Propulsion Technology Lifecycle Operational Analysis

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The paper presents the results of a focused effort performed by the members of the Space Propulsion Synergy Team (SPST) Functional Requirements Sub-team to develop propulsion data to support Advanced Technology Lifecycle Analysis System (ATLAS). This is a spreadsheet application to analyze the impact of technology decisions at a system-of-systems level. Results are summarized in an Excel workbook we call the Technology Tool Box (TTB). The TTB provides data for technology performance, operations, and programmatic parameters in the form of a library of technical information to support analysis tools and/or models. The lifecycle of technologies can be analyzed from this data and particularly useful for system operations involving long running missions. The propulsion technologies in this paper are listed against Chemical Rocket Engines in a Work Breakdown Structure (WBS) format.

The overall effort involved establishing four elements:

(1) A general purpose Functional System Breakdown Structure (FSBS).

(2) Operational Requirements for Rocket Engines.

(3) Technology Metric Values associated with Operating Systems

(4) Work Breakdown Structure (WBS) of Chemical Rocket Engines

The list of Chemical Rocket Engines identified in the WBS is by no means complete. It is planned to update the TTB with a more complete list of available Chemical Rocket Engines for United States (US) engines and add the Foreign rocket engines to the WBS which are available to NASA and the Aerospace Industry.

The Operational Technology Metric Values were derived by the SPST Sub-team in the form of the TTB and establishes a database for users to help evaluate and establish the technology level of each Chemical Rocket Engine in the database. The Technology Metric Values will serve as a guide to help determine which rocket engine to invest technology money in for future development.

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Nomenclature

ATLAS	= Advanced Technology Lifecycle Analysis System
ATK	= Alliant Techsystems
C&C	= Command and Control
CPIA	= Chemical Propulsion Information Agency
ECU	= Engine Control Unit
EIU	= Engine Interface Unit
ETO	= Earth-toOrbit
FSBS	= Functional System Breakdown Structure
GG	= Gas Generator
GHe	= Gaseous Helium
GN_2	= Gaseous Nitrogen
HC	= Hydrocarbon
H&RT	= Human and Robotic Technology
ICD	= Interface Control Document
IEA	= Integrated Electronic Assemblies
LCC	= Life Cycle Cost
LH_2	= Liquid Hydrogen
LO_2	= Liquid Oxygen
Lox	= Liquid Oxygen
LCC	= Life Cycle Cost
LES	= Launch Escape System
LM	= Lunar Module
MLP	= Mobile Launch Platform
MOFCD	= Measurable Operational Functional Criteria Discriminators
NASA	= National Aeronautics and Space Administration
OEPSS	= Operationally Efficient Propulsion System Study
ODF	= Operational Difficulty Factor
OMRS	= Operations and Maintenance Requirements Specification
ORF	= Operations Reliability Factor
Ox	= Oxidizer
QFD	= Quality Function Deployment
RBCC	= Rocket Based Combined Cycle
ROFI	= Radial Outward Firing Initiator
RSRM	= Redesigned Solid Rocket Motor
RSS	= Range Safety System
SPST	= Space Propulsion Synergy Team
SRM	= Solid Rocket Motor
SSME	= Space Shuttle Main Engine
TPM	= Technical Performance Metric
TTB	= Technology Tool Box
TVC	= Thrust Vector Control
US	= United States
WBS	= Work Breakdown Structure

Introduction

In 2004 NASA was developing an "Advanced Technology Lifecycle Analysis System" (ATLAS), which was a spreadsheet application to analyze the impact of technology decisions at a system-of-systems level. At the heart of this ATLAS is an Excel workbook known as the "Technology Tool Box" (TTB). The TTB provides data for technology performance, operations, sand programmatic parameters used by models in the ATLAS library. As emphasized in the name, the models in ATLAS address the lifecycle of technologies.

In support of the development of Operational Technologies and the development of Technology Metric Values for the ATLAS TTB, the SPST was requested to provide the development of Operational Metrics. In response to this request, the SPST developed the Operations Difficulty Factor (ODF) and an Operations Reliability Factor (ORF) for incorporation in the ATLAS TTB database for the first 3 year incremental time frame of 2005--2008 of an intended eleven time frames in the future through the year 2038.

To accomplish the development of these ODFs and ORFs, the SPST first identified Measurable Operational Functional Criteria Discriminators that could be used to develop the Operational Metric Values in the TTB. The process desired was to select a reference technology choice for each technology class and by comparing the technology choices against this reference considering a range of 1.0 to 10. Thus, an order of magnitude from better to worse, setting the reference value at 1.0 and the range for better would be 0.1 to 1.0 and the range for worse would be 1.0 to 10.

The TTB was conceived to support development of technologies starting with incremental time frames 2005– 2008, 2008 – 2011, etc, for each of the technology options considering technology maturation advancement for each period.

The SPST worked two classes of Chemical Rocket Engines, WBS 2.6.1 Earth-to-Orbit (ETO) Propulsion Technology sub-element and WBS 2.6.5 In-space Propulsion (chemical/thermal) Technical sub-element.

The Operational Technology Metric Values derived by the SPST would be used by the ATLAS database users and modelers to help evaluate and establish the technology level of each Chemical Rocket Engine in the database. The Technology Metric Values were included in a Technology Investment Portfolio to serve as a guide to determine which technology would gain the greatest operational improvement for out year investments.

Methodology

The process selected by the SPST considered 16 different propulsion system in the ETO class (WBS 2.6.1) and 13 different propulsion systems in the In-space class (WBS 2.6.5) for evaluation. Some of these propulsion systems were well established operational systems and others were either less mature or notional systems. The SPST had performed a QFD in previous studies that had identified many design discriminators against the desired attributes for an affordable/sustainable space transportation system. These design discriminators were arranged in an order of importance and the top applicable Measurable Operational Functional Criteria Discriminators (MOFCD) were used to perform the evaluation of the selected propulsion systems to determine their ODF and used to perform the evaluation of these propulsion systems ORF.

One additional criterion was added that determined the maturity (a well documented operational definition of discriminator data) for evaluation and understanding. This criteria was evaluated on the basis of a 1 (well defined), 3 (somewhat defined), and a 9 (not well defined at all). This added criterion would add a burden to those systems that were not mature, but could be removed when these technologies were developed and demonstrated as being mature. This allows for selection of future systems for development that show promise in reaching the objective of being more affordable than the present system being used today. Future time frame evaluations would take into account the advances made to mature technology propulsion systems. At this time frame the criterion that was added for the evaluation of this maturity would be reduced; therefore, the raw score for that technology would be reduced from the previous time frame yielding a lower ODF and a new ORF.

It was found that only 28 criteria were evaluated out of a larger group as data was missing in the others which were evaluated with a score of 0 or left blank. This evaluation was performed using a matrix that allowed the evaluation of each propulsion system against each Measurable Operational Functional Criteria Discriminators with the SSME being selected as the reference case for the ETO class and the RL-10 A-4 selected as the reference case for the In-space class. Each propulsion system was evaluated and the scores were added to determine the raw score of each. Each raw score was then normalized against the reference case, e.g., the ODF and ORF and transferred to the ATLAS TTB.

Operational Analysis Results (grouped in three categories)

(1) A general purpose Functional System Breakdown Structure (FSBS).
(2) Work Breakdown Structure (WBS) of Chemical Rocket Engines
(3) Technology Metric Values associated with Operating Systems

1. General Purpose Functional System Breakdown Structure (FSBS):

This generic FSBS (a product of a previous study effort that was discontinued) was requested by our customer as a part of this task. The generic FSBS was developed to provide the capability to analyze technologies within the existing TTB, and would also reflect the Advanced Systems Technology Research and Analysis WBS.

To develop a generic FSBS applicable to all phases and missions of a Space Transportation System, the SPST Sub-team reviewed past Space Transportation Systems and their WBSs, many of which have been used for 50 plus years. A generic FSBS was developed that is applicable to any Space Transportation System (flight system, ground system and ground functional nodes in space or on other planets).

2. Work Breakdown Structure (WBS) of Chemical Rocket Engines

Operational Discriminators and the development of Technology Metric Values for Technologies were defined by reviewing the Chemical Rocket Engines within the ATLAS data base to determine their technology levels for potential Development Technologies to be included in the Human and Robotic Technology (H&RT)'s technology Investment Portfolio. The H&RT requested the SPST Functional Requirements Sub-team to develop the Operational Metrics for the ATLAS TTB. When reviewing the Chemical Rocket Engines in the existing WBS, it became obvious that the list of available Chemical Rocket Engines, both United States (US) and foreign needed to be up-dated to provide a complete-as-possible listing of Chemical Rocket Engines that are or could be available to NASA and the Aerospace Industry.

The WBS 2.6.1 for ETO rocket engines lists thirteen rocket engines, two rocket motors and one propulsion technology. Seven are qualified Liquid Rocket Engines, but only five are still flying; the SSME, RS68, RS27A from the US, the HM 60 from France, and the RD180 from Russia. There are two qualified Solid Rocket Motors' the Apollo LES (retired) and the RSRM still flying both from the US. The RD170 was in the WBS listing, but is no longer in production; therefore, the SPST Sub-team replaced it with the RD173 ETO technology engine, and is identified by a 3 in the fifth digit of the WBS as shown in Table 1.0 below.

WBS 2.6.1 -- ETO Propulsion	
WBS 2.6.1.1.2 – SSME – Reference Engine	US
WBS 2.6.1.1.1 – RS68 – Qualified Engine	US
WBS 2.6.1.1.3 – HM60 – Qualified Engine	France
WBS 2.6.1.1.4 – F-1 – Retired Engine	US
WBS 2.6.1.1.5 – J-2 – Retired Engine	US
WBS 2.6.1.3.1 – RBCC – Technology Engine	US
WBS 2.6.1.3.2 – Linear Aerospike Technology Engine	US
WBS 2.6.1.3.3 – Annular Aerospike Technology Engine	US
WBS 2.6.1.5.1 – Solid/Hybrid – Technology Engine	US
WBS 2.6.1.5.2 – RSRM – Qualified Propulsion	US
WBS 2.6.1.5.3 – Apollo LES Retired Propulsion	US
WBS 2.6.1.6.1 – RS72 – Technology Engine	US/German
WBS 2.6.1.6.2 – RS27A – Qualified Engine	US
WBS 2.6.1.6.3 – RD173 – Technology Engine	Russia
WBS 2.6.1.6.4 – RD180 – Qualified Engine	Russia
WBS 2.6.1.8.1 – MGLV – Concept Technology Propulsion	US

Table 1.0 - WBS 2.6.1 ETO Engines/Propulsion evaluated by the SPST Sub-Team

WBS 2.6.5 for In-space rocket engines identifies eleven rocket engines, one rocket motor and one propulsion technology. Five are qualified Liquid Rocket Engines, but only one is still flying; the RL10A-4. The Chemical Propulsion Information Agency's (CPIA) rocket engine database shows the RL10A-4 and not the RL10A-6 as a viable rocket engine. Therefore, the RL10A-6 was replaced with the RL10A-4 engine in the database. The Solid/Hybrid technology motor was added to the WBS. The RS27A derivative technology engine was added in place of the "No-name LOX/HC" engine. The MB60, the RL60, the Apollo LM Descent, the RS72, the Solid/Hybrid, the OEPSS Concept, and the MGLV Concept Technologies were added and identified by an X in the fifth digit of the WBS number as shown in Table 2.0 below.

WBS 2.6.5 – In-space Propulsion	
WBS 2.6.5.1.1 – RL10A-4 – Reference Engine	US
WBS 2.6.5.1.X – MB60 –Technology Engine	US
WBS 2.6.5.1.X – RL60 – Technology Engine	US
WBS 2.6.5.1.2 – HM60 Derivative – Technology Engine	France
WBS 2.6.5.1.3 – J-2 Retired Engine	US
WBS 2.6.5.1.5 – Apollo CSM SPS – Retired Engine	US
WBS 2.6.5.1.6 – Apollo LM Ascent – Retired Engine	US
WBS 2.6.5.1.X – Apollo LM Descent – Retired Engine	US
WBS 2.6.5.2.1 – RS27A Derivative – Technology Engine	US
WBS 2.6.5.8.X – RS72 – Technology Engine	US/German
WBS 2.6.5.8.X – Solid/Hybrid – Technology Motor	US
WBS 2.6.5.X.X – OEPSS Concept – Technology Engine	US
WBS 2.6.5.X.X – MGLV Concept Technology Propulsion	US

Table 2.0 - WBS 2.6.5 In-space Engines evaluated by the SPST Sub-Team

The SPST Sub-team selected the SSME as the reference ETO engine and all technology ETO propulsion systems were compared to the SSME. For the In-space rocket engines, the RL10A-4 was selected as the reference engine and all In-space technology propulsion systems were compared to the RL10A-4.

(3) Technology Metric Values associated with Operating Systems

In defining a process that could work with multiple objective attributes, the SPST performed a QFD exercise. This process was accomplished in previous studies that had identified the many design drivers that were responsive to the attributes of an affordable / sustainable space transportation system. These design drivers are sometimes referred to as "technical performance metrics" (TPMs); however, in this paper they will be referred to as "operational functional criteria discriminators". These operational design discriminators were arranged in an order of importance and the top applicable 48 measurable operational functional criteria discriminators were used to perform the evaluation of the selected propulsion systems to determine their ODF and the top applicable 48 measurable operational functional criteria discriminators were used to perform the evaluation of these propulsion systems ORF.

Forty-eight Operational Discriminators were used to evaluate the one reference engine and the all the other engines/propulsion systems in the WBS 2.6.1 ETO Propulsion shown in Table 1.0 above. Establishing the SSME as the reference ETO engine with a nominal value of 1.0, and comparing the technology and other engines/propulsion systems on a scale of 0.1 to 10; with 0.1 being an order-of-magnitude better and 10 being an order-of-magnitude worse than the SSME, provided the SPST Sub-team with a structured methodology and technique to derive Technology Metric Values for each Operational Discriminator for each rocket engine/propulsion concept evaluated.

Forty-eight Operational Discriminators were also used to evaluate the one reference engine and all the other engines/propulsion systems in the WBS 2.6.5 In-space Propulsion shown in Table 2.0 above. Establishing the RL10A-4 as the reference In-space engine with a nominal value of 1.0, and comparing the technology and other engines/propulsion systems on a scale of

0.1 to 10; with 0.1 being an order-of-magnitude better and 10 being an order-of-magnitude worse than the RL10A-4, provided the SPST Sub-team with a structured methodology and technique to derive the Technology Metric Values for each Operational Discriminator for each engine evaluated concept evaluated.

Because there wasn't data for all the 48 measurable operational functional criteria discriminators, only 28 criteria are presented in this technical paper as being used to evaluate the propulsion technologies for both the ETO and the In-Space WBS groups. For definition of the 28 measurable operational functional criteria discriminators use, please see the "evaluation products examples" that follow.

One additional criterion was added that determined the maturity (well documented operational definition of these discriminator data) for evaluation and understanding. This criteria was evaluated on the basis of a 1 (well defined), 3 (somewhat defined), and a 9 (not well defined at all). This added criterion would add a burden to those systems that were not mature, but could be removed when these technologies were developed and demonstrated as being mature. This allows for selection of future systems for development that show promise in reaching the objective of being more affordable that the present system being used today. Future time frame evaluations would take into account the advances made to mature technology propulsion systems. At this time frame the criterion that was added for the evaluation of this maturity would be reduced; therefore, the raw score for that technology would be reduced from the previous time frame yielding a lower ODF and a new ORF.

Evaluation Product Examples

The SPST only preformed the first year 2005 evaluation for these selected systems. In addition to evaluating the gains from maturing an advanced design, it can be seen that if a mission requires large thrust values the ODF must be compared with multiples of smaller propulsion systems. Therefore, from a total systems perspective even though the ODF is larger than that of another system, it may be the desired choice.

The following three examples for ETO (WBS 2.6.1) show that with all systems being mature, the SRM has much higher thrust than the other two cases; therefore, if it was replace with another choice, it needs to be relatively close to the SRM's thrust level. The ODF and ORF would not be desirable for the reference system if it required 5-6 units to match the desired required equivalent thrust.

These example propulsion system evaluations make it clear which Operational Discriminators are candidates for improvement if it is desired to improve the operability of any of these mature technologies.

Criteria Discriminators	Ref Technology (SSME) LO_2/LH_2 2.6.1.1.2 (Operational Rocketdyne Engine)	Value	Criteria Factor	RS 68 LO_2/LH_2 2.6.1.1.1 (Operational Rocketdyne Engine)	Value	Criteria Factor	Shuttle SRM Solid 2.6.1.5.2 (Operational ATK Motor)	Value	Criteria Factor
1. Closed Compartments/Confined	Not Rocket Engine Focused	N/A		Not Rocket Engine Focused	N/A		Not Rocket Engine Focused	N/A	
2. Number of Different Operating Fluids Serviced:	LH_2, LO_2, GN_2, GHe, 83282 Hydraulic Oil	5	1	LH_2, LO_2, GHe, 83282 Hydraulic Oil	4	0.8	GN2	1	0.2
3. Number of Ground Servicing Interfaces:	5 Post-flight GN_2 drying purges & 2 Pre-flight GHe, Heated GN_2 conditioning purges	7	1	GHe spin start & GHe purges	2	0.29	T-0 umbillical at the MLP/Aft to provide joint heater power/temperature control & aft skirt heated purge to provide flex joint temp control.	2	0.29
4. Total Number of Tanks in the Architecture:	10 GHe Bottles, 4 Hydraulic Containers, LH2 & LO2 Tanks	16	1	Lox & LH2 tanks, 5/7 He bottles that are thrust dependent (Heavy @ 7)	9	0.56	1 pressure vessel with 4 RSRM segments with 7 joints	1	0.1
5. Total Number of Vehicle Support Systems:	LH2 tank & feed-system, LO2 tank & feed-system, He pneumatic supply sys, Heated GN2 purge sys, Lox anti-geysering sys, GO2 tank pressurization sys, GH2 tank pressurization sys, POGO suppression sys, Two hydraulic supply sys, LH2 recirculation conditioning sys, LO2 bleed conditioning sys, TVC sys, Four TVC controllers, Two 28volt power supply sys, Two 400cycle AC power supply sys, Three Vehicle C&C (EIU) sys, Instrumentation interface sys, & TPS heat shield	26	1	LH2 tank & feed-system, LO2 tank & feed-system, He pneumatic supply sys, Lox anti-geysering sys, GO2 tank pressurization sys, GH2 tank pressurization sys, POGO suppression sys, hydraulic supply sys, LH2 bleed conditioning sys, LO2 bleed conditioning sys, 3 TVC sys, TVC controllers, Two 28volt power supply sys, Two 400cycle AC power supply sys, Instrumentation interface sys, & TPS heat shield	24	0.92	Range Safety Sys, Pyrotechnic nozzle separation sys, 2 Ignition Firing Sys, TVC sys, Four TVC controllers, Two 28volt power supply sys, instrumentation interface sys, Two Integrated Electronic Assemblies (IEA)	14	0.54
6. Total Number of Ground Interface Functions Required:	Source is the Design Ref.Doc. ICD's, e.g., test ports, nozzle covers, inspection interface points.	25	1	Source is the Design Ref.Doc. ICD's, including nozzle, 2 exhaust and 5 drain line covers, 2 TP inspection ports, 2 GG pyro igniters, ROFI	13	0.52	Source is the Design Ref.Doc. ICD's leak test ports (12), joint heaters - power & monitoring (9)	21	0.84
7. Total Number of Separate Identified Vehicle Systems (lack of discipline functional integration):	Not Rocket Engine Focused	N/A	1	Not Rocket Engine Focused	N/A		Not Rocket Motor Focused	N/A	
8. Number of Separate Electrical/Electronic Interfaces:	Please see electrical listing in item #9	12	1	2 GG pyro igniters, ancillary valves switch position, TVC1/Roll Control Nozzle primary and complementary, TVC2 primary and complementary, 2 power supply channels to ECU, 6 instrumentation, ROFI for main combustion chamber	16	1.33	Please see electrical listing in item #9		1.91

9. Number of Mechanical Element Mating Operations:	(12) Mech & (12) Ele: LH_2 & LO_2 feedlines, GH_2 & GO_2 presslines, GHe & GN_2 Supply lines, Hydraulic Supply & Return lines, LH2 Conditioning Bleedline, Gimbleblock & (2) TVC Actuators and (2)AC & (2)DC power, (2) Command/Data, a Command only, main fuel valve heater & (4) Instrumentation Electrical Connectors	24	1	(16) ele & (22) mech: pump inlets, ox bleed, ox dome purge, Inter Propellant Seal (IPS), ox & fuel tank pressurants, GG fuel purge, fuel sys purge, GG ox purge, 2 TVC hydraulic supply & return, bleed valve actuation, fuel bleed, Fuel Bleed-Drain/Diverter Valve, barrier purge, 4 structural attach points, spin start, hydraulic turbine exhaust	38	1.58	(18) Mech & (23) Ele: (4) Motor segment mating, (3) Leak check segment/segment joints, mating to aft. Skirt, mating to nozzle, leak check nozzle joint, mate S&A Leak Check (3) aft structural struts to ET, mate forward structural attachment to ET, attach (2) TVC actuators, install electrical tunnel, mate (2) electrical cables to igniters, mate electrical cables to instrumentation, mate electrical cables to safe & arm device for Range Safety sys, (2) TVC actuator ele connections, (8) ele. connectors to joint heaters and to ground interface per motor, (8) ele. connectors to joint heater instrumentation and to ground interface per motor	43	1.79
10. Number of Safing Operations at Landing:	High pressure bottles must be vented to 50% level before personnel exposure.	1	1	Safe the GG igniter sys & vent high pressure bottles to 50% level	2	2	Safe the ignition sys, inspect the pyrotechnic nozzle separation sys, safe the range safety sys, remove and dispose RSS	4	4
11. Number of Safety Driven Limited Access Control Operations:	Engine Handling, Inert Purging, Pressurizing to Flight Values	3	1	Engine Handling, Inert Purging, Pressurizing to Flight Values, & ROFI installation	4	1.33	(5) motor major component inspections and handling, (7) structural element mating operations/motor, installation of ignition Safe & Arm Device, installation of range safety ordnance, ordnance electrical connections	16	5.33
12. Number of Commodities used that Require Medical Support Operations or Routine Training:	Working with inert gases, in confined spaces, and with cryogenics requires special training.	3	1	Working with inert gases, in confined spaces, and with cryogenics requires special training.	3	1	All Solid Rocket handling operations, all ordnance device handling operations, with inert gases	3	1
13. Total Number of Active Components:	Main fuel valve, Main Lox valve, Ox Preburner lox supply valve, Fuel preburner lox supply valve, Heated GN2 purge valve, Lox dome purge valve, Fuel coolant supply valve, Fuel coolant system He purge valve, High pressure lox turbopump, Low pressure lox turbopump, High pressure fuel turbopump, Low pressure fuel turbopump, Pneu shutdown supply valve, Flow meter, Six augmented spark igniters, (2) TVC actuators, POGO & five propellant valve solenoids and five check valves	33	1	Fuel pump, LOX pump, 4 main valves, 3 bleed valves, 1 FDDV, 9 check valves, & 3 TVC actuators	22	0.67	Flex nozzle, Safe & Arm device for motor ignition, and Safe, nozzle separation sys & Safe, Arm device for the Range Safety sys, and (2) TVC gimbal actuators	6	0.18

14. Number of Safety Driven Safety Functional Requirements to Maintain Safe Control of System during Flight and Ground Operations:	LO2 antigysering, cryo-conditioning/bleed for eng. Start (Lox & Fuel), pogo suppression, ignition over-pressure, safety purges for start & shutdown, ignition, pneumatic shutdown & Lox turbopump seal	9	1	Haz gas system, engine cryo conditioning, IPS purge, barrier purges, pre-start purges, MECO purge, & LO2 antigysering	7	0.78	Nozzle separation device during descent, Range safety distruction sys & safe & arm device for ignition sys	3	0.33
15. Number of Critical - 1 (Crit-1) System Functional Failure Modes:	Source is the Design Ref. For Crit 1 & 1R Hardware Items & the USA report 9/28/2004	550 Crt 1 & 1R with 313 Crt 1 & 237 Crt 1R per engine	1	FMECA	234	0.43	Source is the Design Ref. For Crit 1 & 1R Hardware Items & the USA report 9/28/2004 OMRSD File V Vol 1	141 Crt 1 & 1R with 90 Crt 1 & 51 1R per motor	0.26
16. Number of Intrusive Data Gathering Devices:	10 Temperature, 19 Pressure, 1 Flow-rate, Lox anti-flood valve sensor, 5 propellant flow control valves sensors, Lox recirc. Isolation valve sensor, Lox and fuel bleed valve sensors, & 6 igniter sensors Instrumentation	45	1	Pressure & temp sensors	16	0.36	pressure sensors (Operational pressure transducer, OPT)	3	0.1
17. Number of Maintenance Actions Planned Between Missions:	Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS)	~ 112	1	N/A	N/A		(Salvage & reuse) Must recover from ocean, rough clean motor, dissemble, return to manufacture for reload, and totally rebuild both at manufacture and launch site for next flight	ATK @ Utah, HG-AF, ARF buildup, RPSF ~132 tasks & MLP ~ 164 tasks	2.64
18. Number of Maintenance Actions Unplanned Between Missions:	Source is the Problem Reporting and Corrective Action (PRACA) & Planning and Scheduling Sys (CAPSS) As-run Data	~ 25	1	N/A	N/A		Varies between missions, but it is suggested some rework of assembly of motor	TBD	
19. Expected Operational Lifetime - Firings:	Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS)	30 starts/ 15,000 Sec.	1	PIDS	8 starts / 1,200 sec.	3.75	Designed for 20 flights, but splashdown loads vary from flight to flight causing a periodic loss of aft segment	20 flights (starts) @ 122 sec each	1.5
20. Expected Reusability–Number of Firings Before Over-Haul:	Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS)	20	1	Expendable engine; however, certification was for 12 starts and 1800 sec	TBD		Complete Refurb each flight	1	10
21. Expected Reusability (% H/W Replaced per Firing):	Source is the Problem Reporting and Corrective Action (PRACA) & Planning and Scheduling Sys (CAPSS) As-run Data	less than 1%	1	N/A	N/A		Major components are reusable, small parts/ non-configured items are typically not	60 - 90%	10
22. Expected Operational Lifetime - Hours:	Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS)	~ 4 hours	1	335 secs max flight operating time	less than 1 hour	4	The intended reusable aspect of the motor is 20 flights @ 122 sec each and remainder is expendable hardware. Flight data suggests that major flight components, case cyl, aft skirt, stiff rings have less than designed life due to splashdown loads.	less than 1 hour (20 flights @ 122 sec ea.)	4

23. Mean Time Between Failure (MTBF):	Source is: MSFC S&MA Concept Study Support OExS Launch Vehicle Study July 21, 2004	Design Assessment as benign failure MTBF = 769 flights (3844 Catastrophic) with SSME Rel of .9987 (.999974 Catastrophic)	1	Not determined	N/A		Source is: MSFC S&MA Concept Study Support OExS Launch Vehicle Study July 21, 2004	Design Assessment as Catastrophic failure MTBF = 11348 flights with SRM Rel of .999912	0.34
24. Minimize the Number of Hazardous Fluids and Materials Used:	Cleaning solvents, but No special protective garments required	0	1	2 Igniters and 1 ROFI ordnance devices	3	10	Cleaning solvents, (111-Trichlorethane, Spirit 126 and Reveille) but No special protective garments required; however, Handling major ordance devices (solid rocket motor) and Pyrotechnic	2	10
25. Avoid the Use of Toxic Fluids and Materials:	Cleaning solvents, but not considered toxic	0	1	None	0	1	Poly Urethane-Foam application to (3) stiffener rings, ETA ring and PR 855 Foam in ETA ring	2	10
26. Provide Propulsive Sys. That Accomodate a Large Thrust Range:	Thrust range is 65 to 109%	65 / 109% = 44% range	1	Two fixed points of operation, e.g., throttle prior to MECO and G level control	57/102 % = 25% range	1.76	Thrust range is fixed (100 / ~50%) by design, not operationally controllable	N/A	
27. Provide Propulsive Sys. That Accomodate a Large Impulse Control Range with Focus on the Minimum Impluse Side:	Not ETO Rocket Engine Focused	N/A	1	Not ETO Rocket Engine Focused	N/A		Impulse range is fixed by design, not controllable	N/A	
28. Provide Automated Hardware Corrective Action Capability:	Automated SSME shutdown · HPOT IMSL Purge below 170 PSIA · MCC Pressure (differntial) is greater than 200 PSIA from Pc (Calculated) Reference & 400 PSIA during throttling · HPOT Discharge Temp above 1760 ° · HPFT Discharge Temp above 1960 ° Prior to T-0 (Confidence Confirmed) · HPFP Shaft Speed less than 4600 RPM · MCC Pressure below 290 PSIA · MCC Pressure not between 610 – 1000 PSIA · AFV Position less than 80 % · Fuel Preburner S/D Purge Pressure sensor above 715 PSIA or above 100 PSIA later in start · Oxidizer Preburner S/D Purge Pressure sensor above 715 PSIA or above 100 PSIA later in start	10	1	No in-flight redlines; Prior to T-0: MFV position indication >6.5%, GG link break confirmed, MCC igniter firing confirmed, FTP/OTP discharge pressures >204/192 psia, turbine inlet temp 875-1075F, MOV position 81-88% open, GGOV position 68/74% open (last 3 are engine unique and change slightly for each engine)	8	0.8	Safe & arm device actuation during countdown/launch abort back to safe to control igniter assembly	1	10
29. Provided well documented operations definition for criteria data			1			1			1
Notes or Normalized value for this technology option *(These values are for Criteria 29 influence on Criteria Factor only)*			1			1.69			3.28
ADJUSTED: Normalized value for this technology option *(These values are for Criteria 29 influence on Criteria Factor only)*			1			1.66			3.18

Criteria Discriminators	Ref Technology RL10A-4 2.6.5.1.1 (Operational P&W Engine)	Value	Criteria Factor	Saturn J-2 LO_2/LH_2 2.6.5.1.3? (Operational Rocketdyne Engine)	Value	Criteria Factor	OEPSS Focused Concept 2.6.5.?	Value	Criteria Factor
1. Closed Compartments/Confined	Not Rocket Engine Focused	N/A		Not Rocket Engine Focused	N/A		Not Rocket Engine Focused	N/A	
2. Number of Different Operating Fluids Serviced:	LH2, LO2, LHe, & GHe	4	1	LH2, LO2, GH2, GHe, & GN2 (ground only)	5	1.25	*LH2, LO2, & GHe*	3	0.75
3. Number of Ground Servicing Interfaces:	Preflight LHe conditioning/purge	1	1	Pre-flight GHe purging	2	2	Preflight GHe purge	1	1
4. Total Number of Tanks in the Architecture:	LH2 & LO2 Tanks, 2 High pressure GHe bottles (purge & valve control), and TBD HP GHe bottles for Lox & LH2 tank pressurization	6	1	LO2 & LH2 tanks, and 10 amb, 8 cold He bottles, and 1 combined GH2/GHe bottle	22	3.67	LH2, LO2, 2 GHe	4	0.67
5. Total Number of Vehicle Supplied Support Systems:	LH2 tank & feed-system, LO2 tank & feed-system, 2 He pneumatic supply sys, LO2 tank GHe pressurization sys, LH2 tank GHe pressurization sys,GH2 autogenous bleed pressurization sys, TVC sys, 28volt power supply sys, data sys, Overboard vent sys (OVS), & propellant utilization (PU) sys.	12	1	LH2 tank & feed-system, LO2 tank & feed-system, He pneumatic supply sys, GO2 tank pressurization sys, GH2 tank pressurization sys, POGO suppression sys, LH2 recirculation conditioning sys, LO2 bleed/He bubbling conditioning sys, Turbine spin-start system, APS Ullage control eng. sys (2) in support of propellant tank re-pressurization, solid rocket ullage control sys (2) in support of engine restart, Two 28volt power supply sys, Two 56 VDC inverter to 400 cycle AC power supply sys, Vehicle C&C sys, TVC sys, Instrumentation interface sys, TPS heat shield, & hazardous gas detection sys	20	1.67	LH2 sys, LOX sys, GHe sys, LH2 repress sys, GOX repress sys, Overboard vent sys (OVS), (2) 28 volt electrical sys, data sys.	9	0.75
6. Total Number of Ground Interface Functions Required:	LH2 & LO2 leak check connections, turbopump torque measurement at Accessory Drive Pad, Chamber throat plug for pressure checks & solenoid valve vent ports (4 valves) .	8	1	Source is the Design Ref.Doc. ICD's, e.g., test ports, nozzle covers, inspection interface points.			LH2 & LO2 leak check connections, (2) turbopump torque measurement, (4) Chamber throat plug for pressure checks	8	1
7. Total Number of Separate Identified Vehicle Systems (lack of discipline functional integration):	Not Rocket Engine Focused	N/A		Not Rocket Engine Focused	N/A		Not Rocket Engine/Motor Focused	N/A	
8. Number of Separate Electrical/Electronic Interfaces:	Ignition system 28 volt DC power supply (2), ignition system diagnostic (2), ignition system pressure switch (2), FPHT, OPHT,FTIT, RPM, Solenoid valves (4 valves), & 9 instrumentation connectors.	23	1	(6) electrical: (2) 5V/28V DC Power Bus, (2) Command, (2) Instrumentation Electrical Connectors	6	0.26	*(2) primary power connectors & valve control and (2) Instrumentation connectors*	4	0.17
9. Number of Mechanical Element Mating Operations:	Items in #8 plus,(10) Mech: LH2 valve inlet, LO2 valve inlet, Gimbleblock & (2) TVC Actuators, interstage cooldown valve vent port/pump discharge cooldown valve vent port (OVS), GHe bolcking purge line, GHe pneumatic control supply line, GHe engine chilldown supply line, & propellant utilization valve.	33	1	(13) Mech & (6) Ele: LH2 & LO_2 *feedlines, LH2 recirc.line, GH2 & GO_2 presslines, GHe Supply lines, LO2 sys GHe purge sys, TVC Hydraulic Supply & Return lines, Propellant valve actuator He Supply lines, Gimbleblock & (2) TVC Actuators and (2)AC & (2)DC power, (2) Command/Data, a Command only, (4) Instrumentation Electrical Connectors*	19	0.58	*4 electrical connectors and 4 mechanical; LO2 & LH2 feedlines, GH2 & GO2 repress lines*	8	0.24

10. Number of Safing Operations at Landing:	Expendable, however, Reduce HP GHe bottles to 50% flight pressure and safe ordance sys,	2	1	High pressure bottles (GHe & GH2) must be vented to 50% level before personnel exposure	2	1	Reduce HP GHe bottles to 50% flight pressure	1	0.5
11. Number of Safety Driven Limited Access Control Operations:	Engine Handling, blowdown & EMA functional tests (Inert Purging), Pressurizing pneumatic bottles to flight values and connecting pyrotechnics	5	1	Engine Handling, Inert Purging, Pressurizing HP bottles to Flight Values	3	0.6	Engine Handling, blowdown & EMA functional tests (Inert Purging), Pressurizing pneumatic bottles to flight values	4	0.8
12. Number of Commodities used that Require Medical Support Operations or Routine Training:	Working with inert gases, in confined spaces, pyrotechnics, and with cryogenics requires special training.	4	1	Working with inert gases, in confined spaces, and with cryogenics requires special training.	3	0.75	*Working with inert gases, in confined spaces, and with cryogenics requires special training.*	3	0.75
13. Total Number of Active Components:	Fuel inlet shutoff valve, oxidizer inlet shutoff valve, integrated turbopump (fuel pump, oxidizer pump, turbine, & gearbox), interstage cooldown valve, pump discharge cooldown valve, thrust control valve, main fuel shutoff valve, oxidizer flow control valve, solenoid valves (4), igniter/exciter, chilldown pyrovalves (2), and TVC gimbal actuators (2)	17	1	Main fuel valve, Main Lox valve, (2) ASI Lox Supply valve, Gas generator lox supply valve, Gas generator fuel supply valve, Gas generator Oxidizer purge valve, GHe purge valve, Lox dome purge valve, Fuel coolant supply valve, Fuel coolant system He purge valve, High pressure lox/hydraulic turbopump, High pressure fuel turbopump, Pneu valve controls supply valve, 2 ASI type igniters, Lox Anti-flod check valve, Mixture Ratio Control valve, Oxidizer Turbine Bypass valve, (2) fuel & Lox flowmeters, (2) fuel & Lox bleed valves, (2) TVC gimbal actuators, 8 propellant valve solenoids and 5 check valves	38	2.24	(2) Main fuel valve, (2) main ox valve, coolant control valve, fuel turbopump, ox turbopump, igniter fuel valve, igniter ox valve, spark igniter, pneumatic control assembly, purge solenoid valve, & (4) turbopump isolation valves	16	0.94
14. Number of Safety Driven Safety Functional Requirements to Maintain Safe Control of System during Flight and Ground Operations:	Gearbox, fuel pump, oxidizer pump, interpropellant seal pack, main fuel shutoff valve vent cavity, thrust control valve body cavity, oxidizer GHe vent cavity, injector face, pneumatic system control circuit, oxidizer flow control valve PU valve purges. *These (blocking) purges are relative to boost from the ground to space where an atmosphere has enough relative humidity to facilitate H2O aspiration from the cryo-pumping caused by the chilled and pre-chilled hardware. Done by ground systems while on Pad and then by on-board purge tank. Not required for ascent and descent operation on Lunar.*	10	1	Haz gas system, engine cryo conditioning, IPS purge, barrier purges, pre-start purges, MECO purge & POGO suppression sys	7	0.7	*Develope LO2/LH2 with supporting GHe system that controls safety by maximizing a passive approach*	1	0.1
15. Number of Critical - 1 (Crit-1) System Functional Failure Modes:	Source is the Design Ref. For Crit 1 & 1R Hardware Items	TBD	1		TBD		*Minimum # as possible*	TBD	
16. Number of Intrusive Data Gathering Devices:	1 pressure, 1 temps, & 1 speed sensor	3	1	12 Temperature, 16 Pressure, 2 Flow-rate, 18 propellant flow control and bleed valve sensors, & 4 igniter sensors Instrumentation	52	10	*Goal is no intrusive sensors, but provide good health coverage.*	0	0.1
17. Number of Maintenance Actions Planned Between Missions:	Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS) N/A - expendable engine; however, ground test suggest none Required as engine has been restated 7 time in space, but requires the pyrotechnics be replaced before reflight from earth	1	1				*TBD, but see no turnaround maintenance necessary*	0	1

18. Number of Maintenance Actions Unplanned Between Missions:	**Source is the Problem Reporting and Corrective Action (PRACA) & Planning and Scheduling Sys (CAPSS) As-run Data**	**N/A - expendable engine: however, qualificationtest experience suggests 0 actions**	**1**				***TBD, but see no turnaround maintenance necessary***	**0**	**1**
19. Expected Operational Lifetime - Firings:	**Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS), N/A - expendable engine; however, ground test demonstrated 19 engine firings @ 1810 sec ea. Also: 2 flight operations @ 920 sec. QUAL: 27 firings @ 3480 sec ea.**	**27 Starts**	**1**	**Design Requirement: 20 starts & 2250 secs**	**30 starts/3750 secs**	**0.9**		**TBD**	
20. Expected Reusability--Number of Firings Before Over-Haul:	**Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS), N/A - expendable engine; however, ground test demonstrated 19 engine firings @ 1810 sec ea. Also: 2 flight operations @ 920 sec. QUAL: 27 firings @ 3480 sec ea. Earth Shelf Life: 10 years**	**27 Starts**	**1**	**Design Requirement: 20 starts & 2250 secs**	**30 starts/3750 secs**	**0.9**		**TBD**	
21. Expected Reusability (% H/W Replaced per Firing):	**Source is the Problem Reporting and Corrective Action (PRACA) & Planning and Scheduling Sys (CAPSS) As-run Data**	**None (0) for flight qualified engine per items 19 & 20 above**	**1**	**Source is the Problem Reporting and Corrective Action (PRACA) & Planning and Scheduling Sys (CAPSS) As-run Data**	**None (0) for flight qualified engine per items 19 & 20 above**	**1**	***0% replacement***	**0**	**1**
22. Expected Operational Lifetime - Hours:	**Source is the Design Ref.Doc. Of Operations and Maintenance Requirements Specification (OMRS)**	**N/A - expendable engine; however, ground test demonstrated 19 engine firings @ 1810 sec ea. Also: 2 flight operations @ 920 sec. QUAL: 27 firings @ 3480 sec ea. Earth Shelf Life: 10 years**	**1**	**Actual Demonstrated: 111 starts & 20,000 secs**	**111 starts/20,000secs**	**0.24**		**TBD**	
23. Mean Time Between Failure (MTBF):	**Source is the Problem Reporting and Corrective Action (PRACA) & Operations and Maintenance Requirements Specification (OMRS)**	**N/A expendable But: QUAL: 27 firings @ 3480 sec ea.**	**1**	**Design Requirement: 20 starts & 2250 secs**	**30 starts/3750 secs**	**0.9**		**TBD**	
24. Minimize the Number of Hazardous Fluids and Materials Used:	**Cleaning solvents, but No special protective garments required; however, Pyrotechnic valves**	**1**	**1**	**Cleaning solvents, but No special protective garments required**	**0**	**0.1**	***Handling cryogenics and inert gases***	**0**	**0.1**
25. Avoid the Use of Toxic Fluids and Materials:	**Cleaning solvents, but not considered toxic**	**0**	**1**	**Cleaning solvents, but not considered toxic**	**0**	**1**	***Handling cryogenics and inert gases***	**0**	**1**

26. Provide Propulsive Sys. That Accomodate a Large Thrust Range:	Thrust variability for a "fixed" hardware design is tailored using Mixture ratio and fuel control for the expander cycle RL10A-4 or RL10B-2. The RL10E with Electro-mechanical (EMA) controls for two valves permitted a thrust range from 50-100% without flowpath changes. The RL10A-5 had the EMA's and some flowpath changes for the fuel-side to handle additional bypass flow around the turbine and was able to create a 33-100% variability range. Expander cycle is very flexible in variability.	50 - 100% or a delta of 50% range	1	Fixed thrust by design	N/A	*10-100% or 90% range*	90%	0.56
27. Provide Propulsive Sys. That Accomodate a Large Impulse Control Range with Focus on the Minimum Impluse Side:	see items 26 & 28	TBD need value from Russ J	1	Not ETO Rocket Engine Focused	N/A	Not ETO Rocket Engine Focused	N/A	
28. Provide Automated Hardware Corrective Action Capability:	RL10E derivative of RL10A engine with electronic controls demonstrated start to min-thrust, power level check and also had a 50% throttle to maximum delivered impulse capability. The control system design appraoch has matured to the level that prognostication as well as diagnostics for hardware corrective action can be performed with an upgrade to an electronic control.	0	1			*TBD*		

Summary Evaluation Product Results and Conclusions

It can be seen from the tables that follow, that 6 of the 7 candidate technologies evaluated would have an improved operational difficulty factor if matured and had a good chance of being better than the referenced technology for ETO WBS 2.6.1.

The operational reliability factor evaluations could be improved for 7 of the 7 candidate technologies being considered. It is also seen that 5 of the 8 mature candidates showed an improved operational reliability factor over the reference technology for ETO WBS 2.6.1. This assessment indicates that there is room for improving the operational reliability factors using the operational functional criteria discriminators as a guide.

While reviewing the table below for the WBS 2.6.5 In-space propulsion technologies, it can be seen that 6 of the 7 candidate technologies would show an improved operational difficulty factor over the reference case if matured.

The operational reliability factor evaluations could be improved for 7 of the 7 candidate technologies being considered. It is also seen that 3 of the 6 mature candidates showed an improved operational reliability factor over the reference technology for In-space WBS 2.6.5. Again this assessment indicates that there is room for improving the operational reliability factors using the operational functional criteria discriminators as a guide.

In summary this evaluation tool can be used effectively in planning an R & D program for improving the operational reliability and its effectiveness for improved safety as well as increasing the operability of these propulsion candidates. This product or its process should be used in achieving the objectives of affordability, supportability, and sustainability of future space transportation systems by improving their propulsion architectures.

Evaluation Product Results for 2.6.1 ETO Chemical Propulsion System

Criteria Discriminators ROLL-UP CRITERIA VALUE SELECTED:	2.6.1 Chemical Propulsion ETO	**2.6.1.1.1 RS68 LO2/LH2**	**2.6.1.1.2 SSMELO2/LH2**	*2.6.1.1.3 HM60 LO2/LH2*	*2.6.1.3.1 RBCC*	*2.6.1.3.2 Lox/LH2 Linear Aerospike*	*2.6.1.3.3 LO2/LH2 Aerospike Annular*	*2.6.1.5.1 Hybrid SolidFuel/LiqOxid*	**2.6.1.5.2 Shuttle SRM**	*2.6.1.6.1 RS72 NTO/MMH*	2.6.1.6.2 RS27A RP-1/Lox	*2.6.1.6.3 RD173 RP/Lox*	*2.6.1.6.4 RD180 RP/Lox*	*2.6.1.8.1 MGLV*	2.6.1.1.4? F-1 LO_2/RP-1 (Saturn S1C Rocketdyne)	J-2 LO_2/LH_2 2.6.1.1.5? (Saturn SII Rocketdyne)	2.6.1.5.3? (Saturn/Apollo LES ATK Thiokol)
Provide a well documented operations definition (discriminator criteria data) for evaluation and understanding		1	1	9	9	9	9	9	1	3	1	3	3	9	1	1	1
Operational Difficulty Factor Criteria Column Total Value		34.88	27	22.8	33.01	28.93	27.19	32.73	76.35	49.78	43.6	44.25	37.27	25.1	50.4	27.04	17.57
Operational Difficulty Factor Criteria Column Normalized Value ***(These Normalized Values are to be transfered to the ATLAS TTB)***		1.66	1	2.53	1.5	1.61	1.6	2.52	3.18	2.37	2.08	2.21	2.19	1.93	2.65	1.35	1.03
Provide a well documented operations definition (discriminator criteria data) for evaluation and understanding		1	1	9	9	9	9	9	1	3	1	1	1	9	1	1	1
Operational Reliability Factor Criteria Column Total Value		25.05	27	22.75	31.01	26.93	25.19	32.73	48.35	19.78	24.17	24.25	17.27	23.12	32.4	27.04	8.57
Operational Reliability Factor Criteria Column Normalized Value ***(These Normalized Values are to be transfered to the ATLAS TTB)***		1.25	1	2.53	1.55	1.68	1.68	2.52	2.1	1.1	1.21	1.28	1.08	2.1	1.71	1.35	0.5

Evaluation Product Results for 2.6.5 In-Space Chemical Propulsion System

Criteria Discriminators ROLL-UP CRITERIA VALUE SELECTED:	2.6.5 Chemical Propulsion In-Space	2.6.5.1.1LO2/LH2 RL10 A-4	*2.6.5.1.2 LO2/LH2 HM 60 Derivative*	2.6.5.1.2A? LO2/LH2 MB XX (60)	2.6.5.1.2B? LO2/LH2 RL60	2.6.5.2.1 Delta 1st Stage RS 27A LO2/RP 1 Derivative	2.6.5.8.1 (N2O4/ Aerozine 50) Delta 2nd Stage	2.6.5.8.1A RS72 NTO/MMH	*2.6.5.?? Hybrid SolidFuel/LiqOxid*	*2.6.5.?? MGLV*	2.6.5.1.3? J-2 LO2/LH2 (Saturn SIVB Rocketdyne)	2.6.5.1.5? N2O4/Aerozine 50 (Apollo CSM SPS Aerojet)	2.6.5.1.6? RS-1801 N2O4/Aerozine 50 (Apollo LM Ascent Rocketdyne)	2.6.5.1.6? N2O4/Aerozine 50 (Apollo LM Descent TRW)	OEPSS Focused Concept 2.6.5.?
Provide a well documented operations definition (discriminator criteria data) for evaluation and understanding		1	9	3	3	1	1	3	9	9	1	1	1	1	9
Operational Difficulty Factor Criteria Column Total Value		27	19.36	23.4	20.6	47.01	42.86	35.44	22.62	28.73	30.84	25.76	27.89	28.27	21.43
Operational Difficulty Factor Criteria Column Normalized Value ***(These Normalized Values are to be transfered to the ATLAS TTB)***		1	1.94	1.11	1.08	2.35	2.04	1.77	1.89	2.39	1.54	1.29	1.33	1.57	1.07
Provide a well documented operations definition (discriminator criteria data) for evaluation and understanding		1	9	3	3	1	1	3	9	9	1	1	1	1	9
Operational Reliability Factor Criteria Column Total Value		27	22.36	21.15	18.78	40.51	30.53	23.19	22.54	27.3	31.66	15.43	16.64	17.02	22.33
Operational Reliability Factor Criteria Column Normalized Value ***(These Normalized Values are to be transfered to the ATLAS TTB)***		1	1.86	1.11	0.99	1.93	1.61	1.29	1.88	2.73	1.58	0.77	0.79	0.95	1.12

The objective of developing a TTB for the ATLAS for the two WBSs of 2.6.1 and 2.6.5 for chemical propulsion was achieved. The following overall assessment of this project is included below.

OPERATIONAL METRICS DEVELOPMENT / DETERMINATION for ATLAS-TTB

Major observations from process

- Operational improvements aren't always technology constrained, but often driven by design choices – Apollo / Saturn vs. Current
- Traditional process of optimizing for minimum weight at the subsystem, system or contractual element level does not provide overall Space Transportation system for lowest LCC, Highest Reliability or Highest Safety.
- Traditional process was developed for achievement of maximum performance, e.g.,
- "Design Definition Process" needed to achieve Affordable, Sustainable Transportation System must be focus/optimized on major objectives of Lowest LCC, High Dependability, High Operability, and Maximum Mission Assurance/Safety – Followed by performance assessment & adjustment to achieve closure if required.
- Requirements must be defined around the major objectives above
- Must maintain focus on these above objectives throughout the entire design and operations phases

If you do what you have always done, you will get what you got before. Conceptual definition process must be changed.

- **The requirement of "SUSTAINABLE EXPLORATION" must be enforced**

Acknowledgment

The SPST is a national volunteer organization of government, industry, and university experts in space propulsion and propulsion-related technologies. The SPST is unique in its organization, membership and capability. It was chartered in 1991 by NASA and has a diversified membership of retired and active senior engineers, managers and scientist from industry, government and academia who have a wealth of hardware experience. The SPST was, and continues to be, dedicated to the development and operation of safe, dependable, affordable and sustainable space transportation systems. This is generally believed to be the key element in the Nation's ability to meet the goals of a Space Exploration Program. *SPST WEB SITE LINK:* http://spst.services.officelive.com/default.aspx