2025 OPERATIONAL ANALYSIS

A Research Paper
Presented To

Air Force ***2025***

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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Contents

Chapter *Page*

Disclaimer ii

Illustrations iv

Tables v

Executive Summary vi

1 Challenge and Response 1

2 Meeting the Challenge 4
Methodology 4
Comparing Analysis Tools 5
Value-Focused Thinking 6
Value 6
Objectives, Functions, Tasks, and Subtasks 6
Force Qualities 7
Measures of Merit and Scoring Functions 7
Value Model 7
Weights 8

3 The Search for the *2025* Value Model 9
Developing the *2025* Value Model—*Foundations 2025* 10
Objective 10
A Bottom-Up Approach 10
Functions 10
Force Qualities 13
Measures of Merit and Scoring Functions 13
Analytic Advances 14
System Identification 16
Alternate Futures 17

4 Weighting and Scoring 19
Weighting the *Foundations 2025* Value Model Across Alternate Futures 19
Computing System Performance Using Scoring Functions 20
Technology Identifying and Scoring 20
Scoring the Systems 21
Scoring the Technologies 30

5 Conclusions 38
Major Implications of the *2025* Operational Analysis 38
Operational Analysis Lessons Learned 41
Study Limitations 41
Major Implications for the Future 42

Summary ... 42

Appendix — Page

A Foundations 2025 Value Model ... 43

B System Descriptions ... 46

C Alternate Futures Weights ... 53

D Technology Model ... 57

Bibliography ... 60

Illustrations

Figure — *Page*

1-1. 2025 Study Process ... 2

3-1. Complete Listing of Tasks and Subtasks ... 11

3-2. Foundations of 2025 Value Model ... 12

3-3. Operational Analysis Methodology ... 15

3-4. System Functional Hierarchy ... 16

3-5. *2025* Strategic Planning Space ... 17

4-1. System Values for the Baseline Future ... 24

4-2. Final System Values ... 25

4-3. Top Eleven Systems ... 26

4-4. *Awareness* Values ... 27

4-5. Deploy Values - “Halfs” Future ... 28

4-6. Power Values ... 29

4-7. Technology Rankings (All 43 Systems, AU Students Weights) ... 33

4-8. Top Twelve Technology Rankings (All 43 System, AU Students Weights) ... 35

Figure		*Page*
4-9.	Top Twelve Technology Rankings (Top 11 System, AU Students Weights)	36
A-1.	Value Model: Top Level	54
A-2.	Value Model: Awareness	55
A-3.	Value Model: Reach.	56
A-4.	Value Model: Power	56
B-1.	System Hierarchy	57
C-1.	AU Team Weights - Halfs and Half Naughts Future	66
C-2.	AU Team Weights - Gulliver's Travail Future	67
C-3.	AU Team Weights - Zaibatsu Future	67
C-4.	AU Team Weights - Digital Cacophony Future	68
C-5.	AU Team Weights - King Khan Future	68
C-6.	AU Team Weights - 2015 Crossroads Future	69
D-1.	Technology Model - Part I	71
D-2.	Technology Model - Part II	72

Tables

Table		*Page*
1.	Technology Assessment	31
2.	Technology Development Leaders for High Leverage Technologies	32

Executive Summary

In the summer of 1995 the Air Force chief of staff tasked Air University to do a year-long study, ***2025***, to "generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future [, to] detail … new or high-leverage concepts for employing air and space power [, and to] detail … the technologies required to enable the capabilities envisioned." To support this goal a ***2025*** study team conducted an operational analysis to identify high-value system concepts and their enabling technologies in a way that was objective, traceable, and robust. This analysis determined which of the ***2025*** system concepts show the greatest potential for enhancing future air and space capabilities and which embedded technologies have the highest leverage in making the high-value system concepts a reality.

The team developed a model, ***Foundations 2025***, which reflected the overall values held by the ***2025*** participants. The purpose of the model was to quantify and compare different system concepts' contributions to future air and space capabilities. ***Foundations 2025*** is distinguished by the large number of system concepts that can be analyzed, the 30-year focus into the future, and the fact it was developed through a bottoms-up approach. ***Foundations 2025*** offers a potential new framework for future air and space doctrine that can be easily modified (broken into three separate models: *awareness*, *reach*, and *power*) by AF MAJCOMs for use in their mission area analysis process. Thus, the model presented is an aid to current and future senior decision makers concerned with the employment of air and space power.

The ***2025*** study produced a number of excellent system concepts for employing air and space power in the future. Analysis of the highest-value system concepts indicated that the effort to occupy the "high ground" of the future will require air and space forces to possess increased *awareness* and to control the medium of space. The five highest-value system concepts were defined as:

- *Global Information Management System*
- *Sanctuary Base*
- *Global Surveillance, Reconnaissance, and Targeting System*
- *Global Area Strike System*
- *Uninhabited Combat Air Vehicle*

The following six system concepts scored below the top five but were clearly ahead of the others:

- *Space-Based High-Energy Laser*
- *Solar-Powered High-Energy Laser*
- *Reconnaissance unmanned air vehicle (UAV)*
- *Attack Microbots*
- *Piloted single-stage-to-orbit (SSTO) transatmospheric vehicle (TAV)*
- *Uninhabited Air-Launched TAV*

These conclusions regarding the rankings of the system concepts were not affected by any reasonable changes of the weighting scheme in the ***Foundations 2025*** value model.

The study also included an assessment of the enabling technologies on which the system concepts depend. The analysis explicitly took into account the number of system concepts each technology supported, the degree to which each system concept depended on it, and the importance of the system concept. Six high-leverage technologies stood out because they are important to a large number of high-value system concepts:

- *Data Fusion*
- *Power Systems*
- *Micromechanical Devices*
- *Advanced Materials*
- *High-energy Propellants*
- *High-performance Computing*

The major surprise among these results was the importance of continued breakthroughs in the area of power systems. Other moderate-leverage technologies were also important but contributed to only three or four of the high-value system concepts:

- *High-energy Laser Systems*
- *Artificial Intelligence*
- *Optics*
- *Aerospace Structures*
- *Image Processing*
- *Communications*

Advances in these areas show promise to open the way to air and space systems that would dramatically improve the effectiveness of air and space power employment to achieve the US military objectives.

Chapter 1

Challenge and Response

The long range planning process in our Air Force is broken. If we are going to be relevant in the future, we've got to somehow break free of the evolutionary nature of the planning process.

--Gen Ronald R. Fogleman

With these few words, the chief of staff of the Air Force, Gen Ronald R. Fogleman, challenged the participants of the ***2025*** study to generate ideas and concepts on the capabilities the United States will require to dominate air and space forces in the future. When General Fogleman assigned the responsibility for ***2025*** to Air University, he directed the final product be a collection of white papers detailing findings regarding air and space capabilities required for future warfare, new or high-leverage concepts for employing air and space power, and the technologies required to enable the required capabilities.[1]

In response to General Fogleman's tasking, Air University devised a four-phase study process (Figure 1-1.) to stimulate creativity, generate ideas, and evaluate concepts.

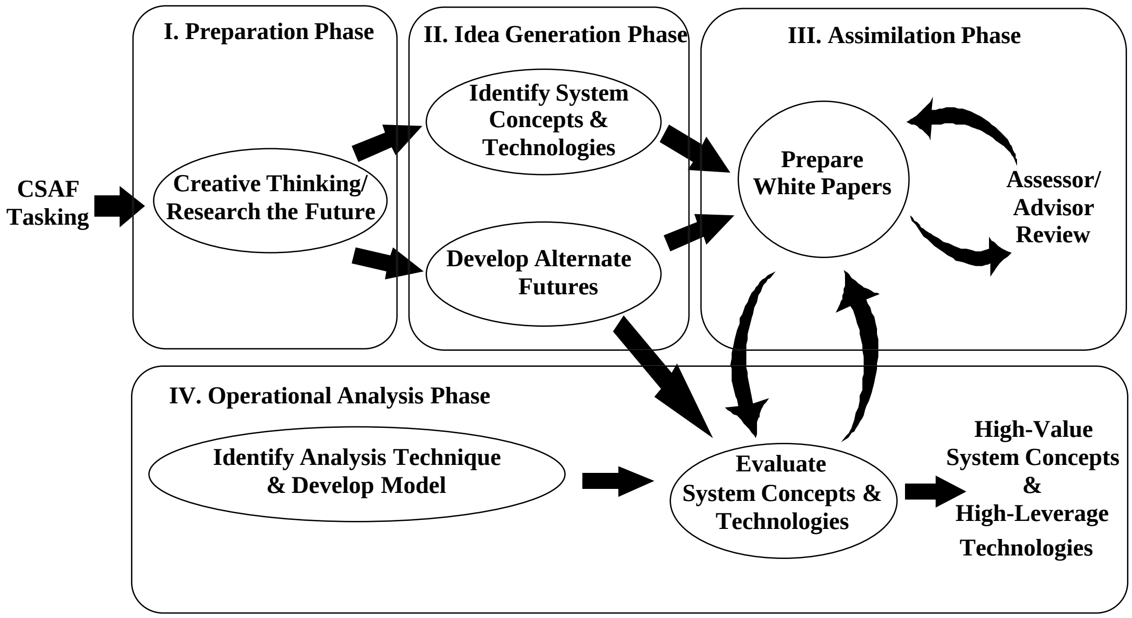

Figure 1-1. 2025 Study Process

In the preparation phase, participants were exposed to a wide variety of creative thinking and problem solving concepts. This phase laid the groundwork for the idea generation phase, in which the participants developed plausible alternative futures as well as future system concepts and technologies. Inputs for the idea generation phase were gathered from a worldwide data call that produced over 1,000 submissions.

In the assimilation phase, the participants were organized into specific writing teams based on operational experience. Each team took a particular area to consider and on which to concentrate their research. After postulating the required capabilities of the future Air Force, each team developed system concepts and technologies from the idea generation phase that could satisfy these future requirements.

This phase produced a large number of system concepts that were described in varying levels of detail, that provided widely different kinds of operational capabilities, and that depended on different levels of advancements in different areas beyond current technology. Clearly, not all of these system concepts could be developed, nor could all of the technologies be aggressively pursued. The study needed to prioritize the relative importance of both future system concepts[2] and their enabling technologies.

An operational analysis was conducted concurrently with the other three phases to aid in this prioritization. Its purpose was to evaluate system concepts and technologies developed in the white papers; specifically, it had three objectives:

1. Assess the potential operational utility of future air and space system concepts.
2. Identify the high-leverage technologies required by those system concepts.
3. Provide an objective, traceable, and robust analysis.

This monograph highlights the main points of this operational analysis. Comprehensive documentation is provided in the ***2025*** Operational Analysis Technical Report.[3]

Notes

[1] Message from General Fogleman to Air University. 23 December 1994.

[2] From this point forward the term *system* will be used when referring to the *system concepts.* The authors recognize that *system* carries the connotation of existing hardware, but it is less cumbersome and all of the systems scored here are futuristic.

[3] *An Operational Analysis for* ***2025:*** *An Application of Value-Focused Thinking to Future Air and Space Capabilities* (Maxwell AFB, AL: Air University, 1996)

Chapter 2

Meeting the Challenge

This section outlines the ***2025*** methods used to evaluate the systems and technologies. It covers the development of the value model to score the systems, the system identification process, the system scoring procedures, the technology identification procedures, and the technology scoring procedures, and ends with an evaluation of which sector (public or commercial) will primarily develop the future technologies.

Methodology

A primary goal of the ***2025*** operational analysis (OA) was to identify the ***2025*** systems that offer the greatest potential to support future air and space operations. To meet this goal, the Analysis team's challenge was to develop a methodology that satisfied a diverse set of criteria. First, the ***2025*** OA needed to be compatible with the Air University academic calendar year. It also needed to be capable of quick implementation after the Air Command and Staff College and Air War College students completed their white papers, which contained conceptual descriptions of the systems.

Second, because 2025 was a study about 30-years into the future, the system descriptions in the white papers lacked engineering detail. Therefore, the OA methodology had to rely on human judgment about operational capability and key enabling technologies.

Third, while the values of the current senior leadership of the Air Force are well documented in strategies, policies, and directives, it is far more difficult to predict what will be important to future leaders.

Fourth, to prevent one set of views or interests from unduly influencing the results, the evaluation methodology had to be free of institutional bias. The methodology should neither unfairly favor nor penalize any potential ***2025*** systems.

Fifth, the results had to be traceable since the ***2025*** system evaluation results would be subject to much scrutiny. The Analysis team members would need to be able to explain for any given system or technology how and why it was scored. The study participants and Air Force senior leadership would be far more likely to accept the results if they could clearly understand how the systems were evaluated.

Sixth, the OA methodology had to be robust enough to apply across a wide range of potential future environments postulated by the ***2025*** Alternate Futures team. Each future described a different political, technological, and social environment (see the Alternate Futures section). The OA methodology had to be able to capture different priorities, that were assigned to air and space functions and tasks in these alternate futures.

Comparing Analysis Tools

Each analysis approach has particular strengths and weaknesses; therefore, the Analysis team examined them in relation to the challenges of the ***2025*** study discussed previously. The team considered the following analysis techniques:

- "Most-to-least dear" with no criteria
- Qualitative comparison with criteria
- Simple quantitative comparison matrix
- Value-focused thinking
- Analytical hierarchy process
- Strategy-to-task
- Futures-to-strategy-to-task
- Common operational objectives of the armed forces
- Cost and operational effectiveness analysis

After considering the advantages and disadvantages of the various approaches, the Analysis team felt that value-focused thinking (VFT)[1] offered the best compromise for satisfying the OA requirements. VFT was particularly suited for structuring the subjective judgments required to evaluate the systems. It also allowed the OA to be completed in the limited time available and, because VFT was used in the

SPACECAST 2020 study, it was well understood and accepted by the Air University senior leadership. In addition, once a value framework was built using VFT, it was very easy to assess systems across several alternate futures. Finally, the VFT methodology enables the OA to be objective, traceable, and robust.

Value-Focused Thinking

VFT begins by identifying the decision maker's values with a hierarchy of objectives. Top-level objectives describe aspirations that are most important to the decision maker. Objectives are decomposed until desired force qualities can be specified and measured. Weights are assigned to signify the relative importance of objectives at every level.

In the VFT methodology, we use several key terms—*value, objectives, functions, tasks, subtasks, force qualities, measures of merit*, *scoring functions, value model,* and *weights.*

Value

The most important concept in VFT is *value*. Keeney says, "Values are what we care about. [Values] should be the driving force for our decision-making."[2] The fundamental precept of VFT is that values are principles used for evaluation.[3]

Objectives, Functions, Tasks, and Subtasks

In VFT, *values* are made explicit with *objectives*, and a hierarchy of objectives is constructed that supports the decision maker's values.[4] Specific, lower-level objectives support the more general, overarching objectives. The Analysis team used the terms *objective*, *functions*, *tasks*, and *subtasks* to designate the tiers in the hierarchy, from highest to lowest, respectively.

Force Qualities

In VFT terminology, a *force quality* defines a desired attribute of a system to achieve a subtask. For example, if the subtask is to "identify," a corresponding force quality might be "accurate." According to Keeney, "[force qualities] should be measurable, operational, and understandable."[5]

Measures of Merit and Scoring Functions

Each force quality has a *measure of merit* that is the metric used to gauge system performance. Each measure of merit has a range of outcomes, from worst to best. To continue with the previous example, if the subtask is "identify" and the force quality is "accurate," then a measure of merit could be "percent of correct identifications."

VFT *scoring functions* provide a quantitative means for measuring the relative system performance for each measure of merit. For example, if the measure of merit is "percent of correct identifications," the corresponding scoring function might convert a system performance of "83 percent correct identifications" into a score of 92.

Value Model

A *value model* is the hierarchical representation of objectives, functions, tasks, subtasks, force qualities, measures of merit, and scoring functions. ***Foundations 2025*** was the value model developed for ***2025***. A value model, called a value tree by some authors, is a branching structure with the most fundamental decision-maker objectives at the top. Keeney uses the term "fundamental objectives hierarchy,"[6] and states, "The higher-level objective is defined by the set of lower-level objectives directly under it in the hierarchy."[7] In other words, the lower-level objectives completely specify their higher-level objective.

Clemen describes five specific characteristics of a value model:[8]

1. It should be complete, encompassing all important facets of the decision.
2. It should be as small as possible.
3. The force qualities should allow straightforward measurement.

4. Objectives should appear only once in the tree.

5. The decision maker should be able to think about and treat the branches of the tree separately.

Combining the first, fourth, and fifth criteria above yields two important properties—the objectives must be "mutually exclusive" (appear only once and can be treated separately) and "collectively exhaustive" (encompass all that the decision-maker values).

Weights

After the hierarchical structure of the value model is complete, the decision maker must determine the relative importance of the functions, tasks, force qualities, and measures of merit. Numerical weights are assigned across each tier of the value model; these weights must satisfy certain mathematical requirements.

Notes

[1] Ralph L. Keeney, *Value-Focused Thinking: A Path to Creative Decision-Making* (Cambridge, Mass.: Harvard University Press, 1992).

[2] Ibid., 3.

[3] Ibid., 6.

[4] Ibid., 33.

[5] Ibid., 112.

[6] Ibid, 78.

[7] Ibid.

[8] R. T. Clemen, *Making Hard Decisions: An Introduction to Decision Analysis* (Boston, Mass.: PWS-Kent, 1991), 435–6.

Chapter 3

The Search for the *2025* Value Model

After the Analysis team selected a value-focused thinking approach, the next step was to either select an existing value model or develop a new one. Identifying a current model proved to be a daunting task because of the scope of the study and the focus on the far future. The participants ranged across all of the military services and also included numerous allies, civilians, government officials, and industry. Any potential model also had to satisfy Clemen's five criteria.[1]

The Analysis team initially searched for a national-level strategic document that identified priorities for future air and space forces. It investigated the following sources:

- *A National Security Strategy of Engagement and Enlargement*
- *National Military Strategy of the United States of America*
- *Defense Planning Guidance*
- Joint Requirements Oversight Council (JROC)/Joint Warfighting Capabilities Assessment (JWCA) categories
- *Global Presence* and *Global Reach, Global Power*
- Common operational objectives of the armed forces
- Draft Air Force Doctrine Document: Air Force Basic Doctrine (AFDD-1)
- *Joint Vision 2010*
- *Cornerstones of Information Warfare*

None of these models met the requirements of ***2025***. Each model was grounded in near- or mid-term thinking, and none seemed to promote thinking "outside of the box" about new ways to employ air and space forces in the far future. Furthermore, each contains traditional biases focusing on how the Air Force is organized, while ***2025*** addresses the dominant employment of air and space forces in the year 2025 and beyond. The only solution was for the Analysis team to develop a new framework to capture the visionary thinking that took place during the study.

Developing the *2025* Value Model—*Foundations 2025*

Developing the ***2025*** value model was a key part of the analysis process. The work began early in ***2025***, and continued for the duration of the study. The final value model, ***Foundations 2025***, was so named because it captured the basic values associated with achieving air and space dominance.

Objective

Before making any progress toward developing a value model, the Analysis team needed a clear statement of the objective. As stated in the introduction, General Fogleman tasked the ***2025*** participants to generate ideas and concepts on the capabilities the United States will require to dominate air and space in the future. This statement was translated into the overarching objective, "Achieve Air and Space Dominance," that became the top tier of ***Foundations 2025***.

A Bottom-Up Approach

With this overarching objective defined, the Analysis team could start specifying subtasks, tasks, and functions. Early on, the team departed from the usual approach to constructing a value model. Conventional value models are built in a top-down fashion; each level of the model hierarchy is derived from the next higher level. In contrast to the top-down method, a bottom-up approach makes no a priori assumptions, and does not establish preconditions. The bottom-up approach results in less institutional bias.

Functions

Functions are the high-level, aggregated tasks that must be accomplished to attain the overarching objective of *air and space dominance*. Three functions for the future Air Force emerged from the task analysis: *awareness, reach,* and *power*. *Awareness* is specified by the tasks *detect, understand,* and *direct*. To have *reach* requires the ability to *deploy, maintain,* and *replenish*. *Power* comes from the ability to *engage* and *survive.* The Analysis team adopted the following definitions for these three functions:

Awareness — knowledge, understanding, or cognizance of some thing or situation through alertness in observing, detecting, and identifying, so as to enable, direct, and communicate an informed decision.

Reach — ability to move to expand the range or scope of influence or effect, and to sustain this influence or effect by maintaining and replenishing.

Power — ability to overtly or covertly affect, control, manipulate, deny, exploit, or destroy targets, including forces, people, equipment, and information, and the ability to survive while affecting targets.

These definitions are based on the tasks in the affinity diagrams upon which the functions were built (fig. 3-1), and they suggest the critical functions of air and space forces in the future do not differ significantly from the functions of today. Where the future begins to diverge from the present is in the detailed means (i.e., tasks and subtasks) by which these functions are accomplished.

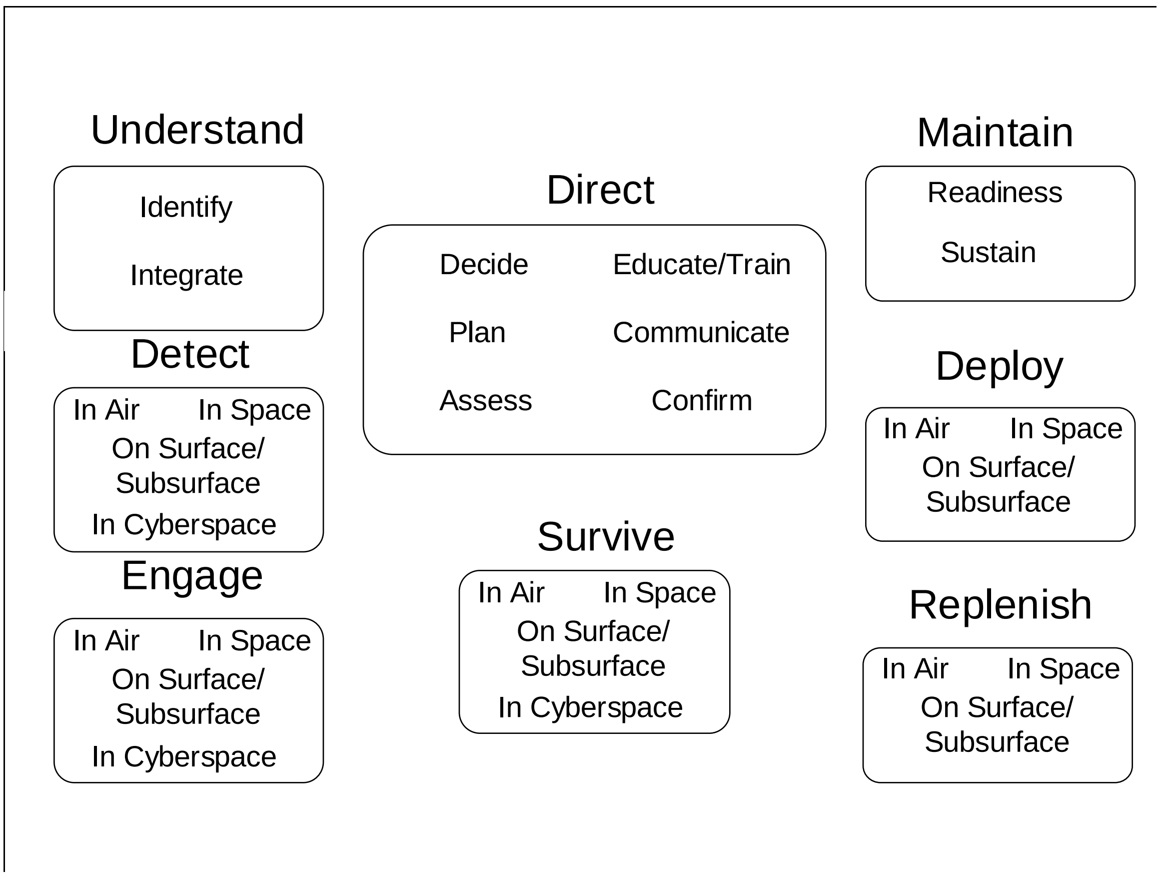

Figure 3-1. Complete Listing of Tasks and Subtasks

The requirement for a set of functions in a value model to be mutually exclusive and collectively exhaustive results in two critical implications. First, these three ***2025*** functions should encompass every future air and space force operational activity. Second, *awareness*, *reach*, and *power* are the only operational activities that contribute to the overarching objective of air and space dominance.

Once the functions were developed, the bottom-up evolution of the subtasks, tasks, and functions in the ***Foundations 2025*** value model was complete. Figure 3-2 depicts the entire framework of mutually exclusive and collectively exhaustive functions, tasks, and subtasks to be accomplished by future air and space forces. Next, force qualities, measures of merit, and scoring functions had to be added to the framework to link operational value to technical metrics.

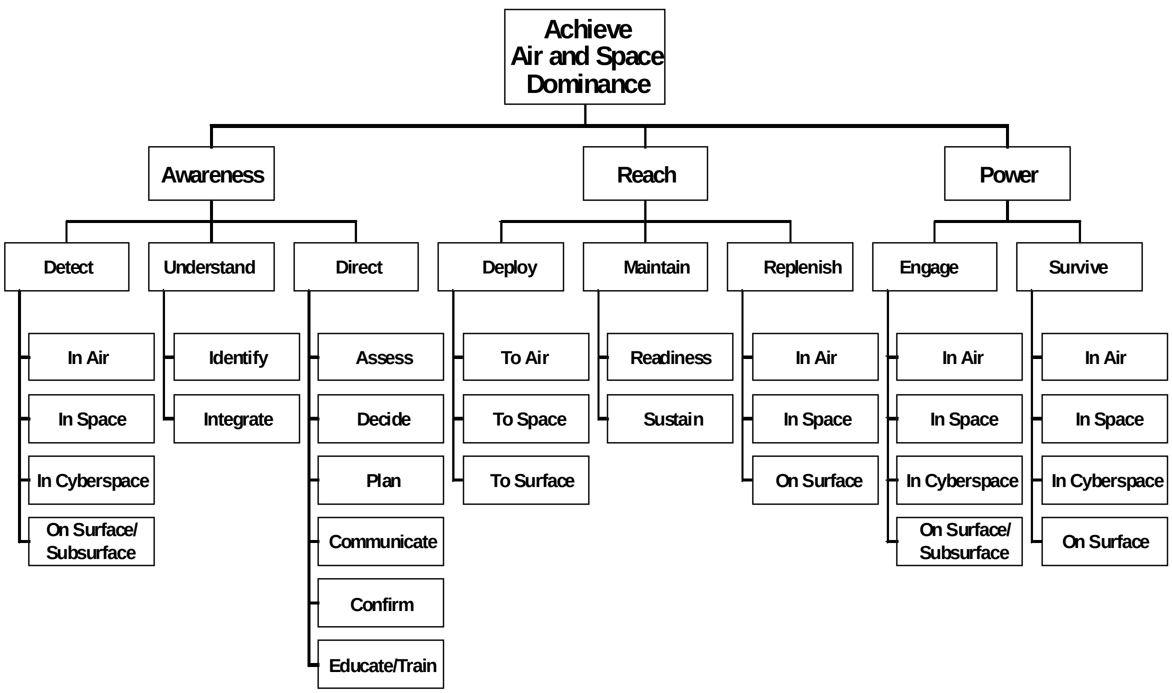

Figure 3-2. Foundations of *2025* Value Model

Force Qualities

Though the framework shown in figure 3-2 represented a major breakthrough, it was not a complete value model. The next step for the Analysis team was to meet with each of the ***2025*** white paper writing teams for a second time to determine *force qualities* based on the teams' operational expertise, research, and thoughts about the future. Force qualities are generally adjectives, since they characterize a system's ability to accomplish a task or subtask. In many cases, the desired force qualities of a future force did not differ from qualities expected of today's force. For example, the force qualities associated with the subtask *identify* were *accurate, timely,* and *traceable*. The goal was to identify only the most important force qualities for each subtask.

These force qualities and their corresponding measures of merit were continually refined during a succession of meetings. After working with each ***2025*** white paper writing team, the Analysis team was able to reduce the list of force qualities from the initial number of about 1,200 to the final number of 134. There are about five force qualities per subtask. The largest number of subtask force qualities was nine and the fewest was two. Appendix A contains the final force qualities for ***Foundations 2025*** organized under the functional categories of *awareness*, *reach*, and *power*.

Measures of Merit and Scoring Functions

Corresponding measures of merit were developed at the same time the Analysis team met with the ***2025*** writing teams to determine force qualities. Each force quality had a measure of merit to calibrate system performance. For example, a force quality of the subtask *deploy to air* was *range*, and the corresponding measure of merit was *miles*. The measures of merit became the horizontal axis for the *scoring functions* used to evaluate the capabilities of future systems.

Analytic Advances

Foundations 2025 represents five important analytic advances. First, the collection of scoring functions serves as an invaluable resource, even outside the ***2025*** study. Second, the use of verbs to specify tasks was a useful step in the value model evolution. Third, the bottom-up approach used in developing ***Foundations 2025*** was significant because no a priori assumptions were made and no preconditions were established. Building from the bottom up allowed ***Foundations 2025*** to be free from institutional bias, an outcome necessary to capture the visionary thinking of ***2025***. Fourth, ***Foundations 2025*** is a very robust value model. With five tiers consisting of an overarching *objective*, three *functions*, eight *tasks*, 29 *subtasks*, and 134 *force qualities* (each with a corresponding *measure of merit* and *scoring function*)—and all weighted across six alternate futures—the model can be used to evaluate very diverse systems. Finally, ***Foundations 2025*** is cast further into the future than any other known military value model.

Figure 3-3 shows the methodology used for the operational analysis. There were two main sets of participants in the operational analysis, first the AU student white paper writing teams (composed of joint and allied officers among the top 20 percent of their year groups) and second, a team of expert technologists. The left-hand column reflects the evaluation of system concepts for operational utility (driven by the operator teams) while the right-hand column identifies and evaluates the underlying high-leverage technologies (driven by the technologists).

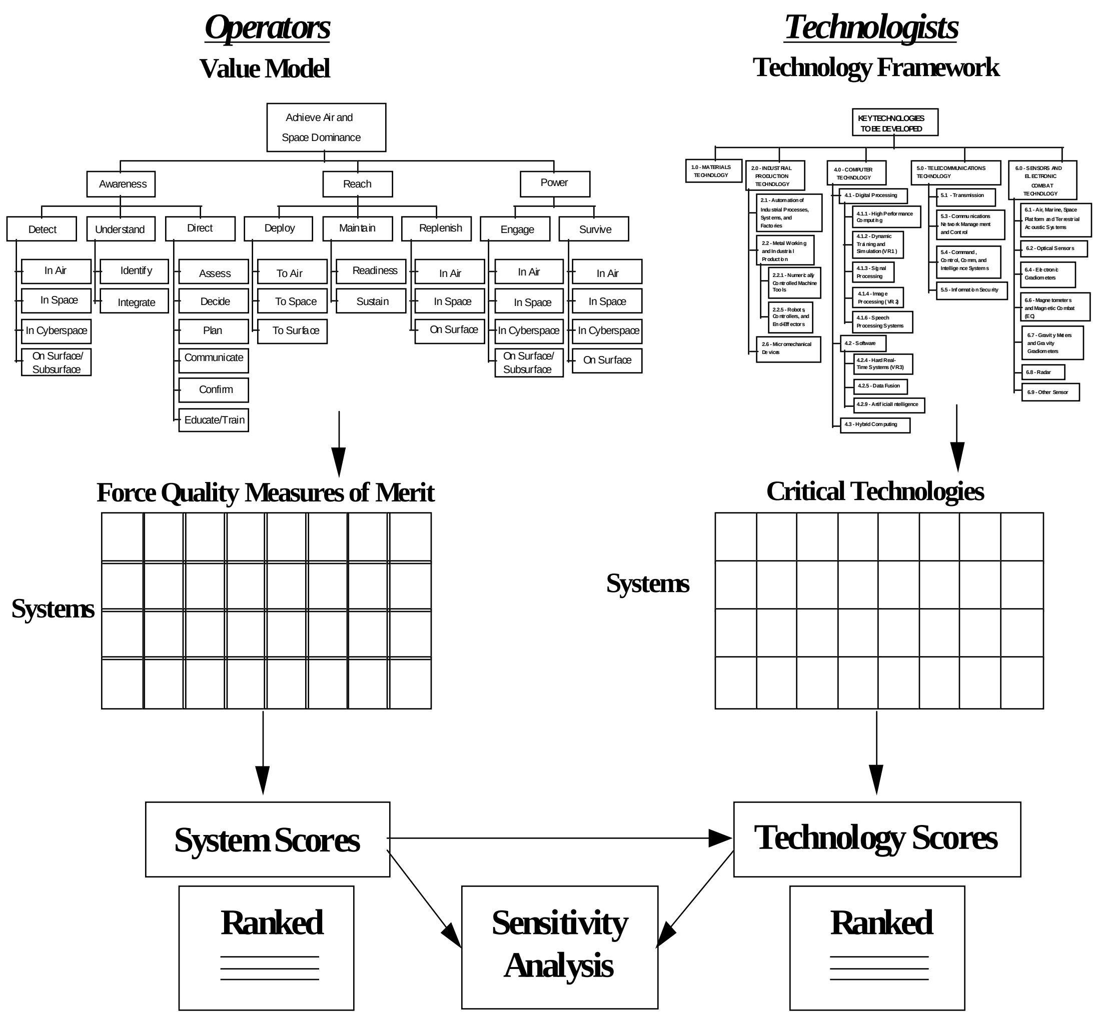

Figure 3-3. Operational Analysis Methodology

For the system concept evaluation, ***Foundations 2025*** was used as the value model. For the technology evaluation, the constructed framework was a logical structuring of technology areas that were mutually exclusive and collectively exhaustive. These hierarchies provided the desired characteristics of objectivity and traceability. The desired robustness quality was assured by performing a sensitivity analysis at the conclusion of the system concept and technology scoring. Specifically, the sensitivity analysis was conducted across a number of plausible alternate futures.

With the development of ***Foundations 2025*** complete, the next step in the ***2025*** operational analysis was to use the model to evaluate systems. The ***2025*** white papers provided the key information for identification and definition of the systems.

System Identification

Following a thorough review of the ***2025*** white papers, the Analysis team identified 43 unique high-leverage systems. For this operational analysis, a system was defined to be "a functionally related group of elements that performs a mission or task." Although some of the identified systems were extracted from a single white paper, many systems, particularly those involving the collection and management of information, were composites drawn from capabilities detailed in several of the papers.

The 43 systems are listed in appendix B, categorized by the major functional areas depicted in figure 3-4. The full descriptions of these systems are found in the ***2025*** Operational Analysis Technical Report.

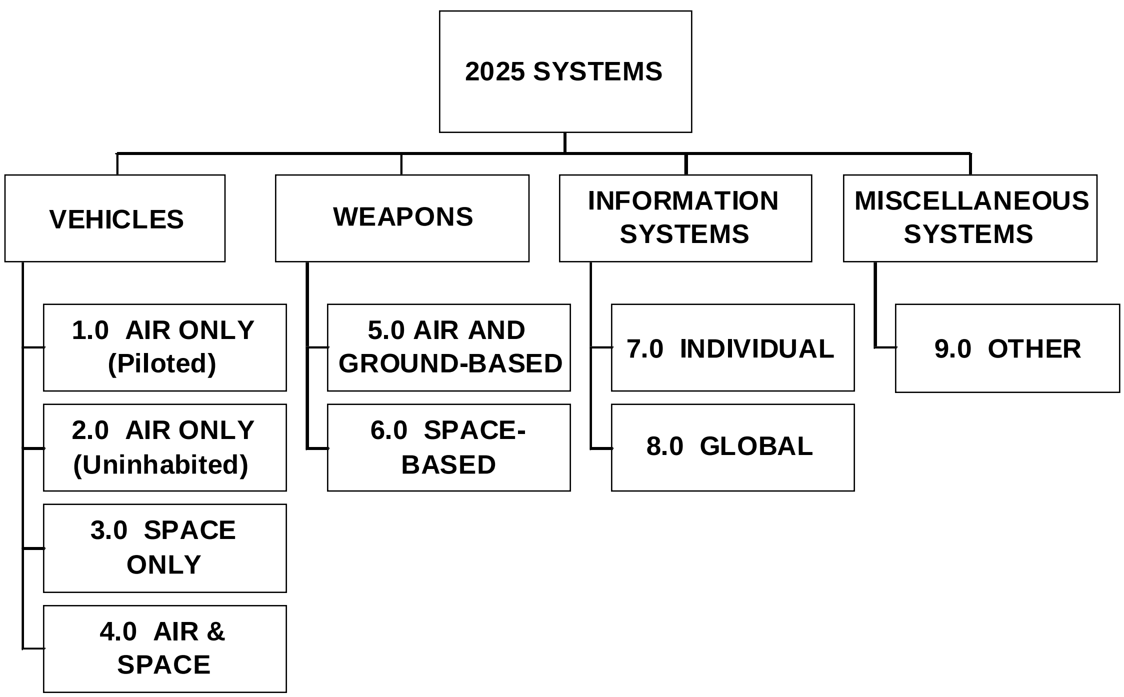

Figure 3-4. System Functional Hierarchy

Alternate Futures

The ***2025*** Alternate Futures team generated and then analyzed over 100 candidate drivers deemed to be forces acting on the future. That team then synthesized and consolidated these candidates into the three most important drivers to define a strategic planning space in which alternate futures could be cast (fig. 3-5). Functional definitions for each of these three drivers are provided below.

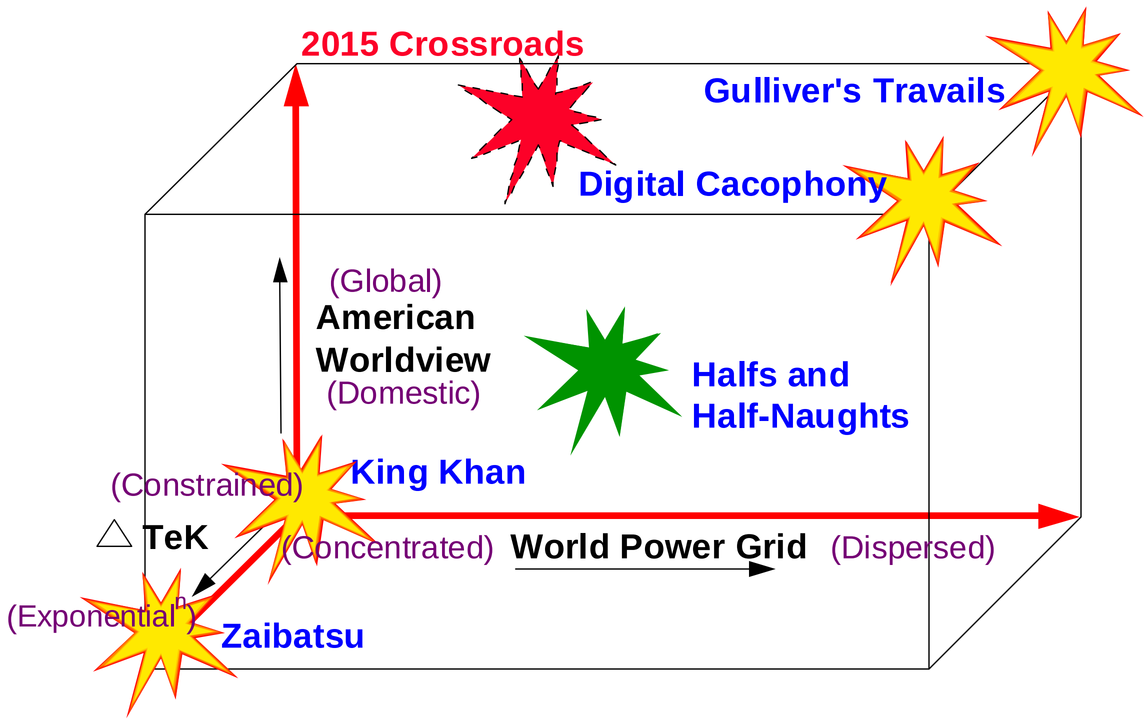

Figure 3-5. *2025* Alternate Futures Strategic Planning Space

American Worldview. — This driver is the US perspective of the world which determines the nation's willingness and capability to interact with the rest of the world. American Worldview captures the dominant US focus regarding international affairs. The US can be primarily internally focused, perhaps even isolationist, or the US can be actively engaged in activities around the world. The poles of American Worldview are domestic and global.

Δ TeK. — This driver is the differential in the growth rate, proliferation, leverage, and vitality of scientific knowledge and technical applications and their consequences. Δ TeK describes the rate of change in both the proliferation and advancement of technology. The two poles of Δ TeK are Constrained and Exponential. Constrained Δ TeK implies that technology is advancing at an evolutionary rate and that its availability is limited to a relatively small number of actors. Exponential Δ TeK occurs when there are revolutionary breakthroughs in technology that are rapidly proliferated throughout the world.

World Power Grid. — This driver describes the generation, transmission, distribution, and control of power throughout the world. This power is a combination of economic, political, and information sources of power as well as military strength. The two poles of this driver are Concentrated and Dispersed. A concentrated world power grid exists when few actors have the means or will to influence others. When a myriad of groups or individuals can change the future, the world power grid is dispersed.

Six alternate futures were chosen from this planning space to provide a diverse set of future conditions against which to evaluate the proposed air and space systems. Four futures are extremes: *Gulliver's Travails, Zaibatsu, Digital Cacophony*, and *King Khan*. The world of *Halfs and Half-Naughts* was chosen for its centrality. Finally, the *2015 Crossroads* future provides a conservative bridge between today and 2025.

In *Gulliver's Travails*, the US is overwhelmed with worldwide commitments, counterterrorism and counterproliferation efforts, humanitarian operations, and peacekeeping operations. In *Zaibatsu*, multinational corporations dominate international affairs, loosely cooperating to create a relatively benign world. *Digital Cacophony* is the most technologically advanced world resulting in great power and independence for the individual, but also creating a world of social isolation, fear, and anxiety. *King Khan* is a world where US dominance has waned due to domestic problems, an economic depression, and overshadowing by a rising Asian colossus. The world of *Halfs and Half-Naughts* is dominated by conflict between the "haves" and "have-nots" and by dynamically changing social structures and security conditions. *2015 Crossroads* uses programmed forces from 1996–2001 to fight a major conflict; it presents the US with a strategic challenge in 2015 that could lead to any of other alternate futures by 2025.

These six alternate futures provided the fulcrum against which the ***2025*** Operational Analysis was applied to determine which of the many systems proposed by the study participants had merit and, hence, should be pursued by the United States Air Force to ensure air and space dominance in the future.

Notes

[1] R. T. Clemen, *Making Hard Decisions: An Introduction to Decision Analysis* (Boston, Mass.: PWS-Kent, 1991), 435–6.

Chapter 4

Weighting and Scoring

This chapter describes how ***Foundations 2025*** was used to evaluate future air and space systems. The process had two steps: first, assign weights to the model hierarchy; second, compute performance scores using scoring functions.

Weighting the *Foundations 2025* Value Model Across Alternate Futures

The first step in using the 2025 value model is for the decision maker to determine the relative importance of the functions, tasks, subtasks, and force qualities. As described in the previous chapter, the decision maker weights functions, tasks, subtasks, and force qualities. Because different futures dictate a different set of required air and space capabilities, the Analysis team obtained value model weights from the ***2025*** participants for the range of potential future worlds postulated by the ***2025*** Alternate Futures team. For each alternate future, the Analysis team used two sets of weights. The first, termed "AU Team weights," is an average of the weights assigned by all student members of the ***2025*** white paper writing teams. The second, denoted "Alt Futures weights," is the weights provided solely by the Alternate Futures team. In general, the Alt Futures weights exhibited greater variation across futures than did the AU Team weights. Weights were held constant for the force qualities and measures of merit because they were not expected to vary much across possible futures. The AU Team weights for each future were considered the baseline weights and are contained in appendix C. The Alternate Futures team weights can be found in the ***2025*** Operational Analysis Technical Report.

Computing System Performance Using Scoring Functions

The Analysis team worked with the Air University student teams to develop a scoring function for each measure of merit.   The development process was iterative: the analysts presented a variety of functional forms on graph paper to the student teams, modifying as necessary to achieve a consensus on the scoring function shape. Computer software allowed the analysts to duplicate these curves within the computer-based value model, and automate the system scoring.

Each system was scored against every metric for each force quality. The system scores for each metric were weighted at each level of the hierarchy by the value weights. As this process is continued—working upwards to the top of the value framework—a weighted average of the system's scores across the entire value framework is developed. This overall weighted average is the overall system value.

Technology Identifying and Scoring

Once the 43 unique systems contained in the white papers were identified, the Analysis team qualitatively analyzed each system to identify which technology areas would be key to achieving the stated system capabilities. Only those technology areas needing development were considered. For example, if a specific technology area was critical to a given system's capability but no new advances were needed in this area for the system to achieve its full capability, then this technology area was not identified as "high leverage" for this particular system.

The team felt it highly desirable to identify and group technologies according to a well-known "gold-standard." Thus, the DOD document entitled *The Militarily Critical Technologies List* (MCTL)[1] was used as the basis for identifying key technology in each system. Across the 43 evaluated systems, 43 key technology areas were identified (this number is a coincidence); they are shown in appendix D.

To eventually rank technologies by their impact on future air and space capabilities, the team assigned a relative weight to each technology embedded in a particular system. The weights selected add up to 100 for each system, and so can be thought of as percentages of the system's dependence on each technology needing development. For example, the five piloted single-stage-to-orbit (SSTO) transatmospheric vehicle (TAV) technologies were weighted as follows:

Technology Area	Weight
Aerospace Structures and Systems	25
High-energy Propellants	25
Ramjet, Scramjet, Combined Cycle Engines	20
Advanced Materials	20
High-performance Computing	10

In this case, since the primary mission of the piloted SSTO TAV is to travel between the surface and low-earth orbit, the highest-leverage technology areas were those of the vehicle's primary propulsion and structural subsystems. Each of these areas were evaluated to be essentially equal in importance. The fifth technology area, high-performance computing, was added not necessarily because of vehicle requirements, but rather because the design process for this type of vehicle will take some advances in computing power. Without advances in high-performance computing, the design process for a TAV with this capability would be impaired. Using this methodology, each of the systems could be scored.

Once the system-versus-technology matrix is developed, the procedure for scoring the technologies is straightforward. For each technology, its contribution to each system is multiplied by the system value, and the resulting products are summed across all systems. The result is a set of technology scores (normalized to a maximum score of 100) that takes into account both the technologies' degree of contribution to future air and space systems and the importance of those systems to air and space operations. This scoring was then repeated for each alternate future since the system values changed with each future.

Scoring the Systems

A team of technical and operational experts scored all 43 systems against each metric in ***Foundations 2025***. The team followed a consensus-seeking approach to obtain each score. The team was not permitted to know the shape of the scoring function and was tasked to determine a score for each metric.

The results of the system scoring are summarized in figure 4-1 and figure 4-2. The vertical axis is the value from the system evaluation on a scale of 0 to 100, where a system value of 0 equates to no score on any of the 134 scoring functions. The horizontal axis is a rank ordering of the systems according to the Analysis team's assessment of the relative amount of technical challenge to develop each system. Figure 4-1 shows the system values for the baseline future. Figure 4-2 shows system values for all six of the alternate futures. Each system's values for the various futures are plotted and connected with a line to show the variation of that system's value across the alternate futures. The spread of values for each system is the result for the corners of the ***2025*** Strategic Planning Space (fig. 3-5). A system's value for any conceivable alternate future can be said with high confidence to lie within the range of the points shown.

The curved dashed line provides a further reference for comparing systems. In the Analysis team's estimation, systems above the line may have sufficient value to offset the technical challenge of producing such a system. Thus, systems to the left of the charts need less value to be attractive options than systems to the right of the chart, because the difficulty of achieving the capability is much less. The location of the line is somewhat arbitrary. It was drawn fairly low so as not to prematurely eliminate any potentially promising systems from consideration.

The highest-value systems evaluated in this study are the Global Information Management System (GIMS), Sanctuary Base, Global Area Strike System (GLASS), Global Surveillance And Reconnaissance System (GSRT), and uninhabited combat air vehicle (UCAV). GIMS has the highest value but high technical challenge; GSRT performs some of the functions of GIMS, but with less technical challenge. Because of this, GSRT could be considered a "stepping stone" to GIMS. Both GLASS and UCAV score well because of a strong Awareness component to complement their Power contributions, and UCAV is the most feasible of all the high-value systems in the near term. The Sanctuary Base has high value but also the highest technical challenge, and may remain infeasible even beyond 2025. The ***2025*** Operational Analysis Technical Report contains tables of each system's value for each future and weight set. Figure 4-3 provides a closer look at the top 25 percent (11 systems) for the AU Team weights.

It is interesting to note the relationship between the Awareness, Reach, and Power contributions to a system's value and the variation between alternate futures. Systems that score similarly in Awareness, Reach, and Power (e.g., GLASS in Figure 4-2) tend to have the least variation; that is, the line connecting their values for each future is short. This is because the weighted average of Awareness, Reach, and Power (the overall value) is insensitive to changes in the weights when the Awareness, Reach, and Power values are of the same magnitude.

The scoring results highlight the fact that a complex system (a system of systems) outperforms any of its components. This is because of the additive nature of the scoring functions. The complex system scores more broadly since it contains the capabilities of all of its components. Conversely, since component systems are unlikely to score in mutually exclusive areas of the value model, the complex system will generally score less than the simple sum of the component system scores.

Finally, Figure 4-4, Figure 4-5, and Figure 4-6 contain graphs similar to that of Figure 4-2, but for the Awareness function, the Deploy task of Reach, and the Power function, respectively, using the AU Team weights. These figures allow the reader to note the systems that score well for a particular function. For example, Figure 4-4 highlights the best systems in terms of the Awareness function. Such a level of detail may prove useful when conducting mission area analysis to determine required improvements for specific functional areas. In fact, the software used in this analysis can display the system values at any level of the value model.

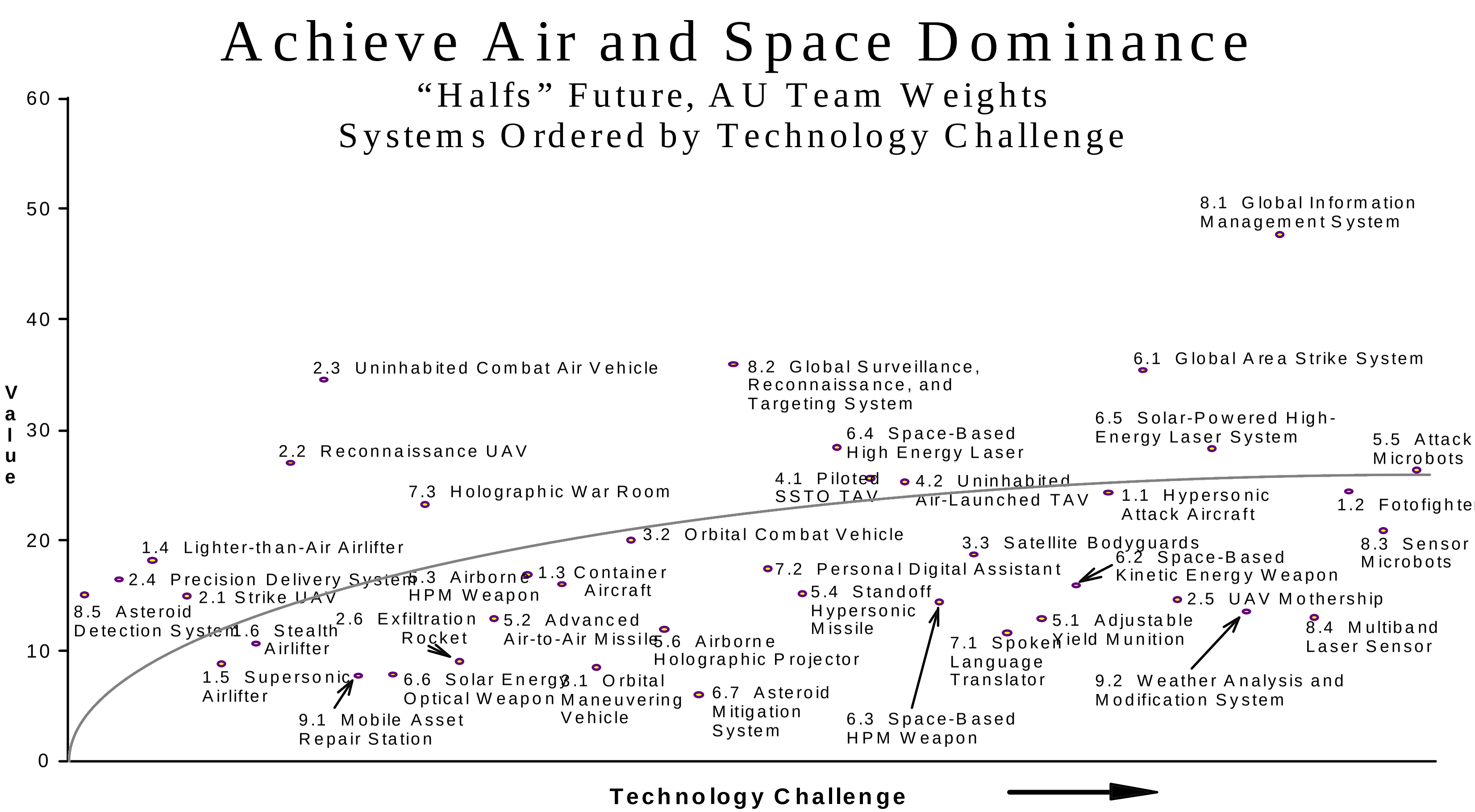

Figure 4-1. System Values for the Baseline Future

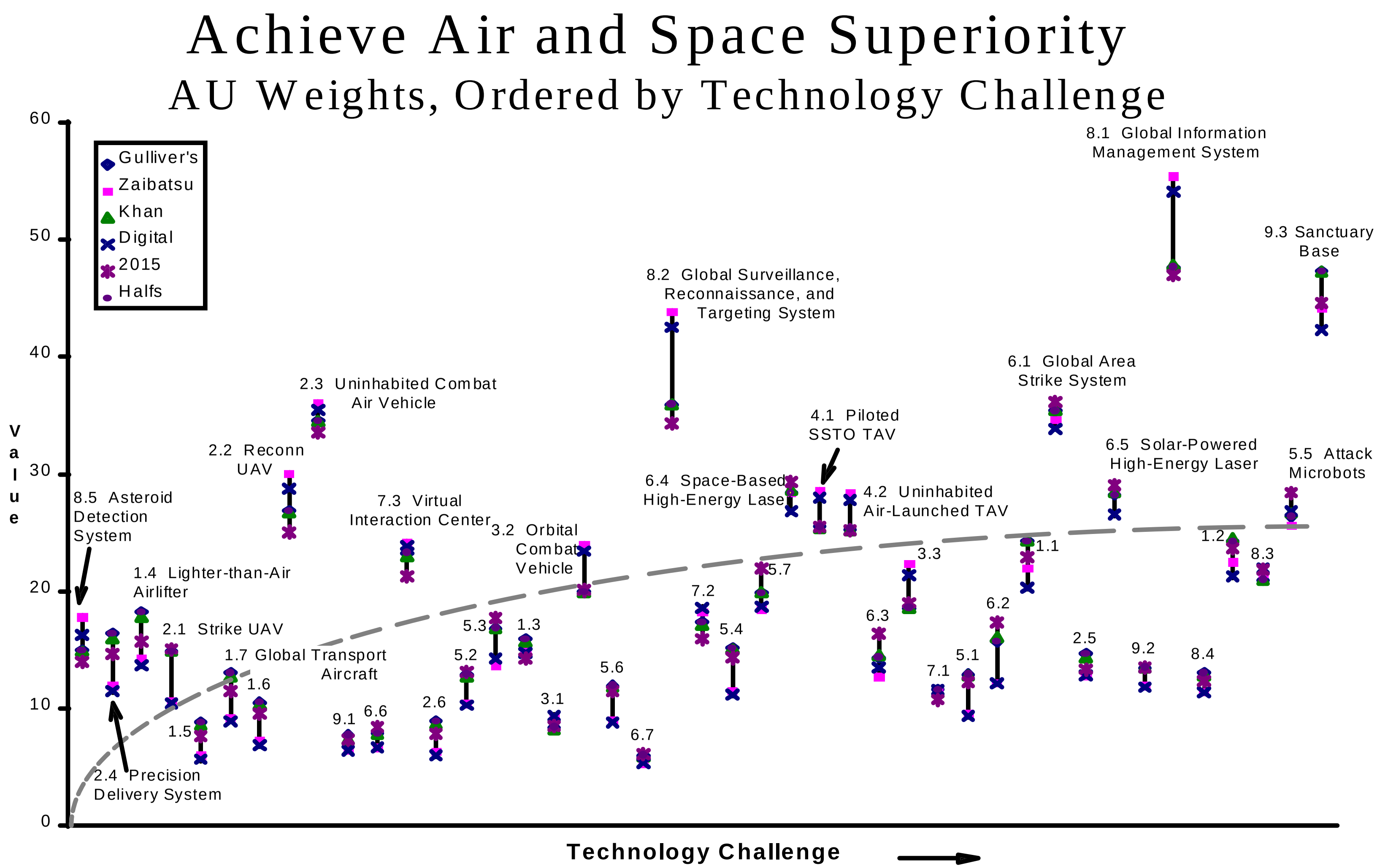

Figure 4-2. Final System Values

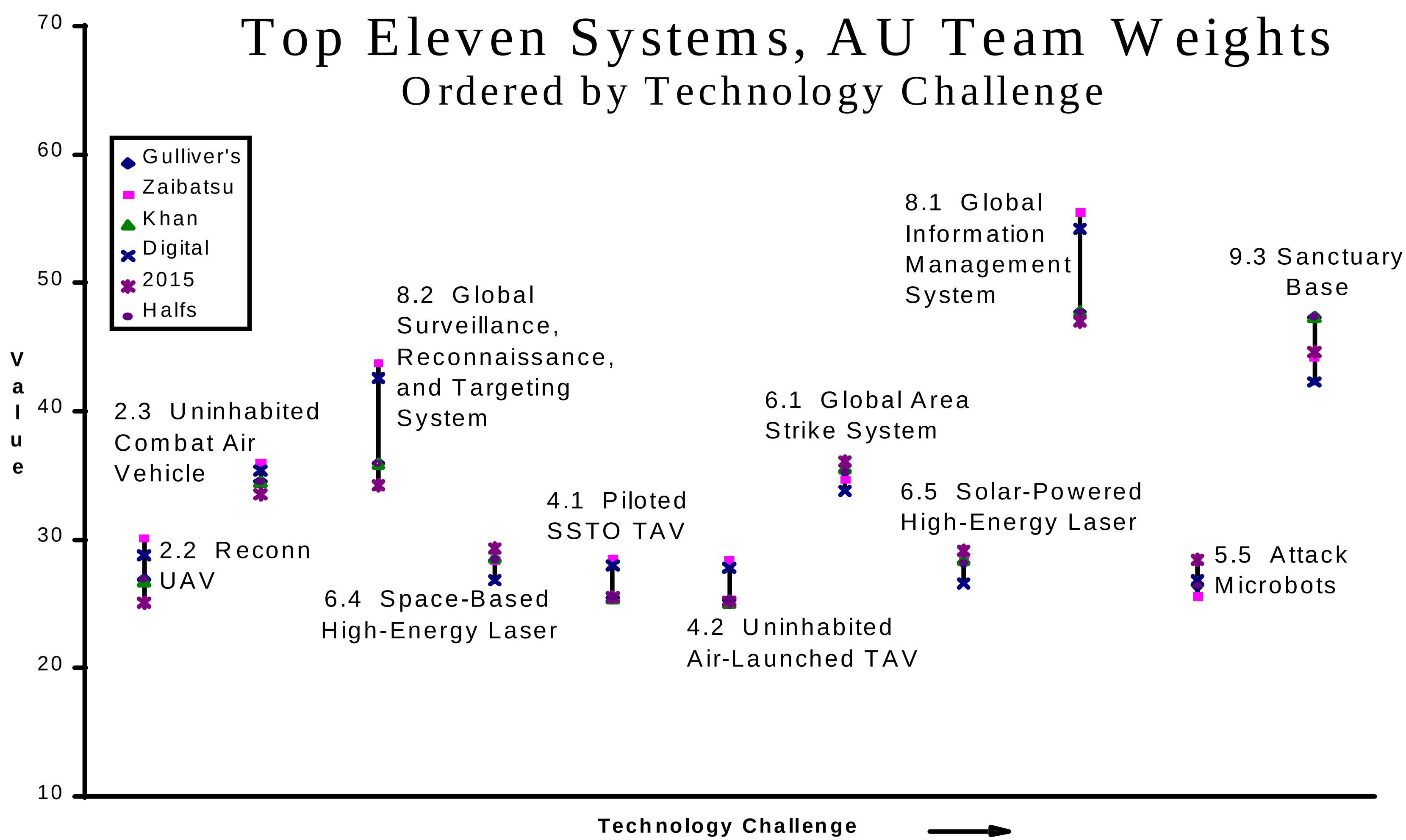

Figure 4-3. Top Eleven Systems

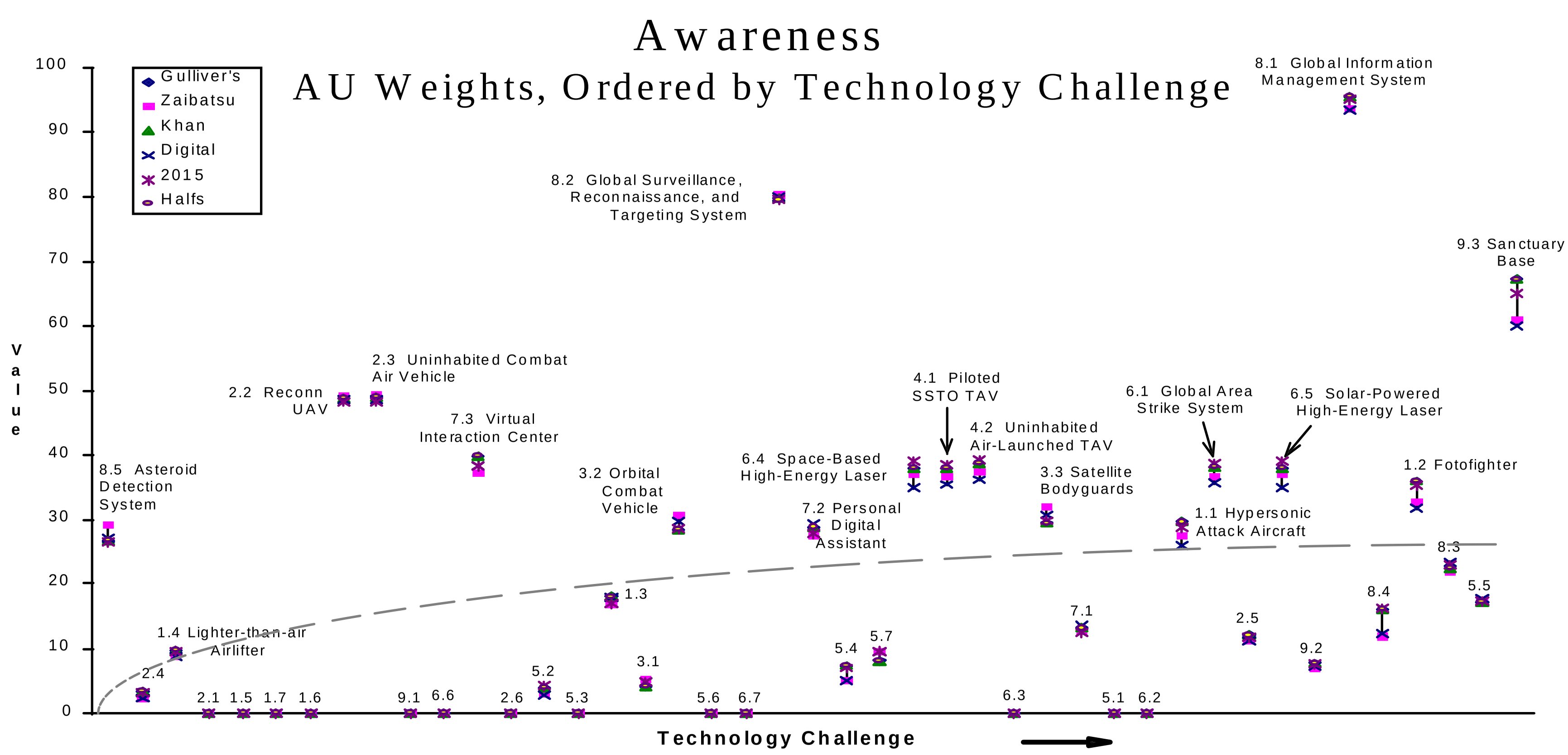

Figure 4-4. ***Awareness*** **Values**

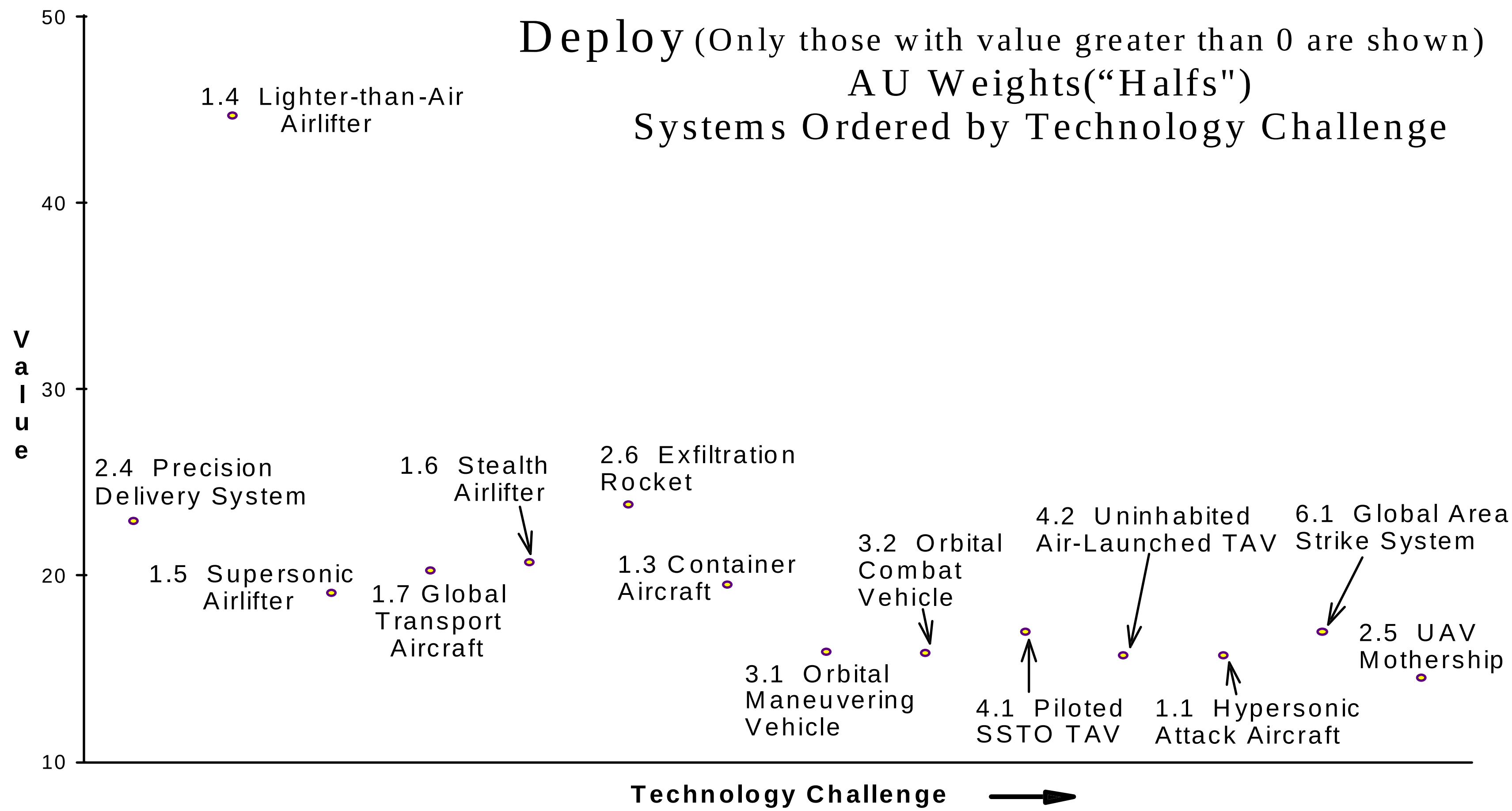

Figure 4-5. Deploy Values - "Halfs" Future

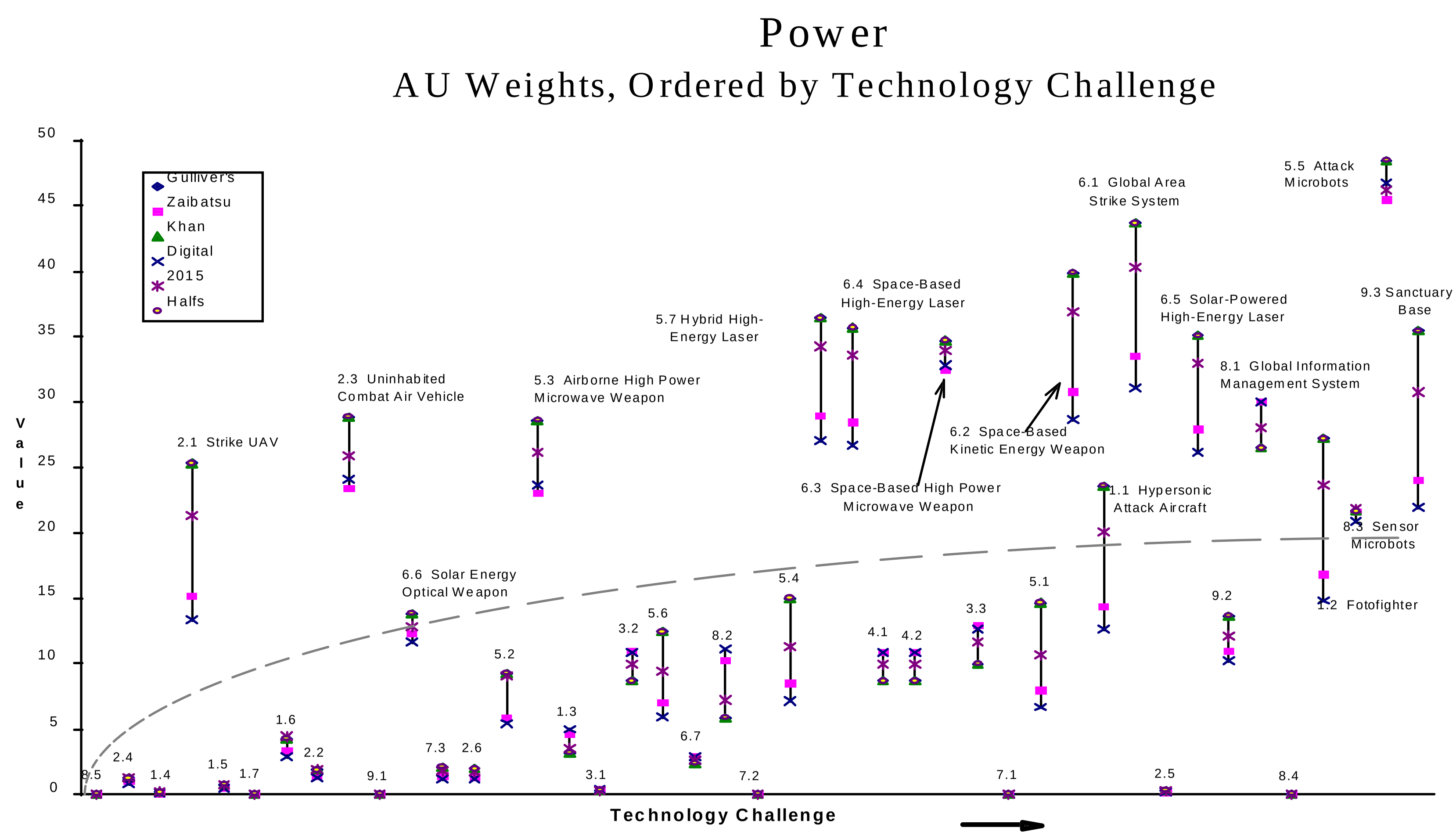

Figure 4-6. Power Values

Scoring the Technologies

The baseline technology assessment is summarized in figure 4-7 for each of the alternate futures. This assessment considers all 43 systems scored, and the Value Model was weighted by all AU white paper writing teams. The score for each technology area was calculated by multiplying the percentage dependence of each of the systems on that development technology by the score that system received in the Value Model. The scores were then summed across all systems with the final result being normalized to a maximum score of 100. These scores are measures of the potential of each enabling technology to improve operational effectiveness in air and space.

In the "Halfs and Half-Naughts" alternate future, which is placed in the center of the strategic planning space for this study, the technology areas clearly divide into three groupings: the top seven technologies (high leverage), the next five technologies (moderate leverage), and the bottom 31 technologies (less leverage). Figure 4-8 shows an expanded view of the top two technology groupings for each alternate future.

As a verification of these results, the Analysis team decided to examine the analysis of the technologies by considering their interaction with only the 11 top-scoring systems. These results are shown in Figure 4-9: the three technology groups generally remained, although the top two groupings contain six technology areas each rather than seven and five, respectively, as in the previous case. The six high-leverage technologies all appeared in the previous high-leverage grouping. Further, 11 of the top 12 technologies remained the same. Lastly, seven of the total 43 technology areas were not applicable when the systems considered were narrowed to the top 11 scorers.

Within technology groupings, the rank changed when going from considering all 43 systems to considering only the 11 top-scoring systems. However, with only three exceptions, technology areas did not change their respective groupings. These exceptions were Aerospace Structures (9.5.4) and Vehicle Flight Control (7.3), which both dropped to a lower-technology grouping—from high and moderate leverage to moderate and less leverage, respectively—and Communications (5.1), which jumped to a higher technology grouping, from lesser leverage to moderate leverage. The results of these two assessments are summarized in table 1 for the high and moderate leverage technologies. The numbers in parentheses indicate the appropriate MCTL category that further defines the technology area.

Table 1

Technology Assessment

	ALL 43 SYSTEMS	TOP 11 SYSTEMS
HIGH LEVERAGE TECHNOLOGIES	Power Systems (10.3) Advanced Materials (1.0) Aerospace Structures (9.5.4) High Performance Computing (4.1.1) Micromechanical Devices (2.6) High-Energy Propellants (12.7) Data Fusion (4.2.5)	Data Fusion (4.2.5) Power Systems (10.3) Micromechanical Devices (2.6) Advanced Materials (1.0) High-Energy Propellants (12.7) High-Performance Computing (4.1.1)
MODERATE LEVERAGE TECHNOLOGIES	Artificial Intelligence (4.2.9) High-Energy Laser Systems (11.1) Vehicle Flight Control (7.3) Image Processing (4.1.4) Optics (10.2)	High-Energy Laser Systems (11.1) Artificial Intelligence (4.2.9) Optics (10.2) Image Processing (4.1.4) Aerospace Structures (9.5.4) Communications (5.1)

A common trend among the higher-leverage technologies was they had wide applicability over the systems. When all 43 systems were considered, the high-leverage technologies scored in at least 13 different systems; the maximum number of systems where any technology area scored was 27. Moderate-leverage technologies scored in eight to 12 different systems. When the systems considered were reduced to the 11 top-scoring ones, the high-leverage technologies scored in at least five systems; the maximum number of systems where any technology area scored was nine. Moderate leverage technologies scored in either three or four different systems. In both assessments, high-performance computing (4.1.1) was the technology area with the broadest coverage over the systems considered.

After each technology area had been scored, AFIT's Graduate School of Engineering assembled a committee from its senior staff to determine the key technology driver, the DOD or the commercial sector, for that particular area. They further ascertained the direction of each developmental effort, whether from the DOD to the commercial sector, from the commercial sector to the DOD, or remaining constant. Table 2 summarizes the key technology development leaders for the high leverage technologies. The ***2025*** Operational Analysis Technical Report provides this data for all 43 technologies.

Table 2

Technology Development Leaders for High Leverage Technologies

KEY TECHNOLOGY	DOD LEAD	BOTH DOD & COMM	COMM LEAD
4.2.5 Data Fusion	X--->		
10.3 Power Systems	X		
2.6 Micromechanical Devices		X--->	
1.0 Advanced Materials		X	
12.7 High-energy Propellants	X		
4.1.1 High-performance Computing			X

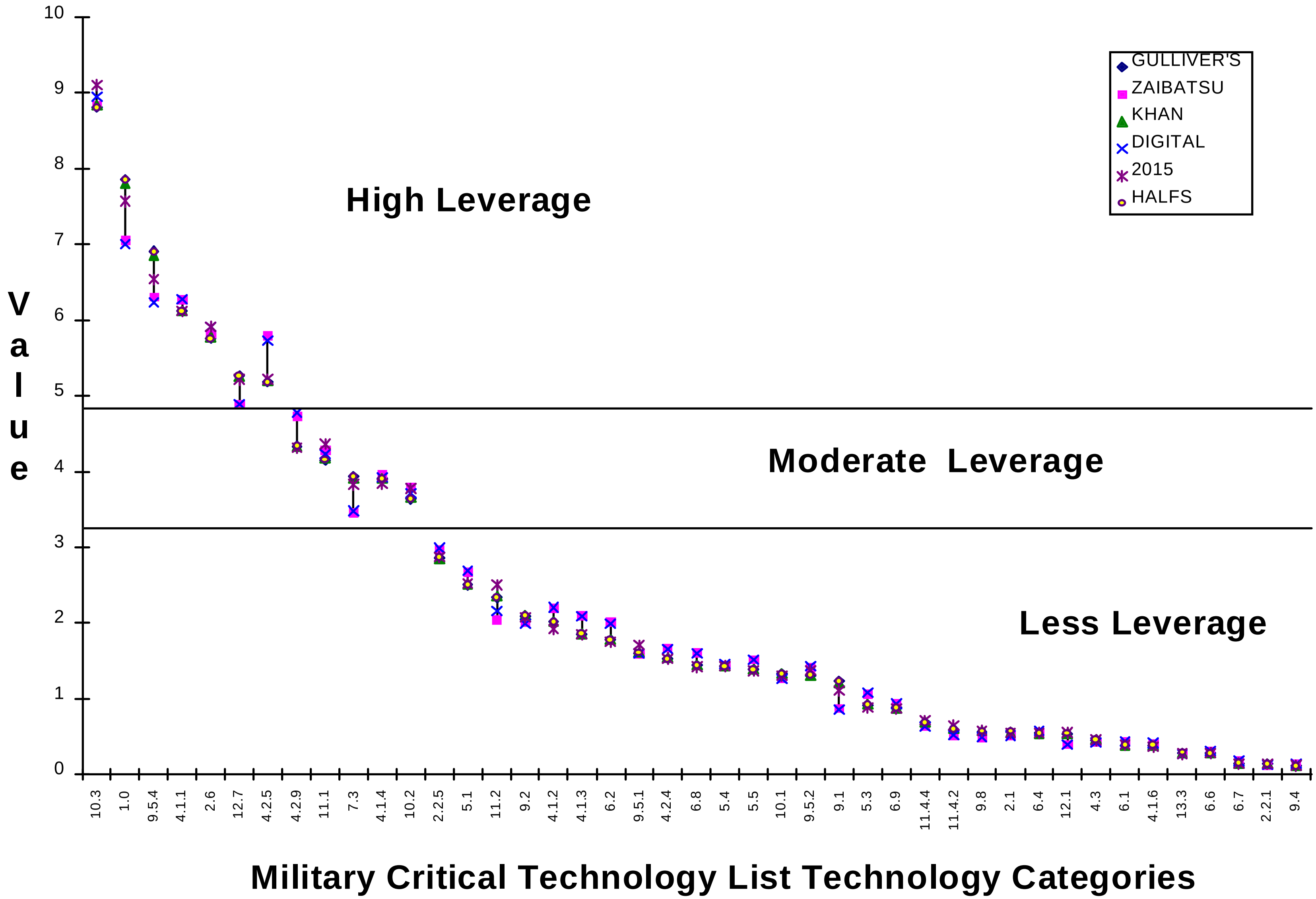

Figure 4-7. Technology Rankings (All 43 Systems, AU Students Weights)

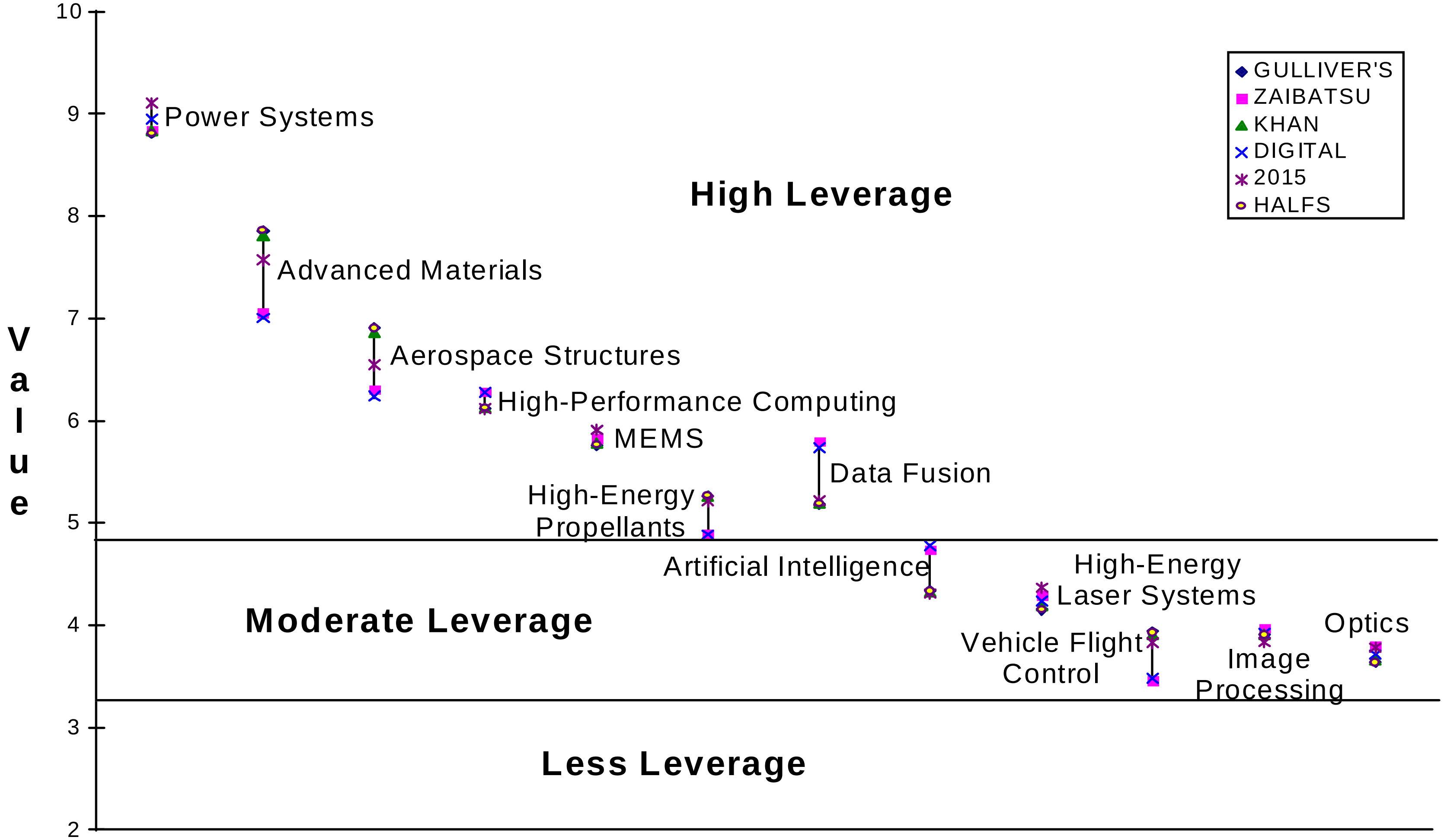

Figure 4-8. Top Twelve Technology Rankings (All 43 Systems, AU Students Weights)

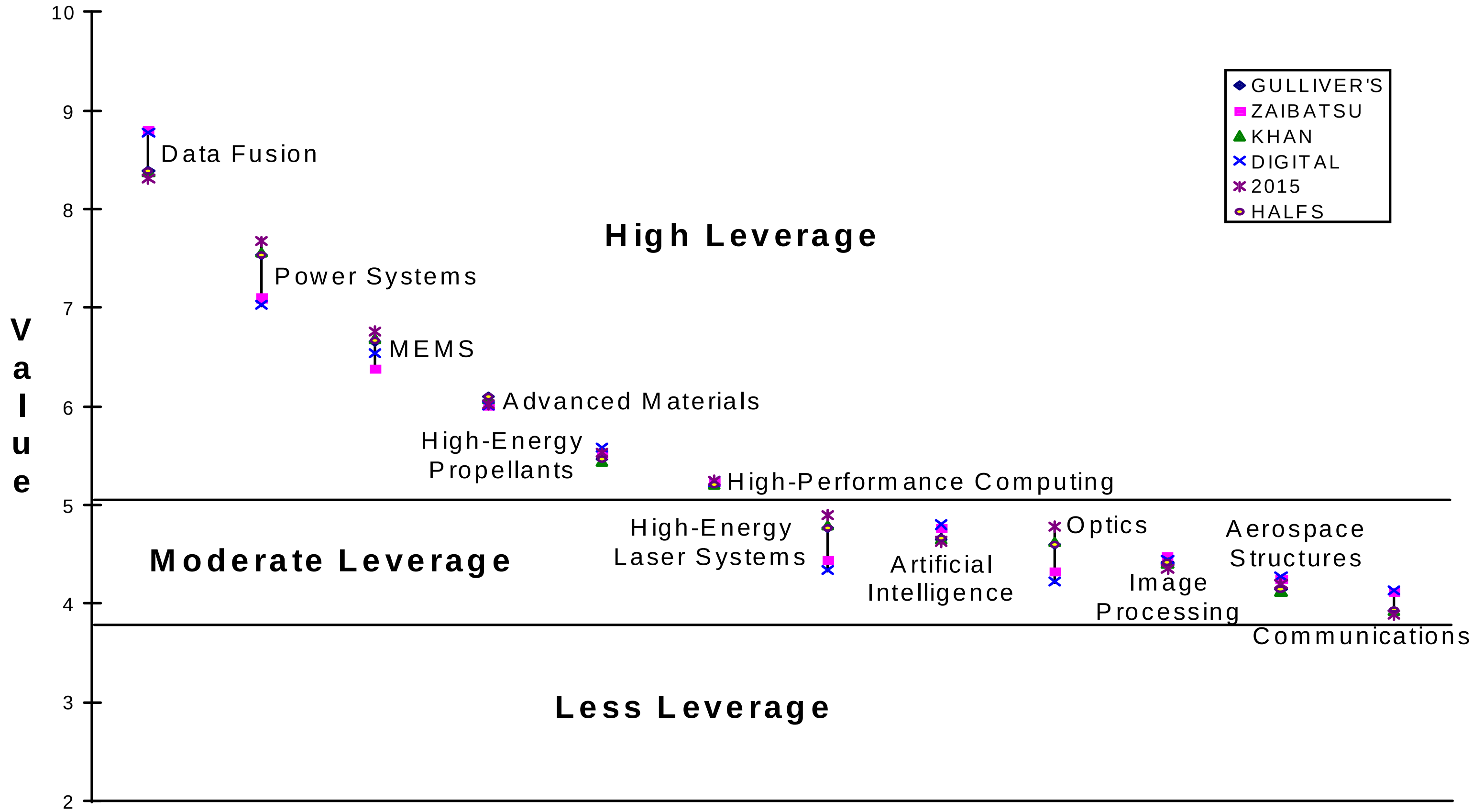

Figure 4-9. Top Twelve Technology Rankings (Top 11 Systems, AU Students Weights)

Notes

[1] *The Military Critical Technologies List* (Washington, D. C.: Office of the Undersecretary of Defense for Acquisition, October 1992).

Chapter 5

Conclusions

The ***2025*** Operational Analysis (OA) was a key milestone in the ***2025*** process and provided a number of unique contributions. Most importantly, it met its fundamental purpose—the OA identified future air and space systems required to support air and space dominance and the key technologies that will make those systems possible. Further contributions are covered in the following order:

- the major implications of the study results,
- the lessons learned during the ***2025*** OA process,
- the limitations of the study, and
- the major implications of the ***2025*** OA for the future.

Major Implications of the *2025* Operational Analysis

This analysis strongly suggests that the high ground of improved *awareness* offers significant potential for achieving future air and space dominance. Typically, top-scoring systems possessed higher degrees of *awareness* and/or were predominantly *space* systems:

- Global Information Management System (GIMS)
- Sanctuary Base (SB)
- Global Surveillance, Reconnaissance, and Targeting System (GSRT)
- Global Area Strike System (GLASS)
- Uninhabited Combat Air Vehicle (UCAV)
- Space-Based High-Energy Laser (Space HEL)

- Solar High-Energy Laser (Solar HEL)
- Reconnaissance Unmanned Air Vehicle (Recon UAV)
- Attack Microbots
- Piloted Single-Stage-to-Orbit (SSTO) Transatmospheric Vehicle (TAV)
- Uninhabited Air-Launched TAV

Seven of the top eight systems emphasized the *awareness* function. GSRT can be thought of as a first generation GIMS; it obtains most of the value of GIMS with much less technological challenge. Both systems scored high because the management of information tasks was assigned high weights by the ***2025*** white paper writing teams. Such systems go beyond data fusion to knowledge fusion; they provide a global view that could revolutionize military operations. Improved awareness is critically important because it enables virtually all other air and space force capabilities.

This analysis also suggests control of the high ground of space will be very important. Of the top 11 systems, only three do not operate in space or use major space-based components. Space-based weapons are significant contributors to the operational effectiveness of future air and space operations. They provide key capabilities in space defense, ballistic missile defense, defense of terrestrial forces, and terrestrial power projection. Of the weapon systems evaluated, the Space HEL laser seems to hold the most promise, largely because its optical system could also be used for surveillance and imaging missions (an *awareness* function). Other systems that scored well were the Solar HEL, the Space-Based Kinetic Energy Weapon, and the Space-Based High-Powered Microwave. *Spacelift* is another essential contributor to future space operations (i.e., reusable transatmospheric vehicles provide critical lift capability to improve virtually all space force capabilities).

This analysis also suggests that improved *power* will be best accomplished through improved speed, precision, and on-station time. The ***2025*** white paper writing teams viewed the reduction of the OODA (observe, orient, decide, act) loop to an OODA "point" as critical to future operations. All of the "shooter" systems that emphasized *awareness* scored high by reducing the time to identify, target, and kill threats. Among these systems are the GLASS, the Space HEL, and the Solar HEL. The envisioned systems emphasized the increased need for precision over mass, especially with respect to avoiding excess collateral damage

The constant quick response requirement of future combat meant many of the systems either were global or used uninhabited air vehicles (UAVs). It is important to note that while the UAVs are uninhabited, none are envisioned as operating autonomously without a human in the loop. Such an improved on-station *power* capability is important because it provides a constant deterrent to enemy forces.

Key to this analysis was the use of several possible alternate futures as the basis for the sensitivity analysis. Because the analysis was conducted across a number of alternate futures and the resulting conclusions remain basically the same across those futures for any reasonable set of weights a future decision maker might apply, this is an excellent initial set of systems to consider for future employment of air and space power.

The technology assessment portion of the study identified six high-leverage technologies that are important to a large number of high-scoring systems:

- Data Fusion
- Power Systems
- Micromechanical Devices
- Advanced Materials
- High-Energy Propellants
- High-Performance Computing

Advances in these areas show promise to substantially improve a wide range of air and space operations. Other technologies were also important, but contributed to only three or four of the high-value systems. Among the top-scoring medium-leverage technologies were:

- High-Energy Laser Systems
- Artificial Intelligence
- Optics
- Aerospace Structures
- Image Processing
- Communications

Some of the high-leverage technologies enabling ***2025*** systems, such as high-performance computing, are being pursued aggressively in the commercial sector. Others, such as power systems, have lower commercial interest. An expanded analysis of the ***2025*** systems and their embedded technologies can help develop the most effective DOD investment strategy.

Operational Analysis Lessons Learned

Foremost among the ***2025*** OA lessons learned was that the value-focused thinking approach worked very well. The ***Foundations 2025*** value model has been used to evaluate systems that span the full range of future air and space combat operations. These systems are conceptual system ideas that will require significant research and development to design and evaluate. The OA provided a structure to incorporate the subjective judgments of operational and technical experts to produce objective, traceable, and robust results.

The focus of the value model, ***Foundations 2025***, was on the employment of air and space forces. This model does not consider the USAF functional areas required to organize, train, and equip. As it became apparent that none of the current doctrinal frameworks were free of these functional views, the value model was developed from the bottom up. In taking this approach, the Analysis team reduced the institutional biases associated with the numerous stovepipes in the current USAF organizational structure.

Study Limitations

It is important to remember that the analysis did not take into account the cost or risk of developing any of the system concepts. It looked only briefly at the technological challenge of each system concept. While this study indicates some systems and technologies that show promise for dramatically improving the effectiveness of air and space operations, there are other important factors that need to be considered before making an investment decision.

A consequence of most value models is that a complex system (or system of systems) that performs many tasks generally outscores a similar system that performs only a few of the tasks. Also, for ***Foundations 2025***, a system's sphere of influence is primarily measured by its range, which is only one force quality. For example, the Sanctuary Base scores high because it has awareness, reach, and power capabilities. Yet, it has a 500-mile range limitation on most of those capabilities. ***Foundations 2025*** would show only a small difference between the Sanctuary Base and a similar system with global range.

Major Implications for the Future

A number of senior decision makers have viewed the model and commented that the best use of ***Foundations 2025*** may be an analysis of systems within the distinct spheres of *awareness, reach, and power.* They envision separating and developing each function of the model further (refining the tasks, subtasks, force qualities, measures of merit, and scoring functions) and studying which *awareness* (or *reach* or *power*) systems are most promising. These three separate models could be effective mission area analysis tools for the major commands.

The completed ***Foundations 2025*** value model is the starting point for *Value Focused Thinking* with the Department of Defense. For any function, task, or subtask, the model can be used to evaluate current and projected systems. Next, the acquisition community can focus on how new concepts can be developed to significantly increase value. Many individual and various creativity techniques can be used to develop these new concepts.

Another opportunity to capitalize on the ***Foundations 2025*** model is to use it as a framework for future air and space doctrine. Because it identifies fundamental functions, tasks, and subtasks, it could be the foundation for joint doctrine for future air and space warriors. The ***2025*** analysis techniques could be used to develop an entirely new joint military doctrine free from current institutional bias.

Summary

The ***2025*** operational analysis is an important point for further discussion and analysis. It completed the ***2025*** process by identifying the most promising systems and enabling technologies required to provide dominant air and space power for Air Force of the twenty-first century.

Appendix A

Foundations 2025 Value Model

This appendix shows the ***Foundations 2025*** Value Model (fig. A-1 through fig. A-4). The full set of scoring functions can be found in the ***2025*** Operational Analysis Technical Report.

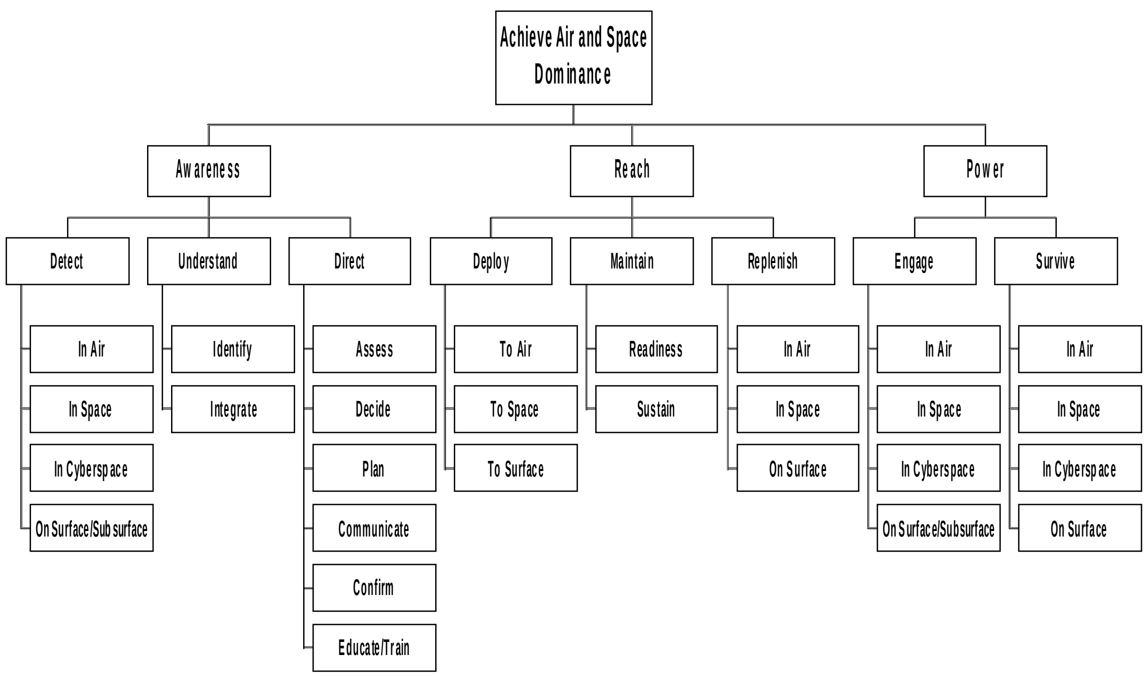

Figure A-1. Value Model: Top Level

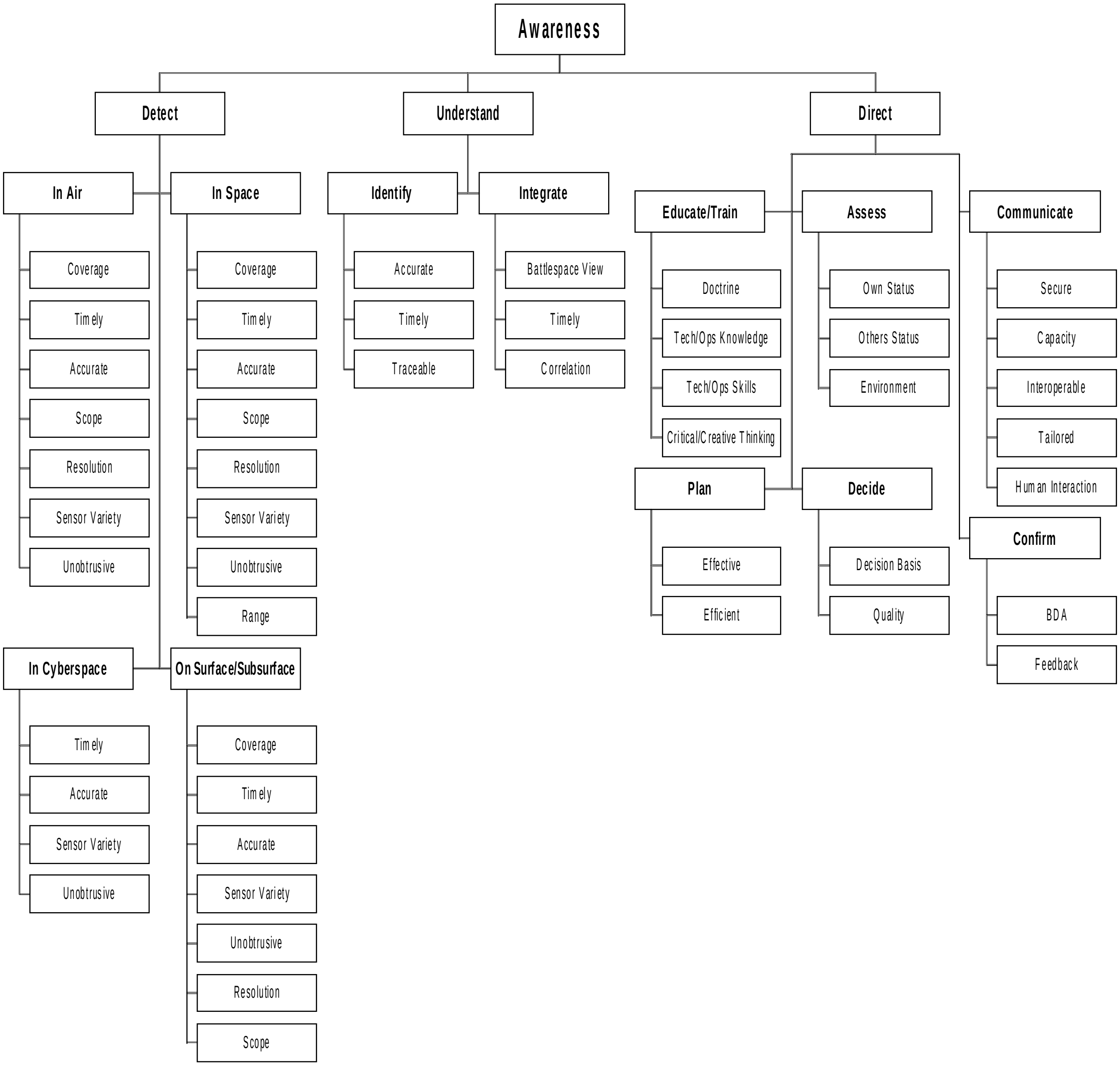

Figure A-2. Value Model: Awareness

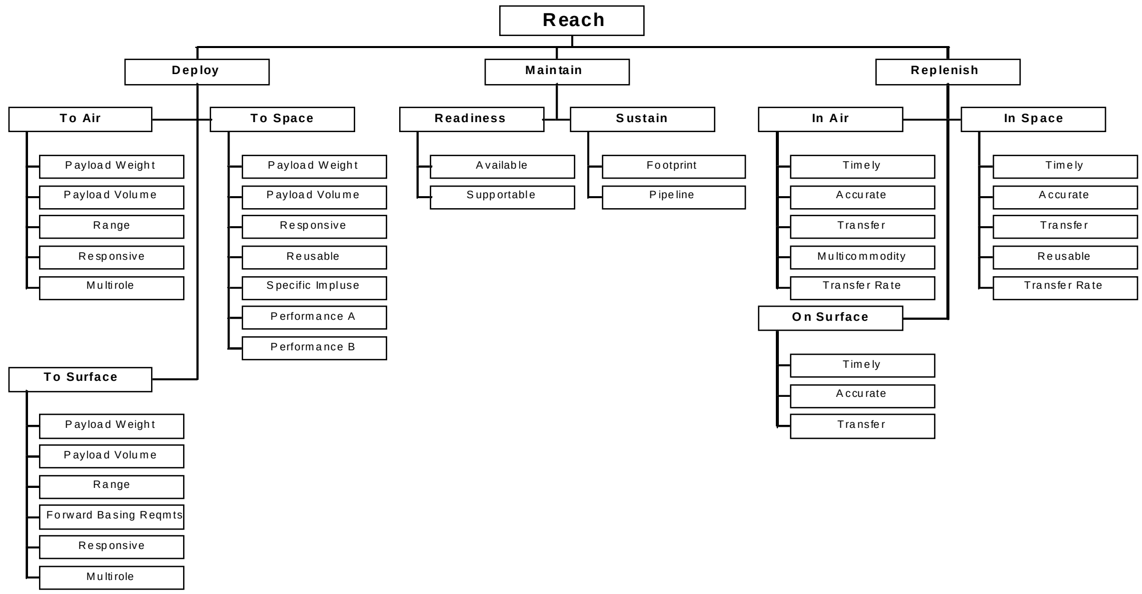

Figure A-3. Value Model: Reach

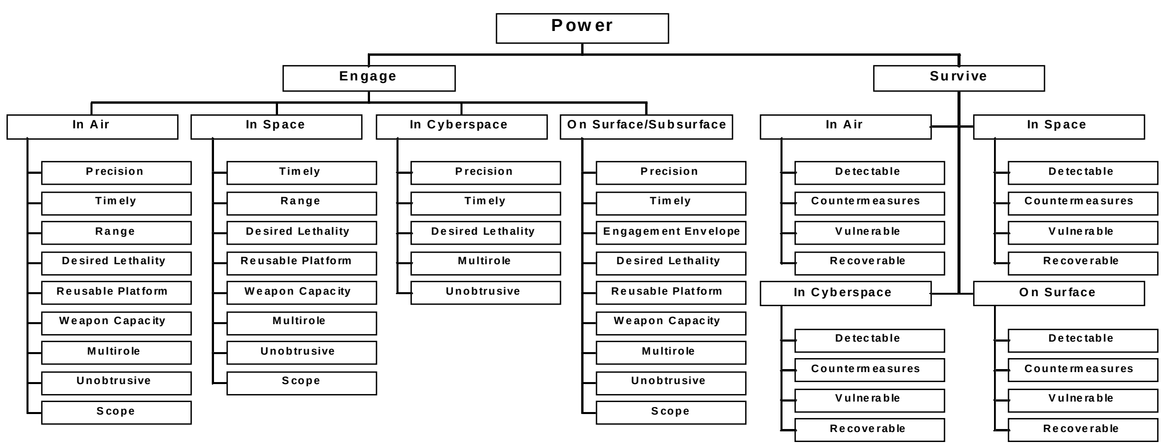

Figure A-4. Value Model: Power

Appendix B

System Descriptions

This appendix provides a short description of each of the 43 systems identified in the *AF 2025* study. Figure B-1 shows the system hierarchy, categorized by functional area. Each system description contains a brief narrative; a more complete description that includes a list of capabilities, a list of enabling technologies, and a list of the ***2025*** white papers relating to the system can be found in the ***2025*** Operational Analysis Technical Report.

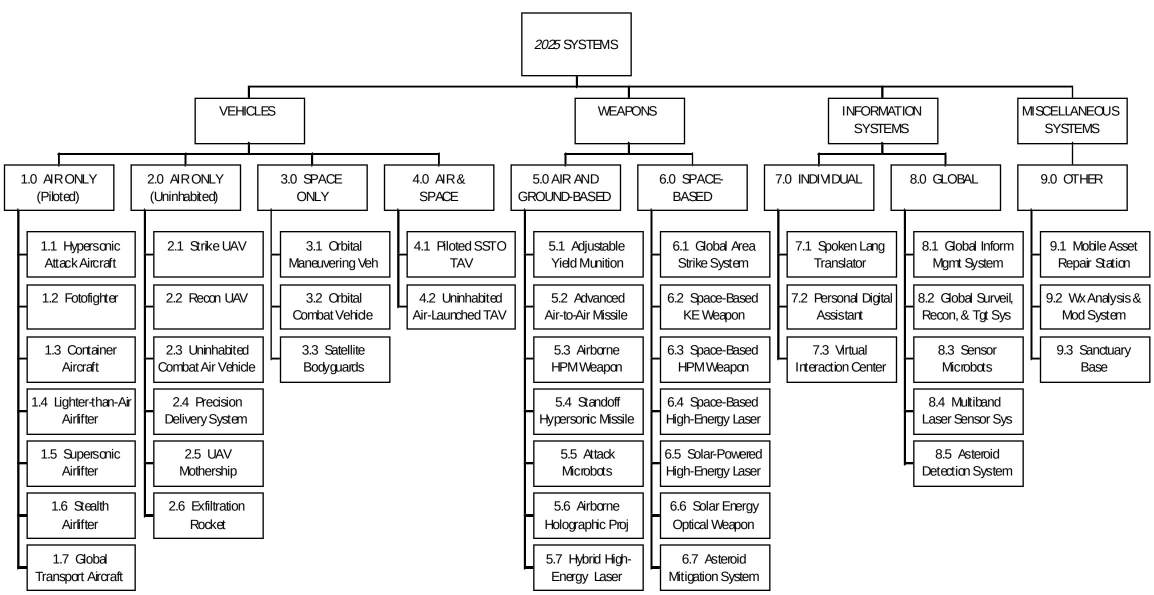

Figure B-1. System Hierarchy

1.1 **Hypersonic Attack Aircraft** A high-speed strike vehicle capable of projecting lethal force anywhere in the world in less than four hours. Operating at Mach 12 and a cruise altitude of 100,000 ft, this vehicle is a reusable two-stage system comprised of an unmanned boost vehicle and a manned hypersonic strike aircraft. The gas turbine-engined boost vehicle requires a conventional runway and accelerates the strike vehicle to Mach 3.5 and 65,000 ft. The strike vehicle then separates and uses a ramjet/scramjet engine to reach its cruise condition. The total system range is 10,000 nautical miles (NM); the hypersonic strike vehicle has an unrefueled range of 5,000 NM. It is capable of launching precision-guided munitions, including the hypersonic air-to-ground missile described in system 5.4, at a standoff distance of 1,450 NM. Alternatively, the platform may be used to transport an uninhabited unmanned air vehicle described in system 4.2.

1.2 **FotoFighter** A highly maneuverable, stealthy, inhabited advanced fighter aircraft whose skin is fitted with an array of diode lasers and sensors. Efficient electronic control of the laser arrays allows this fighter to engage multiple targets simultaneously with varying degrees of lethality. At low powers, the arrays can function as transmitters and receivers for low probability of interception (LPI) communications. Threat detection, target illumination, and tracking are also possible.

1.3 **Container Aircraft** An aircraft consisting of an airlifter in which standard shipping containers form integral structures of the fuselage. The aircraft consists of three baseline sections: the cockpit, the wingbox, and the empennage. In its simplest form, the "short" version—the aircraft is capable of flight by joining the cockpit, wingbox, and empennage directly together. With standard shipping containers installed between the cockpit and wingbox and between the wingbox and the empennage, the aircraft can be configured to carry cargo ("stretch" version). The first wave of container aircraft to arrive in a theater of operations "disassembled." The cockpit then forms a command and control facility, the aircraft engines generate the base power, the wings provide fuel storage, and the containers themselves (when empty) provide shelter for troops, supplies, and equipment. This concept provides a mobile base.

1.4 **Lighter-than-Air Airlifter** A very large capacity, rigid-frame lighter-than-air vehicle that provides one million pound airlift capability with a unrefueled range of 1,2500 NM. This vehicle also has the ability to deploy and recover powered UAVs while stationary or in-transit. Vehicle is able to house support materiel, personnel, and MEDVAC modules depending upon mission requirements.

1.5 **Supersonic Airlifter** A Mach 2.4 supersonic airlifter that provides 50,000 pound airlift capability with a unrefueled range of 5,000 NM. This vehicle provides the capability to deliver military personnel (roughly 150), advanced precision weapons, and appropriate resupply anywhere in the world within hours.

1.6 **Stealth Airlifter (SA)** An all-weather, low-observable aircraft capable of low supersonic cruise and dedicated to special operations forces (SOF). With an unrefueled range up to 4,000 NM, it can be used to insert and extract SOF teams, as well as to extract high value assets (HVA) and weapons of mass destruction. The SA connected to a global information management system (say, GIMS System 8.1) for all source intelligence, weather, navigation, and communications.

1.7 **Global Transport Aircraft (GTA)** A global reach transport airplane of less than one million pounds take off gross weight, capable of carrying 150,000-250,000 pounds 12,000 to 10,000 NM respectively. This vehicle also can deploy powered UAVs and parafoils. The GTA house support materiel, personnel, and MEDVAC modules, depending upon mission requirements. This aircraft also be modified for use as a tanker.

2.1 **Strike UAV** A low-observable, uninhabited air vehicle that loiters subsonically over the region of interest for long periods of time (24+ hours) until directed to strike. Its primary mission is to engage ground targets with standoff precision munitions; however, it also has a limited air-to-air capability. It relies on off-board sensors to supply reconnaissance and targeting information as well as command and control, although it has sufficient on-board sensor capability to allow it to perform preprogrammed missions.

2.2 **Reconnaissance UAV** An uninhabited reconnaissance aerial vehicle (URAV) that can be employed either as an independent system or in conjunction with other airborne, ground-based, and spaceborne systems. The URAV is fitted with a variety of multispectral sensors, such as infrared, optical, radar, and laser, and collects images, signals intelligence (SIGINT), electronic intelligence (ELINT), and other information. It loiters subsonically at very high altitudes over the region of interest for extended periods of time without refueling. The URAV also can be used as part of a bistatic configuration, in which it illuminates the region of interest while different sensors receive and process the information.

2.3 **Uninhabited Combat Air Vehicle (UCAV)** A vehicle that can be employed either as an independent system or in conjunction with other airborne, ground-based, and space-based systems. It carries a suite of multispectral sensors (optical, infrared, radar, laser, etc.) supplies information to its suite of standoff precision guided munitions. UCAV loiters at high altitude over the region of interest for long periods of time (24+ hours) until called upon to strike a target. While in its subsonic loiter mode, it can perform a surveillance and reconnaissance mission for the Global Information Management System (System 8.1). It could be used as part of a bistatic configuration in which it illuminates a region of interest while a different sensor receives and processes the information. As a secondary mission, it can perform electronic countermeasures (ECM) and electronic counter-countermeasures (ECCM) roles.

2.4 **Precision Delivery System** A suite of powered and parafoil UAVs capable of autonomous flight for the purpose of all-weather precision (within 1 meter) airdrop. High altitude (40,000 ft) precision airdrops can be achieved using GPS or INS-guided parafoil delivery systems. This technique allows equipment/supplies to be delivered to forward-deployed forces while transport aircraft remain hundreds of miles from the drop zone. Positions can be determined using light detection and ranging (LIDAR) or a GPS instrumented radio drop sound. Powered UAVs and deliver smaller, high value packages from greater standoff ranges.

2.5 **UAV Mothership** A large capacity, long-loiter-time, uninhabited subsonic air vehicle used to deploy and recover smaller combat UAVs. It also can replenish them with weapons and propellant. This air vehicle has the ability to collect, convert and store solar energy, and then transfer energy through physical means or via beaming to other airborne vehicles such as the FotoFighter (System 1.2).

2.6 **Exfiltration Rocket (ER)** A system designed to quickly extract special operations forces (SOF) teams from the mission area. This system would be brought in during the SOF insertion and assembled at the exfiltration launch site. After mission completion, the SOF team members load themselves and any other items, such as a high value asset (HVA) or weapon of mass destruction (WMD), into the ER and then take off. The payload and passengers are recovered via an air-retrievable payload system or through a “soft” landing in a friendly area.

3.1 **Orbital Maneuvering Vehicle (OMV)** An uninhabited orbital propulsion and docking system used to take payloads from an earth-to-orbit lift vehicle and place them in their final orbital plane, or used to fetch and return orbiting payloads to a central repair and recovery location. The system is be capable of carrying line replaceable units (LRU) to a damaged/degraded satellite and accomplishing on-site repair or replacement. It is designed to allow refueling of civil, commercial, and military satellites as well as the rearming of military space weapons platforms.

3.2 **Orbital Combat Vehicle (OCV)** An uninhabited orbital propulsion and docking system used to take payloads from an earth-to-orbit lift vehicle and place them in their final orbital plane, or used to fetch and return orbiting payloads to a central repair and recovery location. The system can also carry line replaceable units to a damaged/degraded satellite and accomplish on-site repair or replacement. It is designed to allow refueling of civil, commercial, and military satellites as well as the rearming of military space weapons platforms. The OCV is fitted with a medium power high-energy laser system for limited defense and counterspace missions.

3.3 **Satellite Bodyguards** A small constellation of defensive satellites (approximately five)placed in close proximity to the protected asset. “Hunter-killers” actively seek out threats and incapacitate them with directed energy weapons. Detection of threats from the surface or air is done by an off-board sensor suite (say, systems 8.1 or 8.2) and supplied to the “hunter-killer” satellites. Detection of space-based threats is done by the “hunter-killer” satellites themselves. Decoy satellites appear identical (both electromagnetic and visual) to the protected assets to confuse an aggressor; when approached, the decoy can impact and disable the enemy craft.

4.1 **Piloted SSTO Transatmospheric Vehicle** A system that provides space support and global reach from the earth’s surface to low-earth orbit (LEO) using a combination of rocket and hypersonic air-breathing technology. The transatmospheric vehicle (TAV) takes off vertically, is refuelable in either air or space, and can land on a conventional runway. It has a variable payload capacity (up to 10,000 pounds) and performs as both a sensor and weapons platform. Alternate missions include satellite deployment and retrieval from LEO and deployment of an anti-ASAT weapon.

4.2 **Uninhabited Air-Launched Transatmospheric Vehicle** A multirole transatmospheric vehicle (TAV). Launched from an airborne platform (such as System 1.1), it is capable of rapid deployment (or retrieval) of satellites providing communication links, intelligence information, and so forth. It carries a suite of multispectral sensors (optical, infrared, radar, laser, etc.) for surveillance and reconnaissance missions. This TAV is a rocket-powered vehicle approximately the size of an F-15, capable of carrying several small satellites (6 ft x 6 ft x 6 ft, 1000 lbs each) to low earth orbit. Further, it could perform an antisatellite (ASAT) role. This TAV can land on a conventional runway.

5.1 **Adjustable Yield Munition (AYM)** An approach to achieve precise matching of the weapon's effect to the target's characteristics. By manipulating the explosive yield of a weapon (i.e., "dial-a-yield"), together can greatly reduce collateral damage. This is particularly advantageous when flexibility and precision are both required: a platform on patrol, awaiting targets of opportunity, can utilize the same weapon for a hard kill with a large yield or for a surgical, mission-only kill with a tailored yield. One approach to controlling the yield is to change the material composition of the explosive at the molecular level.

5.2 **Advanced Air-to-Air Missile** A long range air-to-air missile that receives real-time target information from off-board sensors and utilizes reactive jets and an on-board computer to acquire, pursue and destroy enemy air assets, including cruise missiles. Terminal tracking and guidance may employ a combination of LIDAR, Infrared (IR), radio frequency (RF), magnetic anomaly detection (MAD), Jet engine modulation (JEM), photographic, and acoustic sensors.

5.3 **Airborne High-Power Microwave Weapon** A pulsed power airborne high power microwave (HPM) system. This medium range weapons system constitutes the primary payload of the host escort defense aircraft. The system generates variable magnitude HPM fields that disrupt or destroy electrical components in the target region. It can engage both air and ground targets.

5.4 **Standoff Hypersonic Missile** An hypersonic air-to-ground missile launched from a hypersonic strike vehicle (System 1.1). It utilizes a scramjet to propel itself at Mach 8 toward the intended high-value target, then glides to target at Mach 4; its flight trajectory is altered as needed via off-board control. Its high-speed air-launched range is 1,450 NM.

5.5 **Attack Microbots** A term that describes a class of highly miniaturized (1 millimeter scale) electromechanical systems being deployable en masse and performing individual or collective target attack. Various deployment approaches are possible, including dispersal as an aerosol, transportation by a larger platform, and full flying/crawling autonomy. Attack is accomplished by a variety of robotic effectors, electromagnetic measures, or energetic materials. Some "sensor microbot" capabilities are required for target acquisition and analysis.

5.6 **Airborne Holographic Projector** A projector system that displays a three-dimensional visual image in a desired location, removed from the display generator. The projector can be used for psychological operations and strategic perception management. It is also useful for optical deception and cloaking, providing a momentary distraction when engaging an unsophisticated adversary.

5.7 **Hybrid High-energy Laser System (HHELS)** A system consisting of several ground-based, multimegawatt high-energy chemical lasers and a constellation of space-based mirrors. HHELS can be used in several modes of operation. In its weapons mode with the laser at high power, it engages air, space, and ground targets by reflecting a laser beam off one or more of the mirrors to the intended target. It can also be used for target tracking, limited space debris removal (1-10 centimeter objects), and replenishment of satellites.

6.1 **Global Area Strike System (GLASS)** A system incorporating of a high-energy laser (HEL) system, a kinetic energy weapon (KEW) system, and a transatmospheric vehicle (TAV). The HEL system consists of ground-based lasers and space-based mirrors which direct energy to the intended target. The KEW system (System 6.2) consists of terminally guided projectiles, with and without explosive enhancers. The TAV (System 4.1) is a flexible platform capable of supporting maintenance and replenishment of the HEL and KEW space assets, and can also be used for rapid deployment of special operations forces. Target definition and sequencing is managed externally (e. g., using GIMS (System 8.1)).

6.2 **Space-Based Kinetic Energy Weapon (KEW)** A general class of low earth orbit (LEO) based weapons that include a variety of warhead types from flechettes and pellets to large and small high density rods. The KEW may be directed at air, space, and ground targets; it achieves its destructive effect by penetrating the target at hypervelocity. Sensor information is provided to the KEW by a main sensor suite off-board of the vehicle (such as GSRT [System 8.2] or GIMS [System 8.1]). However, each armament has a minimal sensor capability (e. g., GPS receiver) and a simple flight control system for maneuver.

6.3 **Space-Based High Power Microwave Weapon (HPM)** A weapon system capable of engaging ground, air, and space targets with a varying degree of lethality. It consists of a constellation of satellites deployed in low-earth orbit (LEO) (approx. 500 NM) that can direct an ultrawideband (UWB) of microwave energy at ground, air, and space targets. Its effect is to generate high electric fields over a target area tens to hundreds of meters in size, thereby disrupting or destroying any electronic components present.

6.4 **Space-Based High-energy Laser (HEL) System** A multimegawatt high-energy chemical laser constellation that can be used in several modes of operation. In its weapons mode with the laser at high power, it can attack ground, air, and space targets. In its surveillance mode, it can operate using the laser at low power levels for active illumination imaging or with the laser inoperative for passive imaging.

6.5 **Solar-Powered High-energy Laser System** A space-based, multimegawatt, high-energy solar-powered laser constellation that can be used in several modes of operation. In its weapons mode with the laser at high power, it can attack ground, air, and space targets. In its surveillance mode, it can operate using the laser at low power levels for active illumination imaging, or with the laser inoperative for passive imaging.

6.6 **Solar Energy Optical Weapon (SEOW)** A constellation of space-based mirrors which allow solar radiation to be focused on specific ground, air, or space targets. The lethality of this system is limited, due to optical diffusion; however, it may prove useful for disruption or perhaps weather control.

6.7 **Asteroid Mitigation System** A system that protects the Earth/Moon system from Earth-crossing objects (ECOs) by either deflecting or fragmenting ECOs such that they no longer pose a threat. Deflection could be accomplished using nuclear explosive devices.

7.1 **Spoken Language Translator** A hand-held or worn device that translates oral communications in near real-time. It enhances multinational operational effectiveness in all areas, including training, diplomacy, special operations, and conventional ground operations. It is capable of one-for-one word substitution in a wide variety of languages, and it provides two-way communications between the owner and another person. The system has a limited ability to compensate for differences in sentence syntactic structures, cultures, dialects, and idioms/slang, and a limited ability to select words according to context. Careful placement of both microphones and both speakers is required for deconfliction (not having to hear both languages simultaneously), limiting the scope of its operation; the system is best suited for controlled two-way communications such as by telephone, radio, or computer. The system also is useful for written text translation.

7.2 **Personal Digital Assistant (PDA)** An individual's connection to the information systems of 2025. This assistant is a hand-held or wristwatch size unit. Input modes include both touch and voice. The PDA is the warrior's secure, high-capacity connection to the distributed C^4I system. The PDA maintains the owner's personal data such as medical and training records. It learns and remembers the owner's preferences and needs so that requests for information are properly tailored. It is self-securing: it recognizes the owner through a number of biometrics which ensures that it cannot be commandeered. In short, the PDA is a single device replaces the cellular telephone, radio, personal computer, identification and banking cards, and any other personal information-management device of the nineties.

7.3 **Virtual Interaction Center** A virtual reality environment in which commanders can immerse themselves in a three-dimensional representation of the battlespace. Information from a global information system, such as GIMS (System 8.1) is displayed in a virtual reality environment, giving the commander situational awareness. The center also has the capability to replay battles and engagements and to simulate "what if" scenarios.

8.1 **Global Information Management System (GIMS)** A pervasive network of intelligent information gathering, processing, analysis, and advisory nodes. It collects, stores, analyzes, fuses, and manages information from ground/air/space sensors and all source intelligence. All types of sensors (i.e., acoustic, optical, radio frequency, olfactory, etc.) are used. However, the true power of this system is its use of neural processing to provide the right type of information based on the user's personal requirements.

8.2 **Global Surveillance, Reconnaissance, and Targeting System (GSRT)** A space-based omnisensorial collection, processing, and dissemination system to provide a real-time information database. This database is used to create a virtual-reality image of the area of interest. This image can be used at all levels of command to provide situational awareness, technical and intelligence information, and two-way command and control.

8.3 **Sensor Microbots** A class of highly miniaturized (millimeter sized) electromechanical air and ground systems capable of being deployed en masse to collect data, perform individual and collective data fusion, and communicate that data for further processing and distribution. Various deployment approaches are possible, including dispersal as an aerosol, transportation by a larger platform, and full flying/crawling autonomy. Data collection is accomplished through miniaturized onboard sensors, typically restricted to one or two sensors per unit due to size and power limitations. Communications are possible by transmission through relay stations ("relaybots") or physical collection of the microbots. Some applications of sensor microbots are security net to guard own assets, surveillance and reconnaissance, and intelligence gathering on adversary assets.

8.4 **Multiband Laser Sensor System** A suite of laser devices that inspects and models target components. Different frequencies of electromagnetic energy vary in their ability to penetrate materials. For a particular material, one frequency will reflect off the surface, another will penetrate. By employing a suite of laser devices over a wide frequency range, planners can accomplish complete internal and external inspection of a structure and develop a full three-dimensional model. This tool can be used for nondestructive inspection of components, target vulnerability analysis, target identification and decoy rejection, and reconnaissance. This suite of laser devices can be carried on an airborne platform, but it clearly has ground-based applications also.

8.5 **Asteroid Detection System** A network of ground and space sensors which search for, track, and characterize space objects that are large enough and in an orbit to threaten the earth-moon system. The system also includes a centralized processing center that fuses data from all of the available sensors, catalogs the known objects, and distributes information to the known authorities.

9.1 **Mobile Asset Repair Station (MARS)** A mobile facility near the battlefront where parts can be repaired or manufactured . In wartime, replacement parts are repaired or manufactured in the theater of operations for a variety of deployed weapon systems through MARS. The mobile facility can be land-based or water-based in the theater of operations, but out of harm's way. The facility features a set of fully-integrated flexible manufacturing systems (FMS) and robotic systems that are linked to the commercial manufacturers. These manufacturers supply the specifications to the FMS which then produces the part or component. Many of the required materials necessary for MARS to manufacture the components obtained from local countries.

9.2 **Weather Analysis and Modification System** A diverse set of weather prediction and modification tools that allows manipulation of small-to-medium-scale weather phenomena to enhance friendly-force capabilities and degrade those of the adversary. Many of the sensors required for this system are assumed to be external e. g., part of the global information management system (GIMS), discussed in System 8.1.

9.3 **Sanctuary Base** A secure, low observable, all-weather forward-operating base that reduces the number of assets requiring protection from attack. The runway, power systems, ordnance storage, aircraft maintenance assets, and C^4I systems are self-maintaining and self-repairing. Base security is highly automated. Chemical/biological hazards are cleaned up by nanobots and biotechnology. Robots perform refueling, weapons loading, maintenance, security, and explosive ordnance destruction.

Appendix C

Alternate Futures Weights

This appendix presents the value model weights (fig. C-1 through fig. C-6) given by the student members of the ***2025*** writing teams (AU team weights) for each of the six alternate futures. The corresponding weights provided by the Alternate Futures team can be found in the ***2025*** Operational Analysis Technical Report.

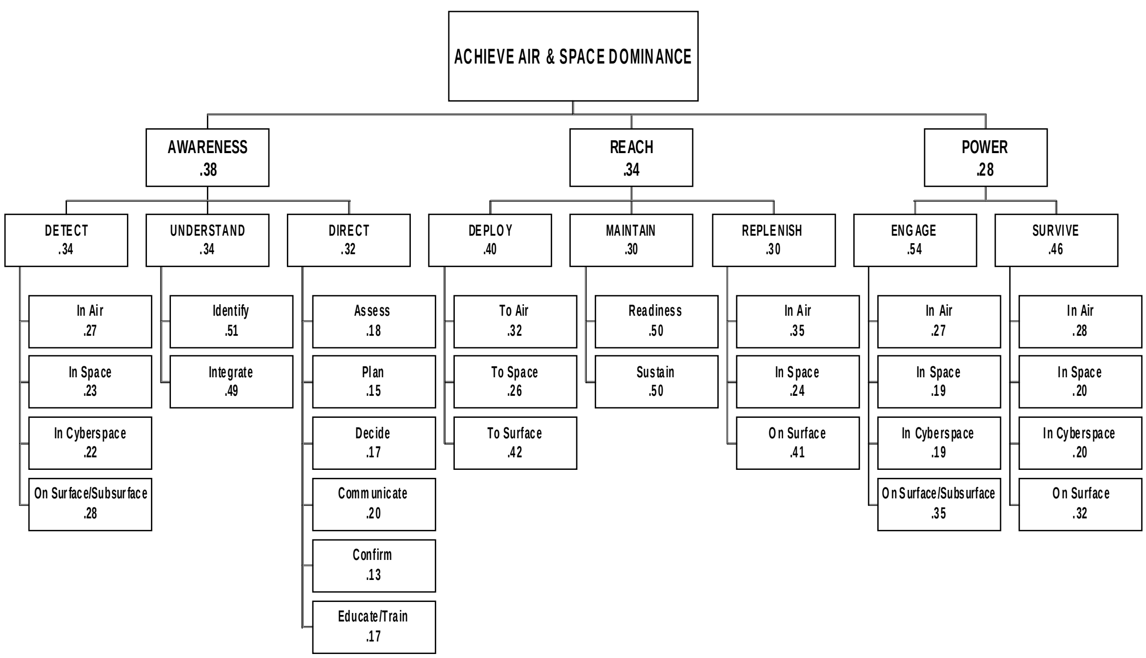

Figure C-1. AU Team Weights - Halfs and Half Naughts Future

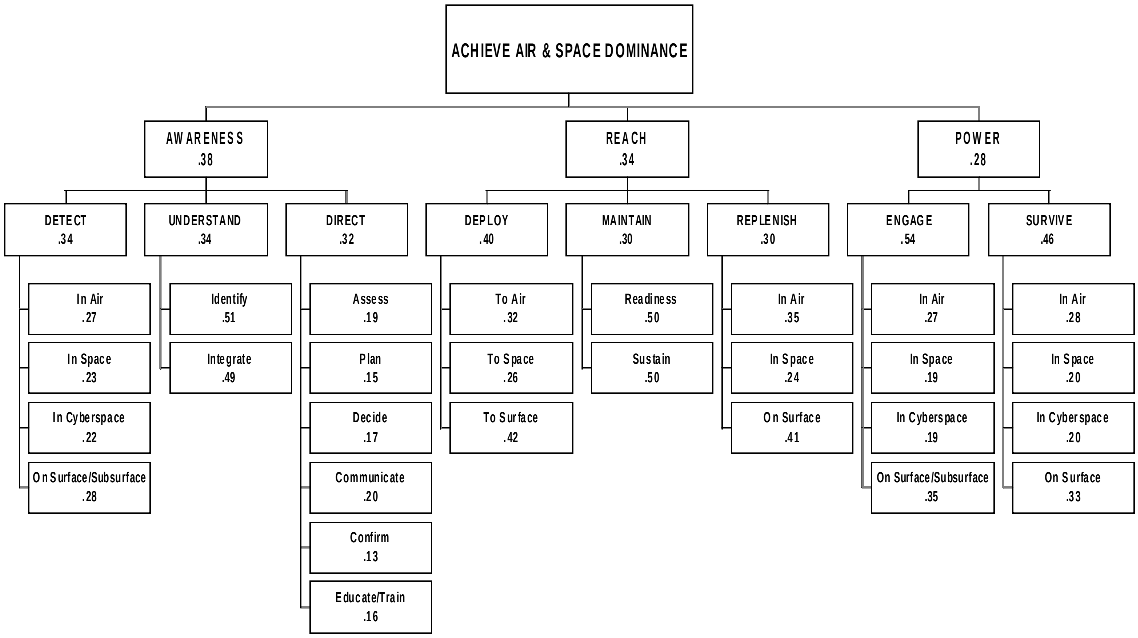

Figure C-2. AU Team Weights - Gulliver's Travail Future

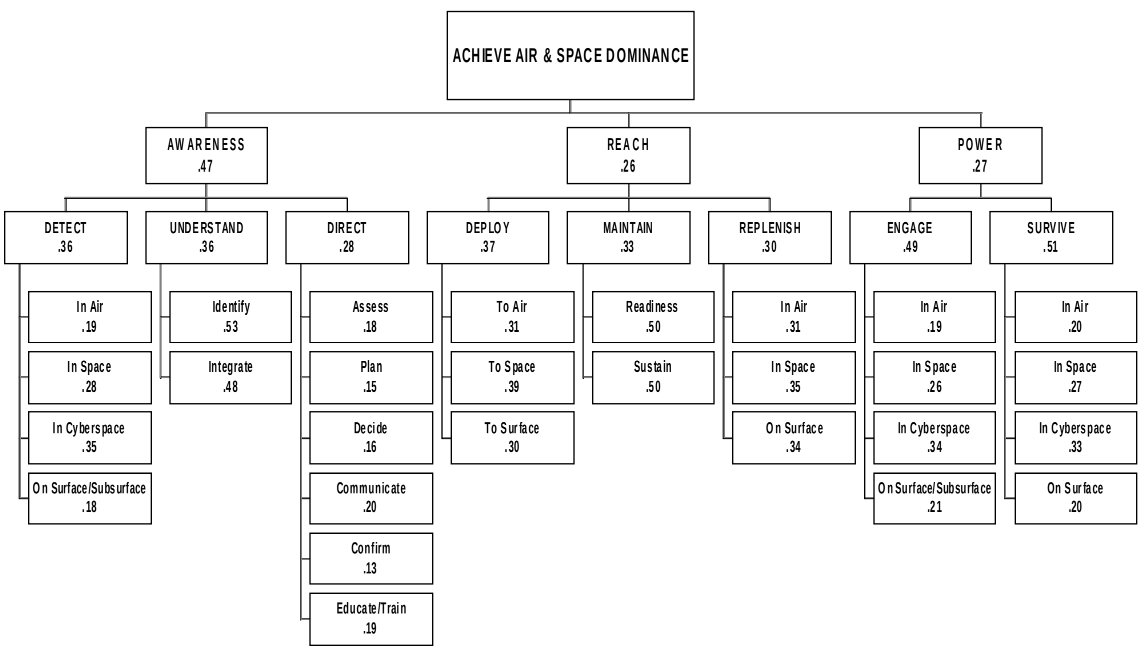

Figure C-3. AU Team Weights - Zaibatsu Future

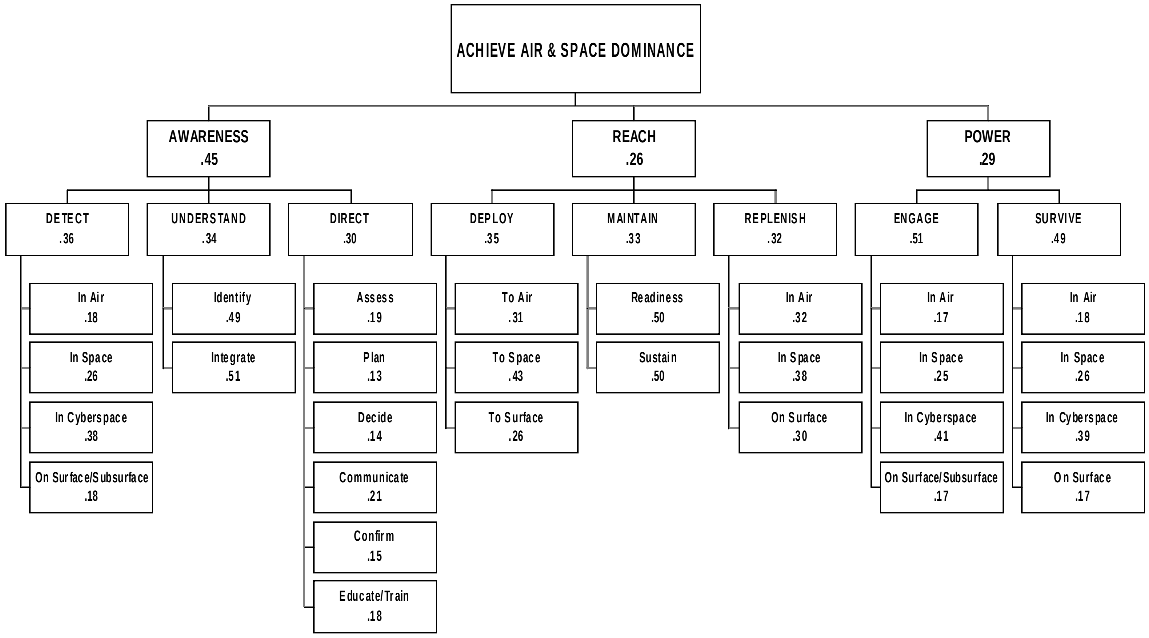

Figure C-4. AU Team Weights - Digital Cacophony Future

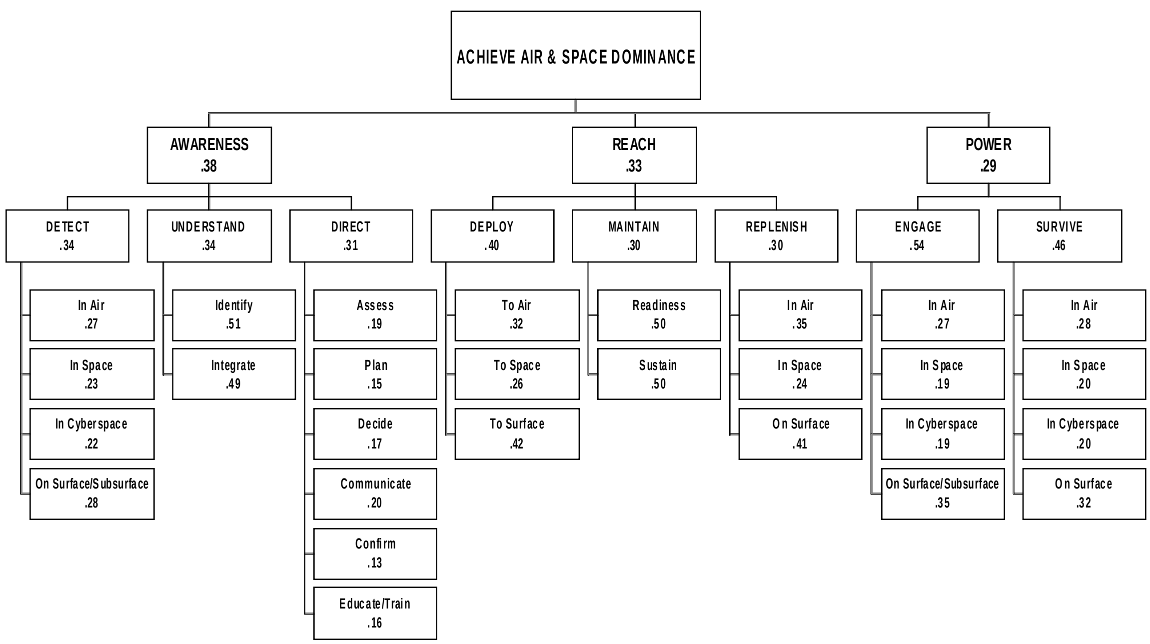

Figure C-5. AU Team Weights - King Khan Future

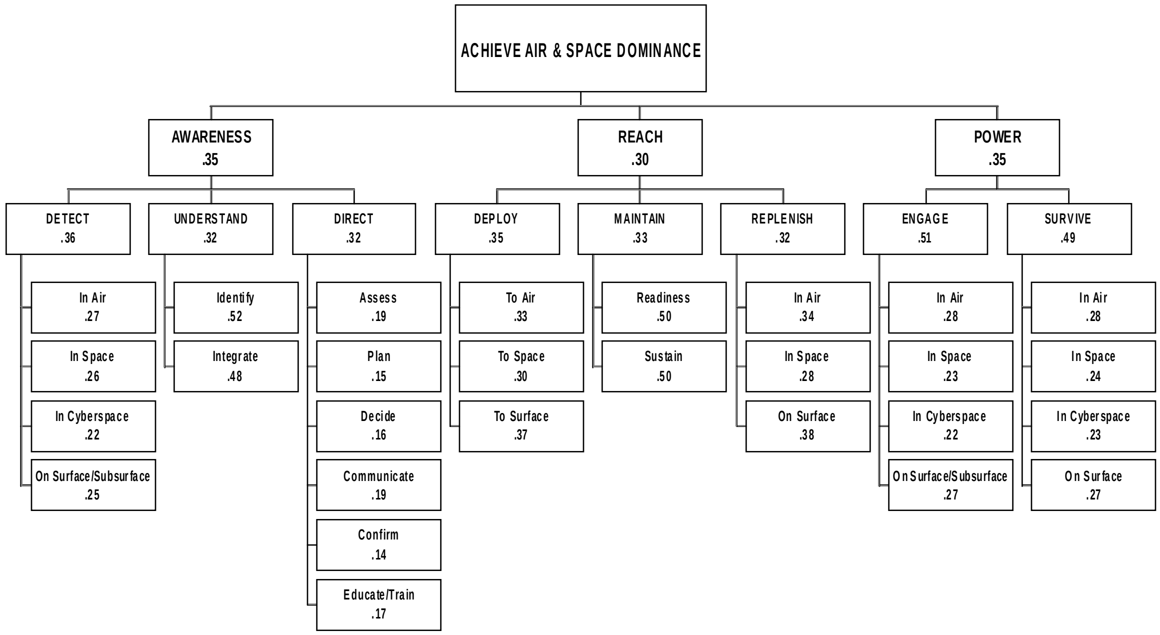

Figure C-6. AU Team Weights - 2015 Crossroads Future

Appendix D

Technology Model

This appendix contains the technology model depicting the leveraging technologies identified during the course of system analysis. The technology names, numbering convention, and descriptions contained in the *Militarily Critical Technologies List* (MCTL) served as the basis for the 2025 Technology Model. Descriptions of these technology areas can be found in the ***2025*** Operational Analysis Technical Report.

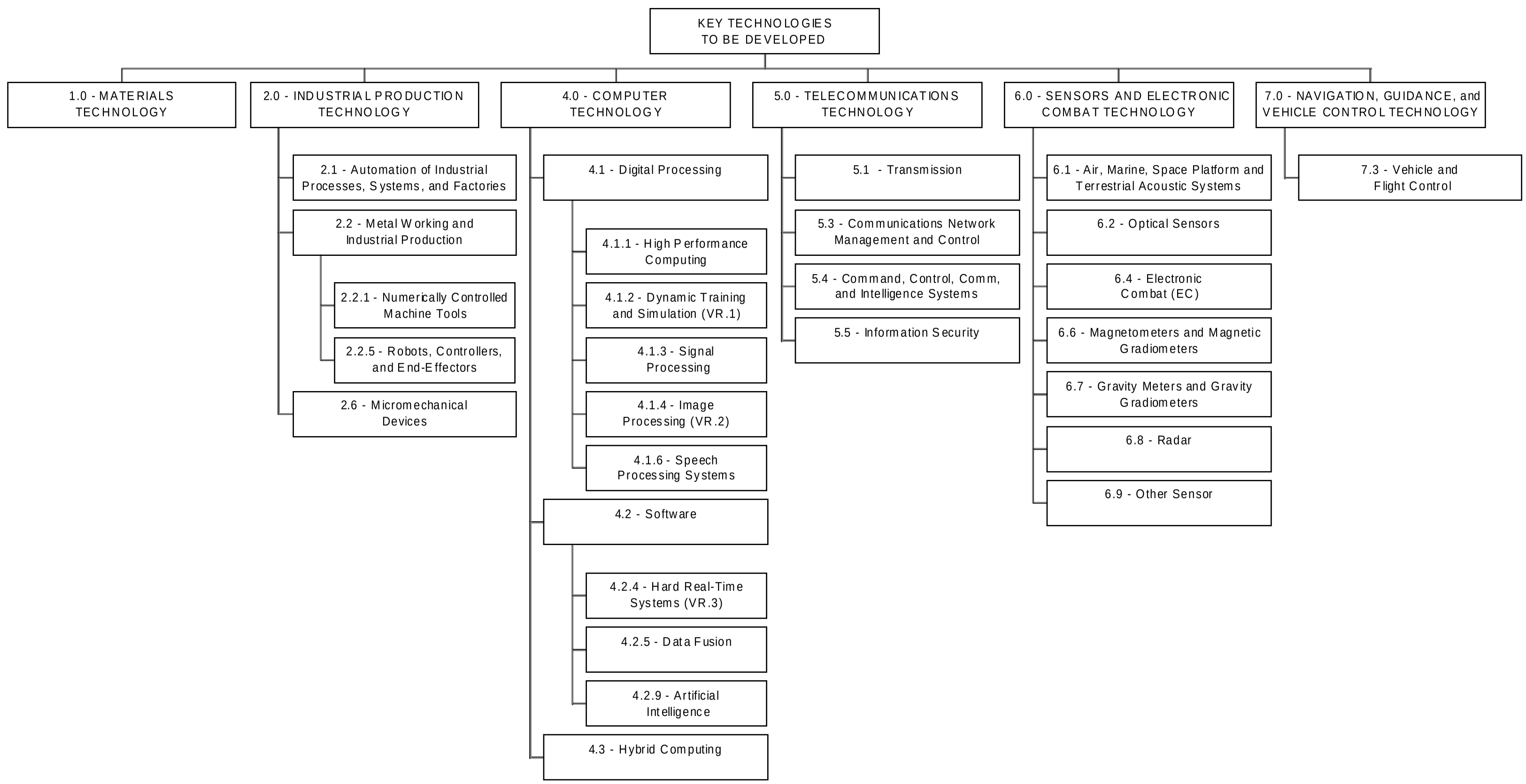

Figure D-1. Technology Model - Part I

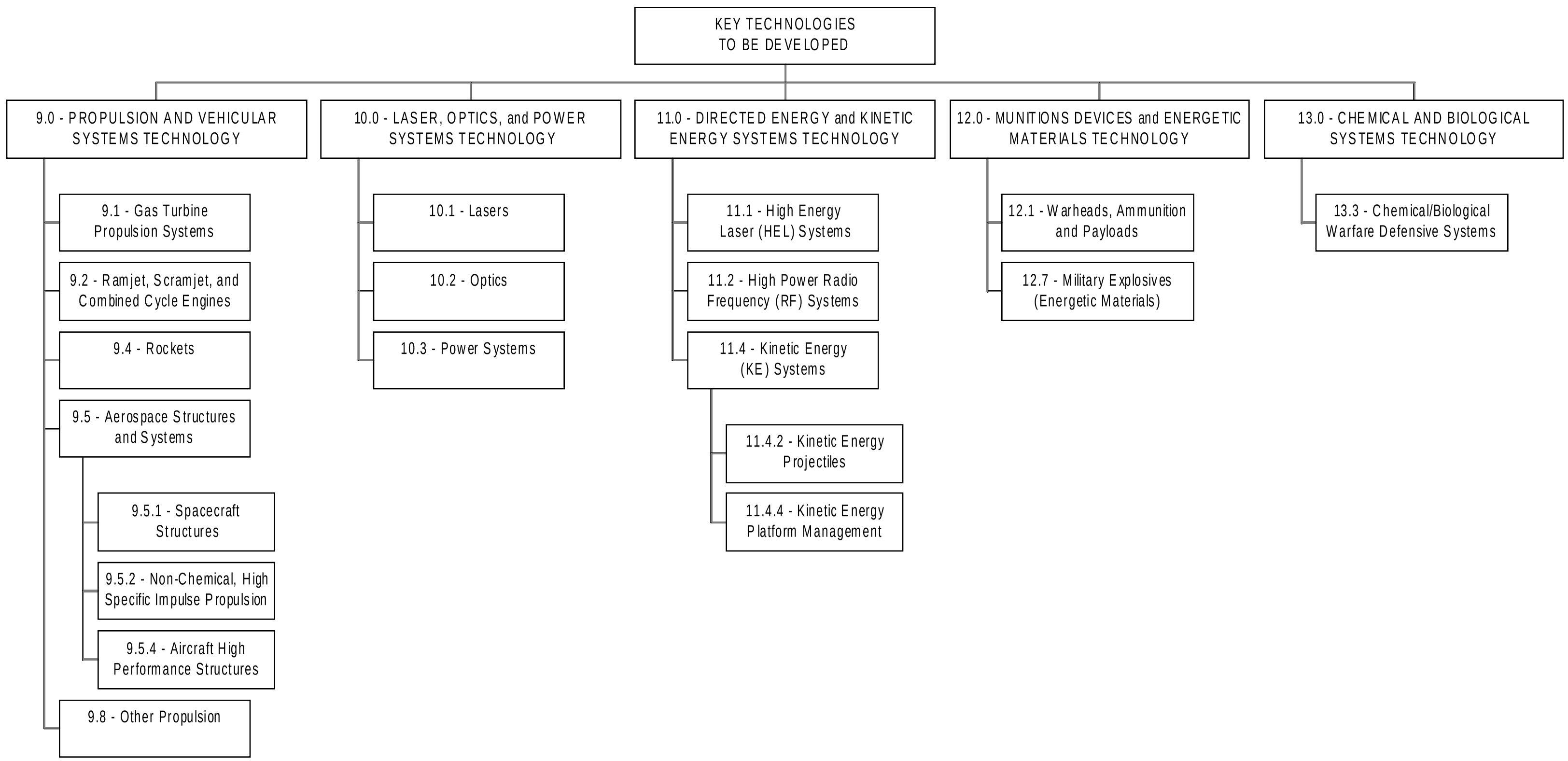

Figure D-2. Technology Model - Part II

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