Time to restart ops	Years	Months	Weeks	Days
		Reliability	0.15		79	Pr{destructive abort}	5%	2-3%	1%	0.50%
		Operability 0.15	Locations	##	80	# locations/orbit plane	1	2	5	10
			Fuel	##	81	Ease of handling	Cryogenic/ toxic	Part non-cryo/toxic	Mostly non-cryo/toxic	All non-cryo/toxic
			Ease of handling	##	82	Percent blue-suit	0%	10%	50%	90%
			Launch ranges	##	83	Number and location	One coastal site	--	Many coastal sites	All CONUS
			Cmd & Control	##	84	Similarity to air ops	Current launch ops	Like Pegasus/ Taurus	Further simplification	Like current air ops
		Environmental impacts	0.10		85	Toxicity and waste	High and much	Mostly dirty	Mostly clean	Clean, low waste
		Survivability	0.10		86	Type bases	Fixed/soft	Dispersed	Mobile/very dispersed	many /hardened/ mobile
		Payload	0.05		87	Max lift/launch	50K	100K	200K	--
	Satellite Control 0.20	Communications	0.33		88	Link reliability	99.999%	--	99.9999%	99.99999%
		Diagnosis	0.33		89	Avg time to diagnose	Hours	90 min	20 min	2 min
		Survivability	0.33		90	Type ground stations	Soft, worldwide	US territory	Mobile backups	Mainly mobile
	Logistics of System 0.18	Sustainability 0.40	S/C--adaptability	0.13	91	HW failure recovery	Redund-ancy only	Ltd. Reconfigure-ability	Major reconfigure-ability	Only minor mission losses
			S/C--upgradability	0.13	92	Design provisions	None	Limited	Major	Mission changes via S/W
			Grd--maintenance	0.13	93	Level of repairs rqd	Compon-ent	Board	LRU	S/W only
			Grd--maint. freq.	0.13	94	Frequency of actions	Daily	Monthly	Many months	Years
			Grd--maint. skills	0.13	95	Type of personnel	Contract specialist	Mix contract	High-skilled military	5-level
			Grd--parts	0.13	96	Type of piece parts rqd	Specialized	Mostly MIL-SPEC	MIL-SPEC	Off the shelf
			Grd--repair	0.13	97	% work value on site	100%	75%	50%	10%
			Grd--reliability	0.13	98	MTBF, critical parts	100% of system life	125% of system life	150% of system life	200% of system life
		Commonality	0.20		99	S/C commonality	System-specific	Modular subsystems	Reconfigure designs	Assemble at launch site
		Interoperability	0.20		100	S/C Interchangeability	None	Alternates available	Standard interface	S/C on any launcher
		Depots/ Infrastructure	0.20		101	Dual-use technology	Ltd use, compon-ents	Expand use	Some dual-use designs	All systems dual-use

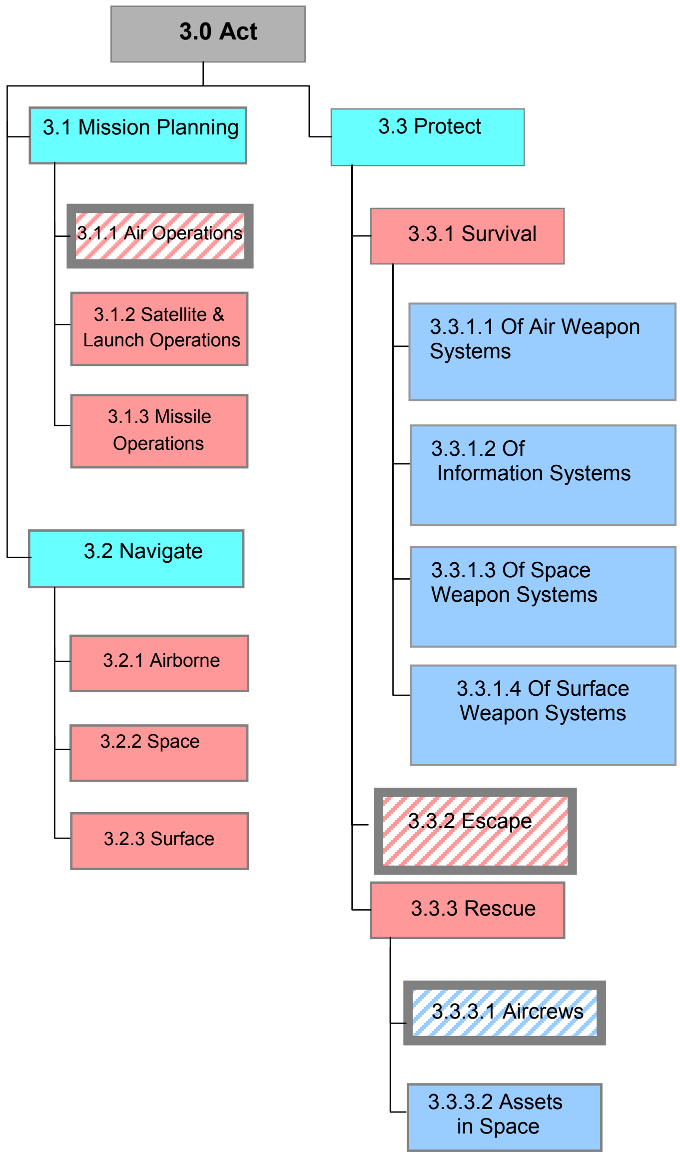
Sub-Appendix 2. Aerospace Investment Model (AIM) Value Hierarchy tailored to AFSPC's needs. The shaded areas represent values that were not applicable to AFSPC and zeroed out.



Sub-Appendix 2 (continued). Aerospace Investment Model (AIM) Value Hierarchy, tailored to AFSPC's needs. The shaded areas represent values that were not applicable to AFSPC and zeroed out.



Sub-Appendix 2 (continued). Aerospace Investment Model (AIM) Value Hierarchy, tailored to AFSPC's needs. The shaded areas represent values that were not applicable to AFSPC and zeroed out.



Appendix C. The Measures and Single-Dimension Value Functions.

General Notes

The values, measures, and single-dimension value functions (SDVFs) were elicited from a set of 9 combat aircrew members representing three services. Four structured discussions were held, interspersed with informal individual interviews. Platforms represented were B-52, F-15C, F-15E, F/A-18, F-14, EA-6B, and CH-46. Additional expertise was provided through electronic correspondence with USAF Weapons School instructors, representing F-15C, B-52, HH-60, and space operations perspectives.

The term subject matter expert (SME) is used below to represent a member of the discussion while Weapons School experts are identified directly. The term air warrior is used to represent all combat aircrews collectively.

Below is a brief commentary of how the scales and SDVFs were elicited, followed by the measures and SDVFs.

Span

Span of communication was found to be poorly represented by continuous numerical scales. Additional distance does not represent additional value to the air warrior, and in some cases it represents less. The ability to communicate across categories of operating locations — area of responsibility (AOR) (the example given was southern Iraq), unified command (the example given was USCENTCOM), hemisphere, and the globe — are considered more accurate discriminants of value. The air warriors deem hemispherical and global span of communications to be relevant for measuring reach-back support communication to CONUS locations, and that the AOR and unified command categories were appropriate for measuring coordination in a joint warfighting environment.

Bandwidth was used as a proxy to represent the volume of information. Although bandwidth does not account for modulation and other schemes of compressing information into a signal, it served as a jumping-off point from which an idea of how much improvement over current capability is desired. The scales for bandwidth are thus expressed as improvement over current capability (e.g., 0 = no improvement over current, 1 = 100% improvement). Although it could be argued that bandwidth would more logically fall under a value such as capacity or volume, the SMEs addressed this and agreed that bandwidth is a constituent of what they termed span of communications.

A common refrain in the discussions over bandwidth was that it feeds its own desire. “If you give me more I will want more” was the common sentiment, from both the SMEs in the facilitated discussions and the experts at the Weapons School. This was particularly true with respect to data communications, especially imagery. One of the examples brought forth by the SMEs was that an imaging capability of 30 frames per second would make the air warrior want 80 frames per second. To represent the insatiable demand for data, a logarithmic scale was selected with a factor of 1000 times the current capability as the upper extreme. The SDVF selected was increasing exponential, and this was validated by the Weapons School experts.

Reliability

Reliability was found to be a critical measure. The SMEs noted that the lack of reliable communication would negate other values represented in the hierarchy. Reliability was defined as the expected time available (uptime) during a particular phase (pre-flight or in-flight), expressed as a percentage of that phase. Thresholds of reliability were established at the base level of the communication branch. The SMEs decided that less than 75% communication reliability in the pre-flight planning timeframe would negate the value accorded to it under span. They set a similar threshold for in-flight communication at 90%.

Reliability was also identified as a measure of navigation. The SMEs determined that it was less important in the pre-flight phase and set the maximum of the scale at 50%. The minimum of the in-flight scale, however, was set at 90% reflecting the importance of recency of update. There were no negating thresholds identified for navigation.

Positioning and Timing Error

Horizontal error and altitude error as measured from true latitude, longitude, and altitude above sea level constitute what the air warrior values in positioning. Although navigation error is commonly measured in meters by the space community, the SMEs thought that feet would be a more familiar unit for air warriors. The SDVF that represents in-flight horizontal error stands out as the only piecewise linear SDVF in the model, representing a “sweet spot” in the middle where value decreases rapidly as error increases, beginning at 50 ft.

Decreases in timing error, as measured by difference from true “Zulu” time, were found to have greater value in the pre-flight phase than in in-flight. The SDVFs for each were decreasing inverse exponential and decreasing linear, respectively, which reflect a greater “payoff” on minimizing error before takeoff.

Timeliness

Navigation timeliness is defined as the delay from update request to update receipt. The air warrior is not concerned about navigation update delay before takeoff, but highly values rapid updates while in the air. On a decreasing inverse exponential scale of 0 to 60 seconds, a value of 0.5 is reached at approximately 5 seconds, less than a twelfth of the distance to the minimum value.

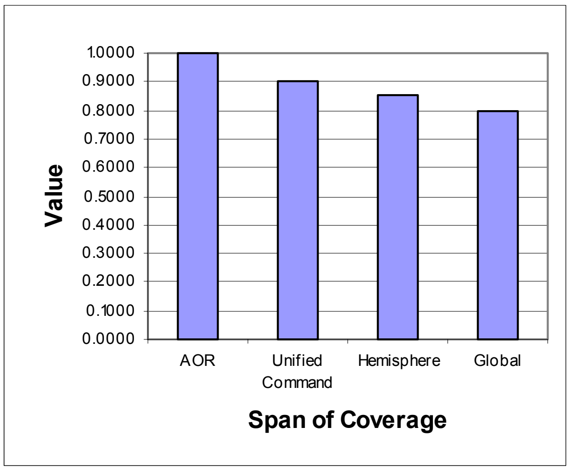
Denial Measures

The SMEs valued any space capability that could deny an adversary military capabilities of his own. Without specific alternatives available to constrain their thinking, this was the most value-focused part of the model. Information denial and threat destruction comprise the first-tier value of denial, with information denial consisting of the other two values found in the first tier, with almost the same structure. The rationale behind this symmetry was that "they're humans, too, and they care about the same things we do." Omitted from the deny navigation values were positioning, timing, and timeliness, with a large premium placed on denying an adversary the reliability of his navigation. The abstractness of thinking like the adversary made it difficult for the SMEs to specify details such as value-eliminating thresholds, and there were none identified.

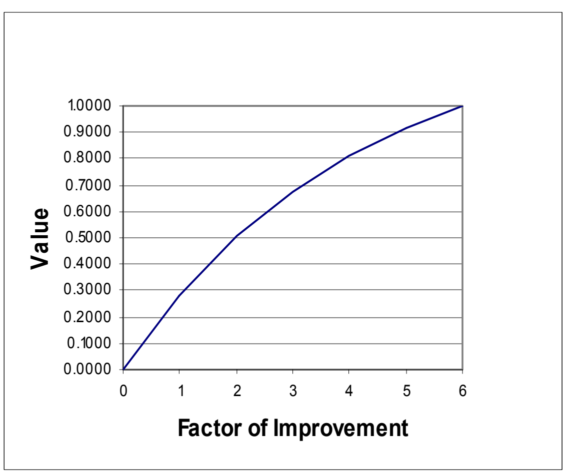
The capability to disable a threat to friendly aircraft was identified as threat destruction, and categorical measures were the best fit. The bomber and fighter pilots' points of view on scaling the threat diverged, but consensus was reached. The threats to friendly aircraft, in increasing order, were listed as Anti-Aircraft Artillery (AAA), tactical surface-to-air missiles (SAMs), strategic SAMs, and airborne aircraft.

Communication

Communication — Pre-flight — Voice — Span: Area of Coverage
Measure: The area of coverage of a space-enabled voice communication system during pre-flight planning.
Scale: categorical   Units: Categories of coverage
Direction: decreasing   SDVF: discrete



Communication — Pre-flight — Voice — Span: Bandwidth (proxy for information volume)
Measure: The bandwidth of a space-enabled voice communication system during pre-flight planning.
Scale: 0 to 6   Units: factor of improvement over current capability
Direction: increasing   SDVF: exponential, $\rho = 4.062$

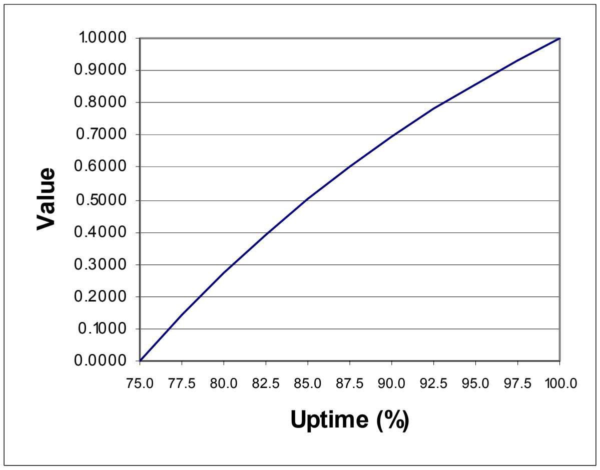


Communication — Pre-flight — Voice — Reliability

Measure: The % of pre-flight planning time space-enabled voice communication is available.

Scale: 75% to 100% | Units: %

Direction: increasing | SDVF: exponential, $\rho = 30.4$

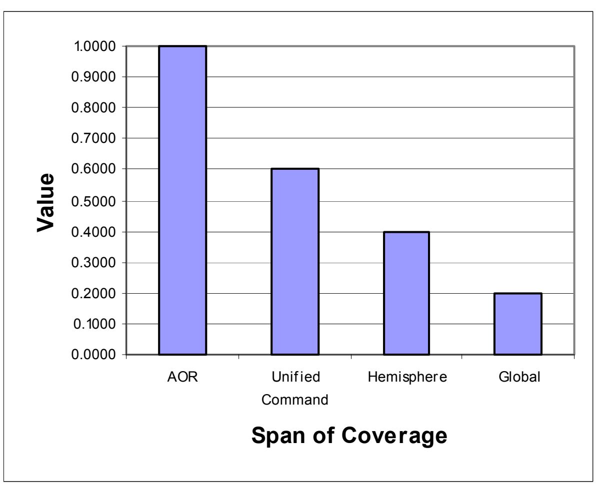


Communication — In-flight — Voice — Span: Area of Coverage

Measure: The area of coverage of a space-enabled voice communication system during in-flight execution.

Scale: categorical | Units: Categories of coverage

Direction: decreasing | SDVF: discrete

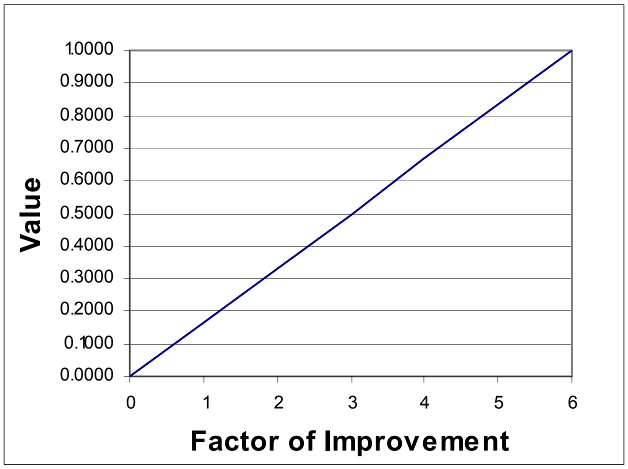


Communication — In-flight — Voice — Span: Bandwidth (proxy for information volume)

Measure: The bandwidth of a space-enabled voice communication system during in-flight execution, as expressed by improvement over current capability.

Scale: 0 to 6 Units: factor of improvement over current capability

Direction: increasing SDVF: linear, slope = 1/6

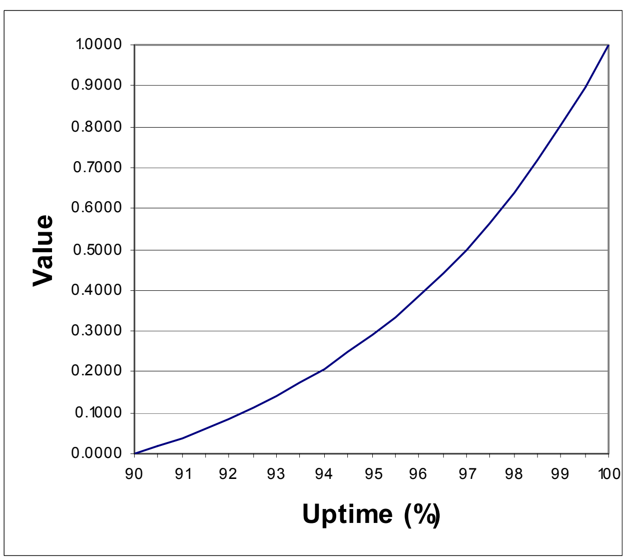


Communication — In-flight — Voice — Reliability

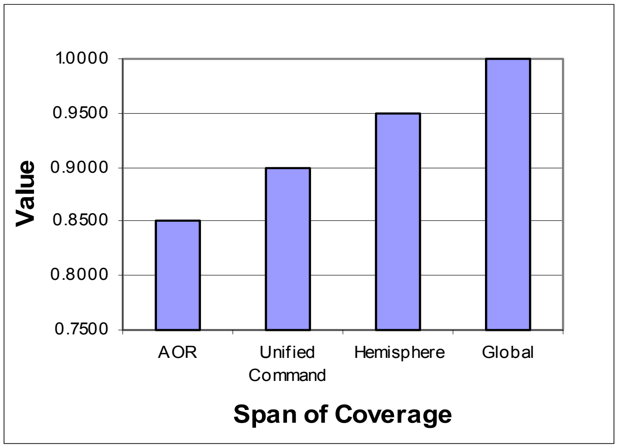
Measure: The % of in-flight execution time space-enabled voice communication is available.

Scale: 90 to 100 Units: %

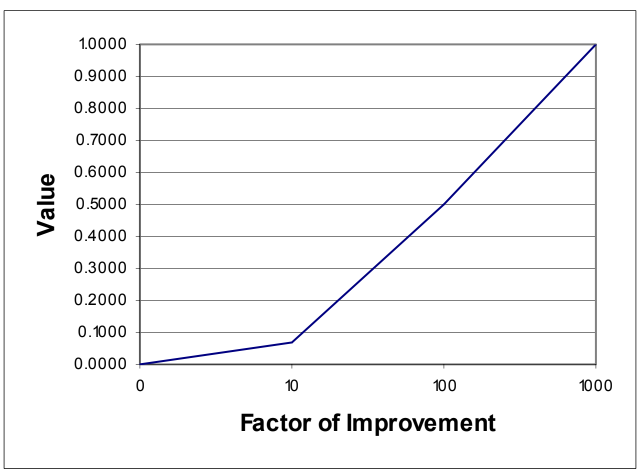
Direction: increasing SDVF: exponential, $\rho = -5.55$



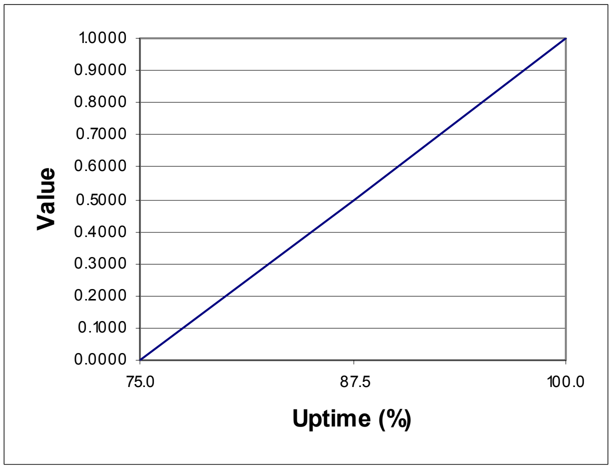
Communication — Pre-flight — Data — Span: Area of Coverage (local weight 0.4)
Measure: The area of coverage of a space-enabled data communication system during pre-flight planning.
Scale: categorical Units: Categories of coverage
Direction: increasing SDVF: discrete



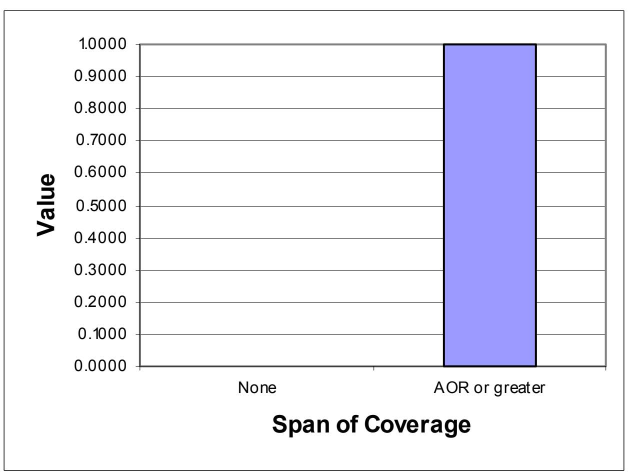
Communication — Pre-flight — Data — Span: Bandwidth (proxy for information volume, local weight 0.6)
Measure: The bandwidth of a space-enabled data communication system during pre-flight planning, as expressed by improvement over current capability.
Scale: 0 to 1000, logarithmic Units: factor of current capability
Direction: increasing SDVF: exponential, $\rho = 144$



Communication — Pre-flight — Data — Reliability
Measure: The % of pre-flight planning time space-enabled data communication is available.
Scale: 75% to 100% Units: %
Direction: increasing SDVF: linear, slope = 1/25



Communication — In-flight — Data — Span: Area of Coverage (local weight 0.4)
Measure: The area of coverage of a space-enabled data communication system during in-flight execution.
Scale: Binary Units: Categories of coverage
Direction: increasing SDVF: binary discrete

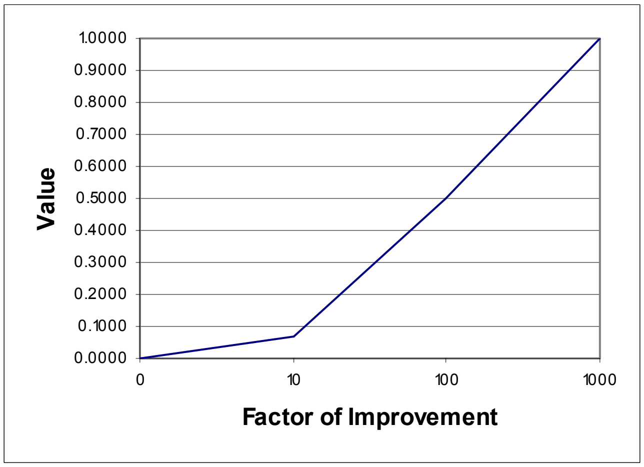


Communication — In-flight — Data — Span: Bandwidth (proxy for information volume, local weight 0.6)

Measure: The bandwidth of a space-enabled data communication system during pre-flight planning, as expressed by improvement over current capability.

Scale: 0 to 1000, logarithmic Units: factor of current capability

Direction: increasing SDVF: exponential, $\rho = 144$

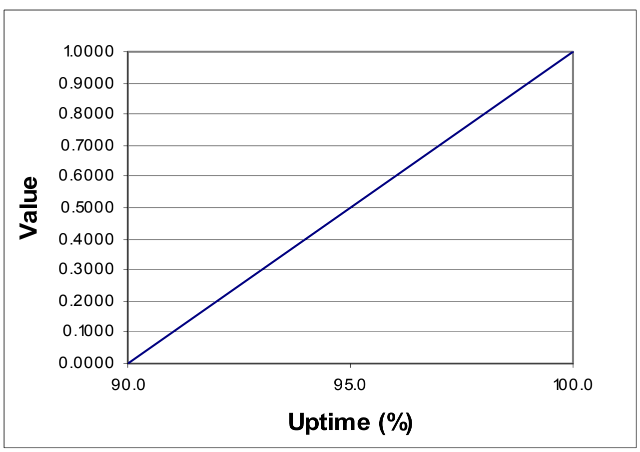


Communication — In-flight — Data — Reliability

Measure: The % of in-flight execution time space-enabled data communication is available.

Scale: 90% to 100% Units: %

Direction: increasing SDVF: linear, slope = 10



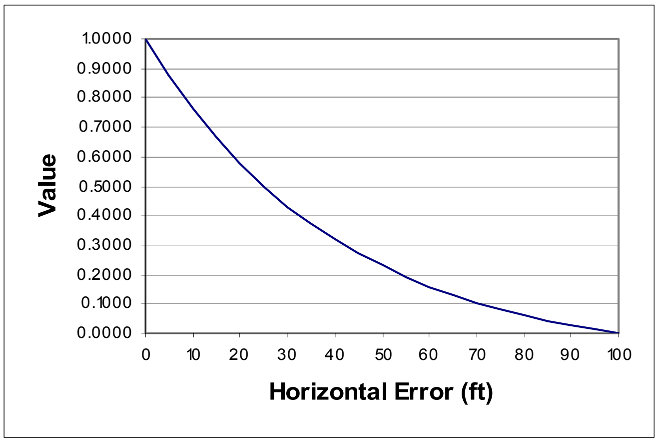
Navigation

Navigation — Pre-flight — Positioning: Horizontal Error (local weight 0.4)

Measure: The error from true horizontal position of the space-based navigation signal in the Pre-flight planning phase of an air operation.

Scale: 0 to 100 Units: ft

Direction: decreasing SDVF: exponential, $\rho = -41$

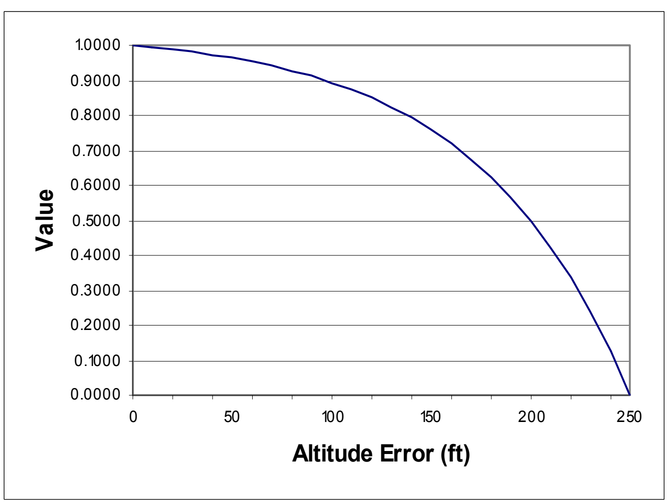


Navigation — Pre-flight — Positioning: Altitude Error (local weight 0.6)

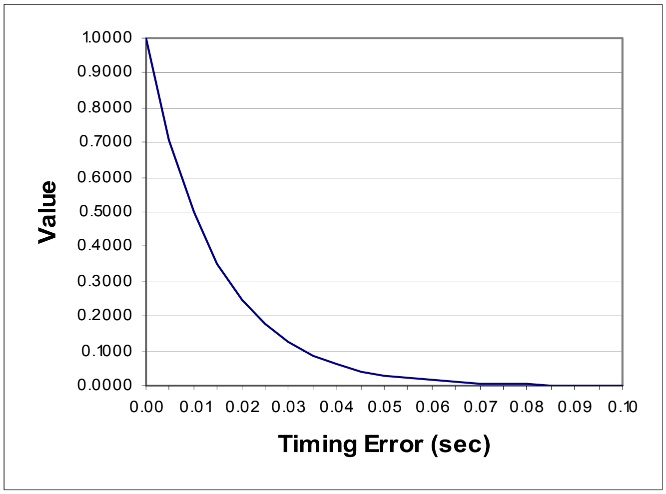
Measure: The error from true altitude position of the space-based navigation signal in the Pre-flight planning phase of an air operation.

Scale: 0 to 250 Units: ft

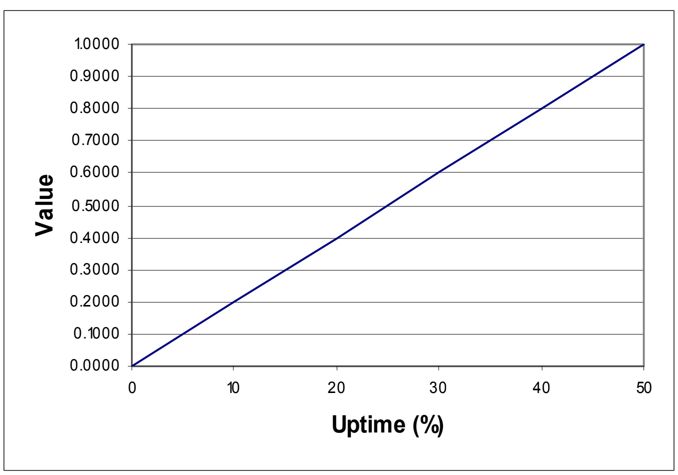
Direction: decreasing SDVF: exponential, $\rho = 76.25$



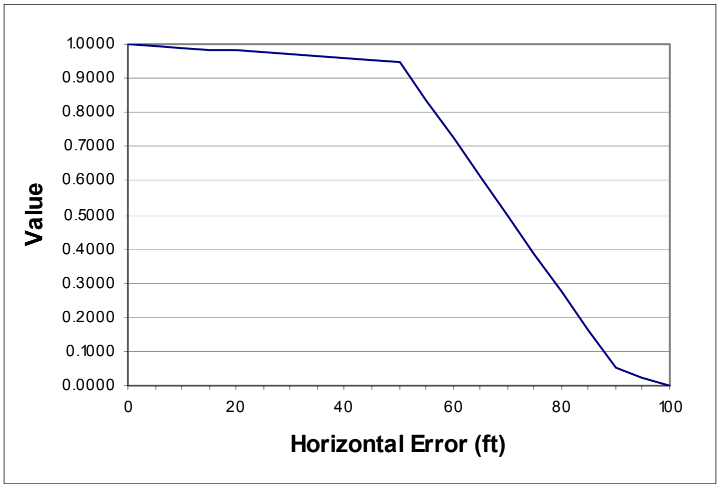
Navigation — Pre-flight — Timing:
Measure: The error from true time of the space-based navigation signal in the Pre-Flight planning phase of an air operation.
Scale: 0 to 0.1 Units: sec
Direction: decreasing SDVF: ρ = -0.0144



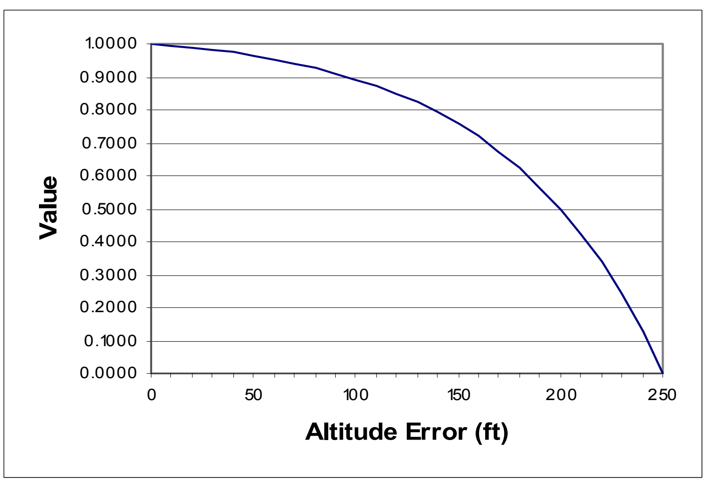
Navigation — Pre-flight — Reliability: Uptime
Measure: The percentage of time that navigation data is available in the pre-flight planning portion of an operation.
Scale: 0% to 50% Units: %
Direction: increasing SDVF: linear, slope = 50



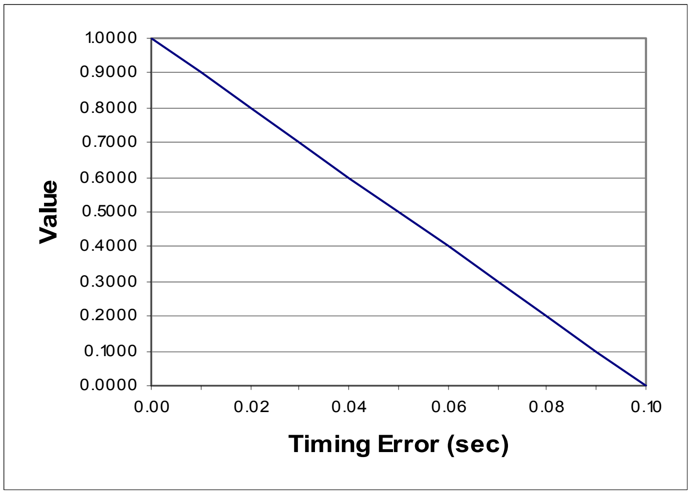
Navigation — In-flight — Positioning: Horizontal Error (local weight 0.4)
Measure: The error from true horizontal position of the space-based navigation signal in the In-Flight phase of an air operation.
Scale: 0 to 100 Units: ft
Direction: decreasing SDVF: Piecewise Linear



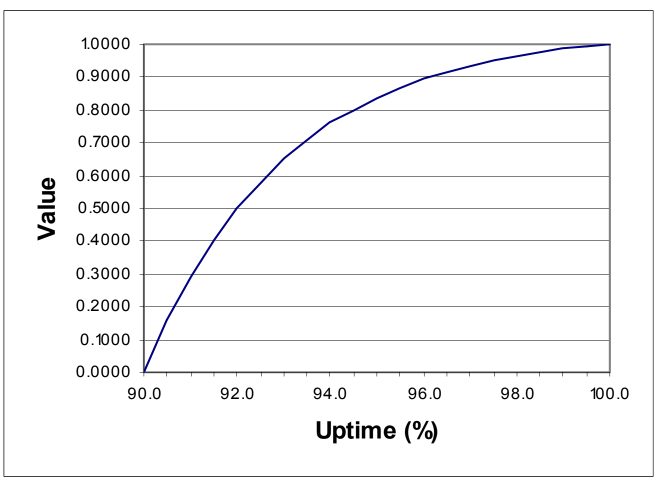
Navigation — In-flight — Positioning: Altitude Error (local weight 0.6)
Measure: The error from true altitude position of the space-based navigation signal in the In-Flight phase of an air operation.
Scale: 0 to 250 Units: ft
Direction: decreasing SDVF: exponential, $\rho = 76.25$



Navigation — In-flight — Timing:
Measure: The error from true time of the space-based navigation signal in the In-Flight phase of an air operation.
Scale: 0 to 0.1 Units: sec
Direction: decreasing SDVF: $v(x) = 1 - 10x$



Navigation — In-flight — Reliability
Measure: The percentage of time that navigation data is available in the In-flight phase of an operation.
Scale: 90% to 100% Units: %
Direction: increasing SDVF: exponential, $\rho = 3.05$

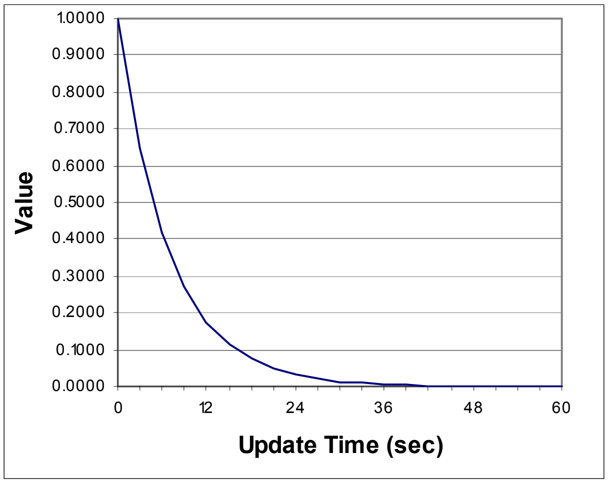


Navigation — In-flight — Timeliness

Measure: The delay between request for navigation system update and receipt in the In-flight phase of an operation.

Scale: 0 to 60 Units: sec

Direction: decreasing SDVF: exponential, $\rho = -6.9$



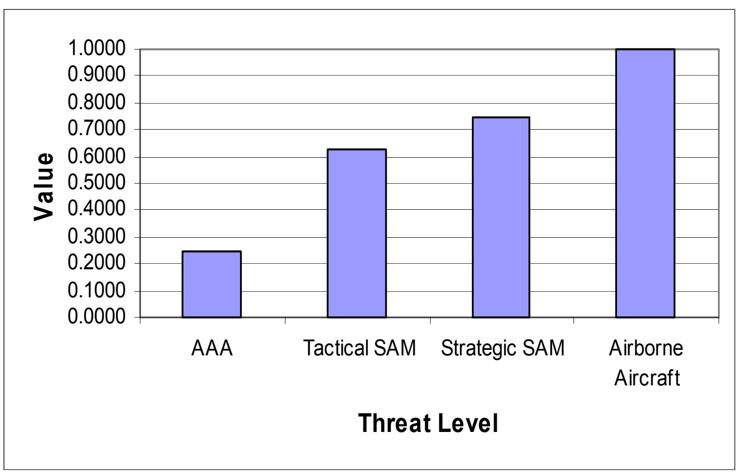
Denial

Denial — Information Denial — Communication
This value is structured identically to **Communication** in the first tier, except that the value is placed on a space-based capability to *deny* an adversary the **Communication** that was valued in the first tier. The same measures and SDVFs apply, but no value preservation thresholds were identified.

Denial — Information Denial — Navigation
This value is divided into pre-flight and in-flight components in the same manner as **Navigation** in the first tier. The SMEs identified **Reliability** as the center of gravity for both the pre-flight and in-flight components, and did not consider an adversary's **Navigation Positioning, Navigation Timing,** or **Navigation Timeliness** worthy of denial.

Denial — Threat Removal
Measure: The capability to disable a threat to friendly aircraft.

Scale: categorical	Units: Categories of threat
Direction: increasing	SDVF: discrete



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Vita

Capt J. Darin "J.D." Loftis earned his bachelor's degree in mechanical engineering from Vanderbilt University. After a tour as a Peace Corps volunteer in the South Pacific, he entered the U.S. Air Force and graduated from Officer Training School in 1996. His first assignment was as a Peacekeeper ICBM combat crewmember at F.E. Warren AFB, where his accolades included Company Grade Officer of the Year for the 400th Missile Squadron. After becoming an ICBM crew instructor, he served in the Emergency War Orders Plans division, where he was responsible for Single Integrated Operational Plan targeting for the 200 ICBMs at F.E. Warren. From there he became one of the five initial Air Force Space Command Vigilant Scholars at the Air Force Institute of Technology.

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14. ABSTRACT
The 2001 Report of the Commission to Assess United States National Security Space Management and Organization recommended that U.S. efforts in national security space be elevated to the highest national security priority. With more focused high-level attention on national security space decisions, a measure that captures and quantifies the value of space capabilities to combat operations professionals is desired. This thesis models what the air warriors desire from space assets in combat.

A Value-Focused Thinking (VFT) approach was used to elicit values from air combat experts with operational experience. An initial Gold Standard value model was constructed and validated by air combat experts with recent experience in joint air operations. The strategic objective, "Leverage National Security Space Capabilities to Enhance Air Combat Operations," was decomposed into values which were structured into a hierarchy. Measures and value functions were identified for the bottom-tier values, which were weighted locally to assess their relative importance.

The research identified measures of merit with thresholds beneath which value at higher levels is eliminated, resulting in a multiplicative value function using indicator variables. An additional result is the separation of communication and navigation measures into pre-flight and in-flight components, which has not been documented in previous literature.

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