NASA METEOROID AND ORBITAL DEBRIS TECHNOLOGY PROGRAM: AN OVERVIEW

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ABSTRACT

The growth of the near-Earth meteoroid and orbital debris environment and the potentially damaging interplanetary meteoroid and meteoroid streams present well documented hypervelocity impact threats to spacecraft. These spacecraft are vital to the scientific, commercial and environmental interests of all space-fairing nations. NASA has established the Meteoroid and Orbital Debris Technology Program (M/OD TP) to 1) provide the needed technologies that support the development of cost-effective spacecraft with high survivability in the presence of these environments, 2) to increase the understanding of the effects of these environments on spacecraft, and 3) to minimize the human contribution to these environments.

1. INTRODUCTION

The NASA Meteoroid and Orbital Debris Technology Program (M/OD TP) was established to provide the technologies that will enable the Agency to meet, with respect to M/OD related issues, its goals of quicker, more cost-effective, higher quality spacecraft development in the coming decades. The program was initiated in October 1996 with the initial release of the NASA M/OD TP Plan (Ref. 1). The plan serves as a guideline and a tool for coordination of the agency-wide research and technology development related to the M/OD technologies. The M/OD TP supports the activities of environment definition and mitigation, design, test, and analysis, and promotes technology transfer to private industry and other Government agencies.

Less than a decade ago, orbital debris was not generally recognized as a serious threat to spacecraft. Because the development of this threat is so recent, NASA's, and indeed the technical community's, technology for dealing with M/OD impacts and effects is still immature. Great strides have been made in a few areas related to the International Space Station (ISS) development. However, in terms of the broader view of spacecraft systems, materials, and structures, current technology is not advanced and its development has been sporadic and in need of better coordination. Additionally, NASA recognizes the need for continued exploration of deep space. The spacecraft used for these long duration missions can encounter, as part of the natural environment, micron-size micrometeoroid particles with velocities in excess of 250 km/s. Understanding the effects of these very small, yet hyperenergetic, impacts on spacecraft function is of great importance to spacecraft developers.

Another area of concern to NASA and the international community is that the continued presence of satellites, payload experiments, and expended spacecraft stages in earth orbits will cause increased orbital debris formation from potential collisions with existing debris. Recently the first collision between two cataloged objects in Low Earth Orbit (LEO) occurred in July 1996 when a French military satellite (Cerise) collided with a piece of an Ariane rocket's third stage, which exploded after it was cast off from its launch in 1986 (Ref. 2). The development of technologies that will help minimize the orbital stay of expended and "lifeless" orbiting structures will help reduce this damaging environment.

2. OVERVIEW OF CRITICAL TECHNOLOGIES

For the spacecraft developer, the meteoroid and orbital debris environments represent a complication, a probable cost impact to the system design and a threat to the successful completion of the spacecraft's mission. To mitigate this threat, the spacecraft design follows a process illustrated by the flow diagram in the lower section of figure 1. Actually, the flow illustrated by this figure will be repeated a series of times as the maturity of the program develops from concept to final design, test and verification. Each time, the process involves greater detail and care in its implementation. The technologies developed under the M/OD TP are selected to: make the process more effective, increase the accuracy of the analysis, and reduce the weight and cost of the final product. To do this, the M/OD TP must provide technology improvements that provide benefits to each stage of the spacecraft development process and the final product. The graph in figure 1. shows how

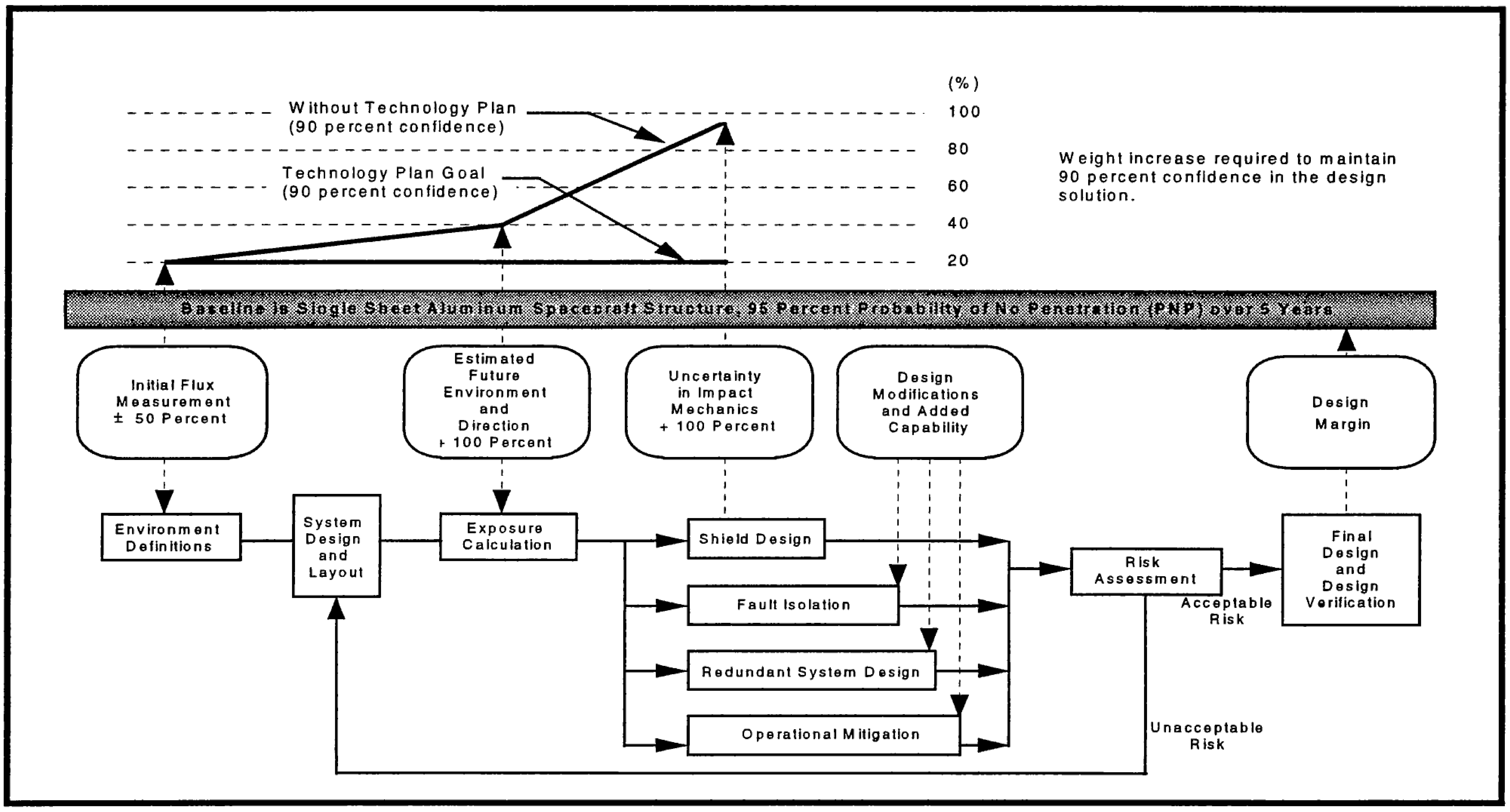

Figure 1. Interrelationships Between Technology Maturity and Spacecraft Design Weight

uncertainty in the engineering process leads to additional weight in the spacecraft to maintain the same reliability. The illustration is based on a single sheet aluminum exterior wall, but would be similar for more complex shielding designs or added redundancy.

Improvements to the spacecraft as a product will go hand-in-hand with improvements in the process for spacecraft development, since understanding the mechanics of M/OD hypervelocity impacts and the multitude of secondary phenomena which accompany an impact will lead to better ways to design and protect spacecraft systems.

As a result of discussions with the technical community, several important program related priorities are emerging. First, a need exists for technology support to programs in all phases of development, from preliminary design to operations. Second, , there is widespread support for the development of inexpensive, standardized, quick-look test methods for material or design screening applications. Third, the very specific program-related testing, analysis and design work needs to be augmented with broader related technologies to address M/OD related spacecraft development problems found in the technical community. Fourth, archiving and easy access to the results is of paramount importance to the technical community.

3. TECHNOLOGY NEEDS

Spacecraft and space system M/OD technology needs differ depending on the stage of development of the program. General survey models and assessment tools, and performance history of previous systems are needed during the conceptual and initial stages of development. During the final design and development stages, specialized tests and response evaluation of specific configurations, detailed modeling of integrated system performance and risk, and optimized design studies are emphasized. Additionally, technologies aimed at reducing the orbital stay of expended and unusable spacecraft are needed. One of the greatest causes of orbital debris generation is collision and break-up of large orbiting debris elements. New technologies that could increase the spacecraft drag, reduce orbital velocities and minimize spacecraft deterioration are also needed.

The NASA M/OD TP has been structured such that the technology needs are separated into two categories: 1) Basic or Broad-Based Technologies and 2) Depth

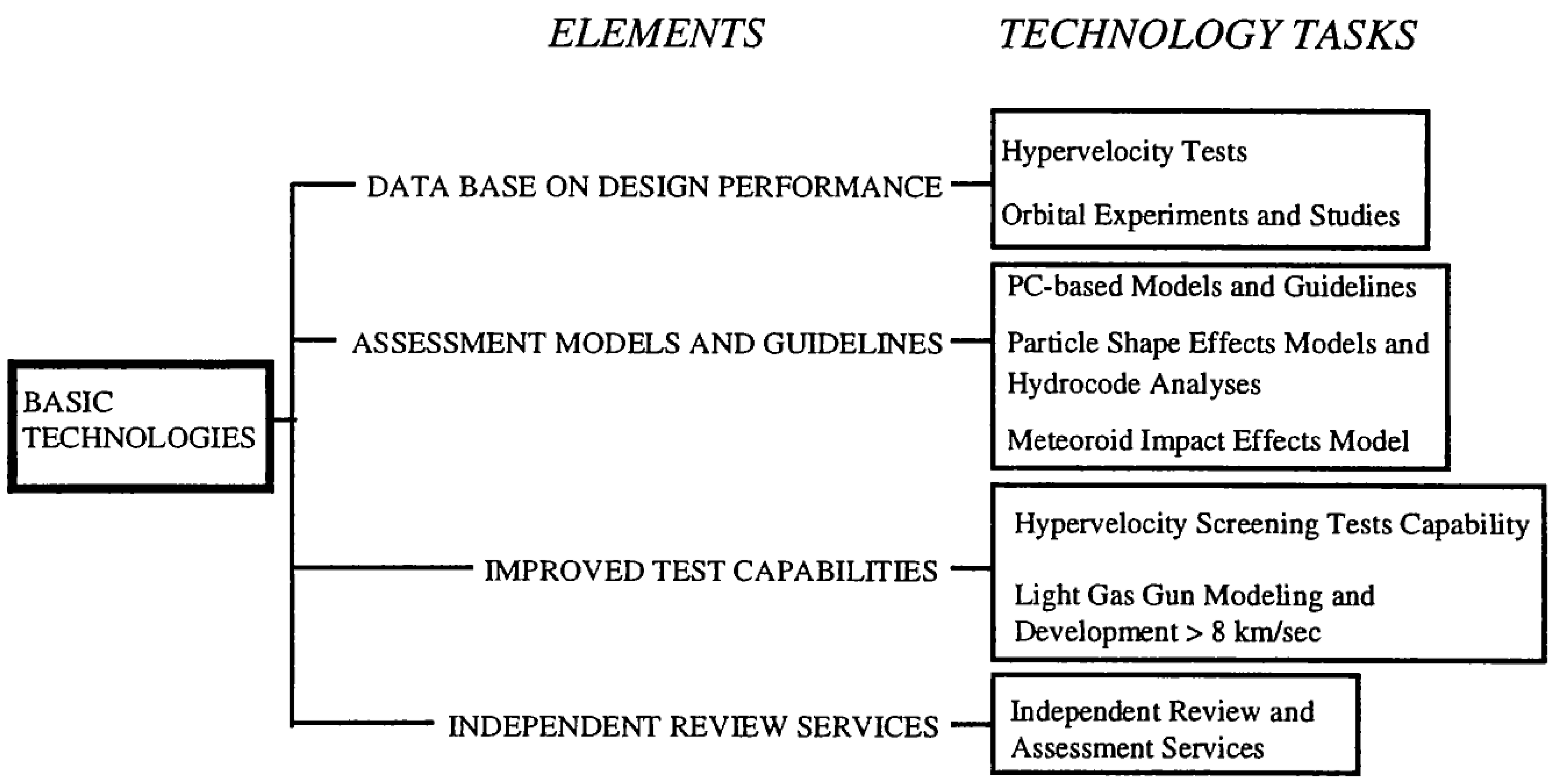

Figure 2. Basic Technologies Elements and Technology Tasks

or Detail Technologies. The Basic Technologies are the suite of tools, data, standards and methodologies that will provide general engineering and scientific information applicable to a broad spectrum of spacecraft. The Depth Technologies will be used to develop the capabilities needed to complete specific spacecraft development once an M/OD issue has been identified. Figures 2 and 3 identify the elements, along with the technology tasks described as needed by many spacecraft development organizations, for the Basic and Depth Technologies respectively.

BASIC TECHNOLOGIES:

Data Base on Design Performance - A consolidated database that will include results from ground-based and on-orbit hypervelocity impacts. This data base will enable the design engineer to become quickly familiar with the state of the art in protection system configurations and assess the merits of various design approaches.

Assessment Models and Guidelines - User-friendly M/OD impact assessment models will be developed to provide a quicker method of evaluating the threat and effects of a M/OD impact on commonly used spacecraft structures and materials. Additionally, guideline documents will be developed that include standard practices for critical and functional failure estimations, and a methodology to establish component-level and system-level failure criteria based on experiences with previous spacecraft programs.

Improved Test Capabilities - With all NASA hypervelocity impact testing consolidated at NASA's White Sands Test Facility (WSTF), a standard test protocol with standard instrumentation and a limited number of shot options will be developed to help evaluate the relative performance of preliminary design options of current configurations. The tests will support the expansion of general knowledge of material and structure performance and specific knowledge for particular common configurations. The data generated will be entered into the data base developed in the Data Base on Design Performance.

Independent Review and Assessment - The M/OD TP will maintain an agency-wide listing of the resources and capabilities in the NASA M/OD technical community. This database will be used to identify the appropriate technical expertise to provide services to frequently needed independent reviews required by spacecraft developers and the safety and quality assurance community on M/OD related products.

DEPTH TECHNOLOGIES:

Performance Models and Supporting Tests - Empirical and semi-empirical models will be developed that will characterize the response of particular structures to hypervelocity impacts. These models will serve to verify and complement existing hydrocode solutions. A substantial number of tests will be needed based on the multiple variables and ranges of velocity that must be examined. Currently, performance equations for very few structural shielding configurations have been substantiated, mainly single-sheet aluminum, multilayer aluminum and multilayer combined with multimaterial shields developed for the International Space Station (ISS).

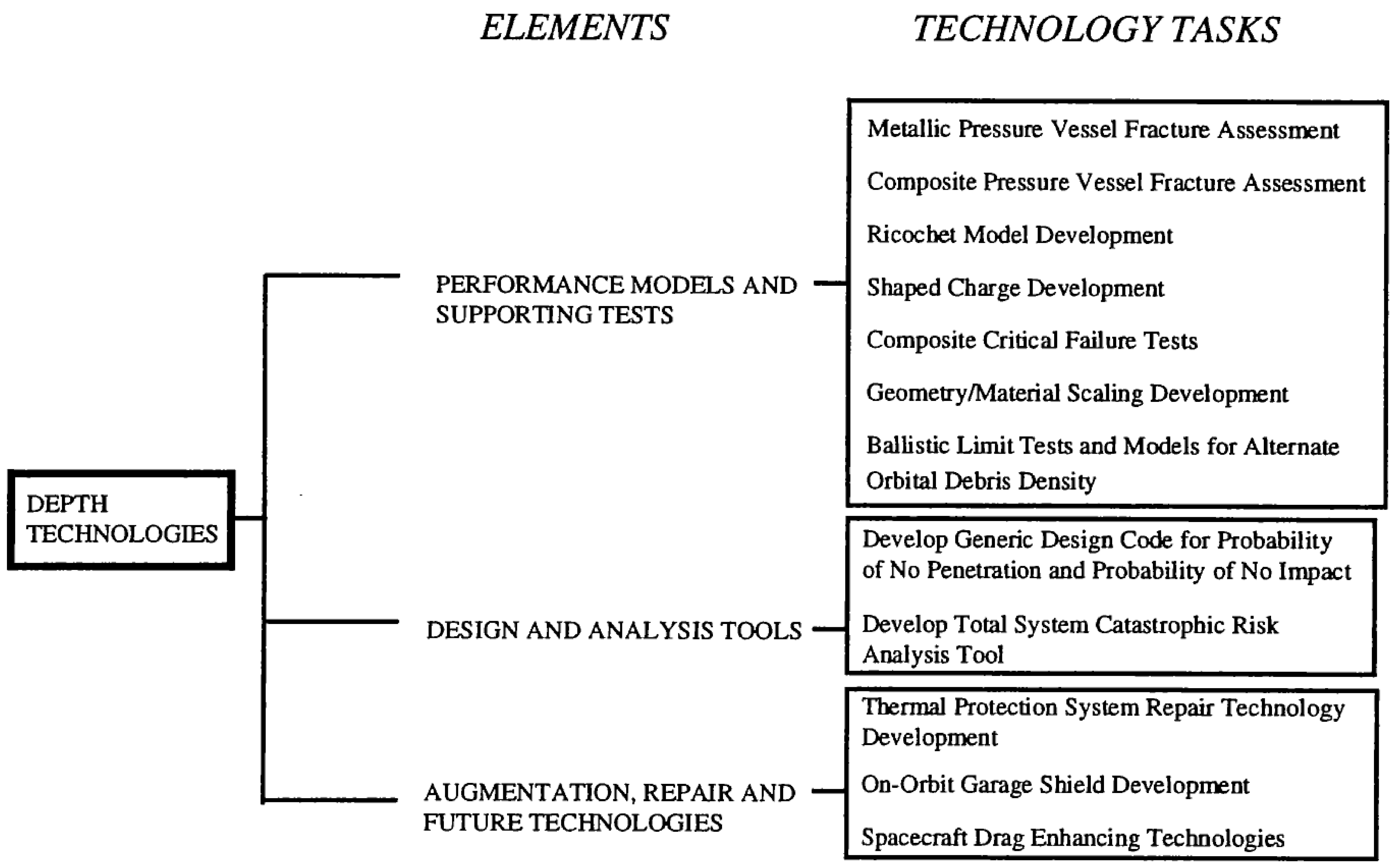

Figure 3. Depth Technologies Elements and Technology Tasks

Design and Analysis Tools - Integrated computer codes, hydrocodes, handbooks and similar tools are needed which can allow the user to bring together a diversity of factors ranging from environment and performance models to spacecraft layout and material options. One such tool is the existing BUMPER code used primarily for ISS. Modifications envisioned to this very successful design code include articulating or spinning systems, performance models for new structures and analysis calculations for critical failures resulting from a penetration.

Augmentation, Repair and Future Technologies - Experience has shown that all orbiting spacecraft will experience degradation due to M/OD impacts. In February of 1997, NASA astronauts performed maintenance on the orbiting Hubble Space Telescope to replace science instruments. During this time contiongency repairs were also made to the multi-layer insulation, damaged by the M/OD environment. Development of repair procedures and kits, and associated inspection techniques for a variety of spacecraft configurations is needed. In addition, drag- and orbit decay-enhancing technologies to reduce the orbital lifetime of expended spacecraft are needed.

4. NASA CAPABILITIES

To establish and maintain a fully integrated M/OD TP, NASA brings together the excellence in resources and knowledge from throughout the Agency.

Marshall Space Flight Center (MSFC) - possesses experience and capability in mutlipartner launch vehicle and spacecraft development and integration. This provides the necessary systems approach for the leadership of an integrated technology program for NASA. MSFC possesses valuable expertise in design, analysis and fabrication of hypervelocity impact protection systems, hydrocode analysis, dynamic fracture assessment and spacecraft risk assessment.

Johnson Space Center (JSC) - is recognized as a world leader in the development of technologies and methodologies for the measurement, modeling and prediction of the Orbital Debris Environment. Through JSC's interaction with international partners, international policies are being established for the reduction and mitigation of the Orbital Debris Environment. Additionally, JSC possesses significant expertise in hypervelocity impact analysis and design of spacecraft systems.

Jet Propulsion Laboratory (JPL) - possesses world-recognized expertise in the development of interplanetary and near-Sun spacecraft missions. Through this expertise, JPL has identified technologies needed to enhance the understanding of the Meteoroid Environment throughout the entire Solar System. Additionally, JPL is working on the development and validation of performance models for single- and multi-surface shields for meteoroid impact velocities in excess of 10 km/sec. They are also investigating new shield design methodologies that allow minimization of risk through multiple design trade-offs and relative mission value evaluations. The methodology is based on assigning criticality levels to specific components and subsystems, establishing a design criteria and developing the optimum shield design as part of an overall system trade.

Langley Research Center (LaRC) - managed the Long Duration Exposure Facility (LDEF) which produced a wealth of knowledge concerning the near-Earth space environment, including M/OD, and its effects on a variety of spacecraft materials. Subsequently LaRC continues to be involved in the on-orbit measurement of the M/OD environment through continued flight experiments.

Ames Research Center (ARC) - The work performed at ARC in aeroballistic research has produced technologies related to Light Gas Gun Optimization. Optimization of gun parameters and configuration may enable tests to be performed repeatedly at velocities in excess of 9 km/sec with minimum deterioration to the gun.

White Sands Test Facility (WSTF) - has a capability unique within the Agency to perform hypervelocity impact tests including impacts in a hazardous environment. Applicable gun ranges and diagnostic equipment within the Agency will be relocated to WSTF to maintain a centralized location for hypervelocity impact testing. WSTF will become the hypervelocity impact testing facility for NASA.

5. TECHNOLOGY HIGHLIGHTS

Several new technology tasks have been initiated. The selection of the tasks are based on producing deliverables within a short period of time to foster continued support for a productive technology program.

Design Guide for Critical Failure - This design guide will provide a standard approach for spacecraft design and assessment to prevent failure of spacecraft critical systems and components. The guide will propose a consistent methodology for determining failures caused by hypervelocity impacts and it will also contain lessons learned from experiences in existing spacecraft programs. The guide will contain the basic assessment methodology, metallic and nonmetallic as well as composite material structural design considerations, electrical and thermal systems design considerations, and special considerations for windows, lenses, pressure vessels and tethers.

PC-Based M/OD Design Tool - The objective of this task is to develop a user-friendly software package that is usable with common 486 personal computer or better. The tool will be designed to determine the probability of no impact or penetration for simple spacecraft geometries. The computer program will have the capability to include new geometries and performance curves, it will be Windows-based and menu-driven and will have basic spacecraft shapes and configurations. Once the program is finalized it will be included in the NASA Space Environments and Effects (SEE) program server for easy access and availability to the technical community.

Composite Critical Failure Tests - Through tests on hardware samples fabricated from a selected group of composite material configurations, a set of damage models will be developed that will identify the failure characteristics of these commonly used aerospace composite materials due to a hypervelocity impact.

Meteoroid Model Updates - This task will formalize the existing JPL Divine meteoroid model code and make it available to the NASA and space user community. The model, currently being used with great success to estimate the directional meteoroid fluences as a function of mission duration for interplanetary missions, will be made user-friendly and prepared for distribution through NASA COSMIC.

6. SUMMARY

The NASA Meteoroid and Orbital Debris Technology Program has been developed with the goal of establishing the necessary technologies that will enable the Agency to meet its goals of quicker, more cost effective development of high quality spacecraft. Through the needs identified by the spacecraft development community, the technology tasks shown in Figures 2. and 3. have been selected, in part, to assure that the integrated program covers the M/OD issues that may arise throughout all phases of the development and fabrication of future spacecraft. Figure 4. shows graphically how the different technology tasks support the various stages in the development of spacecraft.

REFERENCES

1. NASA Meteoroid and Orbital Debris Technology Program Plan, George C. Marshall Space Flight Center, July, 1996.

2. Colliding Space Junk, *Science*, Vol. 273, September 6,1996.

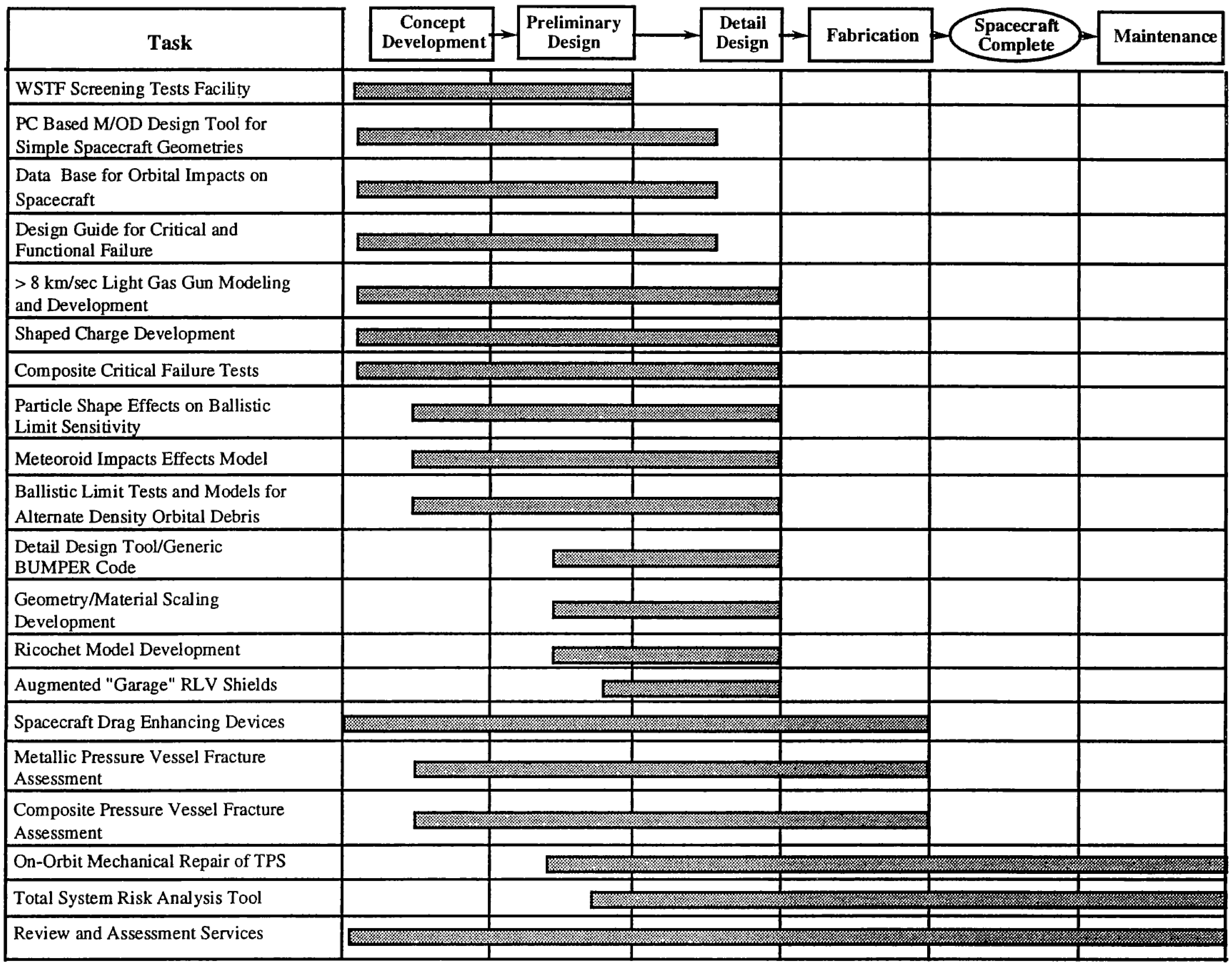

Figure 4. Utilization of M/OD Technology Program Tasks in Spacecraft Development