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RESEARCH AND TECHNOLOGY GOALS AND OBJECTIVES FOR INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM)

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RESEARCH AND TECHNOLOGY

GOALS AND OBJECTIVES

FOR

INTEGRATED

VEHICLE HEALTH MANAGEMENT (IVHM)

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RESEARCH AND TECHNOLOGY GOALS AND OBJECTIVES

FOR INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM)

1.0 Executive Summary

Integrated Vehicle Health Management (IVHM) has been identified by the NASA Office of Space Flight (OSF) as the highest priority technology for present and future space transportation systems. It is highly responsive to the NASA Office of Aeronautics and Space Technology (OAST) Space Research and Technology (R&T) mission in the areas of safety and reliability improvement, cost reduction, mission enhancement, and the enabling of new capabilities and missions. IVHM is viewed as enabling to truly low-cost space transportation (Earth-to-orbit and upper stage), space basing, and long-term manned space missions.

Interest in IVHM has led to joint NASA/industry efforts to foster the development of IVHM capabilities. Within the NASA/industry Strategic Avionics Technology Working Group (SATWG), an IVHM Panel has been formed to address IVHM issues and develop IVHM technology plans. Since the summer of 1990, the IVHM Panel has conducted five workshops. The results of those workshops have led to the development of this document proposing research and technology goals and objectives for IVHM. Program planning for IVHM is being scoped and defined.

The primary purpose for pursuing IVHM is to increase safety and reliability while simultaneously reducing costs (the ability to do more with less). IVHM alone cannot accomplish this, but must be part of an effort to improve overall vehicle design and operations. IVHM is a key new element in those efforts.

Space Transportation requirements that IVHM must address include: safety and reliability; reductions in manpower and costs; rapid turnaround; increased system availability; launch on demand; launch on schedule; and others (see Figure 3 on page 8). Examination of these requirements leads to a definition of IVHM requirement elements that fall into three areas: IVHM System Architecture; Sensors, Effectors, and Test Equipment; and Software (includes the engineering analyses and models to be implemented in software). In these areas, IVHM goals and R&T objectives have been defined that are responsive to requirements (see Figure 6 on Page 17).

Key IVHM goals that have been defined include: system integration of IVHM capabilities; catastrophic failure prevention; automated checkout and testing; automated maintenance requirements determination and scheduling; expanded sensor, instrument, and built-in-test capabilities (including 100% key parameter coverage); modular, reusable software implementations with configuration control; and advanced software management capabilities (including Software safety and reliability, and verification and validation). Based

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on these goals, R&T objectives have been established for the near term (defined as 1994-1998), mid term (1999-2003), and far term (2004-2013).

IVHM R&T objectives have been established that fall into two categories. The first category consists of target improvements in key IVHM-related capabilities such as: failure mode prevention; parameter coverage; monitoring and test componentry reliability; built-in-test coverage; and reduction in resources required to do maintenance, test, checkout, flight operations, and post-operational diagnostics. Progressively demanding target improvements in key parameters are established for the near term, mid term, and far term. The second category of objectives consists of the introduction of new capabilities. These include: special design tools and aids; space-based IVHM; autonomous vehicle IVHM; advanced sensors (e.g., smart sensors and micro-sensors); advanced test/inspection techniques; and advanced modular/reusable software and software management techniques and tools. (See Figure 6.)

The next step is to scope and define IVHM R&T program planning directed toward these objectives. IVHM R&T then will be implemented through the focused technology elements of the OAST Integrated Technology Plan (ITP), including: the Low-Cost Transport Program for commercial Expendable Launch Vehicles (ELVs), the ETO Avionics Program for reusable ETO transportation systems, and the Space Transfer Avionics Program for space-based vehicles and long-term manned space missions.

OAST is conducting IVHM R&T planning in concert with an IVHM Technology Bridging Program being developed by the Office of Space Systems Development (OSSD). These activities will provide for the timely introduction of IVHM technology into space transportation systems. The results of these activities, coupled with complementary design and operational improvements, will produce significant space transportation advances.

2.0 Introduction

Integrated Vehicle Health Management (IVHM) is defined herein as the capability to efficiently perform checkout, testing, and monitoring of space transportation vehicles, subsystems, and components before, during, and after operation. This includes the ability to perform timely status determination, diagnostics, and prognostics. IVHM must support fault-tolerant response including system/subsystem reconfiguration to prevent catastrophic failures; and IVHM must support the planning and scheduling of post-operational maintenance.

The scope of IVHM application includes the entire transportation system. It applies to vehicle ground and flight operations conducted at manufacturing, refurbishment, and test facilities. IVHM applies across the entire life cycle of the vehicle, beginning in the earliest phases of design. It is an active element in developmental testing and certification, and matures with the vehicle in the flight operational phase.

The purpose of this document is to establish the rationale for IVHM and IVHM research and technology planning, and to develop technical goals and objectives. This document is prepared to provide a broad overview of IVHM for technology and advanced development activities and, more specifically, to provide a planning reference from an avionics viewpoint under the OAST Transportation Technology Program Strategic Plan[(1)][1].

2.1 Background

Test, checkout, and monitoring capabilities have always been a necessary part of space transportation systems. When early launch vehicle programs encountered reliability problems, stringent reliability and quality assurance programs were implemented that substantially increased test/checkout monitoring requirements. The need to "man-rate" vehicles for the Mercury, Gemini, and Apollo programs further intensified efforts. These efforts were successful. The reliability of expendable unmanned launch vehicles and upper stages was substantially increased, and the reliability of man-rated systems was raised to even higher levels. However, this success was achieved by instituting time-consuming and labor-intensive launch processing operations and manufacturing processes, and utilizing costly special-purpose, high-reliability components.

With the maturing of expendable launch vehicles (ELVs) and the advent of the Space Shuttle (the first reusable launch vehicle), it became evident that improvements in these processes and operations were needed. In the early 1980s, interest in expanding launch vehicle health management capabilities and making launch operations more efficient led to system studies and subsystem/component developments. Since that time, interest in IVHM potential has increased substantially.

In November 1989, a NASA Strategic Transportation Avionics Technology Symposium was held in Williamsburg, Virginia. As a symposium follow-on, the Strategic Avionics Technology Working Group (SATWG) was established jointly by NASA Headquarters Code M and Code R in early 1990. SATWG subsequently initiated a number of activities and formed four working panels to carry out those activities. One of the panels was the Integrated Vehicle Health Management (IVHM) Panel, formed as a focus of IVHM planning and NASA/industry interaction.

The IVHM Panel held its first meeting in June 1990 in Washington, DC and established a charter and plan of action. Since then, four additional meetings have been held. Significant progress has been made in several areas: definition of IVHM requirements; determination of NASA, DOD, and industry desires, needs and capabilities; and determination of IVHM technology needs, goals, and objectives. IVHM Research and Technology goals and objectives set forth in this document are derived substantially from the proceedings and results of those meetings[(2-7)].

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[1] Superscript numbers in parentheses refer to references listed at the end of this document.

2.2 Justification

IVHM is proposed as a new initiative in space technology for two reasons. First, it has been identified by the NASA Office of Space Flight (OSF) as the highest priority technology need for NASA Space Transportation Systems[8]. Second, it is highly responsive to the NASA Office of Aeronautics and Space Technology (OAST) Space Research and Technology Mission as defined in the 1991 Integrated Technology Plan (ITP) for the Civil Space Program[9].

As part of the 1991 ITP effort, OSF assembled an overall strategic program schedule to support technology planning. Following an extensive effort, with detailed review by top-level OSF management, an array of technology needs were identified. The list included 16 areas judged likely to be driven by NASA investments and/or to be largely unique to NASA programs. The highest priority technology on this list is Integrated Vehicle Health Management (IVHM)[8].

The ITP states that the mission of the Space Technology Directorate is: "...to assure that OAST shall provide technology for future civil space missions and provide a base of research and technology capabilities to serve all national space goals." Accomplishing this mission entails several objectives including:

- Identify, develop, validate, and transfer technology to:
  - Increase mission safety and reliability;
  - Reduce flight program development and operation costs;
  - Enhance mission performance;
  - Enable new missions.

- Provide the capability to:
  - Advance technology in critical disciplines;
  - Respond to unanticipated mission needs."[9]

The goals of IVHM are to:

- Increase safety and reliability providing increased probability of mission success;
- Reduce processing and operations time, manpower and costs.
- Increase system availability and utility;

IVHM will accomplish this by:

- Greatly enhancing the effectiveness of development testing and supporting the development of design data bases and simulations;
- Detecting incipient failure and enabling a response preventing catastrophic failures in test and flight operations;
- Predicting component end-of-life or degradation, enabling timely maintenance action;

- Automating checkout and monitoring functions to significantly reduce manpower requirements (e.g., by eliminating the need for most manual inspection and teardowns);
- Providing greatly improved and responsive analytical capabilities and human/system interfaces greatly amplifying crew capabilities (test crew, launch processing crew, and vehicle crew);
- Drastically reducing the need for scheduled maintenance, converting most maintenance to timely maintenance for cause (detected problem, or end-of-life replacement).

The IVHM R&T program will result in advances in critical technologies such as sensors, ultra-reliable electronics systems, software, and through the application of artificial intelligence (AI) technologies. IVHM technologies are viewed as enhancing for all space transportation systems. IVHM is viewed as enabling to truly low-cost space transportation, and to space basing and long-term space missions.

Figure 1, "IVHM Benefits," delineates the capabilities and the expected derived benefits of IVHM[10].

3.0 IVHM Program Requirements

Potential IVHM applications include all major aerospace systems. Present potential space transportation applications include Space Shuttle, upper stages, and government and commercial Expendable Launch Vehicles (ELVs). Future potential applications include: CTV, STV, ACRV, PLS, HLLV, AMLS, NLS, and NASP. In addition, the Space Exploration Initiative (SEI) will give rise to vehicle and remote base requirements for IVHM.

Summary program milestones for many of the programs listed above are shown in Figure 2. IVHM capabilities will be needed to enable and enhance mission operational requirements in the areas of mission/system affordability, operability and maintainability, and safety and reliability. A summary of operational requirements in these areas for transportation vehicles are shown in Figure 3. These requirements were derived by examining stated requirements for a number of current and proposed future space transportation vehicles -- see Appendix A.[1,3,11-17]

CAPABILITY	BENEFITS	WHY
Automated vehicle checkout	Expedited pre-launch operations; minimize personnel costs Launch commit and Go/No-Go decision process is expedited	Delays, launch aborts and recycles are too expensive in direct and indirect costs; more efficient operations
Autonomous vehicle health management	Maximized mission capabilities and performance; enhanced mission success probability	Alleviates and circumvents effects of in-flight failures and degradations IVHM techniques allow weight and power savings by substituting software intelligence for some physical redundancy
IVHM system architecture and software	Incremental adoption of IVHM concepts and new hardware; minimized technical risks; improves efficiency and robustness	Different systems, technologies and sensors will develop at different times
IVHM sensors	Increased knowledge of complex equipment's health condition	Prognosis and timely fault detection capabilities are required for complex operating in extreme environments
Residual lifetime estimation, dynamic health and status assessment	Enhanced mission success	Component health is continuously monitored and incipient failures are detected before they become acute
	Improved performance margins	Performance red lines can be calculated dynamically and need not rely on statistical estimates of "beginning of life" (optimistic or "end of life" (pessimistic) projections of system capabilities
	Improved cost effectiveness of processing and maintenance operations	System elements may be repaired when needed as opposed to following a periodic (overly conservative) schedule

FIGURE 1. IVHM Benefits[10]

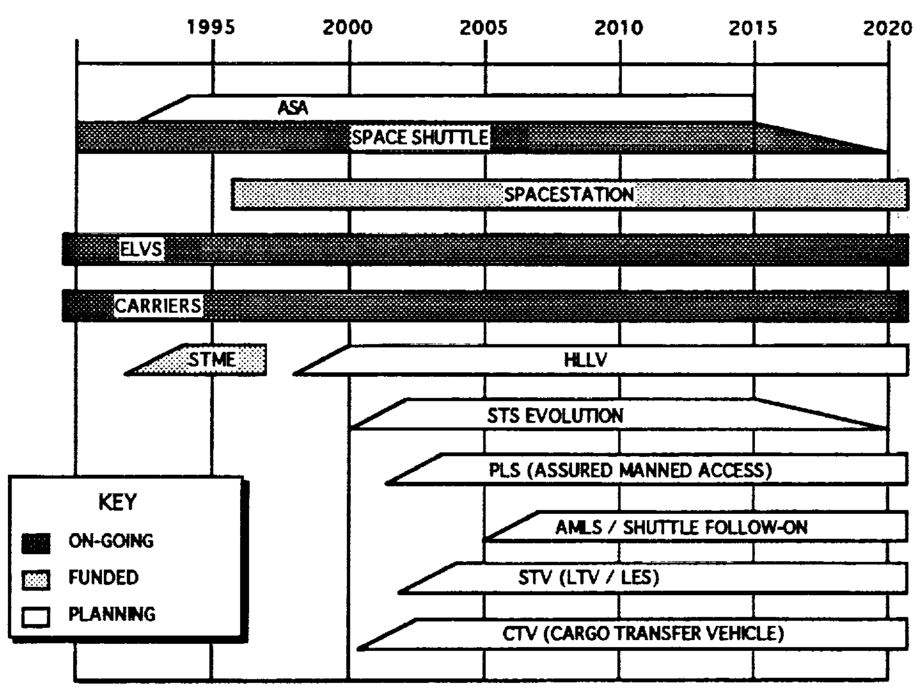

FIGURE 2. Reference Schedule for Vehicle Requirements

IVHM enables and/or supports the vehicle operational requirements shown in Figure 3 by performing key functions which become the IVHM functional requirements. These are:

- Support vehicle DDT&E data base development, model development, FMEA development;
- Support component, subsystem, testing/certification (test data, test safety);
- Provide complete test and checkout of vehicle systems (factory, test site, and launch site);
- Monitor vehicle system and subsystem status;
- Diagnose system, intersystem, and intrasystem problems;
- Predict vehicle health trends;
- Provide timely basis for action to correct problems and prevent failures;
- Perform data analyses and event correlation;
- Provide efficient and effective human/IVHM system interfaces;
- Integrate subsystem health management.

Figure 4 shows how these functional requirements support the vehicle requirements of Figure 3. The scope of the functional requirements emphasizes the point that IVHM is a system level problem.

One important aspect of IVHM is that monitoring, diagnostics, and prognostics performed during test and flight operations may be divided into two elements: one that is time-critical and one that is not. The time-critical element involves sensor measurements and analyses that must provide information to subsystem and vehicle control systems in time to prevent impending catastrophic failures. The non-time-critical element collects sensor and instrument measurements and performs functions necessary for long-term vehicle health.

This includes, for example, data archiving and diagnostics/prognostics for maintenance planning and scheduling.

Time-critical IVHM will be highly integrated with the cognizant avionics/control systems that must effect recovery from hazardous situations. Non-time-critical IVHM may share avionics/controller resources (computer processing, and data handling/storage/transfer), but must do so on a time-available basis. If non-time-critical IVHM demand for shared resources greatly exceeds availability, then separate dedicated resources may be required.

The R&T response to the IVHM functional requirements defined above may be represented as technology elements. These elements are organized into three categories: (1) System Architecture; (2) Sensors, Effectors, and Test Equipment; and (3) Software. Figure 5 shows the relationship between functional requirements and the technology elements. Research and technology in each of these categories and elements are discussed in the following sections.

GENERAL TRANSPORTATION SYSTEM REQUIREMENTS	GENERAL VEHICLE REQUIREMENTS**		
	NEAR TERM (1994 - 1998)	MID TERM (1999 - 2003)	FAR TERM (2004 - 2013)
AFFORDABILITY	Reduced processing / launch crews	Minimum processing / launch crews	Airline-like operations, airport-like infrastructure
	Rapid turnaround (weeks)*	Rapid turnaround (days)*	Rapid turnaround (hours for LVs)*
	Maximize off-pad pre-launch processing	Approach "Ship & Shoot" (ELV from factory, Reuseables from launch-site processing facilities)	Space-based operations for SEI
			Reuseable LV 20 years / 500 flights 10 years space-based vehicle, lifetime
			Multi-year manned mission capability
	(90%)* Availability	(95%)* Availability	(99%)* Availability
		Design for ease-of-maintenance	Maximize vehicle operational autonomy, long-term autonomy for SEI
OPERABILITY AND MAINTAINABILITY	Lauch-on-demand (weeks)*	Launch on demand (days)*	Launch-on-demand (hours)*
	(80%)* launch-on-schedule	(90%)* Launch-on-shedule	(99%)* launch-on-schedule
	Rapid recycle of last several minutes of countdown	24-hour recycle, 8-hour hold	Complete recycle/hold flexibility; or , no countdown - - launch when ready
		Launch Engine-out capability	
	Hold-down check (SSME)	Hold-down check (NLS, others)	
	(>85%)* All-weather capability	(>90%)* All-weather capability	(>95%)* All-weather launch
SAFETY AND RELIABILITY	(>95%)* Mission success for all vehicles	(98%)* Mission Success	(>99.5%)* Mission Success
	Fail-safe abort, fail-operational fly-with-faults capabilities	Fail-safe abort, fail-operational fly-with-faults capabilities (expanded)	

* Numbers in parentheses are indicative of present and proposed future capabilities (see Appendix A), but are not hard requirements. They are included only to show an expected progression of capabilities from near term to far term.

** This table is a requirements summary derived from specific requirements that have been quoted for proposed future space transportation vehicles (see Appendix A).

FIGURE 3. Vehicle Requirements (IVHM Related)

VEHICLE REQUIREMENT	Time Period Requirement Appears. N = Near M = Mid F = Far Term	Support Vehicle D.D.T. & E. database development, model development, FMEA development	Support component, subsystem, vehicle testing (database development test safety)	Provide complete checkout of vehicle systems (factory, test site, launch site)	Monitor vehicle system and subsystem status	Diagnose system, intersystem, and intrasystem problems	Predict vehicle health trends	Provide timely basis for action to correct problems and prevent failures	Perform data analysis and event correlation	Provide efficient and effective human/IVHM system interfaces	Integrate subsystem health management
"Ship-and-shoot" capabilities	N/M			X		X					X
Rapid turnaround	N/M/F			X		X	X		X	X	X
Airline/airport-like operations	F			X	X		X		X	X	X
20 yr/500 flight reuseable LV lifetime	F	X	X								
10 yr space-based vehicle lifetime	F	X	X								
Multi-year manned mission capability	F	X	X				X			X	X
Space-based operations for SEI	F	X	X	X	X	X	X				X
High system availability	N/M/F	X	X			X					
Design for ease of maintenance	M/F	X	X							X	
Launch on demand	N/M/F			X		X	X				X
Launch on schedule	N/M/F				X				X	X	X
Rapid recycle	N/M/F				X				X	X	X
Near all-weather capability	N/M/F			X						X	
Launch Engine-out capability	M	X	X		X	X		X	X	X	
Hold-down check	N/M	X	X		X	X	X	X	X	X	
High mission success percentage	N/M/F			X	X	X	X	X			
Fail-safe, fail-operational capabilities	N/M/F	X			X	X		X	X		

FIGURE 4. IVHM Functional Requirements Supporting Vehicle Requirements

IVHM FUNCTIONAL REQUIREMENTS	SYSTEM ARCHITECTURE				SENSORS AND TEST EQUIPMENT					SOFTWARE			
IVHM TECHNOLOGY ELEMENTS	IVHM Requirements/Approaches	IVHM Design/Evaluation Tools	IVHM Concepts and architectures	System Engineering and Integration	Sensor Reliability	Enhanced Sensing	Advanced/Smart Sensors	Enhanced Ground Test/Inspection	Enhanced Built-in-Test	Requirements	Algorithms/Methods	Development Software	Software Management
Support vehicle DDT&E database development, model development, FMEA development	X	X	X	X	X	X	X	X	X	X	X	X	X
Support component, subsystem, vehicle testing/certification (test data, test safety)	X		X	X	X	X	X	X	X	X	X		X
Provide complete test and checkout of vehicle systems (factory, test site, test launch site)	X		X	X	X	X	X	X	X	X	X		
Monitor vehicle system and subsystem status	X		X		X	X	X			X	X		
Diagnose system, intersystem, and intrasystem problems	X		X	X						X	X		
Predict vehicle health trends	X		X							X	X		
Provide timely basis for action to correct problems and prevent failures	X		X	X	X	X	X	X	X	X	X		
Perform data analysis and event correlation	X		X							X	X		
Provide efficient and effective human/IVHM system interfaces	X	X	X	X						X	X	X	X
Integrate subsystem health management	X	X	X	X						X	X		X

FIGURE 5. IVHM Technology Elements Supporting Functional Requirements

3.1 System Architecture

The targets for implementation of IVHM include: (1) improvements to commercial Expendable Launch Vehicles (ELVs) and upper stages; (2) improvements to the Space Shuttle and associated systems; (3) new clean-sheet IVHM systems for future launch vehicles, space transfer vehicles, and the full spectrum of Space Exploration Initiative (SEI) applications. Addressing this broad range of applications is a significant challenge. One of the keys to success is a concerted effort to develop system definitions responsive to, and optimized for those intended applications. Requirements for accomplishing this objective includes: (1) data base development; (2) concept development and evaluation; (3) architecture definition; and (4) system engineering and integration (SE&I).

IVHM design and development ultimately requires complete and intimate knowledge of the design and operation of the vehicle. This knowledge must exist at the programmatic and systems (e.g., launch vehicle) levels and penetrate to the element (e.g., propulsion system), subsystem (e.g., turbopump), and component (e.g., bearing) levels. In addition to knowledge of design and operation, knowledge of degradation and failure modes is also needed.

The IVHM designer needs access to accurate and complete failure modes and effects analysis (FMEA) information. Much of the data required is developed as a part of the design, development testing, and operations process. However, in many cases degradation and failure modes are insufficiently understood and defined for IVHM design purposes. There is a need for the development of analysis tools to assist in performing FMEAs and generate data bases for IVHM design. IVHM concepts must be developed that are responsive to the specific needs of space transportation vehicles. These concepts must be evaluated to determine and verify their merits and utility. Tools must be developed that are capable of evaluating IVHM and its impact on vehicles. Examples are cost/benefit analyses and failure modes and effects analyses.

One of the key evaluations that must be performed is cost/benefit analysis. Currently, the capability does not exist to fully determine and quantify most IVHM benefits (e.g., safety, reliability, mission success supportability) so that they can be weighed against IVHM costs. IVHM is a concept specifically intended to improve operational characteristics and reduce overall costs. For projected concept applications it must be proven that overall vehicle cost savings due to IVHM greatly exceed the direct cost of developing, implementing, and using IVHM. The development of criteria, methodologies, and models to perform cost/benefit assessment of IVHM is needed. Tools and techniques must be developed that are broadly applicable to different applications, purposes, and users.

Historically, space transportation vehicles have had only one level or tier of monitoring. Vehicle level functions focused on collecting data from the subsystems and transmitting it to the ground. Such systems cannot adequately correlate symptoms between subsystems to detect incompatibilities, faults in interfaces, or failure propagation between subsystems. To move beyond this requires a layered or hierarchical approach. This approach will provide the means of identifying health management functions and where to best implement them. An example of a top level architecture of this type is presented and described in Reference 5.

Architectures for a number of IVHM applications (near term to far term) need to be developed. In developing these architectures a number of tradeoffs and issues will need to be addressed. For example:

(1) Which functions should be manual and which should be automated?

(2) Which functions should be performed on-board and which on the ground?

(3) Which functions should be performed at which levels?

(4) Should functions be centralized or distributed?

(5) Should the subsystem supplier or the integration contractor provide the function[4]?

Systems Engineering and Integration SE&I is needed to establish in some detail how the IVHM architecture will be implemented. The SE&I efforts must focus on a number of problem areas. One is how the various components and elements of the IVHM system (both vehicle based and ground based) will be interfaced and integrated into a complete IVHM system. A second is how the IVHM system will be interfaced to and integrated with the host vehicles. This includes hardware and software (ground and vehicle based), operations and logistics (including manpower), and programmatic organization and function. Time-critical IVHM functions will be highly integrated with vehicle avionics/control systems.

Requirements for the processing handling, storage, and transmission of data and commands will be substantial. Even if a highly distributed architecture is employed, that achieves substantial local data compression, system level cognizance and interrogation capability and controls must be maintained. Distributed architectures will exhibit unique new-data management requirements at the local level and retain significant centralized data management requirements. Data management resources may be shared with other vehicle systems, but the IVHM demand for those resources will be substantial, and the dedication of separate resources may well be required. In addition, the development of much more capable processor/component networking methods is needed.

SE&I efforts must address the evolution of IVHM concept development through operational implementation. To derive maximum benefit from IVHM, IVHM must become an integral part of all phases of the vehicle life-cycle. For example elements of IVHM should be used extensively in vehicle component and subsystem developmental testing. This will accomplish a number of desirable objectives:

(1) It will increase test safety and reduce test costs through the prevention of catastrophic failures;

(2) It will significantly contribute to the development of data bases for FMEAs and other essential analyses;

(3) IVHM will be tested as part of the test program.

Sensors/instrumentation, and testing/analysis will be more extensive during vehicle development and testing than during flight operations. One SE&I requirement will be to reduce to a minimum the number of sensors and components ultimately needed to effectively conduct IVHM in the flight and ground operational phases.

The manpower required to conduct space missions must be reduced. Therefore, very close attention must be paid to the role of humans in the program and the development of the interfaces by which humans interact with the IVHM system. Requirements to optimize human capabilities to conduct oversight interaction and intervention need to be determined, and design requirements for the human-machine interfaces need to be established.

A final SE&I requirement must be to assure that the principles of concurrent engineering are broadly applied to IVHM development beginning with IVHM and vehicle preliminary design activities. This will significantly contribute to optimized IVHM system design and greatly facilitate IVHM vehicle integration.

3.2 Sensors, Effectors, and Test Equipment

Sensors, Effectors, and Test Equipment include all IVHM elements and components that directly monitor and/or test vehicle hardware. On-board the vehicles this includes monitoring sensors and instruments that are passive, and active built-in-test equipment. It also includes associated wiring and connectors. On the ground, it includes manual and automated sensors and instruments, inspection systems, and test systems.

The highest priority requirement is the need to significantly increase the reliability of on-board sensors, instruments, built-in test, and wiring connectors. Past reliability problems have greatly limited the utility and applications of these devices. In many cases, confidence measurements/readouts are insufficient for reliance in making critical real-time decisions. Reliability with respect to permanent and intermittent, hard and soft failures must be improved.

Wiring/connectors (or alternatively, fiber optics) will be used extensively, are vulnerable to wear and damage, and currently represent significant reliability risks. In keeping with requirement for high reliability in the IVHM system, the reliability of wiring/connectors must be improved significantly. Innovative methods for hardening those components without incurring substantial weight or other penalties are needed.

New types of sensors, effectors, instruments, and built-in-test (BIT) are needed to achieve more complete coverage of potential faults and enable more comprehensive system analysis and response. Specific needs must be determined by analyses of system design, operations, failure modes and effects analyses (FMEAs), etc. Examples are zero-gravity fluid-quantity gaging and flowmeters. Where possible, sensors should be designed to be non-intrusive and easily serviced or replaced. In addition, their size, mass, and support requirements (power, communications, data processing) should be minimized. Advances in micro-sensor technology may contribute greatly to satisfaction of some of these requirements, particularly in the area of embedded sensors and effectors.

As one response to the above requirements there is a need to develop "smart" sensors that incorporate a local data processing capability and perhaps even a local power source. In addition, these sensors should incorporate a capability for automatic calibration and validation. This capability will enable local data reduction significantly reducing data storage and data transmission through overburdened communication links. It will also enable local determination of component and sensor health, and significantly reduce the need for sensor redundancy.

3.3 Software Elements

Software includes analytical methods, algorithms, instructions and models needed for IVHM. It also includes the implementation of these elements in computer software languages, development environments and architectures. IVHM requirements for software need to be well developed and understood. These requirements range from applications for individual sensors to applications for the top-level IVHM system. They include: design knowledge capture, failure detection and isolation, diagnostics/prognostics, data compression, automatic calibration and validation of sensors, sensor fusion and analytical redundancy, system modeling, user interface and display support, data management, requirements tracking, and planning and scheduling. In addition to system modeling, capability to model system failures must also be developed so that those failures can be simulated in the IVHM development process.

Approaches to satisfying IVHM software needs must be developed. This includes engineering analyses and methods, and software approaches ranging from conventional programming techniques to AI/expert system, and neural network approaches. Methods of implementing capabilities in software in distributed parallel processing systems also must be developed.

One of the key needs is to develop modular, reusable application software for both centralized and distributed IVHM applications. This includes the development of methods to implement data analysis/processing functions (e.g., data filtering) in a general way within software architectures and provide a very capable and user friendly development environment. Finally, the development of cost effected and efficient means to speed and simplify software management including safety, reliability, and verification and validation (V&V) are needed to realize the full potential of emerging state-of-the-art software capabilities.

4.0 IVHM Research and Technology Goals and Objectives

IVHM Research and Technology Program Goals and Objectives have been developed that are responsive to the requirements identified in Section 3.1. For each of the technology areas: (1) System Architecture, (2) Sensors and Test Equipment, and (3) Software. Figure 6 identifies key technical goals and provides a brief state-of-the-art assessment. The figure then identifies research and technology objectives in the near term, mid term, and far term. Near term is defined as the five-year period of FY 1994-1998; mid term is FY 1999-2003; and far term is the ten-year period of FY 2004-2013.

4.1 System Architectures

The first key technical goal of "System Architecture" is the enabling of Integrated Vehicle Health Management. Current space transportation systems include limited health management capabilities, such as extensive ground checkout and test (mostly manual), propulsion system monitoring, and avionics monitoring and fault-tolerance. However, an integrated capability does not exist. This capability is needed to achieve the other IVHM goals identified in Figure 6.

IVHM concepts and architectures, and systems engineering and integration concepts, will be developed in a program that will explore vehicle designs and operation, including degradation and failure modes, to provide a sound basis for IVHM development. Different vehicle applications will produce different IVHM concepts and architectures. Expendable launch vehicles (ELVs) will favor ground-based systems and will probably emphasize factory checkout over launch site processing, trending toward a goal of "ship-and-shoot" operations. ELVs will want to minimize expensive on-board hardware that is expended with each flight and, where possible, may favor analytical redundancy over hardware redundancy. Reusable vehicles and systems, like the Shuttle Orbiter, are stronger candidates for on-board monitoring, built-in-test, and more autonomous launch operations. A high degree of autonomy will be a requirement for future space-based systems. As part of SE&I related efforts, methods and componentry necessary to perform IVHM data handling, storage, processing, and transmission will be developed. Both centralized and distributed system options will be explored, and the differing requirements of time-critical and non-time-critical data and information will be addressed.

The second goal is catastrophic failure prevention. The Shuttle has limited in-flight engine-out and abort capabilities. However, those capabilities cannot be fully utilized in some cases because insufficient timely information exists to make reliable decisions. The necessary current remedy for this situation is exhaustive post-flight and pre-flight ground checkout and test to assure flight safety. Therefore, one of the key goals of IVHM will be increased ability to identify and provide a timely response to in-flight anomalous and potentially hazardous conditions. The R&T objective will be to progressively reduce the numbers of vehicle catastrophic failure modes for which there is no in-flight response. This R&T objective is established in Figure 6 as a target percent reduction in the number of failure modes not covered. Progressively higher targets are set for the near term, mid term, and far term.

Other NASA R&T programs are addressing this problem directly through redesign to eliminate or ameliorate failures. This program will focus on enabling response to remaining failure modes. Responses to be enabled include fault tolerance, fault avoidance, mission modification, and abort.

Automated checkout and testing is a key system architecture goal, as is automated maintenance requirements determination and checking. Currently, checkout, testing and maintenance planning and scheduling are largely manual tasks. The R&T objective will be to reduce time, manpower, and costs required to perform these tasks. Target reductions are cited in Figure 6. Long-term objectives call for IVHM largely resident within the vehicle to enable vehicle autonomy and space-basing.

The final two goals established for system architecture deal with the role of IVHM in DDT&E, certification, and qualification. First, IVHM design tools (e.g., cost/benefit analysis and failure modes and effects analysis models) will be developed that will contribute significantly to overall vehicle and vehicle support systems design. These tools will facilitate the examination of design strategies and issues, assist the performance of tradeoff analyses and determine the payoff for proposed technology developments. Second, IVHM will become an integral part of development testing from the start. It will contribute significantly to test safety, and produce expanded test results to aid design and augment the design knowledge base.

4.2 Sensors, Effectors, and Test Equipment

In the "Sensors, Effectors, and Test Equipment" area, five key technical goals will be pursued. The first is to develop technology for very highly durable and reliable monitoring componentry. Present componentry (sensors, instruments, wires, connectors, etc.) is susceptible to damage in harsh operational environments and during extensive vehicle manual maintenance/processing procedures. Future trends toward more distributed monitoring systems will only increase the importance of solving the reliability problem. Therefore, one of the R&T objectives will be to progressively increase the reliability of monitoring componentry.

	SYSTEM ARCHITECTURE	SENSORS, EFFECTORS, TEST EQUIPMENT.	SOFTWARE
KEY TECHNICAL GOALS	• Integrated vehicle health management • Catastrophic failure prevention • Automated checkout & testing • Automated maintenance requirements determination, scheduling • Vehicle DDT & E health management data base development • Development and certification test enhancement and support	• Highly durable and reliable componentry • 100%* parameter coverage • Advanced sensor performance, capabilities • Advanced, automated ground test / inspection • Expanded built-in-test in lieu of ground test, inspection • Rapid response to failures	• Time - critical Fault Detection Isolation and Recovery (FDIR) • Efficient IVHM diagnostics, prognostics, data information tracking, scheduling • Modular reuseable application software with configuration control • Advanced software management capabilities for : SW reliability, SW safety , test procedures and management, verification & validation
CURRENT STATE OF THE ART ASSESS-MENT	• Non-integrated health management of systems/ subsystems ground test, flight ops, factory, launch site • Mixed manual and automated test and checkout • Limited mission modification, abort capabilities	• Monitoring componentry is susceptible to damage • Parameter coverage is incomplete • Extensive manual labor in test / inspection procs. • Limited built-in-tests • Limited sensor capabilities(e.g., most are single function, manually calibrated, no data compression)	• Limited diagnostic capability • Very limited prognostic capability • Rudimentary planning, scheduling of maintenace, testing • Rudimentary data and information handling, processing and documentation • Diverse SW languages, development environment • SW safety, reliability issues not well understood
RESEARCH AND TECHNOLOGY OBJECTIVES — NEAR TERM	• 30%* reduction in catastrophic failure modes for which there is no response • Tools for IVHM development; e.g.; cost / benefit, FMEA • IVHM concepts architectures, SE & I developed • 25%* reduction in maintence, test and checkout time, manpower, and costs • 25%* reduction in IVHM flight ops. manpower • 25%* reduction in post-op. diagnostic time, manpower, and costs	• 30%* reduction in failures in monitoring / test componentry • 90%* parameter coverage • Advanced sensor (e.g., smart sensors, microsensors) concepts demonstrated • Advanced, automated ground test, inspection techniques demonstrated • Advaned built-in-test concepts demonstrated	• Concepts demonstrated for: - time-critical FDIR - non-time-critical FDIR - Modular reusable SW w/ config. control • Establish goals for advanced SW management • Automated planning, scheduling of maintenace • Selected FDIR applications developed • SW for design - knowledge capture for IVHM developed • Standardize language, development environment
RESEARCH AND TECHNOLOGY OBJECTIVES — MID TERM	• 60%* reduction in catastrophic failure modes for which there is no response • 50%* reduction in maintenance, test and checkout time, manpower, and costs • 50%* reduction in IVHM flight ops. manpower • 50%* reduction in post-op. diagnostic time, manpower, and costs • IVHM architectures for advanced space transportation	• 60%* reduction in failures in monitoring / test componentry • 95%* parameter coverage • Selected advanced sensors developed • Selected advanced automated ground test and inspection techniques developed • 25%* increase, in built-in-test with corresponding decrease in manual ground test and inspection	• FDIR extended to additional applications • Non-time critical SW develped for all ground-based applications • Advanced SW management developed • Modular , reuseable SW with configuration control developed • SW management concepts demonstrated
RESEARCH AND TECHNOLOGY OBJECTIVES — FAR TERM	• 90%* reduction in catastrophic failure modes for which there is no response • 75%* reduction in maintenance, test and checkout time, manpower, and costs • 75%* reduction in IVHM flight ops. manpower • 75%* reduction in post-op. diagnostic time, manpower, and costs • Spaced-based IVHM • Autonomous vehicle IVHM	• 90%* reduction in failures in monitoring / test componentry • 100%* parameter coverage • Selected advanced sensors, ground test and inspection techniques developed • 50%* increase in built-in-test with correspond-ing decrease in manual ground test and inpection • 90%* built-in-test for space-based vehicles	• FDIR extended and integrated across all applications at the system level • IVHM SW enabling to space - based, autonomous flight ops. developed • Automated SW development / test environment

* Numbers are indicative of present and proposed future capabilities , but are not hard requirements. They are included to show an expected progression of capabilities from near term to far term.

FIGURE 6. Proposed IVHM Reserch and Technology Objectives

While much progress has been achieved in developing sensors and instruments to measure vehicle operating parameters and detect faults, there are important parameters that still cannot be measured reliably (such as fluid flows, zero-g fluid quantity gaging, leaks, etc.). In addition, changing vehicle and component designs can and do create new monitoring challenges. A second R&T goal will be to pursue the identification of new measurement/monitoring concepts and develop new sensors and instruments to progressively increase coverage of high-value parameters. The long-term goal will be to achieve and maintain 100 percent parameter coverage.

A third goal will be to develop advanced sensor capabilities. Current sensor capabilities are to be limited in that most are single function devices that must be manually calibrated, and they have no data compression capabilities. Therefore, an R&T objective will be to develop and demonstrate advanced sensor concepts that incorporate these and/or other capabilities. Examples are smart sensors and micro-sensors. Smart sensors incorporate local data handling and processing and, perhaps, a local power source enabling much more distributed IVHM architectures. Micro-sensors exploit emerging micro-machining technology to create sensors drastically reduced in size. This greatly facilitates integration into the system to be monitored.

Advanced automated ground test and inspection techniques will be pursued as a fourth key technical goal. This goal focuses on one of the highest pay-off potential technology needs identified for current vehicles (ELVs, Shuttle) and the NLS. It is important to note that this effort will focus not only on test equipment for the flight vehicles, but also on test equipment for Ground Support Equipment (GSE) such as propellant storage/handling/loading equipment. It includes test equipment both at the launch/landing sites and at the factory. Extensive manual labor is required in current vehicle processing and maintenance test and inspection procedures. The goal will be to significantly reduce the labor through the development of improved and automated test and inspection procedures and equipment. The R&T objective will be the development and demonstration of selected equipment and techniques. Efforts devoted to this objective will be coordinated with and supported by related software R&T.

A fifth sensors/test equipment goal will be the development of expanded built-in test capabilities that reduce the need for ground test and inspection equipment and labor. Limited built-in-test capabilities already exist (for example, in avionics/control systems). The long-term R&T objective of greatly expanded built-in-test capabilities is driven by SEI-associated space-basing requirements. Systems must be capable of operating in space for long periods of time with the only ground support coming through communications links. In the near and mid terms, developments will be targeted toward built-in-test capabilities that provide significant safety/reliability gains, or ground test and inspection cost/time/manpower savings.

A sixth goal will be to ensure that sensors, effectors, and test systems can provide rapid responses to failures and impending failures.

4.3 Software

One of the key technical goals of software is to enable greatly expanded capabilities to perform time-critical fault-detection isolation and recovery (FDIR). Present diagnostic and prognostic capabilities are very limited as is the ability to respond to hazardous situations. Software technology will be developed that can operate on sensor and other information input to provide a much more accurate and comprehensive understanding of vehicle condition in real time. This information then will be used to make real-time decisions, if necessary, to carry out system operational adjustments, system reconfiguration, mission alteration, or mission abort.

This effort will directly support the IVHM system R&T objective to progressively increase the ability to prevent catastrophic failures. In the near term, the effort will focus on selected applications. It will then expand in the mid term and far term to achieve vehicle system-wide coverage. A combination of conventional and advanced AI approaches will be needed. The time-criticality requirement may favor distributed and parallel processing architectures. One of the key factors will be the effective integration of advanced software with advanced sensing technology and system engineering.

A second goal of software R&T will be to significantly increase the efficiency of long-term integrated vehicle health management. This will address IVHM functions and applications that are non-time-critical and will focus on increasing the effectiveness of IVHM while reducing time, manpower and costs. Functions will include design knowledge capture, diagnosis leading to fault detection and isolation (including intermittent faults), trending analysis and prognosis, maintenance scheduling and planning, data and information handling and tracking, and more effective human-machine interfaces. Currently, many of these functions are labor intensive and time consuming. Also, they are not highly integrated or coordinated with respect to software used. Some procedures and planning activities remain paper-based.

The R&T objectives pursued will correspond to the functions described above. The FDI software will have a degree of commonality with FDIR software used for time-critical IVHM. However, it also will incorporate significant additional capabilities to perform more in-depth analyses for maintenance diagnostic applications. Similar to the time-critical software, effective integration of advanced software, sensors and instruments, test equipment, and systems engineering will be important. Likewise, effective software solutions will combine conventional and AI approaches. This facilitates integration with existing systems/software. It also facilitates the use of existing software management practices for software development and maintenance. Advanced data base management system approaches will be pursued to effectively deal with design knowledge capture, data archiving, and planning and rescheduling functions.

The third key goal is to develop modular reusable software elements and an advanced configuration management system that will support their integration for IVHM. This effort will focus on the creation of software engineering environments incorporating reusable modules that will provide both time-critical and non-time-critical functions required for IVHM. By establishing a library of software components, the development of operational software systems for many different vehicle applications will be facilitated. The configuration management system for the software must be integrated with the overall vehicle configuration management system so that hardware/software interface requirements are identified and satisfied.

The final key software goal is to develop advanced software management capabilities for software safety, reliability, test procedures and management, and verification and validation. Goals for software reliability must be established and methods for evaluating the reliability of safety critical systems developed. Automated test procedures and environments will enable the rapid assessment of software functionality, safety, and reliability. Methods for realtime software verification and validation must be developed from the systems perspective. It is the dependencies between the IVHM hardware and software that are challenging, and the software management system must provide an environment to address these issues.

5.0 Conclusions

IVHM R&T objectives have been established that fall into two categories. The first category is target improvements in key IVHM-related capabilities such as: failure mode prevention; parameter coverage; monitoring and test componentry reliability; built-in-test coverage; and reduction in resources required to do maintenance, test, checkout, flight operations, and post-operational diagnostics. Progressively demanding target improvements in key parameters are established for the near term, mid term, and far term. The second category of objectives is those that represent the introduction of new capabilities. These include: special design tools and aids; space-based IVHM; autonomous vehicle IVHM; advanced sensors (e.g., smart sensors and micro-sensors); advanced test/inspection techniques; and advanced modular/reusable software and software management techniques and tools. (See Figure 6.)

The next step is to scope and define IVHM R&T program planning directed toward these objectives. IVHM R&T then will be implemented through the technology elements of the OAST Integrated Technology Plan (ITP), including: the focused Low-Cost Transport Program for commercial Expendable Launch Vehicles (ELVs), the ETO Avionics Program for reusable ETO transportation systems, and the Space Transfer Avionics Program for space-based vehicles and long-term manned space missions.

OAST is conducting IVHM R&T planning in concert with an IVHM Technology Bridging Program being developed by the Office of Space Systems Development (OSSD). These activities will provide for the timely introduction of IVHM technology into space transportation systems. The results of these activities, coupled with complementary design and operational improvements, will produce significant space transportation advances.

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APPENDIX A

SPACE TRANSPORTATION SYSTEM REQUIREMENTS LISTS

This Appendix consists of summary lists of present and future space transportation system requirements that relate to transportation system affordability, operability and maintainability, and safety and reliability. This information was obtained by surveying available document sources and requesting information from cognizant sources. The information presented was obtained from references 1, 3, and 11-17.

INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM) OBJECTIVE

OAST

- PROVIDE TECHNOLOGY READINESS TO SIGNIFICANTLY IMPROVE THE EFFICIENCY, UTILIZATION, AND QUALITY OF SERVICE OF SPACE TRANSPORTATION SYSTEMS THROUGH THE IMPLEMENTATION OF INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM)

EMPHASIS ON:

- AFFORDABILITY
- OPERABILITY AND MAINTAINABILITY
- SAFETY AND RELIABILITY

VEHICLE REQUIREMENTS SURVEY (IVHM RELATED) - 1

	747-400/B1	NASP DERIVED VEHICLE	SHUTTLE	AMLS
AFFORDABILITY ↕ OPERABILITY AND MAINTAINABILITY ↕ SAFETY AND RELIABILITY	• 747-400 CMCS HAS ON-BOARD CAPABILITIES: - MONITORING - DIAGNOSTICS/ PROGNOSTICS - CREW ALERT - MAINT PLANNING - DATA/MANUALS - FLY WITH FAULTS - MINIMAL TRAINING • HIGHEST LEVEL SYSTEM AVAILABILITY ACHIEVED • B-1B CITS/CEPS - DETECT 95% FAULTS - ISOLATE 65% FAULTS TO LRU, 95% TO 4/5 LRUs INTERACTIVE AIDS - RESOLVE FALSE ALARMS - PROGNOSTICS - MAINT PLANNING - TRAINING AIDS	• AIRLINE OPERATION • INTEGRAL PART OF AIRPORT LIKE INFRASTRUCTURE - PROPELLANTS - PAYLOADS - LINE SERVICING • LAUNCH ON DEMAND • LAUNCH ON SCHEDULE • NIGHT-TIME A-LEVEL MAINTENANCE - LINE PERSONNEL - SQUAWKS - NON-FLIGHT CRIT • B-LEVEL MAINT - 1000 HR CHECKS & INSPECTIONS • C/D-LEVEL MAINT - ALL-THE-TIME MAINTENANCE/ OVERHAUL STATION • AUTONOMOUS OPERATIONS - OPERATING ENVELOPE DEFINED - ENERGY MGMT - THERMAL LIMITS DEF • STATISTICAL VERIFICATION OF COMPONENT/SYSTEM RELIABILITY	• REDUCED FLIGHT OPERATIONS COSTS • REDUCED GROUND OPERATIONS COSTS • 20+ YEAR ADDITIONAL LIFETIME • INCREASED LAUNCH RATE • REDUCED TURNAROUND TIME • LAUNCH ON SHEDULE • GROUND OPERATIONS AUTOMATION • REDUCED RETESTS • REDUCED UNSCHED. MAINTENANCE • HIGH SYSTEM AVAILABILITY • HIGH MISSION SUCCESS PERCENT • FAIL-SAFE, FAIL-OPERATIONAL CAPABILITY	• 240 PROCESSING HOURS TURNAROUND TIME • 10000 HOURS PROCESSING • 500FLIGHT LIFE • INTEGRATED VHM & AVIONICS • ON-BOARD MONITOR - MONITOR STATUS - PORTED TO GROUND • AUTOMATED PROCESSING • LIMITED PAD SUPPORT TO PAYLOAD • LAUNCH ON SCHEDULE • ENGINE-OUT CAPABILITY • CREW ESCAPE MODULE • SAFE ABORT • NO HAZARDOUS MATERIAL DURING PROCESSING

VEHICLE REQUIREMENTS SURVEY (IVHM RELATED) - 2

OAST

	DELTA	ATLAS	TITAN IV	HLLV, e.g., NLS/ALS
AFFORDABILITY ↕ OPERABILITY AND MAINTAINABILITY ↕ SAFETY AND RELIABILITY	• 19 DAY TURNAROUND (2 PADS) • 12+ FLIGHTS/YEAR • 95% AVAILABILITY • SURGE TO 15+/YEAR • MAXIMIZE OFF-PAD PRE-LAUNCH PROCESSING • 92% ALL-WEATHER CAPABILITY • 27 MONTH LAUNCH OPTION LEAD TIME • 12 MINUTE RECYCLE AFTER T-4 • PAYLOAD SEPARATION HARDWARE PROVIDED • ACCESS DOORS, RF TRANSPARENCIES IN FAIRING • 98.5% SUCCESS • SAFE COUNTDOWN ABORT • STRINGENT STAGE AND SUBSYSTEM TESTING	• 38 DAY TURNAROUND (EACH OF 2 PADS) • 8 FLIGHTS/YEAR • SURGE TO 10+/YEAR • CONTINUOUS OFF-PAD PROCESSING ENHANCEMENT PLAN • 95% WINDS ALOFT CAPABILITY • 15-18 MONTH LAUNCH OPTION LEAD TIME • 5 MINUTE RECYCLE AFTER T-5 • PL ADAPTERS & SEP HDW AVAILABLE • ACCESS DOORS IN FAIRING; 2 PL FAIRING VOLUMES AVAILABLE • DEDICATED SPACECRAFT UMBILICALS; COMMON INTERFACE TO VEHICLE AIRBORNE SYSTEMS • CONTROLLED RF/EMI PL ENVIRON W/ EXPLICIT RF ACCESS • ALL VEH AVIONICS EMI/ LIGHTNING PROTECTED • 95% SUCCESS	• 85% ALL-WINDS-ALOFT CAPABILITY • MAINTENANCE DESIGN FOR: - SIMPLE FDI - MINIMAL TRAINING, EQUIPMENT, PERSONNEL • PREVENTATIVE MAINTENANCE DOES NOT INTERRUPT SYSTEM READINESS • ELECTRONICS IS LIGHTNING STRIKE PROTECTED • 99% TITAN SUCCESS • 98% TITAN/CENTAUR SUCCESS	• 6 DAY PAD TURNAROUND TIME • 10-25 FLIGHTS/YEAR • 90% AVAILABILITY • 95% ON TIME • NO SCHEDULE INTERFERENCE WITH SUCCEEDING FLIGHTS • 8 HOUR HOLD • 24 HOUR RECYCLE • PAYLOAD CHANGEOUT UP TO 5 DAYS TO LAUNCH • 35% SURGE • LAUNCH ON DEMAND - 30 DAY CALL-UP - 3 FLIGHTS IN 5 DAYS • DESIGN FOR EASE OF MAINTENANCE • AUTONOMOUS FLIGHT • 98.5% SUCCESS • FAIL-SAFE ABORT • HOLD-DOWN CHECK • ENGINE OUT CAPABILITY

VEHICLE REQUIREMENTS SURVEY (IVHM RELATED) - 3

	PLS ORBITER	SDIO SSTO	STV EO/MOON/MARS	CTV
AFFORDABILITY ↕ OPERABILITY AND MAINTAINABILITY ↕ SAFETY AND RELIABILITY	• 248 PROCESSING HOURS TURNAROUND TIME (PLS ORBITER) • 162 LAUNCH SITE PERSONNEL (PLS ORBITER, SINGLE SHIFT) • 8 FLIGHTS/YEAR • 20 YEAR LIFETIME • LAUNCH ON SCHEDULE • NIGHT LAUNCH • FIT IN ORBITER MID-BODY • SPACE STATION DOCKING • THREE DAY MISSION • NO LONG LIFE ORBITAL DEBRIS • DESIGN FOR EASE OF MAINTENANCE • AIRLINE MAINTENANCE PROCEDURES • AUTON OPERATIONS • IMBEDDED HEALTH MONITORING • SAFE ABORT TO LAND AND WATER	• 7-DAY, 350 MAN-DAY TURNAROUND • AUTOMATED - MANUFACTURE - FLT READINESS - FLT CONTROL SYST VALIDATION - SOFTWARE VALID - CHECKOUT • TWICE NORMAL FLIGHT RATE FOR 30 DAYS • MANNED/UNMANNED OPERATIONS • FAIL-SAFE, ENGINE-OUT CAPABILITIES • CREW ESCAPE ASCENT & ENTRY • INTACT ABORT • HAZARDOUS MATERIAL MONITORING	<u>EARTH ORBIT</u> • ON-ORBIT CHECKOUT <u>MOON</u> • AUTOMATIC REDUNDANCY MANAGEMENT WITH MANUAL OVERRIDE • ON-ORBIT REPAIR VIA ASTRONAUT • BUILT-IN-TEST • DUAL FAULT-TOLERANT • SMART SENSORS • AUTOMATIC SOFTWARE UPDATE AND V&V <u>MARS</u> • MULTI - REDUNDANT FAIL-OPERATIONAL/ FAIL-SAFE • ON-BOARD REPAIR MANUALS/ INSTRUCTIONS/ TRAINING	• 10 YEAR LIFE • UNMANNED REUSEABLE • 3-5 MISSIONS BEFORE REFUELING • SPACE BASED AT SSF OR SEI NODE, BUT: - GROUND REFUELED - GROUND MAINTAINED • 60 DAY TURNAROUND • AUTON. RENDEZVOUS AND DOCKING • SOME SELF CHECKOUT • FAIL-OPERATIONAL/ FAIL-SAFE • POSSIBLE PROPULSION FOR A CRV

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: RST

TO: GOVERNMENT, INDUSTRY AND UNIVERSITY TECHNOLOGY MANAGERS

In January 1992, the Office of Aeronautics and Space Technology (OAST) issued an Integrated Technology Plan (ITP) for the civil space program. This report called for a greatly expanded technology development activity closely coupled to future space mission objectives. OAST, working closely with the user mission offices and the aerospace community, has developed an aggressive set of mission-focused technology plans. Technologies for reliable, affordable, and available space transportation systems are key elements of this integrated plan. Much has been done to revitalize NASA's investment in space technology developments. However, under the current climate of tight federal budgets, funding to fully implement all elements of this plan is clearly beyond the NASA Space R&T fiscal resources.

Integrated vehicle health management (VHM) has been identified by the NASA Offices of Space Flight and Space Systems Development as their highest priority technology for space transportation systems. In response to this vital technology need and working closely with these offices, OAST has prepared a report which establishes research and technology goals and objectives for VHM technologies to support development of future technology and advanced development programs which will address VHM needs.

A copy of this report is being provided to you to serve as a mechanism for coordination with other government, industry and university planners to synergistically plan and pursue technology developments in areas of common interests.

It is my hope that you will take this opportunity to become more familiar with NASA's technology needs and plans for VHM and I encourage you to contact myself or other transportation technology planners at NASA Headquarters or at the NASA Centers. If you need additional information contact me at (202) 453-2857.

David R. Stone
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Transportation and Platforms Division

Enclosure