NASA/TP—1998–208530

IN-15
358489
190

Reusable Rocket Engine Operability Modeling and Analysis

R.L. Christenson and D.R. Komar
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

July 1998

The NASA STI Program Office...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results...even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621–0134
- Telephone the NASA Access Help Desk at (301) 621–0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  800 Elkridge Landing Road
  Linthicum Heights, MD 21090–2934

NASA/TP—1998-208530

Reusable Rocket Engine Operability Modeling and Analysis

R.L. Christenson and D.R. Komar
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

National Aeronautics and
Space Administration

Marshall Space Flight Center

July 1998

Acknowledgments

Many made contributions directly and indirectly to this effort that are much appreciated. These include Robert Beil, Ron Liston, Jennifer Ringelberg, Richard Brown, William D. Morris, Edgar Zapata, Russ Rhodes, Michael Nix, Fred Huffaker, and Barney Holt. A special thanks to Richard Ryan, who supported the requirements definition and to Bruce Fleming, who supported the extensive data collection necessary to conduct these analyses.

Available from:

NASA Center for AeroSpace Information
800 Elkridge Landing Road
Linthicum Heights, MD 21090–2934
(301) 621–0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487–4650

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

ACRONYMS

CAPSS	Computer-Aided Planning and Scheduling System
DAR	deviation approval request
ELV	expendable launch vehicles
EMA	electromechanical actuator
gox	gaseous oxygen
GSE	ground support equipment
HPFTP	high-pressure fuel turbopump
HPOTP	high-pressure oxidizer turbopump
I_{sp}	specific impulse
KSC	Kennedy Space Center
LH_2	liquid hydrogen
LO_2	liquid oxygen
MDT	mean downtime
MR	material review
MS	Microsoft®
MSFC	Marshall Space Flight Center
MTBF	mean time between failure
MTBM	mean time between maintenance
MTTR	mean time to repair
NASA	National Aeronautics and Space Administration
OMEF	orbiter main engine facility
OMI	Operations and Maintenance Instructions
OMRSD	Operations and Maintenance Requirements and Specification Document
OPF	orbiter processing facility
PR	problem report
PRACA	Problem Reporting and Corrective Action
R&R	remove and replace
RLV	reusable launch vehicle
SSME	space shuttle main engine
STS	Space Transportation System
TVCA	thrust vector control assembly
VAB	vehicle assembly building

TECHNICAL PUBLICATION

REUSABLE ROCKET ENGINE OPERABILITY MODELING AND ANALYSIS

1. INTRODUCTION

The reusable launch vehicle (RLV) cooperative development program between NASA and the aerospace industry demands the design of cost-effective vehicles and associated propulsion systems. In turn, cost-effective propulsion systems demand minimal and low recurring costs for ground operations. Thus, the emphasis early on in this program should be effective operations modeling supported by the collection and use of applicable operations data from a comparable existing system. Such a model could support the necessary trades and design decisions toward a cost-effective propulsion system development program. These analyses would also augment the more traditional performance analyses in order to support a concurrent engineering design environment.[1–4]

In this view, functional area analyses are conducted in many areas including operations, reliability, manufacturing, cost, and performance, as presented in figure 1. The design engineer is responsible to incorporate the input from these areas into the design where appropriate. The designer also has the responsibility to conduct within and between discipline design trades with support from the discipline experts. Design decisions without adequate information from one or more of these areas results in an incomplete decision with potential serious consequences for the hardware. Design support activities in each functional area are the same. Models are developed and data are collected to support the model analysis. These models and data are at an appropriate level of detail to match the objectives of the analysis. Metrics are used in order to quantify the output. This is an iterative approach that supports the design schedule with results updated from increasingly more detailed design information.

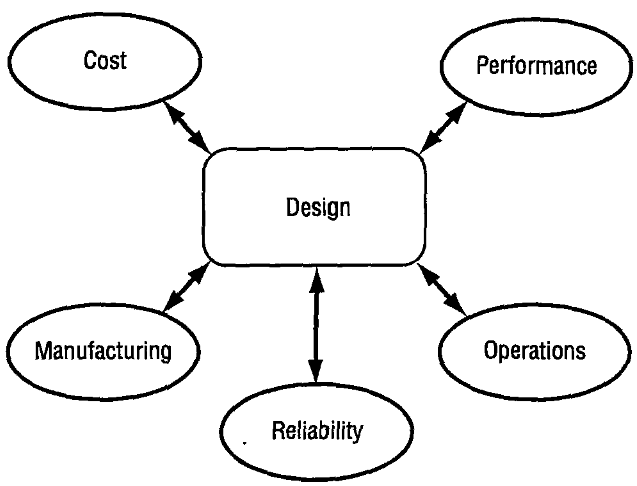


Figure 1. Disciplines in design.

Currently, in aerospace applications, there is a mismatch between the complexity of models (as supported by the data) within the various disciplines. For example, while good engine performance models with accurate metrics exist, the use of absolute metrics of reliability for rocket engine systems analysis is rarely supported. This is a result of the lack of good test data, lack of comparable aerospace systems, and a lack of comparative industrial systems relative to aerospace mechanical systems. Metrics also tend to be less credible for reliability. There is, as yet, not a comparable reliability metric that would allow one to measure and track reliability as the engine specific impulse (I_{sp}) metric allows one to measure and track engine performance. Performance models such as an engine power balance model or a vehicle trajectory model tend to be of good detail, with a good pedigree, and the results well accepted by the aerospace community. The propulsion system designer has to be aware of these analysis fidelity disparities when it becomes necessary to base a design decision on an analysis.

There is a need to develop models to obtain different objectives. Early in a launch vehicle development program, a top-level analysis serves the purpose of defining the problem and securing top-level metrics as to the feasibility and goals of the program. This "quick-look" model effort serves a purpose—it often defines the goals of the program in terms of performance, cost, and operability. It also is explicit about the need to do things differently in terms of achieving more stringent goals. A detailed bottom-up analysis is more appropriate to respond to the allocation based on an indepth study of the concepts. The "quick-look" model is appropriate if the project manager is the customer; the detailed analysis is directed more at the design engineer. Both are of value. The "quick-look" model also may serve the purpose of the allocated requirements model, the model to which comparisons are made to determine maturity of the design. It is inappropriate to use the data that supported the allocation of requirements to also support the detailed analysis. Although often done, this is inappropriate and could lead to misleading results.

The acquisition of good data is a traditional problem for the definition of baseline systems for aerospace launch vehicle operations analyses. For all models developed here, the Space Transportation System (STS) and the space shuttle main engine (SSME) are used as the source of historical reusable vehicle and engine systems operations experience. For the detailed model, the approach demands the identification of the requirements for SSME ground operations and the root source of the requirements. From this, a reusable engine model is developed that is based on the SSME operations model. This is done through incremental modification of the baseline operations model based on the proposed changes from the SSME to the reusable engine. The modifications of these processing activities are based on changes in hardware configuration and technology, processing technology improvements, and operations philosophy. The reusable engine system model is then traceable to past requirements and historical experience. This modeling approach supports credible operations modeling and analysis. In this paper, the baseline SSME model and a demonstration of its utility are presented.

2. BACKGROUND

The lack of historical data in support of aerospace launch vehicle operations analyses is acute. Data are either unavailable due to not being collected or not public, or are so highly aggregated as to mask needed detail at the process level. Top-level models generated by existing data were generally useful only for supporting programmatic goal discussions. Discrete event simulation models have often been models of choice.[5–7]

One approach to aerospace launch vehicle operations analyses is to compare with aircraft data. This information is generally more readily available and in the proper format with data collected from a maintainability point of view. Several papers have taken this approach.[8,9] While this data supports good model development, the question of applicability of results is more of an issue. This is especially true of rocket and aircraft propulsion systems with major differences in configurations, environment, and operating philosophy. Specifically, these differences include operating environment; operating temperatures, pressures, and thrust; ability to idle, taxi, and loiter aircraft engines and vehicles; use of cryogenic fuels on rockets; large performance margins on aircraft; nonintrusive health management of aircraft propulsion systems; and, perhaps the major difference, a philosophy of use with aircraft that tolerates test and operational failures (and even loss of life).

Ground operations analyses have also been conducted for aerospace launch vehicles based on available STS operations data.[10,11] Although the available data were found to be insufficient,[12] existing databases can be augmented by other sources, such as the experience of launch site personnel. This study builds on this approach. The SSME is regarded as the most directly applicable baseline for comparison with future and similar liquid oxygen (LO_2)/liquid hydrogen (LH_2) rocket systems. Thus, for this effort, extensive data collection was undertaken for STS propulsion systems to augment the existing databases. A baseline set of propulsion systems ground operations databases has been developed with the goal of supporting detailed engineering analyses of process and manpower requirements for future propulsion system concepts.

3. OPERABILITY ASSESSMENT METHODOLOGY

A. Approach

The operability assessment methodology described in this document reflects an end-to-end process flow model that models the uncertainties inherent in the attributes of the process flows. This approach attempts to substitute a rigorous and objective structure for more qualitative types of judgments and to focus design experiences to help determine areas of design confidence. It is to be used upfront in the design process and combines past flight vehicle experiences with design analysis to determine cost and schedule parameters of interest. It can be used in the analysis of any process flow where the goal is to optimize processing in order to minimize cost and schedule impacts.

The continuum of process flow activities includes development through manufacturing, assembly, and operations. For this modeling effort, the emphasis will be on the operational phase only. Figure 2 presents the flows of the operational phase of a launch vehicle, a subset of which will be the focus of this analysis.

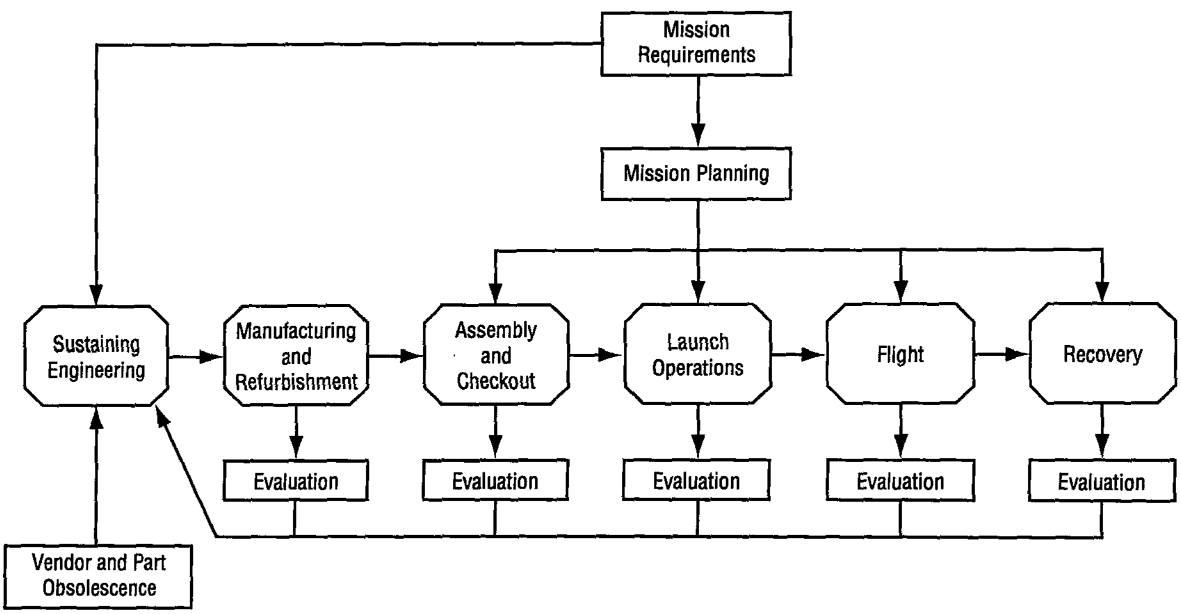


Figure 2. Launch vehicle process flow—operational phase.

The process flow model avoids estimates of cost and schedule parameters based upon nonspecific design characteristics such as weight and the use of integration "scale factors." In this modeling effort, cost and schedule indicators will be based upon realistic, high-fidelity process flows targeted against the current design configuration.

This approach incorporates past vehicle development experiences in terms of experience databases. These are critical parts of this methodology and are explicitly included in the approach. Since it is often difficult to obtain historical data to support these design decisions, a significant effort was undertaken to identify, incorporate, and appropriately structure this information for use with the process flow model.

Figure 3 presents the input flowing to the proposed process flows of a new launch vehicle. The new vehicle requirements and design configuration contribute in the definition of flows as does information gathered relative to historical launch vehicle flows. Data and requirements that are applicable from past launch and flight vehicles, including aircraft, expendable launch vehicles (ELV's), and the STS, may be used to generate or edit proposed flows and will be the main source of what is required (attributes) by these process flows in terms of manpower and schedule. The design and proposed flows will be continually updated, thus the approach is iterative. Also, historical data will be useful in providing insight into the traditional problems associated with the proposed process flow. Finally, new systems may require certain technology or special analyses to determine the operability of the system. This is also input to the process flow definition process. All of this information is, of course, subject to adaptation and interpretation by the design, manufacturing, and operations engineers. These groups and others must be involved at the outset in order for this to be a truly concurrent engineering effort.

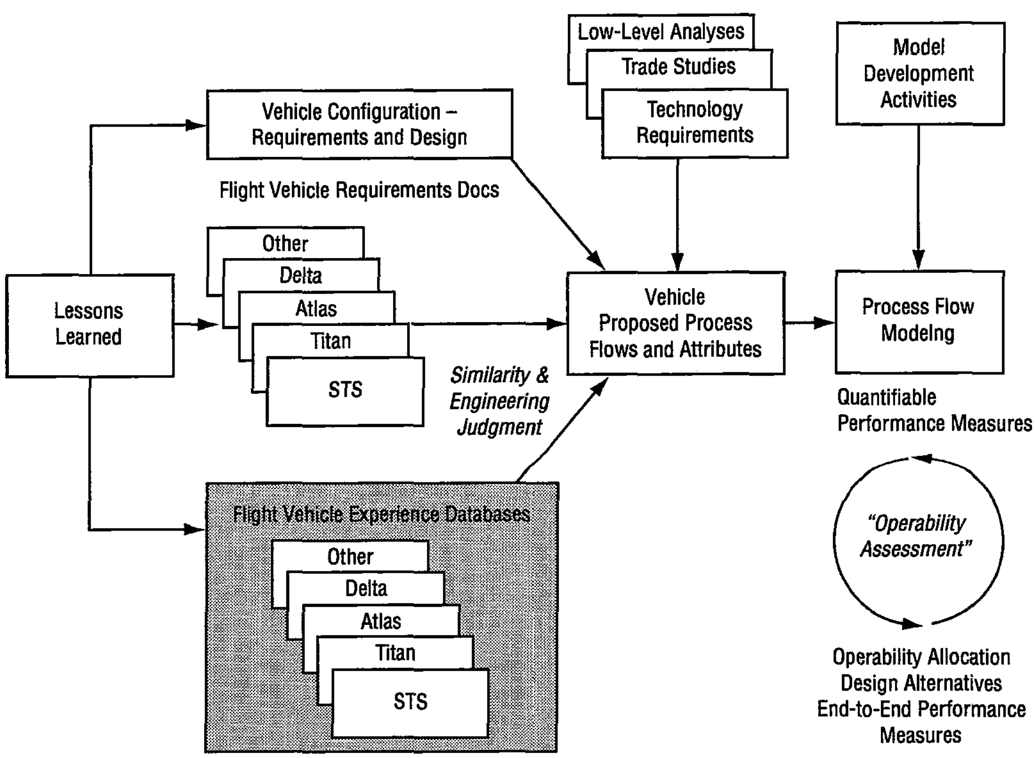


Figure 3. Operability assessment methodology.

The lessons learned on other vehicles implicitly affects current design engineering efforts and also serves to organize the search for applicable historical data. For example, the problems of past hydraulic systems on flight vehicles may cause the design engineer to attempt to include an electromechanical actuator (EMA) subsystem into the current design. Also, this "lesson learned" can serve to organize the identification of historical process flows, requirements, and experiences. Organized appropriately, historic processes associated with hydraulics can be easily pulled from the database, thus facilitating the analysis of this problem area by an appropriate design engineering team. This step of the methodology involves more of a qualitative assessment than a quantitative one. However, there is a structure surrounding the use of "lessons learned" that reflects the need to evolve and iterate this process with the "lesson learned" information.

Once the process flows and associated attributes have been defined, the modeling of the flows to generate quantifiable performance measures can be supported. The probabilistic nature of the system is clear due to the uncertain environment. Sensitivity studies, design change studies, and operability assessment studies are all supported.

A top-down approach is utilized in identifying and tracing process flows. At the outset, this hierarchical method is useful in identifying major cost and schedule drivers and assists in the allocation of scarce resources in the further analysis of the lower-level process flows. The danger of low-level analyses is the danger of misallocation of scarce resources to analyses that are not clearly important cost or schedule drivers. A top-down approach creates traceability of functional flows at each level in the hierarchy. It also serves to document and allocate the top-level program requirements. Its usefulness is limited to a "quick-look" analysis and for comparison purposes with the detailed analyses.

This methodology is designed to incorporate results from bottom-up analyses. Systematic evaluations of low-level process flows in terms of cost and schedule attributes will feed a detailed modeling activity. Once both models exist and comparisons are supported, both goals and actual timelines are subject to change: the top-down apportionment can be reallocated or changed; and the bottom-up reanalyzed and adapted to design changes resulting from changes incorporated into the design influenced by this modeling activity. Given this approach, the initial emphasis of this effort will be on supporting relative comparisons among design changes. Upon completion of an appropriate level of detail, accurate estimates can be generated.

Figure 4 provides an overview of this two-pronged approach. First, a goal timeline is created from a future launch vehicle operations concept. Making this goal reflect an actual design is desirable if such a design exists. However, these are goals, and as such, are meant as comparison points for a bottom-up engineering analysis of a historical baseline system. The second prong is this bottom-up effort, which provides an experience base and supports traceability to design, technology, and process improvements for the future launch vehicle propulsion system. This bottom-up effort is the focus of this paper. A previous paper[13] presented the goal-oriented approach, with both scheduled and unscheduled processing included in the goal flows. By nature, this approach is iterative. Comparing the historical estimates against the goals provides an identification of key differences. Design decisions will seek to lessen these differences—larger differences seeking the most design effort in an appropriate design manpower allocation process. The design will change and so also will the goals. Unrealistic goals and requirements will be identified and adjusted. Trades between performance and operations or cost and operations will be key for the overall risk assessment. A previous paper also laid out an example of such a bottom-up analysis based upon experience

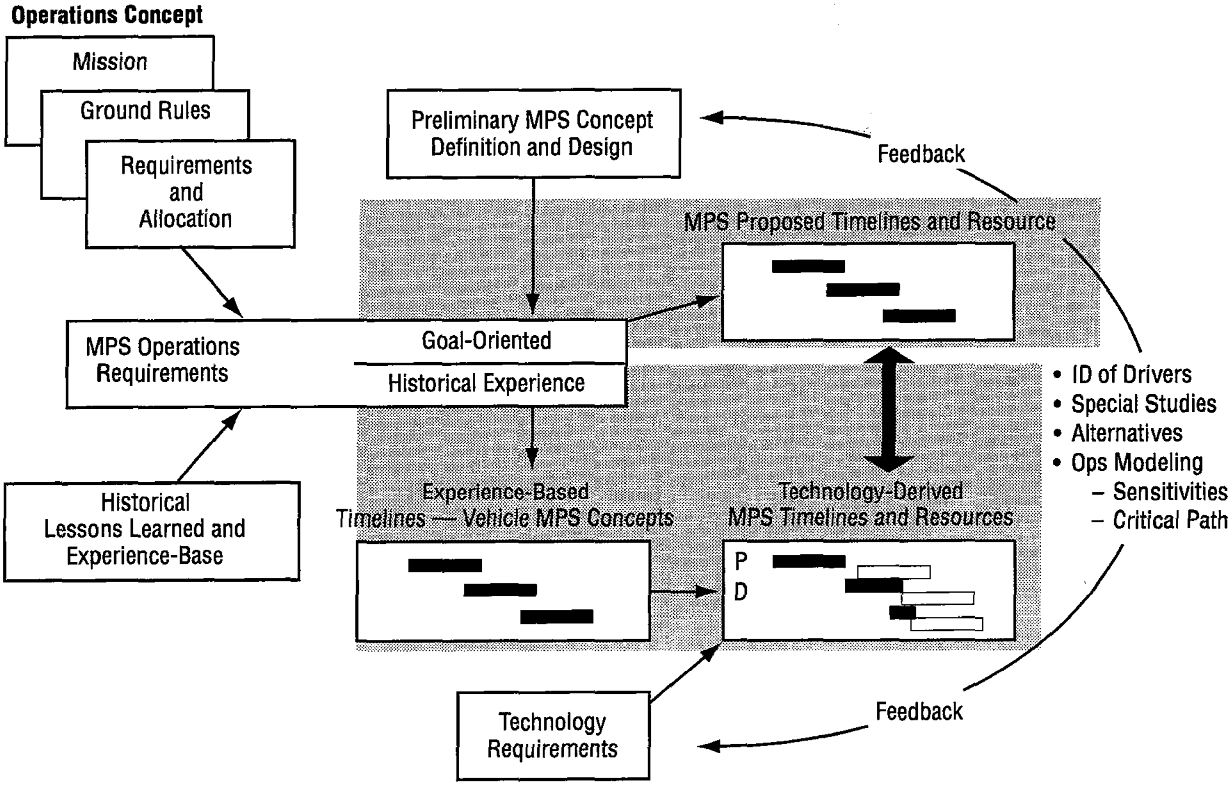


Figure 4. Design-to-operations analysis approach.

data.[14] Yet another paper points out the need to begin with experience-based requirements for this type of bottom-up analysis.[15]

Performance requirements as defined in requirements documents are allocated to a lower level and serve as goals for the system designer. One of the purposes of this effort is for the quantification of operability measures to support the comparison of the design against the requirement. Thus, this methodology serves to verify the relationship between design decisions and the fulfillment of design objectives. Furthermore, an appropriate quantification can serve to support the analysis of the current design suitability against a previous design. In this sense, both absolute and relative measures of merit are generated in this modeling approach. However, before a fully detailed model supporting the generation of absolute measures can be generated, a top-down flow can support the relative model comparison of critical use to the designer. A designer involved in a specific area of design can "stub" in the other parts along with their schedule and cost estimates and work in detail in their appropriate design area.

B. Key Concepts and Definitions

Establishing good measurable metrics is key to any functional area analysis methodology. Following is a discussion of key operability definitions and metrics.

Operability—the ability to support required flight rates and schedules and to meet a variety of operational characteristics while minimizing cost and risk. In this definition, operability is not directly measurable. Common metrics for operability include availability, turnaround time, and dependability. The definition of operability touches upon several key ideas including those of minimizing cost and risk. Risk may be defined as an expression of the likelihood and consequence of an event of interest. Risk involves an attempt to understand the uncertainty in and between the functional areas of the design. This emphasizes the need to model an end-to-end system.

Dependability—probability of achieving a given launch without sliding the schedule on the next launch, given that the system is not in postfailure standdown; if hardware, the ability for the hardware to perform as needed when needed. Often defined in terms of probability of launching within x days of the originally scheduled launch date.

Availability—fraction of time the system is operational rather than in standdown or delay; the probability that a piece of equipment will be capable of performing its mission when needed rather than being unserviceable due to failure, delays, or intentionally or unintentionally removed from service for maintenance or testing; is useful as metric for both hardware and processes; inherent is mean time between failure (MTBF)/(MTBF + mean time to repair (MTTR)); operational is mean time between maintenance (MTBM)/(MTBM + mean down-time (MDT)); also, scheduled time/(scheduled + unscheduled time). This latter definition is more aerospace-oriented given its acknowledgment of few vehicles that require extensive processing due to leading-edge technologies and cryogenic fuel operations. The traditional definition of availability is directed more at the military and commercial aircraft operations where there are large fleets of vehicles and preflight operations are relatively minimal. The process definition of availability is more suitable for this discussion and will be referred to throughout this analysis. Also, in this definition, a system is penalized only for unscheduled maintenance activities that occur on the critical path.

Turnaround Time—a measure of maintenance having to do with time from last recovery to next launch.

Reliability—probability of successfully concluding a mission segment; probability that an item will perform a required function under stated conditions for a stated period of time. Though metrics for reliability are not often included in operations analyses, reliability of the components and systems plays a critical role in determining the operability of the system. The operability study in this paper will include engine reliability measures.

C. Modeling and Uncertainty

The goal of any modeling activity is to accomplish accurate quantification in as realistic an environment as possible. This involves the need for quantifying in the presence of uncertainty. Thus, the model should ultimately be reflective of a probabilistic approach. Uncertainty is not only reflected in the accuracy of the information that exists but also in the availability of information that may lead to an inability to effectively model the system. These are both important pieces of information—manpower can be allocated to obtain the data or to complete the analysis that is required to lessen the uncertainty. The analyses cannot entirely eliminate the uncertainty associated with a process flow but are intended more to understand the extent of the uncertainty. Indeed, if no uncertainty exists in a design, no decisions are necessary.

There are several sources of uncertainty inherent to a process flow, including variation of nominal processing; that is, a process scheduled for 5 hr may actually take 4 hr one time and 6 hr the next. This can be modeled through the selection of an appropriate process time distribution supported by empirical evidence. Other realistic scenarios that will affect the schedule and cost include process failures, equipment failures, and associated unscheduled maintenance activities. Also, delays due to repair times, queuing delays, and waiting for resources can affect the planned schedule. The weather is a major source of delay at time of launch.

D. Process Flow Definition

The types of documents and databases used to generate the process flow for this analysis may be identified. In the case of the world's only RLV, the space shuttle, the documents that describe the requirements and the implementation of the requirements are the Operations and Maintenance Requirements and Specification Documents (OMRSD) and the Operations and Maintenance Instructions (OMI), respectively. Applicable process requirements and flows have been obtained from these sources for the specification of new vehicle operations process flows.

Some attributes of the proposed flows can be obtained from the electronic database system in use by the STS program. The STS Computer-Aided Planning and Scheduling System (CAPSS)[16] contains the nominal schedule and manpower requirements while the Problem Reporting and Corrective Action (PRACA)[17] supplies the information on the problems and off-nominal flows that occur throughout STS processing. Other commercial launch vehicle data such as Titan, Atlas, and Delta operations requirements documents and operations experience databases, if available, can also support this type of analysis. Data requirements include both nominal and off-nominal process times and resource requirements. Mean time to repair along with incidence of repair are typical performance measures derived from such databases.

As stated earlier, the data that supports the allocation process and the data that supports the detailed design evaluation should come from separate sources. In aerospace analyses, this is often not the case, primarily due to the lack of good data. While rough parametrics from one detailed source may feed the allocation process that uses several sources, this kind of analysis should be discouraged. At best, this kind of analysis is redundant and provides little confidence that the conclusions reached are correct. It could lead to inaccurate and misleading conclusions, resulting in a misallocation of design resources.

4. MODELING TOOLS

Several good off-the-shelf software packages fit the need to support operations model development. A process flow model is the model of choice: it allows the analysis of timelines, schedule dependencies, resource requirements, and supports the generation of measures of operability including recurring costs, availability, and dependability. The models used here utilize Microsoft® (MS) Project[18] for deterministic flow analysis and Imagine That!® Extend™ software[19] for probabilistic support. The benefit of MS Project™ as a process modeling tool is its ability to graphically represent detailed tasks in Gantt charts, allocate and track resource levels, and filter project information. Inputs to the model include the task description, resource allocation, task duration, and establishment of task precedence. MS Project™ is generally all that is required to do the "quick-look" analysis—layout top-level requirements and allocations to subsystems and components. Charts, tables, or reports can be customized to output the level of detail desired by the user. Extend™ allows us to apply the model in a discrete-event simulation format. It supports ease-of-input (icon-based), provides good report-generation capabilities, is well supported and tailorable with source code available, and provides animation capabilities useful for display and debugging purposes.

5. BASELINE ENGINE OPERATIONS DATA

A. Data Collection

The data collection process was a considerable part of this activity. This section will discuss this process and the data in some detail. Data were collected from a task-by-task point of view: what is required to complete only this task. Often times data are collected from a time-reporting point of view, making it difficult to determine actual task time. Appendices are provided to this document that will contain the data collected. An overview of the SSME data collection in support of the operations modeling approach is shown in figure 5. The analysis consisted of three parts: deterministic model of allocated processing, deterministic model of unscheduled processing, and the probabilistic model. This section discusses the baseline SSME model in the context of the deterministic modeling approach (both scheduled and unscheduled) and the baseline requirements database that is the foundation for all SSME processing activities. A complete presentation of the SSME operations database resides in appendices A (requirements), B (scheduled), C (unscheduled), and D (results).

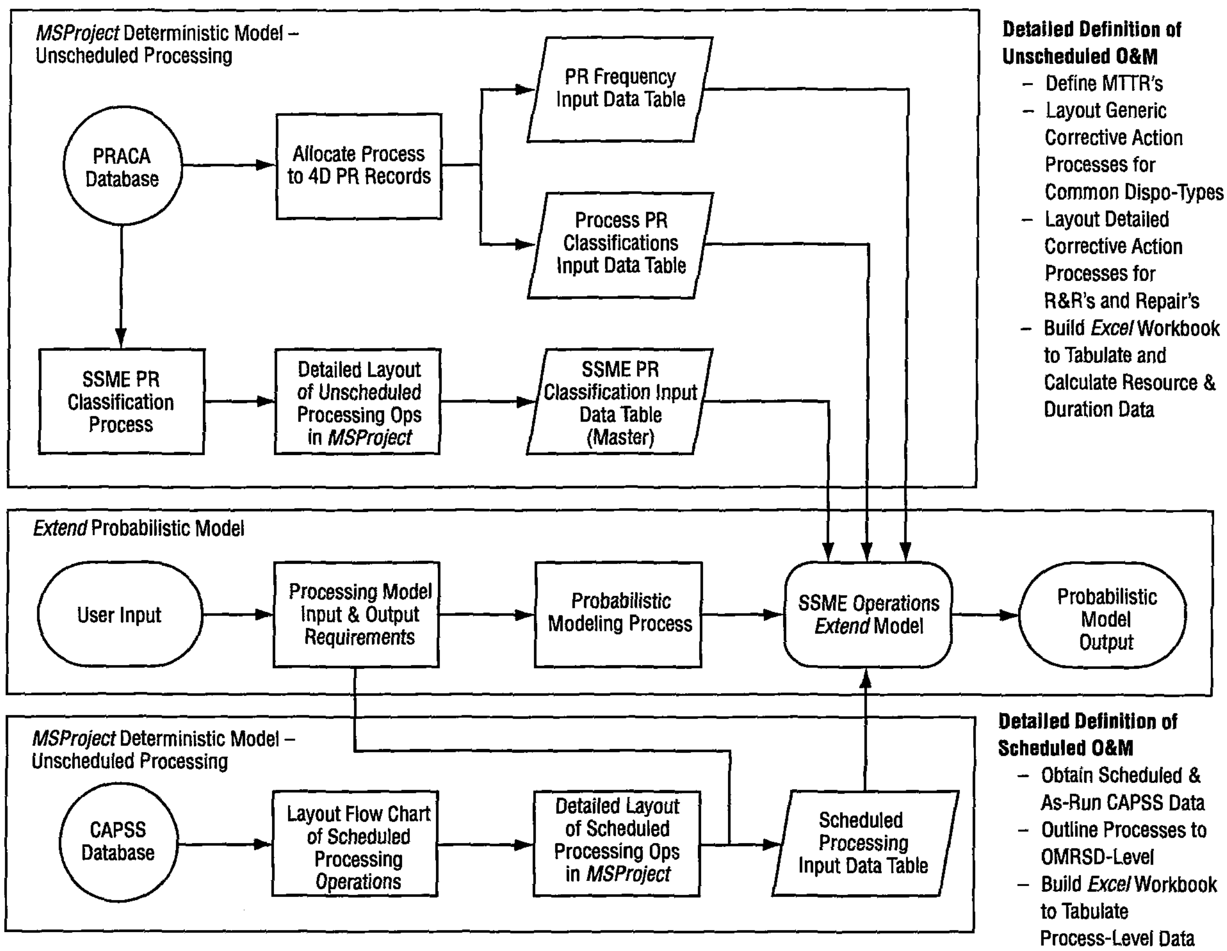


Figure 5. Operations modeling and data collection process.

B. Scheduled Processing

The first step was to define the nominal SSME processing flow. This was accomplished with flowcharts that identified the OMI-level processes and the location/facility in which the process was performed. SSME component life limit issues dictate that engine removal be scheduled each processing flow to allow the SSME's to be processed offline in the orbiter main engine facility (OMEF). Thus, in addition to the every flight requirements defined by OMRSD, nominal processing, for the purposes of the model, included SSME removal in the orbiter processing facility (OPF); SSME processing off-line in the OMEF; high-pressure turbopump removal and installation in the OMEF; and SSME installation in the OPF.

Data collected relative to SSME processing is presented in figures 6–9. Figure 6 identifies the OMI's and the serial and parallel nature of the process flow for the events that occur immediately after flight in the OPF. The engines are then moved to the OMEF. Figure 7 presents the processes and flow for this facility. After processing in the OMEF, the engines are returned to the OPF to be reinstalled on the vehicle. This process is shown in figure 8. After installation, the engine processing steps that occur during the vehicle assembly building (VAB) and pad operations are defined (see fig. 9). The detailed SSME scheduled data that matches the OMI's in figures 6–9 appears in appendix B. These data are quite extensive, breaking out process flow dependencies, clock hour, and manpower requirements by type for each engine process. It should be noted that not all engine processing is fully represented here. Some routine and periodic actions associated with minor OMI's, job cards, or deviation approval requests (DAR's) were excluded in order to present a system that can be represented in a model as an operational system. It is arguable as to whether or not the Shuttle system is a fully operational system. There are too many things that are done that are not necessarily repeatable from a modeling point of view. For example, the exact order of engine processing in the OMEF is subject to visibility, manpower available, and priorities in place at the time of repair, making this aspect difficult to model.

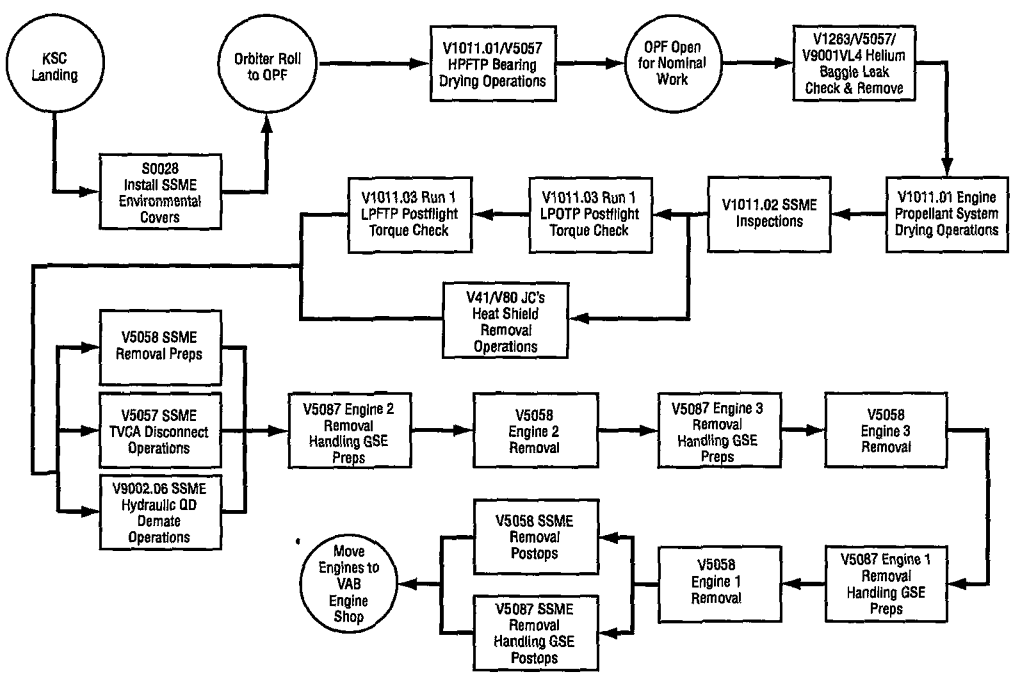


Figure 6. OPF SSME postflight operations.

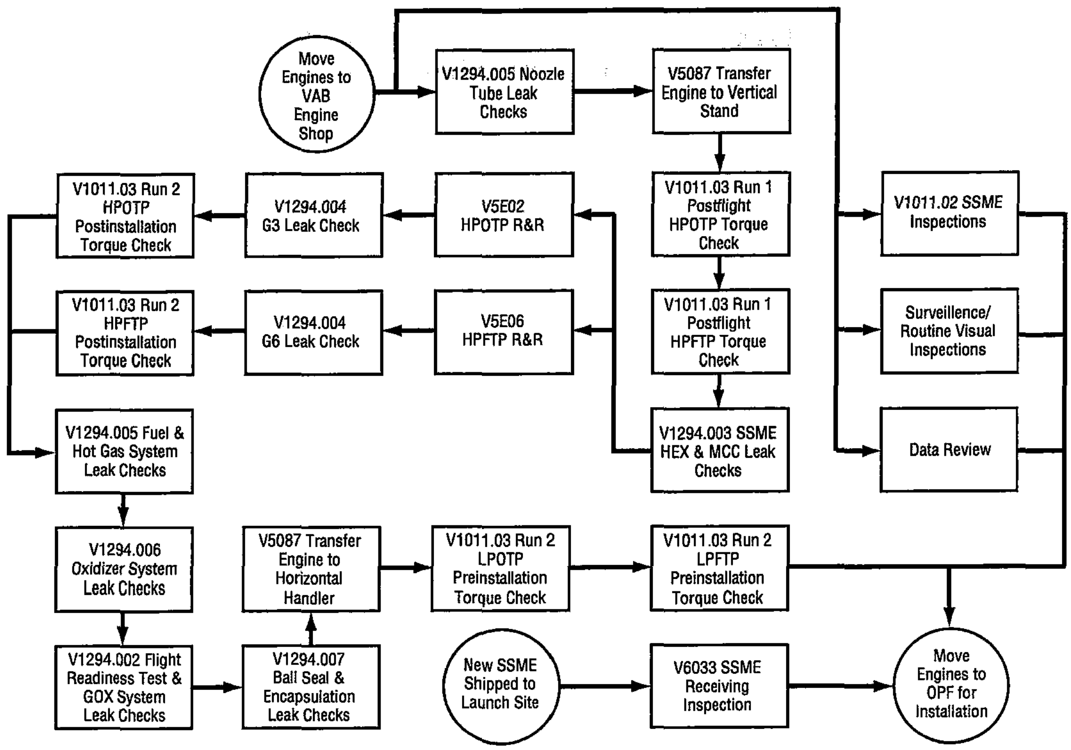


Figure 7. OMEF SSME operations.

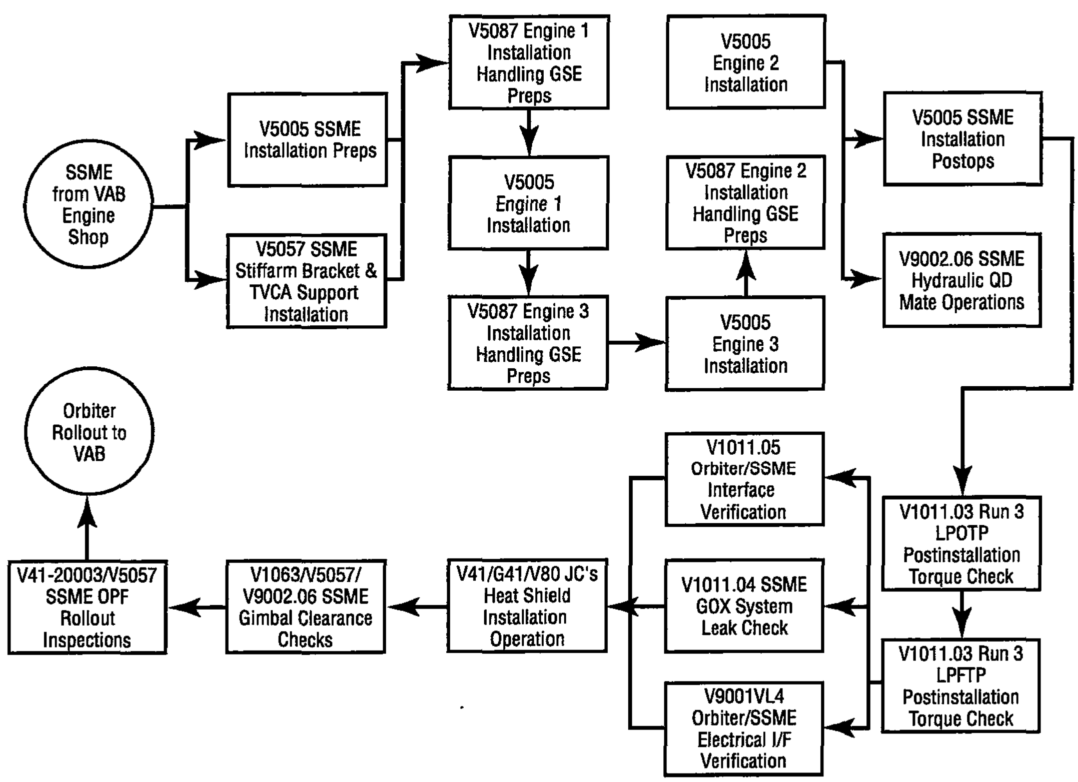


Figure 8. OPF post-SSME installation operations.

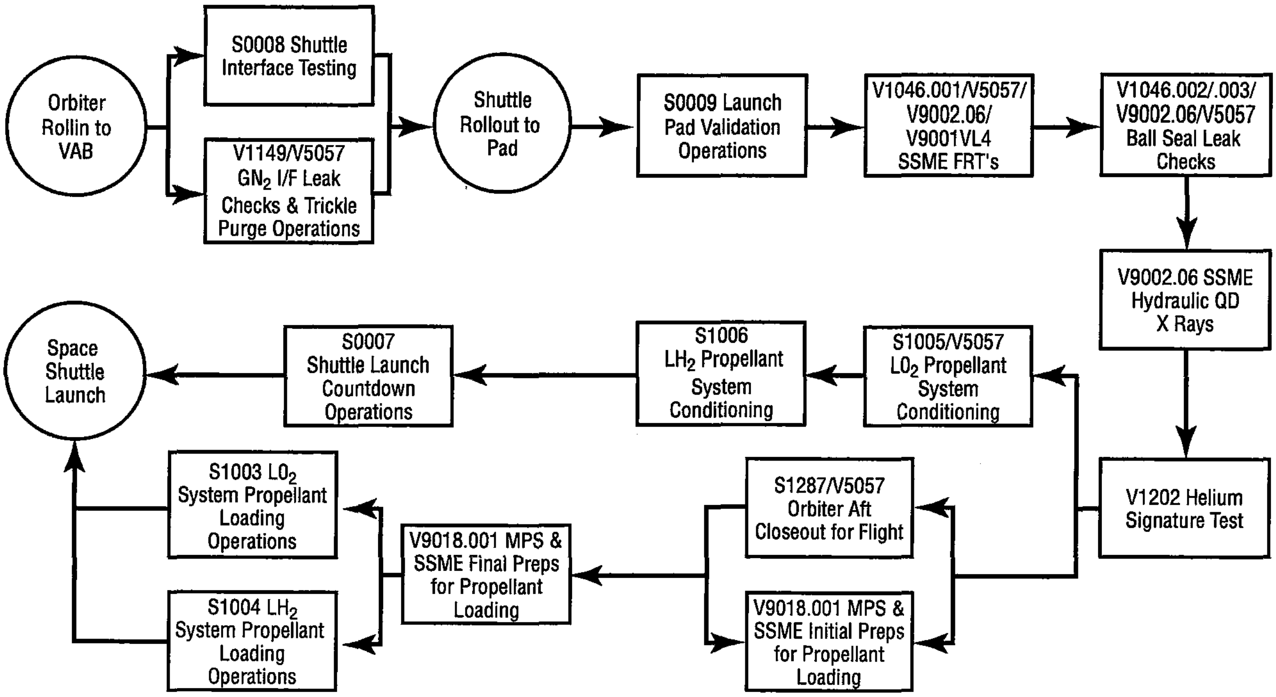


Figure 9. SSME VAB/pad processing operations.

The data that were collected were laid out into Gantt charts and task sheets to a lowest level of detail. Technician, quality control, and engineering resources were identified for each detailed task and the task duration was quantified based upon National Aeronautics and Space Administration's (NASA's) SSME engineering experience at Kennedy Space Center (KSC). Figure 10 exemplifies the level of detail outlined in each deterministic process; in this case, the high-pressure fuel turbopump (HPFTP) removal and replacement. In figure 10, many tasks have been rolled up to subtasks for brevity of presentation.

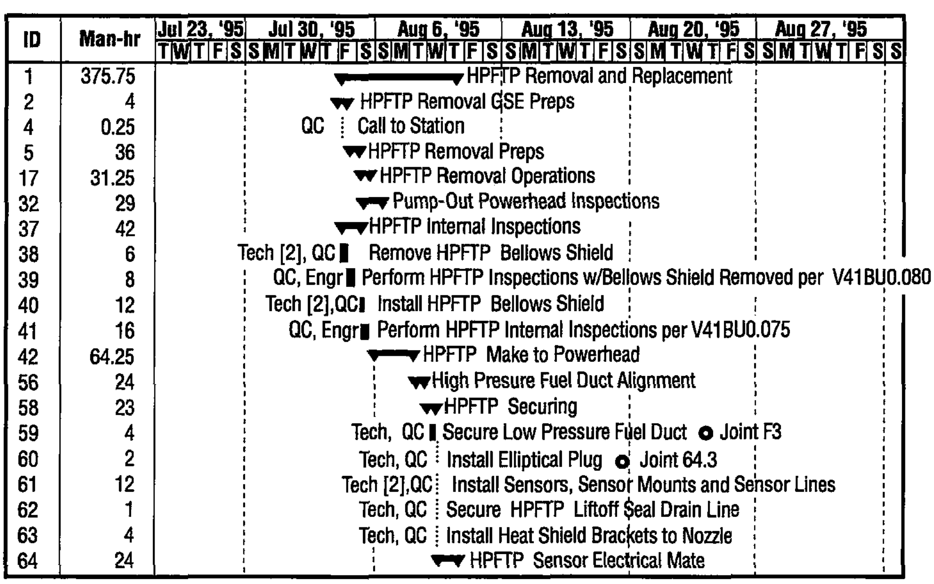


Figure 10. Example of detailed model—HPFTP removal and replace.

Although serial and parallel relationships were established between the detailed tasks and OMI processes within the Gantt charts, it is difficult to accurately predict overall OMI durations or end-to-end vehicle or SSME subsystem processing times. Reasons for this include:

1. Lack of all downtime data including logistic delay time, administrative delay time, and maintenance delays downtime.
2. Interdependence between SSME and other subsystems was not modeled.
3. Other vehicle subsystems not modeled.

While accurate predictions of SSME processing are not always possible with this data, it is appropriate for future launch vehicle engine analysis since these kinds of attributes need not be modeled. Of interest for a future system analysis is the definition of an operational system. It is not desirable to model all the artifacts of the STS processing system as appropriate to the new system. While downtimes will occur for a future system as well, it is premature, without detail, to model those. Of course, a complete vehicle model should represent the engine-vehicle interface and other subsystem operations fully.

The baseline SSME model will provide insight into the actual workload, required subtasks, and the overall processing flow. This actual manhour prediction method differs from top-down manhour estimates in that manhours of downtime are not accounted for. The utility of determining manhours in this fashion is that labor-intensive processing activities are readily identified whereas the actual impact of each processing activity can be masked by downtimes in the top-down approach.

C. Unscheduled Processing

An analysis of SSME unscheduled maintenance operations was performed using the PRACA database. Unscheduled maintenance information from the PRACA database was obtained for 30 STS flights between 1989 and 1994. During this period there were 3,785 problem reports (PR's) that were processed. This is engine PR's only, thus, ground support equipment (GSE), facility, and spares PR's relative to the engine were not included. The PR's were sorted and grouped by component, malfunction, and disposition code. This allowed the filtering of this database into 123 PR classes representing 84 SSME processing flows. PR's were further classified into six types based upon processing action taken. The six types, the 123 classes, and the number of applicable PR's are presented in table 1.

Table 1. SSME PR classification summary.

PP Classification Type	Number of Classes	Number of PR's
Remove and Replace	70	795
MR Repair	13	79
Repair	19	1,121
MR Accept	6	156
Accept	7	137
Waiver/Exception	8	82

This filtering processed 2,370 PR's. PR's that were eliminated from the database during this classification and filtering process included PR's from incomplete processing flows and PR records with insufficient data to allow it to be classified.

Each PR will fall into one of the six classification types. These types were categorized based upon the disposition code in the PRACA database and limited to the detail provided therein. These represent the most common actions required for each PR at the lowest level of detail possible. Each classification type was outlined to identify the basic tasks and resources associated with setup, performance, diagnostics, administration, review, and delay times. Figure 11 presents an MS Project™ view of the base remove and replace (R&R) classification type. In addition, an initial attempt at quantifying the resources required was conducted. Note that these are initial estimates until more accurate data can be made available and collected. The actual "hands-on" R&R time is represented by a milestone on line 4. This would be replaced in the model by the actual component R&R timeline.

The classes identify the number of different PR's that fall into each PR type. These are usually associated with components or hardware. In the case of an R&R PR type, the 70 different classes are mostly associated with different hardware or components that require R&R. However, this is not necessarily the case for the other PR types. For example, a large number of PR's were generated due to contamination and corrosion on unidentified hardware. Because the detail in the database did not allow us to associate the corrosion problems with the hardware or component, the contamination and corrosion PR's were separated into five different PR classification types based upon the nature of the disposition (repair, material review (MR) repair, accept, MR accept, or waiver/exception). The five other PR classifications as well as the standard R&R operations by component appear in detail in appendix C.

ID	Duration hr	Man-hr	y Wednesday Thursday Friday Saturday Sunday 4 12 8 4 12 8 4 12 8 4 12 8 4 12 8 4 12
1	8.97	0.5	0.5h PR Performance Time!
2	0.25	0.25	0.25h Determine PR Condition
3	0.25	0.25	0.25h Initiate PR Paperwork
4	0	0	◆ Time/Resources for Corrective Action (Varies w/PR Class.)
5	2	2	2h PR Diagnostics Time!
6	1	1	1h Engr/Mgt Review, Assess PR
7	1	1	1h Engr/Mgt Determine Corrective Action
8	8.48	6.5	6.5h PR Administative Time!
9	0.5	0.5	0.5h QE Research/Validate PR
10	2	2	2h Engr Disposition PR
11	4	4	4h Engr Route PR Through Signature Logo
12	1.5	0	0h PR Delay Time!
13	1	0	0h Engr Disposition PR Closure
14	0.5	0	0h QE Close PR

Figure 11. SSME base R&R.

This PRACA database is limited in that it does not provide resource or task duration information for unscheduled corrective actions. However, PRACA does provide data to determine the frequencies of PR's as well as information to determine what malfunctioned and how the PR was dispositioned. Corrective action processes, including task descriptions, durations, and resource assignments, were defined and quantified by SSME engineering in the same manner as the scheduled processes for each PR classification.

A few low-level processes were set to a standard time for simplicity sake. For example, QC response time was set to one standard value, when in actuality, this value is more dynamic. The unscheduled data as it applies to the six PR classifications appears in appendix C and a summary of the results from the data (relative to SSME) in appendix D.

D. Baseline Requirements Database

Figure 12 describes how the data collected are being applied to the reusable engine analysis. The applicable requirements identified by the STS OMRSD's are mapped to major corresponding STS OMI's (see appendix A). An iterative review process identifies, task by task, the appropriate processing for the future engine operations. Future reusable engine-specific operations are added; SSME operations artifacts are removed; changes to processing facilities and support equipment is identified; and any dependency, timeline, or resource requirements are also specified. This leads to a traceable proposed operations flow prediction and resource estimate. Table 2 displays a sample of the OMRSD/OMI database with comments as to the applicability of the requirements to the reusable vehicle engine.

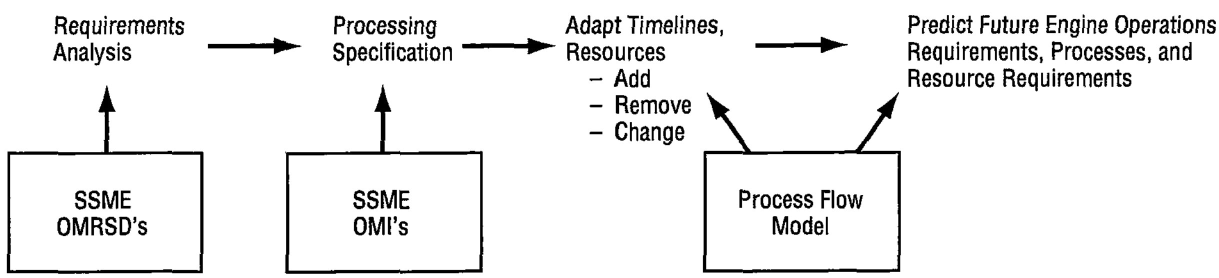


Figure 12. Requirements to process definition.

Table 2. OMRSD/OMI database with requirements rationale.

OMRSD Number	New Engine Use	OMRSD Description (V41 File III Dated 9/15/95)	OPF OMI's	Engine Shop OMI's	VAB/PAD OMI's	OMRSD Rationale/Root Causes
V41BL0.050	n	SSME Weld 22 & 24 Lk Ck	V1011.05 Seq 07	V1294.007 Seq 04	V1046.003 Seq 07	Due to poor processing, HPOTP balance cavity standoff welds are leak checked – No leaks ever verified, but lack of weld penetration up to 90% has been found on these welds. Standoffs have been suspected of leaking and caused return to Canoga.
V41BL0.060-A	n	E1 HPOTP Plug Weld Lk Ck	V1011.05 Seq 09	V1294.004 Seq 04	V1046.004 Seq 04	Plug weld leak occurred on a unit – Concern over these welds leaking either Gox/Helium/Hot gas into boat tail – therefore all external plug welds on the housing are checked
V41AX0.020-A	y	E1 LO_2 Feed (Joint 01) I/F Lk Ck	V1011.05 Seq 07		V1046.003 Seq 05	Ensure joint integrity of LPOTP to pump inlet ducting after engine is installed
V41AX0.020-B	y	E1 LH_2 Feed (Joint F1) I/F Lk Ck	V1011.05 Seq 05		V1046.002 Seq 04	Verify pump inlet joint integrity after installing the LPFTP
V41AX0.020-C	y	E1 GH_2 Press (Joint F9.3) I/F LK CK	V1011.05 Seq 09		V1046.004 Seq 04	Joint integrity Post Engine Installation
V41BL0.033	y	SSME Encapsulation Oxid Sys ISO Test		V1294.007 Seq 04		System leak integrity check for launch – Mat. 1 or Weld Thru-Crack: Seal not Sealed - > Crit. 1
V41BL0.034	y	SSME Encapsulation Hot Gas Sys ISO Test		V1294.007 Seq 04		System leak integrity check for launch – Mat. 1 or Weld Thru-Crack: Seal not Sealed - > Crit. 1
V41BP0.010-A	n	E1 GO_2/GCV Ext Lk Ck & Orifice Verif	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05	Establishes leak test of all gaseous oxygen system joints from the AFV to the orbiter interface on an *each flight basis*
V41AQ0.010-A	y	E1 Sensor Checkout	V1011.06 Seq 02	V1294.002 Seq 06	V1046.001 Seq 04	Planned Preflight Checkout

From table 2, development or definition of an reusable engine operations concept is traced to the SSME experience. This database was developed to link propulsion system concepts and technology candidates to the SSME operations experience. The backbone of the SSME experience is the OMRSD database. Deterministic model data are linked to the OMRSD database for each requirement. Additionally, root causes and/or OMRSD rationales are provided that allow for rapid determination of those OMRSD's affected by technology improvements or hardware configuration changes. From table 2, first row, a requirement was established for SSME weld and leak checks on the high-pressure oxidizer turbopump (HPOTP). The root cause of this requirement is a concern for weld integrity. The OMRSD number, three applicable OMI's, and an applicability column for the new launch vehicle engine are provided. It is interesting to note that this requirement was generated well after the design of the SSME and its processing when potential problems with welds were identified. This specification of postdesign requirements is likely to occur in a new launch vehicle engine as well.

6. MODEL DEVELOPMENT AND RESULTS

The scope of the analysis for this document is a future launch vehicle ground operations analysis that includes shuttle-based uncertainties associated with scheduled and unscheduled maintenance. The emphasis is on propulsion systems and the specific topic is the engine which will be modeled in order to be responsive to the vehicle requirements. Of course, the engine processing is only one part of the overall vehicle processing. Interactions of the engine processing and other subsystems must be taken into account to get a proper estimate of vehicle and even engine flows. The results of this analysis reflect the impact of unscheduled processing on turnaround time in a deterministic model and on launch availability and dependability in a probabilistic model. The attributes of the maintenance activities will be limited to those supported by analysis of the STS PRACA, CAPSS, and Marshall Space Flight Center (MSFC) Propulsion Laboratory operations databases.

Given ground rules and assumptions, key processes were laid out for a fully reusable future launch vehicle engine concept. To avoid proprietary data considerations and to simplify the presentation, a rough-cut engine design is assumed for this analysis. It is essentially SSME-like;[20] a pump-fed LO_2/LH_2 high-thrust engine with pneumatic and EMA valve control (no hydraulics) and health monitoring capabilities. The proposed launch vehicle uses three such engines with engine processing conducted in parallel. From this, a logic model associated with the flow of ground processing is developed. A 40-hr, goal-oriented engine ground flow serves as a baseline to the defined flows. Effectively, this 40-hr timeline was provided as a requirement (baseline allocation) for this model activity. Figure 13 shows the engine flows and the success-oriented timelines by processing facility. Three facilities were assumed after landing—a single processing facility with five bays and two launch pads. From figure 13, engine ground operations processes include drying; access; visual inspections; leak checks; and closeout on each engine in the processing facility and purge; flight readiness test; and launch preparation on the engine set on the pad. An unscheduled maintenance timeline is supported in parallel with the scheduled timeline. Key assumptions and ground rules to this development were 30 flights per year, a five-vehicle fleet, and 7-day missions. Others included minimal and automated operations, separate payload processing, depot maintenance every 20 missions, and automated health monitoring. Manpower assumptions included two shifts per day, 5 days per week for processing facility operations and three shifts per day, 7 days per week for all other processing.

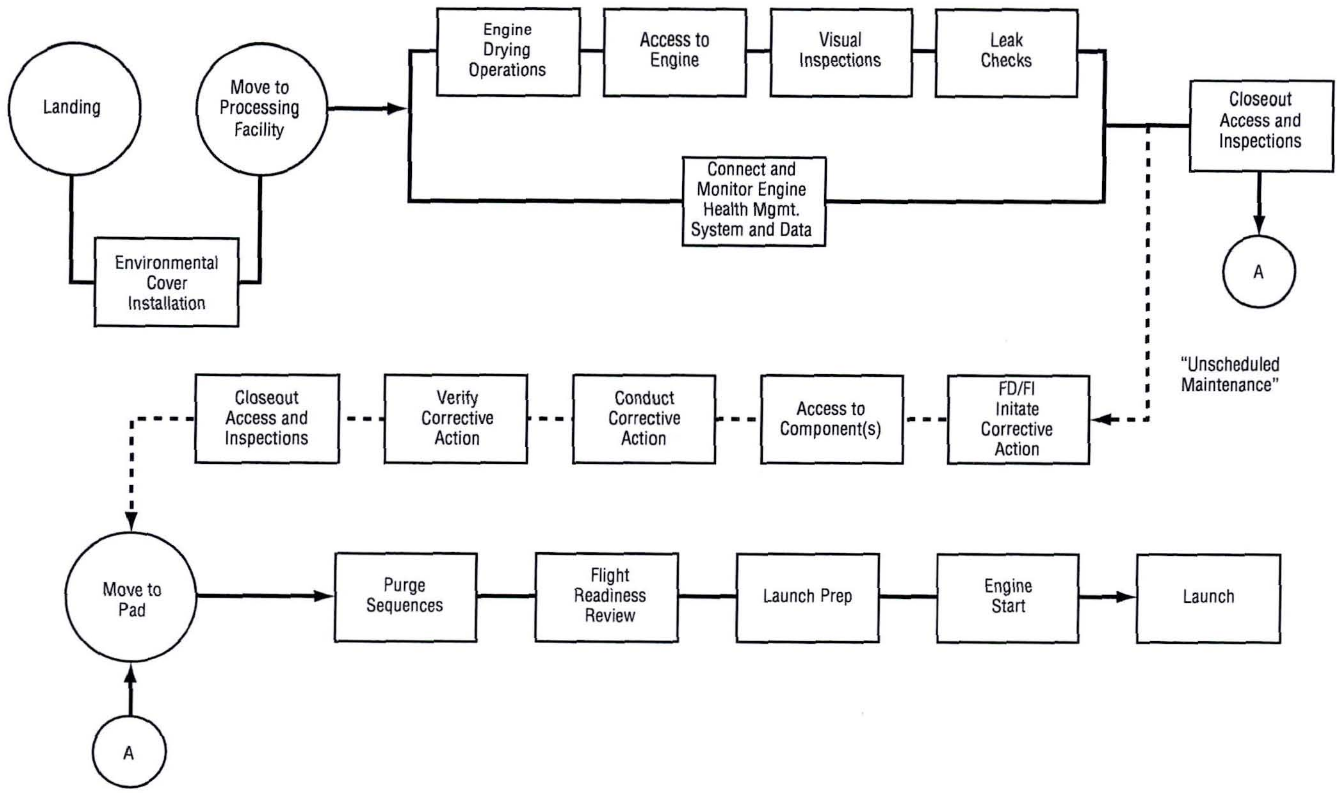
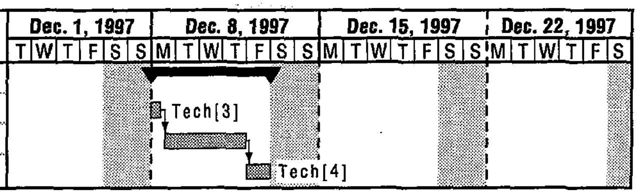


Figure 13. Engine operations processing.

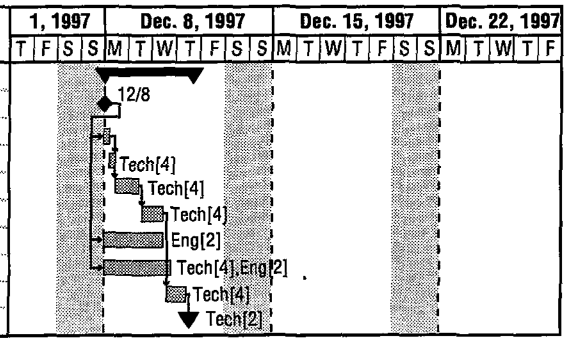
A. Deterministic Model

An MS Project™ model was developed to reflect the processing requirements (top-level and allocated) of the engine system. From the flows defined in figure 13, processing timelines and resources required were input into the MS Project™ scheduler. The tasks were defined to three levels as subprojects. Figure 14 presents the top level to the level of detail at one of the lowest level processes defined here—that of the engine drying operation. Total duration and manpower requirements in the subprocesses of figure 14 can be rolled up to the top level in a very direct fashion. This is the allocated appropriate times and requirements for those systems within the constraint of the overall requirement, which was provided as a top-level requirement; in this case, 40-hr total for the engine. Thus, the times and resources reflect a relative allocation to the subsystems: it remains to be seen, for example, whether or not a gaseous oxygen (gox) system leak check will take the 1 hr allocated, but the 1 hr allocated to this system is consistent with the time allocated for the fuel system leak checks (1 hr). Again, this model serves as the goal-oriented model useful for allocation and comparison with the detailed engineering estimates. In the approach identified in figure 4, this is the top half—the goal-oriented model.

ID	Task Name	Duration (hr)	Work (Man-hr)
1	**Vehicle Engine Processing**	40	348
2	Runway Operations	2	6
3	Processing Facility Operations	30	310
4	Pad Operations	8	32



ID	Task Name	Duration (hr)	Work (Man-hr)
1	**Engine Processing Facility Op**	30	310
2	Start	0	0
3	Engine Drying	3	20
4	Access to Engine	2	8
5	Visual Inspections	8	32
6	Leak Checks	8	32
7	Connect/Monitor Eng HM Sys & Data	20	40
8	Corrective Action	24	144
9	Closeout Access and Inspections	8	32
10	Move to Pad	1	2



ID	Task Name	Duration (hr)	Work (Man-hr)
1	**Vehicle Eng. Drying Operation**	3	20
2	Vehicle in Proper Location in Facility	0	0
3	Establish Access to Engine	0.5	2
4	Initial Power-Up	0.5	1
5	Establish Gr. Sup. Sys. for Drying	0.5	2
6	Conduct Drying Operations	2.5	15
7	Mate GN_2 Purge to Engine	0.25	1
8	Assemble/Mate Hoses/Filters	0.25	1
9	Install Plugs/Gages/Drain Lines	0.25	1
10	Activate Pneumatics/Valves	1	1
11	Conduct Ox. Sys.Drying Purge	1	4
12	Conduct MCC/FPB/Nozzle Drying Purge	0.25	4
13	Perform Dryness Verification	0.25	1
14	Demate Drying Setup	0.25	1
15	Dissassemble Test Setup		1

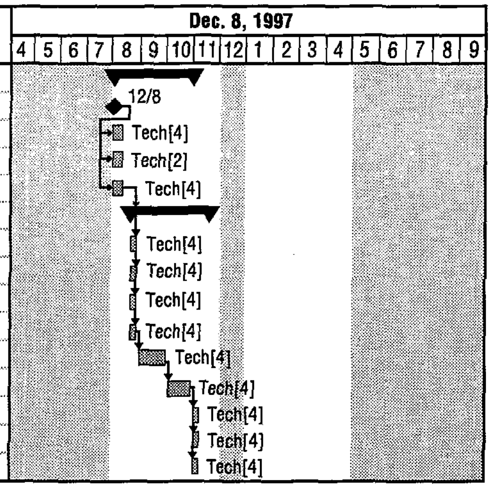


Figure 14. Hierarchical engine model.

This type of modeling often predominates, especially early in design. With an emphasis on new ways of doing business, this goal-oriented modeling is often the only type of modeling undertaken on a program. There are several reasons for this. It can be time consuming and resource intensive to conduct a bottom-up analysis and difficult to present an unpopular result. The weakness of the goal-oriented modeling should be apparent. It often has no basis in reality. One example of how misleading goal-oriented modeling can be was that for the STS program. Early modeling predicted up to 60 flights per year with a 2-wk turnaround time,[21] very different from current shuttle capabilities.

Sensitivity studies of the MS Project™ model and even simple "back of the envelope" analysis can shed some light on the sensitivity of this system. For example, increasing scheduled uncertainty to 50 percent increases total duration, for what is essentially a serial flow, a proportional percentage—from 40- to 60-hr duration with personnel manhours increasing from 319 to 478.5. Concerns with meeting availability and dependability requirements increase also. However, even a 50-percent increase in scheduled processing may not be a serious impact. Adjustments in scheduled timelines or built-in holds can be included to deal with this. Even if dependability is defined as launch within 2 days of scheduled launch, such variation is manageable—an extra 20-hr duration is still within 2 days, if there are multiple shifts per day.

Much more significant is the variation in unscheduled processing. In the baseline case, the unscheduled processing is designed to be in parallel to scheduled processing. Even this can tolerate some additional unscheduled processing before impacting overall flow. However, this assumes sufficient manpower to handle problems in parallel and that problems will occur in parallel. Such an assumption is not credible. For example, if four to six engineers are allocated to handle processing, the extra unscheduled activities cannot be conducted entirely in parallel without a schedule slip—there simply is not enough manpower. Also, if problems occur late in launch to critical path operations, there is a serial effect—problems must be resolved before any more normal launch processing can be supported. Built-in holds can also mitigate the problem of unscheduled processes, especially early in the flow. Late processes, such as pad processes, must attempt to minimize all unscheduled activity.

In this deterministic model, the unscheduled maintenance activities were added to reflect these issues. A notion of unscheduled maintenance considerations should be incorporated into the requirements allocation for accuracy sake. Table 3 lays out the SSME-based experience and the impact per OMI for this analysis. For example, from the historical SSME record, twice as much time is spent on unscheduled maintenance during the visual inspection OMI (V1011.02) than for scheduled maintenance. Table 4 presents the results of this analysis including a run with the unscheduled maintenance data. The first column of the table presents the baseline results—both clock hours and personnel manhour requirements. The second column adds in unscheduled timelines based on STS SSME experience. If the unscheduled activities are assumed to be done in parallel, the overall impact to the timeline is small. That which is not on the critical path has little impact, while adding unscheduled maintenance activities to critical path operations is realistic and has a significant impact. The impact to the overall dependability and availability metrics can also be considerable as will be seen in the next section. Keep in mind that many of the SSME OMI's have already been excluded and that the baseline processing time is allocated. The result in table 4 is more of interest in a relative sense—the duration and manhour requirements practically doubled with experience-based unscheduled maintenance included in the analysis (from 40- to 70-hr duration, 348 to 615.6 man-hour total). Further and more detailed analysis is clearly necessary.

Table 3. SSME unscheduled maintenance experience.

Task Description	OMI Number	% Additional Unscheduled Processing*
Envir. Cover Install	S0028	10
Engine Drying	V1011.01	10
Assess to Engine	V5058/V5057/V5087	10
Visual Inspections	V1011.02	200
Leak Checks	V1294.xx	100
Closeout	S1287/V5057	50
Purge Sequences	V9018.001	10
Flight Readiness Test	V1046/V5057/V9002	75
Launch Prep & Start	S0007	10

* Per SSME Experience, 1989–1994

Table 4. Goal-oriented engine operations timelines.

	40-Hr Goal-Oriented Baseline		40-Hr Baseline With Unscheduled Maint. Included (SSME-Based)*	
Task Name	Duration, hr	Man-hr	Duration, hr	Man-hr
Processing Assessment	40	348	70	615.6
• Landing Operations	2	6	2.2	6.6
• Processing Facility Operations	30	310	59	573.8
– Engine Drying	3	20	3.3	22
– Engine Access	2	8	2.2	8.8
– Inspections	8	32	24	96
– Leak Checks	8	32	16	64
– HM Monitor	[20]	40	[22]	44
– Unscheduled Allocation	[24]	144	[48]	288
– Closeout	9	34	13.5	51
• Pad Operations	8	32	8.8	35.2

* 1989–1994
[ ] Not on critical path

This concludes the discussion of the goal-oriented model and analysis results. Turnaround time and resource requirements have served as primary metrics to this point. Operability metrics such as availability and dependability are more appropriate to a detailed probabilistic model. The probabilistic model and its results are the topics of the next section.

B. Probabilistic Model

1. Overview

The following analysis serves to illustrate the probabilistic approach—modeling to include uncertainty in the analysis. As in the earlier deterministic analysis, the scope of this analysis is a future engine operations analysis that includes uncertainties associated with unscheduled and scheduled maintenance. Consistent with the overall process, requirements were generated from the STS requirements list applicable to this new engine system. Engine design data were assumed for this application and use no proprietary information. Identical to the engine used for the deterministic model analysis, the future engine system is a pump-fed LH_2/LO_2 system with EMA and pneumatic valve actuation (no hydraulics), and active health monitoring. A three-engine vehicle is also assumed for this analysis. The emphasis is on the engine processing, with the vehicle operations requirements allocated out to the engine level. The interest here is on the impact of engine scheduled and unscheduled processing on engine dependability and availability. The data used as baseline for this analysis are those of the shuttle engine system.

2. Operations Concept

Given ground rules and assumptions, key processes were laid out for a fully reusable future launch vehicle concept. These are the same as those laid out for the deterministic model of the previous section with detail of depot maintenance now included. A logic model associated with the flow of ground processing was developed and figure 13 shows these engine flows by processing facility. The assumptions and ground rules are the same as in the deterministic case except for the following. Depot maintenance consists of engine removal and replacement, more detailed tests and checkout, and generally takes 30 days. Automated health monitoring is assumed, although this would only affect diagnostic and isolation time for unscheduled activities. Three vehicles may be on orbit at one time and two vehicles can be in depot maintenance at one time. The resources have been designed for minimal bottlenecks. This includes manpower, which is assumed available when and where needed, given shifting constraints. The block flows reflect periodic and depot maintenance operations that utilize parallelism and adequate manpower. For example, the engine processing for the three-engine vehicle is done in parallel. This provides a much shorter process clock time; however, manpower must be calculated accordingly. Typical engine operations include engine drying, inspection, and leak checks for the routine turnaround operations and engine removal and replacement for the depot maintenance operations. This discrete-event logic flow will be represented in a simulation model to be developed as part of this analysis. This flow will be modeled over a 20-yr lifetime. Results will be presented from a set of Monte Carlo runs.

3. Model Development

A computer program that supports discrete-event simulation on a personal computer was used for this analysis. This package, Extend™, allows icon-based time and event modeling. The package is available commercially and provides ease of use in building models and in specifying output parameters. It supports probabilistic modeling and hierarchical levels of detail for complex systems.

The logic of the operations processes timelines was incorporated into the Extend™ modeling language and runs were made to analyze the parameters of interest. All simulations for this analysis were performed on a PowerMac 7600. This operations model was developed fully from Extend™ library building blocks. Figure 15 presents the top level of the ground operations modeled. The model is reflected in a hierarchy, the lowest level of detail for the processing facility, as presented earlier in figure 13. From figure 15, the processing facility with five bays (three for nominal, two for depot); the two pads; the runway; and vehicle tows are evident. The five vehicles come in as scheduled in the new vehicle block to the appropriate routine processing in the upper three bays or the depot processing in the lower two bays.

This probabilistic detailed model serves as an experience-based model outlined in the approach of figure 4 (lower half of schematic). Results from it are intended to be compared against the goal-oriented model results.

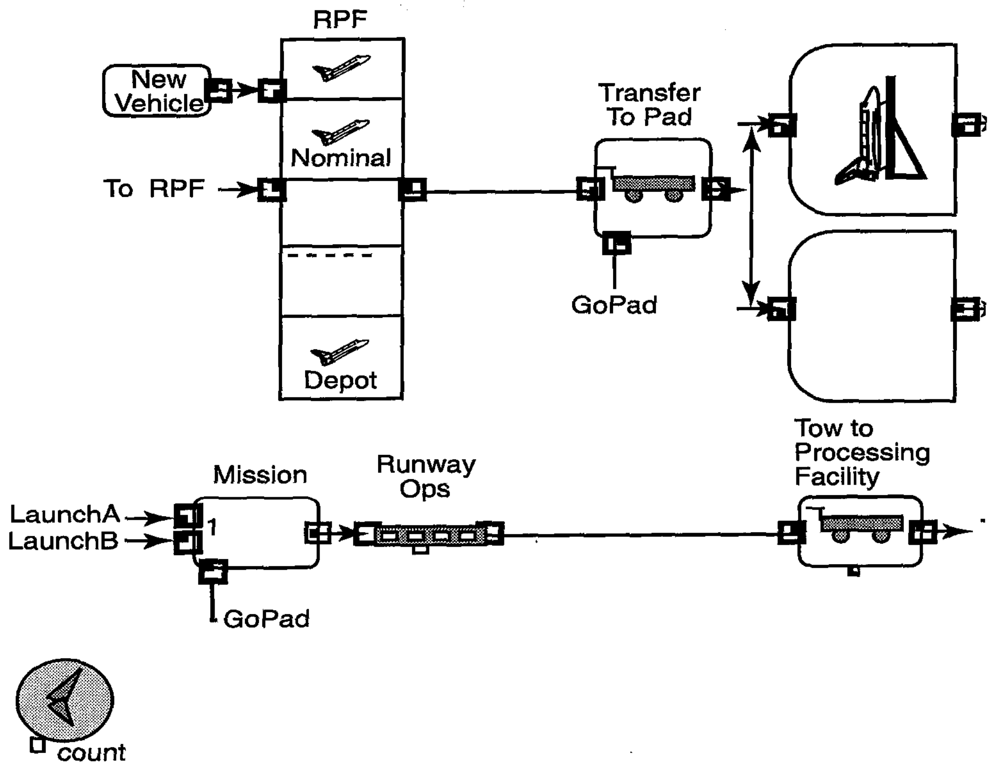


Figure 15. Extend reusable engine operations model.

4. Data and Metrics for Analysis

For this analysis, the data as described in section 5 were used for model data support. As stated earlier, this database keeps track of the ground operations unscheduled and scheduled maintenance activities for SSME processing. Distributions around the scheduled and unscheduled maintenance processing are modeled with a triangular distribution,[22] selected due to its "conservative" nature. Evidence exists that for process simulation the lognormal distribution may be the most appropriate.[23,24] Such evidence also exists relative to some aerospace applications;[25,26] but without actual operational data to support this, the triangular distribution has been chosen. The triangular distribution requires a minimum, a maximum, and a mode. For this application the mode is the selected STS value, the minimum is 5 percent less than the mode, and the maximum 10 percent greater than the mode. These values were accepted during the data collection process by the system engineers as generally representative of actual shuttle engine task processing uncertainty. Extend™ supports many distribution types including the definition of a user input type. If desired, distribution types and parameters can be easily varied as part of a sensitivity study.

Metrics for this analysis include measures of merit for availability and dependability. The measure of availability deemed most suitable for this analysis is the one described earlier in the metrics discussion for process availability—nominal processing divided by total processing which includes nominal and off-nominal processing times. Off-nominal processing time includes unscheduled maintenance, queuing delays, and standdown times due to failures. This is a measure deemed more suitable to spacecraft processing systems due to the processing-intensive nature of cryogenic-fueled rocket systems and small fleet sizes.

The dependability measure is a characterization of the on-time launches. This is reflected in a probability that all vehicles are launched on time (from an engine processing point of view), measured as within 2 days of original launch date.

Requirements for engine processing were collected via the STS requirements list. There are three engines per vehicle with an engine out at liftoff capability. The only unique engine operation process proposed and not covered by STS operations is an engine-to-engine mate process which slightly expands the timelines for inspection and engine R&R.

The reliability of the engine will be modeled as will any associated standdown time due to failures to illustrate the impact of reliability on operability. Standdown time in this case is 4 mo and is a required result of any vehicle failure. A range of reliability values and their impact to the overall processing system will be presented. Appendix E presents the engine out reliability analysis and its impact on engine set reliability that is used in this analysis.

5. Results

The simulation time for the model was set to 20 yr and run in a Monte Carlo environment. A relatively evenly spaced flight manifest spanning this duration served as input for the model. Vehicle flights were staggered so that, at most, three flights were on orbit and, at most, two vehicles (engine sets) would require depot maintenance at any given time.

It was apparent from back of the envelope analysis that the use of the complete shuttle engine database would present a processing timeline that was a factor of 10 over the allocated requirement. Availability for such a system is approximately 70 percent and dependability is very low unless processing start dates were backed up to allow for this extra processing. If enough time is allowed up front, any system can be made technically dependable. Implicit in the measure of dependability is an acceptable and minimal turnaround time. This is a problem in using the STS system. The inherent philosophy and conservatism associated with this manned system leads to intense processing requirements due to extensive checking and double-checking. Using shuttle experience data results in a vehicle that is only capable of five flights per year at the outset. The required processing times preclude any more. This also assumes processing manpower available to process all vehicles in parallel to support a maximum of 25 flights per year. This would result in a prohibitively expensive system. Thus, for this analysis, a decision was made to just use the "active" process conducted on the shuttle engines for this model. This excludes all vehicle setup and access time (except that explicitly allowed); all GSE setup; test setup; and of course, shuttle-specific operations. Clearly as important to the processing requirements for the future engine system is the philosophy of operation. Philosophy changes create the most significant process changes; of course, it remains to be seen whether these changes can be maintained when the actual system is in operation.

Given the above ground rule, a baseline case with no off-nominal (unscheduled maintenance) time was first established. The results for the probabilistic analysis for the operability parameters are presented in table 5. This turnaround baseline required, on average, 109.6 hr per flight. When adjusting for manpower shifting, this translates into just over a 6-day turnaround. The dependability measure assumes launch on time if launch occurs within 2 days of the original scheduled data. This system is appropriately rated at 100 percent for both availability and dependability. Without unscheduled processing time, the only uncertainty in this system is in normal processing and this is not enough to affect on-time launch. It is interesting to note that the original goal for the turnaround of the engine system as presented in the deterministic model was 40 hr. Even with extensive and optimistic ground rules, the projected turnaround is over twice that without considering any unscheduled processing. Extra manpower may make up some of the difference but this also raises the cost to the processing system. Clearly, the original goal must be adjusted to be more realistic.

Table 5. Results of probabilistic analysis.

Case	Availability (%)	Dependability (%)
Full-up STS	70	Low (Assumption Dependent)
Active Processes Only (No Unscheduled)	100	100
Active With STS Unscheduled	82	0
Active With 25% of STS Unscheduled	94	78

When the shuttle-based, off-nominal times were incorporated into the model as reflected in table 5, the turnaround increased to an average of 171.5 hr which translates into a 12-day turnaround (a weekend added since processing facility time goes past 1 wk). With only 6 days allowed for turnaround time with a 2-day buffer, the dependability of this system is zero. Availability of this system is at 82 percent.

It is reasonable to assume that improvements in unscheduled processing and hardware will result in something significantly better than for the shuttle. From table 5, the case where 25 percent of the shuttle unscheduled processing is assumed, the dependability is at 78 percent and the availability at 94 percent. Improvement to 10 percent of shuttle unscheduled processing improves the measures to 100 percent and 96 percent, respectively. The general relationships of process time, dependability, and availability for this system are presented in figure 16. A typical requirement (95 percent) for availability and dependability is also included in this figure. Availability varies from 100 to 82 percent, based upon the amount of unscheduled processing time. Dependability displays a unique shape—almost a step function. Only between 23 and 27 percent of STS unscheduled process time is any variation evident. This range is reflective of the variation in nominal and off-nominal processing. As such, dependability is a very sensitive measure. First, it is sensitive to the time allowed for processing—in this case, 6 days. Also, it is sensitive to the buffer amount; amount of uncertainty; and staffing schedules. Dependability can be improved by an early processing start or by the use of timing control mechanisms such as built-in holds. It is interesting to note that, traditionally, engine processing delays are not key to the vehicle launch delays and dependability. Weather is the predominant cause of vehicle launch delays.

Other typical results from a discrete event simulation model include resource estimates of interest such as facility utilization rates, manpower usage, and queuing delays. In order to identify areas of improvement for operations, a Monte Carlo analysis of each process was performed by reducing the unscheduled maintenance from the shuttle-based percentage to a 10-percent target. Total manhours, cost per flow, and launch delay time per flight were used to provide a quantifiable measure of improvement. The results from these analyses are shown in table 7 for each engine task in the current processing flow.

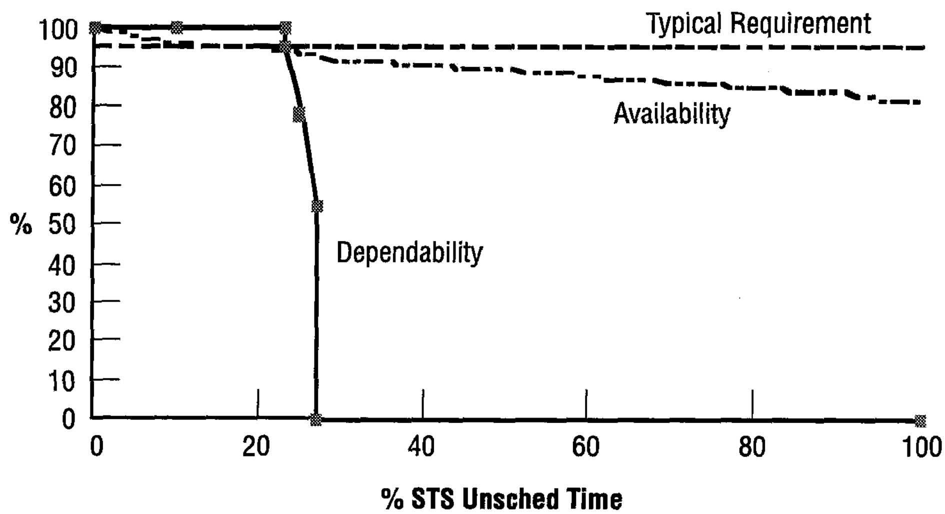


Figure 16. Operability measures by process time.

6. Effect of Uncertainty

Table 6 presents the impact of the incorporation of uncertainty in the model. As discussed earlier, the purpose of modeling this uncertainty is to provide for a more realistic model. The hours presented are the total for the system over the 20-yr period (600 flights). The uncertainty in this case has little impact on the availability measure, given that availability is a ratio of values, both changing in similar fashion. In this case, the impact is small since the processes modeled have relatively low uncertainty in both scheduled and unscheduled activities. Also, consistent with earlier conclusions, the dependability measure shows a high sensitivity to the amount of uncertainty. Indeed the use of the maximum amount of uncertainty for the case here drops this value to zero. Upon further analysis, this was determined to be an effect of processing facility operation being extended past 5 days, resulting in the addition of a weekend to the processing time. These two events were enough to push the launch time past the 2-day buffer allowed. The dependability value is controllable to a large extent through the use of different ground rules, built-in holds, earlier start dates, or additional manpower.

Table 6. Probabilistic model uncertainty impact.

Case	Sched Hr	Unsched Hr	Avail (%)	Dep (%)
25% of STS Unscheduled Mode	166,460	11,482	93.5	78
25% — Min	162,348	10,764	93.8	95
25% — Max	171,552	12,402	93.2	0

7. Reliability Impacts

When a measure of reliability is added to the model, impacts to operability are apparent. In this case, reliability is measured relative to catastrophic failure of the engine, and catastrophic failure of any engine leads to failure of the vehicle. The ground rule at the outset was that the system went into standdown of 4 mo after a failure in order to diagnose, isolate, redesign, or mitigate the problem causing the failure. The reliability impact of lost launches is presented in figure 17. Besides the failures, launches for the next

4 mo are delayed. Out of the 600 launches (rescheduled now over a longer period of time), 126 were canceled given an engine reliability of 0.95. For a reliability of 0.999, the number of lost launches is 1.8. Clearly, a reliability value much lower that 0.999 would be unacceptable to a launch system such as this one. Certain vehicle characteristics mitigate these failures (holddown, engine out), but the engines must be very robust for consistent acceptable operability scores. The relationship of reliability, dependability, and availability of this system as generated from the Extend™ model runs is presented in figure 18. The reliability estimates used for this analysis were as derived in the analysis of table 21 for the engine out at liftoff and catastrophic failure probability of 0.1 case. Clearly, reliability is the single biggest determinant of the operability of the system.

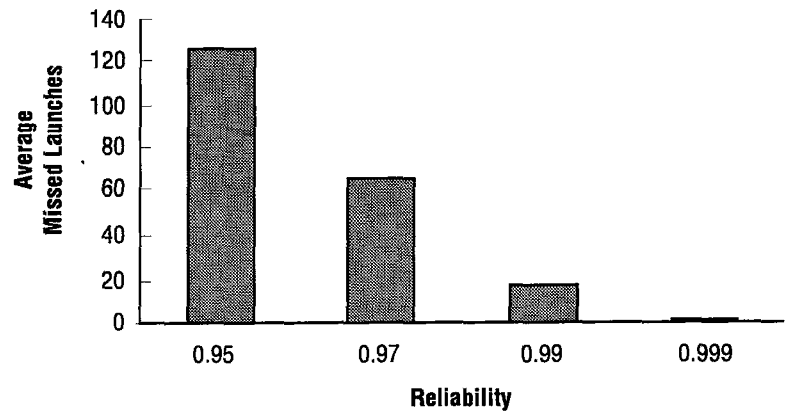


Figure 17. Impact of reliability on operability.

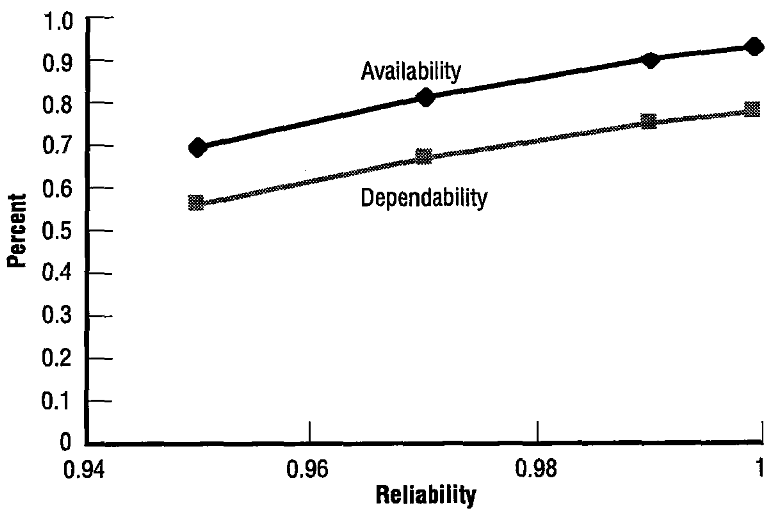


Figure 18. Operability metrics by reliability.

These results indicate the impact of scheduled and unscheduled processing and reliability on the launch system. Values of acceptable availability and dependability requirements would likely be around 95 percent. Considerable improvements in traditional spacecraft engine processing and design are necessary to meet this requirement.

These results indicate a potential manhour cost savings of approximately $115.3K per flight along with a 7.4-hr reduction in the launch delay for the engine set modeled in this flow. The shuttle manpower data were used for this analysis. Figure 19 provides a graphical view of the manhour cost reductions and launch delay reductions for engine processing. While potential reductions are greatest in earlier processes (e.g., visual inspections), it is important to note that later processes may be more critical (e.g., pad activities). Timing controls such as built-in holds will be more effective earlier in the process flow. There is less opportunity for controlling delays late in launch.

Table 7. Engine processing manhours and launch delay reduction.

Process Description	Process MHRS (Sched)	Process MHRS (Total)	Process MHRS Cost-3-Engine Set ($K)	Target Cost Reduction ($K)	Launch Delay Reduction (Hr)
Engine Drying	154	169	20.2	1.7	0.03
Engine Access	20	22	2.6	0.2	0.05
Visual Inspections	374	1,120	134.4	80.7	1.6
Leak Checks	216	432	51.8	23.4	2.4
Closeout Access	140	210	25.2	7.6	1.2
Engine Purge	52	57	6.8	0.2	0.8
Flight Readiness Test	52	90	10.8	1.4	0.5
Launch Preparation	40	44	5.3	0.1	0.8

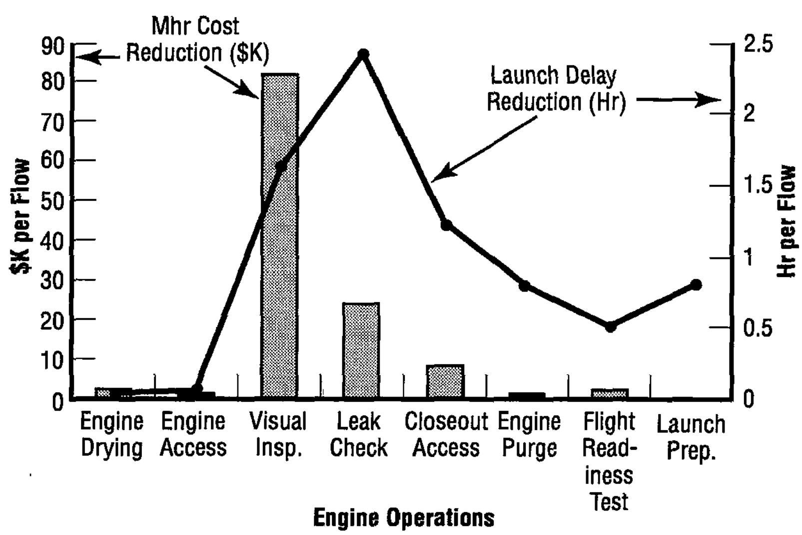


Figure 19. Engine operations manhours/cost analysis.

By using the shuttle-based results and the process target results, a relationship between percent nominal processing and clock hours or manhour cost can be determined for each process analyzed. This type of relationship provides a means to estimate how much improvement is needed to reduce the manhour cost of a given process to a specified target value, and where the improvements are most needed.

7. CONCLUSIONS

Deterministic and probabilistic operations models of engine processing flows have been constructed to illustrate the methodology defined in this document. The goal was to select appropriate metrics, develop a model, and conduct an appropriate design operations analysis. This supports design trade studies where operations will be considered equally with performance analyses. Traditionally, this has been a serious shortcoming of disciplines such as design operations. It has not been understood how to conduct such an analysis and what measures of merit to use. This analysis presents such an approach and applies it to a future engine concept. These models support trade and sensitivity studies allowing users to investigate "what if" scenarios to support design decisions. With the availability and dependability measures, it provides a means to quantitatively analyze scheduled and unscheduled maintenance activities for operations analysis.

The applications of this approach illustrate the traditional outcome in aerospace launch vehicle operations modeling. The difference between processing goals and initial historical-based operations estimates is large. This is at least in part due to the lack of good and accepted operations modeling techniques which use well-understood and interpretable metrics. The approach described here attempts to correct this problem by offering a rigorous process and good baseline data to identify operations concerns.

The results presented here represent a first iteration in an operations analysis process outlined in figure 4 for a hypothetical engine concept. Deterministic, goal-oriented modeling provides a top view of the requirements and allocations. The bottom-up, probabilistic analysis provides the operations processing estimates to compare against the goals and requirements. The first iteration involved the use of the STS engine (SSME) experience base. Further iterations will adjust this baseline to better estimates based upon actual design decisions. All specifications of processing are subject to requirements traceability via the STS requirements database.

Engine system scheduled and unscheduled maintenance impacts in the proposed launch vehicle flows have been identified. Critical path processes will have the greatest impact on launch delay. It is interesting to note that noncritical path processes defined in the initial operations concept may end up as critical path processes once an incidence of historical unscheduled maintenance activities is considered. From the results it is clear that the single biggest determinant of operability measures is reliability. While hardware reliability improvements are critical to improving operability, these results also point to improvements in corrective maintenance processing activities as critical to improved turnaround times and operability measures for future launch systems.

APPENDIX A—Engine Operations Requirements Database

Table 8 presents SSME operations requirements (OMRSD's) and other pertinent information to support definition and traceability for future engine requirements.

Table 8. Engine requirements database.

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BL0.050	SSME WELD 22 & 24 LEAK CHECK	PKSC, NRAT	HPOTP	V1011.05 Seq 07	V1294.007 Seq 04	V1046.003 Seq 07				Due to poor processing, HPOTP balance cavity standoff welds are leak checked -- No leaks ever verified, but lack of weld penetration up to 90% has been found on these welds. Standoffs have been suspected of leaking and caused return to	Aft Compartment overpressurization or fire
V41BL0.060-A	E1 HPOTP PLUG WELD LEAK CHECK	PKSC, NRAT	HPOTP	V1011.05 Seq 09	V1294.004 Seq 04	V1046.004 Seq 04	V1294.005 Seq 07			Plug weld leak occurred on a unit -- Concern over these welds leaking either Gox/Helium/Hot gas into boattail -- therefore all external plug welds on the housing are checked	Aft Compartment overpressurization or fire
V41AX0.020-A	E1 LO2 FEED (JOINT O1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Ensure joint integrity of LPOTP to pump inlet ducting after engine is installed	Aft Compartment overpressurization or fire
V41AX0.020-B	E1 LH2 FEED (JOINT F1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Verify pump inlet joint integrity after installing the LPFTP	Aft Compartment overpressurization or fire
V41AX0.020-C	E1 GH2 PRESS (JOINT F9.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 09		V1046.004 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-D	E1 LO2 BLEED (JOINT O15) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-E	E1 LH2 BLEED (JOINT F4.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-F	E1 HELIUM (JOINT P1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 12		V1046.001 Seq 05	V1046.006 Seq 04		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-G	E1 GN2 (JOINT N1) I/F LK CK	ER, PR, OMDP	Lines/Ducts			V1149 Seq 15	V1046.006 Seq 03		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-H	E1 HYD - PRESS (JOINT H1) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E18	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-I	E1 HYD - RETURN (JOINT H17) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E18	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.050-A	E1 GO2 ORB/SSME INTERFACE FLANGE LEAK CHECK	A, ER	Lines/Ducts			V1046.005 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41BL0.031	SSME ENCAPSULATION POWER HD LEAK CK	EKSC & ER	Powerhead		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.032	SSME ENCAPSULATION FUEL SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.033	SSME ENCAPSULATION OXID SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.034	SSME ENCAPSULATION HOT GAS SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BP0.010-A	E1 GO2/GCV EXT LK CK & ORIFICE VERIF	EKSC, I	Valves	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05	V1294.006 Seq 05			Establishes leak test of all gaseous oxygen system joints from the AFV to the orbiter interface on an each flight basis.	Aft Compartment overpressurization or fire
V41AQ0.010-A	E1 SENSOR CHECKOUT	EKSC, ER, LRU	Instrumentation	V1011.06 Seq 02	V1294.002 Seq 06	V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Planned Preflight Checkout	Erroneous shutdown, loss of vehicle
V41AU0.013-A	E1 OPERATIONAL INSTRUMENTATION VERIFICATION	A, ER	Instrumentation			V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Erroneous shutdown, loss of vehicle
V41BU0.250-A	E1 SENSOR IR VERIFICATIONS	EKSC, LRU	Instrumentation	V1011.02 Seq 07						Functional check of each turbine discharge temp	Erroneous shutdown, loss of vehicle
V41BP0.020-A	E1 HEX COIL LEAK TEST	A, EKSC, PLRU	HEX	V1011.04 Seq 02	V1294.003 Seq 03	V1046.005 Seq 06			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BP0.030	SSME HEX COIL PROOF TEST	PLRU	HEX	V1011.04 Seq 03	V1294.003 Seq 04	V1046.005 Seq 07			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.086	HEX EDDY CURRENT INSPECTIONS (TIME & CYCLE)	TC	HEX	V1011.02 Seq 11					HEX	Thin Walls from Bracket Wear, Manuf -> Thru-Crack, HG Leakage to Tank, Crit. 1	Fire, Uncontained engine failure
V41BU0.115	HEAT EXCHANGER INSPECTION	TC	HEX		V5E02 Seq 14				HEX	Visible Impact Damage, Bracket Wear -> Thru-Crack -> HG to Tank, Crit 1; Turn. Vane Cracks -> Loss of Vane Impact MI Post -> Damage or Crit 1.	Fire, Uncontained engine failure
V41BU0.125	HEX VISUAL INSPECTION	PLRU	HEX		V5E02 Seq 12				HEX	HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.075-A	E1 HPFTP INTERNAL INSPECTION	PKSC	HPFTP	V1011.02 Seq 08					TURBOPUMPS	Verify no inlet or discharge sheet metal cracking; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking. (All inspections completed with	Fire, Uncontained engine failure
V41BU0.079	HPFTP FIRST STAGE BLADE 22X INSPECTION	TC, DCE	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no blade cracking due to previous occurrences of airfoil cracking	Fire, Uncontained engine failure
V41BU0.080	HPFTP TURBINE INSPECTION (TIME & CYCLE)	PKSC	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no inlet or discharge sheet metal cracking including weld 450 and the turning vanes; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking via	Fire, Uncontained engine failure
V41BU0.087	HPFTP BELLOWS HEIGHT VERIF	PLRU	HPFTP		V5E06 OSSU 2				TURBOPUMPS	Verify bellows height adequate to provide proper preload on the bellows at installation. Incorporated as a result of a previous failure of the bellows.	Fire, Uncontained engine failure
V41CB0.050-A	E1 HPFTP TURBINE BEARING DRYING	EKSC	HPFTP	V1011.01 Seq 03		V9018.002 Seq 04	V1038VL2 Seq 07		TURBOPUMPS	Ensure all moisture is removed from the bearing area after a test/flight	Fire, Uncontained engine failure

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BU0.390-A	E1 LPFD OVALITY CHECK	F	Lines/Ducts	V1011.02 Seq 10			V9018.002 Seq 10		DUCTS	Contingency test performed only when the LPFD helium barrier system has been damaged. Object is to detect potential duct collapse or separation from the layer of insulation by measuring the roundness of the duct.	Fire, Uncontained engine failure
V41BU0.400	PERFORM LPFD XRAY INSPECTION	F	Lines/Ducts	TBD					DUCTS	Contingency reqmt preformed only when the ovality check indicates that some damage or collapse has occurred in the LPFD. The cross section is X-rayed in an attempt to verify	Fire, Uncontained engine failure
V41BS0.050	HPOTP/AT TORQUE TEST	EKSC, RI, PLRU	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.040-A	Fire, Uncontained engine failure
V41BS0.065	HPOTP/AT INVESTIGATIVE TORQUE	F	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.042	Fire, Uncontained engine failure
V41BU0.405	SSME LPFD TRIPOD LEGS INSPECTION	DCE	Lines/Ducts	TBD					DUCTS	Performed to insure LPFD structural integrity. Inspection is *performed if post flight data evaluation reveals HPFTP* unacceptable synchronous frequencies.	Fire, Uncontained engine failure
V41BU0.065-A	**E1 ATD BLOCK I/II HPOTP INTERNAL INSPECTION**	PKSC, NRAT	HPOTP	V1011.02 Seq 08					TURBOPUMPS	No HPOTP/AT internal inspections were made during certification. Inspections of the turbine, mainstage pump and PBP inlets, and all three bearings have been added only because the inspections aren't time consuming and because	
V41BS0.010-A	E1 LPFTP TORQUE TEST	A, RI, PSI, ER, PLRU	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Verify rotor is free to rotate prior to testing	Fire, Uncontained engine failure
V41BU0.127	HPOTP/AT PBP TIEBOLT LOCK	F	HPOTP	V1011.03					TURBOPUMPS		*Fire, Uncontained engine failure*
V41BU0.128	HPOTP/AT CONTAMINATION INSPECTION	A, PKSC	HPOTP	V1011.0? Seq ??					TURBOPUMPS		Fire, Uncontained engine failure
V41CB0.065	SSME HPOTP/AT TURBINE BEARING DRYING	PKSC	HPOTP	V1011.01 Seq 03	V1294.008 Seq 04	V9018.002 Seq 04			TURBOPUMPS	Verify all moisture is removed from the bearing area after a test/flight.	Fire, Uncontained engine failure
V41BS0.011	LPFTP INVESTIGATIVE TORQUE	F	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Investigative torque check if the specification limits are exceeded - torque check failure generally lift-off seal binding or laby seal - copper plating rub	Fire, Uncontained engine failure
V41BS0.030-A	E1 LPOTP TORQUE TEST	A, RI, PSI, ER, PLRU	LPOTP	V1011.03 Seq 05	V5E23				*TURBOPUMPS*	*Done to ensure rotor is not bound up prior to start -- concern* over contamination if high and also start characteristics if rotor is slow to spin -- contamination has been found that bound the rotor and bearing wind-up can also routinely causes failure of	*Fire, Uncontained engine failure*
V41BS0.031	LPOTP INVESTIGATIVE TORQUE	F	LPOTP	V1011.03 Seq 05					TURBOPUMPS	Performed to free the rotor if possible - done only if needed -- must make torque return to normal value or pump is removed	Fire, Uncontained engine failure
V41BS0.032-A	E1 LPOTP SHAFT TRAVEL	A, ER, PLRU	LPOTP	V1011.03 Seq 05	V5E23				TURBOPUMPS	Bearing wear on LPOTP thrust bearing must be monitored	Fire, Uncontained engine failure
V41BR0.040-A	E1 MAIN INJECTOR LOX POST VACUUM DECAY	DLP	Main Injector	V1011.02 Seq 08					*COMBUSTION*	*LOX Post integrity check - Impacted or Defected Post Plugged* & Plug Damaged -> Loss of Plug, Increase Damage to Post -> Loss of Post, Crit. 1	*Fire, Uncontained engine failure*
V41BU0.034-A	E1 MAIN INJECTOR LOX POST BIASING	EKSC	Main Injector	V1011.02 Seq 04					COMBUSTION	Under Bias (cant) -> Flow Erosion MCC H/G Wall -> Repair or Crit. 1 Leak; Under Bias -> Combustion Performance Loss	Fire, Uncontained engine failure
V41BQ0.165	MCC ISOLATION LEAK TEST	F	MCC		V1294.003 Seq 06				COMBUSTION	Mat.'l Debond @ Liner Aft -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if Increase.	Fire, Uncontained engine failure
V41BQ0.240-A	E1 MCC LINER CAVITY DECAY CHECK	EKSC, LRU	MCC		V1294.003 Seq 05				COMBUSTION	*Burst Diaphragm Damage, Internal Liner To Structure Thru-*	*Fire, Uncontained engine failure*
V41BU0.031-A	E1 MCC BONDLINE ULTRASONIC INSPECTION	EKSC	MCC	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	Fire, Uncontained engine failure
V41BU0.081-A	MCC INJECTOR INSPECTION WITH HPFTP REMOVED	PLRU	MCC		V5E06 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-A	MCC INJECTOR INSPECTION WITH HPOTP REMOVED	PLRU	MCC		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BQ0.160-A	E1 THRUST CHAMBER NOZZLE LEAK TEST	EKSC	*MCC/Nozzle*	*V1011.05 Seq 09*	*V1294.011 Seq 08*	*V1046.004 Seq 04*	*V1038VL2 Seq 08*		*COMBUSTION*	*Cold or Hot Wall Thru-Crack; Degraded Liner Mat.'l or Bebond* -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if Increase. If no action required then data used to adjust engine performance predictions	*Fire, Uncontained engine failure*
V41BQ0.200-A	E1 MCC TO NOZZLE SEAL LEAK TEST	EKSC, LRU, I	MCC/Nozzle	V1011.05 Seq 08	V1294.004 Seq 03	V1046.004 Seq 08			COMBUSTION	G-15 Seal Thermal Degradation -> Aft Compartment Leak, Crit.	Fire, Uncontained engine failure
V41BQ0.167	SSME NOZZLE ENCAPSULATION LEAK TEST	F	Nozzle		V1294.010 Seq 03				COMBUSTION	Cold or Hot Wall Thru-Crack like Crown Erosion, Brazeless Tube Ends -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if	Fire, Uncontained engine failure
V41BU0.353-D	NOZZLE VISUAL INSPECTION	EKSC	Nozzle	V1011.02 Seq 05			*V1038VL2 Seq 08*		*COMBUSTION*	*Eroded Tube Crowns -> Leakage up to Crit 1; Tube Bulges ->* Trip HG Flow or Shock Wave -> Dyn. Destruction NZ, Crit 1; Re entry Annealing -> Mat.'l Degradation, Burst -> Crit. 1	*Fire, Uncontained engine failure*
V41BU0.353-E	NOZZLE PARENT METAL DISCOLORATION INSPECTION	EKSC	Nozzle	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Eroded Tube Crowns -> Leakage up to Crit 1; Tube Bulges -> Trip HG Flow or Shock Wave -> Dyn. Destruction NZ, Crit 1; Re entry Annealing -> Mat.'l Degradation, Burst -> Crit. 1	Fire, Uncontained engine failure
V41BU0.081-B	FUEL SIDE TRANSFER TUBE INSPECTION	PLRU	Powerhead		V5E06 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-B	*OXIDIZER SIDE TRANSFER TUBE INSPECTION*	PLRU	*Powerhead*		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.081-C	FUEL PREBURNER INSPECTION	PLRU	Preburner		V5E06 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.081-D	FPB LINER INSPECTION	PLRU	Preburner		V5E06 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-C	OXIDIZER PREBURNER INSPECTION	PLRU	Preburner		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.082-D	OPB LINER INSPECTION	PLRU	Preburner		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.085	OXID P/B INJECTOR ELEMENT INSP	TC, MSP	Preburner		V5E02 Seq 14				COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Loss of Post into Turbine, Crit. 1 or Internal Leakage -> Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.088	SSME FUEL P/B INJECTOR ELEMENT INSP (IF ONE OR MORE PINS FOUND MISSING)	MSP	Preburner	TBD					COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Plug Post & Use or Loss of Post into Turbine, Crit. 1 or Internal Leakage Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.105	FPB INJECTOR OXID POSTS INSP	TC	Preburner		V5E06 Seq 12				COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Plug Post & Use or Loss of Post into Turbine, Crit. 1 or Internal Leakage Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.570	FPB DIFFUSER INSPECTION	DCE	Preburner	TBD					COMBUSTION	Contingency reqmt performed to inspect for cracks in FPB diffuser. This reqmt will be invoked only if data evaluation of HPFTP turbine discharge temp deems it necessary	Fire, Uncontained engine failure
V41BU0.032	OPB FACEPLATE FLATNESS CHECKS	DCE	Preburner						COMBUSTION	Integrity check after "POP" - "POP" Damage , Bowing Indication of Braze Cracks -> Loss of Element into Turbine, Crit 1; of Internal Leakage -> Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.040-A	E1 COMPONENTS INTERNAL INSPECTION	EKSC	System	V1011.02 Seq 08						Boroscope inspection of accessible engine areas without disassembly	Fire, Uncontained engine failure
V41CB0.020-A	E1 ENVIR CLOSURE INSTALLATION	EKSC	System	S0028 Seq 19			S0026			Insure that LPFD helium barrier system is functional to preclude cryopumping in the event of a launch scrub which can lead to a collapse of the duct.	Fire, Uncontained engine failure
V41BQ0.080	RIV OVERRIDE SEALS LEAK TEST (TIME & CYCLE)	TC	Valves	TBD						Periodic (every 10 starts). To verify that the RIV shaft seals maitain override opening pressure within the RIV.	Fire, Uncontained engine failure
V41BQ0.100	AFV SEAT AND SHAFT SEAL LEAKAGE	A, GP	Valves	V1011.04 Seq 07		V1046.005 Seq 05				No LOX in HEX prestart - Crit 1	Fire, Uncontained engine failure
V41BQ0.101	AFV SHAFT AND SEAT ISOLATION	F	Valves	V1011.04 Seq 07		V1046.005 Seq 05				Isolation check if the V41BQ0.100 leakage limits are exceeded	Fire, Uncontained engine failure
V41BQ0.170-A	E1 PROP VALVE ACT PNEU SEAL LEAK	EKSC, LRU	Valves	V1011.05 Seq 12	V1294.002 Seq 10	V1046.006 Seq 04	V1011.06 Seq 03	V5E17 Seq 09		Valve/Seal Leakage - LRU Integrity Check	Fire, Uncontained engine failure
V41BQ0.171	PROP VALVE ACT PNEU SEAL ISO TEST	F	Valves	TBD						Isolation check if the V41BQ0.170-A leakage limits are	Fire, Uncontained engine failure
V41BR0.030-A	E1 AFV CRACKING PRESSURE TEST	EKSC, LRU	Valves	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05				Verify proper AFV operation - Crit 1	Fire, Uncontained engine failure

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BU0.220-A	AFV FILTER INSPECTIONS	A	Valves	V1011.04 POSU 5	V1294.002 POSU 6	V1046.005 POSU 2				Contamination check to verify that filter is not plugged which could lead to a collapse of the HEX.	Fire, Uncontained engine failure
V41BU0.220-D	AFV FILTER REPLACEMENT	A	Valves	V1011.04 Seq 07		V1046.005 Seq 05	V5005 POSU 3	V5087 Task 28		Contamination check to verify that filter is not plugged which could lead to a collapse of the HEX.	Fire, Uncontained engine failure
V41BQ0.010-A	E1 FUEL TP L/O/MFV BALL SEAL LK TEST	EKSC, ER	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.007 Seq 03	V1046.002 Seq 03				Verify no LPFTP or HPFTP lift-off seal carbon nose leakage or main fuel valve ball seal leakage. (Fuel system pressurized, measure leakage into hot gas system)	Hazardous gas buildup
V41BQ0.011	FUEL TP L/O/MFV SEALS ISOLATION TEST	F	HPFTP, LPFTP, MFV	TBD						Isolation check if the V41BQ0.010-A leakage limits are	Hazardous gas buildup
V41BQ0.020-A	E1 FUEL TP PIST/NAFLEX/MFV LK CK	EKSC	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.005 Seq 03	V1046.002 Seq 06				Verify no LPFTP or HPFTP large diameter secondary seal leakage or Naflex or MFV leakage (Fuel system pressurized, measure leakage out of the fuel component drain)	Hazardous gas buildup
V41BQ0.021	FUEL TP PIST/NAFLEX/MFV ISO TEST	F	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.005 Seq 03	V1046.002 Seq 06				Isolation check if the V41BQ0.020-A leakage limits are	Hazardous gas buildup
V41BQ0.050-A	E1 COMB HOT GAS SYS SEAL LEAK TEST	EKSC, LRU	System	V1011.05 Seq 09	V1294.005 Seq 06	V1046.004 Seq 04				Verify no LPFTP or HPFTP small diameter secondary seal leakage or other system leakages (Hot gas system pressurized, measure leakage out of the fuel component drain)	Hazardous gas buildup
V41BS0.043-B	E2 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT		V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS		
V41BS0.043-C	E3 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT		V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS		
V41BQ0.051	SSME HOT GAS SYS SEAL LK ISO TEST	F	System	TBD						Isolation check if the V41BQ0.050-A leakage limits are	Hazardous gas buildup
V41BQ0.052-A	E1 SSME COMB HOT GAS TO FUEL SYS REV LK CK	PKSC	System	V1011.05 Seq 09	V1294.005 Seq 06	V1046.004 Seq 04				Verify no reverse LPFTP or HPFTP carbon nose leakage (Hot gas system pressurized, measure leakage into fuel system) Incorporated when the pump end to turbine end leak check did not detect existing carbon nose leakage.	Hazardous gas buildup
V41BQ0.053	SSME HOT GAS REVERSE ISO LK CK	F	System	TBD						Isolation check if the V41BQ0.052-A leakage limits are	Hazardous gas buildup
V41BQ0.030-A	E1 FUEL BLEED VALVE SEAT LEAK TEST	EKSC, LRU	Valves	V1011.05 Seq 04	V1294.005 Seq 03	V1046.002 Seq 05				Valve Leakage Check	Hazardous gas buildup
V41BU0.030-B	E2 COMPONENTS EXTERNAL INSPECTION	EKSC		V1011.02 Seq 04						Handling Damage, Clearence Checks, Loose Spot Welds on or Melted TPS	
V41BU0.030-C	E3 COMPONENTS EXTERNAL INSPECTION	EKSC		V1011.02 Seq 04						Handling Damage, Clearence Checks, Loose Spot Welds on or Melted TPS	
V41BQ0.032	FUEL BLEED VALVE BELLOWS LEAK TEST	LRU	Valves	V1011.05 Seq 10	V1294.005 Seq 03	V1048.002 Seq 07				LRU - Remove and replace verification	Hazardous gas buildup
V41BU0.031-B	E2 MCC BONDLINE ULTRASONIC INSPECTION	EKSC		V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	
V41BU0.031-C	E3 MCC BONDLINE ULTRASONIC INSPECTION	EKSC		V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	
V41BQ0.034	OXID BLEED VALVE BELLOWS LEAK TEST	LRU	Valves	V1011.05 Seq 11	V1294.006 Seq 03	V1048.003 Seq 09				LRU - Remove and replace verification	Hazardous gas buildup
V41BS0.020-A	E1 HPFTP TORQUE TEST	A, RI, PLRU	HPFTP	V1011.03 Seq 09	V5E06 OSSU 1				TURBOPUMPS	Verify the rotor is free to rotate prior to testing	Improper start, Ox rich resulting in engine fire
V41BS0.021	HPFTP INVESTIGATIVE TORQUE	F	HPFTP	V1011.03 Seq 09	V5E06 OSSU 1				TURBOPUMPS	Investigative torque check if the specification limits are exceeded	Improper start, Ox rich resulting in engine fire
V41AL0.010-A	E1 GIMBAL ELECTRICAL BONDING TEST	I, ER	Avionics				V5005 Seq 06		AVIONICS	Verifies proper electrical grounding conditions exist between the SSME gimbal bearing and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AL0.020-A	E1 ELECTRICAL INTERFACE PANEL BONDING TEST	I, ER	Avionics				V5005 Seq 06		AVIONICS	Verifies proper electrical grounding conditions exist between the SSME electrical interface panel and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AL0.030-A	E1 SSME/TVC ELECTRICAL BONDING TEST	A, I, ER	Avionics			S1287 OSSU 3			AVIONICS	Verifies proper electrical grounding conditions exist between the SSME TVC actuator attach points and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AN0.010-A	E1 SSME CONTROLLER POWER APPLICATION	A, ER	Avionics					V9001VL4 Seq 02	AVIONICS	Defines the proper sequencing of cockpit switches for application of SSME controller power as well as the values of the monitored responses. Identifies the constraints for cooling air and FACOS power.	Unscheduled Maintenance Action or Launch Delay
V41AN0.020-A	E1 AC POWER REDUNDANCY VERIFICATION	A, ER	Avionics			V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Provides for SSME AC power redundancy verification while controllers are under power load.	Unscheduled Maintenance Action or Launch Delay
V41AN0.022-A	E1 CONTROLLER POWER SUPPLY REDUNDANCY VERIF	A, LRU	Avionics	V1011.06 Seq 02	V1294.002 Seq 08	V1046.001 Seq 04		V9001VL4 Seq 09	AVIONICS	Performs a redundancy verification of the SSME controller power supplies. Controller channels A&C and B&C are verified. This procedure also verifies the backup memory power is functional and verifies the AC supplied +10 V	Unscheduled Maintenance Action or Launch Delay
V41AN0.023-A	E1 CONTROLLER 28V MEMORY TEST	LRU	Avionics		V1294.002 Seq 03				AVIONICS	Verifies the capability of the 28 volt DC and battery systems are holding up the controller memory.	Unscheduled Maintenance Action or Launch Delay
V41AN0.035-A	E1 COMMANDED CONTROLLER CHECKOUT	A, ER, LRU	Avionics	V1011.06 Seq 02	V1294.002 Seq 07	V1046.001 Seq 04		V9001VL4 Seq 09	AVIONICS	Controller Changeout Verification. Functional hardware and software checkout.	Unscheduled Maintenance Action or Launch Delay
V41ZA0.010	SSME HARNESS REPLACEMENT RETEST	LRU	Avionics		V5E02 Seq 27				AVIONICS	Defines the continuity and insulation resistance tests to be performed on any replacement harness installed on an engine	Unscheduled Maintenance Action or Launch Delay
V72AQ0.020-A	EIU 1 READINESS TEST	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		Unscheduled Maintenance Action or Launch Delay
V41AU0.060-A	E1 GIMBAL BEARING SENSOR CHANNELIZATION VERIF	ER, LRU	Instrumentaiton			V1046.001 Seq 12		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.090-A	E1 POST-FLT STRAIN GAGE CHECKOUT	A, EKSC	Instrumentaiton	V1011.02 Seq 04					AVIONICS	Part of this check is Weld #3 Strain Gage checkout -- needed to ensure electrical continuity of gage after bond is assured	Unscheduled Maintenance Action or Launch Delay
V41AU0.090-D	E1 POST-FLIGHT SENSOR CHECKOUT	A, EKSC	Instrumentaiton					V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.016-A	E1 MADS INSTRUMENTATION VERIFICATION	A, ER	Instrumentation			V1046.001 Seq 13		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.020-A	E1 SKIN TEMP CHANNELIZATION VERIFICATION	ER, LRU	Instrumentation	V1011.06 Seq 08	V1294.002 POSU 11	V1046.001 Seq 13			AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.042-A	E1 HPOTP STRAIN GAGE DEBOND TEST	A, PLRU, I, NRAT	Instrumentation		V5E02 Seq 27 & V1294.002				AVIONICS	Weld #3 Strain gage in place to detect uneven bearing wear -- debond test needed to ensure acceptable data on next flight	Unscheduled Maintenance Action or Launch Delay
V41AP0.020-A	E1 MFVA PRI HEATER POWER ON COMMAND	I	Valves						AVIONICS	Changeout Verification	Unscheduled Maintenance Action or Launch Delay
V41AP0.020-D	E1 MFVA SEC HEATER POWER ON COMMAND	I	Valves						AVIONICS	Changeout Verification	Unscheduled Maintenance Action or Launch Delay
V41BU0.351-A	E1 POST FLIGHT MCC LINER POLISHING	EKSC	MCC	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Remove Liner Roughness from Intense Environ. -> Erosion -> Leakage, Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.352-A	E1 PRELAUNCH MCC LINER POLISHING	A	MCC			S1287 OSSU 9			COMBUSTION	Remove Surface Oxiditation -> Erosion -> Leakage, Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.093	HGM FUEL SIDE DYE PEN INSP (PHASE II)	TC	Powerhead		V5E06 Seq 12				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.096	HGM OXID SIDE DYE PEN INSP (PHASE II)	TC	Powerhead		V5E02 Seq 14				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.097	HGM FUEL SIDE DYE PEN INSP (PHASE II+)	TC	Powerhead		V5E06 Seq 12				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.098	HGM OXID SIDE DYE PEN INSP (PHASE II+)	TC	Powerhead		V5E02 Seq 14				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V72AQ0.040-A	VERIFY SSME 1/EIU 1 COMMAND PATH	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V72AQ0.050-A	VERIFY SSME 1/EIU 1 STAT CHANNEL	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		
V72AQ0.060-A	EIU 1 FM SYSTEM INTERFACE DATA	LRU	Avionics			S0017VL13 Seq 42			AVIONICS		
V72AW0.030-A	EIU 1 POWER REDUNDANCY	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		
V41BU0.420-A	E1 HEAT SHIELD BLANKET INSPECTION	A	Heat Shield			S1287 Seq 04			HEAT SHIELD	Thermal Deformations -> Aft Leak to Atmosphere -> ¿Crit. 1?	
V41BU0.421-A	E1 EMHS INSPECTION	A	Heat Shield	V41-40018					HEAT SHIELD		
V41BU0.050	HYDRAULIC DRAIN LINE INSPECTION (TIME & CYCLE)	TC	Lines/Ducts		V1294.002 Seq 19	V1046.001 Seq 13			HYDRAULIC	Periodic inspection (every 10 tests) of hydraulic actuator shaft seals.	
V58AG0.121-A	SUPPLY QD PRE-MATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS	Verify Configuration	
V58AG0.121-B	RETURN QD PRE-MATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS	Verify Configuration	
V58AG0.123-A	SUPPLY QD DEMATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS		
V58AG0.123-B	RETURN QD DEMATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS		
V41CB0.060-A	E1 MCC INJECTOR INSPECTION	EKSC	MCC	V1011.01 POSU 5	V1294.008 Seq 02		V1038VL2 Seq 08		COMBUSTION	H2O or Contaminants in Acoustic Cavities	
V41CB0.065-A	E2 SSME NOZZLE BUMPER INSTALLATION	PLCL	Nozzle	S0028 Seq 19			S0026	V1038VL2 Seq 14	COMBUSTION	Install Protective Bumpers for Ground Transport prior to STS Stack -> Aft Manifold Impact, Thru-Crack -> Leakage to or	
V41BQ0.090-A	E1 PCA FUEL SIDE INTERNAL LEAK TEST	EKSC, LRU	PCA	V1011.05 Seq 12	V1294.002 Seq 10	V1046.008 Seq 04	V1011.06 Seq 03			Combined test demonstrates that the emergency shutdown PAV vent port seal is not leaking beyond acceptable limits. Also checks fuel purge and bleed valve solenoids and fuel	
V41BQ0.091-A	E1 PCA LO2 SIDE INT/HPV ST/SFT SL LKG	EKSC, LRU	PCA	V1011.05 Seq 12	V1294.002 Seq 10	V1046.008 Seq 04	V1011.06 Seq 03			Combined test demonstrates that the emergency shutdown solenoid vent port seal is nto leaking beyond acceptable limits. Also the HPV poppet and shaft seals are verified.	
V41BQ0.092	PCA LO2 SIDE/HPV LKG ISOLATION	F	PCA	TBD						Performed only when combined test indicates excessive	
V41AS0.020-A	E1 PNEUMATIC CHECKOUT	EKSC, ER, LRU	Pneumatics	V1011.06 Seq 04	V1294.002 Seq 11	V1046.001 Seq 06			ENGINE	Planned Preflight Checkout	
V41BU0.073-A	E1 PNEUMATIC VENT FLANGE VERIFICATION	TC, LRU	Pneumatics		V1294.002 Seq 10					Flow Verification	
V41BU0.030-A	E1 COMPONENTS EXTERNAL INSPECTION	EKSC	System	V1011.02 Seq 04						Handling Damage, Clearence Checks, Loose Spot Welds on or Melted TPS	
V41BU0.033	FUEL SYSTEM LAI INSPECTION	EKSC	System	V1011.02 Seq 04							
V41BU0.380-A	E1 HELIUM BARRIER SYS INSPECTION	A, LRU	System			S1287 Seq 06	V9018.002 Seq 07		DUCTS	Verify Bag Intact	
V41BU0.510-A	E1 SSME TO ORBITER GIMBAL CLEARANCE CHECK	ER, MOD, LRU	System	V1063 Seq 14						Interference Check	
V41BU0.520-A	E1 GIMBAL CLEARANCE CHECK	ER, MOD, LRU	System	V1063 Seq 14							
V41BU0.530-A	E1 SSME-TO-EMHS CLEARANCE CHECK	A	System	V41-50024					HEAT SHIELD		
V41BW0.031-A	E1 PREPS FOR OPF ROLLOUT	A	System	V41-20003						Verifies that the engine is configured for transfer from the OPF. TVC actuator locks restrain engine movements and covers protect against contamination	
V41BW0.034	INSTL SSME STORAGE/SHIPPING COVERS	ERS	System	V5057						Defines the conditions governing use of the subject protective covers	
V41BW0.050	OPENING CLOSEOUT COVERS	ENV	System	V5057							
V41CB0.010	SSME POSITIONING POST LANDING	PLCL	System				S0026			Minimize rain or other contaminants entry into the nozzle	
V41CB0.012-A	E1 HE BARRIER SYS INSPECTION POST FLIGHT	EKSC	System	V1263 Seq 04		V9018.002 Seq 07	V1038VL2 Seq 06		DUCTS	Verify Bag Intact	
V41CB0.030	FERRY FLIGHT SET INSTALLATION	FF	System				V1038VL2 Seq 06			Install Protective Covers, etc. for "Piggy-Back" Fly	
V41CB0.080-D	ENGINE DRYING - 1ST PURGE (PHASE II)	EKSC	System		V1294.008 Seq 04				COMBUSTION	Controls the criteria used to perform engine drying operations following each flight. Pressures, temperatures, minimum durations and configurations are defined	
V41CB0.080-E	ENGINE DRYING - 2ND PURGE (PHASE II)	EKSC	System		V1294.008 Seq 04				COMBUSTION	Controls the criteria used to perform engine drying operations following each flight. Pressures, temperatures, minimum durations and configurations are defined	
V41CB0.081	DRYNESS VERIFICATION (PHASE II)	EKSC	System		V1294.008 Seq 05				COMBUSTION	Requires a verification of dryness, defined by a maximum moisture criteria. to be performed following completion of drying	
V41AS0.030-A	E1 FRT CHECKOUT	EKSC, ER, LRU	Systems	V1011.06 Seq 06	V1294.002 Seq 13	V1046.001 Seq 08			ENGINE	Planned Preflight Checkout	
V41AS0.030-D	E1 FRT PNEUMATIC SHUTDOWN SEQ DATA VERIF	EKSC, ER, LRU	Systems	V1011.06 Seq 08	V1294.002 Seq 19	V1046.001 Seq 13			ENGINE	Planned Preflight Checkout	
V41BU0.130-A	E1 YAW MPS TVCA ALIGNMENT	LRU, 1ST	TVC	TBD							
V41BU0.130-B	E1 PITCH MPS TVCA ALIGNMENT	LRU, 1ST	TVC	TBD							
V41AS0.010-A	E1 ACTUATOR CHECKOUT	EKSC, ER, LRU	Valves	V1011.06 Seq 05	V1294.002 Seq 12	V1046.001 Seq 07			ENGINE	Planned Preflight Checkout	
V41BQ0.040-A	E1 OXIDIZER PROP VLVS/PRG C/V LEAK TEST	EKSC, I	Valves	V1011.05 Seq 09	V1294.012 Seq 04	V1046.004 Seq 04	V1294.005 Seq 06			Check Valve Failure - Contamination; STS-55 abort investigation risk mitigation	
V41BQ0.041	OXIDIZER PROP VLVS/PRG C/V ISOLATION TEST	F	Valves		V1294.012 Seq 04					Isolation check if the V41BQ0.040-A leakage limits are exceeded	
V41BQ0.120-A	E1 LO2 PROP VALVE BALL SEAL LEAK	EKSC, ER	Valves	V1011.05 Seq 07	V1294.007 Seq 03	V1046.003 Seq 04				Valve Leakage - LOX system integrity check	
V41BQ0.121	LO2 PROP VALVE BALL LKG ISOLATION	F	Valves	TBD						Isolation check if the V41BQ0.120-A leakage limits are	
V41BQ0.130	RIV SHAFT SEAL LEAK TEST (TIME &	TC	Valves	TBD						Valve Leakage	
V41BQ0.140-A	E1 RIV SEAT FLOW TEST	EKSC	Valves	V1011.05 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.141-A	E1 OBV SEAT LEAK TEST	EKSC, LRU	Valves	V1011.05 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.150-A	E1 GCV CHECK VALVE LEAK TEST	EKSC, LRU	Valves	V1011.04 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.180	HPV CHECK VALVE LEAK TEST	TC	Valves	TBD						Valve Leakage	
V41BQ0.190	OPOV SLEEVE TEST & WINDOW CALIB	I, LRU	Valves		V1294.002 Seq 14	V5E17 Seq 09				Sets Open Loop Command % - Used to adjust start sequence	
V41BQ0.191	FPOV SLEEVE TEST & WINDOW CALIB	I, LRU	Valves		V1294.002 Seq 14	V5E18				Sets Open Loop Command % - Used to adjust start sequence	
V41BU0.070-A	E1 AFT CLOSEOUT INSPECTION	A	Valves			S1287 OSSU 8				Final look before launch	

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BL0.050	SSME WELD 22 & 24 LEAK CHECK	PKSC, NRAT	HPOTP	V1011.05 Seq 07	V1294.007 Seq 04	V1046.003 Seq 07				Due to poor processing, HPOTP balance cavity standoff welds are leak checked -- No leaks ever verified, but lack of weld penetration up to 90% has been found on these welds. Standoffs have been suspected of leaking and caused return to Canoga	Aft Compartment overpressurization or fire
V41BL0.060-A	E1 HPOTP PLUG WELD LEAK CHECK	PKSC, NRAT	HPOTP	V1011.05 Seq 09	V1294.004 Seq 04	V1046.004 Seq 04	V1294.005 Seq 07			Plug weld leak occurred on a unit -- Concern over these welds leaking either Gox/Helium/Hot gas into boattail -- therefore all external plug welds on the housing are checked	Aft Compartment overpressurization or fire
V41AX0.020-A	E1 L02 FEED (JOINT 01) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Ensure joint integrity of LPOTP to pump inlet ducting after engine is installed	Aft Compartment overpressurization or fire
V41AX0.020-B	E1 LH2 FEED (JOINT F1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Verify pump inlet joint integrity after installing the LPFTF	Aft Compartment overpressurization or fire
V41AX0.020-C	E1 GH2 PRESS (JOINT F9.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 09		V1046.004 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-D	E1 L02 BLEED (JOINT 015) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-E	E1 LH2 BLEED (JOINT F4.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-F	E1 HELIUM (JOINT P1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 12		V1046.001 Seq 05	V1046.006 Seq 04		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-G	E1 GN2 (JOINT N1) I/F LK CK	ER, PR, OMDP	Lines/Ducts			V1149 Seq 15	V1046.006 Seq 03		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-H	E1 HYD - PRESS (JOINT H1) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E18	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-I	E1 HYD - RETURN (JOINT H17) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E18	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.050-A	E1 G02 ORB/SSME INTERFACE FLANGE LEAK CHECK	A, ER	Lines/Ducts			V1046.005 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41BL0.031	SSME ENCAPSULATION POWER HD LEAK CK	EKSC & ER	Powerhead		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.032	SSME ENCAPSULATION FUEL SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.033	SSME ENCAPSULATION OXID SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.034	SSME ENCAPSULATION HOT GAS SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BP0.010-A	E1 G02/GCV EXT LK CK & ORIFICE VERIF	EKSC, I	Valves	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05	V1294.006 Seq 05			Establishes leak test of all gaseous oxygen system joints from the AFV to the orbiter interface on an each flight basis.	Aft Compartment overpressurization or fire
V41AQ0.010-A	E1 SENSOR CHECKOUT	EKSC, ER, LRU	Instrumentation	V1011.06 Seq 02	V1294.002 Seq 06	V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Planned Preflight Checkout	Erroneous shutdown, loss of vehicle
V41AU0.013-A	E1 OPERATIONAL INSTRUMENTATION VERIFICATION	A, ER	Instrumentation			V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Erroneous shutdown, loss of vehicle
V41BU0.250-A	E1 SENSOR IR VERIFICATIONS	EKSC, LRU	Instrumentation	V1011.02 Seq 07						Functional check of each turbine discharge temp	Erroneous shutdown, loss of vehicle
V41BP0.020-A	E1 HEX COIL LEAK TEST	A, EKSC, PLRU	HEX	V1011.04 Seq 02	V1294.003 Seq 03	V1046.005 Seq 06			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BP0.030	SSME HEX COIL PROOF TEST	PLRU	HEX	V1011.04 Seq 03	V1294.003 Seq 04	V1046.005 Seq 07			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.086	HEX EDDY CURRENT INSPECTIONS (TIME & CYCLE)	TC	HEX	V1011.02 Seq 11					HEX	Thin Walls from Bracket Wear, Manuf -> Thru-Crack, HG Leakage to Tank, Crit. 1	Fire, Uncontained engine failure
V41BU0.115	HEAT EXCHANGER INSPECTION	TC	HEX		V5E02 Seq 14				HEX	Visible Impact Damage, Bracket Wear -> Thru-Crack -> HG to Tank, Crit 1; Turn. Vane Cracks -> Loss of Vane Impact MI Post -> Damage or Crit 1.	Fire, Uncontained engine failure
V41BU0.125	HEX VISUAL INSPECTION	PLRU	HEX		V5E02 Seq 12				HEX	HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.075-A	E1 HPFTP INTERNAL INSPECTION	PKSC	HPFTP	V1011.02 Seq 08					TURBOPUMPS	Verify no inlet or discharge sheet metal cracking; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking. (All inspections completed with turbopump ins	Fire, Uncontained engine failure
V41BU0.079	HPFTP FIRST STAGE BLADE 22X INSPECTION	TC, DCE	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no blade cracking due to previous occurrences of air oil cracking	Fire, Uncontained engine failure
V41BU0.080	HPFTP TURBINE INSPECTION (TIME & CYCLE)	PKSC	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no inlet or discharge sheet metal cracking including weld 450 and the turning vanes; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking via dy	Fire, Uncontained engine failure
V41BU0.087	HPFTP BELLOWS HEIGHT VERIF	PLRU	HPFTP		V5E06 OSSU 2				TURBOPUMPS	Verify bellows height adequate to provide proper preload on the bellows at installation. Incorporated as a result of a previous failure of the bellows.	Fire, Uncontained engine failure

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41CB0.050-A	E1 HPFTP TURBINE BEARING DRYING	EKSC	HPFTP	V1011.01 Seq 03		V9018.002 Seq 04	V1038VL2 Seq 07		TURBOPUMPS	Ensure all moisture is removed from the bearing area after a test/flight	Fire, Uncontained engine failure
V41BQ0.110-A	E1 HPOTP PRIMARY OXID SEAL LEAK TEST	PKSC, NRAT	HPOTP	V1011.05 Seq 07	V1294.006 Seq 03	V1046.003 Seq 07				Checks for excessive leakage of LOX/GOX from the HPOTP seal -- Protects against excessive flow overcoming the barrier seal and from having excessive tankage losses during the chill down of the engine. Kel-F seal does wear during operation.	Fire, Uncontained engine failure
V41BS0.040-A	E1 HPOTP TORQUE TEST	EKSC, RI, PLRU, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Done to ensure rotor is not bound up prior to start -- concern over contamination if high and also start characteristics if rotor is slow to spin -- contamination has been found around the rotor but only once enough to effect start (rusted P/E bearings)	Fire, Uncontained engine failure
V41BS0.042	HPOTP INVESTIGATIVE TORQUE	F, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Done only to run in a high torque pump to bring the torque value below spec requirements	Fire, Uncontained engine failure
V41BS0.043-A	E1 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Locking feature was overcome on a HPOTP PBP impeller bolt lock during torque tests/spinning of pump for inspections. Recurrence control is to only turn the pump in the bolt tightening direction during inspections and to check the locking feature after al	Fire, Uncontained engine failure
V41BS0.046	HPOTP MICROSHAFT TRAVEL	PKSC, NRAT	HPOTP	V1011.03 Seq 06					TURBOPUMPS	Turbine bearings have worn very quickly in past -- this measurement is to ensure that the bearings are still capable of 1 flight prior to a launch.	Fire, Uncontained engine failure
V41BQ0.110-A	E1 ATD BLOCK I/II HPOTP PRIMARY OXID SEAL LEAK TEST	PKSC, NRAT	HPOTP	V1011.05 Seq 07	V1294.006 Seq 03	V1046.003 Seq 07				This leak check was never performed during HPOTP/AT certification. The data obtained is erratic and is probably indicative of only gross seal imperfections (which would most likely be detected through torque checks). It is currently an OMRSD requirement	Fire, Uncontained engine failure
V41BU0.065-A	E1 HPOTP INTERNAL INSPECTION	PKSC, NRAT	HPOTP	V1011.02 Seq 08					TURBOPUMPS	Visual inspections of turbine hardware (sheetmetal/ nozzles/ blades) due to cracking and erosion seen in the past, of the main pump inlet / inducer due to cavitation damage and contamination found in the past, of the PBP impeller inlet due to locking feat	Fire, Uncontained engine failure
V41BU0.066-A	E1 HPOTP TIP SEAL RETAINER INSPECTION	PKSC, NRAT	HPOTP						TURBOPUMPS	Verifies 1st stage tip seal retainer screws have not rotated. Could lead to blade failure.	Fire, Uncontained engine failure
V41BU0.390-A	E1 LPFD OVALITY CHECK	F	Lines/Ducts	V1011.02 Seq 10			V9018.002 Seq 10		DUCTS	Contingency test performed only when the LPFD helium barrier system has been damaged. Object is to detect potential duct collapse or separation from the layer of insulation by measuring the roundness of the duct.	Fire, Uncontained engine failure
V41BU0.400	PERFORM LPFD XRAY INSPECTION	F	Lines/Ducts	TBD					DUCTS	Contingency reqmt preformed only when the ovality check indicates that some damage or collapse has occurred in the LPFD. The cross section is X-rayed in an attempt to verify presence of damage.	Fire, Uncontained engine failure
V41BS0.050	HPOTP/AT TORQUE TEST	EKSC, RI, PLRU	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.040-A	Fire, Uncontained engine failure
V41BS0.055	HPOTP/AT INVESTIGATIVE TORQUE	F	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.042	Fire, Uncontained engine failure
V41BU0.405	SSME LPFD TRIPOD LEGS INSPECTION	DCE	Lines/Ducts	TBD					DUCTS	Performed to insure LPFD structural integrity. Inspection is performed if post flight data evaluation reveals HPFTP unacceptable synchronous frequencies.	Fire, Uncontained engine failure
V41BU0.065-A	E1 ATD BLOCK I/II HPOTP INTERNAL INSPECTION	PKSC, NRAT	HPOTP	V1011.02 Seq 08					TURBOPUMPS	No HPOTP/AT internal inspections were made during certification. Inspections of the turbine, mainstage pump and PBP inlets, and all three bearings have been added only because the inspections aren't time consuming and because some 'human error' could be	
V41BS0.010-A	E1 LPFTP TORQUE TEST	A, RI, PSI, FB, PLRU	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Verify rotor is free to rotate prior to testing	Fire, Uncontained engine failure
V41BU0.127	HPOTP/AT PBP TIEBOLT LOCK INSPECTION	F	HPOTP	V1011.03					TURBOPUMPS		Fire, Uncontained engine failure
V41BU0.128	HPOTP/AT CONTAMINATION INSPECTION	A, PKSC	HPOTP	V1011.0? Seq ??					TURBOPUMPS		Fire, Uncontained engine failure
V41CB0.085	SSME HPOTP/AT TURBINE BEARING DRYING	PKSC	HPOTP	V1011.01 Seq 03	V1294.008 Seq 04	V9018.002 Seq 04			TURBOPUMPS	Verify all moisture is removed from the bearing area after a test/flight.	Fire, Uncontained engine failure
V41BS0.011	LPFTP INVESTIGATIVE TORQUE	F	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Investigative torque check if the specification limits are exceeded - torque check failure generally lift-off seal binding or laby seal - copper plating rub	Fire, Uncontained engine failure

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BS0.030-A	E1 LPOTP TORQUE TEST	A, RI, PSI, ER, PLRU	LPOTP	V1011.03 Seq 05	V5E23				TURBOPUMPS	Done to ensure rotor is not bound up prior to start -- concern over contamination if high and also start characteristics if rotor is slow to spin -- contamination has been found that bound the rotor and bearing wind-up can also routinely causes failure of	Fire, Uncontained engine failure
V41BS0.031	LPOTP INVESTIGATIVE TORQUE	F	LPOTP	V1011.03 Seq 05					TURBOPUMPS	Performed to free the rotor if possible - done only if needed -- must make torque return to normal value or pump is removed	Fire, Uncontained engine failure
V41BS0.032-A	E1 LPOTP SHAFT TRAVEL	A, ER, PLRU	LPOTP	V1011.03 Seq 05	V5E23				TURBOPUMPS	Bearing wear on LPOTP thrust bearing must be monitored	Fire, Uncontained engine failure
V41BR0.040-A	E1 MAIN INJECTOR LOX POST VACUUM DECAY	DLP	Main Injector	V1011.02 Seq 08					COMBUSTION	LOX Post integrity check - Impacted or Defected Post Plugged & Plug Damaged -> Loss of Plug, Increase Damage to Post -> Loss of Post, Crit. 1	Fire, Uncontained engine failure
V41BU0.034-A	E1 MAIN INJECTOR LOX POST BIASING	EKSC	Main Injector	V1011.02 Seq 04					COMBUSTION	Under Bias (cont) -> Flow Erosion MCC H/G Wall -> Repair or Crit. 1 Leak; Under Bias -> Combustion Performance Loss	Fire, Uncontained engine failure
V41BQ0.165	MCC ISOLATION LEAK TEST	F	MCC		V1294.003 Seq 08				COMBUSTION	Mat.'l Debond @ Liner Aft -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if increase.	Fire, Uncontained engine failure
V41BQ0.240-A	E1 MCC LINER CAVITY DECAY CHECK	EKSC, LRU	MCC		V1294.003 Seq 05				COMBUSTION	Burst Diaphragm Damage, Internal Liner To Structure Thru-Crack	Fire, Uncontained engine failure
V41BU0.031-A	E1 MCC BONDLINE ULTRASONIC INSPECTION	EKSC	MCC	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	Fire, Uncontained engine failure
V41BU0.081-A	MCC INJECTOR INSPECTION WITH HPFTP REMOVED	PLRU	MCC		V5E08 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-A	MCC INJECTOR INSPECTION WITH HPOTP REMOVED	PLRU	MCC		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BQ0.180-A	E1 THRUST CHAMBER NOZZLE LEAK TEST	EKSC	MCC/Nozzle	V1011.05 Seq 08	V1294.011 Seq 08	V1046.004 Seq 04	V1038VL2 Seq 08		COMBUSTION	Cold or Hot Wall Thru-Crack; Degraded Liner Mat.'l or Rebond -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if increase. If no action required then data used to adjust engine performance predictions	Fire, Uncontained engine failure
V41BQ0.200-A	E1 MCC TO NOZZLE SEAL LEAK TEST	EKSC, LRU, I	MCC/Nozzle	V1011.05 Seq 08	V1294.004 Seq 03	V1046.004 Seq 08			COMBUSTION	G-15 Seal Thermal Degradation -> Aft Compartment Leak, Crit. 1	Fire, Uncontained engine failure
V41BQ0.187	SAME NOZZLE ENCAPSULATION LEAK TEST	F	Nozzle		V1294.010 Seq 03				COMBUSTION	Cold or Hot Wall Thru-Crack like Crown Erosion, Brazeless Tube Ends -> Repair; UAI Performance Loss; Crit 3 to Crit 1 if increase.	Fire, Uncontained engine failure
V41BU0.353-D	NOZZLE VISUAL INSPECTION	EKSC	Nozzle	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Erosed Tube Crowns -> Leakage up to Crit 1; Tube Bulges -> Trip HG Flow or Shock Wave -> Dyn. Destruction NZ, Crit 1; Re-entry Annealing -> Mat.'l Degradation, Burst -> Crit. 1	Fire, Uncontained engine failure
V41BU0.353-E	NOZZLE PARENT METAL DISCOLORATION INSPECTION	EKSC	Nozzle	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Erosed Tube Crowns -> Leakage up to Crit 1; Tube Bulges -> Trip HG Flow or Shock Wave -> Dyn. Destruction NZ, Crit 1; Re-entry Annealing -> Mat.'l Degradation, Burst -> Crit. 1	Fire, Uncontained engine failure
V41BU0.081-B	FUEL SIDE TRANSFER TUBE INSPECTION	PLRU	Powerhead		V5E08 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-B	OXIDIZER SIDE TRANSFER TUBE INSPECTION	PLRU	Powerhead		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.081-C	FUEL PREBURNER INSPECTION	PLRU	Preburner		V5E08 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.081-D	FPB LINER INSPECTION	PLRU	Preburner		V5E08 Seq 12				COMBUSTION	Inspect when HPFTP Removed	Fire, Uncontained engine failure
V41BU0.082-C	OXIDIZER PREBURNER INSPECTION	PLRU	Preburner		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.082-D	OPB LINER INSPECTION	PLRU	Preburner		V5E02 Seq 14				COMBUSTION	Inspect when HPOTP Removed	Fire, Uncontained engine failure
V41BU0.085	OXID P/B INJECTOR ELEMENT INSP	TC, MSP	Preburner		V5E02 Seq 14				COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Loss of Post into Turbine, Crit. 1 or Internal Leakage -> Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.088	SAME FUEL P/B INJECTOR ELEMENT INSP. (IF ONE OR MORE PINS FOUND MISSING)	MSP	Preburner	TBD					COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Plug Post & Use or Loss of Post into Turbine, Crit. 1 or Internal Leakage Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.105	FPB INJECTOR OXID POSTS INSP	TC	Preburner		V5E06 Seq 12				COMBUSTION	Damaged Posts Pinned, Loss of Pins -> Increase Damage to Post -> Plug Post & Use or Loss of Post into Turbine, Crit. 1 or Internal Leakage Overheat Turbine, Crit. 1	Fire, Uncontained engine failure
V41BU0.570	FPB DIFFUSER INSPECTION	DCE	Preburner	TBD					COMBUSTION	Contingency reqmt performed to inspect for cracks in FPB diffuser. This reqmt will be invoked only if data evaluation of HPFTP turbine discharge temp deems it necessary	Fire, Uncontained engine failure

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BU0.032	OPB FACEPLATE FLATNESS CHECKS	DCE	Preburner						COMBUSTION	Integrity check after "POP" - "POP" Damage , Bowing Indication of Braze Cracks -> Loss of Element into Turbine, Crit 1; of Internal Leakage -> Overheat Turbine, Crit.	Fire, Uncontained engine failure
V41BU0.040-A	E1 COMPONENTS INTERNAL INSPECTION	EKSC	System	V1011.02 Seq 08						Boroscope inspection of accessible engine areas without disassembly	Fire, Uncontained engine failure
V41C80.020-A	E1 ENVIR CLOSURE INSTALLATION	EKSC	System	S0028 Seq 19			S0026			Insure that LPFD helium barrier system is functional to *preclude cryopumping in the event of a launch scrub* which can lead to a collapse of the duct.	Fire, Uncontained engine failure
V41BQ0.080	RIV OVERRIDE SEALS LEAK TEST (TIME & *CYCLE*)	TC	Valves	TBD						Periodic (every 10 starts). To verify that the RIV shaft seals maitain override opening pressure within the RIV.	Fire, Uncontained engine failure
V41BQ0.100	AFV SEAT AND SHAFT SEAL LEAKAGE	A, GP	Valves	V1011.04 Seq 07		V1046.005 Seq 05				No LOX in HEX prestart - Crit 1	Fire, Uncontained engine failure
V41BQ0.101	AFV SHAFT AND SEAT ISOLATION	F	Valves	V1011.04 Seq 07		V1046.005 Seq 05				Isolation check if the V41BQ0.100 leakage limits are exceeded	Fire, Uncontained engine failure
V41BQ0.170-A	E1 PROP VALVE ACT PNEU SEAL LEAK TEST	EKSC, LRU	Valves	*V1011.05 Seq 12*	*V1294.002 Seq 10*	*V1046.006 Seq 04*	*V1011.05 Seq 03*	*V5E17 Seq 09*		Valve/Seal Leakage - LRU Integrity Check	Fire, Uncontained engine failure
V41BQ0.171	PROP VALVE ACT PNEU SEAL ISO TEST	F	Valves	TBD						Isolation check if the V41BQ0.170-A leakage limits are exceeded	Fire, Uncontained engine failure
V41BR0.030-A	E1 AFV CRACKING PRESSURE TEST	EKSC, LRU	Valves	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05				*Verify proper AFV operation - Crit 1*	*Fire, Uncontained engine failure*
V41BU0.220-A	AFV FILTER INSPECTIONS	A	Valves	V1011.04 POSU 5	V1294.002 POSU 6	V1046.005 POSU 2				Contamination check to verify that filter is not plugged which could lead to a collapse of the HEX.	Fire, Uncontained engine failure
V41BU0.220-D	*AFV FILTER REPLACEMENT*	A	Valves	V1011.04 Seq 07		V1046.005 Seq 05	V5005 POSU 3	V5087 Task 28		Contamination check to verify that filter is not plugged which could lead to a collapse of the HEX.	Fire, Uncontained engine failure
V41BQ0.010-A	E1 FUEL TP L/O/MFV BALL SEAL LK TEST	EKSC, ER	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.007 Seq 03	V1046.002 Seq 03				Verify no LPFTP or HPFTP lift-off seal carbon nose leakage or main fuel valve ball seal leakage. (Fuel system pressurized, measure leakage into hot gas system)	Hazardous gas buildup
V41BQ0.011	FUEL TP L/O/MFV SEALS ISOLATION TEST	F	HPFTP, LPFTP, MFV	TBD						Isolation check if the V41BQ0.010-A leakage limits are exceeded	Hazardous gas buildup
V41BQ0.020-A	E1 FUEL TP PIST/NAFLEX/MFV LK CK	EKSC	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.005 Seq 03	V1046.002 Seq 06				*Verify no LPFTP or HPFTP large diameter secondary seal* leakage or Naflex or MFV leakage (Fuel system pressurized, measure leakage out of the fuel component drain)	*Hazardous gas buildup*
V41BQ0.021	FUEL TP PIST/NAFLEX/MFV ISO TEST	F	HPFTP, LPFTP, MFV	V1011.05 Seq 05	V1294.005 Seq 03	V1046.002 Seq 06				Isolation check if the V41BQ0.020-A leakage limits are exceeded	Hazardous gas buildup
V41BQ0.050-A	E1 COMB HOT GAS SYS SEAL LEAK TEST	EKSC, LRU	System	V1011.05 Seq 09	V1294.005 Seq 06	V1046.004 Seq 04				Verify no LPFTP or HPFTP small diameter secondary seal *leakage or other system leakages* (Hot gas system pressurized, measure leakage out of the fuel component drain)	Hazardous gas buildup
V41BS0.043-B	E2 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT		V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS		
V41BS0.043-C	E3 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT		V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS		
V41BQ0.051	SSME HOT GAS SYS SEAL LK ISO TEST	F	System	TBD						Isolation check if the V41BQ0.050-A leakage limits are exceeded	Hazardous gas buildup
V41BQ0.052-A	E1 *SSME COMB HOT GAS TO FUEL SYS* REV LK CK	*PKSC*	*System*	*V1011.05 Seq 09*	*V1294.005 Seq 06*	*V1046.004 Seq 04*				Verify no reverse LPFTP or HPFTP carbon nose leakage (Hot gas system pressurized, measure leakage into fuel system) Incorporated when the pump end to turbine end leak check did not detect existing carbon nose leakage.	Hazardous gas buildup
V41BQ0.053	SSME HOT GAS REVERSE ISO LK CK	F	System	TBD						Isolation check if the V41BQ0.052-A leakage limits are exceeded	Hazardous gas buildup
V41BQ0.030-A	E1 FUEL BLEED VALVE SEAT LEAK TEST	EKSC, LRU	Valves	V1011.05 Seq 04	V1294.005 Seq 03	V1046.002 Seq 05				Valve Leakage Check	Hazardous gas buildup
V41BU0.030-B	E2 COMPONENTS EXTERNAL INSPECTION	EKSC		V1011.02 Seq 04						*Handling Damage, Clearance Checks, Loose Spot Welds* on or Melted TPS	
V41BU0.030-C	E3 COMPONENTS EXTERNAL INSPECTION	EKSC		V1011.02 Seq 04						Handling Damage, Clearance Checks, Loose Spot Welds on or Melted TPS	
V41BQ0.032	FUEL BLEED VALVE BELLOWS LEAK TEST	LRU	Valves	V1011.05 Seq 10	V1294.005 Seq 03	V1046.002 Seq 07				LRU - Remove and replace verification	Hazardous gas buildup
V41BU0.031-B	E2 MCC BONDLINE ULTRASONIC INSPECTION	EKSC		V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	
V41BU0.031-C	E3 MCC BONDLINE ULTRASONIC INSPECTION	EKSC		V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Internal Debonds -> Emplosion, Crit 1; External Leak, UAI to Crit 1	
V41BQ0.034	OXID BLEED VALVE BELLOWS LEAK TEST	LRU	Valves	V1011.05 Seq 11	V1294.006 Seq 03	V1046.003 Seq 09				LRU - Remove and replace verification	Hazardous gas buildup
V41BS0.020-A	E1 HPFTP TORQUE TEST	A, RI, PLRU	HPFTP	V1011.03 Seq 09	V5E06 OSSU 1				TURBOPUMPS	Verify the rotor is free to rotate prior to testing	Improper start, Ox rich resulting in engne fire
V41BS0.021	*HPFTP INVESTIGATIVE TORQUE*	*F*	*HPFTP*	V1011.03 Seq 09	V5E06 OSSU 1				TURBOPUMPS	Investigative torque check if the specification limits are exceeded	Improper start, Ox rich resulting in engne fire

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41AL0.010-A	E1 GIMBAL ELECTRICAL BONDING TEST	I, ER	Avionics				V5005 Seq 06		AVIONICS	Verifies proper electrical grounding conditions exist between the SSME gimbal bearing and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AL0.020-A	E1 ELECTRICAL INTERFACE PANEL BONDING TEST	I, ER	Avionics				V5005 Seq 06		AVIONICS	Verifies proper electrical grounding conditions exist between the SSME electrical interface panel and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AL0.030-A	E1 SSME/TVC ELECTRICAL BONDING TEST	A, I, ER	Avionics			S1287 OSSU 3			AVIONICS	Verifies proper electrical grounding conditions exist between the SSME TVC actuator attach points and the orbiter structure. Test performed each time the bonding straps are disturbed.	Unscheduled Maintenance Action or Launch Delay
V41AN0.010-A	E1 SSME CONTROLLER POWER APPLICATION	A, ER	Avionics					V9001VL4 Seq 02	AVIONICS	Defines the proper sequencing of cockpit switches for application of SSME controller power as well as the values of the monitored responses. Identifies the constraints for cooling air and FACOS power.	Unscheduled Maintenance Action or Launch Delay
V41AN0.020-A	E1 AC POWER REDUNDANCY VERIFICATION	A, ER	Avionics			V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Provides for SSME AC power redundancy verification while controllers are under power load.	Unscheduled Maintenance Action or Launch Delay
V41AN0.022-A	E1 CONTROLLER POWER SUPPLY REDUNDANCY VERIF	A, LRU	Avionics	V1011.06 Seq 02	V1294.002 Seq 08	V1046.001 Seq 04		V9001VL4 Seq 09	AVIONICS	Performs a redundancy verification of the SSME controller power supplies. Controller channels A&C and B&C are verified. This procedure also verifies the backup memory power is functional and verifies the AC supplied +10 V reference diode.	Unscheduled Maintenance Action or Launch Delay
V41AN0.023-A	E1 CONTROLLER 28V MEMORY TEST	LRU	Avionics		V1294.002 Seq 03				AVIONICS	Verifies the capability of the 28 volt DC and battery systems are holding up the controller memory.	Unscheduled Maintenance Action or Launch Delay
V41AN0.035-A	E1 COMMANDED CONTROLLER CHECKOUT	A, ER, LRU	Avionics	V1011.06 Seq 02	V1294.002 Seq 07	V1046.001 Seq 04		V9001VL4 Seq 09	AVIONICS	Controller Changeout Verification. Functional hardware and software checkout.	Unscheduled Maintenance Action or Launch Delay
V41ZA0.010	SSME HARNESS REPLACEMENT RETEST	LRU	Avionics		V5E02 Seq 27				AVIONICS	Defines the continuity and insulation resistance tests to be performed on any replacement harness installed on an engine	Unscheduled Maintenance Action or Launch Delay
V72A00.020-A	EIU 1 READINESS TEST	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		Unscheduled Maintenance Action or Launch Delay
V41AU0.060-A	E1 GIMBAL BEARING SENSOR CHANNELIZATION VERIF	ER, LRU	Instrumentation			V1046.001 Seq 12		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.090-A	E1 POST-FLT STRAIN GAGE CHECKOUT	A, EKSC	Instrumentation	V1011.02 Seq 04					AVIONICS	Part of this check is Weld #3 Strain Gage checkout -- needed to ensure electrical continuity of gage after bond is assured	Unscheduled Maintenance Action or Launch Delay
V41AU0.090-D	E1 POST-FLIGHT SENSOR CHECKOUT	A, EKSC	Instrumentation					V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.016-A	E1 MADS INSTRUMENTATION VERIFICATION	A, ER	Instrumentation			V1046.001 Seq 13		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.020-A	E1 SKIN TEMP CHANNELIZATION VERIFICATION	ER, LRU	Instrumentation	V1011.06 Seq 08	V1294.002 POSU 11	V1046.001 Seq 13			AVIONICS	Instrumentation integrity checkout	Unscheduled Maintenance Action or Launch Delay
V41AU0.042-A	E1 HPOTP STRAIN GAGE DEBOND TEST	A, PLRU, I, NRAT	Instrumentation		V5E02 Seq 27 & V1294.002				AVIONICS	Weld #3 Strain gage in place to detect uneven bearing wear -- debond test needed to ensure acceptable data on next flight	Unscheduled Maintenance Action or Launch Delay
V41AP0.020-A	E1 MFVA PRI HEATER POWER ON COMMAND	I	Valves						AVIONICS	Changeout Verification	Unscheduled Maintenance Action or Launch Delay
V41AP0.020-D	E1 MFVA SEC HEATER POWER ON COMMAND	I	Valves						AVIONICS	Changeout Verification	Unscheduled Maintenance Action or Launch Delay
V41BU0.351-A	E1 POST FLIGHT MCC LINER POLISHING	EKSC	MCC	V1011.02 Seq 05			V1038VL2 Seq 08		COMBUSTION	Remove Liner Roughness from Intense Environ. -> Erosion -> Leakage, Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.352-A	E1 PRELAUNCH MCC LINER POLISHING	A	MCC			S1287 OSSU 9			COMBUSTION	Remove Surface Oxiditation -> Erosion -> Leakage, Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.093	HGM FUEL SIDE DYE PEN INSP (PHASE II)	TC	Powerhead		V5E06 Seq 12				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.096	HGM OXID SIDE DYE PEN INSP (PHASE II)	TC	Powerhead		V5E02 Seq 14				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.097	HGM FUEL SIDE DYE PEN INSP (PHASE II+)	TC	Powerhead		V5E06 Seq 12				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V41BU0.098	HGM OXID SIDE DYE PEN INSP (PHASE II+)	TC	Powerhead		V5E02 Seq 14				COMBUSTION	Liner Mat.'l & Transfer Tube Weld Thru-Cracks -> By-pass Flow Performance Loss	Unscheduled Maintenance Action or Performance loss
V72AQ0.040-A	VERIFY SSME 1/EIU 1 COMMAND PATH	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		
V72AQ0.050-A	VERIFY SSME 1/EIU 1 STAT CHANNEL PATH	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		
V72AQ0.060-A	EIU 1 FM SYSTEM INTERFACE DATA	LRU	Avionics			S0017VL13 Seq 42			AVIONICS		

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V72AW0.030-A	EIU 1 POWER REDUNDANCY VERIFICATION	A, LRU	Avionics				V9001VL4 Seq 02		AVIONICS		
V41BU0.420-A	E1 HEAT SHIELD BLANKET INSPECTION	A	Heat Shield			81287 Seq 04			HEAT SHIELD	Thermal Deformations -> Aft Leak to Atmosphere -> ,Crit. 1?	
V41BU0.421-A	E1 EMHS INSPECTION	A	Heat Shield	V41-40018					HEAT SHIELD		
V41BU0.050	HYDRAULIC DRAIN LINE INSPECTION (TIME & CYCLE)	TC	Lines/Ducts		V1294.002 Seq 19	V1048.001 Seq 13			HYDRAULIC	Periodic inspection (every 10 tests) of hydraulic actuator shaft seals.	
V58AG0.121-A	SUPPLY QD PRE-MATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS	Verify Configuration	
V58AG0.121-B	RETURN QD PRE-MATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS	Verify Configuration	
V58AG0.123-A	SUPPLY QD DEMATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS		
V58AG0.123-B	RETURN QD DEMATE INSPECTION	I	Lines/Ducts				V9002.06 Seq 03		HYDRAULICS		
V41C90.060-A	E1 MCC INJECTOR INSPECTION	EKSC	MCC	V1011.01 POSU 5	V1294.008 Seq 02		V1038VL2 Seq 08		COMBUSTION	H2O or Contaminants in Acoustic Cavities	
V41C80.065-A	E2 SSME NOZZLE BUMPER INSTALLATION	PLCL	Nozzle	S0028 Seq 19			S0026	V1038VL2 Seq 14	COMBUSTION	Install Protective Bumpers for Ground Transport prior to STS Stack -> Aft Manifold Impact, Thru-Crack -> Leakage to or Burst, Crit. 1	
V41BQ0.090-A	E1 PCA FUEL SIDE INTERNAL LEAK TEST	EKSC, LRU	PCA	V1011.05 Seq 12	V1294.002 Seq 10	V1046.008 Seq 04	V1011.06 Seq 03			Combined test demonstrates that the emergency shutdown PAV vent port seal is not leaking beyond acceptable limits. Also checks fuel purge and bleed valve solenoids and fuel purge PAV.	
V41BQ0.091-A	E1 PCA LO2 SIDE INT/HPV ST/SFT SL LKG	EKSC, LRU	PCA	V1011.05 Seq 12	V1294.002 Seq 10	V1046.006 Seq 04	V1011.06 Seq 03			Combined test demonstrates that the emergency shutdown solenoid vent port seal is nto leaking beyond acceptable limits. Also the HPV poppet and shaft seals are verified.	
V41BQ0.092	PCA LO2 SIDE/HPV LKG ISOLATION	F	PCA	TBD						Performed only when combined test indicates excessive leakage.	
V41A50.020-A	E1 PNEUMATIC CHECKOUT	EKSC, ER, LRU	Pneumatics	V1011.08 Seq 04	V1294.002 Seq 11	V1046.001 Seq 06			ENGINE	Planned Preflight Checkout	
V41BU0.073-A	E1 PNEUMATIC VENT FLANGE VERIFICATION	TC, LRU	Pneumatics		V1294.002 Seq 10					Flow Verification	
V41BU0.030-A	E1 COMPONENTS EXTERNAL INSPECTION	EKSC	System	V1011.02 Seq 04						Handling Damage, Clearance Checks, Loose Spot Welds on or Melted TPS	
V41BU0.033	FUEL SYSTEM LAI INSPECTION	EKSC	System	V1011.02 Seq 04							
V41BU0.380-A	E1 HELIUM BARRIER SYS INSPECTION	A, LRU	System			61287 Seq 05	V9018.002 Seq 07		DUCTS	Verify Bag Intact	
V41BU0.510-A	E1 SSME TO ORBITER GIMBAL CLEARANCE CHECK	ER, MOD, LRU	System	V1063 Seq 14						Interference Check	
V41BU0.520-A	E1 GIMBAL CLEARANCE CHECK	ER, MOD, LRU	System	V1063 Seq 14							
V41BU0.630-A	E1 SSME-TO-EMHS CLEARANCE CHECK	A	System	V41-50024					HEAT SHIELD		
V41BW0.031-A	E1 PREPS FOR OPF ROLLOUT	A	System	V41-20003						Verifies that the engine is configured for transfer from the OPF. TVC actuator locks restrain engine movements and covers protect against contamination	
V41BW0.034	INSTL SSME STORAGE/SHIPPING COVERS	ERS	System	V5057						Defines the conditions governing use of the subject protective covers	
V41BW0.060	OPENING CLOSEOUT COVERS	ENV	System	V5057							
V41C80.010	SSME POSITIONING POST LANDING	PLCL	System				S0026			Minimize rain or other contaminants entry into the nozzle	
V41C80.012-A	E1 HE BARRIER SYS INSPECTION POST FLIGHT	EKSC	System	V1263 Seq 04		V9018.002 Seq 07	V1038VL2 Seq 05		DUCTS	Verify Bag Intact	
V41C80.030	FERRY FLIGHT SET INSTALLATION	FF	System				V1038VL2 Seq 06			Install Protective Covers, etc. for "Piggy-Back" Fly	
V41C80.080-D	ENGINE DRYING - 1ST PURGE (PHASE II)	EKSC	System		V1294.005 Seq 04				COMBUSTION	Controls the criteria used to perform engine drying operations following each flight. Pressures, temperatures, minimum durations and configurations are defined	

Table 8. Engine requirements database (Continued).

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41CB0.080-E	ENGINE DRYING - 2ND PURGE (PHASE II)	EKSC	System		V1294.008 Seq 04				COMBUSTION	Controls the criteria used to perform engine drying operations following each flight. Pressures, temperatures, minimum durations and configurations are defined	
V41CB0.081	DRYNESS VERIFICATION (PHASE II)	EKSC	System		V1294.008 Seq 05				COMBUSTION	Requires a verification of dryness, defined by a maximum moisture criteria. to be performed following completion of drying operation	
V41AS0.030-A	E1 FRT CHECKOUT	EKSC, ER, LRU	Systems	V1011.06 Seq 06	V1294.002 Seq 13	V1046.001 Seq 08			ENGINE	Planned Preflight Checkout	
V41AS0.030-D	E1 FRT PNEUMATIC SHUTDOWN SEQ DATA VERIF	EKSC, ER, LRU	Systems	V1011.06 Seq 08	V1294.002 Seq 19	V1046.001 Seq 13			ENGINE	Planned Preflight Checkout	
V41BU0.130-A	E1 YAW MPS TVCA ALIGNMENT	LRU, 1ST	TVC	TBD							
V41BU0.130-B	E1 PITCH MPS TVCA ALIGNMENT	LRU, 1ST	TVC	TBD							
V41AS0.010-A	E1 ACTUATOR CHECKOUT	EKSC, ER, LRU	Valves	V1011.06 Seq 05	V1294.002 Seq 12	V1046.001 Seq 07			ENGINE	Planned Preflight Checkout	
V41BQ0.040-A	E1 OXIDIZER PROP VLVS/PRG C/V LEAK TEST	EKSC, I	Valves	V1011.05 Seq 09	V1294.012 Seq 04	V1046.004 Seq 04	V1294.005 Seq 06			Check Valve Failure - Contamination; STS-55 abort investigation risk mitigation	
V41BQ0.041	OXIDIZER PROP VLVS/PRG C/V ISOLATION TEST	F	Valves		V1294.012 Seq 04					Isolation check if the V41BQ0.040-A leakage limits are exceeded	
V41BQ0.120-A	E1 LO2 PROP VALVE BALL SEAL LEAK TEST	EKSC, ER	Valves	V1011.05 Seq 07	V1294.007 Seq 03	V1046.003 Seq 04				Valve Leakage - LOX system integrity check	
V41BQ0.121	LO2 PROP VALVE BALL LKG ISOLATION TEST	F	Valves	TBD						Isolation check if the V41BQ0.120-A leakage limits are exceeded	
V41BQ0.130	RIV SHAFT SEAL LEAK TEST (TIME & CYCLE)	TC	Valves	TBD						Valve Leakage	
V41BQ0.140-A	E1 RIV SEAT FLOW TEST	EKSC	Valves	V1011.05 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.141-A	E1 OBV SEAT LEAK TEST	EKSC, LRU	Valves	V1011.05 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.150-A	E1 GCV CHECK VALVE LEAK TEST	EKSC, LRU	Valves	V1011.04 Seq 06	V1294.006 Seq 03	V1046.003 Seq 06				Valve Leakage	
V41BQ0.180	HPV CHECK VALVE LEAK TEST	TC	Valves	TBD						Valve Leakage	
V41BQ0.190	OPOV SLEEVE TEST & WINDOW CALIB	I, LRU	Valves		V1294.002 Seq 14	V5E17 Seq 09				Sets Open Loop Command % - Used to adjust start sequence	
V41BQ0.191	FPOV SLEEVE TEST & WINDOW CALIB	I, LRU	Valves		V1294.002 Seq 14	V5E18				Sets Open Loop Command % - Used to adjust start sequence	
V41BU0.070-A	E1 AFT CLOSEOUT INSPECTION	A	Valves			S1287 OSSU 8				Final look before launch	

APPENDIX B—Scheduled SSME Operations Data

The following spreadsheets present the detailed data collection from SSME processing experience at KSC relative to scheduled activities. Tables 9–12 present the summary information relative to figures 6 through 9. Following that, the specific processing tasks for the four flows appear in tables 13–16. Finally, an example of the existing level of detail supporting the flow layouts is presented in table 17. Note also that a zero in a work column only reflects that no engine processing personnel are required for that task.

Table 9. OPF SSME postflight planned operations.*

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/98)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41BL0.050	SSME WELD 22 & 24 LEAK CHECK	PKSC, NRAT	HPOTP	V1011.05 Seq 07	V1294.007 Seq 04	V1046.003 Seq 07				Due to poor processing, HPOTP balance cavity standoff welds are leak checked -- No leaks ever verified, but lack of weld penetration up to 90% has been found on these welds. Standoffs have been suspected of leaking and caused return to Canoga	Aft Compartment overpressurization or fire
V41BL0.060-A	E1 HPOTP PLUG WELD LEAK CHECK	PKSC, NRAT	HPOTP	V1011.06 Seq 09	V1294.004 Seq 04	V1046.004 Seq 04	V1294.005 Seq 07			Plug weld leak occurred on a unit -- Concern over these welds leaking either Gox/Helium/Hot gas into boattail -- therefore all external plug welds on the housing are checked	Aft Compartment overpressurization or fire
V41AX0.020-A	E1 LO2 FEED (JOINT D1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Ensure joint integrity of LPOTP to pump inlet ducting after engine is installed	Aft Compartment overpressurization or fire
V41AX0.020-B	E1 LH2 FEED (JOINT F1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Verify pump inlet joint integrity after installing the LPFTP	Aft Compartment overpressurization or fire
V41AX0.020-C	E1 GH2 PRESS (JOINT F9.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 09		V1046.004 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-D	E1 LO2 BLEED (JOINT O15) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 07		V1046.003 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-E	E1 LH2 BLEED (JOINT F4.3) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 05		V1046.002 Seq 04			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-F	E1 HELIUM (JOINT P1) I/F LK CK	ER, PR, OMDP	Lines/Ducts	V1011.05 Seq 12		V1046.001 Seq 05	V1046.006 Seq 04		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-G	E1 GN2 (JOINT N1) I/F LK CK	ER, PR, OMDP	Lines/Ducts			V1149 Seq 15	V1046.008 Seq 03		DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-H	E1 HYD - PRESS (JOINT H1) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E16	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.020-I	E1 HYD - RETURN (JOINT H17) I/F LK CK	ER, PR, OMDP	Lines/Ducts		V5E17 Seq 09		V5E16	V9002.06 Seq 05	DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41AX0.050-A	E1 GO2 ORB/SSME INTERFACE FLANGE LEAK CHECK	A, ER	Lines/Ducts			V1046.005 Seq 05			DUCTS	Joint Integrity Post Engine Installation	Aft Compartment overpressurization or fire
V41BL0.031	SSME ENCAPSULATION POWER HD LEAK CK	EKSC & ER	Powerhead		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.032	SSME ENCAPSULATION FUEL SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.033	SSME ENCAPSULATION OXID SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BL0.034	SSME ENCAPSULATION HOT GAS SYS ISO TEST	F	System		V1294.007 Seq 04				ENGINE	System leak integrity check for launch - Mat.'l or Weld Thru-Crack; Seal not Seated -> Crit. 1	Aft Compartment overpressurization or fire
V41BP0.010-A	E1 GO2/GCV EXT LK CK & ORIFICE VERIF	EKSC, I	Valves	V1011.04 Seq 07	V1294.002 Seq 17	V1046.005 Seq 05	V1294.006 Seq 05			Establishes leak test of all gaseous oxygen system joints from the AFV to the orbiter interface on an each flight basis.	Aft Compartment overpressurization or fire
V41AQ0.010-A	E1 SENSOR CHECKOUT	EKSC, ER, LRU	Instrumentation	V1011.06 Seq 02	V1294.002 Seq 08	V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Planned Preflight Checkout	Erroneous shutdown, loss of vehicle
V41AU0.013-A	E1 OPERATIONAL INSTRUMENTATION VERIFICATION	A, ER	Instrumentation			V1046.001 Seq 04		V9001VL4 Seq 02	AVIONICS	Instrumentation integrity checkout	Erroneous shutdown, loss of vehicle
V41BU0.250-A	E1 SENSOR IR VERIFICATIONS	EKSC, LRU	Instrumentation	V1011.02 Seq 07						Functional check of each turbine discharge temp	Erroneous shutdown, loss of vehicle
V41BP0.020-A	E1 HEX COIL LEAK TEST	A, EKSC, PLRU	HEX	V1011.04 Seq 02	V1294.003 Seq 03	V1046.005 Seq 06			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BP0.030	SSME HEX COIL PROOF TEST	PLRU	HEX	V1011.04 Seq 03	V1294.003 Seq 04	V1046.005 Seq 07			HEX	Mat.'l (stringer) or Weld Thru-Crack; HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.086	HEX EDDY CURRENT INSPECTIONS (TIME & CYCLE)	TC	HEX	V1011.02 Seq 11					HEX	Thin Walls from Bracket Wear, Manuf -> Thru-Crack, HG Leakage to Tank, Crit. 1	Fire, Uncontained engine failure
V41BU0.115	HEAT EXCHANGER INSPECTION	TC	HEX		V5E02 Seq 14				HEX	Visible Impact Damage, Bracket Wear -> Thru-Crack -> HG to Tank, Crit 1; Turn. Vane Cracks -> Loss of Vane Impact MI Post -> Damage or Crit 1.	Fire, Uncontained engine failure
V41BU0.125	HEX VISUAL INSPECTION	PLRU	HEX		V5E02 Seq 12				HEX	HPOTP Installation Impact Hole -> HG to Tank; Crit. 1	Fire, Uncontained engine failure
V41BU0.075-A	E1 HPFTP INTERNAL INSPECTION	PKSC	HPFTP	V1011.02 Seq 08					TURBOPUMPS	Verify no inlet or discharge sheet metal cracking; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking. (All inspections completed with turbopump ins	Fire, Uncontained engine failure
V41BU0.070	HPFTP FIRST STAGE BLADE 22X INSPECTION	TC, DCE	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no blade cracking due to previous occurrences of air oil cracking	Fire, Uncontained engine failure
V41BU0.080	HPFTP TURBINE INSPECTION (TIME & CYCLE)	PKSC	HPFTP		V5E06 Seq 14				TURBOPUMPS	Verify no inlet or discharge sheet metal cracking including weld 450 and the turning vanes; no nozzle cracking or erosion; no blade cracking, platform cracking, or erosion; no fishmouth seal cracking or missing pieces; no bellows shield cracking via dy	Fire, Uncontained engine failure
V41BU0.087	HPFTP BELLOWS HEIGHT VERIF	PLRU	HPFTP		V5E06 OSSU 2				TURBOPUMPS	Verify bellows height adequate to provide proper preload on the bellows at installation. Incorporated as a result of a previous failure of the bellows.	Fire, Uncontained engine failure

*Based upon three-engine set

Table 10. OMEF SSME planned operations.*

OMRSD NUMBER	OMRSD DESCRIPTION (V41 FILE III DATED 9/15/95)	OMRSD EFFECTIVITY	Component	OPF OMI's	ENGINE SHOP OMI's	VAB/PAD OMI's	OTHER OMI's	RT OMI's	SUBSYSTEM CODE	OMRSD RATIONALE/ROOT CAUSES	Root Cause Categories
V41CB0.050-A	E1 HPFTP TURBINE BEARING DRYING	EKSC	HPFTP	V1011.01 Seq 03		V9018.002 Seq 04	V1038VL2 Seq 07		TURBOPUMPS	Ensure all moisture is removed from the bearing area after a test/flight	Fire, Uncontained engine failure
V41BQ0.110-A	E1 HPOTP PRIMARY OXID SEAL LEAK TEST	PKSC, NRAT	HPOTP	V1011.06 Seq 07	V1294.008 Seq 03	V1046.003 Seq 07				Checks for excessive leakage of LOX/GOX from the HPOTP seal -- Protects against excessive flow overcoming the barrier seal and from having excessive tankage losses during the chill down of the engine. Kel-F seal does wear during operation.	Fire, Uncontained engine failure
V41BS0.040-A	E1 HPOTP TORQUE TEST	EKSC, RI, PLRU, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Done to ensure rotor is not bound up prior to start -- concern over contamination if high and also start characteristics if rotor is slow to spin -- contamination has been found around the rotor but only once enough to effect start (rusted P/E bearings)	Fire, Uncontained engine failure
V41BS0.042	HPOTP INVESTIGATIVE TORQUE	F, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Done only to run in a high torque pump to bring the torque value below spec requirements	Fire, Uncontained engine failure
V41BS0.043-A	E1 HPOTP IMPELLER LOCK VERIF	PKSC, PLRU, NRAT	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Locking feature was overcome on a HPOTP PBP impeller bolt lock during torque tests/spinning of pump for inspections. Recurrence control is to only turn the pump in the bolt tightening direction during inspections and to check the locking feature after al	Fire, Uncontained engine failure
V41BS0.045	HPOTP MICROSHAFT TRAVEL	PKSC, NRAT	HPOTP	V1011.03 Seq 06					TURBOPUMPS	Turbine bearings have worn very quickly in past -- this measurement is to ensure that the bearings are still capable of 1 flight prior to a launch.	Fire, Uncontained engine failure
V41BQ0.110-A	E1 ATD BLOCK I/II HPOTP PRIMARY OXID SEAL LEAK TEST	PKSC, NRAT	HPOTP	V1011.06 Seq 07	V1294.008 Seq 03	V1046.003 Seq 07				This leak check was never performed during HPOTP/AT certification. The data obtained is erratic and is probably indicative of only gross seal imperfections (which would most likely be detected through torque checks). It is currently an OMRSD requirement	Fire, Uncontained engine failure
V41BU0.065-A	E1 HPOTP INTERNAL INSPECTION	PKSC, NRAT	HPOTP	V1011.02 Seq 08					TURBOPUMPS	Visual inspections of turbine hardware (sheetmetal/ nozzles/ blades) due to cracking and erosion seen in the past, of the main pump inlet / inducer due to cavitation damage and contamination found in the past, of the PBP impeller inlet due to locking feat	Fire, Uncontained engine failure
V41BU0.066-A	*E1 HPOTP TIP SEAL RETAINER INSPECTION*	*PKSC, NRAT*	*HPOTP*						TURBOPUMPS	Verifies 1st stage tip seal retainer screws have not rotated. Could lead to blade failure.	Fire, Uncontained engine failure
V41BU0.390-A	E1 LPFD OVALITY CHECK	F	Lines/Ducts	V1011.02 Seq 10			V9018.002 Seq 10		DUCTS	Contingency test performed only when the LPFD helium barrier system has been damaged. Object is to detect potential duct collapse or separation from the layer of insulation by measuring the roundness of the duct.	Fire, Uncontained engine failure
V41BU0.400	PERFORM LPFD XRAY INSPECTION	F	Lines/Ducts	TBD					DUCTS	Contingency reqmt preformed only when the ovality check indicates that some damage or collapse has occurred in the LPFD. The cross section is X-rayed in an attempt to verify presence of damage.	Fire, Uncontained engine failure
V41BS0.050	HPOTP/AT TORQUE TEST	EKSC, RI, PLRU	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.040-A	Fire, Uncontained engine failure
V41BS0.055	HPOTP/AT INVESTIGATIVE TORQUE	F	HPOTP	V1011.03 Seq 06	V5E02 Seq 25				TURBOPUMPS	Replaced by V41BS0.042	Fire, Uncontained engine failure
V41BU0.405	SSME LPFD TRIPOD LEGS INSPECTION	DCE	Lines/Ducts	TBD					DUCTS	Performed to insure LPFD structural integrity. *Inspection is performed if post flight data evaluation reveals HPFTP unacceptable synchronous frequencies.*	Fire, Uncontained engine failure
V41BU0.065-A	E1 ATD BLOCK I/II HPOTP INTERNAL INSPECTION	PKSC, NRAT	HPOTP	V1011.02 Seq 08					TURBOPUMPS	No HPOTP/AT internal inspections were made during certification. Inspections of the turbine, mainstage pump and PBP inlets, and all three bearings have been added only because the inspections aren't time consuming and because some "human error" could be	
V41BS0.010-A	E1 LPFTP TORQUE TEST	A, RI, PSI, ER, PLRU	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Verify rotor is free to rotate prior to testing	Fire, Uncontained engine failure
V41BU0.127	HPOTP/AT PBP TIEBOLT LOCK INSPECTION	F	HPOTP	V1011.03					TURBOPUMPS		Fire, Uncontained engine failure
V41BU0.128	HPOTP/AT CONTAMINATION INSPECTION	A, PKSC	HPOTP	V1011.07 Seq 22					TURBOPUMPS		Fire, Uncontained engine failure
V41CB0.085	SSME HPOTP/AT TURBINE BEARING DRYING	PKSC	HPOTP	V1011.01 Seq 03	V1294.008 Seq 04	V9018.002 Seq 04			TURBOPUMPS	Verify all moisture is removed from the bearing area after a test/flight.	Fire, Uncontained engine failure
V41BS0.011	LPFTP INVESTIGATIVE TORQUE	F	LPFTP	V1011.03 Seq 04					TURBOPUMPS	Investigative torque check if the specification limits are exceeded - torque check failure generally lift-off seal binding or laby seal - copper plating rub	Fire, Uncontained engine failure

* OMEF data reflects single-engine processing. For complete model, processing timelines must consider number of engines per vehicle.

Table 11. OPF post-SSME installation planned operations.*

Process	Sub-Process	Process Description	Duration (PD)	Tech MHrs	QC MHrs	Engr MHrs	Total MHrs
V5005		SSME Installation Preps	**24.00**	31	37	13	81
	V5057	Stiffarm Bracket & TVCA Support Installation	4.00	8	4	0	12
V5087		Engine 1 Installation Handling GSE Operations	**5.00**	19	4	11.5	34.5
V5005		Engine 1 Installation Operations	**7.00**	42	12	25	79
V5087		Engine 3 Installation Handling GSE Operations	**5.00**	19	4	11.5	34.5
V5005		Engine 3 Installation Operations	**7.00**	42	12	25	79
V5087		Engine 2 Installation Handling GSE Operations	**5.00**	19	4	11.5	34.5
V5005		Engine 2 Installation Operations	**7.00**	42	12	25	79
V5005		Post-SSME Installation Operations	**32.00**	88	56	0	144
	V9002.06	SSME Hydraulic QD Demate Operations	4.00	4	4	0	8
V1011.03 Run 3		LPOTP Post-Installation Torque Check	**12.00**	12	12	12	36
V1011.03 Run 3		LPFTP Post-Installation Torque Check	**6.00**	6	6	6	18
V1011.05		Orbiter/SSME Interface Verification	**72.25**	59	50.5	24.5	134
	V1011.04	SSME GOX System Leak Checks	14.00	20	12	10.5	42.5
	V9001VL4	Orbiter/SSME Electrical Interface Verification	8.00	0	8	8	16
V41/G41/V80 JC's		Heat Shield Installation Operations	**126.00**	704	352	0	1056
V1063		SSME Gimbal Clearance Checks	**17.50**	34.5	31.5	42	108
	V5057	TVCA Pinning Operations	4.00	8	4	0	12
	V9002.06	SSME Hydraulic QD Leak Checks	1.00	1	1	1	3
V41-20003		SSME OPF Roll-Out Inspections	**19.00**	11	11	6	28
	V5057	Thrust Chamber & Miscellaneous Cover Installation	4.00	4	4	0	8
	V5057	TVCA Midstroke Lock Installation	4.00	8	4	0	12

* Based upon three-engine set

Table 12. SSME VAB/pad processing planned operations.*

Process	Sub-Process	Process Description	Duration (PD)	Tech MHrs	QC MHrs	Engr MHrs	Total MHrs
S0008		Shuttle Interface Testing	**38.00**	0	0	0	0
	V1149	GN2 Interface Leak Check & Trickle Purge Ops	30.00	9.75	11.25	12.75	33.75
	V5057	Thrust Chamber Cover Removal & Installation	1.00	1	0	0	1
S0009		Launch Pad Validation	**44.00**	4	4	4	12
V1046.001		SSME Flight Readiness Test & Checkout	**21.00**	2	9	12	23
	V9002.06	Preps for SSME Hydraulic Operations	3.00	2	0	1	3
	V5057	TVCA Midstroke Lock Removal	4.00	8	4	0	12
	V9001VL4	SSME Controller Power-Up Operations	2.00	0	6	8	14
V1046.002		LH2 System Ball Seal Leak Check	**3.00**	6	5.5	4	15.5
	V9002.06	SSME/TVC Actuator Hydraulic Power Dwon Securing Rqmts	2.00	1	0	1	2
	V5057	TVCA Midstroke Lock Installation	1.50	3	1.5	0	4.5
V1046.003		LO2 System Ball Seal Leak Check	**1.00**	1	2	2	5
V9002.06		SSME Hydraulic QD X-Rays	**4.00**	4	4	0	8
V1202		Orbiter Aft Helium Signature Test	**34.00**	7	5.5	5.5	18
S1005		LO2 Propellant System Conditioning	**6.50**	3.75	0	0	3.75
	V5057	SSME Chamber Cover Removal/Drain Line Adapter Installation	2.00	2	2	0	4
S1006		LH2 Propellant System Conditioning	**9.50**	0	0	0	0
	V9001VL4	SSME Controller Power-Up Operations	**2.00**	0	2	4	6
S1287		Orbiter Aft Closeout for Flight	**100.00**	48	42	66	156
	V9018.001	MPS & SSME Initial Preps for Propellant Loading	8.00	8	8	8	24
	V5057	TVCA Midstroke Lock Removal	34.00	68	34	0	102
	V5057	SSME Protective Cover Removal	8.00	8	0	0	8
S0007		Shuttle Launch Countdown Operations	**181.37**	12	83	153	248
	V9018.001	MPS & SSME Final Preps for Propellant Loading	8.00	3	3	0.25	6.25
	S1003	LO2 Propellant System Loading Operations	24.87	0	24.87	49.75	74.62
	S1004	LH2 Propellant System Loading Operations	24.87	0	0	0	0

* Based upon three-engine set

Table 13. OPF rollin to SSME removal tasks.

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**OPF Roll-In to SSME Removal**	**271.9h**	**1305h**		
2	Orbiter at OPF Door/S0028	0h	0h		
3	**HPFTP Bearing Drying Operations/V1011.01**	**24.75h**	**98.25h**		
4	Extend Platforms 10S and 19S/V1011.01/V35xx	0.5h	1.5h		Tech[2],QC
5	Remove SSME Environmental Closures	0.5h	0.5h	4	Tech
6	Mate Bearing Drying Flexhoses	2h	4h	5	Tech,QC
7	Retract Platforms 10S and 19S/V1011.01/V35xx	0.5h	1.5h	6	Tech[2],QC
8	MCC Acoustic Cavity Inspections/Install Throat Plugs	4h	8h		Tech,QC
9	Mate Bearing Drying Exhaust Duct	4h	12h	8	Tech[2],QC
10	Install SSME Bellows and Miscellaneous Covers/V5057	3h	6h	19	Tech,QC
11	Establish Safety Clears	0.25h	1.25h	9	Tech[2],QC,Safety,Engr
12	HPFTP Bearing Drying Purge Initiated	0h	0h	11	
13	Perform SSME Bearing Drying	8.5h	42.5h	12	Tech[2],QC,Safety,Engr
14	Perform Filter Inspection and Cleaning	2.5h	5h	13	Tech,QC
15	Disassemble Test Setup and Remove Throat Plugs	8h	16h	13	Tech[2]
16	**Establish Aft Access**	**5h**	**0h**		
17	Install Entry Level Platforms/V35-00001	2h	0h		
18	Install Floor Level Platforms/V35-00001	3h	0h	17	
19	Aft Access Available	0h	0h	16,18	
20	OPF Bay Open for Normal Work	0h	0h	19	
21	Orbiter Initial Power-Up	0h	0h		
22	**Helium Baggie Leak Check/V1263**	**12.5h**	**43.75h**	**20**	
23	Install TVCA Midstroke Locks/V5057	3h	9h	20	Tech[2],QC
24	Verify Throat Plugs Removed and MPS/SSME Helium Tanks Pressurized	0.25h	0.75h		QC,Engr[2]
25	SSME Controller Initial Power-Up/V9001VL4	4h	8h		Engr,QC
26	Establish Safety Clears for Helium System Activation	0.25h	1.5h	24,25	Tech,QC[2],Safety,Engr[2]
27	Perform SSME 750 psi Helium System Activation	0.75h	4.5h	26	Tech,QC[2],Safety,Engr[2]
28	Perform LPFD Helium Barrier Inspection per V41CB0.012	3h	15h	27	Tech,QC[2],Engr[2]
29	Perform SSME 750 psi Helium System Securing	0.5h	1h	28	QC,Engr
30	Install LPFD Purge Blanking Plate Adapter/Remove Baggies	4h	4h	29	Tech
31	**SSME Drying Operations/V1011.01**	**45.5h**	**173h**	**22**	
32	Mate GN2 Purge QD to Orbiter @ PD14	4h	12h		Tech[2],QC
33	Install Heise Gages @ TP24 and TP25	1h	2h	32	Tech,QC
34	Assemble/Mate 15 Purge Hose/Filter Assemblies	8h	16h	20	Tech,QC
35	Remove Joint F6.10/F6.11 Plugs/Boroscope for Moisture	2h	4h		Tech,QC
36	Install Joint F6.10/F6.11/G4.3/N16 Adapters	1h	2h	35	Tech,QC
37	Loosen Bolts @ Joint N14 Plate	0.5h	1h	36	Tech,QC
38	Install LPFTP Anti-Rotation Tool	0.75h	1.5h	37	Tech,QC
39	Install Shim @ Joint D35.2/N11.2 Transducer Stack	0.75h	1.5h	38	Tech,QC
40	Install Shim @ MCC Pc Transducer/Inspect for Moisture	3h	6h	39	Tech,QC

Table 13. OPF rollin to SSME removal tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
41	Install Throat Plug/Monitor Gage/Drain Line Adapters	3h	6h	34	Tech,QC
42	Mate Flexhoses @ HPOTP Turbine Primary Drain Adapters	1h	2h	41	Tech,QC
43	Mate Flexhoses @ Joints F6.10/F6.11/G4.3/N16 Adapters	2h	4h	42	Tech,QC
44	Mate Throat Plug/HPOTP Ox Seal/Turb Sec Seal to OPF Vent System	3h	6h	41	Tech,QC
45	Perform Engineering/Safety Walkdown of Drying Setup	2h	6h	44	Safety,Engr[2]
46	V1011.01 Call to Station	1h	7h	45	Tech[3],QC,Engr[3]
47	Configure/Prep GSE Panels	1h	7h	46	Tech[3],QC,Engr[3]
48	Establish Safety Clears for SSME Pneumatics Activation	0.25h	2h	46	Tech[3],QC,Safety,Engr[3]
49	Activate SSME Pneumatics/Verify SSME Valve Positions	0.5h	3.5h	48,47	Tech[3],QC,Engr[3]
50	Apply MPS LO2 and LH2 System Blanket Pressure	1h	7h	49	Tech[3],QC,Engr[3]
51	Establish Safety Clear of Level 10/19 Platforms	0.25h	2h	50	Tech[3],QC,Safety,Engr[3]
52	Initiate HPOTP Turb Pri Seal/Ox System Drying Purge per V41CB0.080	0.75h	5.25h	51	Tech[3],QC,Engr[3]
53	HPOTP Turb Pri Seal/Ox System Drying Purge Active Monitoring	2h	6h	52	Tech,QC,Engr
54	Secure HPOTP Turb Pri Seal/Ox System Drying Purge	0.25h	1.75h	53	Tech[3],QC,Engr[3]
55	Switch Flexhose from Turbine Primary to Turbine Secondary Adapters	0.5h	3.5h	54	Tech[3],QC,Engr[3]
56	Mate Turbine Secondary Seal to OPF Vent System	0.5h	3.5h	55	Tech[3],QC,Engr[3]
57	Initiate MCC/FPB/Nozzle Drying Purge per V41CB0.080	0.75h	5.25h	56	Tech[3],QC,Engr[3]
58	MCC/FPB/Nozzle Drying Purge Active Monitoring	2h	6h	57	Tech,QC,Engr
59	Secure MCC/FPB/Nozzle Drying Purge	0.25h	1.75h	58	Tech[3],QC,Engr[3]
60	Perform HPOTP Dryness Verification per V41CB0.081	2h	6h	59	Tech,QC,Engr
61	Demate Flexhoses @ Joints F6.10/F6.11/G4.3/N16 Adapters	0.5h	1h	60	Tech,QC
62	Torque Joint N14 Plate	0.25h	0.5h	61	Tech,QC
63	Remove Shims/Torque MCC Pc Transducer and D35.2/N11.2 Stack	1h	2h	62	Tech,QC
64	Tee-Connect Turb Pri to Turb Sec/Connect to Lo Press Manifold	1h	2h	63	Tech,QC
65	Perform MCC/FPB/Nozzle Dryness Verification per V41CB0.081	2h	6h	64	Tech,QC,Engr
66	Disassemble Test Setup/Route Filters for Bubble Point Analysis	12h	24h	65	Tech,QC
67	**SSME Inspections and Checkouts in OPF/V1011.02**	**44h**	**140h**	**31**	
68	Perform Megger GR1864 Setup	8h	8h		Tech
69	Perform E1 External Inspections (excluding Nozzle) per V41BU0.030	4h	8h	68	QC,Engr
70	Remove E1 Internal Inspection Port Hardware	4h	4h	69	Tech
71	Perform E1 Quick Look Internal Inspections	8h	16h	70	QC,Engr
72	Secure E1 Inspection Port Hardware	4h	8h	71	Tech,QC
73	Perform E2 External Inspections (excluding Nozzle) per V41BU0.030	4h	8h	68,69	QC,Engr
74	Remove E2 Internal Inspection Port Hardware	4h	4h	73	Tech
75	Perform E2 Quick Look Internal Inspections	8h	16h	74,71	QC,Engr
76	Secure E2 Inspection Port Hardware	4h	8h	75	Tech,QC
77	Perform E3 External Inspections (excluding Nozzle) per V41BU0.030	4h	8h	68,69,70	QC,Engr
78	Remove E3 Internal Inspection Port Hardware	4h	4h	77	Tech
79	Perform E3 Quick Look Internal Inspections	8h	16h	78,75	QC,Engr
80	Secure E3 Inspection Port Hardware	4h	8h	79	Tech,QC

Table 13. OPF rollin to SSME removal tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
81	Perform HPOTP Strain Gauge Bonding Inspections per V41AU0.090	4h	12h	68	Tech,QC,Engr
82	Perform TDT Sensors Resistance Measurements per V41BU0.250	4h	12h	81	Tech,QC,Engr
83	**SSME Post-Flight Low Pressure Pump Torque Checks**	**18h**	**54h**	**67**	
84	Engine 1,2,3 LPFTP Torque Checks/V1011.03 Run 1	6h	18h		Tech,QC,Engr
85	Engine 1,2,3 LPOTP Torque and Travel Checks/V1011.03 Run 1	12h	36h	84	Tech,QC,Engr
86	**SSME Heat Shield Removal Operations/V41-40021,22,23,24,25,26**	**58h**	**276h**	**67**	
87	Remove DMHS Carrier Panels/V80-05907,33,35	40h	120h	23	Tech[2],QC
88	Remove DMHS Splice/Perimeter Hardware/V41-40021,22,23	4h	12h		Tech[2],QC
89	Install E1 Lower Splice Platform	0h	0h		
90	Position Davit Crane to 19W Platform	2h	6h		Tech[2],QC
91	Begin Heat Shield Removal Operations	0h	0h	87,88,89,90	
92	Remove E1 Left Hand DMHS/V41-40021	1h	10h	91	Tech[6],QC,Safety,Engr[2]
93	Remove E1 Lower Splice Platform	0h	0h	92	
94	Remove E2 Left Hand DMHS/V41-40022	1h	10h	93	Tech[6],QC,Safety,Engr[2]
95	Remove E2 Right Hand DMHS/V41-40022	1h	10h	94	Tech[6],QC,Safety,Engr[2]
96	Remove E2 Right Hand EMHS/V41-40025	1h	10h	95	Tech[6],QC,Safety,Engr[2]
97	Remove E2 Left Hand EMHS/V41-40025	1h	10h	96	Tech[6],QC,Safety,Engr[2]
98	Reposition Davit Crane to 19E Platform	2h	6h	97	Tech[2],QC
99	Remove E3 Right Hand DMHS/V41-40023	1h	10h	98	Tech[6],QC,Safety,Engr[2]
100	Remove E3 Left Hand DMHS/V41-40023	1h	10h	99	Tech[6],QC,Safety,Engr[2]
101	Remove E3 Left Hand EMHS/V41-40026	1h	10h	100	Tech[6],QC,Safety,Engr[2]
102	Remove E3 Right Hand EMHS/V41-40026	1h	10h	101	Tech[6],QC,Safety,Engr[2]
103	Install E2/E3 Lower Splice Platform	0h	0h	102	
104	Remove E1 Right Hand DMHS/V41-40021	1h	10h	103	Tech[6],QC,Safety,Engr[2]
105	Remove E1 Right Hand EMHSV41-40024	1h	10h	104	Tech[6],QC,Safety,Engr[2]
106	Reposition Davit Crane to 19W Platform	2h	6h	105	Tech[2],QC
107	Remove E1 Left Hand EMHS/V41-40024	1h	10h	106	Tech[6],QC,Safety,Engr[2]
108	Remove E2/E3 Lower Splice Platform	0h	0h	107	
109	Stow Davit Crane	2h	6h	108	Tech[2],QC
110	**SSME Removal Operations**	**64h**	**520h**	**109,86**	
111	**Engine Removal Preps**	**12h**	**129h**		
112	**Demate SSME Hydraulic QD's/V9002.06**	**7h**	**29h**	**86**	
113	Perform Orbiter Hydraulic System Venting	4h	20h		Tech,Safety,Engr[3]
114	Demate E1 Hydraulic Return QD @ Joint H17	0.25h	0.75h	113	Tech,QC,Engr
115	Perform E1 Hydraulic Return QD Demate Inspection per V58AG0.123-D	0.25h	0.75h	114	Tech,QC,Engr
116	Demate E1 Hydraulic Supply QD @ Joint H1	0.25h	0.75h	115	Tech,QC,Engr
117	Perform E1 Hydraulic Supply QD Demate Inspection per V58AG0.123-A	0.25h	0.75h	116	Tech,QC,Engr
118	Demate E2 Hydraulic Return QD @ Joint H17	0.25h	0.75h	117	Tech,QC,Engr
119	Perform E2 Hydraulic Return QD Demate Inspection per V58AG0.123-E	0.25h	0.75h	118	Tech,QC,Engr
120	Demate E2 Hydraulic Supply QD @ Joint H1	0.25h	0.75h	119	Tech,QC,Engr

Table 13. OPF rollin to SSME removal tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
121	Perform E2 Hydraulic Supply QD Demate Inspection per V58AG0.123-B	0.25h	0.75h	120	Tech,QC,Engr
122	Demate E3 Hydraulic Return QD @ Joint H17	0.25h	0.75h	121	Tech,QC,Engr
123	Perform E3 Hydraulic Return QD Demate Inspection per V58AG0.123-F	0.25h	0.75h	122	Tech,QC,Engr
124	Demate E3 Hydraulic Supply QD @ Joint H1	0.25h	0.75h	123	Tech,QC,Engr
125	Perform E3 Hydraulic Supply QD Demate Inspection per V58AG0.123-C	0.25h	0.75h	124	Tech,QC,Engr
126	Orbiter Interface Hardware Verification (Aft)	4h	8h		Tech,QC
127	LH2 Foam Removal (Aft)	8h	16h		Tech,QC
128	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h		
129	PVD Controller Duct Removal (Aft)	6h	18h	128	Tech[2],QC
130	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	129	
131	Calibrate Force Gages (Roc)	8h	16h		Tech,QC
132	Orbiter Preps (Roc)	4h	8h		Tech,QC
133	Electrical Interface Demates (Aft)	4h	8h		Tech,QC
134	Engine Preps (Roc)	4h	8h		Tech,QC
135	Orbiter Helium Handvalve Installation (Aft)	2h	4h	133	Tech,QC
136	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	135	
137	Demate Fluid System Interfaces (Roc)	2h	8h	136,131,127	Tech[3],QC
138	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	137	
139	Install Interface Support Panel (Roc)	2h	6h	138	Tech[2],QC
140	**Engine 2 Removal GSE Handling Operations (Roc)/V5087**	**8h**	**36h**	**111**	
141	Verify Lift Truck, Carrier and Rail Table Proofload Validations	0.5h	1h		Tech,QC
142	Install Lift Spoon	0.5h	1h	141	Tech,QC
143	Mount Rail Table on Lift Truck	1h	4h	142	Tech[2],QC,Engr
144	Mount Carrier on Rail Table/Lift Truck	2h	8h	143	Tech[2],QC,Engr
145	Perform Dummy Load Brake Test without Engine	3h	21h	144	Tech[4],QC,Safety,Engr
146	Transport Lift Truck/Hyster to OPF for Engine 2 Removal	1h	1h	145	Engr
147	**Engine 2 Removal Operations**	**8h**	**75h**	**140**	
148	Position Installer for Engine 2 Removal	2h	10h	111	Tech[2],QC,Engr[2]
149	Mate Installer to Engine 2	2h	30h	148	Tech[7],QC[2],Safety[2],Engr[4]
150	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	149	
151	Demate Engine from Orbiter	2h	30h	150	Tech[7],QC[2],Safety[2],Engr[4]
152	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	151	
153	Transport Engine 2 to VAB	1h	1h	152	Engr
154	Install Orbiter Engine 2 Interface Covers	2h	4h	151	Tech,QC
155	**Rotate Engine 2 to Horizontal Handler/V5087**	**2h**	**14h**	**153**	
156	Install Rotating Sling and Unload Carrier/Engine	0.5h	3.5h		Tech[4],QC,Safety,Engr
157	Mount Carrier on Skid	0.5h	3.5h	156	Tech[4],QC,Safety,Engr
158	Transfer Engine 2 to Horizontal Handler	1h	7h	157	Tech[4],QC,Safety,Engr
159	**Engine 3 Removal GSE Handling Operations (Roc)/V5087**	**6h**	**30h**	**158**	
160	Mount Carrier on Rail Table/Lift Truck	2h	8h		Tech[2],QC,Engr

Table 13. OPF rollin to SSME removal tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
161	Perform Dummy Load Brake Test without Engine	3h	21h	160	Tech[4],QC,Safety,Engr
162	Transport Hyster to OPF for Engine 3 Removal	1h	1h	161	Engr
163	**Engine 3 Removal Operations**	**8h**	**75h**	**147**	
164	Position Installer for Engine 3 Removal	2h	10h	162	Tech[2],QC,Engr[2]
165	Mate Installer to Engine 3	2h	30h	164	Tech[7],QC[2],Safety[2],Engr[4]
166	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	165	
167	Demate Engine from Orbiter	2h	30h	166	Tech[7],QC[2],Safety[2],Engr[4]
168	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	167	
169	Transport Engine 3 to VAB	1h	1h	168	Engr
170	Install Engine 3 Interface Covers	2h	4h	167	Tech,QC
171	**Rotate Engine 3 to Horizontal Handler/V5087**	**2h**	**14h**	**169**	
172	Install Rotating Sling and Unload Carrier/Engine	0.5h	3.5h		Tech[4],QC,Safety,Engr
173	Mount Carrier on Skid	0.5h	3.5h	172	Tech[4],QC,Safety,Engr
174	Transfer Engine 3 to Horizontal Handler	1h	7h	173	Tech[4],QC,Safety,Engr
175	**Engine 1 Removal GSE Handling Operations (Roc)/V5087**	**6h**	**30h**	**174**	
176	Mount Carrier on Rail Table/Lift Truck	2h	8h		Tech[2],QC,Engr
177	Perform Dummy Load Brake Test without Engine	3h	21h	176	Tech[4],QC,Safety,Engr
178	Transport Hyster to OPF for Engine 1 Removal	1h	1h	177	Engr
179	**Engine 1 Removal Operations**	**8h**	**75h**		
180	Position Installer for Engine 1 Removal	2h	10h	178	Tech[2],QC,Engr[2]
181	Mate Installer to Engine 1	2h	30h	180	Tech[7],QC[2],Safety[2],Engr[4]
182	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	181	
183	Demate Engine from Orbiter	2h	30h	182	Tech[7],QC[2],Safety[2],Engr[4]
184	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	183	
185	Transport Engine 1 to VAB	1h	1h	184	Engr
186	Install Engine 1 Interface Covers	2h	4h	183	Tech,QC
187	**Rotate Engine 1 to Horizontal Handler/V5087**	**6h**	**30h**	**185**	
188	Install Rotating Sling and Unload Carrier/Engine	0.5h	3.5h		Tech[4],QC,Safety,Engr
189	Mount Carrier on Skid	0.5h	3.5h	188	Tech[4],QC,Safety,Engr
190	Transfer Engine 1 to Horizontal Handler	1h	7h	189	Tech[4],QC,Safety,Engr
191	Stow SSME Handling GSE/V5087	4h	16h	190	Tech[2],QC,Engr
192	**Post-Engine Removal Operations**	**6h**	**12h**	**179**	
193	Interface Hardware Inspections	4h	8h	186	Tech,QC
194	Gimbal Bolt/Nut Torque Cycle	2h	4h	186,193	Tech,QC
195	SSME Removal Operations Complete/OK to Proceed with MPS Operations	0h	0h	193,194	

Table 14. Engine shop turnaround tasks.*

ID	Task Name	Duration	Work	Predecessors
1	**Engine Shop Turnaround!**	**252.75h**	**1330h**	
2	Nozzle Tube Leak Checks/V1294.005!	3h	6.5h	
3	SSME Inspections in Engine Shop (continued)/V1011.02!	252.75h	135.75h	
4	Vertical Stand Available	0h	0h	
5	Transfer Engine to Vertical Stand/V5087!	3h	32.5h	4
6	HPOTP Post-Flight Torque Check/V1011.03 Run 1!	3.75h	11.25h	5
7	HPFTP Post-Flight Torque Check/V1011.03 Run 1!	3.5h	10.5h	6
8	HEX Coil Post-Flight Leak Check/V1294.003!	8h	9h	7
9	MCC Liner Cavity Decay Check/V1294.003!	3.25h	8.25h	8
10	HPOTP Removal and Replacement/V5E02!	97.75h	435h	6,8,9
11	HPFTP Removal and Replacement/V5E06!	101.25h	375.75h	7,8,9
12	Fuel and Hot Gas System Internal and External Leak Checks/V1294.005!	8.75h	21.25h	11
13	LOX System Internal and External Leak Checks/V1294.006!	8.5h	20.25h	12
14	SSME Flight Readiness Test and Checkout/V1294.002!	50.25h	124h	13
15	GOX System Internal and External Leak Checks/V1294.002!	2.75h	12h	14
16	Rotate Engine to Horizontal Handler/V5087!	4.25h	38.5h	15
17	Fuel and LOX Ball Seal Leak Checks/V1294.007!	3.5h	7.5h	16
18	Move Engine to VAB Transfer Aisle!	0h	0h	17
19	Engine Encapsulation Leak Check/V1294.007!	23.5h	68.5h	18
20	Move Engine to Engine Shop!	0h	0h	19
21	LPFTP Torque Check!	1.25h	3.75h	20
22	LPOTP Torque and Shaft Travel!	3.25h	9.75h	21

* Lowest level of detail not shown but available for all subtasks. See table 17 for examples.

Table 15. Engine installation to OPF rollout tasks.

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**Engine Installation to OPF Roll-Out!**	**40.09d**	**2207h**		
2	**Engine Installation Operations/V5005!**	**11.5d**	**733.5h**		
3	**Engine Installation Preps!**	**3d**	**241h**		
4	**Installation Preps in OPF!**	**3d**	**93h**		
5	Remove/Inspect Orbiter Interface Covers (Aft)!	24h	0h		
6	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h		
7	Remove PVD Controller Duct	2h	4h	6	Tech,QC
8	Photograph Fluid Interface Panels per V41DC0.030	1h	2h	7	QC,Engr
9	Remove Test Plate/Inspect Orbiter LO2 Feedlines per V41BU0.360	4h	12h	8	Tech,QC,Engr
10	Remove Test Plate/Inspect Orbiter LH2 Feedlines per V41BU0.360	4h	12h	9	Tech,QC,Engr
11	Inspect SSME Controller Purge Line	1h	2h	10	Tech,QC
12	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	11	
13	Remove Test Plate/Inspect Orbiter LO2/LH2 Bleed Lines	4h	8h	12	Tech,QC
14	Remove Test Plate/Inspect Orbiter LO2/LH2 Pressurization Lines	4h	8h	13	Tech,QC
15	Remove Test Plate/Inspect Orbiter GHe/GN2 Supply Lines	4h	8h	14	Tech,QC
16	Perform MPS Test Requirements (Aft)	4h	8h		QC,Engr
17	Perform Engine Interface Flange Leak Check Port Verification (Aft)	4h	8h		Tech,QC
18	**Perform Orbiter Preps for SSME Installation (Roc)!**	**0.5d**	**21h**		
19	Verify Body Flap Full Down	0h	0h		
20	Perform Gimbal Interface Nut/Bolt Verification	1h	1h		QC
21	Install Stifarm Brackets and TVC Actuator Supports per V5057	4h	12h		Tech[2],QC
22	Perform Pre-Installation Inspection of Joint O1/F1 Interface Seals	4h	8h		Tech,QC
23	**Installation Preps in Engine Shop!**	**1.5d**	**148h**		
24	Install AFV/Helium Baggie Purge Adapters	4h	8h		Tech,QC
25	Install Liquid Air Insulators	12h	24h		Tech,QC
26	Perform SSME Engineering Walkdowns	12h	108h		Tech[3],QC[3],Engr[3]
27	Remove/Inspect Engine Interface Covers	4h	8h		Tech,QC
28	**Engine 1 Installation GSE Handling Operations/V5087!**	**0.63d**	**34.5h**	**5**	
29	Verify Lift Truck, Carrier and Rail Table Proofload Validations	0.25h	0.5h		Tech,QC
30	Transfer Engine to Carrier from Horizontal Handler	1.5h	6h	29	Tech[2],QC,Engr
31	Establish Safety Clears for Engine Lifting Operations	0.25h	3h	30	Tech[7],QC,Safety,Engr[3]
32	Mount Carrier/Engine on Rail Table/Lift Truck	2h	24h	31	Tech[7],QC,Safety,Engr[3]
33	Transport Hyster to VAB for Engine 1 Installation	1h	1h	32	Engr
34	**Engine 1 Installation Operations!**	**0.88d**	**79h**	**28**	
35	Position Hyster/Installer for Engine 1 Installation	2h	26h		Tech[7],QC[2],Safety,Engr[3]
36	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	35	
37	Engine 1 Mate to Orbiter	4h	52h	36	Tech[7],QC[2],Safety,Engr[3]
38	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	37	
39	Transport Hyster to VAB	1h	1h	38	Engr
40	**Engine 3 Installation GSE Handling Preps/V5087!**	**0.63d**	**34.5h**	**39**	
41	Verify Lift Truck, Carrier and Rail Table Proofload Validations	0.25h	0.5h		Tech,QC
42	Transfer Engine to Carrier from Horizontal Handler	1.5h	6h	41	Tech[2],QC,Engr
43	Establish Safety Clears for Engine Lifting Operations	0.25h	3h	42	Tech[7],QC,Safety,Engr[3]
44	Mount Carrier/Engine on Rail Table/Lift Truck	2h	24h	43	Tech[7],QC,Safety,Engr[3]
45	Transport Hyster to OPF for Engine 3 Installation	1h	1h	44	Engr

Table 15. Engine installation to OPF rollout tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
46	**Engine 3 Installation Operations!**	**0.88d**	**79h**	**34**	
47	Position Hyster/Installer for Engine 3 Installation	2h	26h	40	Tech[7],QC[2],Safety,Engr[3]
48	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	47	
49	Engine 3 Mate to Orbiter	4h	52h	48	Tech[7],QC[2],Safety,Engr[3]
50	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	49	
51	Transport Hyster to VAB for Engine 2 Installation	1h	1h	49	Engr
52	**Engine 2 Installation GSE Handling Preps/V5087!**	**0.63d**	**34.5h**	**51**	
53	Verify Lift Truck, Carrier and Rail Table Proofload Validations	0.25h	0.5h		Tech,QC
54	Transfer Engine to Carrier from Horizontal Handler	1.5h	6h	53	Tech[2],QC,Engr
55	Establish Safety Clears for Engine Lifting Operations	0.25h	3h	54	Tech[7],QC,Safety,Engr[3]
56	Mount Carrier/Engine on Rail Table/Lift Truck	2h	24h	55	Tech[7],QC,Safety,Engr[3]
57	Transport Hyster to OPF for Engine 2 Installation	1h	1h	56	Engr
58	**Engine 2 Installation Operations!**	**0.88d**	**79h**	**52**	
59	Position Hyster/Installer for Engine 2 Installation	2h	26h		Tech[7],QC[2],Safety,Engr[3]
60	Terminate Aft Compartment ECS Purge Air per V3555	0h	0h	59	
61	Engine 2 Mate to Orbiter	4h	52h	60	Tech[7],QC[2],Safety,Engr[3]
62	Reinitiate Aft Compartment ECS Purge Air per V3555	0h	0h	61	
63	Transport Hyster to VAB	1h	1h	62	Engr
64	Aft Swings Closed	0h	0h	63	
65	**SSME 1,2,3 Interface Securing Operations!**	**4d**	**152h**	**64**	
66	Interface Hardware Installation/GSE Removal	32h	96h		Tech[2],QC
67	Controller Coolant Duct Installation	8h	16h	64	Tech,QC
68	Electrical Interface Connection	16h	32h	64	Tech,QC
69	Mate Hydraulic QD's per V58AG0.121/V9002.06	4h	8h	64	Tech,QC
70	SSME Interface Securing Complete	0h	0h	66	
71	**SSME/MPS Integrated Testing!**	**11.28d**	**246.5h**	**70**	
72	**Low Pressure Pump Post-Installation Torque Checks/V1011.03 Run 3!**	**2.25d**	**54h**		
73	Engine 1,2,3 LPFTP Torque Checks	6h	18h		Tech,QC,Engr
74	Engine 1,2,3 LPOTP Torque Checks	12h	36h	70,73	Tech,QC,Engr
75	**Orbiter/SSME Interface Verification!**	**9.03d**	**192.5h**		
76	GSE Configuration for Leak Checks/V1011.04	4h	4h	74	Tech
77	**Fuel Interface Leak Check/V1011.05!**	**0.44d**	**11h**	**76**	
78	Install Throat Plugs	2h	2h		Tech
79	Activate MPS 750 psi Pneumatics	0.25h	1.5h	78	Tech[2],QC[2],Engr[2]
80	Pressurize MPS LH2 Manifold	0.25h	1.5h	79	Tech[2],QC[2],Engr[2]
81	Perform Fuel Feed Joint F1 I/F Leak Checks per V41AX0.020/.030/.040	0.5h	3h	80	Tech[2],QC[2],Engr[2]
82	Perform Fuel Bleed Joint F4.3 I/F Leak Checks per V41AX0.020/.030/.040	0.5h	3h	81	Tech[2],QC[2],Engr[2]
83	**LH2 Manifold Decay Test/V1009.05!**	**1d**	**0h**	**77**	
84	Perform LH2 Manifold Decay Test per V41...	8h	0h		
85	Vent Fuel System Manifold	0.25h	0h		
86	Secure MPS 750 psi Pneumatics	0.25h	0h	82	
87	SSME Electrical Interface Verification/V9001VL4	8h	16h	86	QC,Engr
88	**GOX System Interface Leak Check/V1011.04!**	**1d**	**33.5h**	**87**	
89	Mate Pneumatic Flexhoses/Leak Check Setup	2h	6h		Tech[2],QC
90	Close LO2 Prevalves and Pressurize GO2 Pressurization System	0.5h	3h	89	Tech[2],QC[2],Engr[2]

Table 15. Engine installation to OPF rollout tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
91	Power Up SSME Controllers per V9001VL4	0.5h	3.5h	90	Tech[2],QC[2],Engr[3]
92	Perform AFV Crack/Full Open Test per V41BR0.030	0.5h	3.5h	91	Tech[2],QC[2],Engr[3]
93	Power Down SSME Controllers per V9001VL4	0.5h	3.5h	92	Tech[2],QC[2],Engr[3]
94	Perform GO2/GCV Ext Leak Check and Orifice Verif. per V41BP0.010	0.5h	3h	93	Tech[2],QC[2],Engr[2]
95	Perform GO2 I/F Temperature Xducer Leak Check per V41AY0.320	0.5h	3h	94	Tech[2],QC[2],Engr[2]
96	Perform GO2 I/F Flange Leak Check per V41AX0.050	0.5h	3h	95	Tech[2],QC[2],Engr[2]
97	Perform Combined AFV Seat/Shaft Seal Flow Test per V41BQ0.100	0.5h	3h	96	Tech[2],QC[2],Engr[2]
98	Disassemble Test Setup	2h	2h	97	Tech
99	**Install Joint O18.1 Flight Plates/V1011.04!**	**2h**	**5h**	**88**	
100	Install AFV Filter/Seal per V41BU0.220	1h	3h		Tech,QC,Engr
101	Secure Joint O18.1's	1h	2h	100	Tech,QC
102	**LOX Interface Leak Check/V1011.05!**	**7h**	**32h**	**99**	
103	Configure SSME Drain Lines	1h	1h		Tech
104	Perform MPS 750 psi Pneumatic System Activation	0.5h	3h	103	Tech[2],QC[2],Engr[2]
105	Perform LO2 Manifold Pressurization	0.5h	3h	104	Tech[2],QC[2],Engr[2]
106	Perform LO2 Feed Joint O1 I/F Leak Checks per V41AX0.020/.030/.040	1h	6h	105	Tech[2],QC[2],Engr[2]
107	Perform LO2 Bleed Joint O15 I/F Leak Checks per V41AX0.020/.030/.040	1h	6h	106	Tech[2],QC[2],Engr[2]
108	Perform LO2 System Interface Mass Spec Leak Checks	1h	6h	107	Tech[2],QC[2],Engr[2]
109	Perform Joint O18.1 External Leak Check	0.5h	3h	108	Tech[2],QC[2],Engr[2]
110	Vent LO2 Feed and MPS 750 psi Systems	0.5h	3h	109	Tech[2],QC[2],Engr[2]
111	Secure LO2 Leak Check Setup	1h	1h	110	Tech
112	GSE Configuration for Hot Gas Leak Checks/V1011.05	2h	2h	102	Tech
113	Install Throat Plugs/V1011.05	2h	4h	112	Tech,QC
114	**Hot Gas System Interface Leak Checks/V1011.05!**	**6h**	**22.5h**	**113**	
115	Configure SSME Drain Lines	0.5h	0.5h		Tech
116	Configure GH2 Pressurization System for Flow Test	0.5h	0.5h		Tech
117	Perform GH2 Pressurization System Flow Test per V41BZ0.080	0.5h	1.5h	116	Tech,QC,Engr
118	Perform GH2 I/F Pressure Xducer Leak Check per V41AY0.350	1h	6h	117	Tech[2],QC[2],Engr[2]
119	Perform GH2 Press Joint F9.3 I/F Leak Check per V41AX0.020/.030/.040	1h	6h	118	Tech[2],QC[2],Engr[2]
120	Perform GH2 System Interface Mass Spec Leak Checks	0.5h	3h	119	Tech[2],QC[2],Engr[2]
121	Vent Hot Gas System	0.5h	3h	120	Tech[2],QC[2],Engr[2]
122	Perform PD16 Hardware Installation	1h	1h	121	Tech
123	Secure Hot Gas Leak Check Setup	1h	1h	122	Tech
124	Throat Plug Removal/V1011.05	2h	2h	114	Tech
125	**Pneumatic System Interface Leak Checks/V1011.05!**	**3.5h**	**12.5h**	**124**	
126	Configure SSME Drain Lines	0.5h	0.5h		Tech
127	Perform SSME 750 psi Pneumatic System Activation	1h	5h	126	Tech,QC[2],Engr[2]
128	Perform Pneumatic I/F Joint P1 Leak Check per V41AX0.020/.030/.040	1h	5h	127	Tech,QC[2],Engr[2]
129	Secure SSME 750 psi Pneumatic System	1h	2h	128	QC,Engr
130	Fuel System Interface Insulation Installation/V1011.05	24h	48h	125	Tech,QC
131	**SSME Engine and Dome Mounted Heat Shield Installation Operations!**	**126h**	**1056h**	**125**	
132	Position Davit Crane on 19R/G41-20017	2h	12h		Tech[4],QC[2]
133	Install E-1 R/H EMHS/V41-50024	2h	12h		Tech[4],QC[2]
134	Install E-3 L/H EMHS/V41-50026	2h	12h	133	Tech[4],QC[2]
135	Install E-3 R/H EMHS/V41-50026	2h	12h	134	Tech[4],QC[2]
136	Verify E-3 EMHS Splice Line Hardware Torque Complete/Verify Bolt Protrusion Complete	0h	0h	135	Tech[4],QC[2]

Table 15. Engine installation to OPF rollout tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
137	Install E-3 R/H DMHS/V41-50023	2h	12h	136	Tech[4],QC[2]
138	Install E-3 L/H DMHS/V41-50023	2h	12h	137	Tech[4],QC[2]
139	Position Davit Crane on 19L/G41-20017	1h	6h	138	Tech[4],QC[2]
140	Install E-1 L/H EMHS/V41-50024	2h	12h	139	Tech[4],QC[2]
141	Install E-2 L/H EMHS/V41-50025	2h	12h	140	Tech[4],QC[2]
142	Install E-2 R/H EMHS/V41-50025	2h	12h	141	Tech[4],QC[2]
143	Verify E-1 EMHS Splice Line Hardware Torque Complete/Verify Bolt Protrusion Complete	0h	0h	142	Tech[4],QC[2]
144	Verify E-2 EMHS Splice Line Hardware Torque Complete/Verify Bolt Protrusion Complete	0h	0h	143	Tech[4],QC[2]
145	Install E-1 L/H DMHS/V41-50021	2h	12h	144	Tech[4],QC[2]
146	Install E-2 R/H DMHS/V41-50022	2h	12h	145	Tech[4],QC[2]
147	Install E-2 L/H DMHS/V41-50022	2h	12h	146	Tech[4],QC[2]
148	Position Davit Crane on 19R/G41-20017	1h	6h	147	Tech[4],QC[2]
149	Install E-1 R/H DMHS/V41-50021	2h	12h	148	Tech[4],QC[2]
150	Lower Davit Crane from Level 19/G41-20017	2h	12h	149	Tech[4],QC[2]
151	Heat Shield Securing/Splice Line Configuration/V41-5002x	48h	288h	150	Tech[4],QC[2]
152	Install Carrier Panels/V80-95907,33,35	98h	588h	150	Tech[4],QC[2]
153	**SSME Gimbal Clearance Checks!**	**17.5h**	**123h**		
154	Pin TVC Actuators/V1063/V5057	4h	12h	152	Tech[2],QC
155	Install Marking Tape on SSME Nozzle Tubes	2h	2h	154	Tech
156	Perform SSME Heat Shield Verification	1h	1h	155	Tech
157	Hydraulic System Power-Up/V1063/V9002.01	2h	20h	156	Tech[3],QC[3],Engr[4]
158	MPS TVC Full Excursion Gimbal Clearance Checks/V1063	4.5h	45h	157	Tech[3],QC[3],Engr[4]
159	SSME TVC Toe-In Clearance Checks/V1063	1.5h	15h	158	Tech[3],QC[3],Engr[4]
160	SSME TVC Actuator Drift Test/V1063	1.5h	15h	159	Tech[3],QC[3],Engr[4]
161	Orbiter Hydraulic Power-Down/V1063/V9002.01	1h	10h	160,162	Tech[3],QC[3],Engr[4]
162	Hydraulic QD Leak Checks per V41AX0.020/.030/.040/V9002.06	1h	3h	157	Tech,QC,Engr
163	**SSME OPF Roll-Out Inspections/V41-20003!**	**19h**	**48h**	**153**	
164	Perform SSME Valve Position Verification	2h	10h		Tech,QC,Safety,Engr[2]
165	TVC Actuator Midstroke Lock Installation/V5057	4h	12h	164,162	Tech[2],QC
166	Thrust Chamber Cover Installation/V5057	2h	4h	165	Tech,QC
167	Verify Thrust Chamber Covers Installed per V41BW0.031	0.25h	0.5h	166	Tech,QC
168	Verify Bellows Covers Installed per V41BW0.031	0.25h	0.5h	167	Tech,QC
169	Verify TVC Actuators Connected per V41BW0.031	0.25h	0.5h	168	Tech,QC
170	Verify Midstroke Locks Installed per V41BW0.031	0.25h	0.5h	169	Tech,QC
171	Install Miscellaneous Covers per V5057	2h	4h	170	Tech,QC
172	Visually Inspect Engine Components for Damage	8h	16h	171	Tech,QC
173	Aft Closeout for OPF Roll-Out Complete	0h	0h	163	
174	Orbiter Roll-Out to VAB	0h	0h	173	

Table 16. VAB rollin to launch tasks.

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**VAB Roll-In to Launch!**	**464.87h**	**592.35h**		
2	**Orbiter/ET Mate Operations/S0004!**	**144h**	**0h**		
3	Orbiter in Transfer Aisle	0h	0h		
4	Connect Sling/Preps for Orbiter Lift	8h	0h	3	
5	Rotate Orbiter to Vertical/Disconnect Aft Sling	8h	0h	4	
6	Orbiter/ET Softmate	8h	0h	5	
7	Orbiter/ET Hardmate	4h	0h	6	
8	Sling Removal	4h	0h	7	
9	TSM Connect	16h	0h	8	
10	Umbilical Mate	16h	0h	8	
11	Monoball Connect/Closeout	24h	0h	9	
12	Hazardous Gas Leak Checks	8h	0h	9	
13	Ultrasonic Inspections	4h	0h	10	
14	TSM Static Measurement	8h	0h	9	
15	External Umbilical Can Closeout	8h	0h	12,14	
16	Ready for Orbiter Power-Up	0h	0h	15	
17	Umbilical Foaming	40h	0h	15	
18	Purge Curtain Installation	40h	0h	17	
19	**Shuttle Interface Testing/S0008!**	**38h**	**0h**		
20	Shuttle Interface Testing Preps	18h	0h		
21	Orbiter Power-Up	0h	0h	20	
22	Orbiter System Checks	8h	0h	21	
23	S0008 Testing	4h	0h	20	
24	ET/SRB Power-Up	0h	0h	23	
25	ET/SRB System Checks	8h	0h	24	
26	SRB TVC Actuator Testing	4h	0h	25	
27	Connect SRB TVC Actuators	4h	0h	26	
28	**Umbilical Interface Leak Checks/V1149!**	**30h**	**33.75h**		
29	**Umbilical Interface Leak Check Preps!**	**12h**	**2h**		
30	Perform GN2 Flowmeter Setup	4h	0h		
31	Perform LO2/LH2 TSM Line Verification	4h	0h		
32	**Perform SSME Trickle Purge Activation**	**1.5h**	**2h**	**31**	
33	Verify PD14 GN2 Purge T-0 Disconnect Mated	0h	0h		
34	Perform Thrust Chamber Cover Removal/V5057	1h	1h		Tech
35	Activate/Verify SSME Trickle Purge per S00000.100	0.5h	1h	34	Tech,QC
36	Perform TP8 Configuration	4h	0h	31	
37	Perform PD4/PD5 HUMS Leak Check Preps	8h	0h	31	
38	Perform Mass Spec Leak Check Preps	8h	0h	31	
39	Perform Mass Spec Leak Check Machine Preps	2h	0h	31	
40	**Umbilical Interface Leak Check Operations!**	**18h**	**31.75h**	**29**	

Table 16. VAB rollin to launch tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
41	Orbiter MPS Helium Fill QD Leak Check	2h	0h		
42	17 Inch Disconnect Timing Checks/200 psi Leak Checks	8h	0h	41	
43	MPS LOX Fill and Drain QD Leak Check	4h	0h	42	
44	MPS LH2 Fill and Drain QD Leak Check	4h	0h	43	
45	**SSME GN2 Heater Checkout/GN2 Leak Checks!**	**4h**	**25.75h**		
46	Configure Heater Power Circuit Breakers	0.25h	1h		Tech,QC,Engr[2]
47	Verify Panel Valve Configuration	0.25h	1h	46	Tech,QC,Engr[2]
48	Perform Automated GN2 Panel Valve Checkout	0.5h	2h	47	QC,Engr[2],Tech
49	Close TSM GN2 Supply Valve	0.25h	1.25h	48	Tech[2],QC,Engr[2]
50	Pressurize GN2 Panel	0.25h	1h	49	Tech,QC,Engr[2]
51	Establish Safety Clears	0.25h	2h	50	Tech[2],QC[3],Safety,Engr[2]
52	Open TSM GN2 Supply Valve	0.25h	2h	51	Tech[2],QC[3],Engr[2],Safety
53	Verify No Leakage @ PD14 GN2 Purge Interface per S00000.020	0.25h	2h	52	Tech[2],QC[3],Engr[2],Safety
54	Perform Bubble Soap Leak Check of TSM GN2 Lines	0.25h	2h	53	Tech[2],QC[3],Engr[2],Safety
55	Perform Orbiter GN2 Joint Leak Check	0.25h	2h	54	Tech[2],QC[3],Engr[2],Safety
56	Perform SSME GN2 Joint Leak Check	0.25h	2h	55	Tech[2],QC[3],Engr[2],Safety
57	Perform GN2 I/F Joint N1 Leak Check per V41AX0.020/.030/.040	0.25h	2h	56	Tech[2],QC[3],Engr[2],Safety
58	Perform SSME GN2 Heater Checkout	0.5h	4h	57	Tech[2],QC[3],Engr[2],Safety
59	Secure GN2 Flow	0.25h	1.5h	58	Tech[2],QC[2],Engr[2]
60	**SSME MFV Heater T-0 Interface Verification!**	**2h**	**6h**	**59**	
61	Power Up Distributor Panels	0.25h	0.75h		QC,Engr[2]
62	Close Panel Circuit Breakers	0.25h	0.75h	61	Tech,QC,Engr
63	Perform MFV Heater Checkout per S00000.101	1h	3h	62	Tech,QC,Engr
64	Open Panel Circuit Breakers	0.25h	0.75h	63	Tech,QC,Engr
65	Power Down Distributor Panels	0.25h	0.75h	64	QC,Engr[2]
66	**VAB Roll-Out Operations/A5214!**	**44h**	**0h**		
67	Roll-Out Preps	24h	0h	2	
68	Shuttle Transfer to Launch Pad	12h	0h	67	
69	Crawler Transport Operations	8h	0h	68	
70	Launch Pad Validation Preps/S0009 POSU's	12h	0h	67	
71	Shuttle 1st Motion to Pad	0h	0h	68	
72	MLP Harddown at Pad!	0h	0h	71,69	
73	**Launch Pad Validation/S0009!**	**44h**	**12h**	**72**	
74	Perform PD15/PD16 Connect	44h	0h		
75	Perform A2202 Firex Verification	8h	0h		
76	Activate Pad Helium Supply Panel	8h	0h		
77	Activate SSME Trickle Purge	4h	12h		Tech,QC,Engr
78	Activate T-0 Trickle Purge	8h	0h		
79	Perform LDB Safing Panel Verification	8h	0h		
80	Perform Propellant System Switch Validation	8h	0h		

Table 16. VAB rollin to launch tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
81	Perform Recirc Pump Switch Validation	8h	0h		
82	Perform ET OI Power Up	8h	0h		
83	Perform ET OI Instrumentation Checks	8h	0h		
84	Perform ET Level Sensor Cals	8h	0h		
85	Perform Valve Verifications for G2340 LO2/LH2 Checkouts	8h	0h		
86	Perform ET OI Power Down	8h	0h		
87	Extend RSS	0h	0h	73	
88	**Engine Flight Readiness Testing/V1046.001I**	**21h**	**52h**		
89	**Preps for SSME Hydraulic Operations/V9002.06**	**7h**	**15h**		
90	SSME Engineering Determine Configuration Required Configuration for Hydraulics	1h	1h		Engr
91	Perform TVC Actuator Preps for Hydraulic Operations/V5057	4h	12h	90	Tech[2],QC
92	Remove Drain Line Adapters and Environmental Throat Plugs	1h	1h	91	Tech
93	Perform SSME LPFD Helium Barrier Purge System Venting	1h	1h	92	Tech
94	SSME Controller Power-Up/V9001VL4	1h	7h	89	QC[3],Engr[4]
95	Shuttle Flight Control System Activation Complete	0h	0h	94	
96	SSME Controller Load and Sensor Checkout/V9001VL4	1h	7h	95	QC[3],Engr[4]
97	Hydraulic System Pressurization Complete	0h	0h	96	
98	Activate SSME 750 psi Pneumatics	0.5h	3.5h	97	QC[3],Engr[4]
99	SSME Hydraulic System Conditioning and Actuator Checkout	0.5h	3.5h	98	QC[3],Engr[4]
100	SSME Flight Readiness Test	2h	16h	99	Tech,QC[3],Engr[4]
101	SSME Controller Power-Down	0h	0h	100	
102	**Hydraulics and Flight Control Closeout OperationsI**	**9h**	**0h**	**101**	
103	Aerosurface and SSME Cycling/V1308	3h	0h		
104	Hydraulic System Compressibility/V9002.07	1.5h	0h	103	
105	Frequency Response Testing/V1034	3h	0h	103	
106	Hydraulic System Closeouts and Securing/V9002.02	3h	0h	105	
107	SSME Pneumatics Secured	0h	0h	105	
108	**SSME Ball Seal Leak Check Operations/V1046.002/V1046.003I**	**4h**	**27h**	**88**	
109	Install Base Heat Shield Access Ladder/V35-00008	1.5h	4.5h	106	Tech[2],QC
110	**SSME/TVC Actuator Hydraulic Power-Down Securing Requirements/V9002.06**	**3.5h**	**6.5h**		
111	SSME Engineer Determine Required Power Down Configuration	1h	1h		Engr
112	Install Midstroke Locks/V5057	1.5h	4.5h	111	Tech[2],QC
113	Vent Bleeder Plug at Joint P20.2	1h	1h	112	Tech
114	Install SSME Throat Plugs/V1046.002	2h	6h		Tech,QC,Safety
115	Fuel Valve Ball Seal Leak Check/V1046.002	1h	5h	114	Tech,QC[2],Engr[2]
116	Oxidizer Valve Ball Seal Leak Check/V1046.003	1h	5h	115	Tech,QC[2],Engr[2]
117	SSME Hydraulic QD X-Rays/V9002.06	4h	8h	116	Tech,QC
118	LO2 Feed/SSME Pneumatics Vented	0h	0h	114	
119	LH2 Feed Vented	0h	0h	115	
120	GO2 Blanking Plate Installation/T1402I	6h	0h	119	

Table 16. VAB rollin to launch tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
121	GH2 Blanking Plate Installation/T1401!	6h	0h	120	
122	Orbiter/ET 17 inch Disconnect Cavity Purge Verification/V1149!	8h	0h	120,121	
123	**Helium Signature Test/V1202!**	**34h**	**18h**	**120,121**	
124	**SSME Preps for Helium Signature Test!**	**7h**	**18h**		
125	Install Drain Line Closures	1h	1h		Tech
126	Establish Safety Clears/OK for Thrust Chamber Entry	1h	3h	125	Tech,QC,Safety
127	Perform MCC Liner Taping	2h	6h	126	Tech,QC,Safety
128	Install Throat Plug and Monitor Gage Manifold	2.5h	7.5h	127	Tech,QC,Safety
129	Mate Flexhose Between Supply Panel and Manifold	0.5h	0.5h	128	Tech
130	Perform PV13 GN2 Panel Setup	7h	0h	127	
131	Haz Gas Detection System Preps	3h	0h	130	
132	Pre-Test Helium Intrusion Test	4h	0h	131	
133	MPS GH2/LO2 Feed and SSME Hot Gas System Test	3h	0h	132	
134	GO2 System Test	2h	0h	133	
135	LH2 Feed System	2h	0h	134	
136	Orbiter Post-Test Operations	9h	0h	135	
137	GO2 Blanking Plate Installation/T1402!	6h	0h	135	
138	GH2 Blanking Plate Installation/T1401!	6h	0h	137	
139	**Ordnance Installation Operations - Part 1!**	**40h**	**0h**		
140	Ordnance Installation/PIC Resistance Checks/S5009	16h	0h	138	
141	Ordnance Closeouts/S5009	24h	0h	140	
142	**Pre-Launch Hypergolic Propellant Loading Operations/S0024!**	**64h**	**0h**		
143	Propellant Loading Operations/S0024	40h	0h	141	
144	Propellant Loading Closeouts/S0024	24h	0h	143	
145	**Ordnance Installation Operations - Part 2!**	**48h**	**0h**		
146	SRSS System Test	8h	0h	144	
147	Ordnance Connect/PIC Resistance Checks/S5009	16h	0h	146	
148	Ordnance Closeouts/S5009	24h	0h	147	
149	**LOX System Dewpoint and Conditioning/S1005!**	**6.5h**	**7.75h**	**148**	
150	SSME Thrust Cover Removal/Drain Line Adapter Installation/V5057	2h	4h	147	Tech,QC
151	Rocketdyne Tech on Station for Dewpoints	2.75h	2.75h	150	Tech
152	Orbiter and ET OI Power-Up	0.5h	0h	150	
153	SSME Trickle Purge Securing	1h	1h	152	Tech
154	MPS 750 psi Pneumatics Activation	1.5h	0h	152	
155	ET LOX Tank, SSME, TSM Vent and Engine Bleed Dewpoint	1.5h	0h	153	
156	Main Fill and Drain Dewpoint	1.75h	0h	154	
157	LOX ET Pressure Maintenance	2.5h	0h	154	
158	**LH2 System Dewpoint and Conditioning/S1006!**	**9.5h**	**6h**	**149**	
159	LH2 and MPS/SSMEC Power-Up	2h	6h	150	QC,Engr[2]
160	ET/Orbiter Purge and Sample	5h	0h	159	

Table 16. VAB rollin to launch tasks (Continued).

ID	Task Name	Duration	Work	Predecessors	Resource Names
161	Transfer Line Purge and Sample	1.5h	0h	160	
162	Vaporizer Purge	1h	0h	161	
163	**Orbiter Aft Closeout/S1287!**	**100h**	**290h**	**148**	
164	Aft Confidence Test - Pre-Door Installation	12h	0h	148	
165	SSME MCC Polishing	8h	24h	164	Tech,QC,Safety
166	TVC Actuator Flight Closeout and Insulation Installation/V5057	34h	102h	164	Tech[2],QC
167	MPS Engineering Verification and Walkdown	8h	0h	164	
168	MPS Initial Preps for Flight/V9018.001	8h	0h	167	
169	PD15/PD16 ET Standby Pressure Monitor Securing	8h	0h	167	
170	EMHS Insulation Inspection per V41BU0.420	8h	24h	168,169	Tech,QC,Safety
171	SSME Engineering Walkdown	8h	40h	170	Engr[5]
172	SSME Initial Preps for Flight/V9018.001	8h	24h	171	Tech,QC,Engr
173	SSME Quality Walkdown per V41BU0.070	16h	32h	171	Tech,QC
174	MPS VJ Line Checks/V9019	8h	0h	173	
175	Verify Midstroke Locks Removed	0h	0h	173	
176	LPFD Baggie Installation	6h	18h	173	Tech,QC,Engr
177	LPFD Baggie Leak Check per V41BU0.380	2h	10h	176	Tech,QC[2],Engr[2]
178	EMHS Debris Shield Removal	8h	8h	177	Tech
179	MPS Protective Cover Removal/V35-00002	16h	0h	176,174	
180	SSME Protective Cover Removal/V5057	8h	8h	179	Tech
181	MPS Solenoid Protective Cover Removal/V35-00003	8h	0h	179	
182	Install Aft 50-1/50-2 Doors for Flight	4h	0h	181,180,181	
183	MPS Functional Verification for Flight - Post-Door Installation/V9018.001	8h	0h	181	
184	**S0007 Launch Countdown Operations!**	**364.87h**	**137.85h**		
185	**S0007 Launch Countdown Preps!**	**80h**	**36h**	**163**	
186	S0007 Launch Countdown Preps	80h	0h	163	
187	SSME Drag On Panel Purge Preps/S0007VL1 POSU 8	12h	36h		Tech,QC,Engr
188	S0007 Seq 14: T-43 hours to T-11 hours!	64h	6.25h	163,186	QC,Engr[2]
189	S0007 Seq 15: T-11 hours to T-6 hours!	7h	21h	188	QC,Engr[2]
190	S0007 Seq 16: T-6 hours to Launch!	8.87h	26.6h	189	QC,Engr[2]
191	Shuttle Liftoff!!	0h	0h	190	
192	S0007 Seq 17: Post-Launch Securing Operations	16h	48h	191	QC,Engr[2]

Table 17. Example of detailed data for scheduled processing in OMEF.

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**SSME Inspections in Engine Shop (continued)/V1011.02!**	**67.98h**	**135.75h**		
2	**External Inspections!**	**67.98h**	**36h**		
3	Perform Nozzle External Inspections per V41BU0.030	8h	24h		Tech,QC,Engr
4	Perform Liquid Air Insulator Inspections per V41BU0.033	2h	4h	3	QC,Engr
5	Perform Main Injector LOX Post Bias Checks per V41BU0.034	4h	8h	4	QC,Engr
6	**MCC and Nozzle Inspections!**	**17.5h**	**34.5h**		
7	Install Thrust Chamber Protective Liner	0.5h	0.5h		Tech
8	Perform Post-Flight Nozzle Inspections per V41BU0.353	2h	4h	7	QC,Engr
9	Perform Post-Flight MCC Liner Inspection per V41BU0.351	4h	8h	8	QC,Engr
10	Perform Post-Flight MCC Liner Polishing per V41BU0.351	8h	16h	9	Tech,QC
11	Post-Polishing MCC Liner Inspection per V41BU0.351	1h	2h	10	QC,Engr
12	Perform MCC Bondline Ultrasonic Inspection per V41BU0.031	2h	4h	11	QC,Engr
13	**Internal Inspections!**	**16.25h**	**65.25h**	**6**	
14	Perform Flow Recirculation Inhibitor Inspection per V41BU0.040	1h	1h		Engr
15	Perform Main Injector Face Side Inspections per V41BU0.040	4h	4h	14	Engr
16	Perform Main Combustion Chamber Inspections per V41BU0.040	2h	4h	15	QC,Engr
17	Perform Fuel Preburner Internal Inspection per V41BU0.040	4h	8h		QC,Engr
18	Perform Oxidizer Preburner Internal Inspections per V41BU0.040	4h	4h		Engr
19	Perform Main Injector Internal Inspections per V41BU0.040	4h	4h	17,18	Engr
20	Verify Heat Exchanger Coils Internal Inspection performed per V5E02	0.25h	0.25h	19	QC
21	Perform HPFTP Internal Inspections per V41BU0.075	8h	24h		Tech,QC,Engr
22	Perform HPOTP Internal Inspections per V41BU0.065	8h	16h		Tech,Engr

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**HPFTP Post-Flight Torque Check/V1011.03 Run 1!**	**3.5h**	**10.5h**		
2	Remove HPFTP Thrust Bearing Housing @ Joint F3.1	0.5h	1.5h		Tech,QC,Engr
3	Install HPFTP Torque Tool	0.5h	1.5h	2	Tech,QC,Engr
4	Perform HPFTP Torque Check per V41BS0.020	0.5h	1.5h	3	Tech,QC,Engr
5	Perform HPFTP Shaft Position and Axial Travel per V41BS0.020	1.5h	4.5h	4	Tech,QC,Engr
6	Install Protective Cover @ HPFTP Joint F3.1	0.5h	1.5h	5	Tech,QC,Engr

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**HPOTP Post-Flight Torque Check/V1011.03 Run 1!**	**3.75h**	**11.25h**		
2	Remove HPOTP Torque Access Plate @ Joint O9.1	0.25h	0.75h		Tech,QC,Engr
3	Perform HPOTP Torque Check per V41BS0.040	0.5h	1.5h	2	Tech,QC,Engr
4	Perform HPOTP Shaft Travel Measurement per V41BS0.044	2h	6h	3	Tech,QC,Engr
5	*Perform PBP Impeller Bolt Lock Inspection per V41BS0.043*	0.5h	1.5h	4	Tech,QC,Engr
6	Install HPOTP Torque Access Plate @ Joint O9.1	0.5h	1.5h	5	Tech,QC,Engr

APPENDIX C—Unscheduled SSME Operations Data

Figures 20–24 and tables 18–19 present the detailed data collected from SSME processing experience at KSC relative to unscheduled activities. Figures 20–24 present the remaining unscheduled processing classification types. The sixth, base R&R, is presented in section 5. Following these figures, an unscheduled summary data table (table 18) is presented. Finally, an example of the existing level of detail supporting the flow layouts is presented in table 19.

ID	Duration (hr)	Man-hr	y Wednesday Thursday Friday Saturday Sunday
1	24.43	1	1h MR Accept Performance Time!
2	0.25	0.25	QC Determine PR Condition
3	0.25	0.25	QC Initiate PR Paperwork
4	0.5	0.5	0.5h Apply MR ID (if Required)
5	0.5	0.5	0.5h MR Accept Administative Time!
6	0.5	0.5	Engr QE Research/Validate PR
7	11.98	12	12h MR Accept Diagnostics Time!
8	8	8	Engr Engr/Mgt Review, Assess PR
9	4	4	Engr Engr/Mgt Determine Corrective Action
10	13.9	0	0h MR Accept Delay Time!
11	1	0	Engr Disposition PR/MR Accept Rationale
12	8	0	Engr Route PR through Signature Loop
13	2	0	0h Engr Disposition PR Closure
14	0.5	0	0h QE Close PR

Figure 20. Base MR accept.

ID	Duration (hr)	Man-hr	y Wednesday Thursday Friday Saturday Sunday
1	33.42	1	1h MR Repair Performance Time!
2	0.25	0.25	0.25h Determine PR Condition
3	0.25	0.25	0.25h Initiate PR Paperwork
4	0	0	◆Time/Resources for Corrective Action (Varies)
5	0.5	0.5	0.5h Apply MR ID (if Required)
6	11.98	12	12h Mr Repair Diagnostics Time!
7	8	8	8h Engr/Mgt Review, Assess PR
8	4	4	4h Engr/Mgt Determine Corrective Action
9	32.43	12.5	12.5h MR Repair Adminstrative Time!
10	0.5	0.5	0.5h QE Research/Validate PR
11	4	4	4h Engr Disposition PR/MR Repair Rationale (Varies)
12	8	8	8h Engr Route PR through Signature Loop
13	2.5	0	0h MR Repair Delay Time!
14	2	0	0h Engr Disposition PR Closure
15	0.5	0	0h QE Close PR

Figure 21. Base MR repair.

ID	Duration (hr)	Man-hr	Wednesday / Thursday / Friday / Saturday / Sunday (4 12 8 4 12 8 4 12 8 4 12 8 4 12 8 4 12)
1	0.48	0.5	0.5h PR Performance Time
2	0.25	0.25	0.25h Determine PR Condition
3	0.25	0.25	0.25h Initiate PR Paperwork
4	0.5	0.5	0.5h PR Administrative Time
5	0.5	0.5	0.5h QE Research/Vaildate PR
6	5	5	5h PR Diagnostics Time
7	4	4	4h Engr/Mgt Review/Assess PR
8	1	1	1h Engr/Mgt Determine Corrective Action
9	9.48	9.5	9.5h PR Delay Time
10	4	4	4h Engr Disposition PR
11	4	4	4h Engr Rt PR through Signature Loop
12	1	1	1h Engr Disposition PR Closure
13	0.5	0.5	0.5h Engr Disposition PR Closure

Figure 22. Base PR accept.

ID	Duration (hr)	Man-hr	Wednesday / Thursday / Friday / Saturday / Sunday (4 12 8 4 12 8 4 12 8 4 12 8 4 12 8 4 12)
1	6.98	0.5	0.5h PR Performance Time
2	0.25	0.25	0.25h Determine PR Condition
3	0.25	0.25	0.25h Initiate PR Paperwork
4	0	0	Time/Resources for Corrective Action (Varies w/PR Classification)
5	2	2	2h PR Diagnostics Time
6	1	1	1h Engr/Mgt Review/Assess PR
7	1	1	1h Engr/Mgt Determine Corrective Action
8	6.5	4.5	4.5h PR Administrative Time
9	0.5	0.5	0.5h QE Research/Validate PR
10	0	0	Engr Disposition PR (Varies with Repair Classification)
11	4	4	4h Engr Rt PR through Signature Loop
12	1.5	0	0h PR Delay Time
13	0	0	0h Engr Disposition PR Closure
14	0.5	0	0h QE Close PR

Figure 23. Base PR repair.

ID	Duration (hr)	Man-hr	Wednesday / Thursday / Friday / Saturday / Sunday (4 12 8 4 12 8 4 12 8 4 12 8 4 12 8 4 12)
1	0.48	0.5	0.5h Waiver Performance Time
2	0.25	0.25	0.25h Determine PR Condition
3	0.25	0.25	0.25h Initiate PR Paperwork
4	0.5	0.5	0.5h Waiver Administrative Time
5	0.5	0.5	0.5h QE Research/Vaildate PR
6	11.98	12	12h Waiver Diagnostics Time
7	8	8	8h Engr/Mgt Review/Assess PR
8	4	4	4h Engr/Mgt Determine Corrective Action
9	16.5	0	0h Waiver Delay Time
10	1	0	0h Engr Disposition PR/Waiver Rationale
11	12	0	0h Engr Rt PR/Waiver Rationale through Signature
12	1	0	0h Waiver Presentation
13	2	0	0h Engr Disposition PR Closure
14	0.5	0	0h QE Close PR

Figure 24. Base waiver/exception.

Table 18. SSME unscheduled processing summary.

ID	SSME PR Classification	Tech Base Perf MHrs	QC Base Perf MHrs	Engr Base Diag MHrs	Engr Base Admin MHrs	Total Base MHrs	Tech Perf MHrs	QC Perf MHrs	Engr Perf MHrs	Total Perf MHrs	Total MHrs	No. Techs	No. QCs	No. Engrs
1	48hr Drying OMRSD Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
2	AFV Filter R&R	0	0.5	2	6.5	9	1	1	8.5	10.5	19.5	1	1	1
3	Baggie Hose R&R	0	0.5	2	6.5	9	1.25	1.25	0	2.5	11.5	1	1	0
4	Baggie Hose Repair	0	0.5	2	4.5	7	1	1	0	2	9	1	1	0
5	Baggie R&R	0	0.5	2	6.5	9	1.5	1.5	0	3	12	1	1	0
6	Baggie Repair	0	0.5	2	4.5	7	0.75	0.75	0	1.5	8.5	1	1	0
7	Battery R&R	0	0.5	2	6.5	9	1.25	1.25	0	2.5	11.5	1	1	0
8	Burst Diaphragm R&R	0	0.5	2	6.5	9	0.5	0.5	0	1	10	1	1	0
9	Contamination MR Repair	0.5	0.5	12	12.5	25.5	1.25	1.25	0	2.5	28	1	1	0
10	Contamination Repair	0	0.5	2	4.5	7	1.75	1.75	0	3.5	10.5	1	1	0
11	Contamination/Corrosion Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
12	Contamination/Corrosion MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
13	Contamination/Corrosion Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
14	Controller R&R: Post-FRT	0	0.5	2	6.5	9	154.5	74.25	93.25	322	331	na	na	na
15	Controller R&R: Pre-FRT	0	0.5	2	6.5	9	35.5	14.5	13	63	72	na	na	na
16	Coolant Diffuser R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
17	Coolant Duct R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
18	EDNI Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
19	EDNI MR Repair	0.5	0.5	12	12.5	25.5	5.5	5.5	0	11	36.5	1	1	0
20	EDNI R&R	0	0.5	2	6.5	9	7	7	0	14	23	1	1	0
21	EDNI Repair	0	0.5	2	4.5	7	6	6	0	12	19	1	1	0
22	Elliptical Plug R&R	0	0.5	2	6.5	9	1	1	0	2	11	1	1	0
23	Engine Assembly R&R	0	0.5	2	6.5	9	8	8	8.5	24.5	33.5	1	1	1
24	Engineering Change	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
25	Flange Sealing Surface MR Repair	0.5	0.5	12	12.5	25.5	3.5	3.5	24.5	31.5	57	1	1	1
26	Flange Sealing Surface Repair	0	0.5	2	4.5	7	4	4	6.5	14.5	21.5	1	1	1
27	FPB Oxidizer Supply Duct R&R: Post-HPOTP	0	0.5	2	6.5	9	22.5	14.5	1	38	47	na	na	na
28	FPB Oxidizer Supply Duct R&R: Pre-HPOTP	0	0.5	2	6.5	9	13	9	0	22	31	na	na	na
29	Fuel Bleed Duct R&R	0	0.5	2	6.5	9	5	5	0	10	19	1	1	0
30	Functional Failure Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
31	Functional Failure Clean/Adjust	0	0.5	2	4.5	7	4	4	0	8	15	1	1	0
32	Functional Failure MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
33	Functional Failure Reperform/Retest	0	0.5	2	4.5	7	2.5	2.5	0	5	12	1	1	0
34	Functional Failure Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
35	GCV Assembly R&R	0	0.5	2	6.5	9	3	3	0	6	15	na	na	na

Table 18. SSME unscheduled processing summary (Continued).

ID	SSME PR Classification	Tech Base Perf MHrs	QC Base Perf MHrs	Engr Base Diag MHrs	Engr Base Admin MHrs	Total Base MHrs	Tech Perf MHrs	QC Perf MHrs	Engr Perf MHrs	Total Perf MHrs	Total MHrs	No. Techs	No. QCs	No. Engrs
36	Hardware Configuration Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
37	Hardware Configuration MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
38	Hardware Configuration MR Repair	0.5	0.5	12	12.5	25.5	2.5	2.5	0	5	30.5	1	1	0
39	Hardware Configuration Reinstallation	0	0.5	2	4.5	7	3	3	0	6	13	1	1	0
40	Hardware Configuration Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
41	Hardware Crack/Weld Defect MR Repair	0.5	0.5	12	12.5	25.5	7.5	7.5	0	15	40.5	1	1	0
42	Hardware Crack/Weld Defect Repair	0	0.5	2	4.5	7	8	8	0	16	23	1	1	0
43	Hardware Damage Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
44	Hardware Damage MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
45	Hardware Damage MR Repair	0.5	0.5	12	12.5	25.5	3.5	3.5	0	7	32.5	1	1	0
46	Hardware Damage Repair	0	0.5	2	4.5	7	4	4	0	8	15	1	1	0
47	Hardware Damage Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
48	Harness Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
49	Harness MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
50	Harness MR Repair	0.5	0.5	12	12.5	25.5	2	2	0	4	29.5	1	1	0
51	Harness R&R: Post-FRT	0	0.5	2	6.5	9	11	4	4	19	28	na	na	na
52	Harness R&R: Pre-FRT	0	0.5	2	6.5	9	3	3	0	6	15	1	1	0
53	Harness Repair	0	0.5	2	4.5	7	2.5	2.5	0	5	12	1	1	0
54	Heat Shield Clip/Bracket R&R	0	0.5	2	6.5	9	1	1	0	2	11	1	1	0
55	Hot Gas Manifold R&R	0	0.5	2	6.5	9	4	4	8.5	16.5	25.5	1	1	1
56	HPFD R&R: Pad	0	0.5	2	6.5	9	70.75	27.25	9	107	116	na	na	na
57	HPFD R&R: Shop Post-FRT	0	0.5	2	6.5	9	37.25	26.75	8	72	81	na	na	na
58	HPFD R&R: Shop Pre-HPFTP R&R	0	0.5	2	6.5	9	23.25	13	2.5	38.75	47.75	na	na	na
59	HPFTP Bellows Shield R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
60	HPFTP R&R: Pre-R&R	0	0.5	2	6.5	9	0	0	0	0	9	na	na	na
61	HPFTP Thrust Bearing Housing R&R	0	0.5	2	6.5	9	8	8	0	16	25	1	1	0
62	HPOTP Preburner Volute R&R	0	0.5	2	6.5	9	16	16	0	32	41	1	1	0
63	HPOTP R&R: Pre-R&R	0	0.5	2	6.5	9	0	0	0	0	9	na	na	na
64	HPOTP Turbine Housing R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
65	HPV Assembly R&R	0	0.5	2	6.5	9	8	8	0	16	25	1	1	0
66	Hydraulic QD R&R	0	0.5	2	6.5	9	6	6	0	12	21	1	1	0
67	Igniter R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
68	Line Assembly R&R	0	0.5	2	6.5	9	5	5	0	10	19	1	1	0
69	LOX Post Support Pin R&R	0	0.5	2	6.5	9	0	10	8.5	18.5	27.5	0	1	1
70	LPFD R&R: OPF/Pad	0	0.5	2	6.5	9	64.75	24.75	5.5	95	104	na	na	na

Table 18. SSME unscheduled processing summary (Continued).

ID	SSME PR Classification	Tech Base Perf MHrs	QC Base Perf MHrs	Engr Base Diag MHrs	Engr Base Admin MHrs	Total Base MHrs	Tech Perf MHrs	QC Perf MHrs	Engr Perf MHrs	Total Perf MHrs	Total MHrs	No. Techs	No. QCs	No. Engrs
71	LPFD R&R: Shop Pre-HPFTP R&R	0	0.5	2	6.5	9	23.5	11.5	2.5	37.5	46.5	na	na	na
72	LPFT Discharge Duct R&R	0	0.5	2	6.5	9	26	10	0	36	45	na	na	na
73	LPFT Drive Duct R&R	0	0.5	2	6.5	9	25	10	0	35	44	na	na	na
74	LPFTP R&R	0	0.5	2	6.5	9	53.5	29	11.5	94	103	na	na	na
75	LPOD R&R	0	0.5	2	6.5	9	57.25	26.25	4	87.5	96.5	na	na	na
76	LPOTP R&R	0	0.5	2	6.5	9	52.5	28.5	13	94	103	na	na	na
77	Main Injector Assembly R&R	0	0.5	2	6.5	9	4	4	8.5	16.5	25.5	1	1	1
78	MCC Assembly R&R	0	0.5	2	6.5	9	4	4	8.5	16.5	25.5	1	1	1
79	MCC Roughness Repair	0	0.5	2	4.5	7	4	4	6.5	14.5	21.5	1	1	1
80	Miscellaneous Hardware Config. MR Repair	0.5	0.5	12	12.5	25.5	2	2	0	4	29.5	1	1	0
81	Miscellaneous Hardware Config. Repair	0	0.5	2	4.5	7	2.5	2.5	0	5	12	1	1	0
82	Miscellaneous Hardware Damage MR Repair	0.5	0.5	12	12.5	25.5	2	2	0	4	29.5	1	1	0
83	Miscellaneous Hardware Damage Repair	0	0.5	2	4.5	7	2.5	2.5	0	5	12	1	1	0
84	Miscellaneous Hardware R&R	0	0.5	2	6.5	9	6	6	0	12	21	1	1	0
85	MOVA R&R: Pad	0	0.5	2	6.5	9	79.5	50.25	62.75	192.5	201.5	na	na	na
86	MOVA R&R: Shop	0	0.5	2	6.5	9	29.25	18.75	3.5	51.5	60.5	na	na	na
87	Nozzle FRI R&R	0	0.5	2	6.5	9	221.5	119.25	54	394.75	403.75	na	na	na
88	Nozzle R&R: Post-Testing	0	0.5	2	6.5	9	245	133.75	65	443.75	452.75	na	na	na
89	Nozzle R&R: Pre-Testing	0	0.5	2	6.5	9	213.5	111.25	54	378.75	387.75	na	na	na
90	Nozzle TPS MR Repair	0.5	0.5	12	12.5	25.5	5.5	5.5	0	11	36.5	1	1	0
91	Nozzle TPS R&R	0	0.5	2	6.5	9	8	8	0	16	25	1	1	0
92	Nozzle TPS Repair	0	0.5	2	4.5	7	4	4	0	8	15	1	1	0
93	Nozzle Tube Leak MR Accept/Waiver	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
94	Nozzle Tube Leak MR Repair	0.5	0.5	12	12.5	25.5	7.5	7.5	24.5	39.5	65	1	1	1
95	OPB Oxidizer Supply Duct R&R	0	0.5	2	6.5	9	6	4	0	10	19	na	na	na
96	Orifice R&R	0	0.5	2	6.5	9	2	2	0	4	13	1	1	0
97	PCA Assembly R&R	0	0.5	2	6.5	9	12	12	0	24	33	1	1	0
98	Pogo Baffle R&R	0	0.5	2	6.5	9	51.25	24.25	4	79.5	88.5	na	na	na
99	Powerhead Assembly R&R	0	0.5	2	6.5	9	4	4	8.5	16.5	25.5	1	1	1
100	Requirement/Documentation Change	0	0.5	12	0.5	13	0	0	0	0	13	0	0	0
101	RIV Assembly R&R	0	0.5	2	6.5	9	6.75	6.75	0	13.5	22.5	na	na	na
102	Seal R&R	0	0.5	2	6.5	9	1	1	0	2	11	1	1	0
103	Sensor Accept	0	0.5	5	0.5	6	0	0	0	0	6	0	0	0
104	Sensor Mount R&R	0	0.5	2	6.5	9	1	1	0	2	11	1	1	0
105	Sensor MR Accept	0.5	0.5	12	0.5	13.5	0	0	0	0	13.5	0	0	0
106	Sensor R&R: Post-Checkouts	0	0.5	2	6.5	9	19	8	8	35	44	na	na	na

Table 18. SSME unscheduled processing summary (Continued).

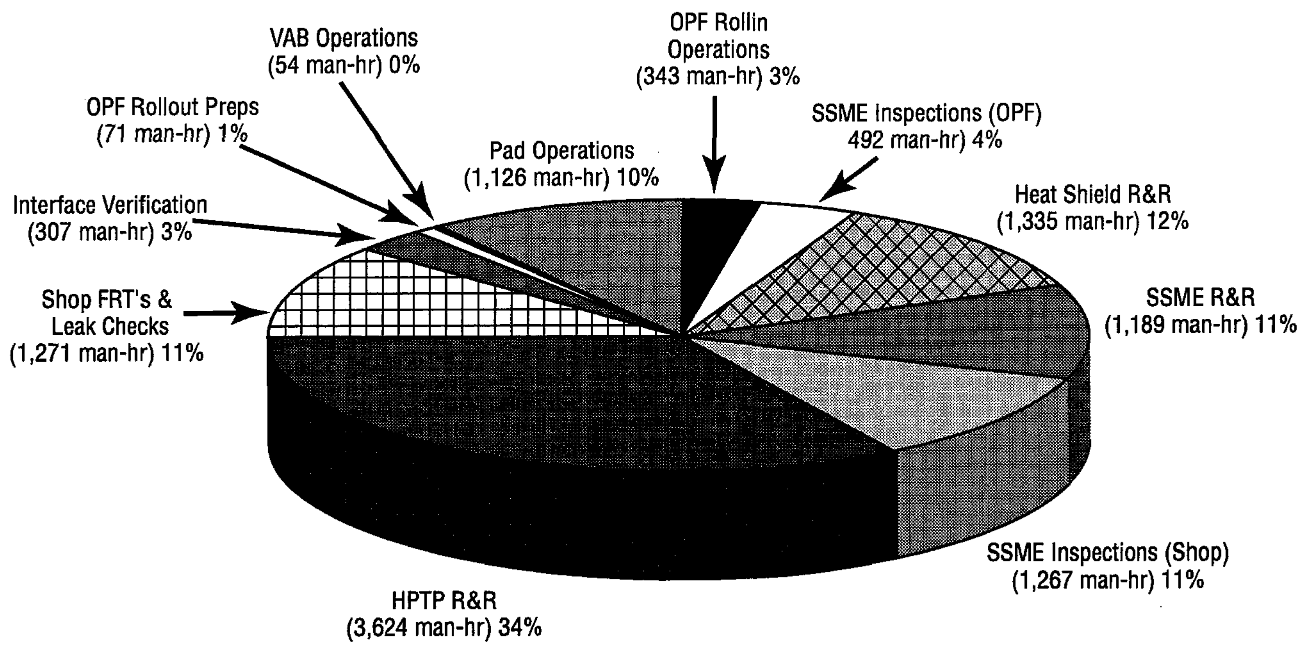
ID	SSME PR Classification	Tech Base Perf MHrs	QC Base Perf MHrs	Engr Base Diag MHrs	Engr Base Admin MHrs	Total Base MHrs	Tech Perf MHrs	QC Perf MHrs	Engr Perf MHrs	Total Perf MHrs	Total MHrs	No. Techs	No. QCs	No. Engrs
107	Sensor R&R: Pre-Checkouts	0	0.5	2	6.5	9	1	1	0	2	11	1	1	0
108	Sensor Repair	0	0.5	2	4.5	7	2.5	2.5	0	5	12	1	1	0
109	Stud/Bolt R&R	0	0.5	2	6.5	9	3	3	0	6	15	1	1	0
110	Surface Corrosion MR Repair	0.5	0.5	12	12.5	25.5	3.5	3.5	0	7	32.5	1	1	0
111	Surface Corrosion Repair	0	0.5	2	4.5	7	4	4	0	8	15	1	1	0
112	Surface Discoloration MR Repair	0.5	0.5	12	12.5	25.5	3.5	3.5	0	7	32.5	1	1	0
113	Surface Discoloration Repair	0	0.5	2	4.5	7	4	4	0	8	15	1	1	0
114	Threads Damage Repair	0	0.5	2	4.5	7	3	3	0	6	13	1	1	0
115	TVCA Pin R&R	0	0.5	2	6.5	9	5	5	0	10	19	1	1	0
116	Valve Actuator R&R: Pad Post-Testing	0	0.5	2	6.5	9	99.5	63	74	236.5	245.5	na	na	na
117	Valve Actuator R&R: Pad Pre-Testing	0	0.5	2	6.5	9	49.25	31.5	14.75	95.5	104.5	na	na	na
118	Valve Actuator R&R: Shop Pre-Testing	0	0.5	2	6.5	9	49.25	31.5	14.75	95.5	104.5	na	na	na
119	Valve R&R: Pad	0	0.5	2	6.5	9	127.75	80.25	93.5	301.5	310.5	na	na	na
120	Valve R&R: Shop Post-Testing	0	0.5	2	6.5	9	127.75	80.25	93.5	301.5	310.5	na	na	na
121	Valve R&R: Shop Pre-Testing	0	0.5	2	6.5	9	77.5	48.75	18.25	144.5	153.5	na	na	na
122	HPFTP R&R: Post-R&R	0	0.5	2	6.5	9	197	122.75	56	375.75	384.75	na	na	na
123	HPOTP R&R: Post-R&R	0	0.5	2	6.5	9	239.5	142.25	53.25	435	444	na	na	na

Table 19. Example of detailed data for unscheduled processing.

ID	Task Name	Duration	Work	Predecessors	Resource Names
1	**LPFTP Removal and Replacement/V5E24!**	**37.5h**	**94h**		
2	**LPFTP GSE Removal Preps!**	**2h**	**6h**		
3	Verify Proofload	2h	4h		Tech,QC
4	Perform LPFTP Receiving Inspection	1h	2h		Tech,QC
5	**LPFTP Removal Preps!**	**20.5h**	**25.5h**		
6	LAI Removal	2h	2h		Tech
7	Disconnect LPFTP Drain Line @ Joint D17	0.5h	0.5h	6	Tech
8	Disconnect LPFD @ Joint F2	3h	3h	7	Tech
9	Support LPFD	0.5h	0.5h	8	Tech
10	Disconnect LPFT Drive Duct @ Joint F8	3h	3h	9	Tech
11	Support LPFT Drive Duct	0.5h	0.5h	10	Tech
12	Disconnect LPFT Discharge Duct @ Joint F9	3h	3h	11	Tech
13	Support LPFT Discharge Duct	0.5h	0.5h	12	Tech
14	Demate Connectors @ LPFT Speed Transducer Joint F1.1	1h	1h	13	Tech
15	Install Handler Sling	1h	1h	14	Tech
16	Reference Check Joints F2, F8 and F9	5h	10h	15	Tech,QC
17	Horizontal Handler Removal Preps	0.5h	0.5h	16	Tech
18	**LPFTP Removal from Engine!**	**7.25h**	**23.5h**	**5**	
19	Establish Safety Clears for LPFTP Removal	0.25h	1.5h		Tech[3],QC,Safety,Engr
20	Connect J-Hook to Handler Sling	1h	6h	19	Tech[3],QC,Safety,Engr
21	Lower LPFTP to Floor	1h	6h	20	Tech[3],QC,Safety,Engr
22	Install LPFTP into Shipping Container	5h	10h	21	Tech,QC
23	**LPFTP Installation!**	**2.25h**	**13.5h**	**21**	
24	Establish Safety Clears for LPFTP Installation	0.25h	1.5h		Tech[3],QC,Safety,Engr
25	Connect J-Hook to Handler Sling	1h	6h	24	Tech[3],QC,Safety,Engr
26	Install LPFTP onto Engine	1h	6h	25	Tech[3],QC,Safety,Engr
27	**LPFTP Securing!**	**11.5h**	**24.5h**	**23**	
28	Torque and Stretch Joint F9	2h	4h		Tech,QC
29	Torque and Stretch Joint F8	2h	4h	28	Tech,QC
30	Torque and Stretch Joint F2	2h	4h	29	Tech,QC
31	Install LPFTP Speed Transducer @ Joint F1.1	1h	2h	30	Tech,QC
32	Perform Electrical Connector Mates	2h	4h	31	Tech,QC
33	Secure LPFTP Drain Line @ Joint D17	0.5h	1h	32	Tech,QC
34	Perform LPFTP Torque Check	1.5h	4.5h	33	Tech,QC,Engr
35	RTV Bolt Heads @ Joints F2, F8 and F9 and Reinstall LAI	0.5h	1h	34	Tech,QC
36	Retest Verification!	1h	1h	27	Engr

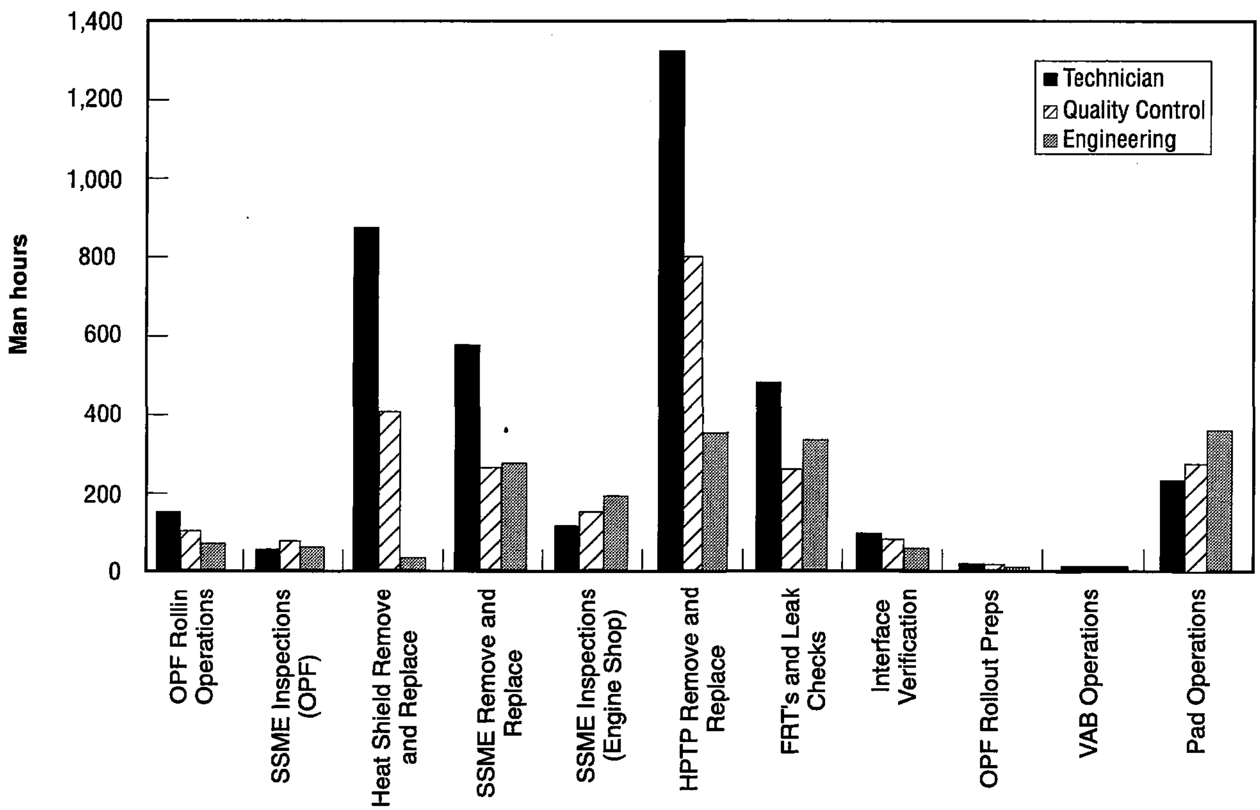
APPENDIX D—Pertinent SSME Results From Analysis of Data Collected

Figures 25–28 present examples of the fidelity of results supported by the data collected. These results, of course, apply to SSME processing and are subject to the assumptions, ground rules, and constraints described in section 5.



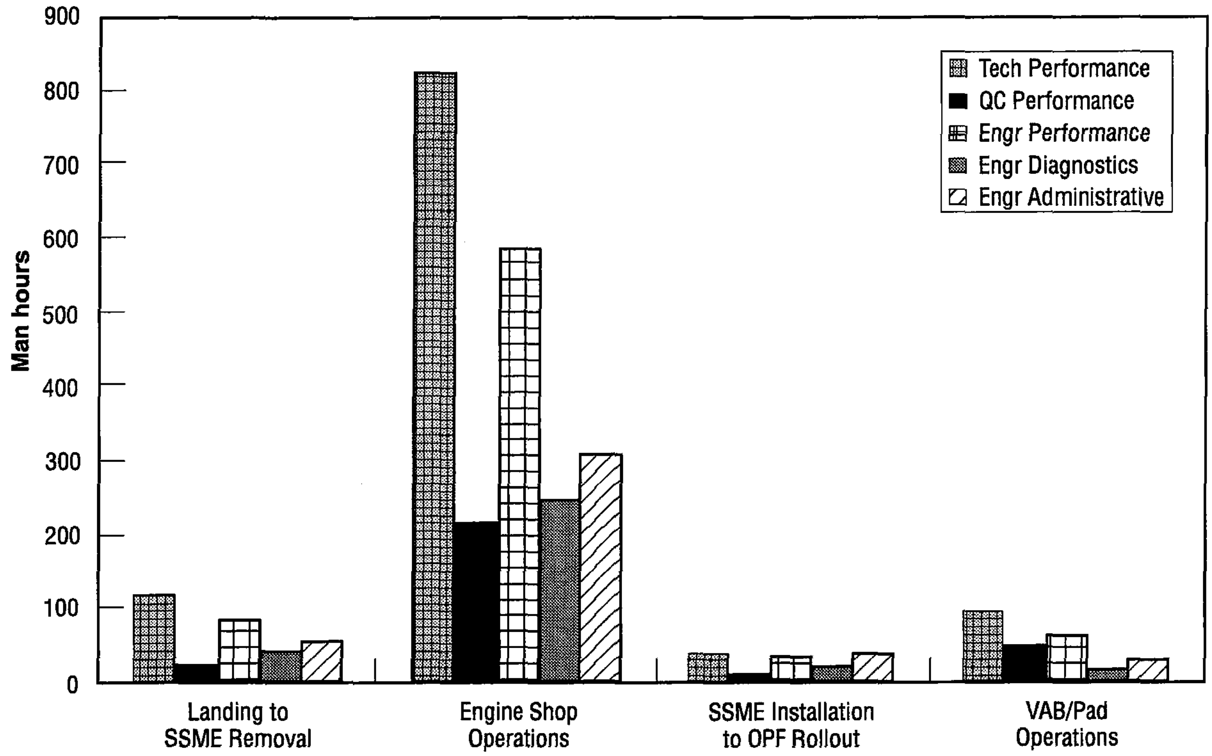
*Based upon three-engine processing

Figure 25. Total SSME manhours by process type.*



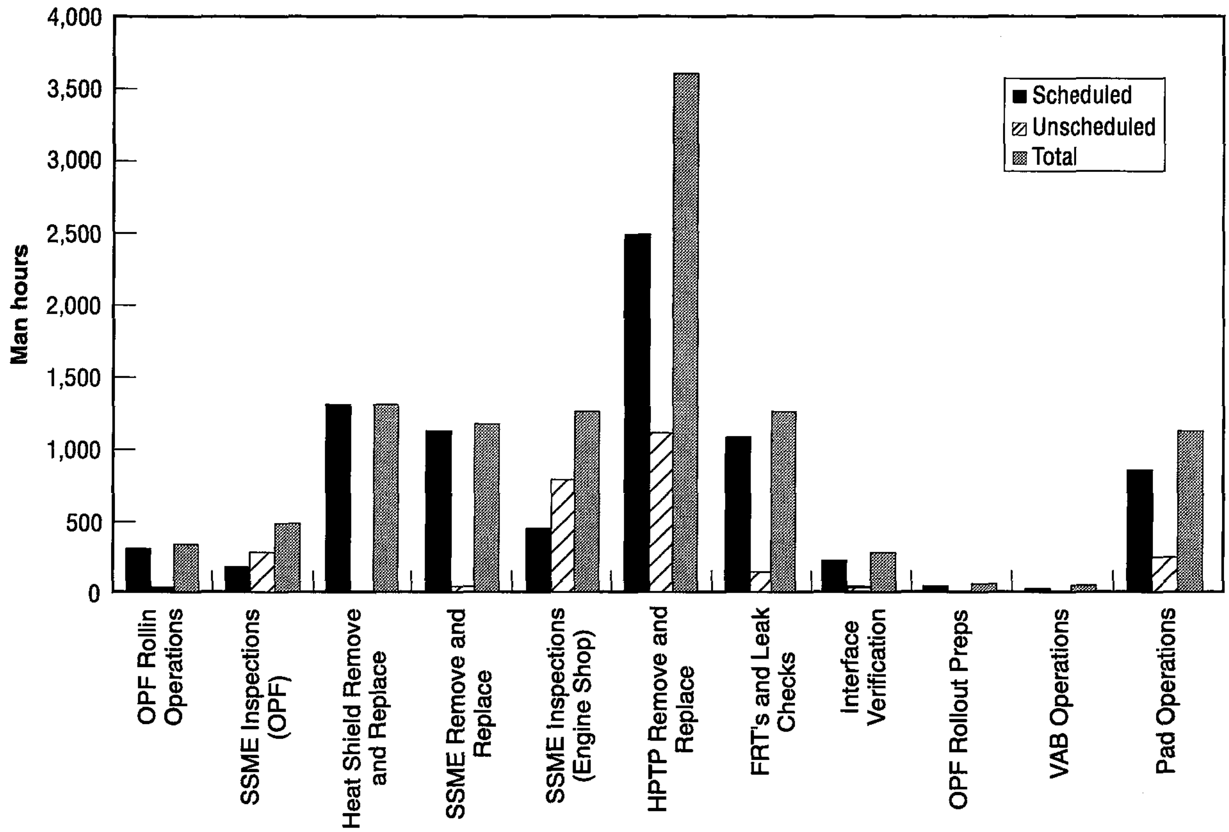
*Based upon three-engine processing

Figure 26. Scheduled SSME manhours by process type.*



*Based upon three-engine processing

Figure 27. Unscheduled SSME manhours by process type.*



*Based upon three-engine processing

Figure 28. SSME manhours by process type.

APPENDIX E—Reliability of Engine Sets With Engine Out Capability

The reliability estimates of future launch vehicles can be further refined upon receipt of more accurate estimates of engine reliability, catastrophic failure probabilities, coverage time, and trajectory requirements. This is a discussion of the effect of engine out capability and time of engine out on the reliability of aerospace vehicles. This study looks at sample data, sets out basic formulas, and presents results related to the issue of engine out. For the purpose of this study, only engine data will be considered. Upstream component reliabilities such as tanks, feed systems, power systems, etc. will be omitted.

Certain definitions are important to this discussion. Engine failure is failure to provide the level of thrust desired at the time desired. Catastrophic failure in an engine is a failure that results in a failure of a second engine in an engine set. Benign failure is the proportion of failures where failure does not result in catastrophic failure. Time of engine out refers to the time at which an engine can be shut down and the remaining engines will still provide the necessary thrust to achieve the desired orbit. Time of engine out refers to a known event.

Engine out capability is generally believed to provide increased overall engine set reliability. For example, using a binomial distribution[27,28] to analyze the example of three engines with one engine out at launch is as follows:

$R = p^n + np^{n-1}(1-p)$; where R is the engine set reliability, p the engine reliablity, and n the number of engines with one engine out capability.

A comparison between a two-engine set with no engine out capability and a three-engine set with one engine out capability is presented in table 20.

Table 20. Engine out capability comparison.

Engine Reliability (R)	Two Engines/ No Out (R=p2)	Three Engines/ One Out (R)
0.95	0.903	0.993
0.97	0.941	0.997
0.99	0.98	0.9997
0.999	0.998	0.999997

With a baseline engine reliability at the above values, there is a significant gain displayed by a three-engine set with one engine out as opposed to the two-engine set with no engine out capability. The gain diminishes as the engine reliability improves.

This analysis is now expanded. The cases need to be examined where catastrophic failure fraction and coverage times are varied. The formula that incorporates time of engine out and benign failure fraction is:[29]

$$R_{EO} = S^n T_d^n R^n [1 + T_u^{n-1} bn(R^{-c} - 1)] \ .$$

The parameters in the formula are:

R = Engine reliability
R_{EO} = Engine set reliability
S = Startup reliability
T_d = Throttle-down reliability
T_u = Throttle-up reliability
b = Benign failure fraction
c = Coverage
n = Number of engines.

For the following analysis, the formula will be simplified by setting both the throttle reliability and and startup reliability to 1. It is assumed, in this case, that throttling is accomplished within design margins and that startup reliability is ensured by some event such as holddown, both reasonable assumptions.

One study of the SSME[30] has suggested that such a catastrophic failure could occur in the main engines approximately 17 percent of the time (benign failure fraction of 83 percent). This is derived data based on a small amount of data—almost all main engine tests have occurred singly and the study concluded that only 3 of 17 failures could have resulted in a second engine failure. This conclusion was generated based on the incidence of explosions and test stand damage that occurred. The small amount of data, typical in the aerospace industry, makes it difficult to draw definitive conclusions or to use confidence intervals.

Another factor to be considered in overall engine set reliability is the time of engine out. If all three engines are needed for 100 sec of flight and then only two are necessary to obtain orbit, this time of engine out translates to an increased reliability for the engine system.

With example engine reliability, table 21 can be generated. Two conclusions can be drawn. First the probability of catastrophic failure rather quickly degrades the increase of reliability gained due to engine out capability. From table 21, at 0.97 reliability and engine out at time 0, a catastrophic failure probability increase from 0.1 to 0.25 results in a decline in reliability from 0.9889 to 0.9762 for the three-engine case. Still, this is considerably higher than the two-engine, no out case reliability of 0.941.

Second, it is evident that reliability can be gained if some engine out time is possible. For example, if engine out is possible for two-thirds of the flight (0.97 engine reliability and 0.2 catastrophic failure factor), then the reliability goes from 0.913 to 0.9578—a significant gain. Note that the engine reliability at t=1 for all catastrophic failure factor values is equal to the n engines/no out capability since this is equivalent to all engines being necessary for the full-duration flight.

Table 21. Engine out and time of engine out comparison.

Engine Reliability	Catastrophic Failure Probability	Engine Out Time	Three Engines/ One Out Reliability
0.95	0.1	0	0.9792
		0.33	0.9383
		0.67	0.8969
		1	0.8574
	0.2	0	0.9657
		0.33	0.9293
		0.67	0.8925
		1	0.8574
	0.25	0	0.9589
		0.33	0.9248
		0.67	0.8903
		1	0.8574
0.97	0.1	0	0.9889
		0.33	0.9635
		0.67	0.9376
		1	0.9127
	0.2	0	0.9804
		0.33	0.9578
		0.67	0.9348
		1	0.9127
	0.25	0	0.9762
		0.33	0.9550
		0.67	0.9334
		1	0.9127
0.99	0.1	0	0.9968
		0.33	0.9880
		0.67	0.9790
		1	0.9703
	0.2	0	0.9938
		0.33	0.9860
		0.67	0.9780
		1	0.9703
	0.25	0	0.9924
		0.33	0.9850
		0.67	0.9776
		1	0.9703
0.999	0.1	0	0.9997
		0.33	0.9988
		0.67	0.9979
		1	0.9970
	0.2	0	0.9994
		0.33	0.9986
		0.67	0.9978
		1	0.9970
	0.25	0	0.9992
		0.33	0.9985
		0.67	0.9977
		1	0.9970

REFERENCES

1. Ryan, R.; et al.: "*Working on the Boundaries: Philosophies and Practices of the Design Process*," NASA–TP–3642, July 1996.

2. Blanchard, B.S.; and Fabrycky, W.J.: *Systems Engineering and Analysis*, Prentice-Hall, Englewood Cliffs, NJ, 1981.

3. Gaubatz, W.A.; et al.: "*Translating SSTO System Operability and Supportability Requirements into Measures of System Effectiveness*,"AIAA 96–4247, September 1996.

4. Ryan, R.; and Verderaime, V.: "*Systems Design Analysis Applied to Launch Vehicle Configuration*," NASA–TP–3326, MSFC, January 1993.

5. NLS/ALS Project Office, "*Launch Operations Concerns and Operations Enhancing Technology*," NASA-MSFC, AL, 1990.

6. Banks, J.; and Carson; J.S.: *Discrete-Event System Simulation*, Prentice-Hall, Englewood Cliffs, NJ, 1990.

7. Joshi, B.; et al.: "*Optimization of Operations Resources via Discrete Event Simulation Modeling*," AIAA–96–4181, September 1996.

8. Morris, W.D.; et al.: "*Defining Support Requirements During Conceptual Design of Reusable Launch Vehicles*," AIAA–95–3619, September 1995.

9. Weber, T.F.: "Reliability and Maintainability in Space Systems Design," Aerospace Design, No. 93–1025, February 1993.

10. Fleming, B.: *Launch Vehicle Maintenance Analysis Final Report*, MCR–92–1341, November 1992.

11. Huffaker, F.; and Fleming, B.: "*Operations Database Development for VRC*," AIAA–96–4244, September 1996.

12. Findlow, F., et al.: "*Available Shuttle System Database Idenfication and Pathfinder RM&S Data Search—Final Report*," Lockheed-Martin Corp., May 1995.

13. Christenson, R.L.; and Holt, J.B.: "*Future Launch Vehicle Propulsion Systems Operability Analysis*," AIAA–95–4068, September 1995.

14. Komar, D.R.; and Christenson, R.L.: "*Reusable Launch Vehicle Engine Systems Operations Analysis*," AIAA–96–4246, September 1996.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
July 1998

3. REPORT TYPE AND DATES COVERED
Technical Publication

4. TITLE AND SUBTITLE
Reusable Rocket Engine Operability Modeling and Analysis

5. FUNDING NUMBERS

6. AUTHORS
R.L. Christenson and D.R. Komar

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M–879

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TP–1998–208530

11. SUPPLEMENTARY NOTES
Prepared by Propulsion Laboratory, Science and Engineering Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified—Unlimited
Subject Category 15
Standard Distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This paper describes the methodology, model, input data, and analysis results of a reusable launch vehicle engine operability study conducted with the goal of supporting design from an operations perspective. Paralleling performance analyses in schedule and method, this requires the use of metrics in a validated operations model useful for design, sensitivity, and trade studies. Operations analysis in this view is one of several design functions.

An operations concept was developed given an engine concept and the predicted operations and maintenance processes incorporated into simulation models. Historical operations data at a level of detail suitable to model objectives were collected, analyzed, and formatted for use with the models, the simulations were run, and results collected and presented. The input data used included scheduled and unscheduled timeline and resource information collected into a Space Transportation System (STS) Space Shuttle Main Engine (SSME) historical launch operations database. Results reflect upon the importance not only of reliable hardware but upon operations and corrective maintenance process improvements.

14. SUBJECT TERMS
EP73 operations analysis, operability, engine operations, reliability, availability, dependability, turnaround time, rocket engine, maintainability, scheduled and unscheduled maintenance, SSME operations data, reusable launch vehicle

15. NUMBER OF PAGES
90

16. PRICE CODE
A05

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassifed	Unclassified	Unclassified	Unlimited

15. Christenson, R.L.; and Ryan, R.M.: "*Critical Operations Analysis for a Future Reusable Engine*," unpublished, September 1997.

16. NASA–KSC, *STS CAPSS,* 1981–current.

17. NASA–KSC, *STS PRACA Database*, 1989–1994.

18. *MS Project User's Manual*, Microsoft Corporation, Redmond, WA, 1992.

19. *Extend™ User's Manual,* Imagine That®, Inc., San Jose, CA, 1995.

20. Rocketdyne, *SSME Orientation,* NASA Contract NAS8–40000, December 1991.

21. Jenkins, D.R.: *Space Shuttle,* Broadfield Publishing, Florida, 1992.

22. Law, A.; and Kelton, W.: *Simulation Modeling and Analysis*, McGraw-Hill, Inc., New York, 1991.

23. Hines, W.W.; and Montgomery, D.C.: *Probability and Statistics in Engineering and Management Science,* Wiley, NY, 1980.

24. Kapur, K.C.; and Lamberson, L.R.: *Reliability in Engineering Design*, Wiley, New York, 1977.

25. Morris, W.D.; et al.: "*Analysis of Shuttle Orbiter Reliability and Maintainability Data for Conceptual Studies*," AIAA–96–4245, September 1996.

26. Pierce, C.W.; "*A Cost Analysis of Integrated Vehicle Health Management as Applied to the Shuttle OMS/RCS*," LSO–093–1753, September 1993.

27. Snedecor, G.W.; and Cochran, W.G.: *Statistical Methods*, Iowa State University Press, Ames, Iowa, 1980.

28. Dhillon, B.S.: *Mechanical Reliability: Theory, Models, and Applications,* AIAA, Washington, DC, 20024, 1988.

29. Lee, R.A.; and Steincamp, J.W.: "*Reliability Analysis Techniques for Engine-Out Failures in Main Propulsion Systems*," AIAA–92–1337, March 1992.

30. Scientific Applications International Corporation, "*Current Launch Vehicle Practice and Data Base Assessment*," Astronautics Laboratory, Edwards Air Force Base, CA, 1989.