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Space Shuttle Main Engine (SSME) Options for the Future Shuttle

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SPACE SHUTTLE MAIN ENGINE (SSME) OPTIONS FOR THE FUTURE SHUTTLE

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Abstract

The main engines for the Future Shuttle will focus on improved safety and operability. Performance enhancements may also be required for vehicle safety purposes to achieve more desirable abort scenarios. This paper discusses the potential improvements that will be considered for implementation into the Future Shuttle. Integrated engine and vehicle health management systems will achieve additional system-level reliability improvements over those currently in development. Advanced instrumentation for detecting leaks, analyzing component wear and degradation, and providing sophisticated operational data will be used for reliable engine control and scheduling maintenance operations. A new nozzle and main combustion chamber (MCC) will reduce failure probability by 50% and allow for higher thrust capability without requiring the entire engine to be redesigned. Turbopump improvements may range from minor component improvements to using 3rd-generation pumps built on the advanced concepts demonstrated by the Integrated Powerhead Development (IPD) program and the Space Launch Initiative (SLI) prototype engines.

Introduction

The Space Shuttle is expected to be operational for two to three decades into the 21st century. So the question is not whether there will be a space shuttle, but rather what will it be like. From a propulsion perspective, it will likely continue as a two-stage-to-orbit vehicle. The boosters could be liquid or solid propulsion, but the main engines will remain liquid oxygen (LOX)/liquid hydrogen engines. This paper examines some potential requirements for the Future Shuttle main engines, and presents some options for achieving those goals.

Future Shuttle Engine Requirements

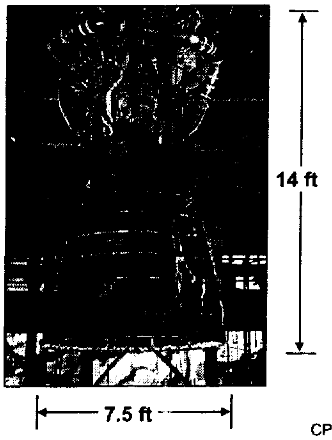
The primary goals of the Space Shuttle Program have been to:

- Fly safely
- Meet the manifest
- Improve mission supportability
- Improve the system

These worthy goals are expected to be the cornerstones for Future Shuttle vehicle and propulsion requirements. SSME safety goals for a future shuttle are likely to include a factor of 3 or more for risk reduction for catastrophic failure and possibly abort-to-orbit (ATO) or abort-to-TAL (Trans-Atlantic Landing) off the launch pad with a single engine out. Meet-the-manifest requirements translate into having a full complement of engines installed and ready on each vehicle. Improve-mission-supportability requirements translate into reduced maintenance and repair work and capability to keep the engines on the vehicle between flights with engine overhaul occurring simultaneously with vehicle overhaul. Improve-the-system requirements can be far reaching and include methods of improving the infrastructure and systems that NASA and the contractors use to execute the Space Shuttle. Skill and knowledge retention and infrastructure capability play an important role in this area as the program continues to mature and obsolescence becomes a greater threat. Privatization of certain parts or aspects of the program is one consideration, and the engine for the Future Shuttle must be developed to be compatible with a wide range of potential systems and infrastructures.

History of SSME Upgrades

To envision where the SSME can go, it is beneficial to examine the current SSME requirements and configuration of the engine and its history of upgrades. Figure 1 shows an SSME and its major requirements; Figure 2 is a summary of the major upgrades since the initial Shuttle flight in 1981 through the first flight of the Block II SSME in 2001. The most significant improvements in the Phase II engine for return to flight after the Challenger incident were safety/reliability/life improvements in turbopump components and new and improved sensors. Major changes in the Block I/IA configurations were the two-duct powerhead with an integral single tube heat exchanger, and a new high-pressure oxidizer turbopump (HPOTP) made by Pratt &



• Propellants	Oxygen/Hydrogen
• Rated power level (RPL) 100%	469,448 lb
• Nominal power level (NPL) 104.5%	490,847 lb
• Full power level (FPL) 109%	512,271 lb
• Chamber pressure (109%)	2,994 psia
• Specific impulse at altitude	452 sec
• Throttle range (%)	67 to 109
• Weight	7,748 lb
• Total program hot-fire time (March 2001)	> 2,929 starts > 972,132 sec

Figure 1. Block II SSME Performance Requirements

Whitney. Block IIA/II upgrades included the large throat MCC, which significantly improved reliability by reducing engine operating environments and a new high-pressure fuel turbopump (HPFTP) also made by Pratt & Whitney. More detail descriptions of various SSME upgrades are presented in reference 1. The improvement of safety resulting from these upgrades is shown in Figure 3 in terms of SSME 3-engine cluster risk reduction and Space Shuttle ascent safety improvement.

Advanced health management system (AHMS) Phase I (Figure 4) is the only major upgrade currently funded and in development. This upgrade includes a new real-time vibration monitor redline for the high-pressure turbopumps. It includes digital signal processors and a high-speed communication bus to analyze and discriminate true rotor unbalance from false signals.

To continue to make sizable safety improvements with component upgrades, attention must be focused on the components with the largest failure fraction, namely the high-pressure turbopumps, MCC, and nozzle. Proposed upgrades in the past sought to accomplish this by designing a more reliable and robust nozzle and MCC to double their reliability. Because the Block II SSME high-pressure turbopumps were just recently certified for flight, improvement in turbopump reliability focused on running the engine at further reduced operating environment (lower temperatures, pressures

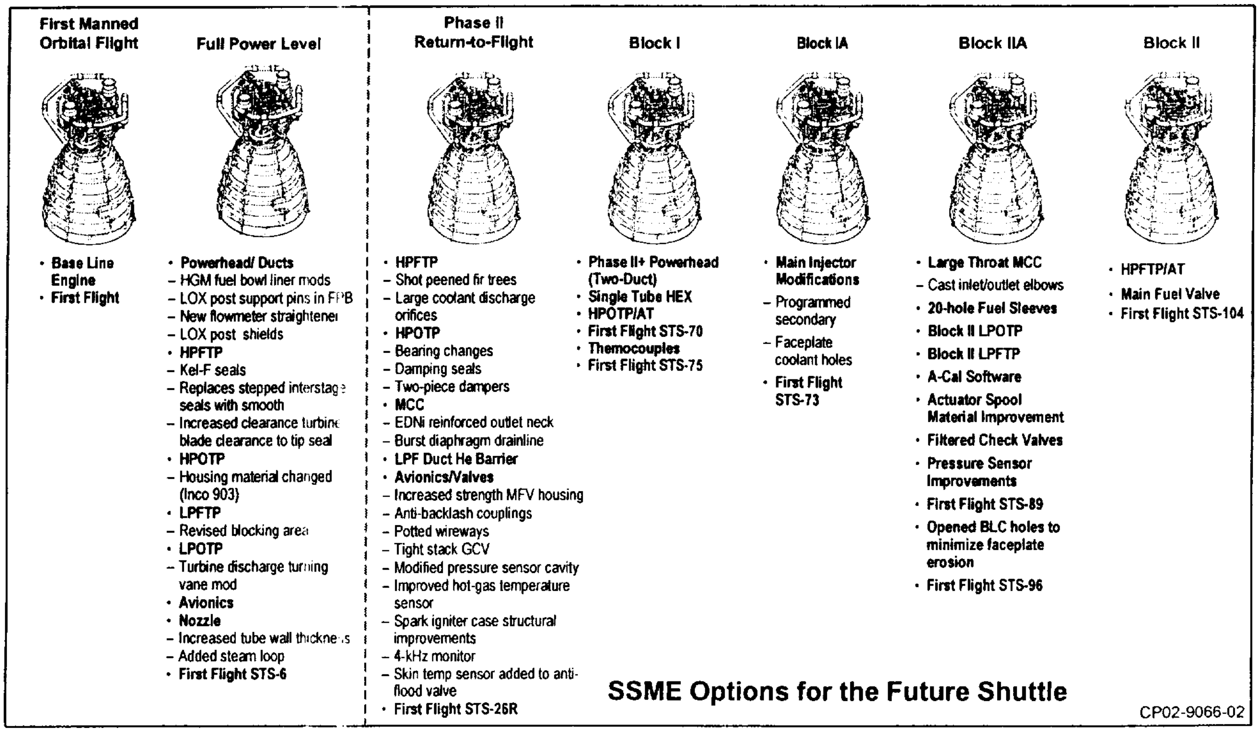


Figure 2. History of Major SSME Upgrades

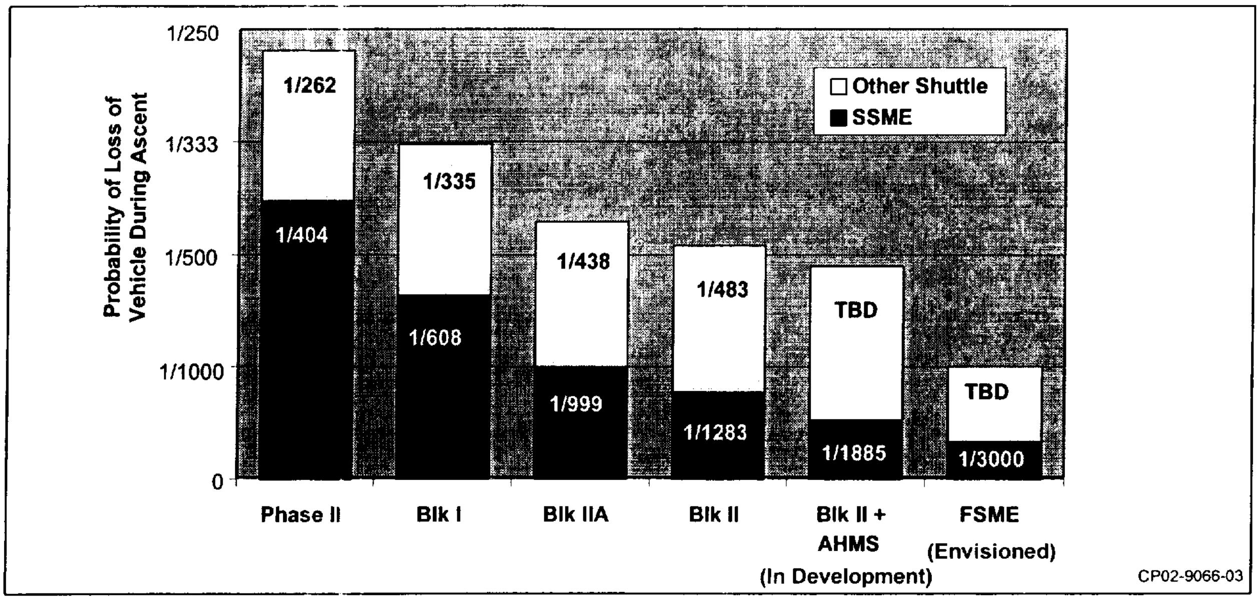


Figure 3. Reliability Improvement of SSME Upgrades

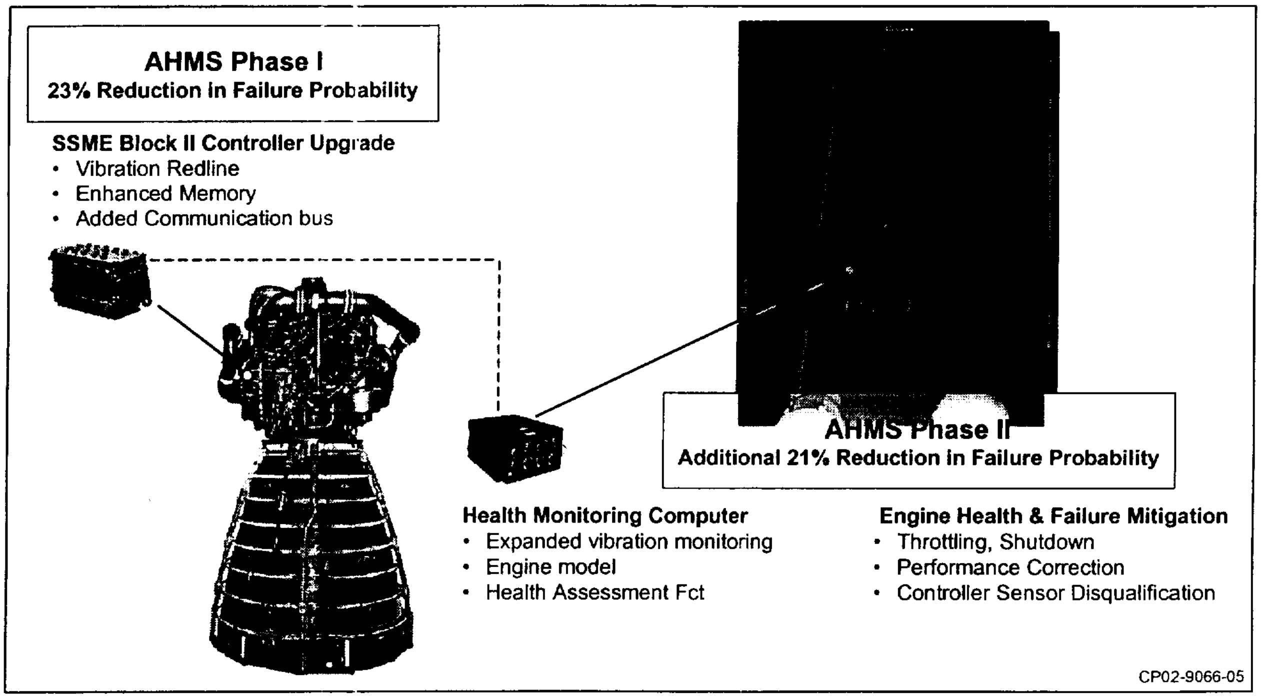


Figure 4. Advanced Health Management Upgrade

and speeds) conditions by increasing the MCC throat diameter versus significant design changes in these new turbopumps.

SSME Options for the Future Shuttle

Changes to the SSME for the Future Shuttle will focus on safety improvements, improved supportability and operability, and eliminating obsolescence issues. Performance enhancements may be required to achieve other top-level shuttle safety goals such as increased thrust to provide safer abort scenarios. Safety improvements will focus on system enhancements and upgrades to components. Figure 5 shows the reliability of the components and suggests that the greatest system impact can be achieved with improvements to the high-pressure turbopumps, nozzle, and MCC. The following

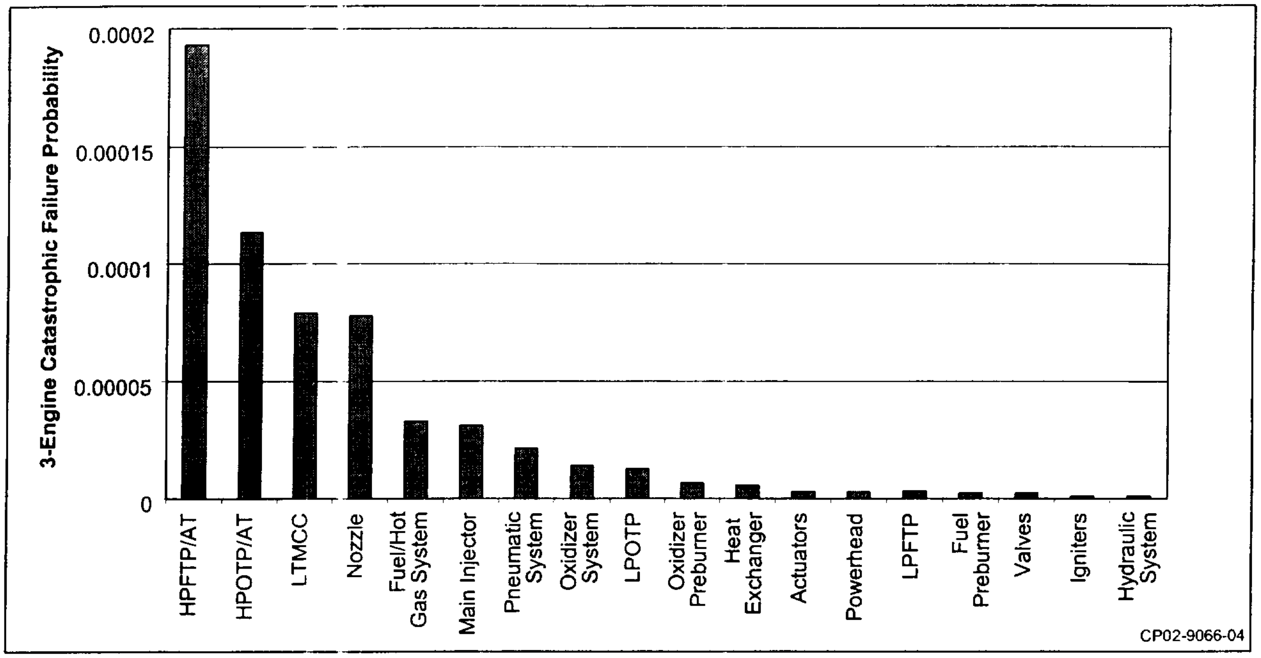


Figure 5. Reliability of SSME Components

are potential upgrades that would achieve the propulsion goals of the Future Shuttle.

Advanced Health Management System. AHMS is a system-level approach for improving safety with goals to improve SSME catastrophic failure reliability and to increase Shuttle mission success probability. The AHMS approach is to:

- Detect and isolate failures with high confidence
- Enhance shutdown, controller sensor disqualification capability
- Provide mitigation options previously unavailable
  - Throttling
  - Performance correction
- Use new options to mitigate credible, potentially catastrophic failure effects that we cannot respond to today

AHMS Phase II received go-ahead in the first quarter of GFY 2002 (Figure 4). Continuing development in 2003 is under assessment and may be developed on SLI funds and implemented on Space Shuttle Program funds. Throttle-down capability extends the time when the engine is providing thrust while reducing stresses on engine, thereby reducing likelihood of catastrophic failure. Performance correction enables a successful mission or more preferred abort by correcting performance impacts of anomalies. Correction of mixture ratio to account for hydrogen leaks in the MCC or nozzle is one example of performance correction. These enhancements are achieved by having a new Health Management Computer (HMC) running a Linear Engine Model assessing all the engine parameter measurements and determining the engine problem and necessary corrective action. An Advanced Real Time Vibration Monitoring System (ARTVMS) will further differentiate accelerometer signals into signatures indicative of instabilities, internal wear, and rubbing. These features will all be incorporated into the HMC's open architecture design that will have expansion capabilities to incorporate future emergent technologies.

Channel Wall Nozzle. The SSME nozzle is the only engine component that has not been through a major upgrade. A channel wall nozzle with milled channels and a brazed jacket is expected to be 50% more reliable than the current nozzle with reduced failure causes. Significant benefit is achieved by going from a one-pass cooling circuit to a two-pass scheme allowing the elimination of the coolant feed lines and aft manifold at the highly stressed aft end of the nozzle. It is interesting that a two-pass configuration was the baseline design in 1972 [ref. 2]. Additionally, production cycle time is reduced by one-third (36 to 24 months) with associated cost reductions. Channel wall nozzles have a smooth inside surface as compared to the conventional tube nozzles, and the reduced drag improves specific impulse by ~0.5 second for the SSME. A new nozzle provides an opportunity to create an improved, redundant seal at the nozzle/MCC interface joint as well as making the thermal protection system on the nozzle more robust, thereby reducing maintenance operations.

Main Combustion Chamber (MCC). A new MCC design would also have a 50% reduction in failure probability using a high-isostatic-pressure (HIP) braze fabrication process. This process has been successfully used on the X-33 aerospike engine combustors and the RS-68 (Delta IV Vehicle engine) combustion chamber. The current SSME MCC is fabricated using an electrodeposition process that has longer cycle time, more potential failure causes, and requires substantial process maintenance. One important aspect of a new MCC design would be potentially increasing the throat diameter, which can have significant impact on reducing the engine operating environments and increasing the reliability and life of the other engine components, particularly the high-pressure turbopumps.

Turbopumps. Without question, the turbopumps are the most complex and challenging components on a liquid rocket engine. The SSME Program was recently successful in certifying new, more robust high-pressure turbopumps. The life of the HPOTP has proven to be exceptional, and continued testing of the HPFTP is expected to increase its usable life before overhaul to 10 or more flights. Opportunities for increased life and reliability may be achieved by reducing the harsh thermal environment by several methods. One method is modifying the engine operations, primarily the start and shutdown conditions to reduce the thermal strains. Another method for achieving increased life and reliability is to effectively lower the overall parameters by running the engine in a derated or lower power level mode, or by enlarging the MCC throat.

Candidate design changes to the existing turbopumps include improved turbine nozzles and discharge housing, and a nonintrusive speed sensor.

Supportability/Operability Improvements. Keeping the engines on the vehicle is a major goal of the Future Shuttle. Eliminating the need to open ports and inspect components reduce the risk of introducing foreign object debris, creating leaks, and other collateral damage resulting from technicians performing inspections around the hardware in the confined aft compartment. Integrated health management systems with new gas sensors for leak detection, speed sensors that provide turbopump torque data on spin down, and spectrometric measurement of plume species to confirm no adverse wear or erosion of materials are technologies that can be calibrated to eliminate between-flight inspections. Technologies providing spatial temperature measurements of the hot gas in turbines could eliminate intrusive inspections of turbine for erosion cause by hot streaks.

Increased Life Limits—

Required Changes for High Thrust Operation. The SSME is certified for a 109% power-level operation that includes demonstration at 111% operation as part of the certification process. Studies are underway to address the higher thrust needs of a Future Shuttle to achieve ATO or TAL off the launch pad with a single engine out. The first study addresses the maximum thrust capability of the current Block II configuration SSME culminating in a hot-fire demonstration. An additional study focuses on what additional changes are needed beyond the options mentioned to be incorporated into a "Block X" configuration. Although the level of engine changes would be highly dependent on the required thrust, the following areas would be likely candidates:

- High margin main injectors with robust LOX posts.
- Enlarged MCC throat for reduced temperatures, pressures, and speed for increased margins, life, and safety.
- 2nd-generation high-performance low-pressure turbopumps with integrated one-piece rotors/stators, more robust seals and bearings, and higher head capability.
- 3rd-generation advanced high-pressure turbopumps with hydrogen-compatible-base materials; advanced instrumentation for spacial temperature measurements, nonintrusive speed measurements, and propellant flow rates; and hydrostatic bearings.

New Engines. The Future Shuttle may have requirements extending beyond what an SSME could realistically achieve without becoming a completely new engine. The Space Launch Initiative (Figure 6) is developing new technologies and engine concepts that have very challenging goals for increased reliability, reduced cost, and longer operating cycle life. If NASA Marshall Space Flight Center (MSFC) and the engine contractors (Boeing Rocketdyne, Aerojet/Pratt & Whitney Team, and TRW) are successful in demonstrating significant strides in achieving these goals, then a new engine design may be a viable option for the Future Shuttle.

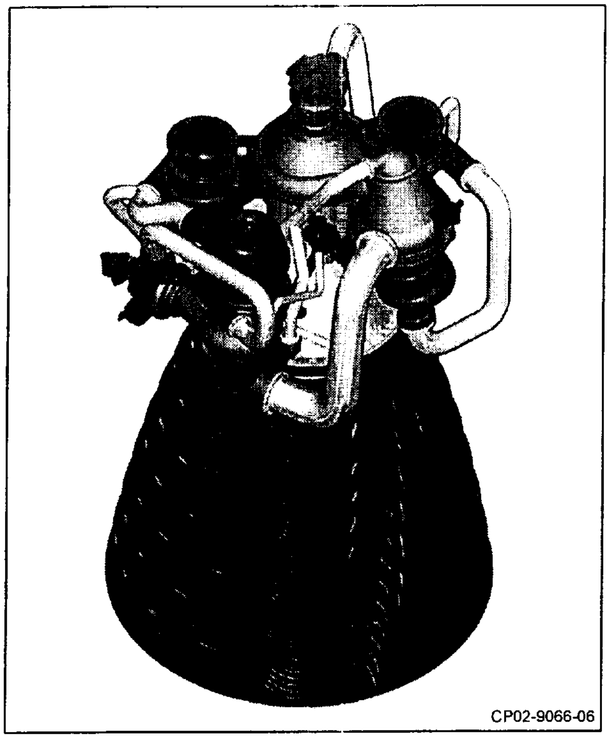


Figure 6. Space Launch Initiative RS-83 Engine Concept

Summary

Now that NASA has targeted the Space Shuttle to operate to 2020, new upgrade options become available for implementation. Safety and operability/ supportability will continue to be the major focus, and improvements to the SSME can provide significant value to the overall Space Shuttle Program. Each upgrade from first fight configuration engine to the robust Block II SSME has substantially increased the safety of the astronauts and the vehicle. Implementing new component designs, engine control system, and robust processes as described above will ensure continued safe operation of the Space Shuttle to 2020 and possibly beyond.

Acknowledgments

1. Marti Willis and Matt Davidson of Boeing Canoga Park for their contributions to the advanced health management descriptions.

2. Bill Rothschild, Charley Hoyt, and Jeff Craddock of Boeing Human Space Flight & Exploration for their funding and support for Future Shuttle propulsion studies.

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