
AIR UNIVERSITY
SPACECAST
2020
INTO THE FUTURE

SPACECAST 2020 was a chief of staff of the Air Force (CSAF)-directed space study, challenged to identify and conceptually develop high-leverage space technologies and systems that will best support the warfighter in the twenty-first century. The study was composed of officers, airmen, and civilians from institutions within Air University and assisted by outside advisory groups made up of the Air Force major command vice commanders, senior retired military officers and distinguished civilians, and technical experts throughout the Department of Defense and civil/commercial laboratories. This is the fourth of four monographs: *Executive Summary, The SPACECAST 2020 Process, The World of 2020 and Alternative Futures,* and *Operational Analysis.*

DISCLAIMER

OPERATIONAL ANALYSIS

Air University • Air Education and Training Command • United States Air Force
Maxwell Air Force Base, Alabama

OPERATIONAL ANALYSIS

Executive Summary

This analysis was conducted to determine which of the SPACECAST 2020 systems concepts showed the greatest potential for enhancing space operations, and which of their embedded technologies have the highest leverage in making high-value systems a reality. The analytical expertise was provided by the Department of Operational Sciences at the Air Force Institute of Technology (AFIT); technology assessments were done by the SPACECAST 2020 Technology Team and practical operational judgments were provided by Air War College and Air Command and Staff College faculty and students. A Value Model was developed based on Joint Space Doctrine to quantify and compare different systems' contributions to various space capabilities. The overall goal of operational analysis was to rank SPACECAST systems and their enabling technologies in a way that was traceable and reflected the value SPACECAST participants attributed to them. Thus, the model presented is an aid to senior decision makers.

Scoring the SPACECAST systems against the Value Model revealed that two system concepts were clearly ahead of the rest:

- Transatmospheric Vehicle (TAV)
- Space-Based High Energy Laser (HEL) System

These two systems scored at about the same high level, but for different reasons. The TAV contributed to virtually all space missions because it made access to space easier. The HEL scored well because it could fulfill a variety of important force application and space defense missions, and its optical system could also provide a surveillance capability. The following five systems also scored clearly ahead of the others, but below the top two:

- Global Surveillance, Reconnaissance, and Targeting (GSRT) System
- Orbit Transfer Vehicle (OTV)
- Kinetic Energy Weapon (KEW) System
- High Powered Microwave (HPMW) System
- Particle Beam (PB) Weapon System

The Global Surveillance, Reconnaissance, and Targeting System was assessed as a high-leverage system because of its ability to greatly enhance the capabilities of terrestrial forces. The high score of the OTV reflects the importance of improved spacelift, along with the top-scoring TAV. The next three systems are space-based weapons that scored well for reasons similar to those of the HEL. These conclusions regarding the rankings of the systems were not affected by any reasonable changes of the weighting scheme in the Value Model.

The study also included an assessment of the technologies on which the system concepts depend. The analysis explicitly took into account the number of systems each technology supported, the degree to which each system depended on it, and the importance of the system

(but not cost or risk). Three technologies (including the two top ranked ones) stood out because they are important to a large number of high-value systems:

- High-Performance Computing
- Micro-Mechanical Devices
- Navigation, Guidance, and Vehicle Control

Three other technologies were also **especially** important, but to a smaller range of systems:

- Materials Technology
- Pulsed Power Systems
- Robotics, Controllers, and End-Effectors

Advances in these areas show promise to open the way to space systems that would dramatically improve the effectiveness of space operations.

Purpose of the Analysis

SPACECAST 2020 produced a large number of system concepts which were envisioned in varying levels of detail, which provided widely different kinds of operational capabilities, and which depended on different levels of advancement in different areas beyond current technology. Clearly not all of these system concepts can be developed, nor can all of the technologies be aggressively pursued. The Air Force needs to prioritize the relative importance of both space systems and technologies. This operational analysis was conducted to answer two basic questions:

1. Which of the SPACECAST 2020 system concepts offer the greatest promise of increasing operational effectiveness?

2. What are the technologies offering the greatest leverage in turning high-value system concepts into operational realities?

Challenge

This operational analysis presented two major technical challenges. The first was that it required estimating the performance of future space systems that are incompletely defined and which often rely on technology that does not yet exist. This meant that inevitably the only data available by which to evaluate them were qualitative human judgments. The team's approach to this challenge was to break the analysis down into many separate evaluations. Even though some individual judgments may lack rigorous precision, the weighted sum of all the judgments will have enough precision for the purposes of the analysis.[1] The second major challenge came from the fact that the analysis required comparison of alternatives that are inherently different sorts of things. For instance, the system concepts included space launch systems, weapon systems, and surveillance systems. It was necessary to rate these different concepts on some sort of common scale so they could be compared to one another. The team's approach was to score the alternatives according to their estimated contribution to *operational effectiveness*, with effectiveness in different areas of space operations being weighted according to their value with respect to space operations as a whole. The details of the methods used to face these two challenges are described below (see Methodology).

In addition to these technical challenges, the analysis team operated under some practical limitations. The conclusions of this analysis should be considered with these limitations in mind: the White Paper system, the Joint Space Doctrine framework, the members of the team, and the time available.

The ground rules of the study were to evaluate the systems and technologies presented in a given set of White Papers. Consequently, the scope of the study was limited to those systems and technologies. It is possible other important systems could be developed which would draw attention to other technologies. These could be evaluated using the methodology of this study. However, the scope of this study was limited to the SPACECAST White Papers presented.

The team used the framework of current Joint Space Doctrine to develop the Value Model. While this provided an excellent start, it is based on current ideas about space operations. It did not allow evaluating systems' contributions to space missions that are not currently envisioned.

The analysis relied to a large extent on human judgments about the systems and technologies. These judgments came from 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. The collective experience, knowledge, and judgment of these individuals were vital to the successful outcome of the study. Finally, the analysis had to be completed within a time period of about four weeks. This is an extremely short time for a problem of this complexity.

Methodology

A wide range of techniques exists to approach a problem like this. The most important tradeoff in picking a technique is depth of analysis versus time. At one extreme, a group of experts can review the alternatives and give a subjective ranking of them. At the other extreme, a full Cost and Operational Effectiveness Analysis can be done, as is usually done before starting development of a major new program. The analysis team selected an approach called Value-Focused Thinking as most appropriate for the task at hand.[2] It allowed the alternatives to be evaluated at an appropriate level of detail, considering their level of definition, and could be completed within the time available for analysis. Value-Focused Thinking requires creating a Value Model of the qualities valued in the alternatives. In this analysis, the alternatives were the proposed system concepts and the qualities were various measures related to operational effectiveness in space. This Value Model takes the form of a hierarchy, starting from broad categories at the top level and specifying the desired qualities in greater detail at lower levels, striving for qualities as concrete as possible and where possible quantifiable. The alternatives are then scored against the qualities at the lowest level of the hierarchy. The qualities are assigned weights based on their overall contribution to the value system, and an alternative's final score is found by multiplying its quality scores by the appropriate weights and summing over all qualities. This gives a rational, traceable, objective, and quantifiable basis for ranking the alternatives. In this analysis, a single system making revolutionary contributions to a very narrow area of activity may score lower than a system making contributions to a large number of areas.

In addition to ranking the system concepts, the operational analysis also had to identify high-leverage technologies whose advancement offers the greatest promise of increasing the effectiveness of space operations. To address this part of the problem, the analysis team evaluated each system concept on the degree to which it depended on advances in various technologies. This produced a system-versus-technology weight matrix. By multiplying it with system scores derived from the Value Model, the relative weights for the technologies were found. This provided a comprehensive method of ranking the various technologies according to the degree to which they supported the most important system concepts. To reduce the technology ranking problem to a manageable size and to focus on its most essential features, a few modifications were made to this procedure, as will be described below.

In summary, this was the general method of the analysis: A Value Model was devised to define the desired force qualities. All systems were scored against all qualities, producing a system-versus-quality matrix. The scores were multiplied by the quality weights and summed, giving system scores. This scoring was used to rank the different system concepts. In addition, a system-versus-technology matrix was developed as described in the preceding paragraph. When multiplied by the system scores, this provided a ranking of the technologies.

Developing the Value Model

The Value Model hierarchy was based on draft JCS Pub 3-14, "Military Space Operations Doctrine," 15 April 1994. That document states that the overall goal of military space operations is to control and exploit space. It provides the top two levels of a value hierarchy for space operations and lists four basic types of space operations:

Force Enhancement:	Assisting terrestrial military forces
Force Application:	Applying military force for ballistic missile defense, for defense of terrestrial forces, or directly against enemy targets
Space Control:	Monitoring space activity, defending against attacks in space, and negating hostile space systems
Space Support:	Launch, satellite control, and logistics operations

In addition, each area of operations is divided into appropriate force capabilities. For instance, under Force Enhancement there are Communications; Navigation and Positioning; Intelligence and Surveillance; Environmental Monitoring; Mapping, Charting, and Geodesy; and Warning, Processing, and Dissemination.[3] There were advantages and disadvantages to using this structure. The major disadvantage was that it did not include a few possible future space missions, such as planetary defense against asteroid impact. On the other hand, it provided an official and authoritative doctrinal architecture comprehensive enough to include all current and the most important future space missions. This seemed to be the best available starting place for the Value Model.

Each of the force capabilities from draft JCS Pub 3-14 was analyzed further to provide a listing of force qualities. These force qualities were the most important characteristics required for operational effectiveness in each capability. As far as possible, they were selected to be concrete and measurable. For instance, the force qualities defined under Communications were Crisis Availability, Capacity, Interoperability, and Security. These force qualities provided a third and in some cases a fourth level of the value hierarchy. An illustration of the top levels of the hierarchy is shown in Figure 1. The complete Value Model is found in the first six columns of the matrix in Appendix 1. The final hierarchy had 98 detailed force qualities or line items at the lowest level of the hierarchy.[4] It was these line items at the lowest levels of the hierarchy that were used to develop measures of merit against which the systems were scored (see Scoring the Systems).

In addition to defining a value hierarchy, it was necessary to assign relative weights to the line items. The challenge here was to assign relative weights in a sensible way to force qualities that are different. This was done by assigning weights at each level of the hierarchy. First, weights were assigned at the top level, to each of the four areas of military space operations. Then, for each of the four, weights were assigned for the subordinate force capabilities, and so on down the hierarchy. To make the workload manageable, sub-teams were asked to look at every branch point and estimate the relative weights of the items at the next level.[5] Each weighting was reviewed by a high-level team, occasionally modified slightly, and incorporated in the larger model. The weights were normalized, i.e., scaled so that all the weights at any one level sum to one. The weight of each line item is then the product of all its inherited weights up the hierarchy. As a mathematical consequence of the normalization, the weights of all line items sum to one.

<table>
<tr><th colspan="12">OVERALL OBJECTIVE: CONTROL AND EXPLOIT SPACE</th></tr>
<tr><th colspan="9">Force Enhancement</th><th>Force Application</th><th>Space Defense</th><th>Space Support</th></tr>
<tr><td colspan="4">Communications</td><td>Navigation and Positioning</td><td>Intelligence and Surveillance</td><td>Environ-mental Monitoring</td><td>Mapping, Charting, and Geodesy</td><td>Warning, Processing, and Dissemination</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Crisis Availability</td><td>Capacity</td><td>Inter-operability</td><td>Security</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Measure of Merit</td><td>Measure of Merit</td><td>Measure of Merit</td><td>Measure of Merit</td></tr>
</table>

Figure 1: Value Hierarchy

Leftmost Branches Expanded

The “standard” value weights are listed in the Value Model in the first six columns of the matrix in Appendix 1. These values represent the team's judgment of the relative value of the force qualities if the future geopolitical system is more or less similar to today (the "SPACECAST 2020 World"). The weights were also estimated for a "Rogue World" scenario, a world in which there are one or a few aggressive, militarized, and sufficiently technologically capable states that are the main threat to world peace. These weights are in Appendix 2. Other weights were also used when performing a sensitivity analysis as described below (see Key Results).

System Identification

Following a thorough review of the SPACECAST 2020 White Papers, the Technology Team identified 19 unique high-leverage space systems (Appendix 3) from which key technology areas could be identified. For this operations analysis, a system was defined to be "a functionally related group of elements that performs a mission or task." Although most of the identified systems were each extracted from a single white paper, several systems, particularly those involving space weaponry, were critical to the capabilities detailed in several of the papers. For example, space-based high energy laser systems were key elements of the white papers on offensive counterspace, defensive counterspace, and force application, and also contributed heavily to the capabilities called out in the paper entitled "Leveraging the Infosphere: Surveillance and Reconnaissance in 2020." In several of the papers, such as the one entitled "Projecting Information Power in War and Peace," no systems could be identified. In these cases, the papers contained a general framework for doing business in given mission areas without a level of detail required for technology identification.

The 19 identified systems were:

1. Refueled Transatmospheric Vehicle (TAV)
2. Orbital Transfer Vehicle (OTV)
3. Orbital Maneuvering Vehicle (OW)
4. Space Modular System(s)
5. Global Surveillance, Reconnaissance, and Targeting System (GSRT)
6. Super Global Positioning System (S-GPS)
7. Space Traffic Control System (SPATRACS)
8. Weather Forecasting System
9. Space-Based Solar Monitoring and Alert Satellite System (SAUSS)
10. Ionospheric Forecasting System
11. Holographic Projector
12. Space-Based High Energy Laser (HEL) System
13. Kinetic Energy Weapon (KEW) System
14. High Powered Microwave (HPMW) System
15. Particle Beam (PB) Weapon System
16. Weather C3 System
17. Solar Mirror System

18. Asteroid Detection System
19. Asteroid Negation System

The full descriptions of these systems are found in Appendix 3.

Scoring the Systems

Scoring 19 systems against 98 line items required 1,862 judgments. A structure was developed to maximize the consistency and objectivity of the judgments. Before any systems were scored, a **measure of merit** was defined for each line item. This was a specific and where possible quantifiable measure of that quality, such as "megabits per second" or 'pounds to orbit." (In a few cases a line item was given two measures of merit.) Four benchmark levels of operational capability were established for each measure of merit, as shown below.

Operational Capability	Score
Current	1
Minor Improvement	2
Significant Improvement	6
Order-of-Magnitude Improvement	10

For instance, the measure of merit for line item 2 (communications capacity) was "decompressed megabits per second" on a satellite communications link. The team's assessment was that a typical current figure was 300 megabits per second, a minor improvement would be 600 megabits per second, a significant improvement would be one gigabit (1,000 megabits) per second, and three gigabits per second per link would be an order of magnitude improvement. These assessments relate the measure of merit to operational effectiveness, and an order of magnitude improvement in effectiveness may not occur at the same point as an order of magnitude (factor of 10) increase in the raw measure of merit. These assessments were connected to a normalized numerical scale by equating current capabilities to 1, minor improvements to 2, significant improvements to 6, and order of magnitude improvements to 10. Both the measures of merit and the operational effectiveness benchmarks were developed by the teams of Air University students and faculty that defined the Value Model. Once the scoring scale had been established in this way, the 19 systems were each scored according to its capability to contribute to the 98 force qualities that the team identified.

Short descriptions of the measures of merit and the four benchmark levels of each are presented in columns 7 through 11 of the matrices in Appendix 1. Full descriptions of the unclassified measures of merit are in Appendix 4. The scores of each system on each line item are listed in Appendix 5, which also gives the systems' raw scores. For technical reasons it was convenient to use a scale running from 0 to 100 percent when doing the score calculations.

These are the scores shown in the appendices. However, in the Value Model of this analysis, a low score corresponds **not** to zero capability but to current capability. After the system scores were calculated on the zero-to-one scale, they were re-scaled so they fell into the more intuitive range where 1.0 represents "current capability" and 10.0 represents "order of magnitude improvement."

Two systems could not be scored because they did not fit into the structure of the Value Model. These were the Holographic Projection (#11) and Asteroid Negation (#19) systems. The teams judgment is that these systems are so far in the future that the inability to score them did not afflict the validity of the analysis.

Technology Identification

Once the 19 unique systems contained in the white papers were identified, the SPACECAST 2020 Technology Team qualitatively analyzed each system to identify which technology development areas would be key to achieving the stated system capabilities. The team felt it was 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) was used as the basis for key technology identification in each system.[7] For the 19 systems evaluated, a total of 25 key technology areas (Appendix 6) were identified. One technology area, virtual reality, was repeatedly mentioned in numerous white papers, but was not explicitly identified in the MCTL. Although called out as a specific technology area, virtual reality is in actuality a combination of several of the technologies called out in the MCTL.

Following are the key technologies identified (full descriptions are in Appendix 6):

1. Data Fusion
2. Electromagnetic Communications
3. Energetic Materials
4. Hard Real-Time Systems
5. High Energy Laser Systems
6. High Performance Computing
7. High Power Microwave Systems
8. Image Processing
9. Information Security
10. Kinetic Energy Systems
11. Lasers
12. Liquid Rocket Propulsion
13. Materials Technology
14. Micro-mechanical Devices
15. Navigation, Guidance, and Vehicle Control
16. Neutral Particle Beam (NPB) Systems
17. Nonchemical High Specific Impulse Propulsion
18. Optics
19. Power Systems and Energy Conversion

20. Pulsed Power Systems
21. Robotics, Controllers, and End-Effectors
22. Sensors
23. Spacecraft Structures
24. Vehicle Survivability
25. Virtual Reality

To eventually rank technologies by their impact on future space capabilities, the team assigned a relative weight to each technology embedded in a particular system as shown in Appendix 7. The weights selected sum to 100 for each system, and so can be thought of as percentages of the system's dependence on each technology. For example, the five Orbital Transfer Vehicle (OTV) technologies were weighted as follows:

Technology	Weight
Nonchemical/High Specific Impulse Propulsion	40
Power Systems and Energy Conversion	20
Micro-mechanical Devices	20
Robotics, Controllers, and End-Effectors	15
Materials Technology	5

In this case, since the primary mission of the OTV is to act as a space "tug" for moving satellites between higher and lower orbits, the highest-leverage technology area is that of the vehicle's primary propulsion subsystem. The other four technologies, although still critical to effective system performance, were of lesser leverage than that of the primary propulsion subsystem. Using this methodology, once all of the systems were scored in the model, the 25 technology areas could be ranked as to their overall impact on future space operations.

Scoring the Technologies

Once the system-versus-technology matrix is in hand, the procedure for scoring the technologies is straightforward. For each technology, its contribution to each system is multiplied by the system score, and the resulting products are summed across all systems. The result is a set of technology scores (in arbitrary units) taking into account both the technologies' degree of contribution to future space systems and the importance of those systems to space operations.

Key Results

Scoring the Systems

The results of the system scoring are summarized in Figure 2. The vertical axis is the rescaled score from the system evaluation (1.0 represents current capability; 10.0 would represent an order of magnitude improvement in operational effectiveness across all force qualities). The horizontal axis is a rank ordering of the systems according to the team's assessment of the degree of advance in current technology the system would require. This is not a quantitative measure; it was done to give an impression of how far in the future the systems lie.[8] The system scores are shown using the "SPACECAST 2020 World" weights, the Value Model force quality weights the team felt were most likely to represent the most likely future. The system scores were also calculated using four other weighting schemes. The first was the Rogue World weights. Three weighting schemes were taken by changing the weights at the highest level of the hierarchy to represent the extreme views of members of the team. The sets of weights were chosen that put the most weight on Force Enhancement (FE) and on Force Application (FA), plus a scheme that put no weight on Space Support (SS). Finally, a survey was given to Air University students asking them to provide top-level weights and the 44 responses were averaged. The results of all these different weight schemes are shown in Table 1. The resulting spread of

Table 1. Sensitivity Analysis Weighting Schemes

Scheme	Force Enhancement	Force Application	Space Control	Space Support
Standard	**0.37**	**0.19**	**0.22**	**0.22**
Rogue World	**0.31**	**0.21**	**0.31**	**0.17**
High FE	**0.40**	**0.10**	**0.30**	**0.20**
High FA	**0.30**	**0.25**	**0.20**	**0.25**
Low SS	**0.48**	**0.24**	**0.28**	**0.00**
Survey	**0.31**	**0.22**	**0.22**	**0.25**

Legend:

FE = Force Enhancement
FA = Force Application
SS = Space Support

* The Rogue World weighting scheme included some changes in the lower levels of the Value Model hierarchy, as shown in Appendix 2.

System Concepts (in order of increasing technological challenge)

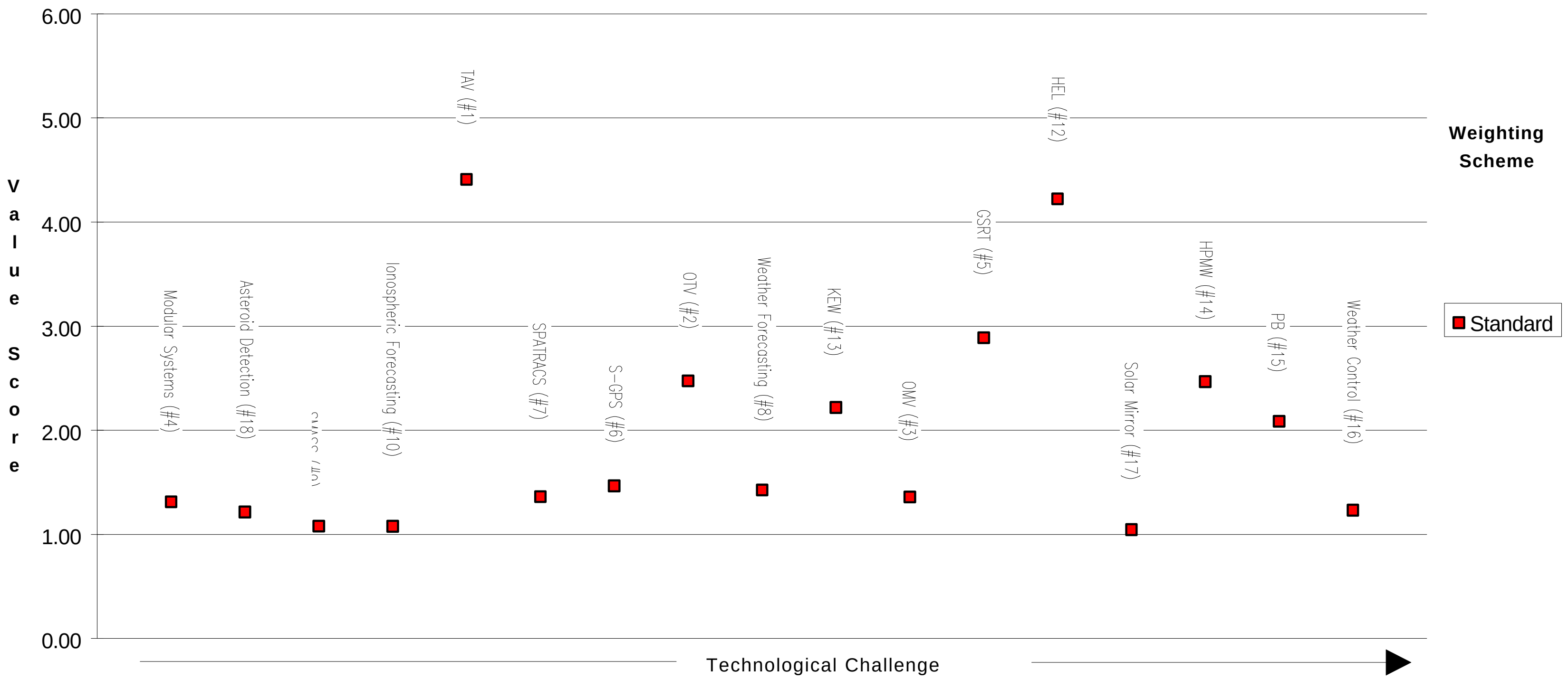

Figure 2: SPACECAST 2020 Operational Analysis Summary

scores for each system can be regarded as similar to error bars in the results of a statistical sampling technique. In other words, a system's score can be said with high confidence to lie within the range of the points shown. A comparison of the scores using the six different weighting schemes is shown in Figure 3.

The most important result of the analysis is that the systems can be divided into three groups based on their scores. The TransAtmospheric Vehicle (#l) and the SpaceBased High Energy Laser (#12) both scored generally in the range of 4,to 5. Five other systems scored generally in the range of 2 to 3: the Global Surveillance, Reconnaissance and Targeting System (#5), the Orbit Transfer Vehicle (#2), the Kinetic Energy Weapon (#13), the High Powered Microwave (#14), and the Particle Beam Weapon (#15). All other systems scored between 1.0 and about 1.6. This result was very robust to changes in the weighting scheme. The TAV scored high because it was assessed as a strong contributor to most space capabilities by making spacelift easier. The High Energy Laser System scored better than the other space-based weapon systems because the system concept included using the laser's optics as an imaging device, so the system contributed to surveillance-related areas as well as to Force Application and active Space Control. In the second group of systems, the GSRT scored highest because it is such a strong contributor to the Force Enhancement area, the most important part of the overall space mission in all weighting schemes. The three space weapons (KEW, HPMW, and PB) score well because they also contribute to high-priority missions in Force Application and Space Control. The OTV has a similar score because it contributes to all missions, though in a more limited way than the TAV. The remaining systems typically scored lower because their contributions were only in narrow ranges of mission areas and force qualities.

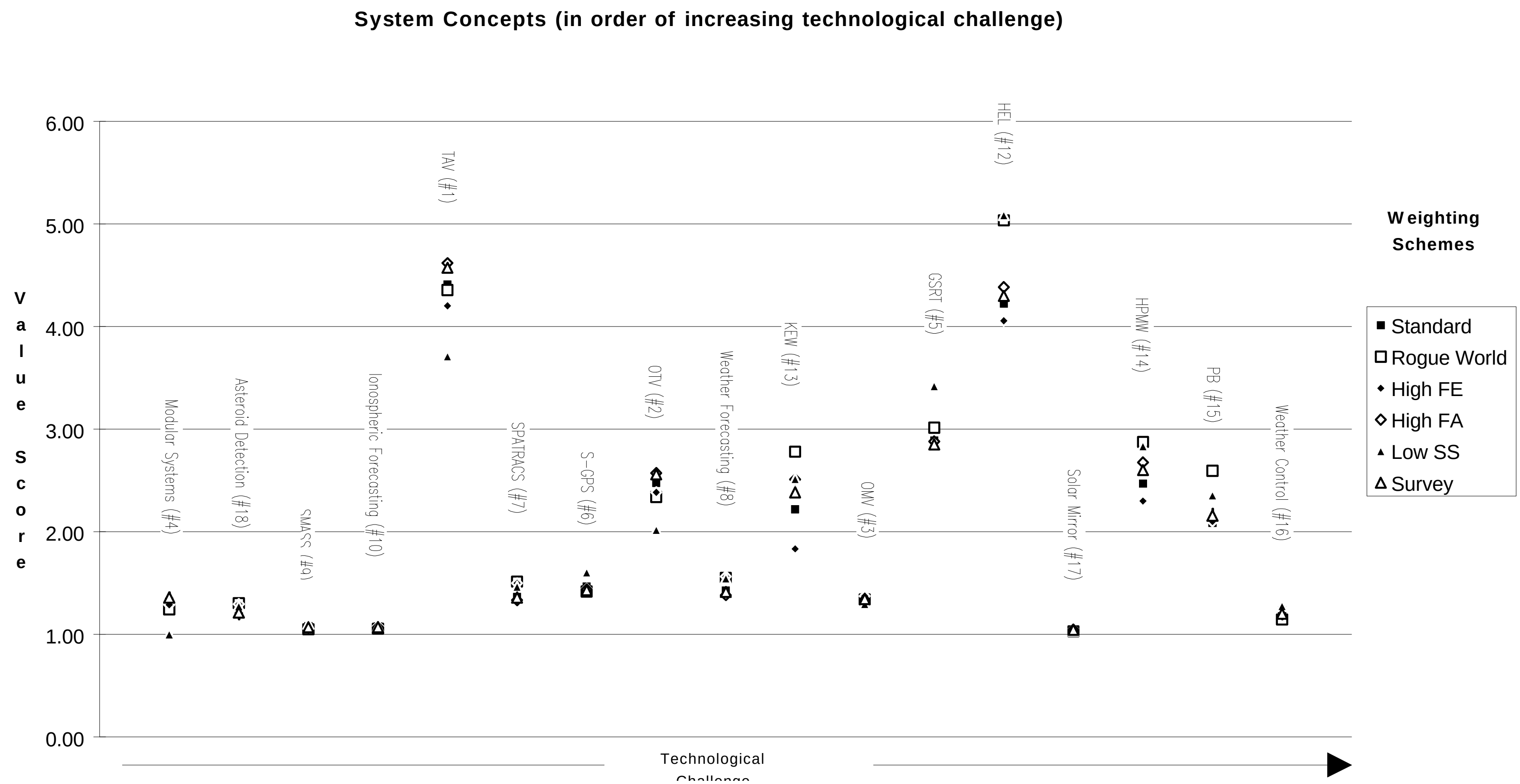

FIgure 3: System Scoring Sensitivity Analysis

Scoring the Technologies

The results of the scoring of the technologies are summarized in Table 2. Because seven of the system concepts strongly outscored the other 12, the team decided to simplify the analysis of the technologies by considering their interaction only with the seven top-scoring systems. The score for each technology was calculated by multiplying the percentage dependence of each of the systems on that technology by the score that system received in the Value Model, then summing across the seven systems.[9] Table 2 lists 20 technologies in order of their scores; five technologies did not contribute to the seven top systems.[10] The scores in Table 2 are measures (in arbitrary units) of the potential of each technology to improve operational effectiveness in space, and can be used to compare the technologies to each other.

Perhaps the most important result of the analysis is the high scores received by High Performance Computing, Micro-mechanical Devices, and Navigation, Guidance, and Vehicle Control (15.9, 11.3, and 9.3, respectively). These three technologies were each important to five or more of the top seven systems. Their high scores are the result of the broad applicability of these technologies to high-value systems.

This is a significant result. All other technologies contributed to only one or two high-value systems. Of these, the high-scoring ones were Materials Technology (11.0), Pulsed Power Systems (10.2), and Robotics, Controllers, and End-Effectors (9.0). The rest of the technologies scored 8.1 or lower and showed no tendency to occur in groups.

Table 2: Technologies Scored Against Top Seven Systems

Critical Technologies	TAV (#1)	OTV (#2)	GSRT (#5)	HEL (#12)	KEW (#13)	HPMW (#14)	PB (#15)	Weighted Technology Score
	System Dependence on Technologies (percent)							
High Performance Computing (#6)	20		20	5	20	5	5	15.9
Micromechanical Devices (#14)	5	20	10	5	15	5	5	11.3
Materials Technology (#13)	30	5						11.0
Pulsed Power Systems (#20)						40	40	10.2
Nav., Guidance, and Vehicle Control (#15)	10			5	25	5	5	9.3
Robotics, Controllers, anmd End-Effectors (#21)	20	15						9.0
Lasers (#11)				25				8.1
Optics (#18)				25				8.1
High Energy Laser Systems (#5)				25				8.1
High Power Microwave Systems (#7)						45		6.6
Power Systems and Energy Conversion (#19)		20		10				6.2
Nonchem. High Specific Impulse Prop. (#17)		40						5.9
Neutral Particle Beam (NPB) Systems (#16)							45	4.9
Kinetic Energy Systems (#10)					40			4.9
Sensors (#22)			25					4.7
Data Fusion (#1)			20					3.8
Energetic Materials (#3)	10							3.4
Image Processing (#8)			15					2.8
Electromagnetic Communications (#2)			10					1.9
Vehicle Survivability (#24)	5							1.7
Total	100	100	100	100	100	100	100	

Launch System Study

Only one launch system was represented among the 19 system concepts, but that system (TAV) scored very highly. The analysis team felt that more exploration of alternative launch systems was called for. Accordingly, they scored five additional current and proposed launch systems: the current Delta II 7925, the Russian Zenit, the proposed Delta Clipper single-stage-to-orbit (SSTO) vehicle, a derivative of the National Aerospace Plane (NASP) using supersonic combustion technology, and a two-stage-to-orbit (TSTO) design launching from a carrier aircraft and called 'White Horse." More complete descriptions of these launch systems are found in Appendix 8. The results of scoring these systems are summarized in Figure 4; the complete data are in Appendix 9. The SPACECAST 2020 World weighting scheme was used. Delta II 7925 and Zenit are essentially current systems, and their scores showed only moderate gains over current practice. Zenit was assessed as significantly more effective than Delta because of better responsiveness, logistics, and support to space missions. The other three systems scored substantially better, all being in the 4.3 range along with the TAV that was among the original systems. These four fully reusable lift systems score similarly because they offer similar advantages over current launch systems. The differences between their scores are probably not significant.

The analysis team also felt that some of the spacelift systems should be considered together because they could be expected to work synergistically if deployed together. In particular, the TAV provides excellent access to near-earth orbit, while the OTV provides easy access between low-, medium-, and high-altitude orbits. The two systems together would provide efficient access to all militarily important regions of space. In addition, the Space Modular System dramatically improves the ease and flexibility of operations in orbit. The team decided to explore the possibility of combining the three systems, and rated them in combination (using the SPACECAST 2020 World weighting scheme). The results are summarized in Figure 5, and the complete scoring data are in Appendix 10. The TAV + OTV and TAV + OTV + Modular Systems combinations outscored any of the 19 single systems. This result illustrates the synergism possible when related systems are combined. However, the combinations offered so much operational capability that the team felt they had difficulty giving them a fair rating within the structure of the Value Model. One should keep in mind that the Value Model was designed to rate single systems. The team feels that these results probably underestimate the true synergism between TAV, OTV, and Modular Systems. In other words, a more detailed analysis of these combinations would probably score them even higher.

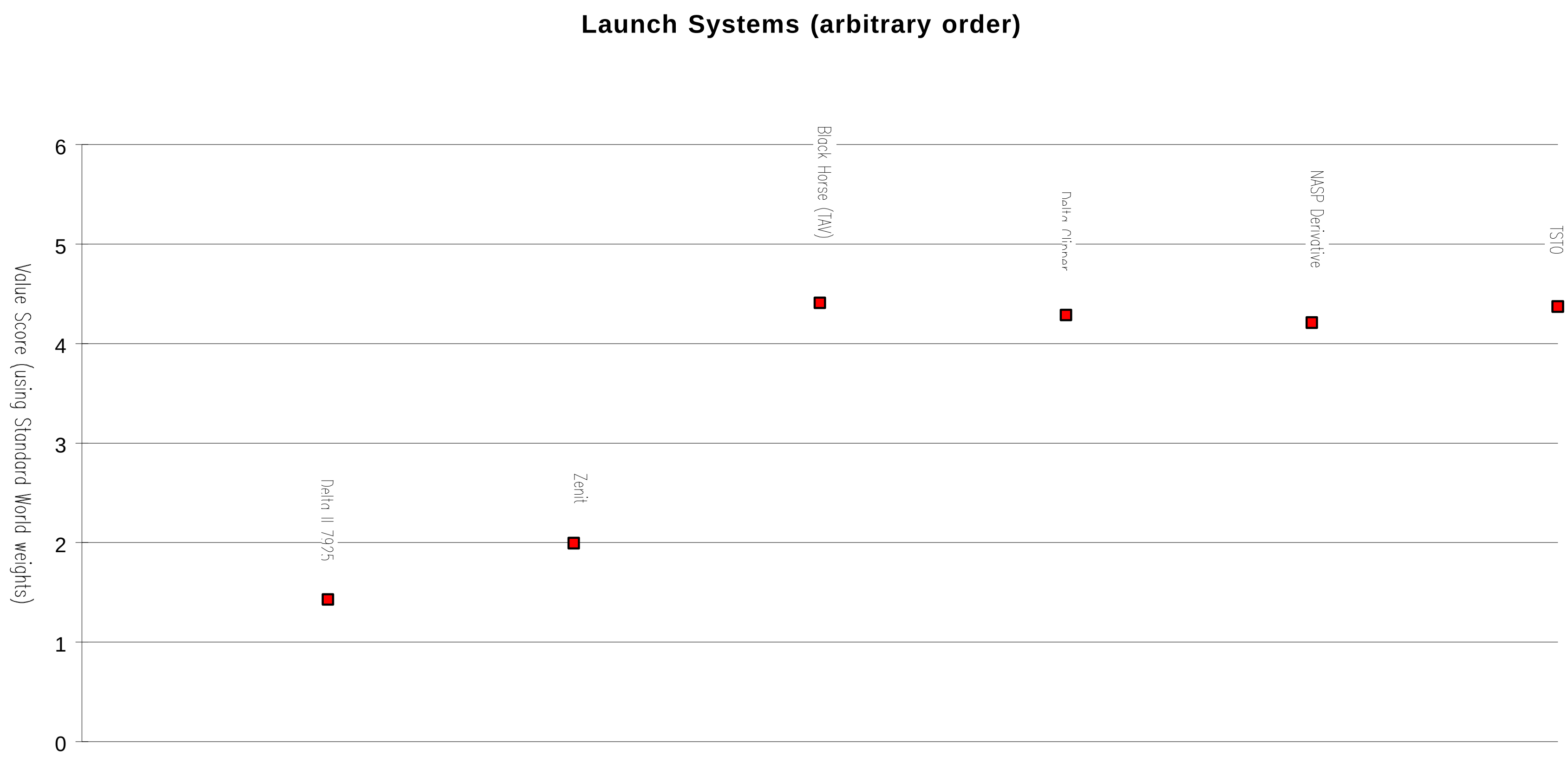

Figure 4: Launch System Study

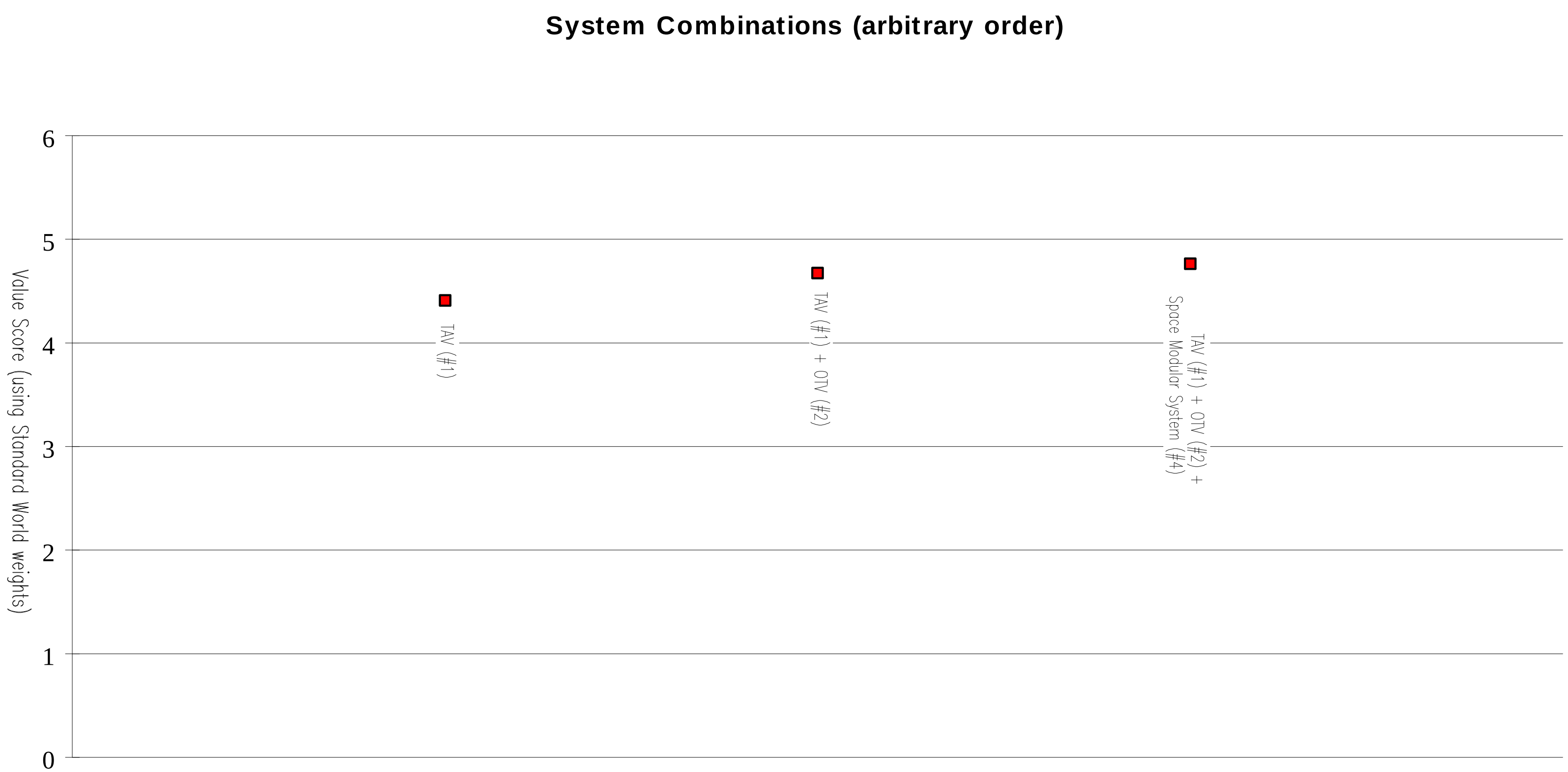

Figure 5: Combined Spacelift Systems

Conclusions

This analysis clearly showed that improved spacelift is one of the most important contributors to future space operations. The most important area here is an improved space launch capability, as exemplified by the reusable TAV. Various other advanced launch systems show equal promise: the Delta Clipper, a NA.SP-derived vehicle, and an aircraft-boosted two-stage-to-orbit system. Such an improved lift capability is important because it improves virtually all space force capabilities. An orbital transfer vehicle is also important for improving spacelift to high-altitude orbits.

This analysis also showed that space-based weapons are at the highest level of importance as contributors to the overall operational efficiency of future space operations. They are important because they provide important capabilities in ballistic missile defense, defense of terrestrial forces, terrestrial power projection, and active space defense. Of the weapon systems evaluated, a High Energy Laser seems to hold the most promise, largely because its optical system could also be used for some surveillance and imaging missions. Other systems that scored well were a Kinetic Energy Weapon, a High Powered Microwave, and a Particle Beam Weapon.

The final system that stood out in the analysis was the Global Surveillance, Reconnaissance, and Targeting System. This system contributes strongly to the Force Enhancement capabilities of space systems. Such a system provides a global view that could revolutionize terrestrial military operations.

The technology assessment portion of the study discovered three critical technologies important to a large number of high-scoring systems. These included the two technologies that were the top scorers over all. The three technologies are:

- High-Performance Computing
- Micro-mechanical Devices
- Navigation, Guidance, and Vehicle Control

An unexpected and important result of the study was that these technologies (particularly Micro-mechanical Devices) scored so highly in the technology evaluation. Advances in these areas show promise to substantially improve a wide range of space operations. Other technologies were also important, but contributed to only one or two of the high-value systems. Among the top-scoring technologies were:

- Materials Technology
- Pulsed Power Systems
- Robotics, Controllers, and End-Effectors

Other technologies scored nearly as well; see Table 2 for the complete list.

It is important to remember that the analysis did not take into account the cost of developing or deploying any of the system concepts. It also looked only briefly at the risk or technological challenge of developing them (as for instance in Figure 3). This was because of the lack of data to support such an analysis, and also because of the SPACECAST 2020 charter to be visionary and future-oriented. While this study indicates some systems and technologies showing promise for dramatically improving the effectiveness or efficiency of space operations, there are other important things that need to be considered before making an investment decision. These include cost and risk.

Some of the high leverage technologies enabling SPACECAST systems, such as high performance computing, are being pursued aggressively in the private sector. Others, such as pulsed power systems, may have lower commercial utility. Further analysis of the SPACECAST systems and their embedded technologies can point the way to an investment strategy maximizing the defense appropriation. These decisions are beyond the scope of the SPACECAST charter.

Finally, the SPACECAST operational analysis model is only a first step. It is offered as a starting point for further elaboration, quantification, and refinement. By assessing what creative thinkers envisioned would make valuable contributions to national security in the far future, operational analysis completes the SPACECAST process that began with creative thinking.

Notes

1. The technical justification for this is found in the Law of Large Numbers.

2. Ralph L. Keeney, *Value-Focused Thinking: A Path to Creative* Decisionmaking (Cambridge, MA: Harvard University Press, 1992).

3. Draft JCS Pub 3-14, "Military Space Operations,' 15 April 1992, Table III-1.

4. The line items were numbered from 1 to 101, with numbers 10, 14, and 20 not used.

5. Some of the weights show more precision than can be justified in a judgment-based study. This is because in some cases the team members were close but not identical in their judgments and agreed to take an average. This results in a spurious impression of precision, but is otherwise harmless.

6. It was difficult to directly score some systems against the measure of merit. For instance, an improved launch system will clearly affect line item 1 (which refers to the number of satellite communications links available) by making it easier and quicker to launch the satellites, but it is difficult to say by how much. Since the purpose of the analysis was to evaluate the potential future benefit of new technology, the team's practice was to score generously when such judgments were called for. Each system was given a score corresponding to its greatest reasonable contribution to the measure in question.

7. *The Militarily Critical Technologies List*, Office of the Undersecretary of Defense for Acquisition, Washington, D.C., October 1992.

8. Two systems were not scored because they did not fit into the structure of the Value Model based on draft JCS Pub 3-14. These were Asteroid Negation and Holographic Projection. They were both assessed as requiring major technology breakthroughs to become effective.

9. For this calculation the nonrescaled SPACECAST 2020 World system score was used. This is the raw score falling in the range of 0 to 100 percent and shown in Appendix 5.

10. These technologies were Hard Real-Time Systems (#4), Information Security (#9), Liquid Rocket Propulsion (#12), Spacecraft Structures (#23), and Virtual Reality (#25).

Appendix 1: Value Model

SPACECAST 2020 VALUE MODEL 27 May 94

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

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
	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

SPACECAST 2020 VALUE MODEL (Part 2)

						Measure of Merit	Current Level (0.0)	Minor Improvement (0.1)	Significant Improvement (0.5)	Order of Magnitude (0.9)
		Acquisition & Tracking	Coverage	##	28	Covered area	--	Most of Eurasia	Half of globe	World
		0.25	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
	Ballistic	Survivability	0.13		31	Qualitative judgment	--	No 1-point	Some capacity	Full capacity
	Missile							failures	concerted attack	major power attack
	Defense	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
Force		Coverage	0.14		34	Defended area	--	--	Regional	Global
Application	0.37	Capacity	0.12		35	RVs handled at a time	--	A few	100	Entire enemy force
0.19		Acquisition & Tracking	Coverage	##	36	Covered area	--	Most of Eurasia	Half of globe	World
		0.20	Accuracy	##	37	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	1 m, ground or air tgt
	Air, Land, & Sea		Discrimination	##	38	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
	Defense from	Survivability	0.17		39	Qualitative judgment	--	No 1-point	Some capacity	Full capacity
	Space							failures	concerted attack	major power attack
		Kill lethality	0.13		40	Pk	--	0.9, fixed targets	0.5, armored vehicles	0.9, ground/air tgts
	0.27	Timeliness	0.23		41	Required warning time	--	Weeks	Days	Minutes
		Coverage	0.27		42	Covered area	--	--	Regional	Global
		Acquisition & Tracking	Coverage	##	43	Covered area	--	Most of Eurasia	Half of globe	World
		0.30	Accuracy	##	44	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	1 m, ground or air tgt
	Power		Discrimination	##	45	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
	Projection	Survivability	0.13		46	Qualitative judgment	--	No 1-point	Some capacity	Full capacity
								failures	concerted attack	major power attack
	0.37	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

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	Effectiveness	##	70	Pr{incapacitate}	--	0.1	0.2	0.7
		0.60								

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)
		Cost	Recurring	##	71	Cost/lb to orbit	$6,500	$5,000	$2,000/lb	$200/lb
	Launch/Lift	0.25	Non-recurring	##	72	Develop/procure cost	$10B	$5B	$2B	$300M
	0.62	Responsiveness	Timeliness	0.17	73	Required warning time	Months	Weeks	Days	Hours
		0.20	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
Space			Post-abort restart	0.17	78	Time to restart ops	Years	Months	Weeks	Days
Support		Reliability	0.15		79	Pr{destructive abort}	5%	2-3%	1%	0.50%
0.22		Operability	Locations	##	80	# locations/orbit plane	1	2	5	10
		0.15	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	V. many/hardened/mobile
		Payload	0.05		87	Max lift/launch	50K	100K	200K	--
	Satellite	Communications	0.33		88	Link reliability	99.999%	--	99.9999%	99.99999%
	Control	Diagnosis	0.33		89	Avg time to diagnose	Hours	90 min	20 min	2 min
	0.20	Survivability	0.33		90	Type ground stations	Soft, worldwide	US territory	Mobile backups	Mainly mobile
		Sustainability	S/C--adaptability	0.13	91	HW failure recovery	Redundancy only	Ltd. reconfigurability	Major reconfigurability	Only minor mission losses
	Logistics of	0.40	S/C--upgradability	0.13	92	Design provisions	None	Limited	Major	Mission changes via S/W
	System		Grd--maintenance	0.13	93	Level of repairs rqd	Component	Board	LRU	S/W only
	0.18		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, components	Expand use	Some dual-use designs	All systems dual-use

/alue Hierarchy with "Rogue World" Weights

)VERALL OBJECTIVE: Control and Exploit Space

					Line Item No.
:orce :nhance- nent **0.31**	Communications **0.20**	Crisis availability	**0.30**		1
		Capacity	**0.30**		2
		Interoperability	**0.10**		3
		Security	**0.30**		4
	Navigation & Positioning **0.17**	Availability	0.10		5
		Data availability	**0.20**		6
		Accuracy	**0.20**		7
		Robustness	**0.50**		8
	Intelligence & Surveillance **0.30**	Processing Speed	**0.27**		9
					10
		ID Capability	**0.27**		11
		Coverage	**0.07**		12
		Day-night, All Weather	**0.40**		13
					14
	Environmental Monitoring and Control **0.05**	Spectral Bands	0.20		15
		Weather Prediction	0.20		16
		Multispectral Coverage	0.20		17
		Weather Detail	0.20		18
		Weather Control	0.20		19
	Mapping, Charting, & Geodesy **0.07**				20
		Surface Characterizatn	**0.33**		21
		Mensuration	**0.33**		22
		Data availability	**0.33**		23
	Warning, Processing, & Dissemination **0.22**	Coverage	0.20		24
		ID Capability	**0.20**		25
		Timeliness	0.40		26
		Security	**0.20**		27

SPACECAST 2020 VALUE MODEL (Part 2)

					Line Item No.
Force Application 0.21	Ballistic Missile Defense **0.43**	Acquisition & Tracking **0.16**	Coverage	0.33	28
			Accuracy	0.33	29
			Discrimination	0.33	30
		Survivability	**0.25**		31
		Kill lethality	**0.17**		32
		Timeliness	**0.11**		33
		Coverage	**0.11**		34
		Capacity	**0.20**		35
	Air, Land, & Sea Defense from Space **0.27**	Acquisition & Tracking **0.13**	Coverage	0.33	36
			Accuracy	0.33	37
			Discrimination	0.33	38
		Survivability	**0.22**		39
		Kill lethality	**0.17**		40
		Timeliness	**0.25**		41
		Coverage	**0.23**		42
	Power Projection **0.30**	Acquisition & Tracking 0.30	Coverage	0.33	43
			Accuracy	0.33	44
			Discrimination	0.33	45
		Survivability	**0.13**		46
		Kill lethality	**0.17**		47
		Timeliness	**0.23**		48
		Coverage	**0.17**		49

SPACECAST 2020 VALUE MODEL (Part 3)

Area	Function	Subfunction	Measure	Weight	Line Item No.
Space Control **0.31**	Surveillance 0.33	Availability 0.33	Coverage	0.20	50
			Revisit Time	0.80	51
		Robustness 0.33	Survivability	0.50	52
			Maintainability	0.50	53
		Accuracy 0.33	Resolution	0.25	54
			Identification	0.25	55
			Track/Predict	0.50	56
	Protection 0.33	Active **0.60**	Maneuver	**0.2**	57
			Jamming	**0.2**	58
			Decoys	**0.2**	59
			Defensive Fire	**0.4**	60
		Passive **0.40**	Redundancy	0.30	61
			CC&D	0.30	62
			Hardening	0.30	63
			Crypto Security	0.10	64
	Negation 0.33	Target Acq 0.20			65
		Destructive ASAT **0.60**	Coverage	0.40	66
			Weapon Capacity	0.30	67
			Effectiveness	0.30	68
		Incapacitating Systems **0.20**	Coverage	0.60	69
			Effectiveness	0.40	70

SPACECAST 2020 VALUE MODEL (Part 4)

					Line Item No.
		Cost	Recurring	0.50	71
	Launch/Lift	0.25	Non-recurring	0.50	72
	0.62	Responsiveness	Timeliness	0.17	73
		0.20	Orbit range	0.17	74
			Surge capability	0.17	75
			Mission range	0.17	76
			Non-destruct abort	0.17	77
Space			Post-abort restart	0.17	78
Support		Reliability	0.15		79
0.17		Operability	Locations	0.20	80
		0.15	Fuel	0.20	81
			Ease of handling	0.20	82
			Launch ranges	0.20	83
			Cmd & Control	0.20	84
		Environmental impacts	0.10		85
		Survivability	0.10		86
		Payload	0.05		87
	Satellite	Communications	0.33		88
	Control	Diagnosis	0.33		89
	0.20	Survivability	0.33		90
		Sustainability	S/C--adaptability	0.13	91
		0.40	S/C--upgradability	0.13	92
	Logistics		Grd--maintenance	0.13	93
	0.18		Grd--maint. freq.	0.13	94
			Grd--maint. skills	0.13	95
			Grd--parts	0.13	96
			Grd--repair	0.13	97
			Grd--reliability	0.13	98
		Commonality	0.20		99
		Interoperability	0.20		100
		Depots/Infrastructure	0.20		101

Appendix 3: White Paper System Descriptions

1. **Refueled Transatmospheric Vehicle** (TAV)

This system provides spacelift and weapons deployment from the earth's surface to low earth orbit using a rocket-powered TAV that takes off from a runway like a conventional aircraft. The vehicle starts with a full load of propellant but minimal oxidizer. It flies up to rendezvous with a subsonic air refueling tanker to pick up a full load of oxidizer before continuing to orbital altitude and speed.

2. **Orbital Transfer Vehicle** (OTV)

An unmanned autonomous boost vehicle used to transfer spacecraft between various orbits, primarily from low earth orbit (LEO) to higher orbits.

3. **Orbital Maneuvering Vehicle** (OMV)

An orbital propulsion and docking system used to take payloads from an earth-to-orbit lift vehicle and then place it in its final orbital plane or used to fetch and return orbiting payloads to a central repair and recovery location. The system would also be capable of carrying line replaceable units (LRU) to a damaged/degraded satellite and accomplishing on-site repair or replacement.

4. **Space Modular System(s)**

A satellite motherboard concept in which the mission support equipment common to all satellites (power generation and distribution; communication transmitters, receivers, and antennas; navigation; computers and data storage; pointing/tracking/station keeping thruster; satellite tracking telemetry and control; cross link; etc.) is placed on-orbit and the separate mission-specific payload packages are lifted to the motherboard for integration with the common elements.

5. **Global Surveillance, Reconnaissance, and Targeting System** (GSRT)

An omni-sensorial collection, processing, and dissemination system to provide a real time information data base. This data base is used to create a virtual reality image of the area of interest. This virtual reality image is then used at all levels of command to provide situational awareness, technical and intelligence information, and two-way command and control.

6. **Super Global Positioning System** (S-GPS)

An advanced Global Positioning System that provides increased positioning accuracy on the order of centimeters, fusion with other sensor assets, enhanced on-board computational capabilities, and a high data rate transmitter using low power and spread spectrum technology.

S-GPS would employ a system of coded signals to provide multilevel fused information and selectable accuracies to deny capability to all but selected users.

7. **Space Traffic Control System** (SPATRACS)

Development of an integrated space traffic control system that will integrate sensor information (on and off board), provide collision avoidance information, and also deconflict flight planning. The system has a space segment consisting of a few small, simple satellites with passive sensors and onboard processing that are responsible for tracking all objects in space. The system also has a central ground facility that would provide fusion with other data from ground-based sensor, validation, and additional analysis.

8. **Weather Forecast System**

Development and operational employment of an integrated weather information system consisting of on-orbit and ground sensors, and high speed information processing centers that produce data bases available to weather information users. These data bases would consist of observational weather data, forecast products, climatological information, and weather advisories and warning information.

9. **Space-Based Solar Monitoring and Alert Satellite System** (SMASS)

A system of satellites to provide multispectral electro-optical imaging of the sun, sunspot mapping and analysis, interplanetary magnetic field mapping, solar flare monitoring/alert capability, plasma particle measurement, solar electromagnetic energy emissions in the extreme ultraviolet, and direct broadcast communication capability with space operation centers on earth and in space. Analysis and forecasting capability would exist on the sensor platforms as well as at the earth or space-based operations center.

10. **Ionospheric Forecasting System**

A system of ground and space-based sensors to monitor and map the earth's ionosphere. The system also includes a control facility to collect and process the data from the sensor network and then disseminate the information to the user community. The potential exists for ionospheric modification to enhance military missions.

11. **Holographic Projector**

A system that could project holograms from space onto the ground, in the sky, or on the ocean anywhere in the theater of conflict for special operation deception missions. This system would be composed of either orbiting holographic projector or relay satellites that would pass data and instructions to a remotely piloted vehicle or aircraft that would then generate and project the holographic image.

12. **Space-Based High Energy Laser (HEL) System**

A space-based, multimegawatt high energy laser system 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.

13. **Kinetic Energy Weapon (KEW) System**

A general class of weapons that include a variety of warhead types from flechettes and pellets to large and small heavy metal rods. They can be augmented with explosive or pyrotechnic devices but generally are not. They achieve their destructive effect by means of the hydrodynamic effect of penetrating the target at hypervelocity.

14. **High Powered Microwave (HPMW) System**

A space-based, high-power microwave weapon system that is capable of destroying ground, air, and space targets.

15. **Particle Beam (PB) Weapon System**

A directed energy weapon system using a tightly focused, high-energy stream of electrically neutral atomic particles traveling near the speed of light. A space-based system to attack and disrupt targets in space or the edge of the atmosphere (ballistic missile defense [BMDI).

16. **Weather C3 System**

A counterforce weather control system for military applications. The system consists of a global, on-demand weather observation system; a weather modeling capability; a space-based, directed energy weather modifier; and a command center with the necessary communication capabilities to observe, detect, and act on weather modification requirements.

17. **Solar Mirror System**

A system of orbital mirrors to redirect solar energy for purposes of controlling terrestrial temperature and cloud patterns.

18. **Asteroid Detection System**

An observation network composed of multispectral ground and space sensors for surveillance, detection, tracking, and characterization of space objects that may pose a threat if they were to collide with the earth. The system also includes a central facility to collect data from all the sensors in the network, maintain a current data base of all known objects, and disseminate collected information to appropriate authorities.

19. **Asteroid Negation System**

A system that would be able to intercept any object that was determined to be a threat to the earth in sufficient time to deflect its course or fragment it into smaller pieces that do not pose a threat. Deflection and fragmentation could be accomplished by a variety of means from nuclear explosive devices, high specific impulse thrusters, kinetic energy projectiles, or directed energy devices.

Appendix 4: Detailed Descriptions of Value Model Measures of Merit

Note: Detailed descriptions should be interpreted in the context of the position of the line in the value hierarchy. For instance, Line Item 1 is in Force Enhancement (Level 1), Communications (Level 2), Crisis availability (Level 3).

Force Enhancement Measures of Merit:

Line Item No.	Measure of Merit	Detailed Description
1	Initial # links in theater	Number of communication links available in theater at the outset of hostilities
2	Decompressed MB/sec	Capacity of each link in megabits per second, including benefits of data compression
3	Common-use systems	Degree to which all comsats can be used by all comm terminals
4	Level of secure links	Command level at which secure links are easily available
5	Crisis Availability	Degree to which nav signal is available in theater
6	Receiver size/cost	Size and cost of device that processes nav signal
7	Location precision	Expected error of navigation fix
8	Resistance to CM	Degree of resistance of common-user signal to countermeasures
9	Auto image processing	Amount of image interpretation that is done by machine
10	(not used)	
11	Image interpretability	Degree of detail that can be seen on an image
12	Area per unit time	Square miles that can be imaged per hour
13	% time data available	Average percent of a day during which an image can be taken of a given location
14	(not used)	
15	Multispectral bands	Number of spectral bands that can be collected at once
16	Prediction	Length of time over which a high-accuracy weather prediction is valid
17	Multispectral revisit time	Average time between viewing opportunities with a multispectral sensor

Line	Measure of Merit	Description
18	Instant WX info	Type of weather information available in near realtime
19	Amount of control	Available control over weather
20	(not used)	
21	Amount of detail	Type of detailed information available about surface and subsurface features
22	Geodetic precision	Precision with which locations are known
23	Time to get new map	Time required to produce and distribute a new map based on existing data
24	Coverage	Type of missiles that can be detected
25	What and where	What type of missile is being tracked and where it is headed
26	Time to tactical warning	Typical elapsed time until tactical user receives warning
27	Resistance to CM	Degree of resistance of spacecraft command and data signals to countermeasures

Force Application Measures of Merit:

28	Covered area	Portion of world covered by system acquisition and tracking subsystem
29	Track accuracy	Expected error in track; portion of world over which this is achieved
30	ID/Discrimination	Degree to which possible RVs can be identified and decoys discriminated from warheads
31	Qualitative judgment	Scorers' judgment on survivability of system
32	Pk	Probability of kill; portion of flight where this is attainable
33	Required warning time	Time required to bring the system to full alert
34	Defended area	Portion of world protected by system
35	RVs handled at a time	Number of re-entry vehicles that can be engaged at once
36	Covered area	Portion of world covered by system acquisition and tracking subsystem
37	Accuracy	Expected error in track; relevant type of target

Line	Measure of Merit	Description
38	ID/Discrimination	Degree to which possible targets can be identified and discriminated from decoys
39	Qualitative judgment	Scorers' judgment on survivability of system
40	Pk	Probability of kill for different terrestrial targets
41	Required warning time	Time required to bring the system to full alert
42	Covered area	Portion of world protected by system
43	Covered area	Portion of world covered by system acquisition and tracking subsystem
44	Accuracy	Expected error in track; relevant type of target
45	ID/Discrimination	Degree to which possible targets can be identified and discriminated from decoys
46	Qualitative judgment	Scorers' judgment on survivability of system
47	Pk	Probability of kill for different terrestrial targets
48	Required warning time	Time required to bring the system to full alert
49	Covered area	Portion of world protected by system

Space Control Measures of Merit:

50	Percent of space	Portion of space that is covered by surveillance system
51	Time to view	Maximum time until an object in orbit can be tracked
52	Qualitative judgment	Scorers' judgment on survivability of system
53	Time to restore	Time to restore full capability after a system failure
54	Target sample distance	Typical minimum resolved distance in image of spacecraft
55	Percent objects ID'd	Percent of possibly hostile spacecraft that are correctly identified
56	Avg # objects lost	Average daily number of space objects whose tracks have been lost
57	Response time	Time required to plan and execute an evasive maneuver
	Delta Velocity	Velocity change of feasible evasive maneuvers
58	Spectral range	Range of radio frequencies over which an attacker can be jammed

Line	Measure of Merit	Description
59	Avg decoys / S/C	Average number of decoys available per spacecraft
	Range of effectiveness	Range of sensors over which decoys are effective
60	Pk	Probability of kill of anti-ASAT weapon
61	Qualitative judgment	Scorers' judgment on survivability of system
62	Pd	Probability of detection
63	Sure safe W on target	Number of watts a spacecraft can receive without risk of damage
64	Percent S/C with crypto	Percent of spacecraft with encrypted uplinks and downlinks
65	Time to produce state vector after launch	Time from hostile spacecraft launch to possession of targeting-quality state vector
66	Percent of S/C	Percent of potentially hostile spacecraft that can be engaged
67	Avg # shots / target	Average number of times each potentially hostile spacecraft can be engaged
68	Pk / shot	Probability of kill for one engagement
69	Percent of systems	Percent of potentially hostile spacecraft that can
70	Pr{incapacitate}	Probability for one engagement that the target will be effectively incapacitated

Space Support Measures of Merit:

Line	Measure of Merit	Description
71	Cost/lb to orbit	Cost per pound to put spacecraft in low Earth orbit
72	Develop/procure cost	Cost to develop and procure a new launch system
73	Required warning time	Time required to prepare for and conduct a space launch
74	Inclinations achievable	Percent of all orbit inclination (0-110 degrees) that a launch system can achieve
75	Increase in rate	Possible increase in launch rate during crisis
76	Missions supported	Number of different spacecraft that a given booster can launch
77	Pr{soft abort|abort}	Probability that a post-liftoff launch abort will not harm the booster or payload
78	Time to restart ops	Time to restart launch operations after a major mishap
79	Pr{destructive abort}	Probability that a launch attempt will not be successful

Line	Measure of Merit	Description
80	# locations/orbit plane	Number of launch sites that can be used to launch into a given orbit plane
81	Ease of handling	The degree to which the booster's propellants are and/or toxic
82	Percent blue-suit	Percent of launch crew that is military personnel
83	Number and location	Number of location of launch ranges needed for space launches
84	Similarity to air ops	Degree to which launch operations resemble typical aircraft operations
85	Toxicity and waste	Toxicity and volume of vented propellants and combustion products
86	Type bases	Number and type (with regard to survivability) of available launch bases
87	Max lift/launch	Maximum payload to low Earth orbit per launch
88	Link reliability	Reliability of comm links in satellite control system
89	Avg time to diagnose	Average time to diagnose and correct a failure in satellite control system
90	Type ground stations	Number and type (with regard to survivability) of satellite control ground stations
91	HW failure recovery	Ability of spacecraft to adapt to hardware failures
92	Design provisions	Degree to which spacecraft can be upgraded
93	Level of repairs rqd	Typical hardware level at which repairs must be made
94	Frequency of actions	Typical frequency of maintenance actions
95	Type of personnel	Type of personnel required for maintenance
96	Type of piece parts rqd	Type of piece parts required
97	% work value on site	Percent of repair work value that is done on-site
98	MTBF, critical parts	Typical mean time between failure of critical parts
99	S/C commonality	Degree of commonality between spacecraft
100	S/C Interchangeability	Degree to which spacecraft can be launched on different boosters
101	Dual-use technology	Degree to which military and civil spacecraft use common designs

Appendix 5: System Concept Scores

	TAV (#1)		**OTV (#2)**		**OMV (#3)**		**Modular Sys. (#4)**		**GSRT (#5)**		**Super GPS (#6)**	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted

No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1	80.0%	2.3%	40.0%	1.1%	30.0%	0.9%						
2												
3												
4												
5	10.0%	0.1%	5.0%	0.0%	10.0%	0.1%					10.0%	0.1%
6												
7											50.0%	0.9%
8											50.0%	1.5%
9									90.0%	3.0%		
10												
11									90.0%	1.8%	50.0%	1.0%
12	90.0%	1.2%	40.0%	0.5%					90.0%	1.2%		
13	90.0%	2.4%	40.0%	1.1%	30.0%	0.8%			90.0%	2.4%		
14												
15												
16												
17	50.0%	0.3%	10.0%	0.1%								
18												
19												
20												
21												
22											10.0%	0.1%
23	90.0%	1.0%										
24	80.0%	1.1%	40.0%	0.5%	30.0%	0.4%						
25												
26												
27												

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1					10.0%	0.3%	10.0%	0.3%		
2							10.0%	0.3%		
3										
4										
5										
6										
7										
8										
9										
10										
11									90.0%	1.8%
12									90.0%	1.2%
13									90.0%	2.4%
14										
15			10.0%	0.1%						
16			10.0%	0.1%	90.0%	0.5%				
17			90.0%	0.5%						
18			10.0%	0.1%	10.0%	0.1%				
19										
20										
21										
22										
23										
24									50.0%	0.7%
25									50.0%	1.0%
26									50.0%	1.3%
27										

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15							50.0%	0.3%				
16							90.0%	0.5%				
17							90.0%	0.5%				
18							90.0%	0.5%				
19							90.0%	0.5%	50.0%	0.3%		
20												
21												
22												
23												
24												
25												
26												
27												

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28	90.0%	0.5%	40.0%	0.2%					90.0%	0.5%		
29									90.0%	0.5%		
30									90.0%	0.5%		
31	90.0%	0.8%	10.0%	0.1%								
32												
33												
34	90.0%	0.8%	40.0%	0.4%								
35	50.0%	0.4%										
36	90.0%	0.3%	40.0%	0.1%								
37											90.0%	0.3%
38												
39	90.0%	0.8%	10.0%	0.1%								
40											10.0%	0.1%
41												
42	90.0%	1.2%	40.0%	0.5%								
43	90.0%	0.6%	90.0%	0.6%					90.0%	0.6%		
44									90.0%	0.6%	90.0%	0.6%
45									90.0%	0.6%		
46	90.0%	0.8%	10.0%	0.1%								
47											10.0%	0.1%
48									90.0%	1.4%		
49	90.0%	1.1%	40.0%	0.5%					90.0%	1.1%		

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28									90.0%	0.5%
29									90.0%	0.5%
30									90.0%	0.5%
31									90.0%	0.8%
32									90.0%	1.4%
33									80.0%	0.8%
34									90.0%	0.8%
35									50.0%	0.4%
36									90.0%	0.3%
37									50.0%	0.2%
38										
39									50.0%	0.4%
40									50.0%	0.3%
41									90.0%	1.0%
42									40.0%	0.5%
43									90.0%	0.6%
44									70.0%	0.5%
45										
46									90.0%	0.8%
47									40.0%	0.5%
48									90.0%	1.4%
49									50.0%	0.6%

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28	90.00%	0.52%			90.00%	0.52%						
29	90.00%	0.52%			50.00%	0.29%						
30	90.00%	0.52%			50.00%	0.29%						
31	50.00%	0.45%			50.00%	0.45%						
32	50.00%	0.80%			50.00%	0.80%						
33	70.00%	0.66%			90.00%	0.85%						
34	50.00%	0.47%			90.00%	0.85%						
35	50.00%	0.42%			50.00%	0.42%						
36	90.00%	0.30%	90.00%	0.30%								
37	50.00%	0.17%	10.00%	0.03%								
38												
39	50.00%	0.43%	50.00%	0.43%								
40	10.00%	0.07%	70.00%	0.46%								
41	60.00%	0.70%	90.00%	1.05%								
42	50.00%	0.68%	90.00%	1.23%								
43	90.00%	0.63%	90.00%	0.63%								
44	10.00%	0.07%	50.00%	0.35%								
45												
46	50.00%	0.45%	50.00%	0.45%								
47	10.00%	0.12%	70.00%	0.83%								
48	60.00%	0.91%	90.00%	1.36%								
49	70.00%	0.89%	90.00%	1.15%								

	TAV (#1)		**OTV (#2)**		**OMV (#3)**		**Modular Sys. (#4)**		**GSRT (#5)**		**Super GPS (#6)**	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50	90.0%	0.4%	40.0%	0.2%					10.0%	0.0%		
51									90.0%	1.8%		
52	50.0%	0.6%	10.0%	0.1%					50.0%	0.6%		
53	50.0%	0.6%	10.0%	0.1%								
54									90.0%	0.6%		
55									90.0%	0.6%		
56									90.0%	1.1%		
57					20.0%	0.2%						
58												
59												
60												
61	50.0%	0.7%	10.0%	0.1%								
62												
63												
64												
65												
66	90.0%	0.5%	40.0%	0.2%								
67	50.0%	0.2%	10.0%	0.0%								
68												
69	90.0%	2.4%	40.0%	1.1%								
70												

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50	10.0%	0.0%	10.0%	0.0%					50.0%	0.2%
51	90.0%	1.8%	90.0%	1.8%					60.0%	1.2%
52	50.0%	0.6%	50.0%	0.6%					70.0%	0.9%
53										
54	30.0%	0.2%	30.0%	0.2%					50.0%	0.3%
55	70.0%	0.4%	70.0%	0.4%					80.0%	0.5%
56	50.0%	0.6%	50.0%	0.6%					80.0%	1.0%
57										
58										
59										
60									90.0%	0.3%
61										
62										
63										
64										
65									70.0%	1.0%
66									90.0%	0.5%
67									90.0%	0.4%
68									90.0%	0.4%
69									90.0%	2.4%
70									90.0%	1.6%

	KEW (#13)		**HPMW (#14)**		**Particle Beam (#15)**		**WX Control (#16)**		**Solar Mirrors (#17)**		**Ast. Det. (#18)**	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50											90.0%	0.4%
51												
52												
53												
54											10.0%	0.1%
55											90.0%	0.6%
56											90.0%	1.1%
57												
58												
59												
60	50.0%	0.1%	90.0%	0.3%	90.0%	0.3%						
61			50.0%	0.7%	50.0%	0.7%						
62												
63												
64												
65	70.0%	1.0%										
66	70.0%	0.4%	90.0%	0.5%	90.0%	0.5%						
67	50.0%	0.2%	90.0%	0.4%	90.0%	0.4%						
68	90.0%	0.4%	90.0%	0.4%	90.0%	0.4%						
69			90.0%	2.4%	90.0%	2.4%						
70			90.0%	1.6%	90.0%	1.6%						

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71	90.0%	1.5%	50.0%	0.9%								
72	60.0%	1.0%	50.0%	0.9%								
73	90.0%	0.4%	50.0%	0.2%								
74	50.0%	0.2%	50.0%	0.2%								
75	100.0%	0.5%										
76	70.0%	0.3%	70.0%	0.3%								
77	90.0%	0.4%	60.0%	0.3%								
78	50.0%	0.2%	20.0%	0.1%								
79	90.0%	1.8%	30.0%	0.6%								
80	100.0%	0.4%	30.0%	0.1%								
81	70.0%	0.3%	10.0%	0.0%								
82	90.0%	0.4%	90.0%	0.4%								
83	100.0%	0.4%										
84	90.0%	0.4%	50.0%	0.2%								
85	80.0%	1.1%	50.0%	0.7%								
86	50.0%	0.7%	50.0%	0.7%								
87			50.0%	0.3%								
88												
89							50.0%	0.7%				
90												
91	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%				
92	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	90.0%	0.2%				
93	50.0%	0.1%										
94												
95	70.0%	0.1%										
96	70.0%	0.1%										
97	70.0%	0.1%										
98												
99	90.0%	0.7%					90.0%	0.7%				
100	90.0%	0.7%			50.0%	0.4%	90.0%	0.7%				
101	90.0%	0.7%	90.0%	0.7%	90.0%	0.7%	90.0%	0.7%				

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71										
72										
73										
74										
75										
76										
77										
78										
79										
80										
81										
82										
83										
84										
85										
86										
87										
88										
89										
90										
91							50.0%	0.1%	50.0%	0.1%
92							50.0%	0.1%	50.0%	0.1%
93										
94										
95										
96										
97										
98										
99										
100										
101										

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71												
72												
73												
74												
75												
76												
77												
78												
79												
80												
81												
82												
83												
84												
85												
86												
87												
88												
89												
90												
91	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%		
92	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%		
93												
94												
95												
96												
97												
98												
99												
100												
101												

Appendix 6: SPACECAST 2020
Critical Technologies

1. **Data Fusion** (MCTL 4.2.5): Data fusion is the technique whereby multivariate data from multiple sources are retrieved and processed as a single, unified entity. Data fusion is fundamental to command and control, with intelligence processing being a major ingredient. A significant set of priority databases is crucial to the effective functioning of the fusion process.

2. **Electromagnetic Communications** (MCTL 5.1.1): This technology covers the development and production of a variety of telecommunication equipment used for electromagnetic transmission of information over any media. The information may be analog or digital, ranging in bandwidth from a single voice or data channel to video or multiplexed channels occupying hundreds of megahertz. Included are onboard satellite communication equipment and laser communication techniques capable of automatically acquiring and tracking signals and maintaining communications through atmospheric, exoatmospheric, and subsurface (water) media.

3. **Energetic Materials** (MCTL 12.7): This technology covers the development, production, and storage of constituent materials into composites or formulations that can be used as high energy propellants. This technology must be available if the ingredients of energetic formulations are to be manufactured safely in adequate quantity and quality for operational propulsion systems.

4. **Hard Real-Time Systems** (MCTL 4.2.4): Technologies required for the processing of data by a computer system that provides a required level of service as a function of available resources, within a guaranteed response time, regardless of the load on the system, when stimulated by an external event. Hard real-time operating systems that provide a shared set of computer resource management services designed and optimized for support of time-critical computer software applications, command and control, and aerospace vehicle navigation.

5. **High Energy Laser Systems** (MCTL 11.1): These technologies cover those required to generate high energy laser (HEL) beams (20 kW or greater average power, 1 kJ or more energy per pulse) at infrared, visible, or ultraviolet wavelengths and project them to a target where they will perform damage ranging from degradation to destruction. Included are those technologies covering HEL beam pointing, tracking control, beam propagation, and target coupling. Technologies required to integrate and implement a HEL system are also included.

6. **High Performance Computing** (MCTL 4. 1. 1): This technology covers the development of extremely high performance digital computers with vector and massive parallel processor architecture. This technology is required not only to process massive amounts of data in real time, but is also critical to the ability to computationally solve design problems in critical areas such as hypersonic aerodynamics, heat transfer, astrophysics, chemistry, and high energy physics.

7. **High Power Microwave Systems** (MCTL 11.2): This technology, also known as high power radio frequency systems technology, covers sources capable of generating sufficient high power microwave (HPMW) power, components for modulating the power, and antenna arrays which are required to direct the energy to a target. Peak powers of 100 megawatts or more, single pulse energy of 100J or more, and average powers of more than 10 kW are required for the development of weapons systems resulting in electrical component upset or burnout and antipersonnel applications.

8. **Image Processing** (MCTL 4.1.4): This technology is used for acquiring, transferring, analyzing, displaying, and making use of image data in real-time or near real time. Included are technologies related to implementation of mobile sensors for real-time target acquisition and guidance, processing and displays of large complex data sets, data transmission and compression techniques, archival storage of imagery data, and real-time displays and three-dimensional presentation.

9. **Information Security** (MCTL 5.5): This technology includes the means and functions for controlling the accessibility or ensuring the confidentiality or integrity of information and communications, as well as the availability of resources. Included under this section are the development and production of equipment for information security functions, including measuring and test equipment, cryptographic material (including documents, devices, equipment, and other apparatus), and software required or modified for the development, production, and use of this equipment.

10. **Kinetic Energy Systems** (MCTL 11.4): This technology is required to propel projectiles at velocities greater than 1.6 km/sec (much higher than conventional gun or rocket systems) to obtain an appropriate combination of properties such as shape, size, density, and ductility at impact velocity. Technologies for precision pointing, tracking, launch, and management of launch platforms are also included. Kinetic energy weapons are especially advantageous for the precision destruction of hard targets and armored vehicles, and the interception and mission denial of aircraft, space vehicles, and similar fast moving targets.

11. **Lasers** (MCTL 10.1): This technology covers the development and production of lasers at power levels described under MCTL 11.1, High Energy Laser Systems. Lasers consist of the laser hardware, the laser medium, mirrors, and other optical components that form the laser oscillator cavity. Lasers may operate in a continuous, single-pulsed, or repetitively pulsed modes depending on the application and requirements. Energy sources (chemical or electrical) required to generate the HEL beam are included under this section.

12. **Liquid Rocket Propulsion** (MCTL 9.4.1): This technology covers liquid propulsion rocket systems that are used to power space launch vehicles to inject payloads into orbit and to change spacecraft orbits. Propellants for these systems include both storable and cryogenic types. The technologies of concern are those associated with the provision of more efficient propulsion through better propulsion control, lightweight motor hardware, and more efficient subsystems.

13. **Materials Technology** (MCTL 1.0): This technology includes multiapplication materials. Metals, alloys, and ceramics (MCTL 1.1) covers classes of metals and noncomposite ceramics with enhanced strength and durability at progressively more severe load bearing and thermal environments. Composite materials (MCTL 1.2) covers high performance organic, metal, carbon, and ceramic matrix composites which result in structural weight reduction, enhanced range, propulsion, and vehicle capabilities to meet operational requirements. Carbon and ceramic composites may provide advanced thermal protection material for advanced aerospace vehicles.

14. **Micro-mechanical Devices** (MCTL 2.6): This technology covers the manufacture of micro-mechanical devices, also known as micro machines, micro robots, and micro sensors, and their integration with microelectronics devices on a single 'chip." Applications of this technology may include high precision mirrors and lenses for high output lasers, gyroscopic control guidance systems, sensors for control systems and miniature engines, accelerometers, transducers, and piezoelectric drives which can revolutionize military systems in terms of size, weight, and performance parameters such as power requirements.

15. **Navigation, Guidance, and Vehicle Control** (MCTL 7-0): These technologies are required for both autonomous and cooperative positioning (navigation), coordination, and control of military force elements. Included are technologies for flight management, vehicle guidance, and control. Accurate positioning and control are essential for the effective coordination of highly mobile military flight vehicles. These capabilities also directly determine the delivery accuracy and lethality of 'smart" weapons.

16. **Neutral Particle Beam (NPB) Systems** (MCTL 11-3.2): Technologies required for generation, propagation, and control of high-intensity atomic beams of hydrogen or its isotopes. Includes high current (tens of milliampere) negative hydrogen ion beam generation and acceleration, high burst power generation, beam control and monitoring subsystems, and target interaction and kill assessment. NPB weapons use projections from a high energy particle accelerator, through a charge neutralization cell, to a distant target. NPBs only have utility in space.

17. **Nonchemical High Specific Impulse Propulsion** (MCTL 9.5.2): This technology covers low-thrust, high specific impulse propulsion devices that can be used for spacecraft station keeping or orbit changes. Specifically, these propulsion systems include, but are not limited to, electrostatic, electrothermal, and electromagnetic systems, which utilize electric power to accelerate propellant gases to high exit velocities.

18. **Optics** (MCTL 10.2): This technology covers those required to develop and produce optics where the criticality of the component is major and the technology involved in the fabrication of key optical components involves techniques and processes which are not generally available in the commercial market. This technology, which includes adaptive optics, allows reconnaissance systems capable of operation without atmospheric distortion and directed energy

systems capable of diffraction-limited performance against space-based or endo-atmospheric targets.

19. **Power Systems and Energy Conversion** (MCTL 10.3.1): These technologies address the generation and delivery of power to meet electrical requirements under specified environmental conditions, and within specific size and weight constraints. These technologies include low power AC and DC power generation for sensitive electronics applications, space-qualified field generation equipment, high energy density systems, energy conversion technologies applied to generation of primary electrical power, techniques for continuous conversion/power generation, and pulse power applications.

20. **Pulsed Power Systems** (MCTL 10.3.3): These technologies cover the development and production of equipment required for moderate and high pulse power systems (greater than 2 megawatts average power with more than 10 kJ per pulse). Included are pulse power subsystems required for active radar and directed energy systems. These technologies address high power solid state control components, switches, and techniques for achieving and preserving fine-grained pulse characteristics in moderate and high power systems.

21. **Robotics, Controllers, and End- Effectors** (MCTL 2.2.5): This technology covers multifunctional manipulation devices employing feedback information from one or more sensors to orient parts, tools, or other devices through variable movements in three-dimensional space. In order to perform complex, high precision tasks, they contain at least three open or closed loop servo devices and have accessible programmability by means of off-line computer or programmable logic controllers.

22. **Sensors** (MCTL 6.0): These technologies include all sensor types that are of military interest. Included are technologies for acoustics, optical sensors, cameras, radar identification, gravity meters, magnetometers, and associated gradiometers. Critical elements include specially developed materials and precision manufacture, integration of the components with processing subsystems, simulation and modeling, and thorough testing for performance and operational robustness.

23. **Spacecraft Structures** (MCTL 9.5. 1): These technologies cover the development and production of dimensionally stable structures for spacecraft which employ techniques for control of structural distortion, including materials designed for zero coefficient of thermal expansion designs to prevent structural outgassing in orbit, and materials that provide high strength and high stiffness. Also included are analysis techniques used to simulate the dynamic interaction of the structure with the spacecraft control system and to provide the means to define a design with the required stability characteristics for precision structures such as optical systems and antennas or with large flexible appendages such as solar panels. This section also covers sensors and actuators used for spacecraft vibration control.

24. **Vehicle Survivability** (MCTL 9.7): These technologies enhance the survivability of US aerospace vehicles to threats of detection and attack by enemy forces. Included under this category are signature-control for avoiding or delaying detection and other measures such as

maneuverability or high speed to reduce engagement opportunity after detection has occurred. Vehicle survivability is achieved or enhanced by denying the enemy the ability to "see" the vehicle through visual, radar, radiated heat, and noise signatures or communications signals.

25. **Virtual Reality:** Virtual reality technologies are actually a combination of those encompassed by Dynamic Training and Simulation (MCTL 4.1.2), Image Processing (MCTL 4.1.4), and Hard Real-Time Systems (MCTL 4.2.4). Dynamic Training and Simulation covers techniques that allow operator feedback into real-time control functions that enhance realism by coordinated multisensor operator inputs. Hard Real-Time Systems involve the processing of data by a computer system providing a required level of service, as a function of available resources, within a guaranteed response time when stimulated by an external event. These technologies enable a human to efficiently operate complex systems from a remote location or 'project" himself into an artificial environment for purposes such as command and control.

Appendix 7: Contributions of Technologies to Systems

Technology (see Appendix 6 for descriptions):

	System	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19	#20	#21	#22	#23	#24	#25	Sum
1	TAV			10			20							30	5	10						20			5		100
2	OTV													5	20			40		20		15					100
3	OMV						10								20			20		15		25				10	100
4	Mod Sys																	15				20		45		20	100
5	GSRT	20	10				20		15						10								25				100
6	S-GPS	20					20			15					15	20				5			5				100
7	SPATRACS		30		10		30																30				100
8	WX F'cast	55					35		10																		100
9	SMASS	20	10				25		15														30				100
10	Iono. F'cast	10			45		15																30				100
11	Holo. Proj.		5			15	10		20			10							20	20							100
12	HEL					25	5					25			5	5			25	10							100
13	KEW						20				40				15	25											100
14	HPMW						5	45							5	5					40						100
15	PB						5								5	5	45				40						100
16	WX C3	10	10		15		50																15				100
17	Mirror															25			25					50			100
18	Ast. Det	5			10		15												20				50				100
19	Ast. Neg															35		65									100

Judgments on Percentage Dependance of Each System on Each Critical Technology

Appendix 8: Spacelift Vehicle Descriptions

Delta 11 7925

Developed from the Thor intermediate range ballistic missile (IRBM) and Vanguard upper stages in 1959 by the Douglas Aircraft Company, the Delta II uses a single RS27 single-start liquid bi-propellant (liquid oxygen-kerosene) engine producing 210k lbs of thrust at sea level with two Rocketdyne verniers providing roll control. A cluster of solid rocket strap-ons around the base of the first stage can be added for additional launch thrust. The 7925 version of Delta II can deliver approximately 11,000 lbs to a 200 NM low earth orbit (LEO) (28.71). Cape Canaveral, with its two Delta launch pads, is the only currently active launch complex. Vehicle integration and checkout typically takes place at the Cape over a 16-week period prior to launch (eight weeks vertical stack time). Cost to commercial users is about $50M per launch at 1990 rates.

Production was closed down in 1984, but the Shuttle failure in January 1986 resulted in production reactivation. In January 1987, the Air Force awarded a production contract for the Delta II as the medium launch vehicle to launch the network of GPS Navstar satellites after that requirement had been off-loaded from the Shuttle.

Zenit

The Russian SL-16 (Zenit) began- flight testing with a suborbital flight on 13 April 1985. It is the first new Russian launcher developed since 1972. The first stage of the Zenit booster is the Energia strap-on (SL-17). There is a two-stage version (Zenit 2) and a three-stage version (Zenit 3). The Zenit uses four RD-170 gimbaled rocket motors burning liquid oxygen and kerosene producing 1.63 million pounds of thrust at sea level. The second stage uses a single RD-120 **fixed** reignitable engine producing 186.5k lbs of thrust. Zenit 2 is capable of placing an encapsulated payload canister with a standardized interface weighing 30,000 lbs into a 100 NM LEO (51.6') from theTyuratam spaceport. Payload volume is 9OM3 for the 13.65m long shroud.

Zenit is assembled horizontally, with the payload integrated on stage 2 before stage 1/2 mating. Assembly of the vehicle alone requires 80 hours increasing to 116 hours with the payload. Transfer to one of two pads is by rail; erection and launch processing is highly automated, requiring 21-80 hours between initial integration and launch.

The Soviets began discussions for a cooperative launch arrangement with the Australian government in 1986. The program would offer equatorial launches from the Cape York Space Port to be constructed at Queensland on the northern Australian coast. The Australians intend to purchase and launch Zenit boosters using local launch crews trained initially by the Soviets. A similar licensing agreement between the US and Russia should be possible to establish launch capabilities for the Zenit booster from Cape Canaveral and Vandenberg AFB. A follow-on manufacturing arrangement might also be possible. A cooperative technology enhancement program between the two countries to use aluminum-lithium and carbon-carbon composites in place of the titanium in the manufacture of Zenit could result in a lighter weight booster that is less expensive to make and can place a larger payload in orbit.

Transatmospheric Vehicle

In-flight oxidizer transfer to a rocket-powered Transatmospheric Vehicle permits achieving orbit with relatively low weight compared to a fully loaded flight vehicle using a horizontal takeoff from a runway. The weight of many key components, such as wings and landing gear, is substantially reduced because of the lower gross takeoff weight. This manned vehicle takes off like a conventional aircraft under rocket power from two of its seven engines, using jet fuel (JP-5) and a noncryogenic oxidizer hydrogen peroxide. After rendezvous with and oxidizer transfer from a tanker aircraft, the vehicle ignites all seven of its engines, accelerates to high speed, and pulls up into a steady climb into orbit. An estimated 5,000 lbs could be carried to a 100 NM LEO in an encapsulated payload canister with a standardized interface. Noncryogenic, nontoxic propellants permit the propellant transfer to use existing tankers, and a small aircraft similar in size to an F-16 could demonstrate the capability and achieve orbit. The concept is sufficiently simple that relatively little in the way of new facilities or support equipment is required.

Delta Clipper

Delta Clipper is a single stage to orbit (SSTO) fully reusable, vertical takeoff and landing, launch vehicle making use of a simplified launch infrastructure (clean pad) to lower launch costs. The vehicle has a gross lift-off weight of approximately 1.4 million pounds and can carry about 10,000 lbs to a 100 NM LEO in an encapsulated payload canister with a standardized interface. The vehicle uses a ballistic trajectory to achieve and return from orbit, with rocket power providing the control for landing. It is propelled by cryogenic rocket motors using liquid oxygen and liquid hydrogen. The vehicle is not normally manned. An upcoming third test flight of a subscale, proof of concept vehicle, is reportedly to confirm the ability to invert from reentry attitude to landing attitude.

NASP Derived Vehicle
(Scramjet/Rocket SSTO)

A horizontal takeoff and landing single-stage-to-orbit (SSTO) vehicle powered by a hydrogen-fueled propulsion system that integrates ramjet/scramjet engines with small rocket motors for sustained cruise at Mach 5-15 in the atmosphere and a Mach 25 orbital capability. The vehicle would use a combination of engines. A conventional jet for slow speed, with ramjets taking over to carry the craft up to about Mach 6 at which point the scramjets using slush hydrogen for fuel would take it to near orbital velocity.

Small rocket motors would provide the final push to orbit. Gross takeoff weight is estimated at 917,000 lbs. This vehicle is capable of carrying a 25,000 lbs encapsulated payload canister with a standardized interface. This equates to a payload mass fraction of 26%. Because of its weight and takeoff speed requirement, this vehicle would operate from large airfields with long runways such as those at ACC bomber bases and commercial airfields rated to handle Boeing 747 jumbo jets.

Two-Stage-to-Orbit (TSTO)

A design for a small two-stage-to-orbit (TSTO) system that would take maximum advantage of off-the-shelf systems. Using a 747-class carrier aircraft, a small launch vehicle could be deployed at subsonic speeds and moderate altitude (40,000 ft). The advantage gained by the initial velocity and altitude of the carrier aircraft, combined with the reduced drag and improved engine performance (rocket engine performance is altitude dependent) would make this feasible with today's fuels and materials. The spacecraft would be a lifting-body design, to allow efficient energy management on return from orbit and a safe abort mode. The vehicle would use an unpowered Space Shuttle-like glide de-orbit, return, and horizontal landing on a conventional runway. The orbital vehicle would have gross weight including fuel of approximately 150,000 lbs. This is a similar weight to the shuttle Enterprise that was carried and dropped from a 747 for aerodynamic control and landing tests. The rocket engines would be fueled by liquid oxygen and slush hydrogen. The craft would be designed to carry a 5,000 lbs encapsulated payload canister with a standardized interface. Advantages of a TSTO approach include being able to launch from almost any airport, worldwide, with the addition of equipment to fuel the spacecraft and lift it onto the carrier aircraft. The carrier aircraft could fly to any location within its range to launch the spacecraft into the proper orbit. Launching over lightly populated areas or the oceans would reduce safety problems and eliminate noise problems associated with supersonic flow. Launch from altitude, as opposed to horizontal takeoff from the ground, would reduce the size of the wings on the spacecraft considerably, thereby reducing weight of the reentry protection system and overall spacecraft.

Appendix 9: Launch System Scoring Data

	Delta		Zenit		TAV		DC		NASP		TSTO	
Line Item No.	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
1			30.00%	0.85%	80.00%	2.28%	80.00%	2.28%	80.00%	2.28%	80.00%	2.28%
2												
3												
4												
5			10.00%	0.07%	10.00%	0.07%	10.00%	0.07%	10.00%	0.07%	10.00%	0.07%
6												
7												
8												
9												
10												
11												
12			10.00%	0.13%	90.00%	1.19%	90.00%	1.19%	90.00%	1.19%	90.00%	1.19%
13			10.00%	0.26%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%
14												
15												
16												
17			10.00%	0.05%	50.00%	0.26%	50.00%	0.26%	50.00%	0.26%	50.00%	0.26%
18												
19												
20												
21												
22												
23			10.00%	0.11%	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%
24			20.00%	0.27%	80.00%	1.07%	80.00%	1.07%	80.00%	1.07%	80.00%	1.07%
25												
26												
27												

Line Item No.	Delta		Zenit		TAV		DC		NASP		TSTO	
	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
28			10.00%	0.06%	90.00%	0.52%	90.00%	0.52%	90.00%	0.52%	90.00%	0.52%
29												
30												
31					90.00%	0.82%	90.00%	0.82%	90.00%	0.82%	90.00%	0.82%
32												
33												
34					90.00%	0.85%	90.00%	0.85%	90.00%	0.85%	90.00%	0.85%
35					50.00%	0.42%	50.00%	0.42%	50.00%	0.42%	50.00%	0.42%
36			10.00%	0.03%	90.00%	0.30%	90.00%	0.30%	90.00%	0.30%	90.00%	0.30%
37												
38												
39					90.00%	0.78%	90.00%	0.78%	90.00%	0.78%	90.00%	0.78%
40												
41												
42					90.00%	1.23%	90.00%	1.23%	90.00%	1.23%	90.00%	1.23%
43					90.00%	0.63%	90.00%	0.63%	90.00%	0.63%	90.00%	0.63%
44												
45												
46					90.00%	0.82%	90.00%	0.82%	90.00%	0.82%	90.00%	0.82%
47												
48												
49					90.00%	1.15%	90.00%	1.15%	90.00%	1.15%	90.00%	1.15%

Line Item No.	Delta		Zenit		TAV		DC		NASP		TSTO	
	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
50 51					90.00%	0.44%	90.00%	0.44%	90.00%	0.44%	90.00%	0.44%
52 53			10.00% 10.00%	0.12% 0.12%	50.00% 50.00%	0.61% 0.61%	50.00% 50.00%	0.61% 0.61%	50.00% 50.00%	0.61% 0.61%	50.00% 50.00%	0.61% 0.61%
54 55 56												
57 58 59 60												
61 62 63 64					50.00%	0.66%	50.00%	0.66%	50.00%	0.66%	50.00%	0.66%
65												
66 67 68					90.00% 50.00%	0.53% 0.22%	90.00% 50.00%	0.53% 0.22%	90.00% 90.00%	0.53% 0.40%	90.00% 50.00%	0.53% 0.22%
69 70			10.00%	0.26%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%

Line Item No.	**Delta** Line Item Score	Weighted Line Score	**Zenit** Line Item Score	Weighted Line Score	**TAV** Line Item Score	Weighted Line Score	**DC** Line Item Score	Weighted Line Score	**NASP** Line Item Score	Weighted Line Score	**TSTO** Line Item Score	Weighted Line Score
	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
71			50.00%	0.85%	90.00%	1.53%	70.00%	1.19%	60.00%	1.02%	90.00%	1.53%
72	70.00%	1.19%	90.00%	1.53%	60.00%	1.02%	60.00%	1.02%	20.00%	0.34%	60.00%	1.02%
73			50.00%	0.23%	90.00%	0.41%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%
74			10.00%	0.05%	50.00%	0.23%	40.00%	0.18%	60.00%	0.27%	50.00%	0.23%
75			10.00%	0.05%	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%
76	10.00%	0.05%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%
77					90.00%	0.41%	10.00%	0.05%	90.00%	0.41%	90.00%	0.41%
78			30.00%	0.14%	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%
79	90.00%	1.84%	50.00%	1.02%	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%
80					100.00%	0.41%	50.00%	0.20%	100.00%	0.41%	100.00%	0.41%
81					70.00%	0.29%			10.00%	0.04%		
82			90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
83					100.00%	0.41%	90.00%	0.37%	90.00%	0.37%	100.00%	0.41%
84					90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
85	80.00%	1.09%	80.00%	1.09%	80.00%	1.09%	90.00%	1.23%	80.00%	1.09%	80.00%	1.09%
86					50.00%	0.68%	50.00%	0.68%	50.00%	0.68%	50.00%	0.68%
87												
88												
89												
90												
91					50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
92			50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
93	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
94												
95			50.00%	0.10%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
96			50.00%	0.10%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
97			30.00%	0.06%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
98												
99			90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%
100			50.00%	0.40%	90.00%	0.71%	90.00%	0.71%	10.00%	0.08%	90.00%	0.71%
101			50.00%	0.40%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%

Appendix 10: Scoring Data for Combined Spacelift Systems

	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
Line Item No.	System Score:	0.34106	System Score:	0.36761	System Score:	0.37653
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
1	80.00%	2.28%	90.00%	2.56%	90.00%	2.56%
2						
3						
4						
5	10.00%	0.07%	20.00%	0.15%	20.00%	0.15%
6						
7						
8						
9						
10						
11						
12	90.00%	1.19%	95.00%	1.26%	95.00%	1.26%
13	90.00%	2.38%	95.00%	2.51%	95.00%	2.51%
14						
15						
16						
17	50.00%	0.26%	70.00%	0.36%	70.00%	0.36%
18						
19						
20						
21						
22						
23	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%
24	80.00%	1.07%	95.00%	1.27%	95.00%	1.27%
25						
26						
27						

Line Item No.	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
28	90.00%	0.52%	95.00%	0.55%	95.00%	0.55%
29						
30						
31	90.00%	0.82%	95.00%	0.86%	95.00%	0.86%
32						
33						
34	90.00%	0.85%	95.00%	0.89%	95.00%	0.89%
35	50.00%	0.42%	50.00%	0.42%	50.00%	0.42%
36	90.00%	0.30%	95.00%	0.32%	95.00%	0.32%
37						
38						
39	90.00%	0.78%	95.00%	0.82%	95.00%	0.82%
40						
41						
42	90.00%	1.23%	95.00%	1.30%	95.00%	1.30%
43	90.00%	0.63%	90.00%	0.63%	90.00%	0.63%
44						
45						
46	90.00%	0.82%	95.00%	0.86%	95.00%	0.86%
47						
48						
49	90.00%	1.15%	95.00%	1.21%	95.00%	1.21%

Line Item No.	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
50	90.00%	0.44%	95.00%	0.46%	95.00%	0.46%
51						
52	50.00%	0.61%	70.00%	0.86%	70.00%	0.86%
53	50.00%	0.61%	70.00%	0.86%	70.00%	0.86%
54						
55						
56						
57						
58						
59						
60						
61	50.00%	0.66%	60.00%	0.79%	60.00%	0.79%
62						
63						
64						
65						
66	90.00%	0.53%	95.00%	0.56%	95.00%	0.56%
67	50.00%	0.22%	60.00%	0.26%	60.00%	0.26%
68						
69	90.00%	2.38%	95.00%	2.51%	95.00%	2.51%
70						

Line Item No.	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
71	90.00%	1.53%	95.00%	1.62%	95.00%	1.62%
72	60.00%	1.02%	60.00%	1.02%	60.00%	1.02%
73	90.00%	0.41%	95.00%	0.43%	95.00%	0.43%
74	50.00%	0.23%	60.00%	0.27%	60.00%	0.27%
75	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%
76	70.00%	0.32%	90.00%	0.41%	90.00%	0.41%
77	90.00%	0.41%	90.00%	0.41%	90.00%	0.41%
78	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%
79	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%
80	100.00%	0.41%	100.00%	0.41%	100.00%	0.41%
81	70.00%	0.29%	70.00%	0.29%	70.00%	0.29%
82	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
83	100.00%	0.41%	100.00%	0.41%	100.00%	0.41%
84	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
85	80.00%	1.09%	80.00%	1.09%	80.00%	1.09%
86	50.00%	0.68%	50.00%	0.68%	50.00%	0.68%
87			50.00%	0.34%	50.00%	0.34%
88						
89					50.00%	0.73%
90						
91	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
92	50.00%	0.10%	50.00%	0.10%	90.00%	0.18%
93	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
94						
95	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
96	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
97	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
98						
99	90.00%	0.71%	90.00%	0.71%	95.00%	0.75%
100	90.00%	0.71%	90.00%	0.71%	95.00%	0.75%
101	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%