TURNAROUND TIME MODELING FOR CONCEPTUAL ROCKET ENGINES

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ABSTRACT

Recent years have brought about a paradigm shift within NASA and the Space Launch Community regarding the performance of conceptual design. Reliability, maintainability, supportability, and operability are no longer effects of design; they have moved to the forefront and are affecting design. A primary focus of this shift has been a planned decrease in vehicle turnaround time. Potentials for instituting this decrease include attacking the issues of removing, refurbishing, and replacing the engines after each flight.

With new reusable engine designs required to have a turnaround time of two weeks or less, it is important to understand the operational affects of an engine on turnaround time, ground support personnel and equipment. One tool for visualizing this relationship involves the creation of a Discrete Event Simulation (DES). A DES model can be used to run a series of trade studies to determine if the engine is meeting its requirements, and, if not, what can be altered to bring it into compliance. Using DES, it is possible to look at the ways in which labor requirements, parallel maintenance versus serial maintenance, and maintenance scheduling affect the overall turnaround time.

A detailed DES model of the Space Shuttle Main Engines (SSME) has been developed. Trades may be performed using the SSME Processing Model to see where maintenance bottlenecks occur, what the benefits (if any) are of increasing the numbers of personnel, or the number and location of facilities, in addition to trades previously mentioned, all with the goal of optimizing the operational turnaround time and minimizing operational cost. The SSME Processing Model was developed in such a way that it can easily be used as a foundation for developing DES models of other operational or developmental reusable engines. Performing a DES on a developmental engine during the conceptual phase makes it easier to affect the design and make changes to bring about a decrease in turnaround time and costs.

INTRODUCTION

In 1998, Rick Christenson and D.R. Komar of NASA-MSFC published a report entitled Reusable Rocket Engine Operability Modeling and Analysis[1]. In their report they stated that an effective operations model supported by data from an existing system would help in designing a new propulsion system for minimal ground support. For their report, Mr. Christenson and Mr. Komar collected maintenance data on the SSME from the Shuttle Program. The data collected contained over 1000 planned maintenance tasks, including the mean duration, predecessors, and labor requirements for each task, in addition to data on unplanned maintenance. With the help of NASA-MSFC's Barney Holt, Mr. Christenson and Mr. Komar developed a DES of the SSME maintenance process based upon the data they had collected.

Their original SSME Processing Model was developed using an off the shelf program called Extend, developed by Imagine That![2]. Extend is a discrete event simulation tool that allows designers to develop dynamic models of real-life processes in a wide variety of fields by creating models from building blocks, exploring the process involved, determining relationships, and then changing assumptions to arrive at an optimum solution. The original SSME Processing Model captured the SSME maintenance that is performed on the runway, Orbiter Processing

conflicts to occur. Of the 1000 plus maintenance tasks that had been identified, only 60 high level tasks were included in the original model along with a number of unplanned maintenance tasks which had been identified.

In 2002 a new effort began to increase the capabilities of the original SSME Processing Model and develop a method in which the SSME Processing Model could be used as the foundation for other engine models. In addition to enhancing the model itself an additional objective was to update the data used by the model. The original data was from the 1998 time frame when engine maintenance was still performed in the VAB. By 2002 the SSME Processing Facility had been built and the SSME maintenance had moved out of the VAB. Also, between 1998 and 2002 several upgrades to the engines were made which have had an effect on the maintenance tasks. The original SSME Processing Model was used as the starting point for developing the new SSME Processing Model.

The SSME Processing Model focuses on the same key areas of operations for the SSME as the original model and includes the SSME processing facility, where six SSMEs can be worked on simultaneously as well as depot maintenance, and engine retirement. Figure 1 shows the opening screen of the SSME Processing Model and the seven areas of operations.
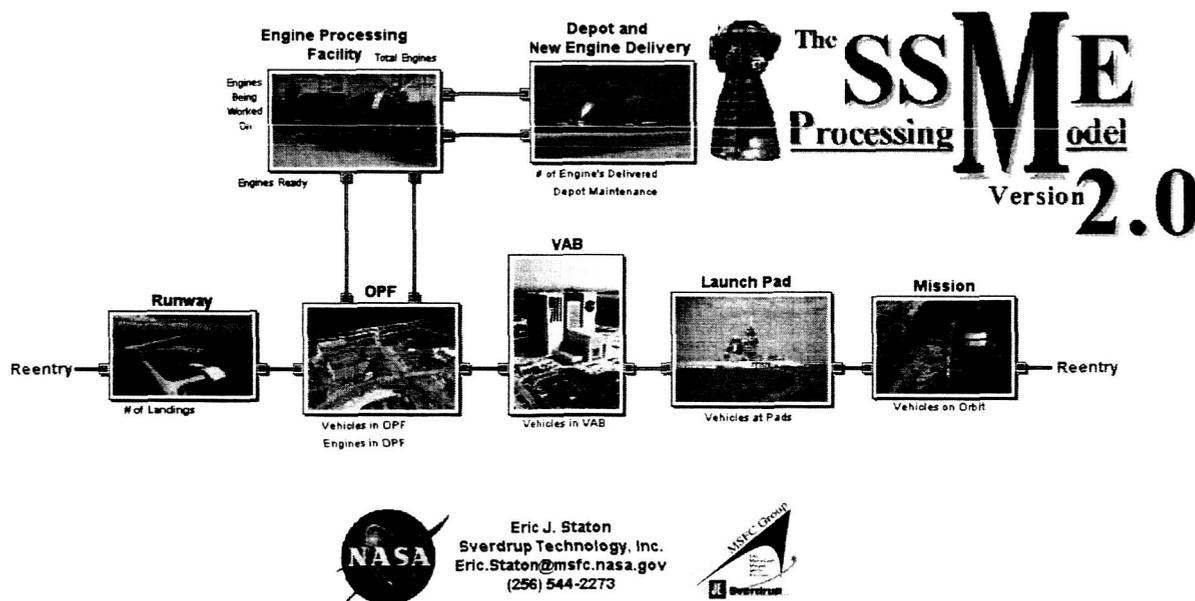

Figure 1: SSME Processing Model

SSME PROCESSING MODEL

When developing the new SSME Processing Model a major objective that needed to be met was its evolution into a generic Engine Processing Model that could easily be modified to represent other engines. This meant building into the SSME Processing Model features that would not specifically apply to SSME processing flow, but rather would be flexible enough to handle different types of processing flow. In this way, a number of trade studies could be performed by changing the processing flow and exploring the design space. To accomplish this objective a number of capabilities needed to be added to the model signifying a major departure from how the original model was setup.

INDIVIDUAL ENIGNES

A major difference between the original and new SSME Processing Models is how the engines are dealt with. The original model treated the engines as a cluster, if one engine was removed all the engines were removed. This method of modeling worked for the SSME model

capabilities were added to the model representing a major departure from how the original model was setup.

Individual Engines: A major difference between the original and new SSME Processing Models is how the engines are dealt with. The original model treated the engines as a cluster. If one engine was removed, then all the engines were removed. This method of modeling worked for the SSME model, but is extremely limiting to the design space. Many of the engines and vehicles currently in the conceptual design phase call for engine maintenance to be performed on the vehicle. The engines are removed per a maintenance schedule or as necessitated by unplanned maintenance. With unplanned maintenance it may be necessary to remove only one engine and not the cluster. In order to remove a single engine, it became necessary for the model to deal with the engines individually.

This methodology opens up the design space in which trade studies can be performed using this model. It is now possible to introduce scheduled maintenance that is tied to the number of flights of individual engines. For a conceptual vehicle with four engines, the model can handle the most extreme case in which one engine is removed and sent to the engine shop for maintenance, another engine is removed for depot maintenance, a third engine is removed and retired, and the last engine is left onboard the vehicle for regular maintenance.

Excel Database: One of the major objectives for the new SSME Processing Model was to create a generic model that could easily be modified to represent other engines. Altering the model to treat the engines individually was the first step. The second step was to remove the engine specific data from the model leaving a generic core. To accomplish this objective, an Excel database was developed to hold all the engine data. A portion of the SSME Processing Model Excel database is shown in Figure 2.

Built into Extend is the ability to link a model to an Excel file. At the beginning of the simulation, Extend reads all the data from an Excel file into a Global Data Array that is accessed by the model throughout the simulation. Dealing with engine data in this way has many advantages. A major advantage is centrally located user input data. When changes were made to maintenance tasks in the original SSME model, the user had to locate the specific task and make the required changes. If a large number of changes were needed, it would be time intensive to locate each maintenance task and make the changes. Using the Excel database, all the maintenance information is centrally located making it easy to input significant changes to the data without ever touching the model.

The Excel database, as shown in Figure 2, is broken down into several sections. The first section deals with identifying the maintenance task. The first column shows the Task ID Number. It is through this number that the model knows which maintenance task is being performed. The next column in the database is a list of all the maintenance tasks performed. The next section deals with the distribution associated with each task. For the SSME Processing Model it is assumed that a lognormal distribution is applied with a mean and standard deviation provide by the user. The mean and standard deviation are represented by Parameter1 and Parameter2, respectively. Parameter3 is reserved for instances where the user chooses to use a distribution that requires three parameters. The next section of the database deals with Technical, Quality Control, Safety, and Engineering labor requirements and categories. These categories represent the number of personnel required to perform each task. The final section of the database deals with the frequency at which specific events occur. The first of these columns dictates task frequency. A (1) indicates that a task is performed every flight, a (2) indicates the task is performed once every two flights. The next three columns deal with how often an engine is removed and sent to the engine shop, how often an engine is sent for depot maintenance, and the life of an engine.

GLOBAL ARRAY DATA

#	Task	Distribution	Parameter1	Parameter2	Parameter(3	Total Mhrs	Tech Personnel	Quality Personnel	Safety Personnel	Eng. Personnel	Task Frequency	Eng. Removal Frequency (Flts)	Eng Depot Frequency (Flts)	Eng. Life Expectancy
1	Runway OPS													
2	Install Environmental...													
3														
4	Runway OPS													
5	Nozzle External Inspections & Bearing Drying	LogNormal	1.33	0.40	0.00	2.67	2.00	1.00	0.00	0.00	1.00			
6	AFT Section - SSME External Inspections & Install Miscellaneous Covers	LogNormal	2.93	0.93	0.00	11.73	2.00	1.00	0.00	1.00	1.00			
7	LPF Duct Bag Pressurization Inspection, Bag Removal, & Install P20.2	LogNormal	1.33	0.40	0.00	4.00	2.00	1.00	0.00	0.00	1.00			
8	Install Ferry Flight Throat Plugs & Drain Line Adapters	LogNormal	1.33	0.40	0.00	4.00	2.00	1.00	0.00	0.00	1.00			
9	Nozzle Tube Leak Checks	LogNormal	1.00	0.40	0.00	4.00	2.00	1.00	0.00	0.00	1.00			
10	MPS/SSME System Pressure Decay Checks	LogNormal	0.33	0.30	0.00	3.00	1.00	1.00	0.00	1.00	1.00			
11	Position Engines & Install TVC Ferry Locks	LogNormal	0.33	0.10	0.00	0.67	1.00	1.00	0.00	0.00	1.00			
12	Nozzle to Tail Cone Measurements	LogNormal	2.00	0.60	0.00	6.00	2.00	1.00	0.00	0.00	1.00			
13	Remove SSME Miscellaneous Covers for Aft Closeout	LogNormal	0.87	0.20	0.00	1.33	1.00	1.00	0.00	0.00	1.00			
14		LogNormal	2.67	0.80	0.00	8.00	2.00	1.00	0.00	0.00	1.00			
15	Orbiter w/OPF Door/SD...													
16	OPF Bay Open for Normal Work													
17	Orbiter Initial Power-Up													
18														
19	Install Entry Level Platforms/V35-00001	LogNormal	0.67	0.20	0.00	0.00	0.00	0.00	0.00	0.00	1.00			
20	Install Floor Level Platform/V35-00001	LogNormal	1.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	1.00			
21														
22														
23	Remove Nozzle Bumpers (if Req.)	LogNormal	0.33	0.10	0.00	0.33	1.00	1.00	0.00	0.00	1.00			
24	Remove Environmental Covers	LogNormal	1.00	0.30	0.00	1.00	1.00	1.00	0.00	0.00	1.00			
25	HPFTP Bearing Drying Ops/V1011.01													
26	Extend Platforms 10S and 19S/V1011.01	LogNormal	0.17	0.05	0.00	0.50	2.00	1.00	0.00	0.00	1.00			
27	Remove SSME Environmental Closures	LogNormal	0.17	0.05	0.00	0.17	1.00	1.00	0.00	0.00	1.00			
28	Mate Bearing Drying Flexhoses	LogNormal	0.67	0.20	0.00	1.33	1.00	1.00	0.00	0.00	1.00			
29	Retract Platforms 10S and 19S/V1011.01/V35xx	LogNormal	0.17	0.05	0.00	0.50	2.00	1.00	0.00	0.00	1.00			
30	MCC Acoustic Cavity Inspections/Install Throat Plugs	LogNormal	1.33	0.40	0.00	2.67	1.00	1.00	0.00	0.00	1.00			
31	Mate Bearing Drying Exhaust Duct	LogNormal	1.33	0.40	0.00	4.00	2.00	1.00	0.00	0.00	1.00			
32	Install SSME Bellows and Miscellaneous Covers/V5057	LogNormal	1.00	0.30	0.00	2.00	1.00	1.00	0.00	0.00	1.00			
33	Establish Safety Clears	LogNormal	0.08	0.03	0.00	0.42	2.00	0.00	0.00	1.00	1.00			
34	HPFTP Bearing Drying Purge Initiated	LogNormal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00			
35	Perform SSME Bearing Drying	LogNormal	2.83	0.85	0.00	14.17	2.00	1.00	0.00	1.00	1.00			
36	Perform Filter Inspection and Cleaning	LogNormal	0.83	0.25	0.00	1.67	1.00	1.00	0.00	1.00	1.00			
37	Disassemble Test Setup and Remove Throat Plugs	LogNormal	2.67	0.80	0.00	5.33	2.00	0.00	0.00	0.00	1.00			
38	Install Bellows & Miscellaneous Covers	LogNormal	1.33	0.40	0.00	4.00	2.00	1.00	0.00	0.00	1.00			
39	LPF Duct Bag Pressurization Inspection, Bag Removal, & Install P20.2	LogNormal	0.67	0.20	0.00	2.00	2.00	1.00	0.00	0.00	1.00			
40	Hydraulic Power-Up & Install TVC Locks	LogNormal	0.67	0.20	0.00	1.33	2.00	1.00	0.00	0.00	1.00			

Figure 2: Excel Database

Frequencies: Allowing the SSME Processing Model to deal with the engines individually enables the model to handle maintenance schedules. Using the Excel database the user can change any of the frequencies to develop a maintenance schedule that is applied to all engines. The user can then perform trade studies using the frequencies to produce a desired turnaround time. The frequencies developed by performing trade studies become requirements for designers . The component's development could work toward developing a component reliability that generates the required frequency and predetermined turnaround time.

Unplanned Maintenance: A major advantage of modeling engines individually and developing a maintenance schedule is the ability to introduce unplanned maintenance. Within the new SSME Processing Model there is a block that deals with unplanned maintenance. The unplanned maintenance represents the probability of detecting something during post-flight maintenance checks that requires an engines removal, regardless of the engine's maintenance schedule. This probability is tied to the number of flights the engines have made. The higher the number of flights, the greater the probability that something will occur requiring the engine's removal. With this capability in the model, it is possible to have an engine cluster that contains engines that are at different places in their maintenance schedules, creating a realistic processing flow. This variability is another component to the trade space that effects turnaround time.

Serial and Parallel Maintenance: Another capability of the SSME Processing Model is the ability to simulate maintenance task as either serial or parallel processes. By changing the succession in which tasks are performed, the user can perform a number of trades to determine the effect on turnaround time. If there is a significant benefit to performing a series of task in parallel it could have an effect on the design. The design would need to allow room for the required personnel to complete the tasks simultaneously.

Labor Resources: Tied closely to the issue of serial and parallel maintenance are the effects of labor resources and the constraints they put on the simulation. As tasks are changed from serial to parallel, or parallel to serial, the minimum number of resources required change. If a number of tasks are being performed in parallel because they decrease the overall turnaround time the results should be weighted against the cost of having a larger work force. Does the saving in turnaround time justify the cost of the additional personnel? With any trade study the minimum number of resources should be examined to determine if the turnaround time saving offsets the increase in cost.

Work Shifts: In addition to determining the number of personnel necessary to perform the required tasks, the number of shifts worked has an impact on turnaround time and costs. For the SSME Processing Model, it is assumed that there are two eight hours shifts per day, five days a week, and 52 weeks a year. When performing trade studies it may be beneficial to simulate a single work shift for certain facilities, such as the runway, and three shifts working in other areas like the OPF bays. Built into Extend is the ability to set up a work schedule that includes as much detail as the user deems necessary. A user could simulate work schedules that have down times due to holidays or lunch hours.

Modeling Assumptions: Even with the bulk of the engine specific data centrally located in an Excel database, there are still a number of engine specific assumptions built into the model that can be changed for new engine concepts or trade studies. These assumptions are generally program level, such as the number of spare engines present in the simulation, the total number of engines in the program, and how many engines are on a vehicle. Also, the user can change the number of facilities being simulated. The model is setup in such a way that the user can easily change the number of OPF bays or number of launch pads to be simulated without making extensive changes to the model.
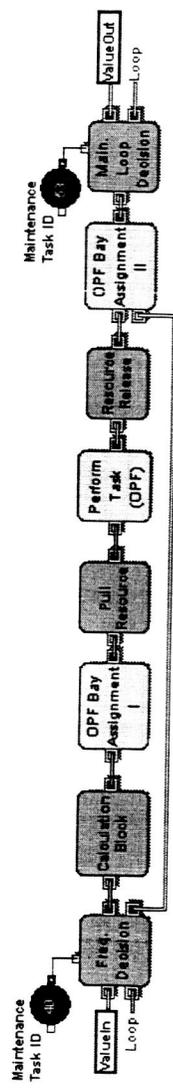
SSME Maintenance Block: At the heart of the SSME Processing Model is the Engine(s) Maintenance Task Block. The Engine(s) Maintenance Task Block, as shown in Figure 4, has been customized for the maintenance performed in the OPF and is comprised of several components; the Frequency Decision Block, Calculation Block, OPF Bay Assignment I Block, Pull Resource Block, Perform Task (OPF) Block, Resource Release Block, OPF Bay Assignment II Block, Maintenance Loop Decision Block, and Maintenance Data Block. The Maintenance Data

Block located across the bottom of the Engine(s) Maintenance Task Block is the only part of the block requiring user inputs. The Start and End Task ID Numbers are the only engine specific data captured by the Engine(s) Maintenance Task Block. The ID Numbers translate directly to the ID Numbers in the Excel database. For the example shown in Figure 4, Tasks 40 through 53 are performed in serial by this specific block. The user also specifies which type of distribution will be used to calculate the task duration and the resource pools to be used. There are four resource pools used, Technical, Quality Control, Safety, and Engineering, but there are individual resource pools used for the runway, OPF, VAB/Pad, engine shop and depot maintenance, therefore, the resource pool being used needs to be specified.

When an engine cluster enters the Engine(s) Maintenance Task block, the first component in the maintenance flow is the Frequency Decision block responsible for determining whether the maintenance task is performed based upon the task frequency and the number of engine flights. If maintenance is performed, the engine proceeds to the Calculation Block shown in Figure 5. The Calculation Block is where task duration and man-hours are calculated based upon data in the Excel database. The areas of the Calculation Block titled Task Decision Maker, Labor Data Retrieval, and Parameter Retrieval contain a number of Global Array Blocks as shown in Figure 6. These are responsible for retrieving specific data from the database based upon inputs that specify the row and column in the database where the required data is located. The column value is a constant and does not change while the row value is equal to the Task ID Number of the task being performed. Based upon the series of tasks specified by the user, the model will change the Global Array Block row value so the appropriate maintenance task data is retrieved from the database. Data retrieved from the database in the Calculation Block is used by the Maintenance Calculation Block, shown in Figure 7, to calculate task duration and technical, quality control, safety, and engineering man-hours required.

The next step in the Engine(s) Maintenance Task block is to separate the engines into their respective OPF bays. Since the SSME Processing Model treats the engines individually, and the processing flow for each OPF bay over lays each other, it is important to keep track of which engine belongs in which bay. It is important to know the location of each engine because in certain facilities, such as the OPF, one engine in a cluster is worked on at a time, and it is important to make sure the maintenance task has been performed for each engine in the cluster before beginning the next maintenance task. The accounting of the engines is performed by the OPF Bay Assignment I and OPF Bay Assignment II blocks.

Upon exiting the OPF Bay Assignment I block, engines enter the Pull Resource block. Here, the required personnel are pulled from their respective resource pools so that the engine and personnel can proceed to the Perform Task block. The Perform Task block holds the engines and resources for a period equivalent to the task duration calculated by the Calculation Block. Next the engines enter the Resource Release block where the personnel are released back to the resource pools to be used in the next maintenance task. The last component of the Engine(s) Maintenance Task block is the Maintenance Loop Decision block which is responsible for making sure all maintenance tasks specified by the user have been performed. If not, the engines are sent back to the beginning of the block for performance of the next maintenance task until all specified tasks have all been performed.

Figure 4: New SSME Maintenance Block Structure
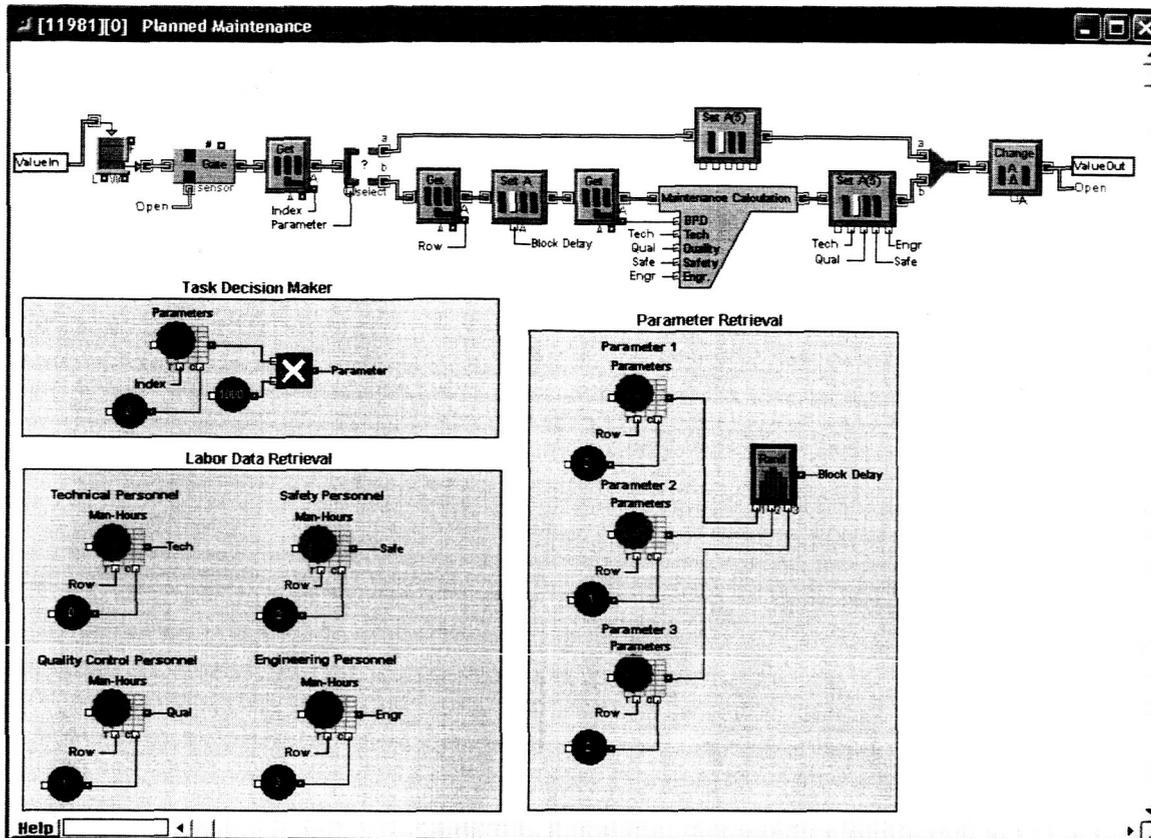
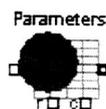**Figure 5: Calculation Block**

Figure 6: Global Block

Figure 7: Maintenance Calculation Block

SSME TRADE STUDY

Using the SSME Processing Model it is possible to perform a series of trade studies to determine ways of decreasing the turnaround time of the SSMEs. The following is an example trade study showing how turnaround time for SSMEs can be decreased simply by changing a few assumptions. In this trade study, four case studies were performed in addition to the nominal. For all the case studies, the general assumptions were that the simulation would model the Shuttle maintenance flow simulating a single Orbiter and three SSMEs. Additional assumptions are two eight hour shifts per day, five work days per week, and fifty-two weeks per year.

Nominal Case: The SSME Processing Model was run without any changes to the model. These results would resemble the actually turnaround time of the SSMEs from landing to launch. For the nominal case the turnaround time is 1504 work hours or 4.7 months.

Case Study 1: The first case study uses the nominal case with the added assumption of three spare engines being configured so that when one cluster of engines is removed another cluster is ready to be installed. The result for this study is a turnaround time of 989 work hours or 3.1 months.

Case Study 2: The second case study uses the nominal case, but it is assumed that the engines can remain on the vehicle while maintenance is performed. Study 2 also assumes personnel working the engines would have unlimited access to the aft compartment of the Orbiter and would not be impeded by crews working on the Orbiter. While the engine crews would have unlimited access to the engines, the constraints of the vehicle and space available require that only one engine worked on at a time. The turnaround time for this case is 2010 work hours or 6.3 months.

Case Study 3: The third case study builds off Case Study 1 with the added assumption that the SSMEs are installed on a new vehicle that has space available to allow work crews to work on all three engines simultaneously. This case study is setup to show advantages, if any, gained by having dedicated crews working on each engine. The result for this study is a turnaround time of 390 hours or 1.3 months.

Case Study 4: The final case study takes Case Study 3 a step further and makes the assumption that all three engines could be removed as a cluster instead of individually. The result of this study is a turnaround time of 343 hours or 1.1 months.

Summary: The results of these five cases can be seen in Table 1 and in Figure 8. An important part of any trade study is examining the affect on turnaround time. The trade studies performed here focus on only a few contributing factors. For Case Study 1 it was assumed that there were three spare engines in the flow such that when an engine cluster was removed another was waiting to be installed. This saves over 500 work hours and allows the vehicle to get an extra flight in each year. What this example doesn't take into account is the additional cost to the program of having an additional three engines just for an extra flight a year. If the Shuttle program operated this way, a fleet of three Orbiters, an additional nine SSMEs, would need to be purchased. What needs to be examined are the cost benefits of purchasing three additional engines versus having three flights a year instead of two.

Not only is it important to take into consideration all aspects of turnaround time, such as cost or personnel, but to be able to examine why the trade studies produce the results. This can clearly be seen with Case Study 2. It is normally argued that on vehicle maintenance would have a large impact on decreasing turnaround time. Case Study 2 shows that the turnaround time increases by over 500 work hours. In this example it was assumed that the engines would remain on the vehicle and that each engine would be worked on one at a time. While this eliminates the time required to remove and replace the engines, it increases required engine turnaround time, this results because, the SSME Processing Facility, the engines have their own bay and can be worked on simultaneously, while in the OPF, they have to be worked serially because of space constraints in the aft compartment of the Orbiter.

Other constraints that are at a constant tug with turnaround time are number of personnel and personnel cost. When examining case study three and four it is assumed that the "new" Orbiter has the room in the aft compartment to work on the engines simultaneously, and case study four assumes that the engines can be removed and replaced as a cluster. In order to work on the engines simultaneously, it would require that two additional crews be hired such that each engine would have a dedicated crew, and for Case Study 4 and new engine carrier would have to be purchased. It may be that for Case Study 3 the additional personnel required, and the cost associated, are out-weighted by the fact that the vehicle is achieving nine flights per year instead of three. For Case Study 4 it could turn out to be that the cost associated with a new engine handler, which can remove all three engines at the same time, out weights the benefits of gaining an extra flight a year. Both of these case studies require an in depth examination of all the possible contributing factors.

Table1: SSME Trade Study Results

| | Turnaround Time | | # of |
	Hours	Months	Flts./Year
Nominal*	1504	4.7	2
Case Study 1**	989	3.1	3
Case Study 2***	2010	6.3	1
Case Study 3****	390	1.3	9
Case Study 4*****	343	1.1	10

*   Shuttle Normal Operations
**   Spare Engine – Nominal Flow + Three Spare Engines
***   Maintenance Onboard Vehicle (No Spare Engines)
**** Spare Engines – Work on all three Engines Simultaneously While on Vehicle
***** Spare Engines – Work on all three Engines Simultaneously + Remove and Replace
       Engines as a Cluster
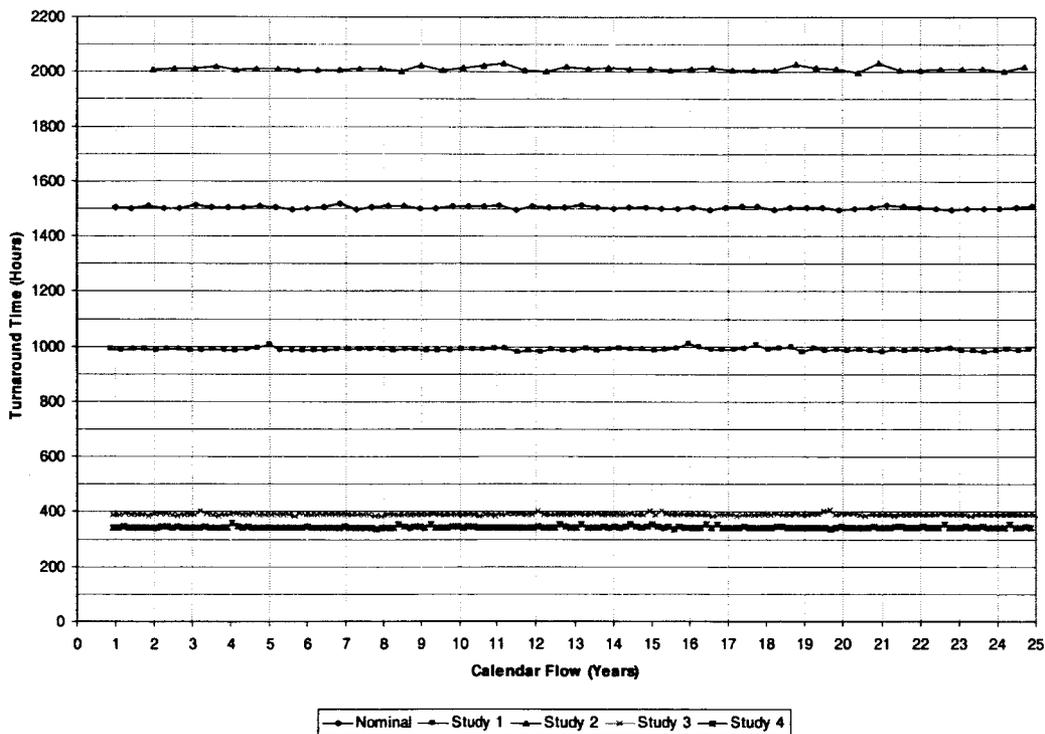
Figure 8: Turnaround Time (Landing to Launch)

One of the important aspects of a trade study, as shown in this example, is to demonstrate how changing a few assumptions can dramatically alter turnaround time and have an effect on the design of the vehicle. However, as shown with the SSME example, there are a number of factors such as cost, personnel requirements, and others that would need to be examined to fully explore the design space. When developing a model for a reusable engine in the conceptual design phase it is important to fully explore the design space to develop and optimize the turnaround time while minimizing cost and personnel.

SUMMARY AND CONCLUSIONS

The SSME Processing Model allows users to simulate the maintenance required by the SSMEs and then perform a number of trades to explore the design space in hopes of determining optimum solutions for decreasing turnaround time and cost. This same process can be

performed on conceptual engines and the results given to designer engineers. By performing trade studies it could be determined whether it would be beneficial to have a particular part removed once every tenth flight due to the amount of time required remove and replace the component, or once every fifth flight. This information could be turned into a reliability used by designers to meet the objective of a pre-determined desired turnaround time. If it is not possible to reach such a reliability, the model could be amended and the trades run again with the new inputs. As the design matures, the data in the model can be updated allowing the model to stay a step ahead of the design, performing trade studies and providing feed back to the designers regarding operational concepts that need to be met.

FUTURE WORK

Currently the SSME Processing Model only simulates planned maintenance performed on the SSMEs. The next step in the development of the SSME Processing Model is the addition of unplanned maintenance. In the research completed in 1998 by Mr. Christenson and Mr. Komar data was collected on unplanned maintenance which was included in the original model. In the process of developing a new SSME Processing Model, it was convenient to remove the unplanned maintenance in order to validate the model. Now that the model has been validated, the unplanned maintenance can be added back into the model.

Another aspect of the SSME Processing Model that still requires work is upgrading the model from Extend Version 5 to Extend 6 with Industry. Industry is an add -on package developed by Simulation Dynamics that contains several capabilities that could be beneficial to the SSME Processing Model. One feature of Industry is a database capability that would eliminate the need for the Excel database and allow all the engine specific data to reside in a database located within Extend. This capability allows for changes to be made to the database while the simulation is running. A user could be running a simulation that uses two shifts per day and during the simulation change the number of shifts to three and see instantly the effect on efficiency instead of having to start another simulation. Another feature developed by Simulation Dynamics is a Design of Experiments (DoE) block which allows the user to set up a DoE and then begin the simulation which would perform each case in the DoE. After the first case is run the model makes the corresponding changes to the data/model and begins the simulation with a new set of assumptions. Such a feature would be extremely useful in determining optimum operating conditions.

REFERENCES

1. Christenson, R. L.; and Komar, D. R.: "*Reusable Rocket Engine Operability Modeling and Analysis,*" NASA-TP-1998-208530, July 1998.

2. *Extend*™ *User's Manual,* Imagine That®, Inc., San Jose, CA, 2000.