Overcoming the S&T Assessment Uncertainty Principle

An Approach to Enterprise-Wide Assessment of the DOD S&T Program

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Executive Summary

The science and technology (S&T) program supported by the Department of Defense (DOD) is a large undertaking (~$11B in 2004) aimed at ensuring continued technological superiority of the U.S. military. Exercising stewardship over this program is of great importance. In this regard the program is subjected to numerous reviews dealing with its relevance, viability and productivity. At various levels of detail, every element of the program is reviewed. However, the sum of all the reviews does not constitute an assessment of the entire DOD S&T enterprise. This study examines why this is the case and examines the prospects for rectifying this situation.

An effective enterprise-wide assessment (EWA) would contribute to the ability of the Director of Defense Research and Engineering (DDR&E) to provide oversight to enhance the content of the S&T portfolio through metrics of program quality, performance, and relevance. It would increase collaboration between projects with aligned objectives and provide a knowledge base of the S&T program sufficient to justify the investment to the services and Congress. An effective EWA would also support the services in that it would focus their internal topical reviews to problem areas identified in the EWA. It would also provide them a broader insight into the entire S&T program and their place within it. This would result in greater program coordination and reliance on other service programs. Also, an EWA could form the basis of an interrelated community of experts across the entire S&T spectrum.

Principal Findings

- Many different and valuable reviews of the DOD S&T program are conducted. However, there is no obvious way (short of drastically increasing the resources available to the review process) to modify the current review structure so as to produce a coherent EWA. The underlying problem is the sheer magnitude and breadth of the program. This results in an inability to assess it in scientific and technical detail and to simultaneously examine the entire program. We refer to this conundrum as the S&T assessment uncertainty principle. A new methodology must be developed to overcome this uncertainty principle if an EWA is to be institutionalized.

- The current documentation of the DOD S&T program does not reflect the state of the art of information technology, is marginal for exercising stewardship over the program, and is inadequate for the conduct of an EWA.

- DOD does not access systematically the breadth of scientific and technical knowledge and expertise that is potentially available to it. The establishment of and ready access to communities of experts that cover all DOD areas of scientific and technical interest would be of great value in itself and will be required for an EWA.

- The current state of the art and expected advancements in information technology and library science offer the best hope of resolving the above concerns.

- An EWA will be viable only if it adds value to the parties involved and emerges as a byproduct of the normal process of doing business.

Principal Recommendations

- The principal investigators of the various DOD S&T projects/work units should be taught and required to document their projects/work units in terms of the very specific CEST issues that they are funded to resolve. These issues should be stated at the level at which people are actually performing work rather than in terms of general objectives.

- S&T project documentation requirements should be standardized across DOD and should contain the information needed for an EWA. Funding for a project/work unit should not be released until the organization responsible for the project/work unit submits satisfactory documentation to the Defense Technical Information Center (DTIC). The DTIC database that results from proper documentation of the program will be broadly valuable across DOD (DDR&E, funding agencies, performers, etc.) independent of the EWA. The needed information is available at the performer level and can and should be documented routinely. This documentation is required as a matter of stewardship and will be needed for an EWA. An essential element of the documentation is a succinct statement of the critical enabling S&T (CEST) issues being addressed by the funded program so that an expert in the specific topical area being pursued can quickly assess the viability of the project/work unit meeting stated plans and milestones.

- National communities of experts should be established for each of the specific CEST issues being addressed. The tools of information technology and library science must be utilized to accomplish this. Some DOD research investment may be required to resolve DOD specific issues in this regard. The establishment of the communities of experts will be of great value in itself and will be required for an EWA.

- For an EWA, the approach of collecting the review teams at a central location for the purpose of holding hearings must be abandoned and replaced by a distributed assessment process that exploits the documentation of all of the CEST issues, advances in information technology and library science, and the readily available access to geographically distributed communities of experts. The EWA should be conducted as a targeted survey of the appropriate communities of experts.

- A full EWA as envisioned by this study should not be initiated in the short term. Many details need to be addressed before such an assessment could be undertaken. Certain aspects of the proposed process should be examined via the conventional review process. For example, automated techniques for forming communities of experts could be tested by employing them as part of establishing the conventional review teams. Test cases should be conducted to clarify how to document the program in terms of CEST and to examine and resolve problems that confront the distributed assessment approach. These test cases should address classified distributed assessments (e.g., utilizing SIPRnet) and unclassified distributed assessments. DOD should be an active participant in the national efforts that are underway to take advantage of the ongoing revolution in library science (e.g., text retrieval).

If the processes described in this study could be implemented they would have a number of spin-offs. For example, the supporting DTIC database could be interrogated so as to compare the actual program of record with the DOD S&T investment strategy. It would also establish a broad database of experts covering most of the S&T areas of interest to DOD. It may be that the most valuable result of this approach to an EWA would be the establishment and maintenance of a detailed database for the funded S&T program and the development of a large community of experts who have a connection with and interest in DOD S&T. It is also worth noting that while the proposed methodology is directed at assessing the funded program of record it could, if successfully implemented, provide significant feedback to the important matter of program formulation.

1. Introduction

The U.S. Department of Defense (DOD) sponsors one of the world's largest science and technology (S&T) programs. In FY 2004 the DOD S&T appropriation was about $11 billion. This sum, while less than three percent of the DOD budget, is larger than the entire defense budgets of all but eleven of the world's countries and all but four of the NATO nations. This large investment has allowed the United States to maintain its technological advantage over potential adversaries. It has undoubtedly saved the lives of tens of thousands of U.S. men and women in uniform as well as prevented countless civilian casualties. Because of its impact, the matter of exercising stewardship over this large investment is of great importance. Stewardship in this context has many dimensions. These include, among others: program formulation; the appropriation of the needed funds; oversight of expenditures; and the review and assessment of the viability and productivity of the funded program. While all of these dimensions are important and interdependent, this paper focuses on the latter dimension—namely the review and assessment of the viability and productivity of the funded program.

The very size of the program confronts this aspect of stewardship with a conundrum. This conundrum can be illustrated by examining the scale of the effort that would be required to assess the program in detail by conventional means at the level where the work is actually done. For S&T work, scientific and technical teams typically function in groups of three to five people. This corresponds to an average investment "unit" of about $1 million. An $11 billion S&T program will consist roughly of 1,100 such units. This overestimates the number of units because of funds that are expended on hardware purchases. However, the correction for such purchases will not substantially change the conclusions regarding conducting a complete detailed review of the program. A proper scientific and technical review involves examining the program at about the $1 million level. A conventional review process would convene a team of 5–10 experts to examine the program in detail. For each unit the review team would require perhaps one day of preparation, one day of hearings and interaction with the performers, and one day of travel. A single review team may review several related units, however, a proper expert review will add one day for each additional unit. Therefore, 1,100 S&T units would require 16,000 to 32,000 reviewer work days and the participation of several thousand reviewers. Compensation for the review team's workdays would cost between $20 million and $40 million. The travel and per diem costs would be in the $3 million to $6 million range. An estimate of the reviewer cost for the complete review of the program is therefore, in the $25–50 million or range.

The other major cost lies in the preparation for the reviews. The scientists and engineers to be reviewed will begin preparation several months prior to the review. The experience of the authors suggests that each member of the S&T unit will spend 5–10 days of preparation for each day of review. Therefore, the low estimate of the number of workdays that would be spent in preparation for a complete review of the S&T program is about 80,000 workdays. This corresponds to a total preparation cost of about $100 million. Therefore, the total cost for a complete conventional review would be in the range of $125 million to $150 million. In relative terms this is only one percent of the DOD S&T program. In absolute terms however, it is a considerable amount of money to spend on a review process. In addition to the financial costs one must also consider the impact on the program itself of such a massive review. There is also the matter of finding several thousand expert reviewers who are in a position to devote so much time to such reviews. Furthermore, there is the non trivial matter of managing the logistical aspects of such a review.

The practical consequence of the above is that the DOD has been forced to make tradeoffs regarding the types of reviews and the program coverage of reviews. A tradeoff can be envisioned through the simple empirical mathematical relationship:

$$\Delta T \, \Delta P > C \, . \qquad (1.1)$$

Here C is a constant related to the resources (funds, manpower, time, complexity, etc.) that one is willing to apply to the review process, ΔT represents the uncertainty that an assessment strives to achieve in its understanding of scientific and technical details, and ΔP represents the corresponding uncertainty that will result in the assessment's ability to understand the total program. We will refer to this inequality as the assessment uncertainty principle (in analogy to the uncertainty principle of quantum mechanics). The assessment uncertainty principle says that, for a given value of C (i.e. allocation of resources to the review process) an assessment must trade off the detail at which the S&T program is examined against the amount of the program to be assessed. A very detailed examination of the S&T (small ΔT) will generally result in a large uncertainty in the total program coverage (i.e. large ΔP). One can, of course, simultaneously achieve, in principle, any desired value of ΔP and ΔT by investing sufficient resources to make C small enough. This is because the assessment uncertainty principle is not a physical law but results from limitations of resources (people, time, funds) available for conducting assessments. Such an undertaking, however, requires a very substantial investment of resources (funding and otherwise) that the DOD has not been willing to make.

The practical consequence of the assessment uncertainty principle has been that the DOD conducts detailed scientific and technical assessments on small portions of the S&T program and conducts management oriented assessments of the full program (or large portions thereof). Both types of assessment are quite valuable and are done routinely and professionally by DOD. This situation does, however, lead to concerns regarding what is actually being done at the S&T level in this large and extraordinarily important program. This concern is felt especially keenly at the highest levels of DOD where stewardship for the entire program resides. In an attempt to redress this situation Dr. John Hopps, then Deputy DDR&E and DUSD (Labs), requested that the authors attempt to construct a methodology that would permit an enterprise-wide assessment (EWA) of the entire DOD S&T program. Of special interest was the alignment of the DOD laboratory system in terms of its people, programs and facilities against the transformational goals of OSD, the Services and the Agencies. It was agreed that a valid assessment of this alignment could only be done within the context of the overall DOD R&E enterprise. The term *enterprise-wide assessment* was, therefore, taken to include all performers (i.e. industry, DOD labs, universities, etc.). It is important to understand that a key objective of the study was to propose a methodology that provided coverage of the entire S&T program and not just selected pieces of the program. This has a profound impact on the options that are available. For example, techniques have been developed to assess the overall quality of the program by using statistical sampling methods for selecting the programs to be reviewed or for evaluating the impact of particular programs (e.g. see R.N. Kostoff, "An Assessment of the Basic Energy Sciences

Program," DOE/ER – 0123, March 1982; R.N. Kostoff "The Handbook of Research Impact Assessment" DTIC Technical Report ADA 296021, 1997). Such approaches are very valuable as indicators of overall quality. However, they do not satisfy the entire enterprise requirement of this study, nor do they provide an adequate forcing function regarding the documentation of the entire program.

The early phases of the study brought to mind Edison's famous comment when asked if he ever became discouraged working so long without results: "Results? Why I know 50,000 things that won't work". In this study, as with most others, it was found that things are the way they are for a reason. The first major finding of the study was that the database needed to undertake such an assessment did not exist. It had been hoped that the DD1498 documentation would provide a rudimentary database for some preliminary work and form a base from which to evolve the required documentation. However, the maintenance of that database was found to be no longer required. That was unfortunate, because that database was the only one that provided any detailed scientific and technical information on the entire program. It was quickly realized that an entirely new database would be required to support an EWA. This led to inquiries into whether the data formats for the conventional review processes and the methodology used by those processes could form the basis for an EWA. It ultimately became clear that the conventional review processes could not be morphed into a tool for an EWA. The S&T assessment uncertainty principle simply would not allow it. Fortunately, unlike the uncertainty principle of quantum mechanics, the S&T assessment uncertainty principle is not a law of nature. It is an empirical relationship that is determined by the assessment process itself and the tools that are employed to support that process. The study examined what it was about the conventional assessment methodology that resulted in inequality (1.1). It became clear that the ponderous, manpower-intensive character of the conventional review process and the current methods of program articulation and documentation were among the major driving factors that impose the inequality and determine the constant C.

After considerable deliberation regarding alternate approaches, the study came to the conclusion that the most promising approach to an EWA involves assessing the entire program at a fine level of scientific and technical detail. This contradicts the assessment uncertainty principle (unless one is willing to drastically increase the resources available for the review process) and is completely orthogonal to the conventional review processes. This somewhat surprising conclusion has its basis in the reality of how one actually decides whether or not a particular scientific and technical approach to address a particular problem has merit. In the early phases of decision one does not convene a massive review. Rather, one identifies one or perhaps several individuals who have detailed knowledge and specific expertise in the scientific and technical areas being proposed. A brief conversation (by phone or meeting) is held during which the expert is given a brief description of the proposed approach and asked to provide an "on the spot" opinion regarding the viability of the proposed approach. If the individual is truly expert and if the problem/approach is carefully and succinctly stated then the "on the spot" opinion is often remarkably accurate. The secret of success here is to find the right individuals who truly understand the specific S&T involved and to pose the question to them properly and succinctly.

The study ultimately focused on how the above approach might be extended/institutionalized for the purpose of an EWA. The remainder of this paper offers some observations and conclusions in this regard. The keys to success for an EWA will be found in the proper documentation of the program, the careful and succinct identification of the CEST issues that the projects are funded to resolve, the ability to rapidly establish "communities of experts" in these CEST areas, the use of a distributed assessment process employing survey techniques, and the employment of advanced information S&T (most especially advances in library science). Advances in library science are now occurring at a remarkable pace and will change forever how S&T knowledge is accessed and how S&T programs are assessed. It is significant that each of these “keys to success” would be valuable to the DOD S&T program independent of an EWA. It is also worth noting that, while the proposed methodology is directed at assessing the funded program of record it could, if successfully implemented, have significant feedback on the important matter of program formulation.

2. Relationship of Current DOD S&T Documentation to Proposed Assessment

Proper documentation of the DOD S&T program plays an essential role in the assessment methodology proposed in this paper. This section briefly examines current documentation from the perspective of what this study recommends regarding documentation. An essential element of the on-line assessment approach developed in this report is a searchable database that defines the critical descriptive elements and metrics needed for an assessment. Chief among these are the objectives of critical enabling S&T (CEST). Furthermore, these CESTs must be developed at the work unit level for a rapid and accurate assessment by an expert reviewer. In terms of existing S&T databases, the authors of this report have assumed that, in order to properly manage the S&T program, the data needed for an assessment already exists, at least at the performer level. The authors have also concluded that there has been no central, detailed, DOD S&T database at the work unit level since the requirement for submission of the DD 1498 data form was eliminated a few years ago. Therefore, the data at the work unit level exists at the performer level but is not formally provided to DDR&E.

In response to the E-Government (E-Gov) Act of 2002, DDR&E in May 2005 launched an R&E Portal maintained by DTIC. Presently the portal will include links to the existing databases that DDR&E maintains, plus the following.

- New E-Gov database of current R&E project summaries
- Research and Development Descriptive Summaries (RDDS)
- Budget Estimate Submission (BES)
- Joint Warfare S&T Plans
- Defense Technology Objectives (DTO)
- Basic Research Plan (BRP)
- Defense Technology Area Plan (DTAP)

The portal will also include data on the S&T workforce and links to other DOD news and data.

The New E-Gov database of current project summaries could be an appropriate vehicle to establish the database required for this study. At the present time, the data requested for this section of the report is designed to facilitate sharing of general information on the program in order to establish contacts between interested parties. The data required to assess the programs, especially the CESTs, are not called for. If DDR&E wishes to implement the assessment approach developed in this report, the data call requirements for the S&T submissions to DTIC for the R&E Portal could be modified to include the required level of project description needed to perform an assessment. The information required to implement the proposed assessment methodology is displayed in Appendix A as a sample Work Unit Summary form. If DDR&E alternatively wishes to use the proposed assessment process for selected topical reviews rather than a global assessment, individual data forms can be required.

A brief description of the other databases linked to the E-Portal follows. The RDDS and BES are both budget submit documents used for the appropriation of funding by Congress. Work descriptions are brief and at a high level. CESTs are not discussed at this level of description. The Joint Warfare S&T Plans focus is on S&T vision, strategy and planning with limited technology description. The DTOs and the BRP comprise the most extensive current database of S&T. However, DTOs only address 40 percent of the program and are more focused toward objectives and milestones than to CESTs. The DTAP presents DOD objectives and investment strategy for ten technology areas critical to DOD acquisition looking across Service and Agency efforts. As with the other documents it is not written at the work unit level.

There are a few other databases and program descriptions that are maintained by DOD or the Services. For example, the DOD maintains a Militarily Critical Technologies List (MCTL) as part of the Militarily Critical Technologies Program (MCTP). While the scope of this program is to determine existing technologies of use to potential adversaries there are features of this program of interest to this report. In particular the MCTP maintains a roster of about 1,000 subject matter experts from the military Services, DOD, other federal agencies, industry, and academia. These subject matter experts are analogous to the community of experts proposed to assess the DOD S&T enterprise. The MCTP however does not use search engine technology to find experts and the scope of the MCTL is only a subset of the DOD S&T enterprise. Another feature of the MCTL is the generation of data sheets that require Critical Technology Parameters that are defined at the same level as this report recommends. Due to the nature of the MCTL however, these Critical Technology Parameters represent existing technology and are not future project objectives as defined in this study.

Each of the Services documents its own programs. There is no common format and this information is not generally distributed. The Army produces a fairly comprehensive two volume report on its S&T program entitled *Army Science & Technology Master Plan.* While this plan is comprehensive, it only gives project descriptions for the Army Technology Objectives (ATOs were adopted by DDR&E as DTOs). As with DTOs, the AROs only represent part of the Army program and do not provide the CESTs necessary for the proposed assessment methodology.

NASA has generated a promising database that has provided a rough template for this study. A brief description of the NASA Technology Inventory will be found at Appendix C.

A key element for an EWA is a searchable database of the entire program that is generated at the performer level. A comprehensive, searchable database that documents the DOD S&T program at the performer level should exist independent of the desire for an EWA. Technology allows for the creation of such a database; routine documentation of the program at the performer level permits it and stewardship for the program requires it.

This study concludes that a comprehensive programmatic database, similar to the form DD1498, be established as a requirement for work units in DOD and be maintained by DTIC. Aside from the necessity of a comprehensive database to perform a meaningful EWA, better program documentation will provide other benefits such as more effective development of cohesive major S&T initiatives such as development of hypersonic flight vehicles.

The authors contend that the information to generate an assessable database exists at the performer level, and the electronic means to collect and distribute the information needed for an assessment exists at DTIC through the E-Portal for S&T. However, the requirement to provide DDR&E with this level of work unit detail does not exist. Such a requirement is a necessary component of an EWA.

3. Established Review Processes

Background

The purpose of this section is to briefly describe the current methods that the services, DDR&E, and Congress employ to assess the S&T program. As will be shown, there are several review processes in place in the services, DDR&E, and congressional staff. It is probably fair to say that at some level of detail every element of the S&T program funded by DOD is subjected to some type of review. However, there is no uniformity across or even within services as to the level of granularity and the composition of a review body. The purposes of these individual reviews vary according to the needs and management structure of the reviewing organizations. Also there is no uniformity in the documentation of reviews, and what documentation there is is often not generally distributed to the broad S&T community. Therefore, the sum of all current reviews and documentation does not represent an enterprise wide assessment (EWA).

An effective EWA would contribute to DDR&E's ability to provide oversight to enhance the content of the S&T portfolio through metrics of program quality, performance and relevance. It would increase collaboration between projects with aligned objectives and provide a knowledge base of the S&T program sufficient to justify the investment to the services and Congress. An effective EWA would also support the services in that it would focus their internal topical reviews to problem areas identified in the EWA. It would also provide a broader insight into the entire S&T program and the place of the services within it. This would result in greater program coordination and reliance on other service programs. Also, an EWA could form the basis of an interrelated community of experts across the entire S&T spectrum.

The starting point for an EWA is a review of the current review processes and an assessment of strengths and shortcomings. In support of this objective, a framework is presented that characterizes current assessments and reviews of the S&T program by the purpose of the review; the level of detail or granularity of the subject matter; and the composition of the reviewing body. In a broad sense, program reviews can be divided into two categories: planning reviews, where the objective is to assess a program prior to initiation to determine if the work is worth funding (is this the right job?), and technical reviews, where the objective is to determine the quality and progress of the work (is the job being done right?). A further objective is to determine if the work is legitimately S&T or should be a higher category of funding. The program assessment methodology proposed in this study is focused on the technical reviews and assumes that the objectives of the program are in line with the needs of the military users. A third type of review that evaluates completed work done in the past provides hindsight lessons learned and program accomplishments. This type of review is not germane to this report.

The following sections will include a broad description of the established review processes, followed by the details of current reviews by the services, DDR&E, and congressional staff. This will be followed by commentary on strengths and shortcomings and, finally, by conclusions.

Types of Reviews and Purpose

Table 3.1 portrays the current types of reviews in effect for the DOD S&T program. The three columns are in decreasing order of granularity and increasing order of comprehensiveness. The first column, Technical Subject, examines a project at the level where the work is actually done. The responsible briefer to a review panel is generally the principal investigator. Because of the many thousands of S&T projects at this level of granularity, the entire program cannot be reviewed at this level using conventional review procedures. At best, 20 percent of the S&T program is currently evaluated at this level. Increasing this fraction significantly would place unacceptable demands in terms of time and money on performers and reviewers. In addition, there are difficulties in assembling a review board with enough members that there is sufficient member expertise as well as a balance of strong opinions predicated on the members' work or bias in the subject being reviewed. Therefore, the current Technical Subject Reviews, while sufficient in detail, lack the comprehensiveness for an EWA and are difficult and time consuming to conduct. This fact leads to consideration of a new type of review process, as discussed subsequently in this report, that aims to provide both the detail and comprehensiveness that lead to an EWA.

Table 3.1 Types of Conventional Reviews and Purpose

Types of Reviews

Conducted by

	Technical Subject	Subject Area Overview	Investment Oversight/ Audit
Service Internal Management (peer level technical experts & management)	Technical quality Technical progress	Resource balance between projects	Program execution, obligation, and expenditure
Technology User Community (customers of technology e.g. Syscoms & operational forces)	Response to requirements and emerging transition opportunities		
Department of Defense (DDR&E)	Ad hoc issue resolution	Program oversight (TARA)	Program execution, obligation, and expenditure
Congress (Congressional Armed Services staff)	Ad hoc, special interest, topical	Program element funding level adjustment	Program element funding level adjustment

Despite the difficulties inherent in conducting an EWA at the scientific and technical subject, project, or work unit level (the terms are used interchangeably here), this is the appropriate level at which to evaluate the program. In S&T, the devil is in the details. The work unit is where the work actually gets done. At this level, an expert in the technical discipline under review can readily assess the technical merit of the approach and the feasibility of meeting time and cost metrics, evaluate whether the work is S&T in character, and evaluate the competence of the performers. Reviews held at higher levels of aggregation serve other purposes, such as ensuring program balance and response to requirements. Reviewers of programs at higher levels of aggregation are also often reviewing projects in which they are not experts. This leads to longer discussion and, therefore, more time needed to reach decisions. Only the subject level review gets at the actual details of the work with specialist reviewers, who can usually quickly and accurately determine the value of the work. Even at this level, the small number of specialists can result in parochial interests influencing the review.

The next column, Subject Area Overviews, represents the collection of S&T projects that lie in a common discipline. For example, the DDR&E taxonomy of Platforms, Weapons, Space, Information Technology, Materials, Human Systems, Environments, and Sensors/EW forms a fairly comprehensive technology review format, although even at this level DDR&E does not conduct a comprehensive review. Another example of a Subject Area Overview is a review of a focused initiative (e.g., the National Aerospace Initiative), that incorporates many diverse technologies. At this level of granularity, much of the S&T program can be reviewed, although usually not in a given year. The DDR&E Technology Review and Assessment (TARA) process has reviewed the program at the Subject Area level on a rolling schedule of half the program every year (this process is under review and is subject to change). These reviews are a tradeoff between comprehensiveness and level of detail and represent DDR&E's current review management tool. However, for an EWA, the TARA process fails to provide both enough detail and enough comprehensiveness.

The final column, Investment Oversight/Audit, has the least technical content, is the most comprehensive, and is budgetary in nature. These reviews mostly deal with program execution, funding obligation rates, and expenditures. As such, they do not address the level of program detail necessary for an EWA.

The four rows represent an ascending managerial level of program oversight. Program development and execution responsibility is primarily at the service level, so the most detailed and comprehensive reviews are conducted at this level. The services review the program at many levels of granularity including technical subject reviews focused on the quality of the work, the relevance of the work to service needs, the progress of the work in terms of cost and milestones, and evaluate whether the work is really S&T or in fact a higher category of funding. Technical experts and stakeholders in the program generally conduct these reviews. As mentioned earlier, there is no consistency in these reviews across services and even within services. The conduct of these reviews is generally given to the first or second level of service program management. Due to the overall size of even the individual service programs, senior service S&T managers are usually involved only in selected topical reviews and in issue resolution at the technical subject level. Senior service S&T oversight is more generally focused at the Subject Area level with the objective of decisionmaking across S&T priorities. The technology user communities, the customers of technology, are usually more involved in program formulation and approval than in technical quality and execution reviews. The user community's primary concern is that technology is addressing service requirements. In addition, however, users are involved in program reviews of technologies near completion and transition to engineering development. These are generally 6.3 advanced development reviews.

The preceding discussion of the customers and audience for current reviews raises the associated issue that, while there is currently no EWA, there is also no current service requirement or ownership for this product. To be useful, an EWA would need to strengthen the service programs but not significantly increase time and money spent on reviews. In this regard, the EWA proposed here might actually reduce the number of conventional topical reviews by highlighting only the potential problem areas for topical reviews.

Conventional Review Process

While table 3.1 portrays a matrix of types of reviews and purposes of reviews as well as differences in the details of individual review processes, there are common elements that conventional reviews share. First, an external review needs to be distinguished from routine supervisory management. The principal distinguishing factor of the external review is the review board composed of individuals outside the project being reviewed and selected from the community of experts in the discipline to be reviewed. The purpose of the review board is to strive for impartial judgment as well as an external perspective. For program credibility and program defense, an external review is essential. For a completely independent review, the review can be "contracted out" to an organization such as the National Research Council (NRC). Each of the services maintains study boards (e.g., the Army Study Board) that generally do studies and analyses but also provide program review boards. Predominately, however, the services develop their own stable of external reviewers. These reviewers are often technical experts with previous professional experience within the services programs. Retired military officers are also often solicited for their background in service requirements.

The selection of the actual reviewers is critical to any review process and is a core issue of the EWA process analyzed in this report in which potential reviewers are identified by a computer search based on CEST objectives associated with the project to be reviewed. Individuals with technical competence developed through work in any field will have biases shaped by their experience and affiliations. To compensate for this, a sufficient pool of reviewers is required to balance out bias and provide a level of statistical sampling. Many current reviews suffer from choosing reviewers too close to the program that do not subject the program to difficult questions.

External reviews tend to be very time consuming, hence the difficulty of performing an enterprise assessment. For an important review, one that can influence the direction and the funding of the project being reviewed, significantly more time is spent in preparation of briefing material, analysis, and documentation of results than in the review itself. Frequently, reviews require presentations in a prescribed format, resulting in the creation of dedicated briefing materials. The presenters often give dry runs of their presentations to their management and may redo their presentations as a result. Reviewers are often given read-ahead material to prepare them for the briefings. Scoring sheets are usually developed to correlate reviewer comments. Following a review, the review board customarily provides preliminary feedback followed by a report.

The DOD S&T enterprise now exceeds $11B a year. If a representative project or work unit were about $1M a year (three or four investigators, plus project expenses) 11,000 projects would require reviews. DOD has not considered it a priority to perform 11,000 reviews at the project level and, therefore, from a corporate viewpoint, only looks at a fraction of its projects (about 20 percent) at a detailed level each year. The enterprise is only viewed in its entirety in very large chucks at the program element level. An EWA at the detailed project level will require a process different from the conventional external review.

Service and DDR&E Reviews

Each of the services manages its S&T programs differently, particularly the 6.2 Applied Research program and the 6.3 Advanced Development program, but each service has a research office. The Army Research Office (a subordinate organization of the Army Research Lab), is under the authority of the Deputy Assistant Secretary for Research and Technology who reports to the Army Acquisition Executive. The director of the Air Force Office of Science Research reports to the Air Force Research Laboratory Commander. The Chief of Naval Research reports to the Assistant Secretary of the Navy for Research, Development and Acquisition. The Navy has had a tradition of funding a larger 6.1 account than the other services, and it manages all of its S&T, 6.1-6.3, under the Chief of Naval Research, Office of Naval Research. The Marine Corps S&T program, a small component of Naval Research (~ $30M / year), is also managed at the Office of Naval Research to provide synergy with related Navy S&T. The Air Force S&T program is executed by the Air Force Research Laboratory. The Army does not centrally manage S&T programs under a single organization. The Army has four Major Commands and one Field Operating Agency of Headquarters DA that own all of the laboratories. The predominant funding for Army S&T is managed by Army Materiel Command's Research Development and Engineering Command, approximately 80 percent of the $1.7B annual Army S&T budget. Of the three services, the Air Force has given the highest priority to science and engineering education to its military officers hence the management and execution of the Air Force programs utilizes a higher proportion of service men and women than the other services (with the Navy having the highest proportion of civilians). With different management structures and personnel among the services it is to be expected that different assessment processes are in place together with different documentation procedures.

Army Review Process. Most Army 6.2 and 6.3 programs are managed as Army Technology Objectives (ATOs) (DDR&E has adopted the Army framework of ATOs as DTOs for its own TARA reviews). These ATOs are 3–5 years in length and have defined milestones and deliverables. The Army reviews these programs annually at the Army S&T Executive level in a largely internal review process. The remainder of the Army S&T program is managed at the Army Research and Development Center and Laboratory level, generally employing a peer review process. The Army documents its program in the Army S&T Master Plan, which is published biennially.

Air Force Review Process. The Air Force has the most comprehensive review process for its S&T programs. The Air Force Science Advisory Board reviews the program assessing five of the ten Directorates each year. The reviews are intensive, generally a week long, and the review of the five Directorates takes about two months every year. The Basic Research program is reviewed by the Science Advisory Board within this process when it reviews the AFOSR which is a directorate in AFRL.

Navy and Marine Corps Review Process. The Navy differs significantly from the Army and Air Force both in management structure of S&T and consequently in reviews. Also, in recent years, the introduction of the Future Naval Capabilities (FNC) initiatives has changed both management and review processes for the Navy and Marine Corps. S&T is centrally managed at the Office of Naval Research for the Navy and Marine Corps. The 6.1 and part of the 6.2 program are managed by six S&T departments, each employing peer review processes differing in detail and documentation. The FNC's comprise the 6.3 program and the remainder of the 6.2 program and are matrix managed in ONR. The FNC's are strongly influenced by the user community who are active in its review process. The NRL has its own peer review process for its corporate S&T programs.

DDR&E Review Process. The Technology Area Review and Assessment (TARA) process is currently DDR&E's principal review process. TARA review panels are selected by DDR&E from a community of experts selected by the DDR&E staff responsible for a particular area review. Because of the broad nature of these reviews the board tends to be selected from technology generalists familiar with the DOD S&T program together with some specialists. While these area reviews are a week in length they only look in detail at Defense Technology Objectives (DTOs) that represent less than 40 percent of the entire program. Programs are selected as DTOs based on joint service participation and are most often 6.3 or late 6.2 in nature. While technology objectives are discussed in the TARA the level of detail is rarely at the CEST level.

The TARA board is also provided a broad but brief overview of the remainder of the program at these system level reviews.

Congressional Staff Reviews. As a part of the budgetary process, congressional staff members from the House and Senate Armed Service Authorization and Appropriations Committees review the service programs at the budgetary Program Element level. While these reviews are comprehensive they do not represent an EWA. Since the nature of these reviews is for funding justification, the services use these reviews to sell their programs, and problem areas are underplayed. Congress is left to make funding decisions without the context of the overall needs, opportunities, and priorities of the S&T enterprise. An EWA could contribute to better congressional understanding of the S&T program and, hopefully, to better funding decisions.

Current Review Process Strengths and Shortcomings

With the exception of the TARA review, the current multiple review processes are designed to meet individual service needs and management objectives. The principal strengths of the current reviews in practice are that the services take ownership of them, do not feel threatened by external oversight (hence, are more open in providing information), and are more inclined to act on internally generated recommendations and criticisms than on those recommended by DDR&E. The service reviews at the Army and Air Force Directorate or ONR levels are generally intensive and employ peer reviewers. An assumption inherent in this report is that, at the service performer level, the perception is that there is an adequate review process for their needs, and additional reviews would be a burden with little benefit to them.

Despite these strengths, there are still serious shortcomings in the current review process. A significant shortcoming is that there is no EWA of the DOD S&T program. The DDR&E TARA process is the closest attempt but is incapable of examining the enterprise at a granularity sufficient to understand the program at the work unit level, nor is it comprehensive. Since the TARA process uses the conventional review method of a review board convened for several days of review, the overall size of the S&T program is too large to address conventionally, even looking at only half of the program every year. The lack of an EWA means that overall judgments of the program become qualitative, difficult to put into perspective, and subject to criticism. For example, there is limited ability to ensure jointness between related efforts, and it is difficult to compare work done by DOD to that of other agencies, such as DOE and NASA ,or to other performers both national and international.

Another major shortfall is that the portfolio of current reviews is conducted at many different levels of granularity with nothing approaching a common format, even within individual services. Because of this, the individual reviews cannot be coherently combined into a comprehensive picture of the enterprise. Another shortfall is that the documentation of service reviews is not generally available across DOD, further limiting an enterprise-wide picture. Finally, current reviews have made little use of information technology tools that could reduce travel, speed the process, correlate material, and review results.

Conclusions Regarding Conventional Reviews

The desire to introduce an overall S&T assessment of the S&T enterprise at a level of granularity sufficient to justify and manage the program raises a conundrum, the so-called S&T uncertainty principle. On the one hand is the expectation that an enterprise-wide assessment would strengthen the program, explain the quality and relevance of the work, and support justification of the large DOD investment in S&T. On the other hand, the work load of such an assessment using conventional review techniques would create a massive overload of work on the performer base. It would be strongly resisted and would likely prove to be untenable. The search for a resolution of this conundrum forms the basis of this study.

While extensive review processes exist, the sum of these reviews does not constitute an EWA. Differences in granularity, comprehensiveness, review-board composition, format, documentation and even the review objectives of current reviews do not result in a homogeneous understanding of the program. In addition, critical review material is generally not released by the services. An EWA of the S&T base would be of significant value to the DOD. A searchable database coupled with the powerful search engines already in use and under further refinement might offer a powerful new tool to DOD for program assessment while adding little to the work load of the S&T workforce. For example, an EWA applied to the major challenge posed by Improvised Explosive Devices (IED's) might not only help fund promising ideas but might also eliminate investment in technological projects that experts would rule incapable of addressing the issues. A key tenet of this study is that the coupling of the best review expertise, obtained by computer search, to a work project completely within their field of knowledge will result in a very rapid and accurate assessment of the work effort.

An EWA would create a vehicle for DOD to gain access to a "community" of scientific and technical experts that will not only contribute to assessing the program but will open DOD to the broader S&T done in other agencies, the private sector, and the global community. Even if not applied across the entire enterprise (especially in its first applications), this computer based review methodology might be of significant value in selecting reviewers and accessing related work for a more conventional board review. In fact, this application would be a good first test of its utility.

4. An Approach to Enterprise-wide Assessment

Background

The previous section suggests that it is unrealistic to approach an EWA of the total DOD S&T Program using the conventional review process. The scope of such an undertaking would be unmanageable and, if done, the volume of the resulting reports would be so large as to have little management value. A non-conventional approach must, therefore, be considered. Any assessment of the program must have available to it a database that documents the program at a level of detail, a level of completeness and in a format that is compatible with the desired assessment. Therefore, establishing the required documentation of the program will be necessary to any EWA. An assessment will also involve access to individuals who are experts in the topics being assessed. A means of identifying these experts must be in place before an assessment can proceed. The assessment process itself must be defined and put in place. Finally a means of displaying the data generated by the assessment must be developed so that understanding and actions can follow from the assessment. The following paragraphs will address each of these requirements.

Program Documentation

To come to grips with what documentation is necessary for an EWA, it is helpful to consider how S&T is actually done. In this regard, there often is confusion between S&T and capability. This results in a tendency to document the program in terms of desired capability rather than in terms of the details of the S&T that is actually being conducted. As an illustration of this point, consider that hypersonic flight is often viewed as a technology. However, there are many different sciences and technologies that contribute to hypersonic flight. Hypersonic flight is a capability rather than a technology. In general, scientists and engineers each work on a small part of the S&T needed to achieve the capability of hypersonic flight. The array of different scientific and technical disciplines needed to support a capability like hypersonic flight is quite large. The viability of achieving a desired capability will depend on the viability of the S&T programs aimed at resolving the CEST issues that prevent one from just getting on with building the desired capability.

It should be clear from the above that properly defining, identifying, and documenting the CEST issues must be of high priority in preparing for an EWA. It is, therefore, worth spending some time addressing the matter of how CESTs should be defined and documented. For this purpose, we will continue with the example of hypersonic flight. We have chosen this example because it was of special interest to the DDR&E at the time the study was commissioned, it was recently examined by the NRC [“Evaluation of the National Aerospace Initiative,” National Academies Press, 2004] and it illustrates the complexity of properly defining CESTs such that they are useful in the EWA context. There are various levels at which one could identify the CESTs associated with hypersonic flight. For example, as mentioned above, one could define the CEST as “hypersonic technology.” If one chooses this definition, then it is straightforward to employ various readily available S&T databases and search engines to gain information (see figure 4.1

and tables 4.1 through 4.3). The searches were done using the Engineering Compendex (Ei Compendex) database (http://www.ei.org/compendex.html). Articles related to hypersonic technology were identified from the Ei Compendex database for the years 1991 to 2004. The Ei Compendex provides abstracted information from significant engineering and technical literature from around the world. In addition to 4,500 journals, government reports, and books, the database holds over 480,000 records from the published proceedings of selected conferences. A more complete search could be done, e.g., by adding a Science Citation Index (http://scientific.thomson.com/products/sci/) search. However, for the purpose of this discussion the Ei Compendex search is adequate.

From the unfiltered query results, conference papers were separated from the total number of articles. Several ranking functions were used to identify the most prolific authors, journals, institutions, and countries as measured by number of journal articles. To identify overall trends, the numbers of journal articles per year in this area were examined. A ranked list of authors and institutions was created from the residual list of conference articles and papers, as well as the number of conference papers written per country and per year for comparison with the trends in the journal papers. The unfiltered query returned 6,126 results (including journal articles and papers, conference articles and papers, conference proceedings, books, monographs, and dissertations,). Of the 6,126 total, 4,805 were journal articles, and about 1,200 were conference papers. The remaining 120 were a mix of conference proceedings, books, monographs, dissertations, etc. The time history is shown in figure 4.1.

Figure 4.1 Comparison of Journal and Conference Articles Related to Hypersonics (Source: Ei Compendex, 1991-2003)

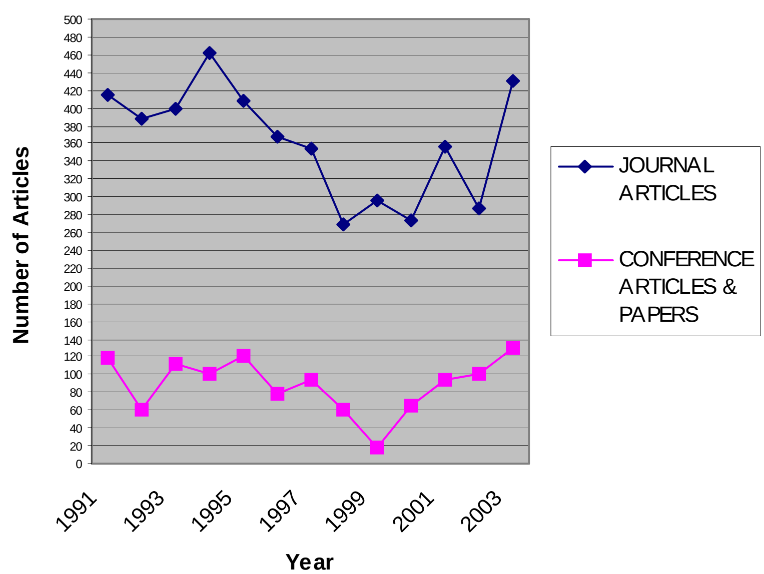

Table 4.1 ranks the number of papers published by country.

TABLE 4.1: NUMBER OF PAPERS PER COUNTRY
Source: Ei Compendex, 1991-2004

COUNTRY	PAPERS
USA	1890
JAPAN	406
CHINA	347
RUSSIA	205
ENGLAND	200
GERMANY	175
TAIWAN	108
INDIA	86
ITALY	79
FRANCE	61
CANADA	59
ISRAEL	55
SOUTH KOREA	53
AUSTRALIA	21
NETHERLANDS	20
BRAZIL	13
GREECE	11
SWITZERLAND	11
SPAIN	9
POLAND	8

The five most published countries included the United States, Japan, China, Russia, and England with the United States having a substantial lead. This figure shows that the number of journal articles published decreased from approximately 460 in 1994 to about 270 in 1998, and then resurged to about 430 in 2003. This resurgence correlates with the establishment of the National Aerospace Initiative in 2001. The average number of journal papers from 1991–2003 is about 362. The average number of conference papers per year is about 89.

Table 4.2 orders the 24 most published organizations.

TABLE 4.2: TOP 24 INSTITUTIONS
Source: Ei Compendex, 1991-2004

INSTITUTION	COUNTRY	PAPERS
NASA LANGLEY RESEARCH CENT	USA	158
NASA AMES RESEARCH CENT	USA	59
TOHOKU UNIV, JPN	JAP	40
OLD DOMINION UNIV	USA	36
BEIJING UNIV OF AERONAUTICS AND ASTRONAUTICS	CHINA	34
UNIV OF MARYLAND	USA	31
VIRGINIA POLYTECHNIC INST	USA	30
NASA LEWIS RESEARCH CENT,	USA	27
NORTH CAROLINA STATE UNIV	USA	27
STANFORD UNIV	USA	27
NORTHWESTERN POLYTECHNICAL UNIV, CHINA	USA	25
UNIV OF TEXAS AT AUSTIN	USA	25
PRINCETON UNIV	USA	24
UNIV OF FLORIDA	USA	22
PENN STATE UNIV	USA	20
NATL AEROSPACE LAB, TOKYO	JAP	19
KYUSHU UNIV	JAP	18
NAGOYA UNIV	JAP	18
SANDIA NATL LAB, ALBUQUERQUE	USA	18
FLORIDA STATE UNIV	USA	17
IOWA STATE UNIV	USA	17
UNIV OF CAMBRIDGE	USA	17
UNIV OF CINCINNATI	USA	16
UNITED TECHNOLOGIES RESEARCH CENT	USA	15

The U.S. Federal laboratories represented include three NASA centers and the Sandia National Laboratories. NASA Langley clearly has been the dominant force in this particular area. No DOD laboratories appear in the “Top 24 Institutions.” The other U.S. institutions are all universities, except for the United Technologies Research Center.

Table 4.3 orders the top 20 journals. The top five journals listed include the AIAA Journal, the Journal of Spacecraft and Rockets, the Journal of Propulsion and Power, the Journal of Aircraft, and the Journal of Thermophysics and Heat Transfer. All of these are published by the AIAA.

TABLE 4.3: TOP 20 JOURNALS
Source: Ei Compendex, 1991-2004

JOURNAL	PAPERS
AIAA Journal	644
JOURNAL OF SPACECRAFT AND ROCKETS	404
JOURNAL OF PROPULSION AND POWER	355
JOURNAL OF AIRCRAFT	219
JOURNAL OF THERMOPHYSICS HEAT TRANSFER	164
NIPPON KIKAI GAKKAI RONBUNSHU, B HEN/TRANSACTI	132
TUIJIN JISHU/JOURNAL OF PROPULSION TECHNOLOGY	108
JOURNAL OF FLUID MECHANICS	99
IZV AN SSSR MEKH ZHIDK GAZA	81
COMPUT FLUIDS	70
INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN	67
J GUID CONTROL DYN	65
TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUT	56
TEPLOFIZIKA VYSOKIKH TEMPERATUR	55
TRANS JPN SOC AERONAUT SPACE SCI	55
JOURNAL OF SOUND AND VIBRATION	53
TEPLOFIZ VYS TEMP	52
AERONAUTICAL JOURNAL	49

Figure 4.1 and tables 4.1 through 4.3 provide information regarding worldwide effort in the area of hypersonic technology and identify the centers of activity in the United States (at least in so far as they participate in the open literature). This material would be useful to and provides

necessary background for an EWA. However, it is far too general in character to form the basis of an EWA. The reason for this relates to the large number of distinctly different scientific and technical disciplines encompassed by the descriptor "Hypersonic Technology." If one attempted an assessment it would be extraordinarily difficult to identify and assemble a group of experts who were qualified to collectively provide a substantive assessment of the area. For example, the NRC study on the NAI noted that hypersonic technology involves several critical technologies.

These include:

- Propulsion
- Thermal environment prediction, protection and management
- Integrated airframe structures and cryogenic tanks
- Vehicle design, optimization and simulation

We will refer to the above as Level 2 descriptors of CESTs and "hypersonic technology" as a Level 1 descriptor. Further examination demonstrates that each of these Level 2 critical technologies subdivides into additional critical technologies. For example, Bowcutt ("Hypersonic Technology Status and Roadmap", Presentation to AIAA HyTASP Program Committee, Dec. 18, 2003, http://www.aiaa.org/Participate/Uploads/TFAB%20HyTASP.pdf) showed that the Level 2 "Propulsion" CEST subdivides into Level 3 CESTs as follows:

- Engine materials
- Cooled engine panels
- Scramjet combustors
- Fuel injectors/Flame holders
- Integrated flow-path-hydrogen
- Integrated flow-path-hydrocarbon
- Engine seals
- Engine active control
- Turbine-Based Combined Cycle (TBCC) hypersonic engine flow-path integration

One can further subdivide the above list of Level 3 descriptors into Level 4 CEST issues, and so forth. This illustrates the difficulty of conducting a conventional assessment of the total DOD S&T program. Each of the subdivisions involves different disciplines and different communities of expertise. The number of experts that one would need to collect together for a conventional assessment is just unreasonable. As discussed in the previous section, this proliferation of disciplines presents a difficult problem even for a focused review of a small subset of the DOD S&T program. It presents an insurmountable problem for a conventional review approach to an EWA of the entire DOD S&T program. However, the next level (Level 4) subdivision approaches the level at which scientists and engineers actually work. This may present an opportunity for a non-conventional approach by exploitation of the fact that Level 4 approaches the point where the various subject matter experts can usually quickly make informed judgments regarding the state of the art and the prognosis for progress in S&T with which they are very familiar. This, however, places significant constraints on the documentation of the program. To explore this point we will examine the Level 4 detail for two of the CESTs identified by

Bowcutt. In particular, we will discuss in some detail “Turbine-Based Combined Cycle (TBCC) hypersonic engine flow-path” and in lesser detail “Engine materials”.

Future hypersonic air-breathing UCAVs for time-critical theater operations, and reusable launch vehicles for prompt global response and routine space access, will require 2–3 propulsion modes to operate across their design speed ranges. One of the most likely propulsion systems for such applications will be the TBCC propulsion plant, which consists of a supersonic (~Mach 4) turbine engine closely integrated with a dual-mode ramjet/scramjet engine. The study authors worked with Kevin Bowcutt of the Boeing Company to construct a hypothetical (but technically realistic) program that would address the key issues associated with the TBCC. It was found that it will be necessary to develop a TBCC engine inlet system that efficiently delivers air flow required by the turbine engine when operating alone, air flow required by the scramjet when operating alone and to both engines simultaneously during the transition from turbine to scramjet. It is also necessary to maintain inlet fluid dynamic stability during mode transition and in all other operational engine modes. One must develop a TBCC engine nozzle system that efficiently expands flow to produce thrust for the turbine engine when operating alone, for the scramjet engine when operating alone, and for both engines when operating simultaneously during mode transition. It is necessary to develop an aircraft and engine flowpath control system that adequately stabilizes and controls the aircraft and TBCC engine flowpaths during engine mode transition and all other flight phases. Lastly, it will be necessary to develop the material, structural, and mechanical design for the articulated TBCC inlet and nozzle systems, and a thermal management system for the turbine engine when it is shutdown but exposed to scramjet flowpath heating. In the following paragraphs we will outline the resultant hypothetical program aimed at achieving these objectives. One of the goals here is to illustrate how one might articulate the CESTs for a program of this nature and how one might document the program so as to be useful to an EWA.

A reasonable approach to the above objectives would be to define TBCC inlet and nozzle geometry and articulation requirements based initially upon knowledge of existing supersonic inlets and nozzles, empirical and theoretical design guidelines and operability (i.e., stability) criteria, engine performance characteristics, and analysis results derived from engineering codes and computational fluid dynamics (CFD). This would be followed by building sub-scale inlet and nozzle models and testing them in wind tunnels, both statically and with dynamic articulation of the variable geometry components. One could then use the knowledge gained from testing and analysis to optimize inlet and nozzle designs. This would be aided by mathematical optimization and multidisciplinary design optimization techniques.

It would also be necessary to develop inlet and nozzle control algorithms, and then test them via dynamic simulation using data derived from testing and CFD analysis. Vehicle stability and control during engine mode transition would be verified via dynamic simulation using CFD-derived aero data in conjunction with inlet and nozzle test data. Wind tunnel tests would be conducted of an aircraft model with variable inlet to verify inlet stability during mode transition, and aero data would be gathered to verify vehicle stability and control during the transition event.

The program would design the structure and mechanisms, including high-temperature seals, for a full-scale TBCC inlet and nozzle, and then bench test critical inlet and nozzle components to verify predicted operation and performance. It would also design a thermal management system (TMS) for the turbine engine flowpath and analyze it using fluid, thermal, and structural analysis codes, and then bench test critical TMS components to verify predicted operation and performance.

The program outlined above involves several Level 4 CESTs that must be resolved for the total program to be successful. The prospects for conducting an EWA would be enhanced if the CESTs could be articulated such that experts in each CEST area could quickly comment on the likelihood of the CESTs being advanced in accordance with the stated program. It is suggested that the following articulation of the CESTs would suffice.

1) Hypersonic engine seals for articulated (i.e., variable geometry) inlet and nozzle structural elements.

2) A dual-flow-path TBCC hypersonic engine inlet that compresses and feeds air to the turbine and scramjet engines, both separately and concurrently. This entails complex variable geometry, high compression efficiency and stable operation for both the turbine and scramjet flow-paths operating separately and simultaneously.

3) A dual-flow-path hypersonic engine nozzle that expands exhaust gases from the turbine and scramjet engines, both separately and simultaneously. This entails complex variable geometry of hot structures and high expansion efficiency for both engine flow-paths operating separately and simultaneously.

4) A post-shutdown hypersonic turbine engine thermal management system (TMS) that maintains turbine material temperature limits when the turbine is shut down and the scramjet is operating adjacent to the turbine flow-path.

5) A hypersonic engine flow-path control system and associated logic and algorithms (i.e., software) that maintain stable engine flow-path operation and thrust performance, and concurrent aircraft stability and control during TBCC mode transition from ramjet to scramjet operation, and vice versa.

The program with the CESTs outlined above becomes complete when milestones, metrics, and funding are assigned to each CEST. At that point the program can be assessed regarding the realism of the milestones, metrics, and funding. Continuing with the above hypothetical example, we propose the milestones, metrics and funding for each CEST illustrated below. We employ a format similar to that used by the NASA Technology Inventory (see Appendix C), and have combined CESTs 2 and 3.

TABLE 4.4 CEST 1: Hypersonic engine seals (U)

Technology Metrics:

Metric	**Metric Unit**	**SOA**	**Planned Value**
Maximum use temperature	Temperature ^{o} F	1400^{o} F (metallic) 1800^{0} F (ceramic)	1800^{o} F (metallic) 2500-3000^{o} F (ceramic)
Durability/life	# of cycles before replacement	1000's for metallic 10 – 100 for ceramic	1000's for <2000^{o} F 100's at 2500^{o} F 10's at 3000^{o} F

Milestones:

TRL	**Year**	**Description**
6	2008	Design and fabricate seals and complete critical component testing in a relevant environment

***Current TRL = 2 – 3**

Funding:

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Funding Profile	$1200K	$1500K	$1800K	$1500K

Technical Work Years

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Technical Work Years	**3**	**4**	**4**	**3**

Suggested Experts:

Last Name*	**First Name***	**Organization**	**Email**	**Phone**
		NASA Glenn Research Center		
		NASA Glenn Research Center		

*names deleted

Table 4.5 CEST 2: Dual flow-path TBCC hypersonic engine inlets and nozzles (U)

Technology Metrics:

Metric	Metric Unit	SOA	Planned Value
Integrated dual inlet operability	# of inlets operating simultaneously at high performance	1	2 at SOA inlet recovery and operability/stability
Integrated dual nozzle operability	# of nozzle operating simultaneously at high performance	1	2 at SOA thrust coefficient

Milestones:

TRL	Year	Description
3	2006	TBCC inlet and nozzle design and analysis
4	2007	Wind tunnel test sub-scale TBCC inlet and nozzle
5	2008	Update inlet and nozzle designs, and tunnel test inlet on a sub-scale aircraft model with an articulated inlet

***Current TRL = 2 – 3**

Funding:

Fiscal Year	2005	2006	2007	2008
Funding Profile	0	$3000K	$4000K	$3000K

Technical Work Years

Fiscal Year	2005	2006	2007	2008
Technical Work Years	**0**	**8**	**8**	**8**

Suggested Experts:

Last Name*	First Name*	Organization	Email	Phone
		Johns Hopkins Applied Physics Laboratory		
		AF Research Laboratory/Propulsion Directorate		
		NASA Langley (Retired)		
		TechLand Research, Inc.		
		NASA Langley (Retired)		

*names deleted

Table 4.6 . CEST 3: High-speed turbine engine thermal management system (TMS); for turbine engine during operation and when shutdown/cocooned during scramjet operation

Technology Metrics:

Metric	Metric Unit	SOA	Planned Value
Maximum turbine engine soak temperature	**Temperature**	**160-200 ^{o} F**	**Maximum of 350-600^{o} F; optimum value must be determined by trade study (limited by fuel coking, lubricants, seals, engine structure, electronics)**
TMS system weight	**Weight**		**No impact to engine thrust-to-weight via highly integrated turbine and scramjet TMS**

Milestones:

TRL	Year	Description
2	**2006**	**Conduct trade study to establish optimum turbine engine soak temperature, and create high-temperature engine component technology development roadmap (which become additional TBCC critical enabling technologies)**
3	**2007**	**TMS design and analysis complete**
4	**2008**	**Critical TMS component bench testing and analysis update**

***Current TRL = 2-3**

Funding:

Fiscal Year	2005	2006	2007	2008
Funding Profile	**N/A**	**$1000K**	**$2000K**	**$3000K**

Technical Work Years

Fiscal Year	2005	2006	2007	20080
Technical Work Years	**0**	**3**	**4**	**5**

Suggested Experts

Last Name*	First Name*	Organization	Email	Phone
		Pratt and Whitney		
		Pratt and Whitney		
		Pratt and Whitney		
		Air Force Research Lab		
		Pratt and Whitney, retired		

*names deleted

Table 4.7. CEST 4: **Hypersonic Engine Control System Development**

Technology Metrics:

Metric	Metric Unit	SOA	Planned Value
Inlet stability during engine mode transition	**Stability margin**	**N/A**	**5%**
Aerodynamic dynamic stability during engine mode transition	**Control system phase and gain**	**N/A**	**6 db gain and 45° phase margins**

Milestones:

TRL	Year	Description
3	2007	**Develop inlet, nozzle and aircraft control laws using aerodynamic propulsion analysis of same. Perform dynamic simulations.**
4	2008	**Use inlet control laws in wind tunnel test of integrated inlet/airframe. Use tunnel data to update control laws and simulations.**

****Current TRL=2.3***

Funding

Fiscal Year	2005	2006	2007	2008
Funding	**$1000k**	**$1500k**	**$1500k**	**$2000k**

Technical Work Years

Fiscal Year	2005	2006	2007	2008
Technical Work Years	3	3	3	4

Suggested Experts:

Last Name*	First Name*	Organization	Email	Phone
		Boeing, Huntington Beach		
		NASA, Dryden		
		Air Force Research Laboratory		
		Boeing, St. Louis		

*names deleted

The above examples suggest a documentation format for a DOD S&T work unit. The basic theme behind the format is the careful identification by the principal investigators of all the CESTs that the work unit is funded to address. The active involvement of the principal investigators in preparing the proper documentation is essential. They are the individuals who best know the program. In this regard it should be noted that the above examples have included a list of recommended assessors. The principal investigator should provide such a list as part of the program documentation. An outline of the suggested format is presented and table 4.8. If the entire DOD S&T program were documented as shown in table 4.8, the resulting database might form the basis for an EWA. The logical custodian for this database is DTIC. For purpose of illustration, Appendix A provides a completed version of table 4.8 for the hypersonic example summarized in tables 4.4 – 4.7.

Table 4.8 : Suggested Work Unit documentation format

Work Unit Summary Form XX-XXXX

1. Title:

2. Date of Summary:

3. Responsible Organization

a. Name:

b. Address:

c. Principle Investigator:

Name	Phone	Email Address

4. Classification Level:

a: Summary Level:

b: Work Level:

5. Military need:

6. Technical Objective:

7. Progress:

8. Critical Enabling Science and Technology (CEST)

a: CEST 1:

Approach

Technology Metrics

Metric	Metric Unit	SOA	Planned Value

Milestones

TRL	Year	Description

*Current TRL =

Page 1

Funding

Fiscal Year	2005	2006	2007	2008	2009
Funding Profile					

Technical Work Years

Fiscal Year					
Technical Work Years					

9. Suggested Experts:

Last Name	First Name	Organization	Email	Phone

Click here to add an additional CEST

10. Total Funding:

Fiscal Year					
Total Funding					

11. Program Participants:

Contracts with whom	
Grants with whom	
Government organization	

12. DoD Subject Areas: http://www.dtic.mil/dtic/subcatguide/

13. Key Words:

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Table 4.8 has been streamlined so as to highlight those elements that are most needed for an EWA. The table would ultimately incorporate additional fields (e.g., program element numbers) to allow traceability to appropriations, etc. The database that would result would be useful independent of an EWA. The NASA Technology Inventory (NTI) database provides a good illustration of such utility. This point is discussed in Appendix C, which provides a brief description of the NTI. It also provides several displays that this study was able to easily construct from the online NTI. These displays are intended to show that the existence of this database and its functionality allow authorized users to inquire about the NASA Technical Program from the highest level of aggregation down to the individual work units with the click of a mouse. This functionality could and should be available to DOD decision makers and performers regarding the DOD S&T program.

Establishing Communities of Experts

The following paragraphs will outline an approach to identifying the needed communities of experts. While the establishment of these communities of experts is a critical aspect of the EWA methodology discussed in this report, it is also in the best interests of DOD independent of an EWA. Science and technology will continue a trend towards increased sophistication and complexity. Keeping current in these developments will become increasingly difficult. This will be exacerbated by the inevitable trend toward globalization of S&T. In order to cope with these developments, DOD must reach out in a constructive fashion to engage the larger U.S. scientific and technical communities regarding S&T for national security. This must be done within the context of a national purpose rather than through some competitive free market process. It is unfortunate that the constructive engagement between the DOD and the U.S. scientific community has greatly diminished over the past thirty years. This situation needs to be rectified. Most American scientists and engineers are well aware that the nation’s long-term strength (military and economic) depends upon the federal government’s stewardship of the nation’s long term S&T investments. Many of these scientists and engineers would be honored to be considered members of a community of experts that is contributing to this national purpose. A public policy to accomplish this should be established, and a public relations program should be mounted to articulate this policy to the nation’s scientific and technical communities. If successfully done it would be therapeutic for the S&T community and would provide the type of access to this community that can be achieved only by tapping into people’s commitment to the nation’s health and wellbeing. Such an undertaking would be a strong motivator for individual scientists and engineers to participate in the EWA discussed below.

Tables 4.4 through 4.7 reduce the program to a succinct statement of CESTs, metrics, milestones, funding, and technical work years. A database of such tables for the entire DOD S&T program might form the basis for an EWA. However, in order to do this the program documentation must enable the finding of appropriate assessors. One would like to identify a large number of assessors in order to gain adequate scientific and technical coverage to avoid some of the “small sample” problems that often occur in the conventional review process. The CESTs may provide the key to doing this. For example, if the CESTs are properly articulated then, by employing available databases and search engines, the tables might form the basis for identifying a pool of active scientists and engineers from which a community of experts could be formed by. It is important to understand that each CEST will have its own community of experts. We will apply this line of reasoning to the CESTs identified above. The first was hypersonic engine seals for articulated inlet and nozzle structural elements. The broad search of the field of hypersonic technology reported in table 4.3 indicates that the AIAA journals have published the largest number of papers in the area of hypersonic technology. It would, therefore, seem reasonable to query the AIAA Electronic Library (http://www.aiaa.org/content.cfm?pageid=406) regarding publications in the area of hypersonic engine seals in order to identify individuals who publish in this area. A query on “hypersonic engine seals” for the period 1995 through 2005 found 25 records that identified 20 U.S. authors along with their affiliated institutions. The same query of the Google search engine identified a number of sites including one that provides the proceedings of the “2002 NASA Seal/ Secondary Air System Workshop.” A simple search of the proceedings table of contents identified 17 additional U.S. authors along with their institutions. A more sophisticated search using the Google Scholar search engine with the same query for the same timeframe yielded 103 U.S. authors along with their affiliations. It is interesting to note that the Google Scholar search identified papers in the AIAA Electronic library that were not identified by the direct search of the AIAA Electronic Library. Also, the direct search of the AIAA Electronic library found some papers not identified by Google Scholar. The total number of individuals identified who had U.S. affiliations was 129. A complete listing of these individual’s organization will be found in Appendix B, table B1. The names of the individuals are not listed for privacy reasons. This group could be considered to be a potential community of experts for the CEST “Hypersonic engine seals.” The time that it took to generate the input for the entire listing of the potential community of experts for hypersonic engine seals was less than a second (plus perhaps another 15 minutes of manual work to eliminate individuals who were clearly inappropriate). The search engines used above did not offer the option of automatically extracting all the authors and their affiliations. This had to be accomplished manually and was unacceptably time consuming for an EWA. However, since the author names and affiliations are machine readable, it should be straightforward to automate this extraction process. Once this is done, arriving at the potential community of experts for each CEST could be totally automated and performed in a matter of seconds.

A large number of search engines are available for scientific and technical inquiries. Some can be utilized at no cost, while others can be quite costly. The latter search engines are best suited when a very complete analysis of an area is desired. However, the establishment of a potential community of experts in an area does not require a complete analysis of all work that has been done in that area. It requires only that a large enough sample be found of individuals who have published recently in the area in question. In the cases examined in this study it was found that the free search engines, such as Google Scholar, provided satisfactory potential communities of experts. It is expected that, in the coming years, these free search engines will improve considerably and that the ability to find satisfactory potential communities of experts rapidly and at no cost will improve accordingly.

We have used the term “potential community of experts” because the listing in table B1 contains individuals who will be well matched to assessing the program outlined in table 4.4 and others who will not be well matched. One could narrow down the community of experts by several methods. At one extreme one could proceed by asking the principal investigator for a particular CEST to identify from table B1 those individuals best suited to perform an assessment (this request could be automatically prompted upon the PI providing documentation of the program). At the other extreme one could interrogate databases such as the Community of Science Expertise database (http://expertise.cos.com/about/expertise.shtml) for each individual listed in table B1 in order to find the best matches for the desired assessment. At the current state of technology this latter approach likely would involve an unacceptable level of human intervention. An intermediate approach would be to have the principal investigator responsible for a particular CEST identify, in his/her formal documentation, a number of individuals believed to be appropriate assessors for the CEST (the "suggested community of experts" shown in tables 4.4 through 4.7) and have the principal investigator, prior to submitting the documentation, gain their agreement to participate in an assessment. One could then automatically provide these individuals a list such as shown in table B1 (with the names included) and ask them to identify individuals from that list whom they believe are well suited to conduct an assessment. This approach has the benefit of putting some distance between the PI and the assessors and having the assessors selected by experts. Another approach would be to use the full list given in table B1 and have the members of the potential community of experts decide as individuals whether or not they are appropriate to participate in the assessment.

The same approach used to construct table B1 was used to identify potential communities of experts for the other CESTs identified in tables 4.5 through 4.7. In these cases the searches were limited to Google Scholar. In case of the CEST "Dual flow path TBCC engine inlets and nozzles," a potential community of experts of 28 individuals was found. For the CEST "Post shutdown turbine engine thermal management System (TMS)" a potential community of experts consisting of 70 individuals was found. For the CEST "Hypersonic Engine Control System Development" a potential community of experts consisting of 134 individuals was found. The names and affiliations of the potential communities of experts will be found in Appendix B, tables B2 through B4. In each of the above cases a potential community of experts was found that is large enough to suggest that meaningful statistics could emerge if a reasonable fraction (say 50 percent) of the potential community of experts agrees to participate in the assessment. In general, a lower limit of about 10 would need to be placed on the size of the final community of experts in order to obtain meaningful statistics.

The turbine based combined cycle (TBBC) engine flow path example discussed above is typical in character of many of DOD programs funded at the advanced 6.2 and 6.3 stage. Such programs often have a systems character to them. Our study finds that, if the CESTs are properly specified, it is straightforward to find a potential community of experts for the various CESTs. The searches we conducted produced 10s to 100 or more potential members for the community of experts associated with a particular CEST. These searches were all performed in less than one second of search time. The DOD S&T program, however, also supports a substantial amount of work that can be generic in character and is often funded at the 6.1 and early 6.2 levels. For example, work on materials as often in this category. This work may investigate materials properties with the objective of identifying material systems that might be useful in some of the stressful environments encountered by DOD systems. This study has found that the basic approach outlined for the TBBC example is applicable to the more generic S&T. The TRL assignment is not particularly useful here because, for these programs, it usually stays in 1-2 range for the program duration. However, the idea of identifying the critical S&T issues being addressed by these programs remains valid. The concepts of the state of the art and planned advances in the state of the art remain valid, as do the concepts of milestones and communities of experts. For these programs, the importance of clearly identifying the CEST is also found to be key. In order to demonstrate some of these points we will consider briefly the topic of hypersonic engine materials. Furthermore, to illustrate the variety of search engines that are readily available, we will use results obtained from the SCIRUS search engine (http://www.scirus.com/srsapp/). Because of the high temperatures encountered in hypersonic propulsion, ceramic matrix composites have been of great interest. If we declare "ceramic matrix composites" as a CEST then, for the period 1995–2005, SCIRUS identifies 1635 records for a full document search. An examination of these records shows that the description "ceramic matrix composites" covers a large number quite different material systems and investigations. It would be difficult to easily extract a viable potential community of experts from this broad listing. Therefore, "ceramic matrix composites" is a Level 1 designation and is not a satisfactory CEST. One must inquire at a more specific level. A significant subfield of ceramic matrix composites is that of fiber reinforced ceramic matrix composites. A full document search at this level and returns 602 records. Examination of these records once again demonstrates many different material systems and investigations are covered by this level of description. This is a Level 2 designation and is not a satisfactory CEST. A scientist or engineer will typically be working on a particular material system such as silicon carbide fiber reinforced silicon carbide (referred to by the community as SiC/SiC). A title search on "SiC/SiC" for the period 1995–2005 identified 112 files. While this is approaching the level where an assessment might be done, it is actually a level 3 designation. Even within this narrow field, scientists and engineers will be working on some particular critical issue, such as the interphase, that transitions the silicon carbide fiber to the silicon carbide matrix. A title search on "SiC/SiC interphase" returns 39 records. This is a Level 4 designation. If one undertakes to identify a community of experts at this level, then one should find individuals who could quickly and authoritatively comment on a DOD S&T program that is conducting working in this narrow area. We suggest that this is the proper level at which to identify the CEST (e.g. "SiC/SiC interphase" for this example).

The results from a search to identify a potential community of experts for a particular CEST can be very dependent on how the CEST is stated. For example, when the term SiC/SiC in the above mentioned title search was replaced with its full name "silicon carbide fiber reinforced silicon carbide" then the SCIRUS search returned only 9 records instead of the 112 returned for the abbreviated name. The reason for this is that the community that works in this area has embraced the designation "SiC/SiC" in their literature. The current search engines are not sophisticated enough to figure this out. One must, therefore, not only define the CEST at the proper level but must also properly name the CEST. The individuals best qualified to do this identification of the CESTs are the principal investigators for the various projects. The principal investigators should be required to identify the CESTs as part of the formal documentation of the program. They should also be required to conduct searches on their proposed CESTs to verify that their definitions identify an adequate number (10–100) of potential members of a community of experts for each CEST and that the listing they are finding includes names that they would expect including some of those they have identified as "suggested experts." They will likely need to iterate the naming of the CEST several times to get it right. This should not be burdensome, because each search typically takes less than a second to accomplish. The proper identification of the CESTs must be included in the formal documentation if there is to be any hope of conducting an EWA. This is because the exact statement of the CEST will form the basis for identifying the individuals who will be asked to perform the assessment. If the CEST is not properly identified, then a valid community of experts will not be found. It would be helpful to get feedback from the expert assessors regarding whether the CEST was properly identified/stated.

Assessment Process

In this section the enterprise-wide assessment methodology is described sequentially. Five major steps are envisaged including the preparation of Work Unit Summary data sheets, extraction of CESTs by DTIC and search for potential reviewers, selection of assessors from the list of potential reviewers, program assessment by the review board and analysis and reports of the assessments. The two highest risk elements in the execution of this proposed process are the formulation of the CESTs in the Work Unit Summaries at the appropriate level and the generation of a community of experts using advanced search engine technology. The sequence is as follows:

1. The PI of the responsible organization prepares a Work Unit Summary document (table 4.8) and submits it electronically to DTIC where it is entered into the appropriate database.

A hypothesis of the proposed review process is that the reviewers, based upon detailed expert knowledge of the particular CESTs of the work unit, can make rapid and accurate assessments of the maturity, impact and feasibility of the work unit. The generation of the CESTs by the principal investigator is therefore, the critical element of the Work Unit Summary. If the CESTs are properly developed at the level that the work is actually performed, search engine technology should be able to retrieve a community of experts from the published literature in that field of knowledge. The PI will also suggest experts that will augment the automated search. Finally, as a test, the PI will run a search of the CESTs to determine if an appropriate community of experts (including some of the suggested experts) is retrieved by the search engine. If not, the CEST description must be modified to produce the desired results.

2. The DTIC automated system extracts the CESTs and conducts an automated literature search to identify a potential community of experts for each CEST.

DTIC is designated as the custodian of the S&T Work Unit Summary database. DTIC will receive the data sheets from the investigating agency and electronically inform DDR&E that it has received the data. DTIC will then use search engine technology to produce a potential community of experts. While this will duplicate to some extent the search done by the PI it will not be time intensive and should be free from any conflict of interest.

3. The suggested experts listed in the Work Unit Summary select the most qualified members from the DTIC generated potential community of experts.

The list of the potential community of experts is automatically made available, via a password controlled web site, to the suggested experts listed in the Work Unit Summary. The responsible organization will have certified at the time of submission of the Work Unit Summary document that the suggested experts are U.S. citizens and have agreed to participate in an assessment. The suggested experts place a check mark next to those individuals on the list who they consider appropriate to act as assessors for the CESTs in question. This input combined with the suggested experts will constitute the communities of experts for the CESTs.

4. The selected expert review members complete the appropriate worksheets and submit them to DTIC.

The selected communities of experts will be provided electronically a survey worksheet (see table 4.9) to complete and return to DTIC. It is expected that the expert reviewers will be able to perform the assessment in a few minutes using their previous experience, the compact assessment worksheet, and the limited information provided to them.

Table 4.9: S&T Assessment Worksheet Assessor:
Background Information
1.Work Unit Title (include classification of title):
2.Responsible Organization:
3.Critical enabling S&T (include classification of entries):

- **a.Approach**
- **b.Metrics**
- **c.Milestones**
- **d.Funding**
- **e.Technical work years**

Assessment:

On a scale of 1-10 (1 is low, 10 is high) score the following:

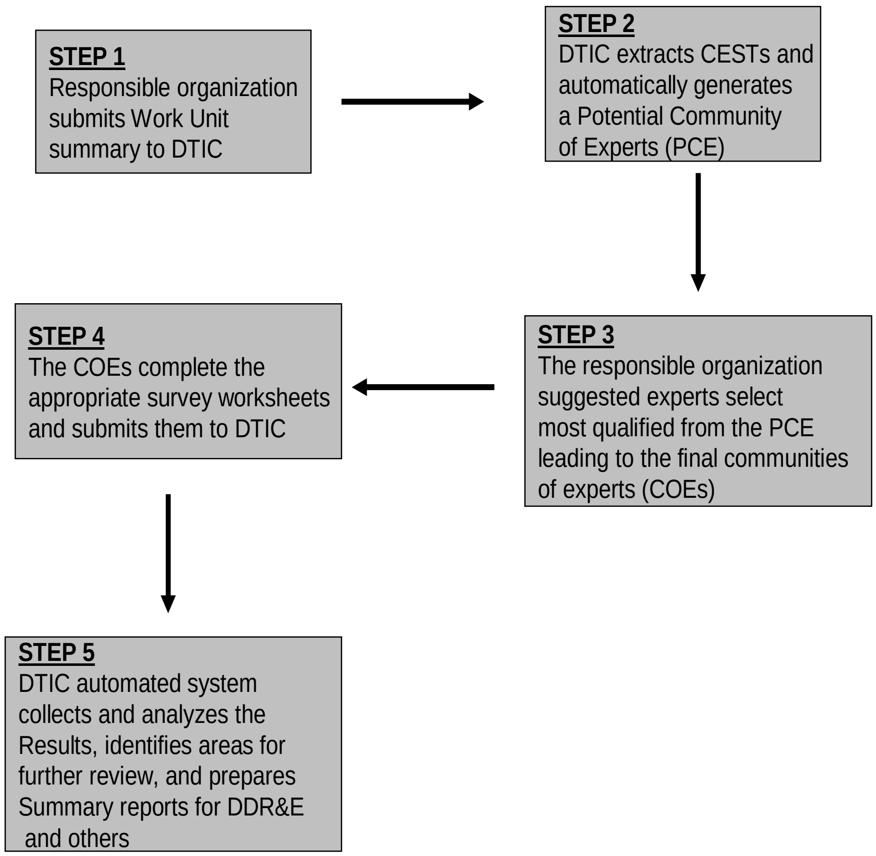
Topic	Score	Comment
Adequacy of funding		
CEST Properly Stated		
Realism of timeframes		
Level of S&T Challenge		
Impact if milestones are met		
Level of maturity of the S&T being pursued		
Likelihood of achieving milestones (item 3.c)		

5. The DTIC automated system will collect and analyze the input from the various communities of experts, identify areas for in depth review, and prepare summary reports for the appropriate DDR&E staff and others (for example the service S&T executives and the organizations responsible for the work being assessed).

If the on-line review indicates the need for an in depth review, the same experts designated for the on-line assessment are appropriate members for an in-depth review. An additional spin-off of the process described here for generating a community of experts is that this process should be of value for selecting reviewers for a conventional review at the detailed technology level. While a search engine would pull up too many names for a broader subject area review, it could still be of value in selecting subject experts to augment the generalists who are typical of the conventional review process.

A simplified flow chart of the envisioned process is presented in figure 4.2:

Figure 4.2 EWA Process Flow Chart



The state of information technology today is not advanced to the point where it would allow full automation of the process outlined above. It is, however, surprisingly close to allowing such an EWA to be undertaken. There are some minor issues that must be resolved such as those associated with extracting individual authors and their affiliations from the archived publications and finding their e-mail addresses. More serious issues must also be resolved such as increasing the search engine capabilities beyond key word searches to the point where they can reliably perform context searches. In this regard the DOD should participate in those efforts that are ongoing to resolve such issues. Active DTIC participation in the NIST and DARPA sponsored Text REtrieval Conference series (TREC) (http://trec.nist.gov/) is recommended for the purpose of benchmarking various approaches to an EWA. In the short term the techniques outlined above could be profitably applied to the conventional review process where manual intervention would be substituted for those processes that are not easily automated with current technology. This would allow the refining of the data documentation requirements.

Displaying Assessment Results

The assessment methodology outlined above will generate a large amount of data. One must, therefore, develop schemes for analyzing the data and displaying it in ways that provide insights into the program. The last three topics in table 4.9 are especially interesting in this regard. They form axes of the three-dimensional data cube shown in figure 4.3. The data could be displayed as three-dimensional scatter plots ranging from that associated with a particular CEST, to a combined scatter plot for all CESTs within a given work unit, all the way up to a scatter plot for all CESTs in the entire DOD S&T program. These scatter plots would provide a quick sense of where in the data cube (likelihood, impact, maturity) the DOD S&T program resides as a function of the level at which it is examined.

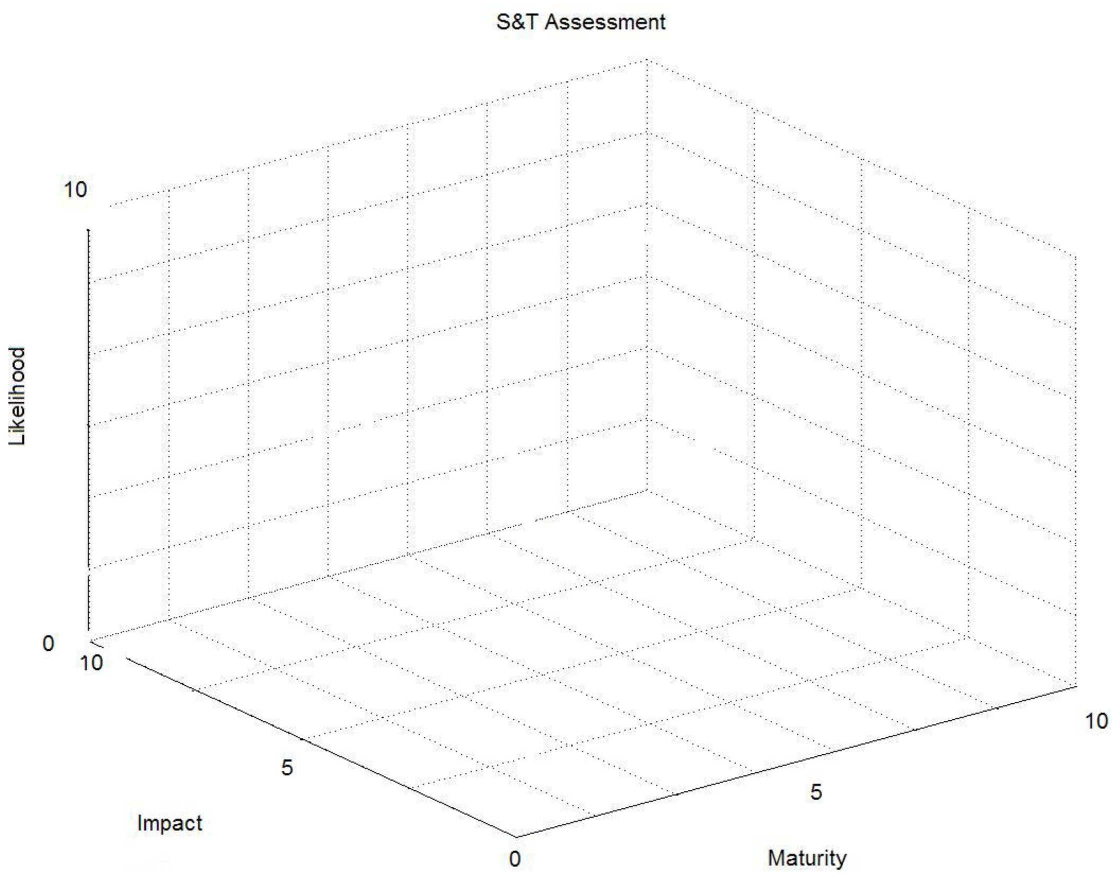


Figure 4.3 Data Cube

Three-dimensional scatter plots, while they contain all of the data are difficult to interpret/visualize. It is often useful to project the data on to the planes that form the data cube. An especially interesting display is the projection of the three-dimensional scatter plot onto the Impact-Maturity plane. This plane could be broken into quadrants as shown in figure 4.4. It would be quite illuminating to see where in this plane the program would cluster. Clustering in the lower left-hand quadrant or the lower right-hand quadrant would likely be viewed as undesirable. Clustering in the upper left-hand or upper right-hand quadrants are more interesting cases. There will be very different opinions regarding in which of these two quadrants the program should reside. The discussion that this data would precipitate would be quite valuable. The projection of the three-dimensional data onto the other two planes would also provide valuable insights regarding the sense of the scientific and technical community relative to the program's health and viability.

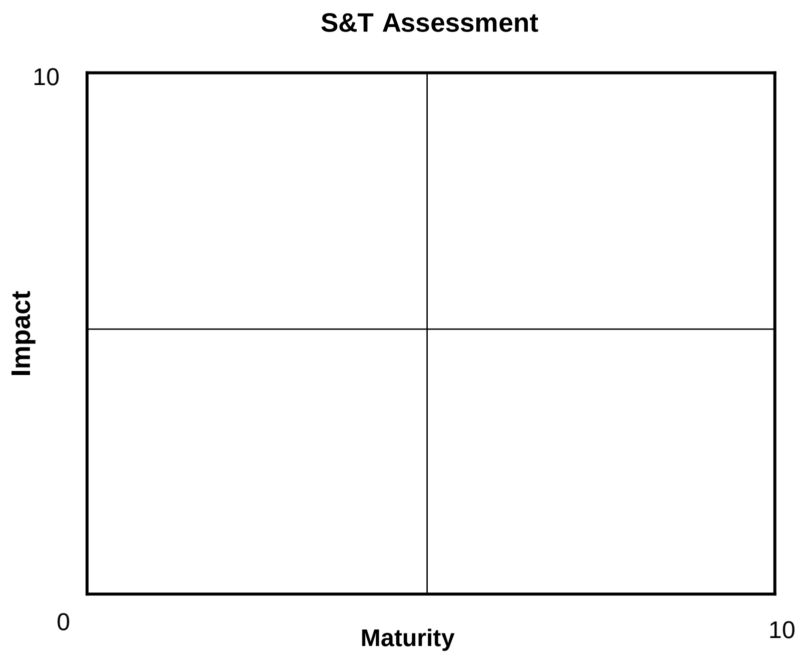
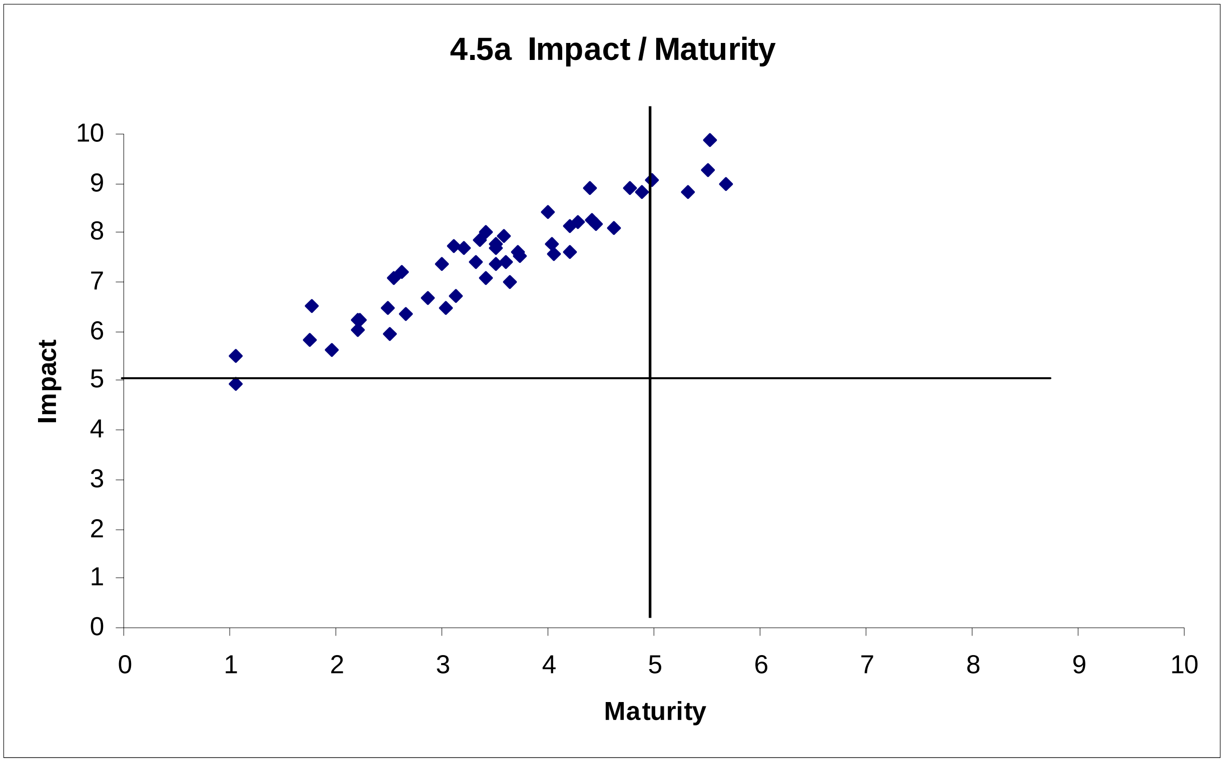
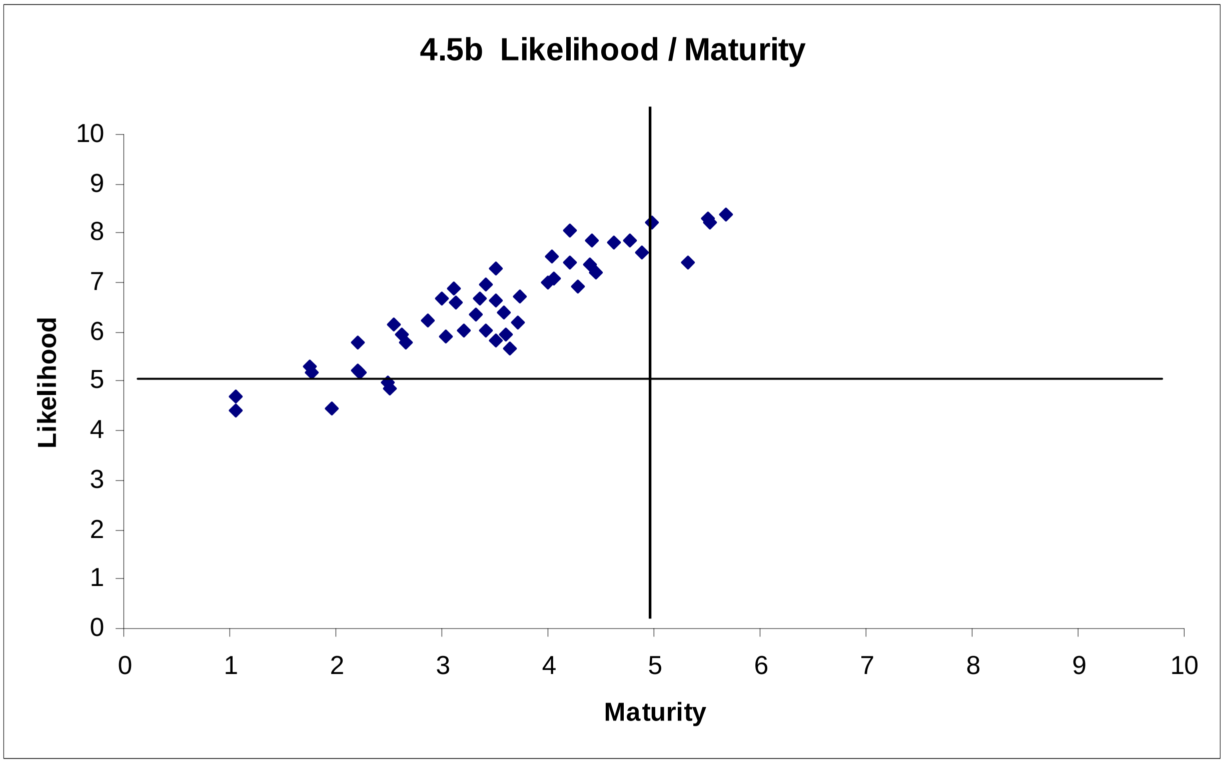


Figure 4.4 Impact-Maturity Plane Template

The survey results could be used as a basis for requesting in-depth reviews of particular areas. For example, programs that fell into the lower two quadrants of figure 4.4 could be automatically identified for further examination. It would also be useful to correlate the Maturity scores with the "color" (6.1, 6.2, and 6.3) of the money used to fund the program. A similar correlation should be done of the maturity levels assigned by the principal investigators and the maturity levels assigned by the assessors. In this regard, it would be important that the assessors are not privy to the maturity levels assigned by the principal investigators. A low degree of correlation in either of the above could form the basis for requesting additional review.

In order to provide a concrete example of the data displays suggested above, the study conducted a simulated assessment of the hypersonic program summarized in Appendix A. The approach used was to establish a reasonable estimate of the mean scores (Impact, Maturity and Likelihood) that the study directors would expect for each of the CESTs if a detailed assessment were made. The simulation then assumed 50 assessors whose scores were distributed normally along each axis (Impact, Maturity, Likelihood) about the means with a standard deviation of 1 (on a scale of 1–10). A small random component was then added to the various scores to avoid the artifact of all points clustering along a line in each two dimensional projection. Figure 4.5 shows the resultant scatter plots for the CEST "Hypersonic engine seals".


4.5a Impact / Maturity
Impact
Maturity
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10


4.5b Likelihood / Maturity
Likelihood
Maturity
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10

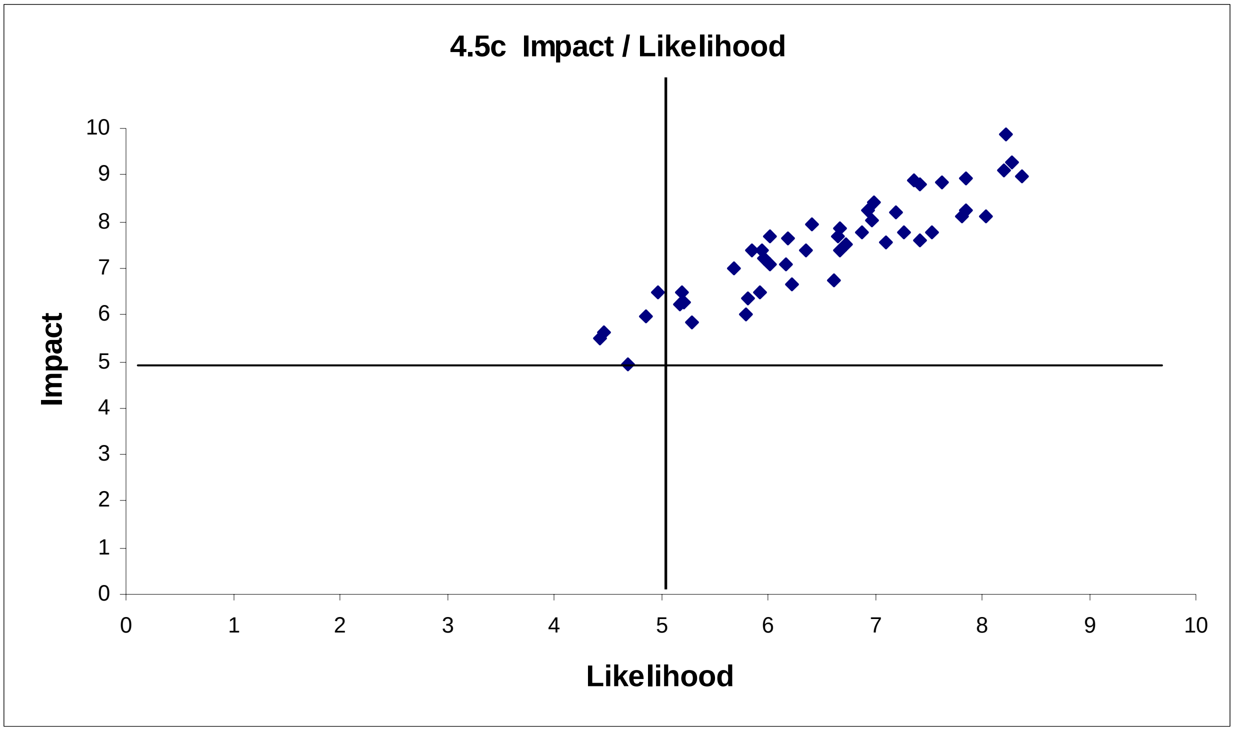
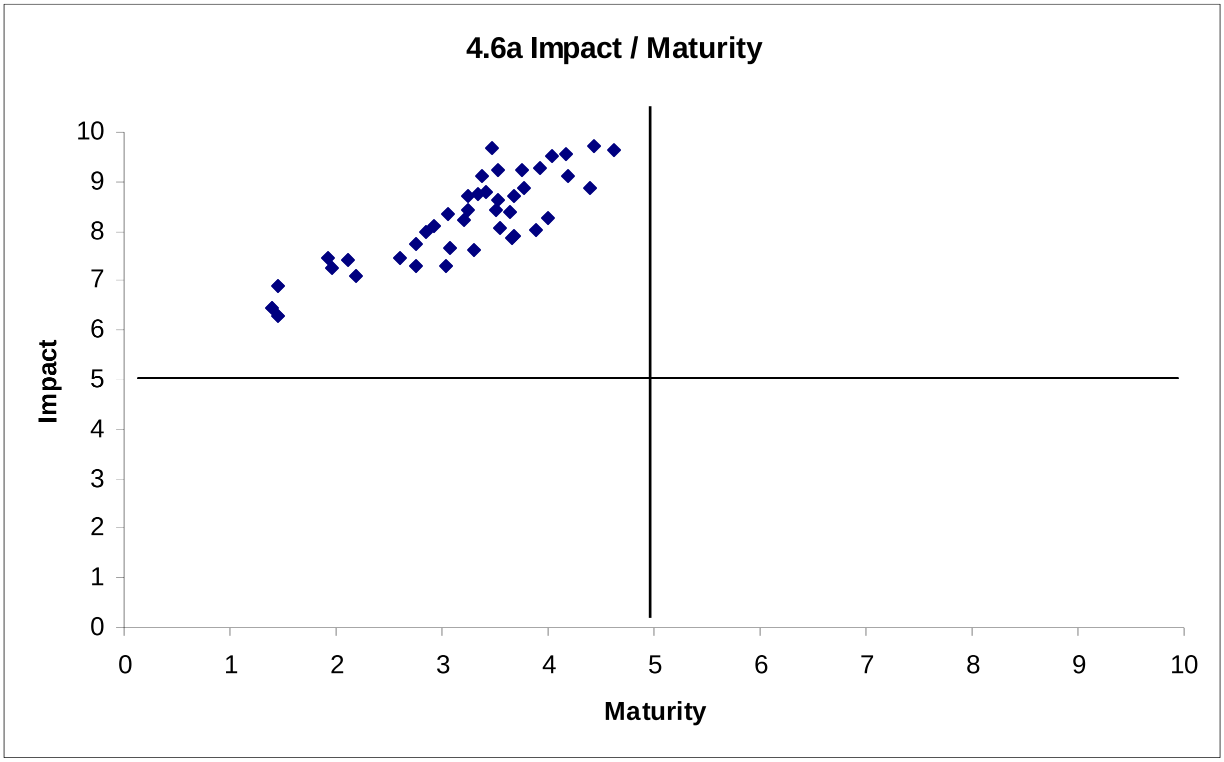
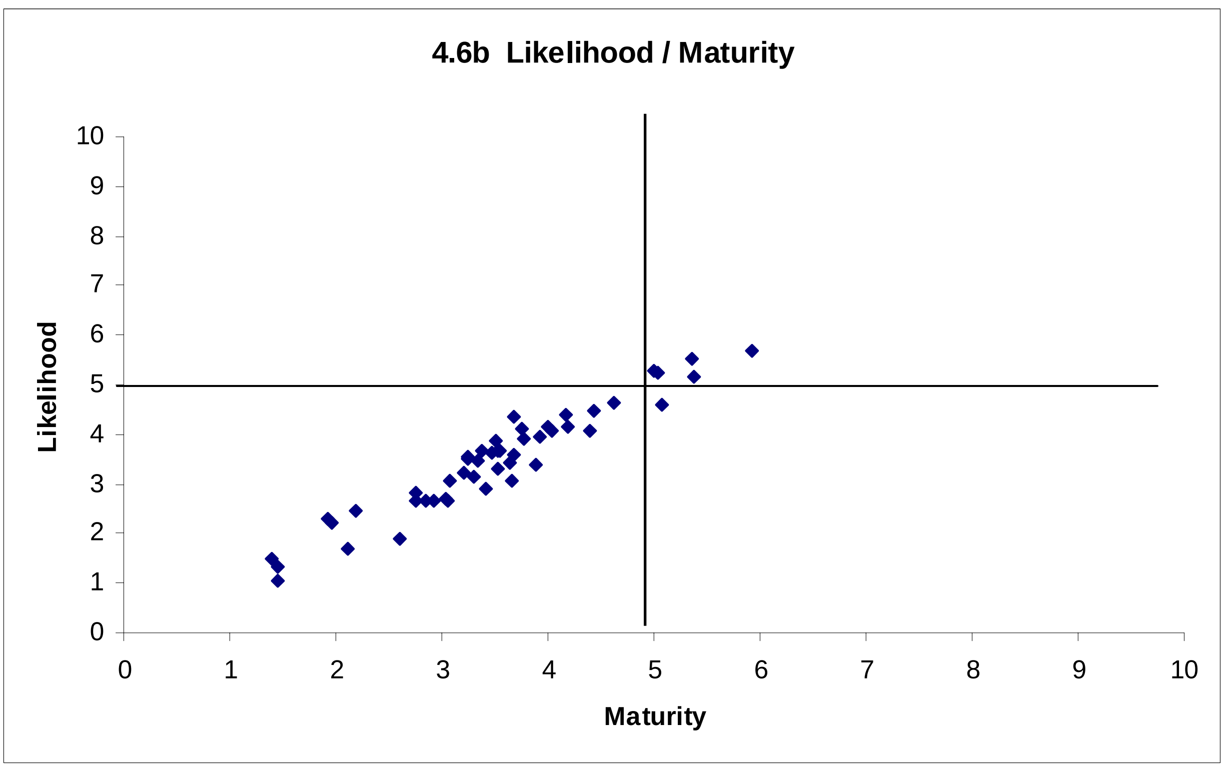


Figure 4.5 Scatter plots for the simulated assessment of CEST "Hypersonic engine seals"

From the above figures one sees that the simulated assessment places this CEST in the upper left-hand quadrant of the Impact-Maturity and Likelihood-Maturity planes and in the upper right-hand quadrant of the Impact-Likelihood plane. The authors would view this as satisfactory for a mature 6.2 or early 6.3 task.

Figure 4.6 present the scatter plots for the CEST "Thermal Management System".





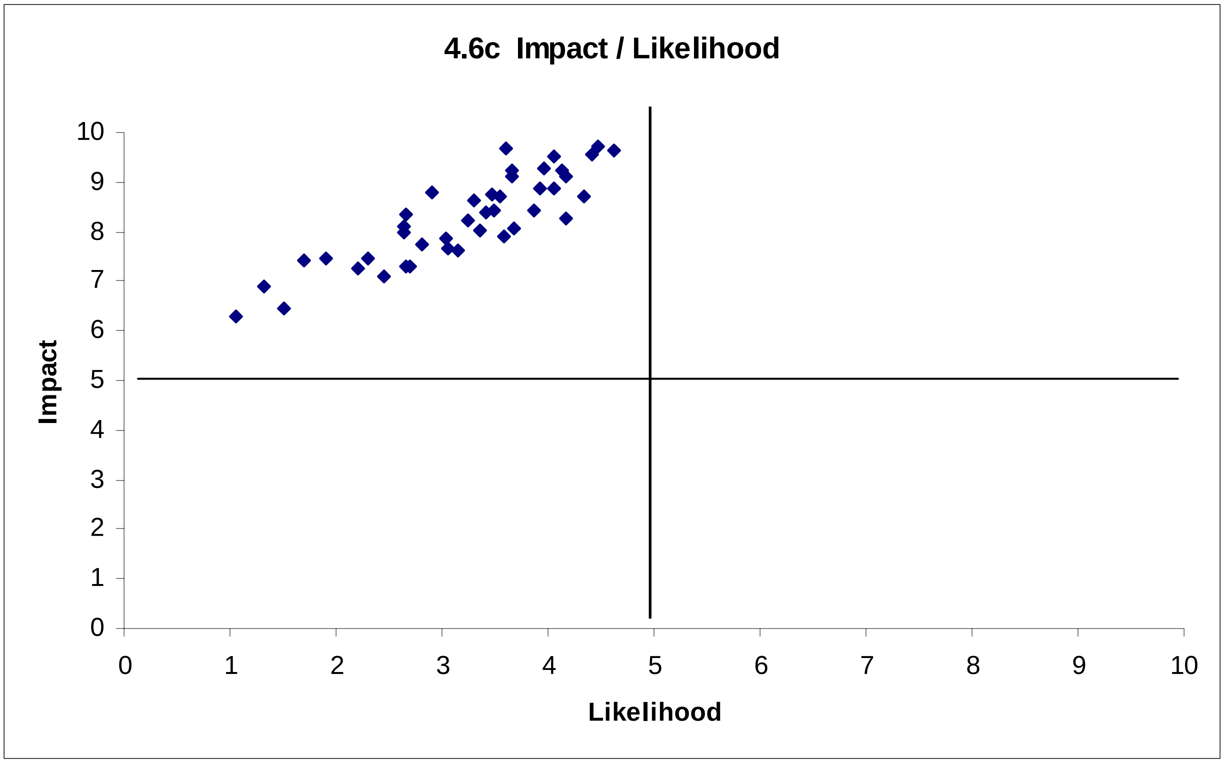


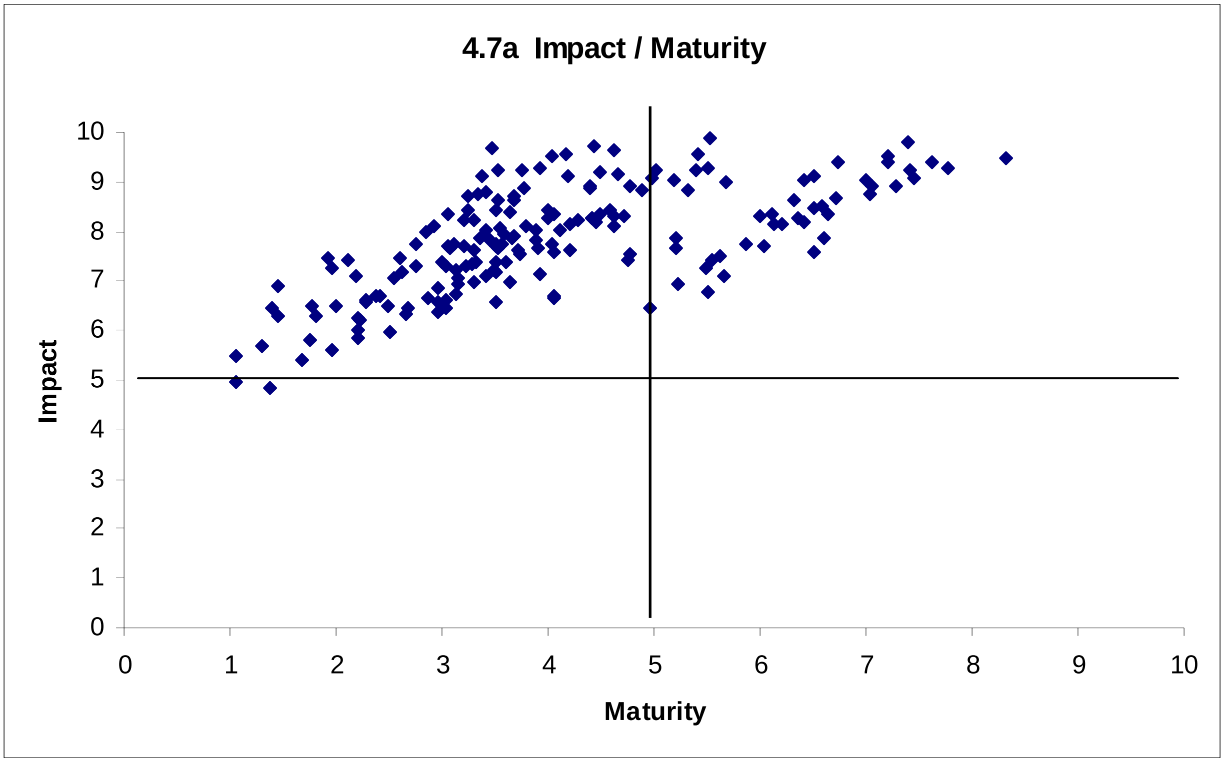
Figure 4.6 Scatter plots for the simulated assessment for CEST "Thermal Management"

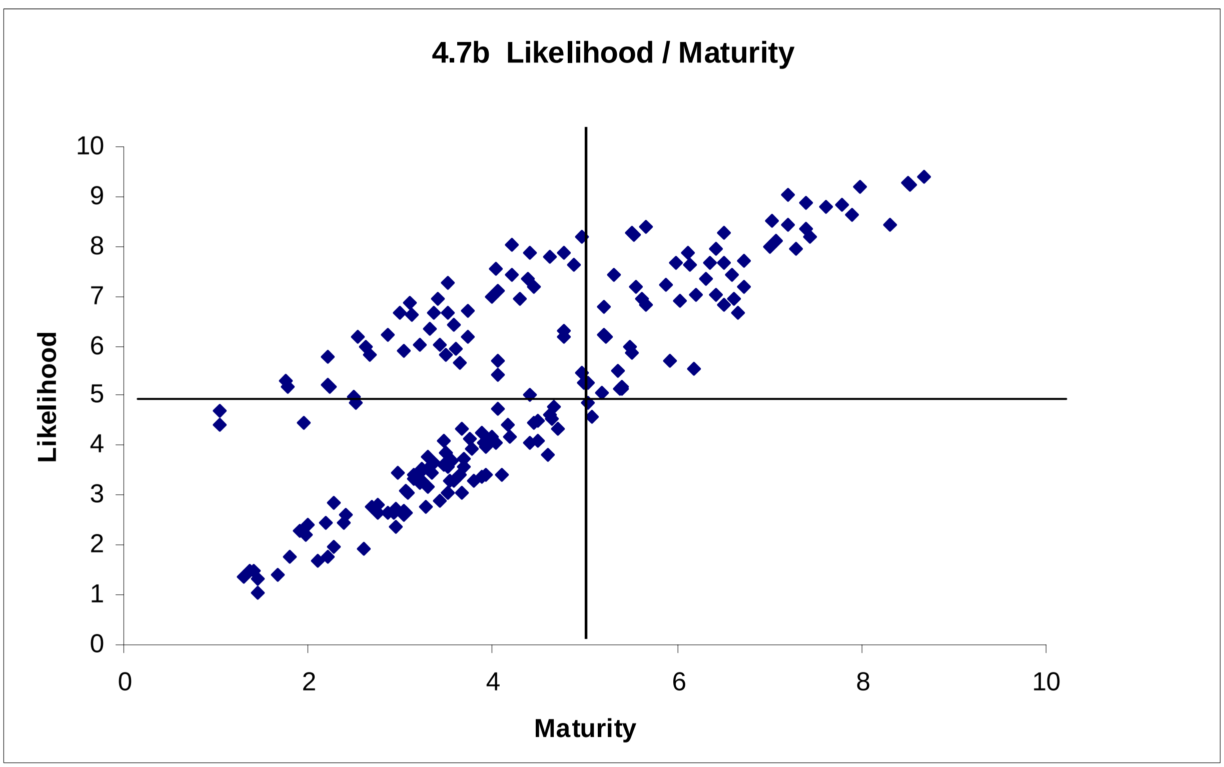
These scatter plots place the program in the upper left quadrants of the Impact-Maturity and Impact-Likelihood planes and in the lower left quadrant of the Likelihood-Maturity plane. The authors would interpret these results as showing a satisfactory 6.2 – 6.3 task but one with considerably more risk than the "hypersonic seals" task. The risk is associated with the technical challenges confronting this CEST. It is important to note that reaching this conclusion requires reviewing all the scores that are required by table 4.9 and not just the scores displayed in the scatter plots shown above.

The scatter plots (not shown) for the simulated assessment of the "dual flow-path" CEST place that CEST in the upper right-hand quadrant for all three 2D projections of the 3D data cube. Such an assessment suggests that the program involves technology that has high impact, is relatively mature, and is relatively low risk. One would expect such a program to be funded primarily with 6.3 funds.

The scatter plots (not shown) for the simulated assessment of the "control systems" CEST place the CEST in the upper left-hand quadrants for the Impact-Maturity projection and the Impact-Likelihood projection, but in the lower left quadrant for the Likelihood-Maturity projection. This implies that the program involves considerable risk. The high-risk assessment in this case resulted not from the technical challenge confronting this CEST but rather from a concern that the funding provided was inadequate for the stated plans and milestones. Here again it should be noted that reaching this conclusion involves scores not shown by the data cube.

The 2D scatter plots that result from combining the simulated assessments for all four CESTs are shown in figure 4.7.





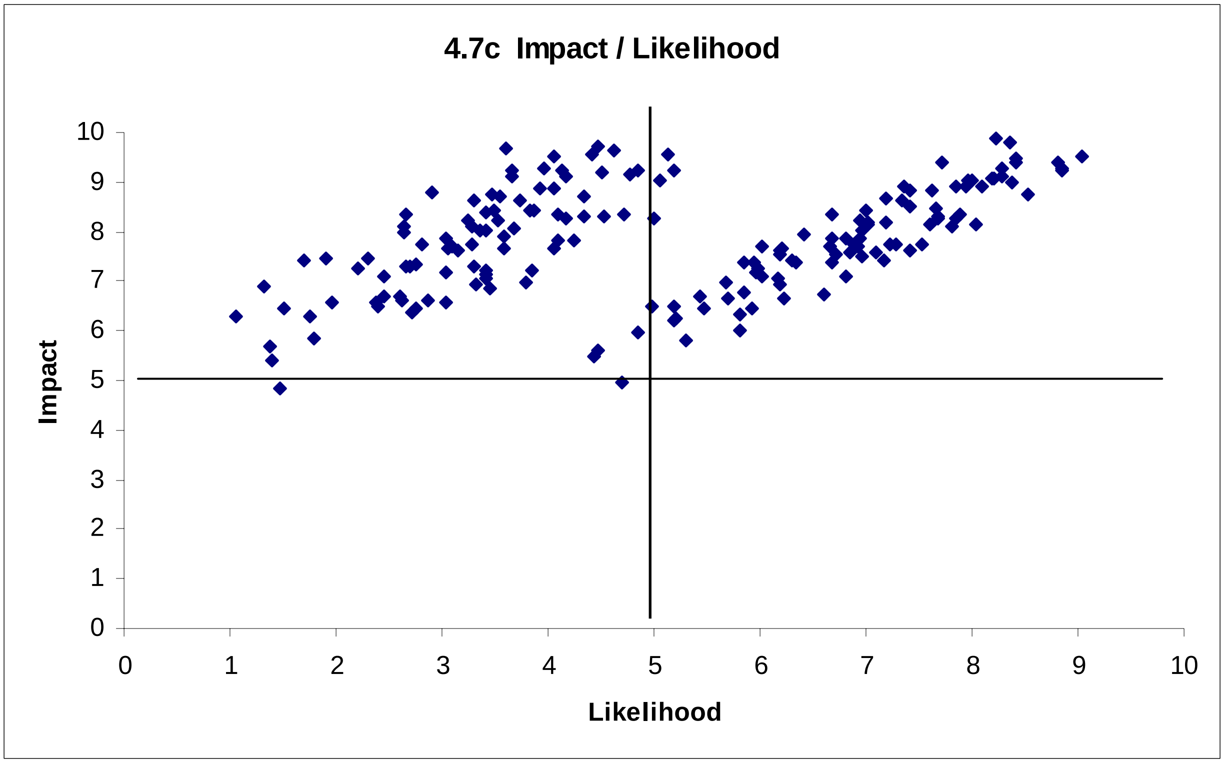


Figure 4.7 Scatter plots for combined scores from the simulated assessment of the Work Unit "Hypersonic Turbine-Based Combined Cycle Engine (Mach 4 turbine and Mach 3.5 to 7 scramjet engine)"

This figure suggests that the program that is summarized in Appendix A is one of high impact and moderate maturity and one that involves some considerable risk. As pointed out above, understanding this risk requires access to data collected as part of the assessment but not shown in figure 4.7. Since the viability of the EWA approach suggested here requires that the entire process be automated it will be necessary that simple algorithms be developed to flag concerns. For example, a program that is deemed risky because of the level of the technical challenges confronting it may very well be a satisfactory program. On the other hand, a program that is deemed to be risky because of inadequate funding would likely not be viewed as satisfactory. Similarly, a program that is assessed to be low impact and low maturity might be a satisfactory program because it involves such new S&T that it is difficult to judge its impact. History has demonstrated many times that new S&T that is originally deemed to be not relevant has turned out to be very important. On the other hand, a program that is assessed to be low impact and high maturity should probably not be part of the DOD S&T program. The development of algorithms to sort out such issues would be required as part of an EWA. These algorithms could be based upon the type of reasoning given above. Figure 4.8 provides a simple decision template based upon the above considerations.

4.8a Impact / Maturity

10

Impact

OK	•OK if maturity centroid is less than 7 •If greater than 7, call to attention of responsible organization
•OK if maturity centroid is less than 3 •If greater than 3 call to attention of responsible organization	Unsatisfactory Call to attention of responsible organization

0

Maturity

10

4.8b Impact / Likelihood

10

Impact

•OK if due to technical challenge •Not OK if due to inadequate funding or unreasonable time frames. Call to attention of responsible organization	•OK if maturity centroid is less than 7 •If greater than 7 probably not S&T. Call to attention of responsible organization
Unsatisfactory Call to attention of responsible organization	Probably not S&T Call to attention of responsible organization

0

Likelihood

10

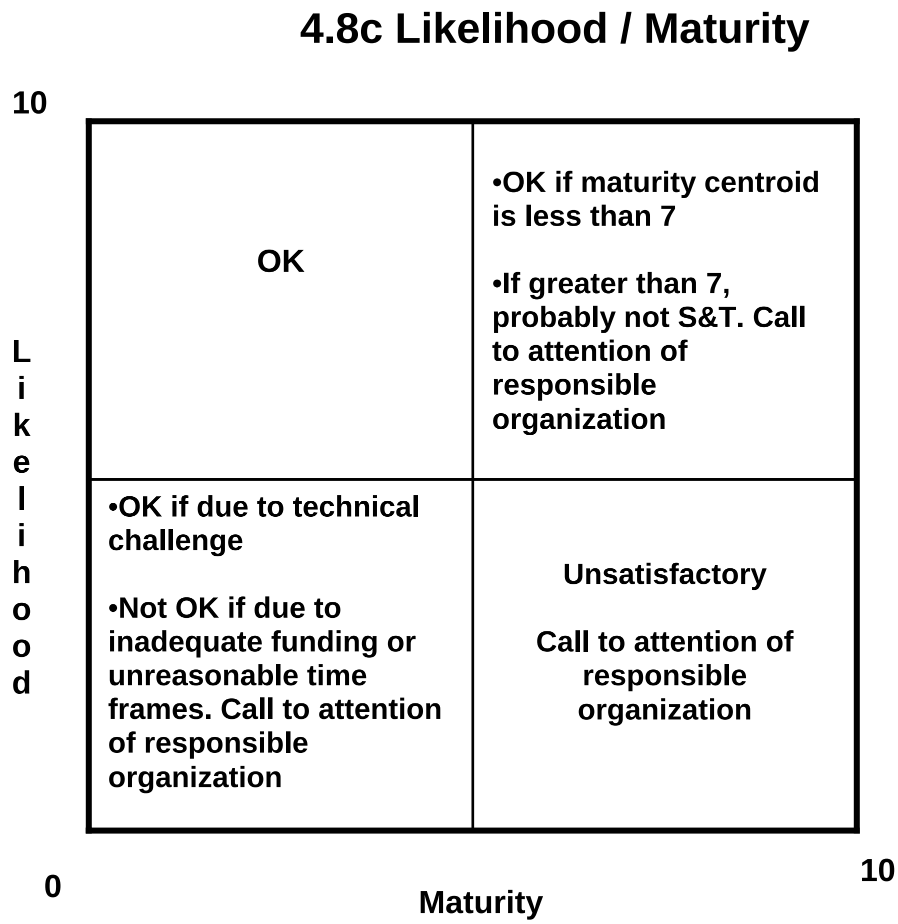


Figure 4.8. Decision criteria for assessments at the individual work unit level or the individual CEST level

The above discussion covers but a few of the ways that the data from an EWA could be displayed and analyzed. For example, there are ten data cubes that could be created (such as a cube with the axes: Adequacy of funding, Realism of time frames, and Level of scientific and technical challenge). Decision criteria could be established for each of these data cubes. Also, evaluation of the first few moments of the rating distributions would be necessary. The matter of how to aggregate the data from the individual CEST scores is not trivial, especially as one moves from a few CESTs (like the case considered above) to large numbers of CESTs (such as for the total program). These issues would best be sorted out by conducting limited testing of the ideas presented above. A reasonable place to start would be to incorporate some of the EWA considerations into the conventional review process and/or to conduct limited tests of the EWA approach on small segments of the program. Such testing would provide guidance as to the practicality and value of the EWA that emerged from this study. It would also be an important step in gaining acceptance of the approach if it turned out be practical and valuable.

5. Conclusions and Recommendations

Four major conclusions have emerged from this study:

- Many different and valuable reviews of the DOD S&T program are currently conducted. However, the aggregation of these reviews does not constitute an EWA. There is no obvious way to modify the current review structure so as to produce an EWA as it has been defined for this study. The underlying problem is the sheer magnitude and breadth of the program. A new methodology will be required if one is to institutionalize an EWA.

- The current documentation of the DOD S&T program does not reflect the state of the art of information technology, is marginal for exercising stewardship over the program, and is not adequate for the conduct of an EWA. The recent introduction of the DDR&E "R&E Portal" will improve this situation. However, the planned documentation of the program will remain inadequate for the conduct of an EWA.

- DOD does not access systematically the breadth of scientific and technical knowledge and expertise that is potentially available to it. The establishment of and ready access to communities of experts that cover all DOD areas of scientific and technical interest would be of great value.

- The current state of the art in and expected advancements in information technology and library science offer the best hope of resolving the above concerns.

These four conclusions lead to several recommendations:

- The principal investigators of the various DOD S&T projects should be taught to and required to document their projects in terms of the very specific CEST issues that they are funded to resolve. These issues should be stated at the level at which people are actually performing work rather than in terms of general objectives.

- S&T project documentation requirements should be standardized across DOD and should contain the information needed for an EWA. Funding for a project should not be released until the organization responsible for the project submits satisfactory documentation to DTIC. The DTIC database that results from proper documentation of the program will be broadly valuable across DOD (DDR&E, funding agencies, performers, etc.) independent of the EWA. The needed information is available at the performer level and can and should be documented as a routine matter. This documentation is required as a matter of stewardship.

- The underlying strategy for an EWA should be to carefully and succinctly state the CEST issues being addressed by the funded program so that an expert in the specific topical area being pursued can quickly assess the viability of the program's meeting stated plans and milestones.

- National communities of experts should be established for each of the specific CEST issues being addressed. The tools of modern information technology and library science must be utilized to accomplish this. Some DOD research investment in library science may be required to resolve DOD specific issues. The establishment of the communities of experts will be of great value independent of the EWA.

- For an EWA, the approach of collecting the review teams at a central location for the purpose of holding hearings must be abandoned and replaced by a distributed assessment process that exploits the documentation of all of the CEST issues, the advances in information technology and library science, and the readily available access to geographically distributed communities of experts. The EWA should be conducted as a targeted survey of the appropriate communities of experts.

- DTIC should be the custodian of the new DOD S&T database and for the automation of and the routine implementation of the EWA. The assessment should ultimately be a routine byproduct of doing business.

- A full EWA as envisioned by this study should not be initiated in the short term. Many details need to be addressed before such an assessment could be undertaken. Certain aspects of the proposed process should be examined via the conventional review process. For example, automated techniques for forming communities of experts could be tested by employing them as part of establishing the conventional review teams. Test cases should be conducted to clarify how to document the program in terms of CEST and to examine and resolve problems that confront the distributed assessment approach. These test cases should address classified distributed assessments (e.g. utilizing SIPRnet) and unclassified distributed assessments. DOD should be an active participant in the national efforts that are underway to take advantage of the ongoing revolution in library science.

If the process described in this report could be implemented it would have a number of spin-offs. For example, the supporting DTIC database could be interrogated so as to compare the actual program of record with the DOD S&T investment strategy. It would also establish a broad database of experts covering most of the S&T areas of interest to DOD. It may be that the most valuable result of this approach to an EWA is the establishment and maintenance of a detailed database for the funded S&T program and the development of a large community of experts who have a connection with and interest in DOD S&T.

APPENDIX A

Work Unit Summary Hypothetical Example

1. Title: Hypersonic Turbine-Based Combined Cycle Engine (Mach 4 turbine and Mach 3.5 to 7 scramjet engine) (U)

2. Date of Summary: 12/08/05

3. Responsible Organization

a. Name: Some DOD Activity **b. Address:** Somewhere, USA

c. Principle Investigator:

Name	Phone	Email Address
John Doe	123-456-7891	jdoe@----.mil

4. Classification Level:

a: Summary Level: U **b: Work Level:** U

5. Military need: Technology relevant to candidate system solutions for Prompt Global Strike, Long Range Strike, and Assured Access to Space:

- Responsive global power projection
- Responsive and persistent ISR
- Responsive global payload delivery
- Responsive space payload delivery

6. Technical Objective: Future hypersonic air-breathing UCAVs for time-critical theater operations, and reusable launch vehicles for prompt global response and routine space access, will require 2-3 propulsion modes to operate across their design speed ranges. One of the most likely propulsion systems for such applications will be the turbine-based combined-cycle engine (TBCC), which consists of a supersonic (~Mach 4) turbine engine closely integrated with a dual-mode ramjet/scramjet engine. In order to proceed along this path it will be necessary to develop a turbine-based combined-cycle (TBCC) engine inlet system that efficiently delivers air flow required by the turbine engine when operating alone, air flow required by the scramjet when operating alone, and to both engines simultaneously during the transition from turbine to scramjet. It is also necessary to maintain inlet fluid dynamic stability during mode transition and in all other operational engine modes. One must develop a TBCC engine nozzle system that efficiently expands flow to produce thrust for the turbine engine when operating alone, for the scramjet engine when operating alone, and for both engines when operating simultaneously during mode transition. It is necessary to develop an aircraft and engine flow-path control system that adequately stabilizes and controls the aircraft and TBCC engine flow-paths during engine mode transition and all other flight phases. Lastly, it will be necessary to develop the material, structural and mechanical design for the articulated TBCC inlet and nozzle systems, and a thermal management system for the turbine engine when it is shutdown but exposed to scramjet flow-path heating

7. Progress: New project

8. Critical Enabling Science and Technology (CEST)

CEST 1: Hypersonic engine dynamic seals for articulated (i.e. variable geometry) inlet and nozzle structural elements. (U)

Approach: Design and test high-temperature seals for a full-scale TBCC inlet and nozzle (Mach 4 turbine and Mach 3.5 to 7 scramjet engine). Consideration will be given to both metallic and ceramic seals.

Technology Metrics:

Metric	**Metric Unit**	**SOA***	**Planned Value**
Maximum use temperature	Temperature ^{o} F	1400^o F (metallic) 1800^0 F (ceramic)	1800^o F (metallic) 2500-3000^o F (ceramic)
Durability/life	# of cycles before replacement	1000's for metallic 10 – 100 for ceramic	1000's for <2000^o F 100's at 2500^o F 10's at 3000^o F

Milestones:

TRL	**Year**	**Description**
6	2008	Design and fabricate seals and complete critical component testing in a relevant environment

***Current TRL = 2 - 3**

Funding:

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Funding Profile	$1200K	$1500K	$1800K	$1500K

Technical Work Years

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Technical Work Years	**3**	**4**	**4**	**3**

* State of the art.

Suggested Community of Experts:

Last Name*	First Name*	Organization	Email	Phone
		NASA Glenn Research Center		
		NASA Glenn Research Center		

***names deleted**

CEST 2: Dual flow-path TBCC hypersonic engine inlets and nozzles (U)

Approach: Define TBCC (Mach 4 turbine and Mach 3.5 to 7 scramjet engine) inlet and nozzle geometry and articulation requirements based initially upon knowledge of existing supersonic inlets and nozzles, empirical and theoretical design guidelines and operability (i.e., stability) criteria, engine performance characteristics, and analysis results derived from engineering codes and Computational Fluid Dynamics (CFD). This would be followed by building sub-scale inlet and nozzle models and testing them in wind tunnels, both statically and with dynamic articulation of the variable geometry components. The knowledge gained from testing and analysis will be used to optimize inlet and nozzle designs. This will be aided by mathematical optimization and multidisciplinary design optimization techniques.

Technology Metrics:

Metric	Metric Unit	SOA	Planned Value
Integrated dual inlet operability	# of inlets operating simultaneously at high performance	1	2 at SOA inlet recovery and operability/stability
Integrated dual nozzle operability	# of nozzle operating simultaneously at high performance	1	2 at SOA thrust coefficient

Milestones:

TRL	Year	Description
3	2006	TBCC inlet and nozzle design and analysis
4	2007	Wind tunnel test sub-scale TBCC inlet and nozzle
5	2008	Update inlet and nozzle designs, and tunnel test inlet on a sub-scale aircraft model with an articulated inlet

***Current TRL = 2 – 3**

Funding:

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Funding Profile	0	$3000K	$4000K	$3000K

Technical Work Years

Fiscal Year	**2005**	**2006**	**2007**	**2008**
Technical Work Years	**0**	**8**	**8**	**8**

Suggested Community of Experts:

Last Name*	**First Name***	**Organization**	**Email**	**Phone**
		Johns Hopkins Applied Physics Laboratory		
		Air Force Research Laboratory/Propulsion Directorate		
		NASA Langley (Retired)		
		TechLand Research, Inc.		
		NASA Langley (Retired)		

*****names deleted

CEST 3: Post shutdown turbine hypersonic engine thermal management system (TMS) (U)

Approach: Design a thermal management system (TMS) for a TBCC engine (Mach 4 turbine and Mach 3.5 to 7 scramjet engine) flow-path and analyze it using fluid, thermal and structural analysis codes, and then bench test critical TMS components to verify predicted operation and performance.

Technology Metrics:

Metric	**Metric Unit**	**SOA**	**Planned Value**
Turbine bay temperature during scramjet operation	Temperature	N/A	Max temperature capability of lowest temperature turbine material (~ 1500^{o} F)

Milestones:

TRL	Year	Description
3	2007	TMS design and analysis
4	2008	Critical TMS component bench testing and analysis update

Funding:

Fiscal Year	2005	2006	2007	2008
Funding Profile	NA	$1000k	$2000k	$3000k

Technical Work Years

Fiscal Year	2005	2006	2007	2008
Technical Work Years	0	3	4	5

Suggested Community of Experts:

Last Name*	First Name*	Organization	Email	Phone
		Pratt and Whitney		
		Pratt and Whitney		
		Pratt and Whitney		
		Air Force Research Lab		
		Pratt and Whitney, retired		

*****names deleted

CEST 4: Integrated high speed airframe and engine control system development **(U)**

Approach: Develop inlet and nozzle control algorithms for a hypersonic Turbine-Based Combined Cycle Engine (Mach 4 turbine and Mach 3.5 to 7 scramjet engine), and then test them via dynamic simulation using data derived from testing and CFD analysis. Vehicle stability and control during engine mode transition will be verified via dynamic simulation using CFD-derived aero data in conjunction with inlet and nozzle test data. Wind tunnel tests will be conducted of an aircraft model with variable inlet to verify inlet stability during mode transition, and aero data will be gathered to verify vehicle stability and control during the transition event.

Technology Metrics

Metric	Metric Unit	SOA	Planned Value
Inlet stability during engine mode transition	Stability margin	N/A	5%
Aerodynamic dynamic stability during engine mode transition	Control system phase and gain	N/A	6 db gain and 45° phase margin

Milestones

TRL	Year	Description
3	2007	Develop inlet, nozzle and aircraft control laws using aerodynamic propulsion analysis of same. Perform dynamic simulations.
4	2008	Use inlet control laws in wind tunnel test of integrated inlet/airframe. Use tunnel data to update control laws and simulations

***Current TRL = 2-3**

Funding

Fiscal Year	2005	2006	2007	2008
Funding Profile	$1000 k	$1500 k	$1500 k	$2000 k

Technical Work Years

Fiscal Year	2005	2006	2007	2008
Technical Work Years	**3**	**3**	**3**	**4**

Suggested Community of Experts:

Last Name*	First Name*	Organization	Email	Phone
		Boeing Huntington Beach		
		NASA Dryden		
		Air Force Research Laboratory		
		Boeing St. Louis		

*****names deleted

9. Total Project Funding:

Fiscal Year	2005	2006	2007	2008
Total Funding	$2200k	$7000k	$9300k	$9500k

10. Program Participants:

Contracts with whom	XYZ Corp.
Grants with whom	TBD
Government organization	Some DOD Activity

11. DOD Subject Areas: (http://www.dtic.mil/dtic/subcatguide/ **)**

- **01-01-Aerodynamics**
- **01-03-Aircraft**
- **01-04-Flight control and instrumentation**
- **21-05-Jet and gas turbine engines**

12. Key Words: Hypersonic turbine-based combined-cycle engine; High-temperature seals; Supersonic inlet; Supersonic nozzle; Turbine engine; Scramjet engine; Supersonic inlet control system; Variable geometry inlet; Variable geometry nozzle.

APPENDIX B

Potential Communities of Experts

The potential community of experts shown here were obtained by on-line computer searches of various databases using search engines such as Scirus, Google, Google Scholar, and the AIAA Electronic Library

Table B1: Potential community of experts for CEST 1: Hypersonic Engine Seals

Number of Individuals Identified	Organization	Organization Location
1	Advanced Components & Materials, Inc	East Greenwich, RI
2	Aerojet	Sacramento, CA
2	Aerothermal and Aero-Optics Evaluation Center	Buffalo, NY
1	Albany Techniweave, Inc.	Albany, NY
8	ATK Thiokol Propulsion Corporation	Brigham City, UT
2	BF Goodrich Aerospace	Chula Vista, CA
1	California Institute of Technology	Pasadena, CA
4	Case Western Reserve University	Cleveland, OH
1	Connecticut Reserve Technologies	Stow, OH
3	Drexel University	Philadelphia, PA
1	Embry-Riddle Aeronautical University	Daytona Beach, FL
4	FDC/NYMA, Inc.	Hampton, VA
3	General Applied Science Laboratories, Inc.	Ronkonkoma, NY
2	General Electric	Cincinnati, OH
2	General Electric Global Research Center	Niskayuna, NY
1	JIAFS, The George Washington University	Hampton, VA
9	Johns Hopkins University, Applied Physics	Laurel, MD
1	Modern Technologies Corporation	Middleburg Heights, OH
3	Mohawk Innovative Technology, Inc.	Albany, NY
2	NASA Ames Research Center	Moffett Field, CA
10	NASA Glenn Research Center	Cleveland, OH
1	NASA Headquarters	Washington, DC
28	NASA Langley Research Center	Hampton, VA
10	NASA Lewis Research Center	Cleveland, OH
2	NASA Marshall Space Flight Center	Huntsville, AL
2	Ohio Aerospace Institute	Beavercreek, OH
4	Orbital Sciences Corporation	Dulles, VA
2	Pennsylvania State University	University Park, PA
1	Refractory Composites Inc.	Glen Burnie, MD
1	Rensselaer Polytechnic Institute	Troy, NY
1	Saint-Gobain Advanced Ceramics	Northboro, MA
2	Sverdrup Technology, Inc.	Brook Park, OH
1	The Advanced Products Company	North Haven, CT
3	The Boeing Company	Long Beach, CA
1	Tribos Engineering, P.C	Niskayuna, NY
7	U.S. Air Force Research Laboratory	Wright-Patterson Air Force Base, OH
1	U.S. Army Research Lab	Adelphi, MD
1	Universal Technology Corporation	Beavercreek, OH
3	University of Akron	Akron, OH
1	University of Minnesota	Minneapolis, MN
1	University of Toledo	Toledo, OH
1	Virginia Tech, Mechanical Engineer Dept.	Blacksburg, VA

Table B2: Potential community of experts for CEST 2: Hypersonic Turbine-Based Combined Cycle Engine (Mach 4 turbine and Mach 3.5 to 7 scramjet engine)

Number of Individuals Identified	Organization	Organization Location
2	Allison Advanced Development Co.	Indianapolis, IN
2	Astrox Corporation	College Park, MD
3	Boeing Corporation	St. Louis, MO
1	Brigham Young University	Provo, UT
1	Johns Hopkins University	Columbia, MD
1	Johns Hopkins University, Applied Physics	Laurel, MD
8	NASA Langley Research Center	Hampton, VA
1	NASA Marshall Space Flight Center	Huntsville, AL
1	Pyrodyne Inc.	Glenwood, MD
1	SAF/AQRT	Washington, DC
2	Spiritech Advanced Products Inc.	Jupiter, FL
2	U.S. Air Force Research Lab	Wright-Patterson AFB, OH
1	University of Florida	Gainesville, FL
2	University of Maryland	College Park, MD

Table B3. Potential community of experts for CEST 3: High-speed turbine engine thermal management system (TMS)

Number of Individuals Identified	Organization	Organization Location
2	Aerojet	Sacramento, CA
5	Air Force Research Laboratory	Wright Patterson AFB, OH
2	Allison Advanced Development Co.	Indianapolis, IN
1	Andrews Space Inc.	Seattle, WA
1	Brigham Young University	Provo, UT
4	FDC/NYMA, Inc.	Hampton, VA
1	Flight Unlimited	Flagstaff, AZ
4	Georgia Institute of Technology	Atlanta, GA
1	Johns Hopkins University	Columbia, MD
2	NASA Dryden Flight Research Center	Edwards, CA
7	NASA Glenn Research Center	Cleveland, OH
1	NASA Headquarters	Washington, DC
15	NASA Langley Research Center	Hampton, VA
1	NASA Marshall Space Flight Center	Huntsville, AL
1	Parks College	St. Louis, MO
1	Pratt & Whitney Space Propulsion	West Palm Beach, FL
6	SAIC	Huntsville, AL
3	SAIC	Torrance, CA
3	Space Works Engineering, Inc.	Atlanta, GA
2	Spiritech Advanced Products, Inc.	Jupiter, FL
3	The Boeing Company	Long Beach, CA
3	The Boeing Company	Seal Beach, CA
1	University of Florida	Gainesville, FL

Table B4. Potential community of experts for CEST 4: Hypersonic Engine Control System Development

Number of Individuals Identified	Organization	Organization Location
5	Air Force Research Laboratory	Wright-Patterson AFB, OH
4	Andrews Space, Inc.	Seattle, WA
1	Boeing Company	St. Louis, MO
1	Boeing Phantom Works	Huntsville, AL
2	Boeing Phantom Works	St. Louis, MO
1	Brigham Young University	Provo, Utah
2	Enercon Systems	Cleveland, OH
3	FDC/NYMA, Inc. Aerospace Sector	Hampton, VA
1	Flight Unlimited	Flagstaff, AZ
1	Flow Parametrics	New Castle, DE
3	General Applied Science Laboratories	Ronkonkoma, NY
1	General Electric	Cincinnati, OH
1	General Electric	Lynn, MA
6	Georgia Institute of Technology	Atlanta, GA
1	International Space Systems, Inc.	Huntsville, AL
2	Johns Hopkins University	Columbia, MD
1	Modern Technologies Corporation	Middleburg Heights, OH
2	NASA Ames Research Center	Moffett Field, CA
3	NASA Dryden Flight Research Center	Edwards, CA
9	NASA Glenn Research Center	Cleveland, OH
1	NASA Headquarters	Washington, DC
32	NASA Langley Research Center	Hampton, VA
6	NASA Lewis Research Center	Cleveland, OH
1	NASA Marshall Space Flight Center	Huntsville, AL
3	Ohio State University	Columbus, OH
1	Parks College	St. Louis, MO
2	Pennsylvania State University	University Park, PA
3	Princeton University	Princeton, NJ
1	Proton Aerospace Corporation	Jupiter, FL
1	QSS Group, Inc.	Cleveland, OH
8	SAIC	Huntsville, AL
2	Spiritech Advanced Products, Inc.	Jupiter, FL
2	TechLand Research, Inc.	North Olmstead, OH
4	The Boeing Company	Seal Beach, CA
1	University of Alabama	Huntsville, AL
1	University of Florida	Gainesville, Florida
2	University of Maryland	College Park, MD

APPENDIX C

NASA Technology Inventory

This information presented in this appendix is taken from several sites that describe the NASA Technology Inventory. The purpose of the NASA Technology Inventory is to document the full scope of NASA's technology investment in order to improve management and communications inside and outside the agency. Each of the 5 NASA Enterprises manages a technology program that is focused on the needs and objectives of that Enterprise. In addition, the enterprises support technology activities within their Advanced Development, and Research and Analysis Programs. Other NASA programs contribute technology as well, including the Cross Enterprise Technology Development Program, the Small Business Innovation Research Program, the Center Director's Discretionary Program, safety and engineering programs, and educational programs. Collectively, all of the technology activities in NASA amount to about $1.6 billion.

The Tech Inventory seeks to capture this spectrum of activities in a common, searchable format. Each input is linked to the Enterprises that would benefit, so that program managers can quickly identify technologies that support their programs. Keywords and a search engine enable technologists to identify related work. Technology Readiness Levels help describe the maturity of programs, and help separate near-term from far-term work. Enterprise-specific fields help NASA managers track their technology programs. Partnership information is collected as a NASA GPRA metric that helps measure the extent of collaboration with other agencies.

For the purposes of this database, technology is defined as the practical application of knowledge to create the capability to do something entirely new or in an entirely new way. This can be contrasted to "scientific research," which encompasses the discovery of new knowledge from which new technology is derived, and engineering, which uses technology derived from this knowledge to solve specific technical problems. When investments are made in a particular technology, it begins to mature—a process of testing and analysis that progressively reduces the programmatic risk of selecting that technology for an application and increases the readiness of that technology for use in a mission. Technology may be described in terms of maturity within a scale of Technology Readiness Levels, which reflect the extent to which the technology has been proven in a realistic situation.

Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The TRL concept is based on a general model for technology maturation that includes: (a) research in new technologies and concepts (targeting identified goals, but not necessary specific systems), (b) technology development addressing specific technologies for one or more potential identified applications, (c) technology development and demonstration for each specific application before the beginning of full system development of that application, (d) system development (through first unit fabrication), and (e) system launch and operations.

Technology Readiness Levels Summary

TRL 1 Basic principles observed and reported

TRL 2 Technology concept and/or application formulated

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 4 Component and/or breadboard validation in laboratory environment

TRL 5 Component and/or breadboard validation in relevant environment

TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 7 System prototype demonstration in a space environment

Discussion of Each Level

The following paragraphs provide a descriptive discussion of each technology readiness level, including an example of the type of activities that would characterize each TRL.

TRL 1

Basic principles observed and reported

This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development. Examples might include studies of basic properties of materials (e.g., tensile strength as a function of temperature for a new fiber).

TRL 2

Technology concept and/or application formulated

Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be "invented" or identified. For example, following the observation of high critical temperature superconductivity, potential applications of the new material for thin film devices (e.g., SIS mixers) and in instrument systems (e.g., telescope sensors) can be defined. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.

TRL 3

Analytical and experimental critical function and/or characteristic proof-of-concept

At this step in the maturation process, active research and development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2. For example, a concept for High Energy Density Matter (HEDM) propulsion might depend on slush or super-cooled hydrogen as a propellant: TRL 3 might be attained when the concept-enabling phase/temperature/pressure for the fluid was achieved in a laboratory.

TRL 4

Component and/or breadboard validation in laboratory environment

Following successful "proof-of-concept" work, basic technological elements must be integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is relatively "low-fidelity" compared to the eventual system: it could be composed of ad hoc discrete components in a laboratory. For example, a TRL 4 demonstration of a new fuzzy logic approach to avionics might consist of testing the algorithms in a partially computer-based, partially bench-top component (e.g., fiber optic gyros) demonstration in a controls lab using simulated vehicle inputs.

TRL 5

Component and/or breadboard validation in relevant environment

At this, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level or system-level) can be tested in a simulated or somewhat realistic environment. From one-to-several new technologies might be involved in the demonstration. For example, a new type of solar photovoltaic material promising higher efficiencies would at this level be used in an actual fabricated solar array blanket that would be integrated with power supplies, supporting structure, etc., and tested in a thermal vacuum chamber with solar simulation capability.

TRL 6

System/subsystem model or prototype demonstration in a relevant environment (ground or space)

A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or subsystem which would go well beyond ad hoc, patch-cord or discrete component level breadboard would be tested in a relevant environment. At this level, if the only relevant environment is the environment of space, then the model/prototype must be demonstrated in space. Of course, the demonstration should be successful to represent a true TRL 6. Not all technologies will undergo a TRL 6 demonstration: at this point the maturation step is driven more by assuring management confidence than by R&D requirements. The demonstration might represent an actual system application, or it might only be similar to the planned application, but using the same technologies. At this level, several-to-many new technologies might be integrated into the demonstration. For example, a innovative approach to high temperature/low mass radiators, involving liquid droplets and composite materials, would be demonstrated to TRL 6 by actually flying a working, sub-scale (but scaleable) model of the system on a Space Shuttle or International Space Station pallet.

In this example, the reason space is the relevant environment is that microgravity plus vacuum plus thermal environment effects will dictate the success/failure of the system and the only way to validate the technology is in space.

TRL 7

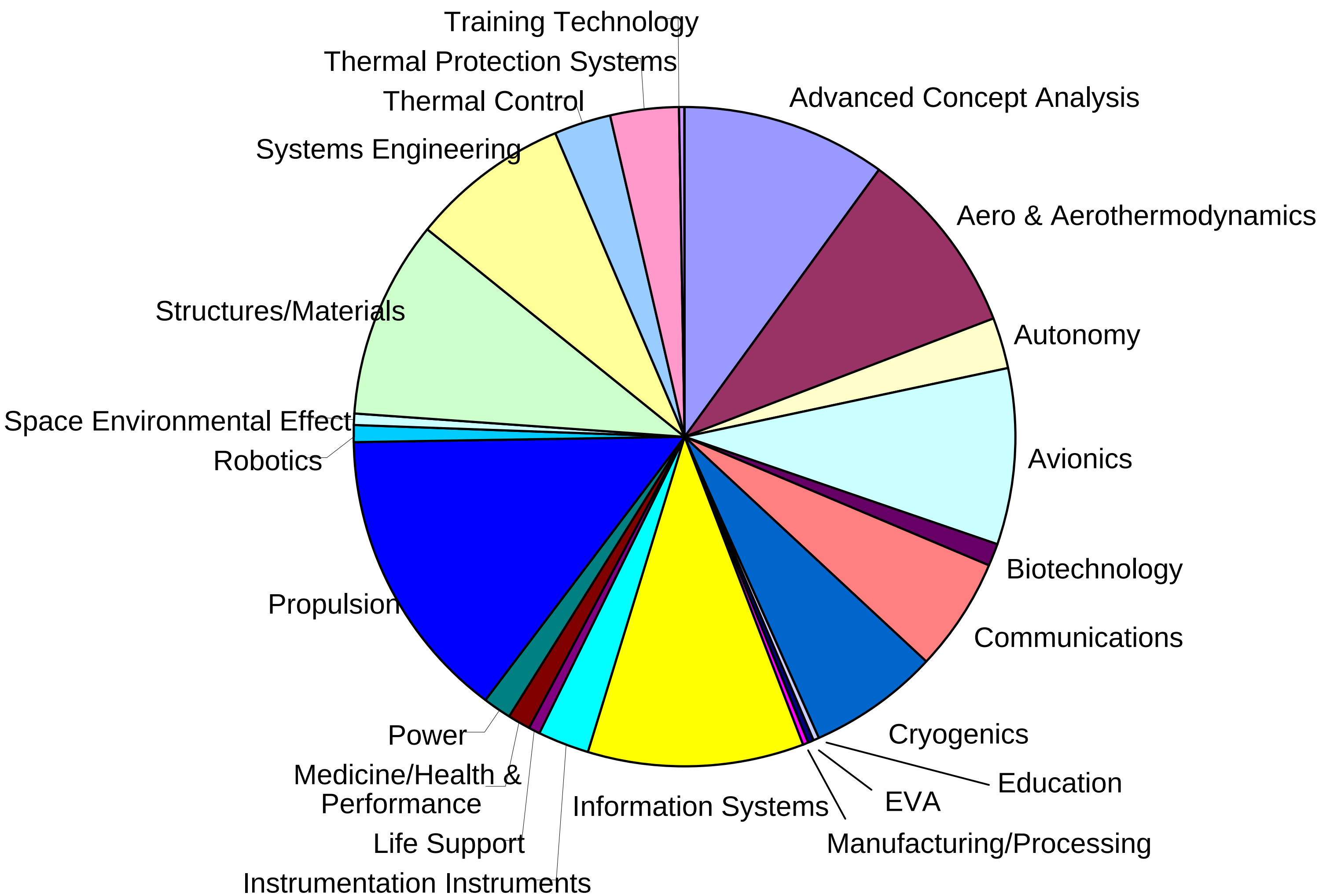
System prototype demonstration in a space environment

TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. It has not always been implemented in the past. In this case, the prototype should be near or at the scale of the planned operational system and the demonstration must take place in space. The driving purposes for achieving this level of maturity are to assure system engineering and development management confidence (more than for purposes of technology R&D). Therefore, the demonstration *must* be of a prototype of that application. Not all technologies in all systems will go to this level. TRL 7 would normally only be performed in cases where the technology and/or subsystem application is mission critical and relatively high-risk. Example: the Mars Pathfinder Rover is a TRL 7 technology demonstration for future Mars micro-rovers based on that system design. Example: X-vehicles are TRL 7, as are the demonstration projects planned in the New Millennium spacecraft program.

The NASA Technology Inventory is available to government employees and a restricted version is available to government contractors. This study accessed the inventory and found its functionality to be quite good. It was straightforward to extract information from the inventory and reconfigure it for specific display purposes. The following sequence of charts represents one such reconfiguration and is meant to illustrate how one can move from the highest level of description in the inventory to its lowest level. Each chart in the sequence was arrived at by a mouse click on a desired part of the previous chart. The first chart is the highest level of aggregation and the last chart is the lowest level. The example sequence tracks the Technology Discipline “Power”. The specific details of the program have been removed since they are not relevant to the purpose here where only functionality is of interest.

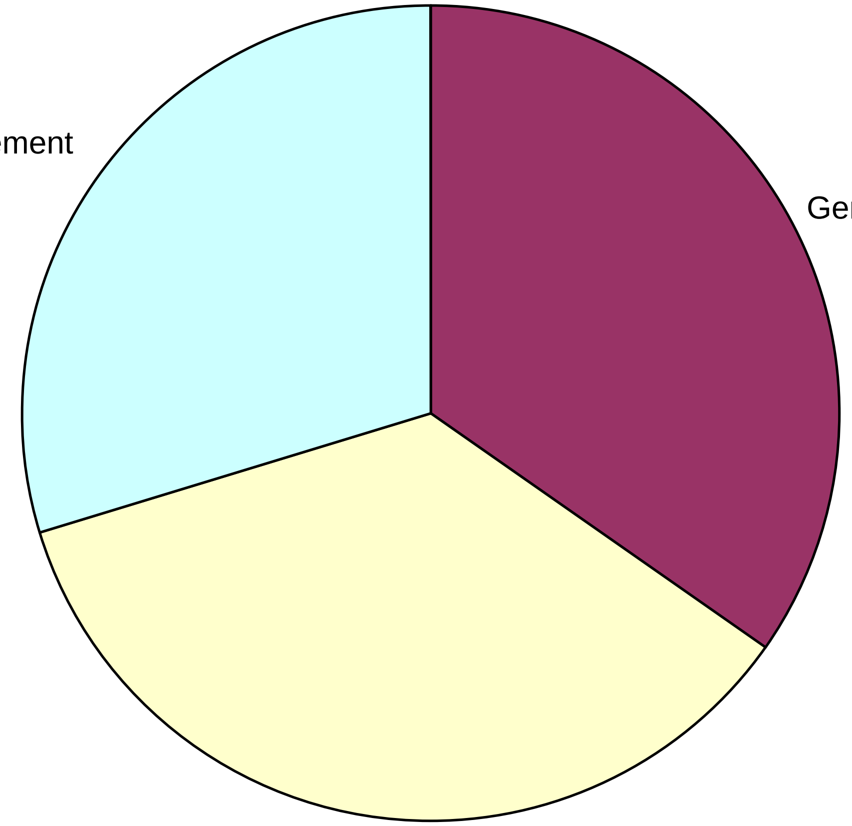
NASA Technology Disciplines: Funding in $K

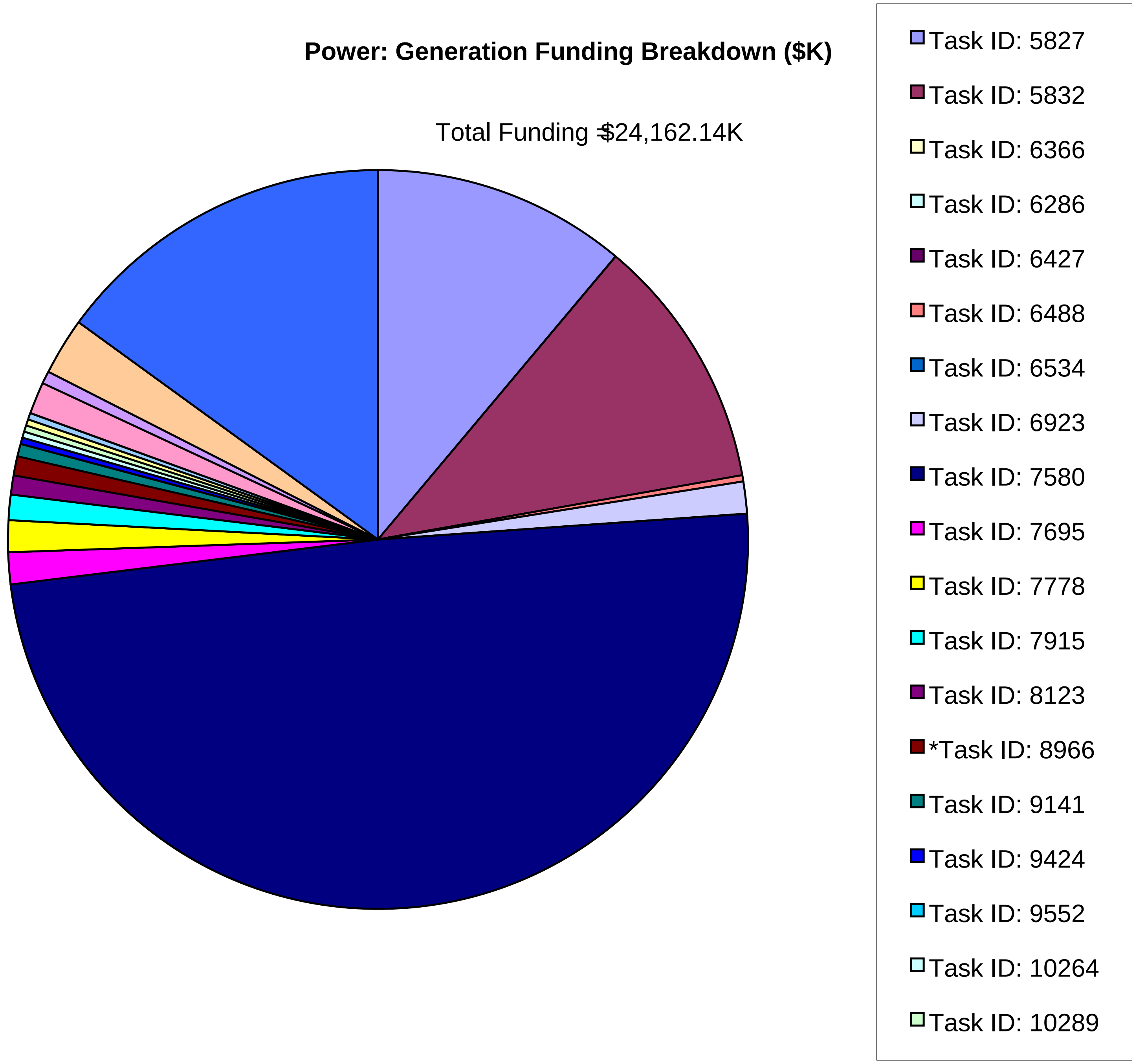
Total Funding = $3,951,991K



NASA Technology Discipline Power: Funding

Total Funding = $60,097K




Power: Generation Funding Breakdown ($K)
Total Funding = $24,162.14K
Task ID: 5827
Task ID: 5832
Task ID: 6366
Task ID: 6286
Task ID: 6427
Task ID: 6488
Task ID: 6534
Task ID: 6923
Task ID: 7580
Task ID: 7695
Task ID: 7778
Task ID: 7915
Task ID: 8123
*Task ID: 8966
Task ID: 9141
Task ID: 9424
Task ID: 9552
Task ID: 10264
Task ID: 10289

Sample Task Description

*Task ID: 5827	Task Name: *Advanced Thin Film Technology for Ultra-lightweight Solar Cell Arrays

*Center	*Sponsor
GRC	AST

Point of Contact

	First Name	Last Name	E-Mail	Phone
Task POC				
Site POC				
COTR				

***Description**

***Objective & Description**

***Technology Disciplines (Specific)**

	FY04 Funding $K	FY04 FTE
Power		
generation		

***Technology Application Areas & Special Categories**

- Terrestrial Atmosphere/Surface Systems
- Space Technology/Spacecraft/Platform
- Space Technology/Constellations
- Space Technology/Planetary Atmosphere/Surface Systems

Technology Metrics

Technology Discipline: Power

Metric	Technology Metric Units	Current State of the Art Value	Planned Value
No metrics entered for this discipline			

Technology Discipline: Power | generation

Metric	Technology Metric Units	Current State of the Art Value	Planned Value
Efficiency	%		
Mass Specific Power	w/kg		
Areal Specific Power	w/m2		
Specific Cost ($/w)			

Metric Comments:

Not Specified

Milestones

TRL	Year	Description
1	2004	
1	2004	
2	2004	
3	2005	
6	2012	

***Maturity Time Frame:** Far

*** Current TRL** = 2

FY	
*NASA Profile in $K	
Civil Service FTE	

NASA Distribution Funding		
Contracts With Whom		
Grants With Whom		
NASA Field Center		
Other (Space Act, etc.)		
Partnership Distribution Funding		
NASA Contributions		
Other Contributions		

***Link to other site**

***Attached Image**

None