NASA-CR-197030

(NASA-CR-197030) PROGRAM TEST OBJECTIVES MILESTONE 3 (Rockwell International Corp.) 78 p

N95-15971

Unclas

G3/05 0030172

NASA
11-05-CR
30172
P- 78

SSD94D0335

Program Test Objectives Milestone 3

Cooperative Agreement NCC8-47

November 15, 1994

T. L. Gaynor
T. L. Gaynor
Principal Investigator

Thomas J Healy
T. J. Healy
Chief Engineer
Advanced Launch Systems

MARSHALL SPACE FLIGHT CENTER

Rockwell Aerospace
Space Systems Division

Integrated Propulsion Technology Demonstrator

Program Test Objectives

November 15, 1994

Prepared by C. Wood
IPTD Task 1 Lead (Rockwell)

Contents

I. Introduction 1

II. Approach 1

III. Relevant Data 2

IV. Discussion 3

1. RLV and ELV Program "Needs" 3

2. IPTD Test Objectives 3

V. Conclusions 4

VI. References 5

Appendix A: Technical Objective Development

Appendix B: Ground Rules and Assumptions from MSFC Reusable Launch Vehicle Concepts' Studies

IPTD Program Test Objectives

I. Introduction

This submittal is in accordance with Payment Milestone No. 3 "Submit Test Objective Definitions" Attachment B, page 1 of Cooperative Agreement No. NCC 8-47. Program test objectives have been developed under Subtask 1.2 of Task 1, "Test Requirements and Plans". Subtask 1.1, "Identify RLV Propulsion System Improvement Needs", was completed per schedule on October 15, 1994. Subtask 1.3, "Prepare Design Requirements; Test Plans, And Procedures", will be completed according to plan on January 31, 1995. The schedule for these subtasks is shown in Figure 1. Throughout the approximately four years duration of the Integrated Propulsion Technology Demonstrator (IPTD) program, these three subtasks of Task I will be repeated at approximately yearly intervals to maintain program direction consistent with need. On that basis the current document may be considered to be an interim document.

II. Approach

The approach to establishing test objectives was as defined in the program plan of August 15, 1994 and shown in Figure 2. A list of references, Section III, was compiled and reviewed by a group of government and contractor specialists working together as a team. Discussions were conducted with personnel having close association with both reusable launch vehicles (RLVs) and expendable launch vehicles (ELVs). Information obtained from these sources was a major contributor in establishing the necessary characteristics and features which future vehicle designs will likely contain.

These data were then evaluated by both government and contractor personnel to determine propulsion related "needs" which the RLV and ELV programs must contain for the respective programs to satisfy program objectives. Technical maturity for implementation of each established technical need was determined and ranked according to the technology readiness ranking level shown in Figure 3. The criticality of each identified "need", as it relates to the RLV and ELV capability to meet future program requirements, was then established. The criteria for determining criticality rating for each need are shown in Table 1. Based on these assessments, and the functional description per program phase envisioned for the IPTD, the applicability of using the IPTD to advance the technology readiness was determined. The results of this activity are presented in tabular form in Table 2.

After technology needs were established for future RLV and ELV programs, efforts were channeled to determine candidate test objectives for the IPTD program. An individual summary sheet has been prepared to further describe each need and is included in Appendix A. Included in each summary sheet is the TRL and criticality ratings assigned, technical rationale/description, a state of the art assessment and the individual test objective relative to the IPTD program. Since approximately fifty technology needs and thus a similar number of specific test objectives were identified, these have been grouped into top level test objectives the IPTD can address shown in Table 3. Test objectives which may not be adequately satisfied by the IPTD and factors which influenced this conclusion are identified in Table 4. As shown in Table 4, the primary limitation to the use of the IPTD is unavailable hardware or system components necessary to demonstrate technology advancements. This is symptomatic of the lack of technology funding available for advanced components and processes over the last several years.

III. Relevant Data

Personnel participating as team members or otherwise contributing to this report included propulsion systems, engine, operations, propulsion research, propulsion test, and avionics personnel. NASA MSFC, KSC, LeRC and ARC had inputs as did Rockwell personnel from California, Alabama and Florida.

Technical "needs" presented in this report have not been mathematically evaluated by the QFD method for establishing relative importance. Technical "needs" have been screened on the basis of engineering experience using the approach previously discussed. Both the propulsion synergy group and operations synergy team utilized the formal QFD method for rating technologies and these results have served as a calibration tool for "needs" not considered by these two teams. Subsequent activities to develop a test plan will require revisiting these activities for a more definitive IPTD configuration definition and provides the opportunity for the QFD method application if considered necessary. Furthermore, current efforts to potentially accelerate and enlarge the scope of the IPTD program, and include systems other than propulsion could invalidate the QFD ranking based only on propulsion system needs.

Technology enhancements are necessary for earth orbit (space) operations such as required for the upper stage of the RLV and ELV. Three specific areas require technology advancements and none of the three are compatible with the IPTD capability. These are: (1) propellant tanks with controlled low heat input (high performance insulated tanks); (2) efficient venting of propellant tanks; and (3) effective fluid management which includes several subjects such as propellant positioning within the tank for engine start, propellant mass determination, effective chilldown of feedlines and engines preparatory to engine start and may include transfer of propellant between two tanks. The TRL/criticality rankings for these tasks are 3/5 and 1/2, respectively.

IV. Discussion

1. RLV and ELV Program "Needs"

Table I has been subdivided into three parts; (1) operability issues; (2) design issues and (3) issues associated with delivering the required payload, although few identified needs will totally fall within one of the three categories. Cost has not been identified with any of the categories since it is involved to some degree in every "need" identified. The technology improvement needs presented for the RLV and ELV programs are not the total list identified, but represent a carefully screened list which includes high pay-off items that will contribute to the overall success of a vehicle in terms of operability, capability and cost. The resultant IPTD test program products are component, subsystem, system technologies that contribute to the maturing of a propulsion candidate in the early years of the program and, in later years, can be used to complete engine system testing to verify performance and other objectives. Some of the technology improvement needs are a subset of a broader improvement need. However, the importance of the individual "need" is believed to justify the limited duplication. For example, item numbers OP-18, "non intrusive leak detection techniques for internal leakage", and OP-20, "dual operating temperature range pressure transducers", are subsets of the higher level improvement need of OP-15, "smart sensors".

2. IPTD Test Objectives

Technical material presented in Appendix A provides not only a test objective for each RLV and ELV improvement need presented in Table 2, but also includes additional technical rationale and state of the art assessment. Some of these improvements can be adequately obtained within the IPTD program while others may depend on technology maturity and availability of component and subsystem hardware for incorporation within the IPTD. Those test objectives currently within this classification are presented in Table 4. Separate technology activities may be required in some instances to satisfactorily resolve some of the technology needs.

The next phase of activity, test plan development, Task 1.3, will select the specific test objectives to be accomplished on the IPTD program. This will be accomplished by structuring the specific test program and will consider not only technical "needs", but also appropriate hardware availability, resources, schedule and other factors.

V. Conclusions

The following conclusions have been developed relative to propulsion system technology adequacy for efficient development and operation of recoverable and expendable launch vehicles (RLV and ELV) and the benefits which the integrated propulsion Technology Demonstrator will provide for enhancing technology.

1. Technology improvements relative to propulsion system design and operation can reduce program cost. Many features or improvement needs to enhance operability, reduce cost and improve payload are identified.

2. The Integrated Propulsion Technology Demonstrator (IPTD) Program provides a means of resolving the majority of issues associated with improvement needs.

3. The IPTD will evaluate complex integration of vehicle and facility functions in fluid management and propulsion control systems, and provides an environment for validating improved mechanical and electrical components.

4. The IPTD provides a mechanism for investigating operational issues focusing on reducing manpower and time to perform various functions at the launch site. These efforts include model development, collection of data to validate subject models and ultimate development of complex time line models.

5. The IPTD provides an engine test bed for Tri/Bi-propellant engine development firings which is representative of the actual vehicle environment.

6. The IPTD provides for only a limited multi engine configuration integration environment for RLV. Multi-engine efforts may be simulated for a number of sub systems and a number of subsystems are relatively independent of the multi engine influences.

VI. References

The enclosed reference list, served as a basis for much of the information contained in this report includes among others: (1) Access to Space Studies; (2) Reusable Launch Vehicle Concepts' Studies; (3) Operationally Efficient Propulsion System Study; (4) Space Propulsion Synergy Group Studies, and (5) Operations Synergy Team Studies. The extensive hands-on RLV experience obtained with Shuttle design and operations has been an important contribution to this study. Ground rules and assumptions from the MSFC reusable launch vehicle concepts' studies are included in Appendix B to assist the reader in understanding the relationship of the IPTD to the objectives of the RLV program.

REFERENCES

1 *Access to Space Study, (Option 3), Final Report, Vol. II, Technology Plan*, Advanced Technology Team, NASA, July 1993

2 *Access to Space Study, (Option 3), Final Report, Vol. III, Design Databook*, Advanced Technology Team, NASA, July 1993

3 *Access to Space Study, Technology Readiness Level Assessment (for Reusable Launch Vehicles)*, briefing by the Advanced Launch Technology Team, NASA, July 1994

4 Craig, Bob, *Fiscal Year 1994 Manufacturing Science and Technology Area Plan*, Document No. AD-B181 343, Report No. WL-TR-94-8000, Headquarters Air Force Material Command, Directorate of Science and Technology, Wright-Patterson AFB, Ohio, March 21, 1994

5 Phillips Lab, *Fiscal Year 1994 Space and Missiles Technology Area Plan*, Document No. AD-B179 827, Headquarters Air Force Material Command, DCS/Science and Technology, Wright-Patterson AFB, Ohio, February 10, 1994

6 Meyer, Lee, *Technology Thrusts, Briefing for Industry,* Phillips Lab and US Air Force Material Command, Propulsion Directorate, August 1993

7 Rockwell, Space Systems Division, *Research and Technology Propulsion and Power Steering Group Technology List for Fiscal Year 1995*, Rockwell/SSD, Downey, CA, August 1994

8 Waldrop, Glen, S., *Operationally Efficient Propulsion System Study (OEPSS) Data Book, Vol. II - Ground Operations Problems,* NASA/KSC Contract NAS10-11568, Report No. RI/RD90-149-2, Rockwell International, Rocketdyne Division, Canoga Park, CA, April 24, 1990

9 Wong, George, S., *Operationally Efficient Propulsion System Study (OEPSS) Data Book, Executive Summary,* NASA/KSC Contract NAS10-11568, Report No. RI/RD90-149-2, Rockwell International, Rocketdyne Division, Canoga Park, CA, April 24, 1990

10 Wood, Charles, Brown, Glenn, S., *Technology Requirements for Cryogenic Propellant Propulsion Systems,* Rockwell Space Systems Division, Report No. SSD 94-MA0037, Huntsville, AL, April 25, 1994

11 Space Propulsion Synergy Group, *Reusable Launch Vehicle Concept's Study,* Steering Committee Meetings, NASA, August 2, 1994, and Working Session Minutes of August 8-10, 1994; August 25-26, 1994; and September 8-9, 1994.

12 *Reusable Launch Vehicle Propulsion Technology Implementation Plan, Executive Summary* - Space Propulsion Synergy Team - October, 1994

13 *Operations Synergy Team, Reusable Launch Vehicle Technology Development and Demonstration Program,* October 1994

14 *Description of Operations and Performance Models - Integrated Propulsion Technology Demonstrator* - Rockwell Space Systems Division - October, 1994

15 *Reusable Launch Vehicle Concepts' Study,* Steering Committee Meeting, August 2, 1994

16 Wright Lab, *FY94 Technology Investment Plan,* Flight Dynamic Directorate, 1994

17 Moorman, Thomas, Lt. Gen., *DoD Space Launch Modernization Plan,* briefing to COMSTAC, 5/10/94

18 Air Force Office of Scientific Research, *FY94 Research Technology Area Plan*, Doc. # AD-B182 350, Bolling AFB, DC 1994

19 Office of Space Systems Development, NASA/HQ, *Access to Space Study, Summary Report,* NASA, January 1994

20 Access to Space Steering Committee, *Access to Space - Option 1, Final Presentation Arnold Aldrich,* NASA, briefing, August 24, 1993

21 *Access to Space - Option 2, Final Presentation,* briefing, August 25, 1993

22 *Access to Space Study,* Advanced Technology Team *(Option 3), Final Report, Vol, I, Executive Summary*, NASA, July, 1993

23 *Access to Space Study*, Advanced Technology Team, *(Option 3), Final Report, Vol.. IV, Operations Plan*, NASA, July, 1993

24 Kahl, Ron, *Shuttle Evolution Option 1, Team Review* briefing, NASA, 4/15/93

Figure 1.
Task 1.0
Test Requirements And Plans

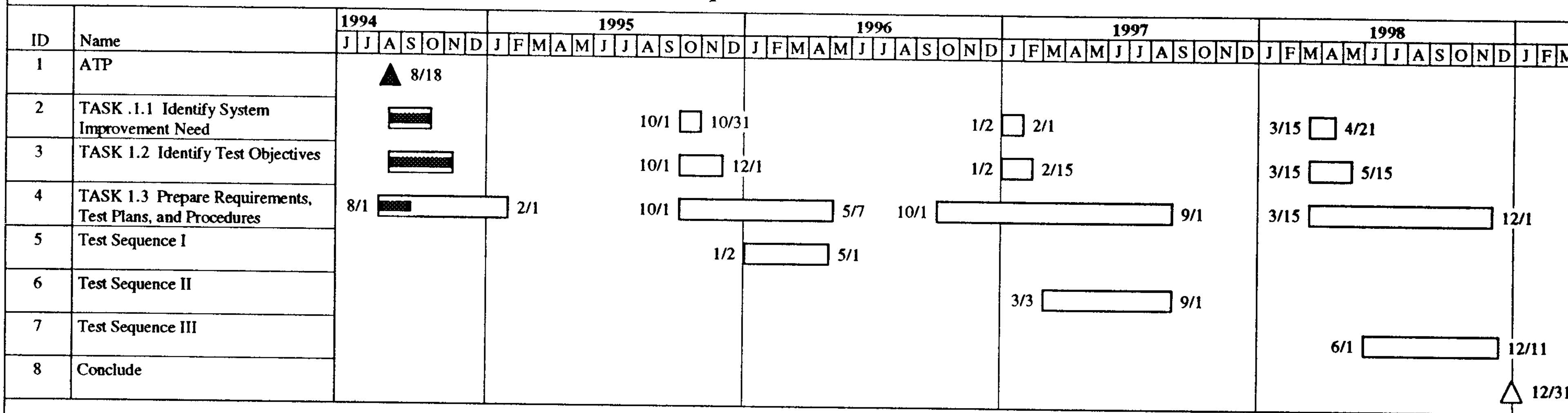
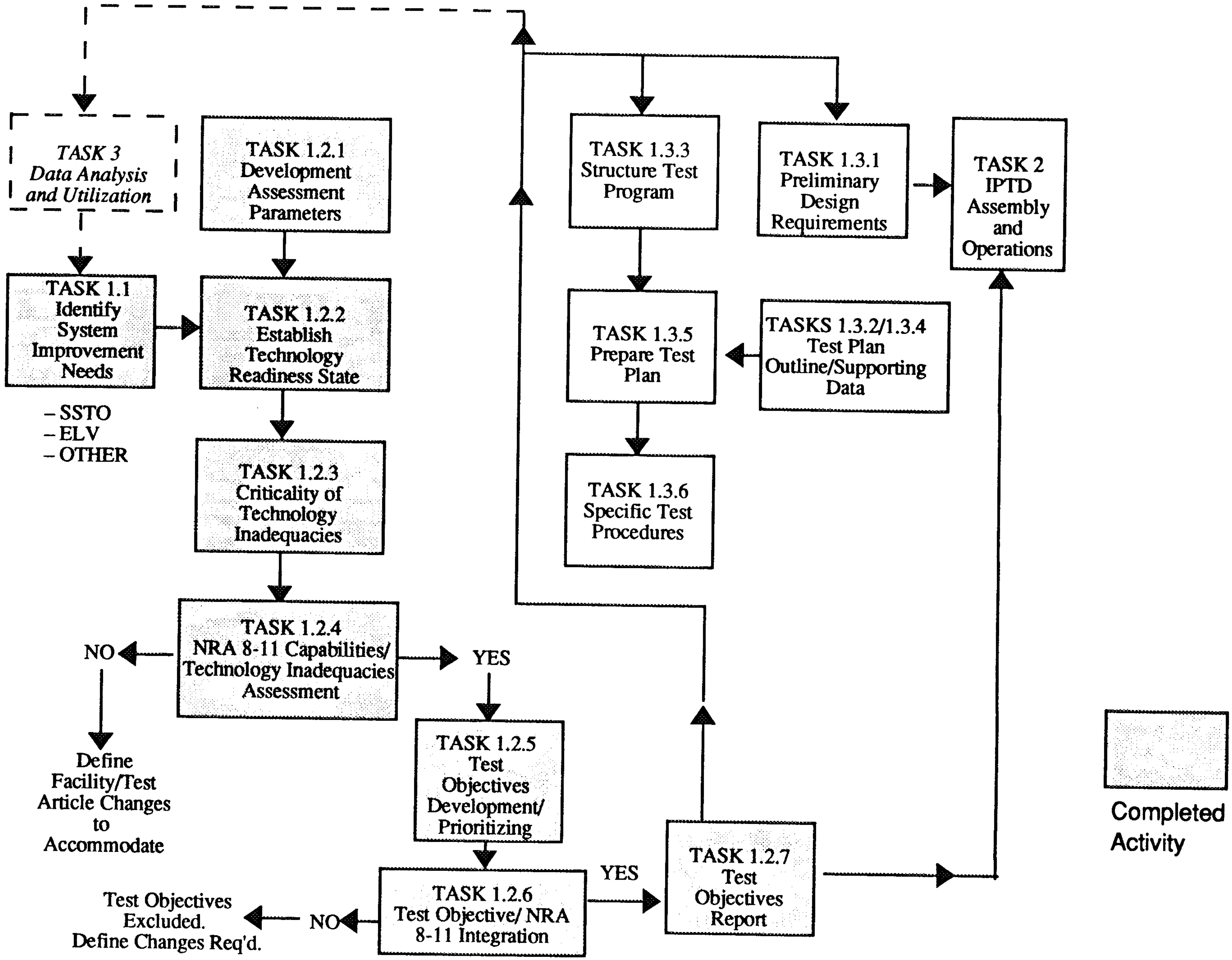


Figure 2 Task 1 Study Flow



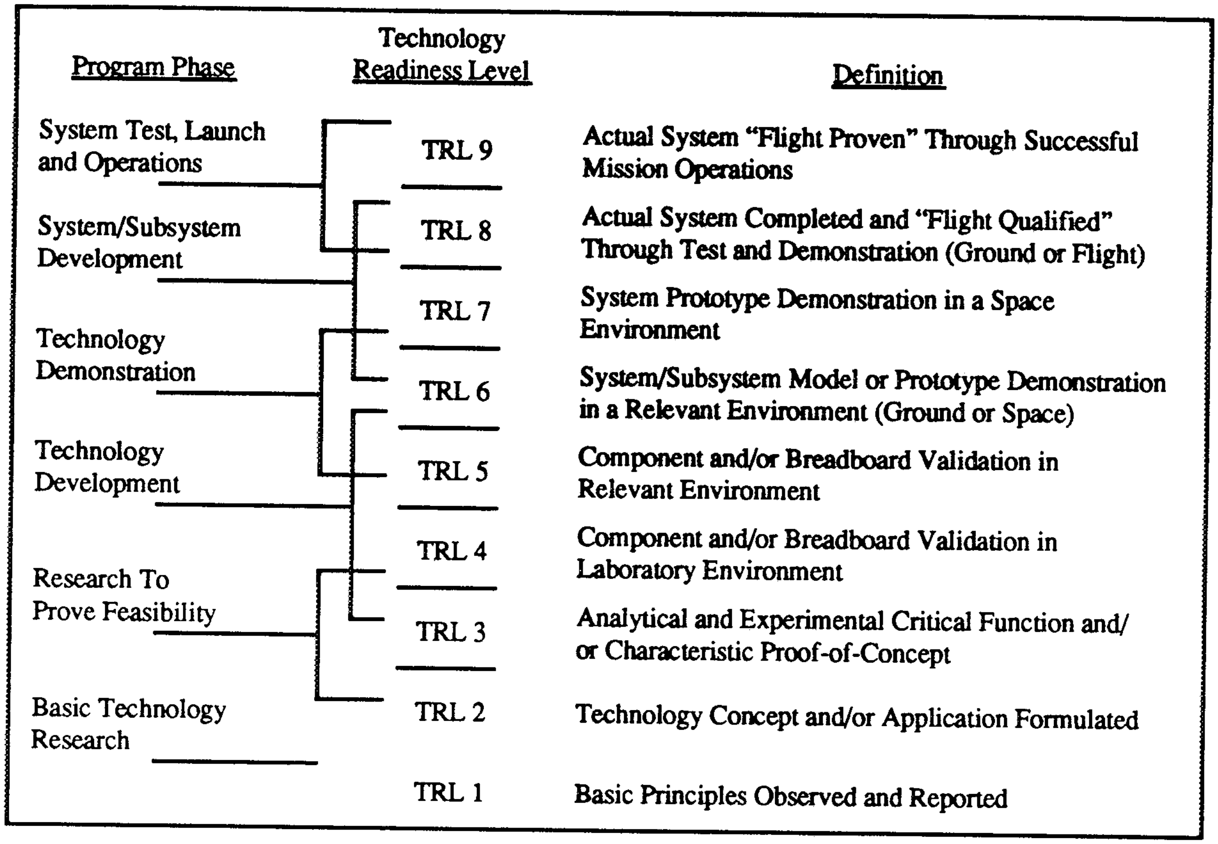


Figure 3. Technology Readiness Level Scale

Table 1. Criticality Readiness Level

Criticality Number	Definition
1	Absolutely necessary: Provides necessary performance/ operability benefits
2	Important: Achieves significant (~ > 50%) amount of program performance/ operability benefits
3	Useful: Achieves some program benefit.
4	Not needed: Existing technology can meet requirements, provide unneeded improvements.

Table 2. RLV/ELV Propulsion System "Needs"

OPERATION

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
OP-01	Automated functional checkout of complete system. Includes detection, analysis and usage monitoring correction (maintenance on demand) (2/2)	System requires complete checkout because health may be unknown	Vehicle health management has not been empirically verified. Technology also incomplete.	End-to-end verification; complete component technology	Performs system autonomous checkout	All	Propulsion	Generic
OP-02	Artifical intellegence/Expert System for monitoring/analysis/ control/ training during pre launch/flight/ post flight. Ground and flight systems (4/1)	Reduces operations cost, enhances safety, enhances launch process	Technology exists. Integrated System development necessary	Data to demonstrate maturity and initiate certification	Provides ideal operations environment	All	Propulsion, facility	Generic
OP-03	Automated leak management - same for flight/ground operations. Detect, locate, assess, corrective action necessary. (4/2)	Labor-intensive manual leak detection methods	Integrated system never evaluated. Technology incomplete	End-to-end verification of advanced concepts	Representation of complete system	2	Propulsion, OMS, other fluid system	Generic
OP-04	Automated propellant loading system with automated recovery from an anomaly (3/1)	Time, manpower, safety	Reliability of automated systems	End to end verification.	Representative of a fully operational system	2	Propulsion	Generic
OP-05	Automated propulsion mission manager (2/1)	Automated, built-in mission manager greatly relieves mission control center functions (Engine, MPS, ETC)	Verification/validation of autonomous system control; inflight operations	Validated on-board mission manager	Autonomous engine control and inflight tests	3	All	Generic
OP-06	Efficient vehicle access for repair/replacement (operability index) (6/1)	Labor-intensive/time consuming operation for access to service	Influence of open/closed boattail on vehicle	Man/machine operations data. Open boattail requires extensive other data	Representation of full system	1	Propulsion, vehicle	Generic
OP-07	Vehicle servicing data (Man/Machine) - Horizontal orientation. LRU scheduled & contingency replacement, model validation, etc. (4/1)	Establishing requirements/models for servicing	New models and models validation.	Man/machine data. Mechanical, electrical, fluid components	Data in operational environment	All	Propulsion, Engine	Generic
OP-08	Vehicle servicing data (Man/Machine) - Verticle orientation. Contingency LRU replacement model validation, etc. (4/1)	Establishing requirements/models for servicing	New models and models validation.	Man/machine timeline data Mechanical, electrical, fluid components	Data in operational environment	All	Propulsion, Engine	Generic
OP-09	Turn around operations model development/validation (4/1)	Acquire data for developing/ validating overall site operational timelines	Data and analysis methods for developing overall site timeline needed.	Man/machine timeline data. obtainable from IPTD	Data in operational environment	All	Propulsion, Engine	Generic
OP-10	Integrated Propulsion system design, MPS, RCS, OMS. (2/2)	Independent systems have own checkout, service requirements and facilities. Combining some/all can reduce timeline and cost	Development of new approach, reliability of new design	Appropriate analysis; partially integrated system data. Fully int. sys. data	Demonstrate integrated system	2,3	Propulsion, Engine, RCS, OMS	Generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

RENG4034

Table 2. RLV/ELV Propulsion System "Needs" (continued)

OPERATION (CONTINUED)

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
OP-11	Efficient/automated post flight prop. tank safing (2/1)	Safe, rapid propellant tank safing approach	Select an approach/develop hardware as required	Component data, system data, time lines.	Validate component/sys. data, develop timelines	2	Propulsion	RLV
OP-12	Umbilical optimization: location, design, individual/ganged, automation (5/1)	Labor-intensive and time consuming operations; complex, costly design; hazardous operations involved.	Selection approach; engineering application; system validation	Component/system data; functional dem. in operations environment	Approach/design validation in operational environment	1,2	Propulsion, Vehicle	Generic
OP-13	EMA for TVC (4/1)	Very labor intensive checkouts. Hydraulic systems require leak checks, de-aeration/filtering, fluid sampling analysis, functional checks	System still in development phase.	End-to-end validation	Representative of operational system	3	Propulsion, RCS, OMS	Generic
OP-14	Electrically actuated cryo valves (Replace pneumatically operated valves) (3/1)	Complex pneumatic system distributed throughout vehicle. Automated checkout difficultly	Integrated system never validated. Requires actuator development including power source mgt.	Actuator dev. effort, end-to- end verification of EMA system; operations data, fault tolerant power supply	Representative of complete system	2	Cryogenic valves, power and control	Generic
OP-15	Smart Sensor technology (3/1)	Automated checkout eliminates man intensive tasks; depends on sensors.	Sensor development required	Component perf. data; data in operational environment.	Provides operational environment	All	Propulsion, RCS, OMS	Generic
OP-16	Smart component technology (3/2)	Time consuming manual checkout and risks of creating new leaks/failure	Smart component development required	Component perf. data; data in operational environment	Provides operational environment	All	Propulsion, RCS, OMS	Generic
OP-17	Improve valve functional operation. (2/2) – Minimize binding – Improve position indication – Other	Frequent valve binding/other difficulties interfering with main KSC flows	Improved component efforts; evaluation in real environment	Component design and test data, functional data in operations environment.	Functional demo in real environment.	2,3	Propulsion, RCS, OMS	Generic
OP-18	Non intrusive leak detection techniques for internal leakage (3/1)	Check for 3 way valve internal leak requires removal and resultant leakage/contamination problems	Development effort req'd. Validation in system environment necessary.	Component design and test data, data in operations environment	Data in operational environment	All	Propulsion, OMS, other	Generic
OP-19	Operationally efficient/leak free mechanical joints and seals (2/1)	Joints leak from design/service deficiencies. Welded/brazed joints avoid leakage but add complication on entry	Replacement designs not validated in system environment. Improved procedures not developed.	Improved component data; data in operating environment	Provides operational environment and improved procedures	2,3	Propulsion, OMS, RCS	Generic
OP-20	Broad operating temp-range pressure transducers. Maintain accuracy for all conditions - Ambient/ cryogenic. (6/2)	Pressure measurement system accuracy inadequate at both ambient/cryo temps; complicates checkout	New type press. transducer sys. necessary. Accuracy necessary.	Component data; data in operational environment	Provides data in operational environment	2,3	Propulsion, RCS, Engine, OMS	Generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

RENG4034

Table 2. RLV/ELV Propulsion System "Needs" (continued)

OPERATION (CONTINUED)

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
OP-21	Substitute system for pyros (4/3)	Installation, removal, check-out of pyros requires personnel removal from vehicle	Replacement hardware unavailable	Component/system development	can provide sys-tem data	2,3	Propulsion, vehicle	Generic
OP-22	Increased sensor reliability (6/2)	Major source of STS failures is sensor related	Sensor technology lagging	Appropriate hardware and validation in operational conditions	Validation in operational environment.	All	Propulsion, RCS, OMS	Generic
OP-23	Capability for quick change out of engine on vehicle, both horizontal and verticle orientation. Quick disconnect capabilities. (1/3)	Enhance time line/reduce la-bor/minimize damage to ve-hicle hardware.	Acceptable design approach to satisfy need	Component data for quick disconnect. Timelines/work space	Develop /integration data. Time lines	1,2	Propulsion; engine, vehicle	Generic
OP-24	Long life component insulation (3/1)	Avoid MPS (Component) insulation servicing between flights - aeroheating and/or cryo exposure	Insulation improvements/ validation necessary. Vehicle configuration unknown.	Development and validation data	Cryo data validation; prticial high temp. validation	2,3	Propulsion, Engine	RLV
OP-25	OPAD integration with automated vehicle operations including usage with tri-propellants engine (4/3)	Automation of display/ con-trol of engine protective sys-tem	Applicability with tri prop. engine	acceptable concept demon-stration with tri propellants	Ideal integ. test facility	3	Propulsion, engine	Generic
OP-26	Minimum maintenance turbopumps (4/2)	Internal inspections require disturbance of sealed joints, is time consuming and involves risks	Built in non intrusive test equip. which continually monitors health.	Development of approp. hardware.	Data source but not unique	3	Engine	RLV
OP-27	H_2 vent without GSE flare stack (1/3)	Complex vehicle vent system and GSE.	Development incomplete	Development data, system application data	System applica-tion data	2,3	Propulsion	Generic
OP-28	Rapid tanking capability (3/3)	Long operational timeline	Effect of faster tanking unknown.	System analysis/data	System data	2,3	Propulsion	Generic
OP-29	Hardware commonality (N/A/1)	Serious logistics problems; hugh inventory, staging areas, shipping, receiving, etc. are labor intensive.	Maintain proper mgmt. em-phasis	None	N/A	N/A	Propulsion, OMS, RCS	N/A
OP-30	Smart / robust tank structure (2/1)	Propellant tank re-cert for reuse	Acceptable approach to be determined, then verified	Development data, integrated validation data	Development and validation data source	2,3	Propulsion, (tank)	RLV
OP-31	Feedline natural convection propellant conditioning (4/3)	Recirculation system is heavy, complex, costly, has numerous failure modes, excessive checkout time required.	Questionable system condi-tioning adequacy. Geyser potential on O2.	System perf. data with vehicle line/turbo pump	Perfect system testbed	All	Propulsion, Engine	Generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

RENG4034

Table 2. RLV/ELV Propulsion System "Needs" (continued)

DESIGN

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
D-01	Determine functional capability of engine in propulsion system test environment (5/1)	Partial vehicle/engine integration	None, although multi engine interaction data not obtained.	Basic data available without selected special hardware.	Integration system data and model validation	3	Propulsion; engine	RLV
D-02	Validate engine imposed vehicle design requirements (5/1)	Partial vehicle/engine integration	None, although multi engine interaction data not obtained.	Basic data available without selected special hardware.	Integration system data and model validation	3	Propulsion; engine	RLV
D-03	Determine functional compatibility of vehicle system and ground/GSE interfacing system (5/1)	Integration of vehicle/engine and GSE	None, although multi engine interaction data not obtained.	Requires selected GSE.	Integration system data and model validation	3	Propulsion, Engine, RCS, Oms	RLV
D-04	Flight system requirements for future avionics technology development as influenced by automated checkout/operations (4/2)	Establish program requirements for future vehicle	None, although multi engine influence missing.	Vital information available from IIPTD.	Automated test activity establishes requirements	1,2,3	Propulsion, OMS, RCS	RLV
D-05	Structured approach to IVHM (4/2)	Minimize IVHM Risk for program implementation	None	Verification of IVHM process	Treat IPTD as system	All	Propulsion, system	Generic
D-06	Simulation based design (4/2)	Reduce design to deployment development costs by extensive simulation, verf. & val. and simulation to control system migration.	High front end design cost required to reduce operations costs.	Development & validation of simulation based design approach.	Develop control system for dev. test	All design	Propulsion, system	Generic
D-07	Reusable object oriented propulsion control software (4/2)	Eliminate repeated development of software code through reuse.	Reusable code dev. for real system has not yet been verf. and validated	Verification that design/ analysis code can transform to control	Leverage matrix "X" code for control sys.	All Design	Propulsion, system	Generic
D-08	Common life cycle data bases (5/2)	Design analysis info typically has not been available to operators.	All design/analysis data not needed for operations. Must prioritize.	Verification that design/ analysis data bases are useful in operations. LCC trades.	Migrate FMEA into real time FMEA for PCCS foundation	Design phase	Propulsion, system	Generic
D-09	Real time geographically distributed simulations (4/2)	National resources (NSFL, LeRC, LRC, JSC) are provided into accessible national test bed.	None	Verification that various models, technologies, etc. can be integrated without leaving home base.	Merge ARC, LeRC, MSFC, other technologies electrically	Design phase	Propulsion, system	Generic
D-10	Determine vehicle external design environment (6/3)	Partial design environments established	None, although multi engine interaction data not obtained.	Basic simple engine data for tri-propellnat engine	Thermal/acoustic data obtained	3	Propulsion, Engine, Vehicle	Generic
D-11	Designer cost estimating models (4/1)	Improve cost estimating/control for new automated design approaches	Developed methods/models and validation data needed.	Known design process and records from design activity	Some required data obtainable from mechanical hardware and automated propulsion control system	Design phase	Propulsion, and propulsion control system	Generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

Table 2. RLV/ELV Propulsion System "Needs" (continued)

PAYLOAD

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
PL-01	Reduced dry weight by using hydro carbon propellant - tri propellant propulsion system (3/2)	Tanks storing low density, high performance propellants are large and heavy	Applied technology inade-quate; adds complexity	Realized sys. perf; operations cost data and time lines, prop. system integration data	Scaleable to operational vehicle	3	Propulsion, Engines	Generic
PL-02	Reduced dry weight by using densified H_2/O_2 propellants (3/2)	Tanks storing low density high performance propellants (H2) are large and heavy	Applied technology inade-quate; adds complexity	Operations cost data/time lines. Systems perf., payload benefit	Ideal integration test bed	2	Propulsion, Vehicle, Engine	Generic
PL-03	Engine/vehicle purge elimination/reduction (2/2)	Eliminate/reduce size of high press. gas storage, regulation and distribution system on ground/vehicle. Eliminate/ reduce leak checks/other labor intense operations	Elimination of engine purge requirement uncertain; purge quanity reduction possible .	Engine test data; hazard analysis	Vehicle purge applications ad-dressed. Test bed for engine not unique although valuable data obtained	2,3	Propulsion, Engine	Generic
PL-04	Early engine validation with unsteady inlet flow. Computerized POGO suppression. (2/4)	Engine stability characteristics for feedline instabilities (pogo)	None, although computerized option requires development	Feedline pulsing device component data. Computerized suppression device component data	Engine/vehicle system development facility	3	Propulsion; engine	Generic
PL-05	Low cost, light weight/long life/feed system (3/3)	Reduce hardware cost and reduce weight	Development hardware re-quired for testing	Component Dev. data and perf. in operational environ ment	Provides opera-tional environment	2,3	Propulsion, OMS, RCS, GSE	Generic
PL-06	Single vehicle and engine control (3/3)	Engine controls separate from vehicle and GSE controls; Leads to incompatible interfaces (EIU) and heavy engine controllers	Concept not developed.	Validated engine/vehicle controlling system	Propulsion system operating environment	2,3	Propulsion, engine	Generic
PL-07	Differential throttling (4/2)	Reduce cost/simplify design/ increase vehicle reliability of thrust vector control/reduce operations	Significant design/ integra-tion effort required	Significant design/ integra-tion then component devel opment and system data	Such a facility/ program required. Major program driver	3 plus	Propulsion, vehicle, engine	Generic
PL-08	Modular propulsion technology (2/2)	Potential weight/cost reduc-tion/reliability increase/ operations enhancement	Significant design/ integra-tion effort required	Significant design/ integra-tion then component devel opment and system data	Such a facility/ program required. Major program driver	3 plus	Propulsion, vehicle, engine	Generic
PL-09	Improved power system; integrated engine/propulsion system/power (4/3)	Battery system weight; fuel cell complexity.	Technical approach selected, hardware delevoped	Sybsystem dev. data	Integration test bed with other systems	2,3	Power	generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

RENG4032.

Table 2. RLV/ELV Propulsion System "Needs" (continued)

PAYLOAD (CONTINUED)

ITEM NO.	TECHNOLOGY IMPROVEMENT NEED (TRL/CRITICALITY)	RATIONALE	ISSUES TO BE ADDRESSED	DATA REQ'D TO RESOLVE ISSUE	APPLICATION OF IPTD	TEST PHASE	DESIGN REQ. FOR*	Vehicle Applic-ability
PL-10	Propulsion/engine system integration (6-7/2-3)	Pressurization geyser prevention, other; engine component development/verificaiton	None	None	Evaluate special component and subsystem approaches	All	Propulsion, engine	Generic
PL-11	Light weight reusable propellant tanks (1/1) (NRA-8-12)	Reduce weight, dev. reuse capability	Technology msut be developed	Extensive dev. data, certification	Tank dev., integration with prop in hostile environment	All	Tank	Generic

* Note: Propulsion includes propellant tankage, main propulsion system, the avionics and instrumentation systems necessary for determining performance and controlling hardware, and ground support equipment (GSE).

RENG4032.

Table 3. IPTD Top Level Objectives

- Determine system to system interaction of a tripropellant vehicle in a relevant environment.
- Validate vehicle/propulsion system imposed engine requirements.
- Assess feasibility of vehicle level health monitoring of propulsion systems and the ability to trend/predict maintenance and health problems without handons inspection.
- Determine the structural acceptability of engine and thrust structure design in the boat tail which was designed to be operationally efficient.
- Determine the minimal operational timelines and procedures needed to maintain safety and health of the system. Also, to recommend design changes that would improve the above desired effects.
- Validate the functional capabilities of propulsion system components/subsystems in the propulsion system environment
- Validate automated test, checkout and monitoring expert systems through the use of a flight environment testbed.
- Provide a systems testbed that can be used to validate component operation in an integrated propulsion system environment.
- Determine functional compatibility and interaction of the vehicle structure, fluid, electrical, and software systems with the ground/GSE interfacing systems.

Table 4. RLV/ELV Improvement Needs Requiring Advanced Components/Hardware Currently Unavailable for IPTD

Item Number	RLV/ELV "Need"	IPTD Contribution Dependent On Development Of Hardware Processes	TRL/ Criticality Rating	Applicability	Remarks
OP-11	Efficient/automated post flight prop-tank safing	X	2/1	RLV	Candidate approach evaluation required; possibly hardware
OP-14	Electrically actuated cryo valves. Replaces pneumatic valves/sys.	X	3/1	Generic	Adequate hardware Availability questionable. Low level activity recently commenced
OP-15	Smart Sensors	X	3/2	Generic	Some test sensors likely available
OP-16	Smart Components	X	2/2	Generic	Hardware not available. Potential NASA funding; real interest shown.
OP-17	Improve valve functional other operation. Binding, position indicators other	X	2/2	Generic	Small effort on position indicators. No other effort to improve.
OP-18	Non intrusive leak detection for internal leakage	X	3/1	Generic	Subset of smart sensors. No known emphasis or hardware
OP-21	Substitute system for pyros	X	4/3	Generic	Technology exist; hardware does not
OP-23	Capability for quick change out of engine on vehicle	X	1/3	Generic	No current emphasis nor hardware
OP-25	OPAD integration with automated vehicle operation including usage with tri-propellant engine	X	4/3	Generic	Success for O_2/H_2 prop. Tri propellant emphasis necessary
OP-26	Minimum maintenance turbopumps	X	4/2	RLV	Hardware availability not assured
OP-27	H2 vent without GSE flare stack	X	1/3	Generic	Successful component program is needed
PL-2	Reduced dry weight by using densified H_2/O_2 propellant	X	3/2	Generic	GSE refrig. system req'd., LeRC possibly provides
PL-6	Low cost, light weight, long life feed system	X	3/3	Generic	Suitable hardware not assured
PL-9	Modular propulsion technology	X	2/2	RLV	Suitable hardware possibly exist. More work needed
PL-10	Improved power system. Integrated engine/prop. sys/power	X	4/3	Generic	Concept dev. necessary. Stray hardware is possible. Work needed
PL-13	Light weight reusable propellant tank	X	1/1	RLV	NRA 8-12 developing. No current IPTD planning

Appendix A

Integrated Propulsion Technology Demonstrator

Test Objective Candidates

Operations — OP-1 through 31

Design — D-1 through 11

Payload Lift Improvement — PL-1 through 11

RLV Need (OP-1, 2)

OP-1: Automated functional checkout includes detection, analysis and correction (maintenance on demand). (TRL 2, Criticality 2).

OP-2: Expert System for monitoring/analysis/control/training during pre-launch/flight/post flight-ground and flight systems. (TRL 4, Criticality 1).

Technical Rationale

Reduce vehicle turn-around costs by reducing the need for ground checkout to determine the health of the flight vehicle.

Present ground turn-around activity is extensive because of the requirement to checkout the flight systems and components in order to insure the health of the vehicle prior to the next flight. Use of in-flight checkout diagnostics will eliminate the need for ground checkout. Addition of this capability requires more on-board instrumentation and computer memory.

State of the Art

Considered early in Shuttle program; however, lack of computer power and weight constraints on instrumentation and system were prohibitive.

Computer capability is now greatly improved and instrumentation technology has advanced. System definition is required to define overall system benefit.

IPTD Test Objective

Design the IPTD Test Article to allow system/component health determination during the test with no between test checkout. Provide end-to-end verification of the complete system. Develop operational data for comparison with current operations.

RLV Need (OP-3)

Automated leak management – detect, locate, assess, determine necessary corrective action (TRL 4, Criticality 2)

Technical Rationale

Objective is an automated leak evaluation system which is common for ground and flight and which can detect, locate, assess leakage and provide advisory response. Capabilities should include multi-component/system monitoring as in an engine compartment of a single/multi-engine vehicle and/or monitoring engines in an open environment. Planned RLV/ELV turn around between flights and launch complex operational efficiencies necessitates that vehicle health be known immediately on mission completion and that leak checks when necessary are efficiently conducted. Several thousand hours are expended per flight for Shuttle leak checks.

State of the Art

The need for improvement relative to today's Shuttle capabilities has been recognized and technology and program funding has been applied to developing new detection methods. Low cost sensors which can be used to monitor a volume, photographic techniques which utilize detectable gas and other techniques are being investigated.

An integrated small leakage detection package was planned for DCX flight in early 1994, but the flight was canceled. This package will be utilized on TTB. A suitable package possessing the characteristics needed for an operational system does not exist but should be available prior to the IPTD first test opportunity in 1996.

IPTD Test Objective

Develop component and system data in an operating environment to support development of an automated leak evaluation system for ground and flight which can detect, locate, assess leakage and provide advisory response. Objective accomplishment is dependent upon test hardware from ongoing technology programs.

RLV Need (OP-4)

Automated propellant loading system with automated recovery from an anomaly. (TRL 3, Criticality 1)

Technical Rationale

Use of a fully automatic propellant loading system will reduce ground operations cost by reducing the size of the support crew required to load the vehicle propellants.

The propellant loading operation is a highly complicated safety critical operation. Use of a well planned out automatic loading system can enhance the system safety as well as reduce the operational costs that result from a large standby support crew. The automatic system can be designed to identify and work around the system and component anomalies quickly and safely.

State of the Art

Automatic control systems are used in other safety critical operations.(Nuclear, chemical and electrical power industries). The technology exists to implement such a capability today.

IPTD Test Objective

Verify the automatic loading system in a "Battleship" environment. All the elements of a loading system are present but are more forgiving than a flight weight vehicle in developing a loading system. System anomalies can be simulated and resolved.

RLV Need (OP-5)

Automated propulsion mission manager (TRL 3, Criticality 1)

Technical Rationale

Current Shuttle operation are predominantly driven by ground operations (KSC ~ 40%) and mission operations (JSC ~ 40%). The JSC contribution consists of astronaut training, avionics/flight software re-certification and mission management. Astronaut training will not be required for RLV and software certification issues have been addressed in another IPTD objective. Efforts should therefore focus on reducing requirements for around the clock standing army mission management operations.

Current Shuttle Flight and Mission Operations are centered at NASA-JSC which require many personnel and control center facilities with large infrastructure costs. Compounding the issue is that many other NASA sites (Goddard, etc.) and contractor operations support centers are fully staffed to support JSC. There has been significant progress at JSC in reducing ops costs by automating mission planning procedures and evaluating downlisted data using advanced diagnostic tools, but these efforts are hampered by the fact that the vehicle was not designed to autonomously provide on-board equivalent functions. Current mission management reduction exercises are hampered by several factors: In some cases not enough data is available to perform in-flight checkout procedures; in most instances limited sample data rates (limited by outdated avionics processing capabilities) do not provide the fidelity to automate the procedures; the advanced software diagnostic tools have not been flight certified and are not allowed in the decision making process; and, there is a cultural resistance to fully automating the procedures with man in the loop. Migrating the technologies to the vehicle to eliminate these mission management issues must be addressed if RLV is to meet low cost turnaround requirements.

State of the Art

Current expendable and reusable launch vehicles are introducing advanced software tools into mission operations centers but certification and wide acceptance of new technologies has not been achieved.

Satellite control centers at JPL, Goddard and DoD Colorado Springs are more automated than launch vehicle centers but are far from reaching full potential. Common satellite and launch vehicle control centers priorities are automated mission planning, automated health and status, and integrated health and status, mission planning, and command sequencer functionality.

Satellite technology centers (JPL and USAF-Phillips Lab) are sponsoring ground based technology migration to vehicle control systems programs. Advanced on-board control is a major satellite technology program and progress to date should be transferred to the launch vehicle arena.

IPTD Test Objective

Establish current Shuttle mission operations timelines and procedures and extrapolate to IPTD environment, automate the mission operation requirements driving these procedures, embed functions in IPTD controller, and compare propulsion subsystem mission operations system impacts. Demonstrate low cost methods to verifying diagnostic software within IPTD mission controller and identify technologies and issues to be addressed prior to full scale development.

RLV Need (OP-6)

Efficient access for repair/replacement of hardware (TRL 6, Criticality 1)

Technical Rationale

To minimize operational cost and achieve planned RLV turnaround times at the launch site requires improved access for simple servicing and for major events as engine removal. Time lines for similar events for Shuttle are unreasonable — greater than 3,000 technician man hours for heat shield removal/replacement. Efficient designs are needed, and timeline developed and evaluated to establish a valid data base and validate models. Designs may include an open verses closed boat tail, an efficient compartment design entry for a closed boat tail configuration and intertank entry plus others.

State of the Art

The approach to resolving subject problem is largely dependent on the degree of openness adopted for the vehicle boat tail. Operations in general terms at the launch site are greatly enhanced by an open boat tail design. Numerous factors such as aerodynamic loading and heating to various vehicle components and engines during both powered flight and re-entry, vehicle control, and other factors also play an important role in the decision process. During the NLS program, studies were conducted of methods to provide protection to engines from both thermal and loads environments and should be helpful. IPTD activities may focus on both the open and closed boat tail design approach, however, should a decision evolve prior to test data accumulation, data may be collected for only one approach.

IPTD Test Objective

Develop operational type data to support future launch site time lines, validate models for managing such activities and develop design approaches which minimize the time required and operations involved in accessing vehicle compartments for servicing of hardware and/or replacing engines.

RLV Need (OP-7, 8, 9)

Vehicle servicing data, LRU replacement, model validation. (TRL 4, Criticality 1).

Technical Rationale

Operational cost on Shuttle is excessive. The RLV/ELV program must drastically reduce operations cost. Many on going Shuttle operation functions must be eliminated for RLV/ELV and the time and cost of performing others must be drastically reduced. This task will emphasize the operations aspects of vehicle maintenance/servicing with the objective of performing necessary operations more efficiently and collecting data to validate operations and models developed for operations planning. This data can ultimately support design methods and operations time lines. It will involve such things as: 1) determine the working space required internal to compartments for performing selected task; 2) component replacement time lines; 3) investigating methods to minimize damage to healthy hardware when servicing adjacent hardware; and 4) etc. Data is needed for a vehicle horizontal orientation (scheduled and contingency maintenance in processing facility) and vertical orientation (contingency maintenance at the pad.)

State-of-the-Art

Rockwell Space Systems Division Report (SSD94D0320) "IPTD Description of Operations and Performance Models" dated October 14, 1994 identified and discussed modeling capabilities in various states of maturity which are critical in developing and managing launch site operations. Needed input and validation data can be provided by the IPTD. The report also addresses propulsion modeling which the IPTD can also provide. The operational model functions noted under technical rationale plus others are contained within the reference and is a worthy data base for future program planning and implementation.

IPTD Test Objective

Develop design and man/machine type data to support operations planning and develop/validate new and existing models for use during future program planning and implementation of subject programs.

RLV Need (OP-10)

Integrated Propulsion System Design (MPS, RCS, OMS) (TRL 2, Criticality 2)

Technical Rationale

Existing OMS/RCS systems use storable, toxic propellants that are not common with RLV & ELV MPS propellants. These subsystems require separate hardware, separate servicing and therefore increased ground operations complexity and cost. Utilizing O2 and H2 propellant for OMS/RCS as well as the main propulsion system, cost would be reduced, and operations would greatly improve. Combining or integrating some aspects of the three propulsion systems could provide additional benefits by reducing hardware complexity.

State of the Art

State of the art operational OMS/RCS systems use storable propellants. Recently, a gaseous O2/H2 RCS was developed by Aerojet and tether tested on the DC-X. This program is continuing to develop a modular system which includes propellant conditioning (liquid to gas) and storage. Further development is required to increase the life of small thrusters and associated turbomachinery. Additionally, improvement is needed for more precise mixture ratio control of the pressure regulators.

Additional data are needed to mature this technology for incorporation into operational vehicles. The propellant consumption for a reference mission profile, including contingencies, needs to be defined to adequately size the system and ensure performance. Checkout data need to be generated so a operability comparison can be made with existing storable systems. Finally, a performance verification is required of the thrusters/engines operation with the integrated system.

IPTD Test Objective

Establish a prototype design, including tanking procedures, propellant storage, conditioning and delivery concepts. Incorporate smart sensors as available and integrate into Automated Checkout and AI/ES. Gather data as described in previous section. Validate operation of thrusters/engines and other components. IPTD integration activity would begin during test phase 2 for available hardware, and would be completed in test phase 3.

RLV Need (OP-11)

Reduce turnaround cost and schedule with an efficient automated method of propellant tank safing. (TRL 2, Criticality 1)

Technical Rationale

Reusable cryogenic propellant tanks must be made safe before allowing personnel access to the vehicle. This access is necessary to perform tasks required to prepare the vehicle for the next flight. Because the time required for tank safing is serial time, it has a direct effect on the total turnaround schedule.

State of the Art

Large reusable cryogenic propellant tanks have not been used in launch vehicles, but a similar tank safing has been required after ground testing of expendable cryogenic tanks. This safing includes boil off of residual liquids, venting of remaining vapors, and purging to reduce propellant vapor concentrations to safe levels. This process typically can take as much as a full work shift to accomplish. This operation may be further complicated by the propellant tanks being in the horizontal.

The design approach to tank safing must be determined and the degree of automation determined. The basic technology exist; however, applying appropriate technologies to achieve a practical solution is the real task. The flight and ground process must be developed along with critical timing to perform necessary operations.

IPTD Test Objective

Methods to be considered for tank safing and the hardware required must be investigated. The IPTD can utilize this information and hardware and obtain data for all necessary propellants which can validate the approach/hardware and collect data suitable for model validation. The time to perform the safing operation is critical for turnaround operational time lines.

RLV Need (OP-12)

Reduce ground processing time and costs with optimized umbilical systems. (TRL 5, Criticality 1)

Technical Rationale

Typical fluid and electrical vehicle to ground umbilical systems are complex, requiring a large amount of time and manpower to install/connect and checkout. For an efficient RLV/ELV, operational optimization of the systems are needed. This optimization must consider the umbilical location, its design, and the degree of automation used for ground processing.

State of the Art

The basic technology exists. Umbilical and disconnect components are available, but should be integrated into an efficient system.

An example is the fly away or lift off umbilical. In this type, vertical motion of vehicle provides the primary separation motion which eliminates GSE actuators used on other systems. In addition, the need for the launch tower or gantry structure may be eliminated.

IPTD Test Objective

Develop umbilical concepts which demonstrate features which enable rapid system ground processing. Test these systems to provide comparative operational cost data and to demonstrate survivability in launch environments.

RLV Need (OP-13)

Reduce vehicle complexity, GSE requirements, and ground processing time by replacing hydraulic TVC actuators with electromechanical actuators (EMA). (TRL 4, Criticality 1)

Technical Rationale

Current practice for thrust vector control of large rocket engines is by engine gimballing with hydraulic actuators. The associated hydraulic system is complex, requiring labor intensive and time consuming checkout and servicing. This includes leak checks, de-aeration/filtering, fluid sample analysis, and functional checks. In contrast, checkout of an EMA system can be fully automated, with significant reductions in time and manpower required.

State of the Art

Large EMA's have been developed. Prototype power and control systems have been tested.

IPTD Test Objective

Assemble and test the complete EMA system, including power and control. Evaluate redundancy and failure management of the complete system. Develop operational data for comparison with conventional hydraulic system operations.

RLV Need (OP-14)

Electrically operated valves. (TRL 3, Criticality 1)

Technical rationale

The pneumatic system associated with large valve operation is complex and increases turnaround operations. By substituting electrically operated valves, the pneumatic system could be eliminated or reduced in size. Furthermore, autonomous checkout systems, linked with the integrated vehicle health monitoring systems, could be incorporated.

State of the Art

In current vehicle designs large cryo valves are actuated by pneumatic pistons with pressure to the pistons controlled by solenoid valves. These designs rely on heavy storage containers, control and distribution systems. Although these types of systems can be used for an RLV/ELV, they may not be compatible with vehicle weight and operational requirements.

Electromechanical actuators for large valves are commonly used in non-aerospace industries, but not in cryogenic environments. This technology has been validated for smaller valves, such as engine valves, in a cryogenic environment, however, the programs addressing larger valves have just recently started.

IPTD Test Objective

Perform tests of a prototype large electromechanical actuated valve to obtain appropriate performance data in a vehicle system environment. Additionally integrate with the IPTD propulsion checkout and control system and validate associated power systems. IPTD integration activity would occur during phases 2 and 3. Component developmental testing should proceed IPTD testing.

RLV Need (OP-15)

Smart sensors (TRL 3, Criticality 1)

Technical Rationale

Smart sensors are needed to provide two RLV features: (1) Automated test and checkout and (2) Increased propulsion sensor reliability. Smart sensors provide the embedded intelligence (located either at the sensor or in the control logic) that will enable automated test and checkout and maintenance on demand operations Smart sensors also increase sensor reliability by providing localized health monitoring algorithms and reducing sensor usage demands by optimizing sensing rates to satisfy the external environment.

Extensive propulsion/avionics test and checkout time is dedicated to sensor calibration, end-to-end signal conditioning, wire/connector, and sensing element verification procedures. These procedures impact other propulsion test procedures and subsystem checkout timelines due to vehicle power activation and power-on monitoring requirements and require extensive operator involvement and knowledge. These procedures can be automated and localized at the sensor and controller through smart sensor development. The principle of maintenance on demand starts at the lowest level of the system, i.e., sensors, and the health and status of sensors is required before the health of the system can be confidently determined.

Improving sensor reliability is essential since current launch vehicle sensor failure rates are extremely high; over 50% of Shuttle MPS on-pad failures are sensor related. Some of these on-pad sensor failures were software related (not the sensor themselves) and launch scrubs could have been averted if the software was able to autonomously evaluate the sensor data and transform it into information in the control software logic.

Sensors are also sampling at data rates that do not best match the external environment and undue usage and sampling consumes sensor life expectancy and degrades sensor reliability over time. Optimizing sensor usage during flight and ground processing (i.e. variable sensing rates) will help improve sensor and propulsion system reliability.

State of the Art

SSME sensor logic is the most advanced of all systems but is only dedicated for launch commit criteria evaluation and not for in-flight sensor/subsystem health monitoring. Sensor validation and other algorithms have been individually developed in the laboratory but the envisioned set of required functional algorithms have not been integrated into one package and the algorithms have not migrated to microprocessor chips. The integrated chips/sensors have not been validated in a realistic cryogenic propulsion environment; and they have not been integrated in a subsystem health management system.

IPTD Test Objective

Emulate smart sensors (within the IPTD controller) in an automated test and checkout demonstration and validate that sensor verification can be autonomously performed during operation. Validate sensing data through a variety of algorithms and methods; compensate for sensor drift; optimally adjust sensing rates by detecting significant events in the propulsion system; reduce sensor data into information through signature recognition techniques; and demonstrate end-to-end autonomous sensor/wire/connector/signal conditioner checkout.

RLV Need (OP-16)

Fluid/mechanical components with built-in-test (Smart Components) (TRL 3, Criticality 2)

Technical Rationale

All next generation launch vehicle programs have promised that fluid systems will use automated test and checkout to verify flight readiness. However there are no fluid systems in the current launch vehicle fleet that can fully perform autonomous redundant on-board self test and the problem stems from limitations at the component level. Fluid/mechanical components include regulators, isovalves, check valves, relief valves and the actuation hardware associated with each component. These components need to provide autonomous test and checkout before autonomous propulsion system test and checkout is realized.

Extensive propulsion test and checkout time is dedicated to component test, removal, inspection and certification procedures. These procedures impact other propulsion test procedures and subsystem checkout timelines due to purge operations, vehicle power activation, power-on monitoring requirements, and require extensive operator involvement and knowledge. Current procedures include functional flow testing, internal/external component leakage, reverse leakage, valve response time, etc. and it is envisioned that RLV will require comparable level of testing. However, this testing (in-flight and/or on-ground) can be automated and built-in-to the components thus eliminating the need for extensive and costly ground support systems and their required infrastructure.

State of the Art

Smart components are being developed for other industries (automotive and commercial aviation) to simplify component validation, fault diagnosis, and replacement. The electronics and microcomputer industries are also pursuing components with 'built-in-test-equipment' (BITE) to reduce maintenance and support costs. As the technology matures, smart components are becoming common place and finding their way into everything from household appliances to commercial jet transports.

IPTD Test Objective

The actual development of prototype components with built-in-test will be provided by MSFC's Robust Sensor Technology Program. The IPTD objective is to provide robust component hardware technology requirements to satisfy the cryogenic and vibration environments of the test stand, test the components on the IPTD, and assess their impact on systems performance and operational goals. The IPTD control system shall also provide simple and low cost interfaces to enable other agencies and contractors to validate their component technologies in a system environment.

RLV Need (OP-17)

Improve valve functional operation. (TRL 2, Criticality 2).

Technical Rationale

Tight clearances result in particle production and bending during the normal operational sequence. Design improvements which minimize binding of check, flow control, fill and drain valves are needed. A survey of Shuttle problem reports for 25 Shuttle flights occurring since STS-51 L indicate 298 functional problems and 704 defect (damage) problems were experienced. These problems should be carefully reviewed with the goal of improving designs. Position indicators for valves also malfunction and result in delays. These problems will adversely effect RLV/ELV rapid turn around and thus operational costs.

State-of-the-Art

Existing valve hardware technology can be used for RLV and ELV. Based on experience difficulties are to be expected which will largely negate RLV and ELV accelerated time line planning. No known valve improvement technology is in progress to improve valve functionality. Some limited IR&D work is directed toward improved position indicators.

IPTD Test Objectives

The IPTD program will be conducted utilizing valve hardware based on today's technology as discussed above and most of the identified test objectives will be satisfied. Some data maybe distorted due to valve functional failures.

A program to improve valve designs in appropriate and testing of improved valves is necessary at the component level. Once component testing is completed the IPTD can provide launch vehicle environments to further verify valve functionality.

RLV Need (OP-18)

Non-intrusive leak detection techniques for internal leak. (TRL 3, Criticality 1)

Technical Rationale

Internal leak checks of 3-way valves can require valve removal or opening of the downstream system. Upon reinstallation of the valve or closing the downstream system, external leak checks are necessary. This may involve external GSE connection, and subsequent interface reverification. This operation can lead to internal contamination, introduction of a potential leak which may have otherwise not existed plus extensive elapsed time, and the resources required to perform the operations. Non-intrusive leak detection techniques are needed to speed system reverification and for troubleshooting efforts.

State of the Art

Very little known active research or development.

IPTD Test Objective

The program objective is to initiate design and develop a suitable test article to demonstrate the ability to perform leak testing of critical components, such as a 3-way and check valves, in-place and without external test equipment connections that themselves need reverification. This includes development of adequate instrumentation sensors to preclude the need for all but failure confirmation.

There is no IPTD test objective prior to hardware availability for testing. Upon hardware availability the IPTD objective would be checkout of the component in an expected operational environment.

RLV Need (OP-19)

Operationally leak-free mechanical joints and seals. (TRL 2, Criticality 2).

Technical Rationale

Develop and demonstrate methods for leak elimination. This will reduce operations time and cost and eliminate launch delays. The time utilized in assuring a leak free Shuttle vehicle before flight is significant and the operational procedures can not be carried on to RLV/ELV. The issues are leak elimination and detection to assure no leakage exists. Leak detection is a separate item in this package.

Leakage can result from either a poor design, improper installation for the selected design or improper servicing. A flawless design improperly serviced may very well leak.

The Shuttle operational time line is frequently impacted by removal of "permanently installed components" which must be removed. This leads to contamination concerns and other issues. The KSC desire is for non-permanent installation techniques if there is any possibility of part removal, which means more joints.

To resolve these issues, zero leak joints, proper installation, damage free servicing and rapid leak detection (covered elsewhere) need to be addressed.

State-of-the-Art

Much of the work relating to mechanical joint design has been done. The joint issue should be examined as a total subsystem considering above discussed features. Testing of advanced seals of various types have been conducted and more tests are planned for 1995. Improvements in sealing techniques may or may not be sufficient. An automated leak detection system which can rapidly determine, locate and assess leakage is essential for flight and all ground operations (covered elsewhere).

IPTD Test Objectives

IPTD can evaluate selected joint/seal designs in a vehicle type environment. Procedures need to be developed to minimize installation and servicing errors. Experience can be obtained relative to all issues discussed.

RLV Need (OP-20)

Dual operating temp range pressure transducer. Maintain accuracy for all conditions-Ambient and Cryogenic. (TRL 6, Criticality 2).

Technical Rationale

A single pressure sensor that can accurately read the system pressure at both cryogenic and ambient temperatures will improve operational efficiency.

Present Shuttle cryogenic pressure sensor accuracy is inadequate for both cryogenic and ambient temperatures. A pressure sensor needs to be developed that can compensate for the thermal environment and still provide accurate data. This will allow the use of a single sensor to read the system pressure over the entire mission. This task can be a sub task to another task - smart sensors. It's special importance to operations justify separate identification.

State of the Art

Sensors are being developed that can determine their own health and re-calibrate themselves as required.

IPTD Test Objective

Demonstrate in a known operational environment the capability of a pressure transducer to adjust its calibration.

RLV Need (OP-21)

Eliminate the need for personnel evacuation from area of vehicle for installation of pyrotechnic devices. (TRL 4, Criticality 3)

Technical Rationale

Replacement of pyrotechnic devices with functionally equivalent electromechanical devices decreases turnaround time by eliminating the need for personnel evacuation during pyro installation, checkout, and removal.

State of the Art

Basic technology exists. Designs must be developed for electromechanical systems for specific applications.

IPTD Test Objective

Demonstrate electromechanical devices which can functionally replace pyrotechnic devices. Provide operational data which can be used to develop cost comparisons between the two types of devices. The IPTD can provide the operational environment suitable for functional demonstration.

Development and demonstration of hardware at the component level must precede integrated system tests on the IPTD.

RLV Need (OP-22)

Robust Sensors (TRL 6, Criticality 2)

Technical Rationale

Improving sensor reliability for RLV propulsion requires a combined effort of smart sensor software (discussed in another objective) and robust sensor hardware. This effort focuses on the hardware issues of reliability - how to make a better sensor. Launch vehicle sensor hardware (sensing elements) are based on outdated technology and need to incorporate commercial sensor improvements that have been developed over the last decade. Additionally, non-intrusive sensing techniques should be investigated to minimize leakage potential at installation sites and to avoid/minimize sensor exposure to cryogenic fluid temperatures.

Current launch vehicle sensor failure rates are extremely high; over 50% of MPS on-pad failures are sensor related. Some of these failures have been hardware related, i.e. crushed diaphragm, broken wire, etc. However, most current sensor reliability development programs are focusing on software development. Hardware improvements must compliment and be fully integrated with the software technologies if the sensor system reliability is to be improved over current program reliability data.

State of the Art

Current launch vehicle sensors use 30-year old technology and have shown only modest reliability improvements (mostly due to manufacturing quality improvements) over that time. Measurement confidence is attempted through application of redundant sensors at the measurement site.

Commercial industries have developed new approaches to sensing and there have been several improvements in non-intrusive and micro-sensing techniques. However, these improvements have not been applied to the launch vehicle environment and subjected to the harsh vibration and temperature environment.

IPTD Test Objective

The actual development of prototype robust sensors will be provided by MSFC's Robust Sensor Technology Program. This program will provide requirements to sensor vendors and build several prototype sensors (pressure, temperature, position indicators). The IPTD objective is to provide sensor hardware technology requirements to satisfy the cryogenic and vibration environments of the test stand, test the sensors on the IPTD, and assess their impact on systems performance and operational goals. The IPTD control system shall also provide simple and low cost interfaces to enable other agencies and contractors to validate their sensor technologies in an system environment.

RLV Need(OP-23)

Quick change out of engine, both horizontal and vertical. Quick disconnect.(TRL 1, Criticality 3).

Technical Rationale

To minimize the time to change out a faulty cryogenic propulsion component, simplified fluid connections must be used. Simplified fluid connections at engine/MPS interface and component-to-component interfaces.

Present Shuttle cryogenic flange and seal design requires multi-bolt flanges and careful handling of the seal and sealing surface to accomplish a leak free connection. New sealing and flange clamping concepts must be developed to reduce turn around.

State of the Art

Conceptual designs for quick engine removal were proposed during the STME development program.

IPTD Test Objective

Verify new quick engine change concepts in an operational environment. Develop operational data for comparison with current engine removal methods.

RLV Need (OP-24)

Long life component insulation for both cryogenic and high temperature applications (TRL 3, Criticality 1)

Technical Rationale

To reduce turn around costs, better component insulation needs to be developed.

Present cryogenic insulation deteriorates with time and cryogenic cycles thus losing it's insulating quality and in some cases resulting in a source for liquefied air formation. Repair operations increase turn around time and costs.

Components of the propulsion system and engine which may be exposed to high temperature environments during powered flight and/or re-entry must not require replacement or repair after each mission otherwise RLV turnaround and operational cost requirements will be jeopardized. A basic decision relative to open vs. closed boat tail may significantly influence the number of components for which this becomes a concern.

State of the Art

Insulation concepts have progressed since the time of the Shuttle design. New materials are available. New concepts must be developed to reduce operational costs.

IPTD Test Objective

Verify the use of new insulation concepts in an operational environment. Develop operational data for comparison with conventional insulation systems.

RLV Need (OP-25)

Optical Plume Anomaly Detector (OPAD) integration with Propulsion Checkout and Control System (PCCS) including usage with tripropellant engine. (TRL 4, Criticality 3).

Technical Rationale

Rapid turnaround and real-time health monitoring are required for the RLV to minimize operational costs. Monitoring the exhaust plume spectra provides a method for early detection of melting or shearing materials in the engines. Signals from the OPAD can be used to save an engine from further damage and to indicate the need for repair.

State-of-the-Art

OPAD systems are being developed for LO2/LH2 engines, currently, by NASA. The ability of the detectors to detect the various metals utilized in SSME has been demonstrated on rocket engine tests at the Stennis Space Center and MSFC. The quantitative measurement capabilities are currently being developed and the ability to detect streaks of impurities in a plume has not been proven. Detection in the plume of a tripropellant engine has not been demonstrated.

IPTD Test Objective

The ability of OPAD to function with a LOX/hydrocarbon plume must be demonstrated in tripropellant engine development tests and tripropellant model engines. The developed system can then be installed on the IPTD and integrated with the PCCS. The system will monitor the engine during firing. The use of non-cryogenic RP will simplify seeding the plume with known quantities of metal salts for system calibration and checkout.

IPTD does not provide any tangible benefit relative to single engine tripropellant engine testing.

RLV NEED (OP-26)

Minimum maintenance turbopumps (TRL 4, Criticality 2)

Technical Rationale

Objectives of this need are to reduce the time and manpower required to prepare and turnaround turbopumps for flight with the ultimate goal of eliminating pre-flight inspection and maintenance of the turbomachinery. The elimination of manpower intensive activities such as pump removal and disassembly to replace low life components is one area that could greatly reduce the operations cost and possibly eliminate the need for an on site engine shop. Furthermore, the number of inspection/checkout procedures that are currently required on the SSME (the world's only reusable engine) must be reduced to external visual, torque checks and shaft travel if the operational goals are to be met on the RLV. To achieve these simple inspection/checkout procedures the engine must be designed with more margins, longer life components, and higher reliability. Methods must also be developed to monitor the engine health throughout flight and then report on the status of the engine for the next flight.

State of the Art

Hydrostatic bearing testing has been demonstrated on test rigs using SSME LO2 pumps. They have the potential to greatly reduce inspection, maintenance and complexity.

Cycle designs which lower the turbine temperatures will eliminate the need for special coating, cooling passages, and reduce turbine blade cracking issues.

Oxygen rich preburners will eliminate the need for an inter propellant purge seal in the turbopumps which will reduce the cost, complexity, and maintenance associated with the pumps, at the same time improving the life, reliability, and stability, while reducing the weight.

Health monitoring and trending technology is being developed that will allow us to take full advantage of the above technologies. Some of these monitoring technologies include non intrusive sensors, plume analysis, and reliable shaft displacement and rotation sensors.

IPTD Test Objectives

The objective of the IPTD is not to develop turbomachinery. However, the IPTD can be used to validate checkout/inspection procedures, health monitoring, and integrated system operation. Also the development of a component and system database through testing would aid in the development of and automated health monitoring and checkout system for ground and flight. Objective accomplishment is dependent upon test hardware from ongoing technology programs.

RLV Need (OP-27)

Reduce vehicle and ground system complexity use of a catalytic device which entrains air or uses vented oxygen to provide a controlled burn of venting hydrogen to replace venting hydrogen from the top or side of a vehicle via a GSE burn stack. (TRL 1, Criticality 3)

Technical Rationale

SSTO vehicles may require venting of hydrogen into the atmosphere without a burn stack. Free venting of hydrogen can produce explosive conditions around the vehicle (DC-X).

State of the Art

Hydrogen/air catalytic devices exist.

IPTD Test Objective

Extensive development testing of a catalytic combustion device must be conducted at the component level to assure functionality at the flow rates and environmental conditions representative of a launch vehicle. Once satisfactorily competed, and the appropriate hazard analyses have been made, the test can be conducted on IPTD. The IPTD would demonstrate a catalytic combustion device that passively entrains oxidizer/air and reliably combusts the vented gas. Temperatures of combustion must be compatible with the vehicle.

RLV Need (OP-28)

Rapid tanking capability (TRL 3, Criticality 3)

Technical Rationale

To reduce the operation costs, the launch vehicle propellant loading timeline should be reduced to the minimum time that is practical (2 hours as a goal).

Present Shuttle propellant loading operation requires an exorbitant amount of time due to compromises with work-around designs and inability to factor operational costs into early "cost-saving" design decisions. The technical expertise exists to reduce the loading timeline to a reasonable value. This will reduce costs in both labor and consumables.

State of the Art

The technical capability to load a vehicle of the SSTO size in 2 hours exists. The Shuttle was designed to be loaded in that amount of time. The facility cryogenic flow rates required to attain this goal were demonstrated during the Saturn program.

IPTD Test Objective

Develop and demonstrate operational approaches required for rapid loading.

RLV Need (OP-29)

Hardware commonalty (TRL - N/A, Criticality 1)

Technical Rationale

The use of common hardware for valving, bellows, elbows, and line sections whenever possible could significantly reduce the storage of spares, reduce the development cost, reduce training, and reduce repair and replacement times.

State of the Art

With the advances in CAD/CAM in the recent years it is now feasible and cost effective to design the entire boat tail system on a computer where the line runs, bends and connections can all be tested before any metal is cut. With this technology it is possible to determine where conflicts in routing with structure will occur and to design them out. Likewise, the system could be used to determine where common hardware can be used or to modify the design to make common hardware usage more convenient.

IPTD Test Objectives

The objective would be to assess the functionality of the computer model design in an operational environment. It would also allow for human design factors to effect the location of hardware for test, checkout, inspection, removal and replacement.

RLV Need (OP-30)

Smart/robust tank structure (TRL 3, Criticality 1)

Technical Rationale

The RLV will depart from previous launch vehicle systems by reusing its cryogenic propellant tanks to reduce per flight costs associated with replacement of staged hardware. This requirement introduces the need for assessing the health status of the propellant tanks and determining their fitness for reuse. To enable automated test and checkout and maintenance on demand operations robust propellant tank systems (tankage, insulation, TPS) with designed in margins combined with embedded/attached sensors to enable critical structural assessments are required.

The RLV vehicle configurations under study all share a common feature: integrated, reusable cryogenic propellant tank systems. Predicted RLV tank inspection requirements span crack/flaw growth, delaminations, surface debonds, tank leakage, tank pressure loads, TPS water content, impact damage and others yet to be defined. Without available data to provide the health status of the propellant tank structure the length and expensive process to inspect for these fault modes will accrue expensive ground turnaround operations and increases program costs.

Two strategies should be applied to achieve operational goals: (1) design in sufficient margin so the propellant tank can be certified for life; (2) embed or attach structural monitoring sensors to provide continuous health status data where robustness is not practically feasible. Robust structures, with self test capabilities, are required to achieve the greatest benefit for autonomous checkout and control and integrated vehicle health management.

State of the Art

Currently there are no operational reusable cryogenic propellant tanks. Current expendable propellant tanks are instrumented to establish propellant quantities and fluid state via fluid property (pressure, temperature, etc.) measurements. The propellant tanks have limited instrumentation to assess the status of the tank structure itself, or, to predict structural failure modes.

The oil refinery and nuclear industries implement automated structural health management using a combination of embedded tank sensor technologies and externally mounted scanning systems. These technologies have not yet migrated to operational launch vehicle programs.

IPTD Test Objective

Validate LO2, LH2, RP-1, and He tank sensor approaches and technologies to provide real-time tank health monitoring, track tank degradation over time, and reduce IPTD downtime between tests due to tank inspections and assess their impact on systems performance and operational goals.

RLV Need (OP-31)

Feedline natural convection propellant conditioning (TRL 4, Criticality 3)

Technical Rationale

Propulsion systems currently use complex/expensive systems for engine thermal conditioning prior to engine start. The RLV requires simple, lightweight, operationally efficient systems, without the need for special conditioning subsystems. Passive recirculation of propellant within propulsion system feedlines can possibly accomplish chill down requirements without any dedicated hardware.

State of the Art

Present cryogenic engines require sub-cooled propellant within the feed systems and portions of engines. Operational vehicles accomplish this by pumped recirculation or bleed either through the engine or overboard. Technology programs are underway to determine proof-of-concept of a passive recirculation system. These programs utilize simulated hardware and are not representative of vehicle designs.

IPTD Test Objective

Investigate Passive Recirculation as a means for propellant conditioning for engine start. Demonstrate and verify that engine start sequence is compatible with passive recirculation. IPTD integration activity would occur during test phase 2 and 3.

RLV Need (D1)

Determine functional capability of engine in propulsion system test environment. (TRL 5, Criticality 1)

Technical Rationale

The capability to properly chill down the engines and the propulsion system must be verified in the system test environment. During engine startup, mainstage and shutdown, the propellant pressures, temperatures and transient conditions at the engine/MPS interface usually differ from those on a single engine test stand. In the care of an enclosed boat tail, the thermal environment may be vastly different, thus influencing avionics component, electrical actuators, other actuating devices, sensor operations, etc. Temperature and flow rates of propellant blocks for pressurization must be measured and controlled. The capability of PCCS to checkout facility and vehicle health prior to engine firing and to monitor performance during operations is important. Rocket propellant (RP) located in close proximity to LH2/LO2 must be carefully managed to prevent undesirable cooling which can lead to thermal gradients and resultant engine damage during engine start as has happened on some previous programs. Elimination/reduction of engine purges - pre-firing, firing, post firing—is another important feature.

State-of-the-Art

There is currently no experience in the United States Space program with tripropellant engines. From a facility/vehicle standpoint the use of both cryogenic and hydrocarbon fuels does not appear to create any obvious technology issues. Elimination of engine purges is highly desirable and a major technology area. Automated vehicle checkout and artificial intelligence/expert system technology are in various stages of development and significant technical challenges retrain. Engine compartment temperature and the influence on component/system operation is a standard engineering issue but may become complex considering requirements for rapid turnaround/easy servicing, etc.

IPTD Test Objectives

One RLV engine will be mounted and fired on the IPTD. Compatibility of the engine with the PCCS and propulsion system will be demonstrated. Engine chilldown timelines and procedures will be established. Data with improved engine/propulsion systems components will be obtained as will data on other issues not discussed, data will be obtained during prefiring, firing and post firing test phases.

RLV Need (D-2)

Validate engine imposed vehicle design requirements. (TRL 5, Criticality 1).

Technical Rationale

The RLV engines will be a new design and are anticipated to be tripropellant engines using LOX, LH2 and RP. Design requirements will be imposed on the vehicle in the following general areas:

Fluid Interface Requirements
Power/Control/Data Interface Requirement
Mechanical Interface Requirements
Static and Dynamic loads
Acoustics
Plume Radiation
Re-entry Heating Protection
Exhaust Contaminants
Fuel Lead Burning Environment
Fuel Lag Burnoff Environment
Gimbal Clearances
Possible Restart Capability

The ability of the propulsion system to meet the applicable requirements is essential to designing the multi-engine vehicle. Accurate measurement of the actual parameter, will provide the data needed to support vehicle design.

The high sensitivity of RLV/ELV payload to performance (1000-1500 pounds per second Isp and 4-5 pounds for each pound of vehicle growth) necessitates an efficiently designed/integrated propulsion system. Advances in CAD/CAM can not only expedite engine, and vehicle design but can be effectively used in integration of the engine and propulsion system.

State-of-the-Art

Necessary technologies exist or are contained in other items discussed within the package. A major challenge is to develop an efficient, light weight engine and propulsion system "package" without sacrificing "robustness". It is of utmost importance that the guidelines and significant issues are understood. Automated design tools, CAD/CAM, and modeling techniques may help in system selection issues as determining the optimum split of responsibilities for such things as gimbal systems, power supplies, thrust mounts, heat shields, etc. The interacting between tankage, lines, valves and engine are complex and need testing to validate models.

IPTD Test Objective

The IPTD can provide valuable data for efficient propulsion system design and integration with engines. It will accurately determine all of the fluid interface requirements such as engine thermal conditioning, NPSP, flowrates, purges, etc. Acoustics, radiation and prestart and post-cutoff fuel burning effects can be measured. Transient and steady state loads and vibration loads applied to the propulsion system can be measured. Much of this data can validate existing or newly developed models/design techniques for later use in actual vehicle designs.

RLV Need (D-3)

Determine functional compatibility of Vehicle system and ground/GSE interfacing system. (TRL 5, Criticality 1)

Technical Rationale

Rapid turnaround of the RLV which involves post-flight safing maintenance and servicing, and on-pad activities, is mandatory to minimize operational costs. Post-landing, the ground based equipment must be capable of handling propellant residuals, possibly in a horizontal position if a winged-body configuration is used. The quantities of residuals will be large in case of a return to launch site (RTLS) abort.

Assuming residual can be dumped prior to landing, a method may be provided to purge the tanks post-landing. The quantity of helium and time for accomplishing this task are yet to be determined, as is the method for handling the purge gas exhaust.

On the launch pad, fluid transfers for tanking, post-abort detanking, venting and pressurization are to be accomplished through umbilicals. Electrical power, and command and data signal interfaces most also function properly. Results from the interface evaluation optimization must be incorporated into the vehicle design.

Hold down and release devices are important and minimizing refurbishment of such hardware is essential to achieving low operational cost and rapid turn around between flights.

State-Of-The-Art

An acceptable approach to removing residuals and safing tanks must be devised. The operability of the system and resultant man/machine interfaces for developing timelines must be developed. A hold down approach incorporating soft release capabilities and minimum refurbishment is not fully developed - requiring extensive design analysis and development/integration test data. Umbilical design technology is possibly adequate; however, efficient integration with the vehicle propulsion system design can be a critical area. Automated prelaunch preparation including vehicle checkout, tanking etc. is under development.

IPTD Test Objectives

The IPTD will evaluate: 1) proper functioning of the lift off umbilicals; 2) capability to handle propellant residuals in a horizontal position; 3) ability of the interface, connection to function as planned; 4) obtain data/simulation data on soft release holddown designs including approaches to minimizing refurbishment; and 5) other essential fluid and electrical functions.

RLV Need (D-4)

Flight system requirements for future avionics technology development as influenced by automated checkout/operations. (TRL 4, Criticality 2)

Technology Rationale

System-level requirements are needed so that they can be allocated to various subsystems of the RLV system. They will be used as the basis for identifying technology development recommendations that ensure operability for the various vehicle/ground subsystems both during ground checkout and during flight.

State of the Art

The RLV requirements that exist are top-level only. They have been gleaned from various sources such as the Option 3 Access to Space study and the National Space Transportation Policy. A basic systems engineering exercise needs to define "system-level" requirements based on the "program-level" requirements which currently exist. These system-level requirements will then be allocated to either the ground system or the vehicle system. Further allocation will be done to the various subsystems on the ground or the vehicle as appropriate.

The subsystems experts will determine what technologies are required in order to meet those requirements in terms of automated checkout/ operations.

Concurrent with the requirements derivation/allocation task, a fault identification process needs to take place to determine the possible ways the subsystems can fail. In conjunction with this, decisions are needed on whether to "manage" the failure, "report" the failure, or "design-out" the failure. The results of this process will determine the "operability" of the overall vehicle system and will further identify technology development requirements.

IPTD Test Objective

IPTD will serve as a technology demonstrator for automated checkout/ operations for the propulsion subsystem. The PCCS, in conjunction with the MAST, will serve as a technology demonstrator for the total vehicle system, providing "proof of concept" for the identified technologies and the requirements derivation/allocation process.

RLV Need(D-5)

A structured process to implementing Integrated Vehicle Health Management (TRL 4, Criticality 2)

Technical Rationale

This is required to ensure that RLV life cycle health management is optimally designed into the system, and verified and tested during certification. Previous launch vehicles did not systematically address IVHM and in most cases it was added after designs were established which resulted in inherently man intensive and costly systems to maintain and operate.

Current launch systems have limited built-in test and monitoring capability which results in extensive GSE to test and certify subsystems and components during ground processing and standing armies during launch and mission operations. IVHM and the related hardware and software technologies will not eliminate all of the issues currently associated with today's high cost operations, but a systematic process performed throughout all phases of the program will optimize the amount of health monitoring, properly locate health monitoring on the vehicle and ground infrastructure, and establish common health monitoring interfaces throughout the system's life cycle.

RLV objectives to achieve "airline like" operations depend heavily on the concept of maintenance-only-on-exception operations. This concept is enabled by the fact that airliner manufactures designed in and validated vehicle health monitoring at the beginning of the program. However, the airline operators have experienced two specific issues that must be addressed by the RLV program. The first is the lack of integration provided by the manufacturer. Airlines are encountering differing and sometimes incompatible interfaces among the on-board health monitoring elements and the vehicle to ground integration is severely lacking (on-board is state of the art; ground is using 20 year technology). The second issue is the amount of false alarms that are frustrating ground operators and causing undue procedures and part replacements.

There are many hardware and software technologies that need to be developed and validated to enable health monitoring and these technologies have been identified in several other objectives. This task is focused on the integration and systematic approach to implementing these technologies into an operationally low cost system.

State of the Art

The current expendable and reusable fleet are automating operations through ground based improvements, but these efforts are severely limited by original vehicle designs that do no offer automated built-in-test. The airline industry provides substantial on-board monitoring but it is not effectively integrated with ground operations and military aircraft is experiencing high false alarm rates with newly introduced systems. The automotive industry is introducing car models with extensive automated vehicle coverage but data is not available for assessment.

IPTD Test Objective

Utilize SSD's IVHM design handbook and treat the IPTD as a system and optimize IVHM functional allocation and system architecture. Concurrently, develop the hardware and software technologies needed for propulsion health management and develop, test, deliver, and demonstrate through the Propulsion Checkout and Control System. Document the IVHM process, provide cost/benefit trades and system reliability impacts, and demonstrate low cost operations.

RLV Need (D-6)

Simulation based design (TRL 4, Criticality 2)

Technical Rationale

Simulations must be utilized to define design requirements for any future launch vehicle including the RLV. These simulations will detail the mechanical/structural elements; fluid subsystems; electrical subsystems, system/subsystem command and control components; and the physical environment in real time. The behavior of the simulated elements, components, and subsystems will define design requirements which will ensure that the vehicle operates in a safe and predictable manner.

Funding for new programs is tightly controlled and the yearly appropriations are level or have only moderate budget growth. Without the funding to support expensive testing and development of flight prototypes, the new program starts, like the RLV, must utilize innovative means, such as simulation based design, to acquire the data necessary to confidently design the launch vehicle which will meet all of the program objectives.

State of the Art

The technology behind simulation based design has advanced rapidly in recent years and is now in use in most industries. Computational fluid dynamics (CFD), finite element modeling (FEM), and real time simulations are used to evaluate the Space Shuttle System and Orbiter when designs, payloads, flight profiles, or mission objectives change. Simulation of systems have already been used to influence the design of the future product for the Advanced Launch System (ALS), the National Aerospace Plane (NASP), and the numerous SSTO technology program conceptual vehicles currently under study.

ARPA has sponsored a technology push to enable an even greater vision of simulation based design which encompasses: changes to data transmission interface standards, development of heterogeneous databases, physics-based engineering analysis, and advanced human/environment interfaces.

IPTD Test Objective

Utilize simulation based design to rapidly develop design requirements and validate system design and implementation. Simulations should include system and component modeling, fault injection and test article/facility control software validation. Provide an interface to the IPTD to predict and assess the performance of the tests as well as substitute simulations with sensors and components. Evolve the simulation software to IPTD control and monitor software.

RLV Need (D-7)

Reusable propulsion control software (TRL 4, Criticality 2)

Technical Rationale

The RLV will require robust and highly integrated propulsion control software to meet the goal of automated test and checkout and maintenance on demand operations. Capability should provide adaptable software over time as historical databases are developed and test and checkout procedures are modified. Reusable, object-oriented propulsion control software is needed - software which can be easily modified to meet the mission and operational requirements of the RLV. Also development and validation of flight critical software is difficult and expensive and reuse of existing propulsion control software throughout a program is a technique to reduce these development and certification costs.

Existing launch vehicle propulsion control software is based on 20-year old operational needs and antiquated software development tools (HAL-S is a one-of-a-kind programming language used for Space Shuttle control). Software must be evolutionary in nature if the hardware in which it executes is subject to evolutionary changes as well. This has been identified as a weakness in the Space Shuttle avionics and control software implementation. In the Shuttle, the software is tied strongly to the hardware which executes it. As microelectronics technology matures, it is becoming favorable to upgrade the Shuttle electronics, but much of the software would have to be completely rewritten to accommodate the new hardware - an unacceptable cost impact to a cost driven RLV program. Had the software been implemented in a highly modular, open-ended application framework (like those available today) then only the affected module of the control software would require change. New hardware modules (with their accompanying software) could be installed as needed without the rigorous end-to-end recertification of the entire control software that we see today.

State of the Art

Reusable, object-oriented software development is the leading edge in software development. Most new commercial software has been rewritten or developed using this approach. Object-oriented programming languages such as Matrix-X (control software) have come to the forefront of software development. The primary reasons for this shift in software development paradigm comes from the fact that: object-oriented code is (1) more modular (and thereby easily reused) and (2) easier to maintain (a change in an object class propagates to all derived object classes).

IPTD Test Objective

Develop object-oriented propulsion control and checkout software using the FMEA fault-trees, digraph, and fault models as the foundation for the code. Evolve the reusable propulsion control software developed in the design/simulation phase throughout the life of the program into the actual IPTD control software, and establish requirements for RLV propulsion flight/ground software development. Document IPTD software development costs and compare to traditional software development efforts.

RLV Need (D-8)

Common life cycle databases (TRL 5 , Criticality 2)

Technical Rationale

Access to historical information and lessons learned during vehicle design and development tests can be useful in operational turnaround and launch and mission operations. The need exists to permanently record and to make available useful design/test information to operators of the future RLV program. Life cycle database concept needs to extend into operations so that system and component usage can be autonomously tracked in support of maintenance on exception philosophies.

Many issues encountered during Shuttle operations have been simulated and/or tested earlier during the program's development history, i.e. MPS anomalies and corrective procedures were demonstrated during the 1970 MPTA testing era. However, this data is not easily accessible to operators, and in most cases the lessons learned are overlooked because of the inherent difficulty in obtaining this information. The problem stems from the limitation of computer hardware and software at the time of early Shuttle testing, but equally important, the concept of common life cycle databases was not properly designed into the Shuttle program. This is equally true in the current expendable launch vehicle fleet.

State of the Art

The computer industry has matured to a point that program data storage and processing requirements can be easily satisfied. Commercial industries routinely rely on historical database analysis during real-time operations and the current launch vehicle fleet is beginning to structure operational databases. These databases are limited to operations data, but it is an important first step in identifying the type and format of data that is truly useful to the operator.

IPTD Test Objective

Design into the PCCS the capability to record all data collected during IPTD design and development: FMEAs, component bench top tests, simulations, and integrated functional tests after installation. As an example of common databases, migrate the design FMEA into the real-time operational PCCS and use the FMEA fault trees, digraphs, and other models as the foundation for autonomous control logic (using reusable object oriented code discussed in another objective). Design into the PCCS and demonstrate the capability to track component and sensor usage during operations and parts replacement/removal based on life expectancy predictions.

RLV Need (D-9)

Real-time geographically distributed simulations (TRL 4, Criticality 2)

Technical Rationale

Designing and developing the RLV ground and vehicle software will be a multiple contractor, multiple government center effort requiring expertise and technologies through-out the nation. Once the software system and support infrastructure has been established, technology development and system build-up will begin using resources that are geographically distributed. A cost effective alternative approach to centrally locating all required resources is to tie these resources together and maximize the site's resources through distributed software interfaces.

There are several RLV technology programs that are already underway and more (technology and ground/flight tests) are expected to support full scale development risk mitigation. These efforts will be developed at several locations (MSFC, KSC, WSTF, contractor sites) with specific technology focuses, but all should be directed towards a common RLV goal of system demonstrations. Additionally, there have many technology programs that the government has sponsored at numerous sites throughout the years. These efforts range from software diagnostics, sensor validation algorithms, component technology development, etc. and many of the efforts can directly support the current and planned RLV technology programs.

There have been several commercial industry applications of real-time distributed simulations. These programs have demonstrated design through certification life cycle cost reductions by "hooking up" multiple vendor technologies during simulation and verification tests. The RLV program can benefit from these commercial applications.

State of the Art

The airline manufactures and in particular the Boeing 777 program are currently implementing real-time geographically distributed simulations in the design and test program phases with significant benefits to date and the military aircraft industry is pushing the envelope of interactive distributed simulations (i.e., the recent RI demo of a flying Maryland F-16 vs. a flying California X-31 vs. San Antonio simulation dog-fight).

IPTD Test Objective

Develop IPTD sensor validation software at LeRC and real-time FMEA models at ARC, integrate into PCCS control logic developed at RI-Downey and demonstrate integrated simulated control at MSFC-MAST. During IPTD operations, provide real-time monitor interface to LeRC, ARC, and Downey and real-time control interface other MSFC test beds and KSC test beds as required.

RLV Need (D-10)

Determine vehicle external design environment (TRL 6, Criticality 3)

Technical Rationale

In the design of the STS, the acoustical and thermal environments were not understood until late in the development program. This caused programmatic risk and weight growth to the vehicle. The SSTO cannot afford a weight growth late in development due to the high sensitivity to performance. Although Lox/LH2 and Lox/RP-1 environments have been characterized on different vehicles the environment of a tripropellant has not been characterized. This test bed will allow for thermal and acoustic testing to be piggybacked off of the existing test plan for very little additional cost or time.

State of the Art

The basic technology exists to characterize the environments in the base and boat tail region due to engine and vehicle interaction.

No testing has been done at a system level on tripropellant environments.

IPTD Objectives

Develop environments database for tripropellant combustion interaction with the engine and vehicle. This database can then be used to validate models and improve prediction capability. Multi engine influence on base heating, ignition over pressure and acoustical environments must be obtained by analysis and later testing.

RLV Need (D-11)

Design cost estimating models. (TRL 4, Criticality 1).

Technical Rationale

RLV/ELV will have strict performance, operability, cost, schedule and safety requirements imposed for development and operations. The capabilities of the designer to accurately estimate cost can be important in early program planning activities as well as during design implementation. Conduct of an RLV/ELV program cannot be along lines of business as usual, ways must be found to do all task in shorter time with less people without sacrificing quality. The effort required to do engineering tasks and the ability to estimate cost of acquiring hardware consistent with the improved way of conducting business is important.

State-of-the-Art

Methods used in past programs exist, can be utilized in new programs but are not optimum.

IPTD Test Objective

Engineering records for the design phase of the IPTD program which will perform to new requirements will be available as a database. Models can be modified for consistency with the new data.

RLV Need (PL-1)

Reduce vehicle dry weight by use of Tripropellant systems. (TRL 3, Criticality 2)

Technical Rationale

Tanks storing low density, high performance propellant such as H_2 are large and heavy. By using higher density RP at lower altitudes instead of H2, the overall tank volume and weight is minimized. Payload criticality for RLV may well require consideration of tripropellants.

State of the Art

There are no U.S. developed tripropellant engines and the technology state within the country is low. NASA has recently initiated technology activity for appropriate components and engine investigations. Engine contractors have initiated activity also. Russia has some development experience with a tripropellant engine and various proven LO2/hydrocarbon and LO2/LH2 engine components are available.

IPTD Test Objectives

IPTD can be used to conduct performance and operational tripropellant engine tests. It is in essence another single engine test facility although the IPTD facility provides the vehicle environment missing at other engine test facilities. Test conducted on this facility will obtain operations data, however this aspect is discussed elsewhere.

RLV Need (PL-2)

Reduce dry vehicle weight by using densified H_2/O_2 propellant. (TRL 3, Criticality 2.)

Technical Rationale

Tanks storing low density high performance propellants such as H_2 are large and heavy. Reducing propellant temperature within tankage a few degrees increases propellant density, reduces necessary tank volume, lowers tank required operating pressure, and results in other benefits. The resultant reduction in weight and other benefits are not without adverse features as operability complexity and additional GSE requirements.

State of the Art

The basic technology exists, although integration of technologies into a vehicle/facility is needed.

Densification was considered for Shuttle in 1994 with a potential of 4,000 to 8,000 pounds payload increase. However, other candidate improvements were selected for implementation. Slush hydrogen, requiring more extensive propellant cooling, has been investigated as technology item for years.

Data are needed to define the GSE equipment needed to reduce propellant temperatures. Operational data associated with such GSE equipment and the loading/unloading of the launch vehicles utilizing these special propellants is required. Development of special design features of the vehicle itself including gradients of propellants within vehicle tankage, special tankage hardware to allow entrance of cold fluid and exiting of relatively warm fluid during tank loading and standby operations, loading sensor requirements, reductions in pressurization system flow rates from the normal, propellant tank vent system requirement and changes to tank insulation requirements is needed.

IPTD Test Objective

Develop densified propellant technology application to launch vehicles sufficiently to establish program merits and design/integration technology for future engineering application. Principal issues to be addressed are stated in state-of-the-art section. Capability will be developed for both H_2 and O_2. IPTD integration activity would occur during test phase 2 and 3.

RLV Need (PL-3)

Reduce vehicle complexity, GSE requirements, and ground processing time by eliminating the need for inert gas purging. (TRL 2, Criticality 2)

Technical Rationale

Current practice is to purge the engines and other systems after exposure to cryogenic propellants in order to remove any propellant residuals. In addition, some engines have required barrier purges during operation to preclude mixing of propellants. If a safe system can be designed without these purges, and if electromechanical valve actuators can be used, then a vehicle without any pneumatics can be conceived. This not only simplifies the flight vehicle, but eliminates the entire associated infrastructure and its servicing and maintenance requirements.

Vacuum inerting of the propulsion system lines would be effective for normal orbital missions, but may not be possible for early aborts. Propellant tanks may not be able to be vacuum inerted without re-pressurization because positive pressure must be maintained in large tanks and repressurization with air during entry presents safety and contamination concerns.

In the event all engine and propulsion system purges cannot be eliminated, the purge quantities must be reduced to minimize propulsion system weight.

State of the Art

Conceptual approaches have been developed for purgeless engines. Basic technology exists for the tank and propulsion system inerting exists but the problems indicated in the Technical Rationale must be addressed.

IPTD Test Objective

Develop and test concepts for tank and propulsion system inerting. Test purgeless engine concepts for effectiveness in providing a safe system. Develop operational data for comparison with conventional purging operations.

RLV Need (PL4)

Early engine validation with unsteady inlet pressure. Computerized Pogo suppression. (TRL 2, Criticality 4).

Technical Rationale

Pogo suppression systems such as the system used on the Orbiter are complex and heavy. On an RLV with multiple engines, having a Pogo suppressor on each engine would reduce payload by more than a thousand pounds. Additionally dynamic characteristics of vehicle feed systems and engines for tripropellant application have not been evaluated and are thus somewhat unknown.

State-of-the-Art

The technology for computerized pogo suppression does not exist and would have to be developed. The capability exists to design propellant supply systems such that high frequency pressure oscillation of approximately 5 Hz and greater can be damped by the design of the feed systems ducts and vehicle structures. For frequencies below approximately 5 Hz the capability of pressure sensors, accelerometers, and computers today are more than adequate to sense low frequency variations in engine inlet pressure and allow the engine controller to compensate. The required controlling system on the engine and cryogenic electromechanical valves that can provide the required response are not available, but can be developed. Values for power control of SSME's currently can control thrust up to a rate of 100% per second (100 thrust to zero thrust).

IPTD Test Objective

The capability of the RLV engines to provide adequate throttle response to simulated pogo pressure oscillations can be verified in the engine development tests. The IPTD can demonstrate the compliance of the propellant supply system. The response of the MPS to step changes of the simulated engine flowrate can be measured and analyzed to support vehicle design. During the IPTD tests with an engine, the engine can be step throttled and the response of the inlet pressures measured and recorded.

RLV Need (PL-5)

Low cost, lightweight, long life feed system (TRL 3, Criticality 3)

Technical Rationale

The objective is to reduce initial and replacement cost, reduce hardware weight thus enhancing payload capability, and reduce operability by minimizing hardware replacement and inventory operations.

Manufacturing techniques and material properties continue to improve thus potentially benefiting today's vehicle programs. Application of composites continue to increase in some industries and Al Li lines and ducts offer potential advantages for future vehicles.

State of the Art

Feed systems utilized in past vehicle programs are expensive and relatively heavy. New technology feed systems compatible with the RLV operational plan are not available for vehicle application although some components have been investigated to a limited extent. (Example—Elbows constructed from casting technology at a fraction of normal elbow construction cost.)

Composite lines and ducts are to be investigated under an MSFC NAR 8-12 task initiated in mid-FY94. Additionally, composite technology is in use in numerous industries and could be utilized to develop a low cost, light weight feed system.

IPTD Test Objective

Assist in accomplishing RLV "needs" through validation of feed system components at the system level in an operational environment. Components will be selected from NASA sponsored technology programs and those available from commercial institutions. Component availability may be restrictive in some areas as advanced component designs do not exist.

RLV Need (PL-6)

A single integrated system for controlling the operation of both the main engine and the rest of the vehicle (TRL 3, Criticality 3)

Technical Rationale

A single computer system can control and monitor all flight systems functions. This eliminates unnecessary duplication of hardware and software and simplifies communication between vehicle elements.

State of the Art

Typically, each main engine has an individual engine controller providing monitoring and control of all engine checkout and operational functions. When installed into a vehicle, the vehicle computer system must communicate with each engine controller to provide commands as start, throttling, and shutdown. In addition, data from the engine controller must be received by the vehicle for evaluation and storage. In the Shuttle, an additional separate avionics unit, the engine interface unit (EIU) must be used at each engine interface to translate commands and data information.

The basic technology does exist for a common control system, but integration issues must be resolved. In addition, a system for single engine tests must be provided.

IPTD Test Objective

Test concepts for a common vehicle/engine control system. Provide operational data which can be used to develop cost comparisons between the common system and dedicated separate engine controllers.

RLV Need (PL-7)

Differential throttling (TRL 4, Criticality 2)

Technical Rationale

The commonly used approach of engines with gimbaling capabilities for thrust vector control of launch vehicles is an acceptable approach for RLV. However, with six to eight engines which RLV is expected to require, the integrated system becomes complex, heavy, and costly. Varying the thrust of individual engines on an RLV for thrust vector control (differential throttling) is an alternate approach. There are several advantages — lighter weight, lower cost, less hardware, less space between engines all of which would yield a potentially smaller vehicle base area, less vehicle drag, and simplified base heat shield. The system has disadvantages, such as the absence of a nozzle positioning device for selective nozzle positioning during re-entry.

State of the Art

Individual component, subsystem technologies exist today. Differential throttling has been utilized for small rocket systems. Integrated systems data for large vehicles with large numbers of engines does not exist.

IPTD Test Objective

IPTD is not a program as currently structured to evaluate differential throttling of multi-engine vehicle configurations. The program can be designed to collect end-to-end data for the control system and the response characteristics of a single engine in an operational environment.

RLV Need (PL-8)

Modular propulsion technology (TRL 3, Criticality 2)

Technical Rationale

Integrating the engine and vehicle design will provide ease of access to the engine components without removing the engine, reducing operational costs and turnaround time. It also allows the engine C.G. to be shifted forward which is beneficial to the vehicle design. Management of component or element failure can be enhanced with manifolding and/or cross-strapping. Vehicle payload may be increased and vehicle base area reduced.

State of the Art

Technology exists. Requires intensive design integration.

IPTD Test Objective

Provide the capability to work out the integrated design problems and disciplines for a modular propulsion system.

Demonstrate the system with the complete engine and associated support sub-systems. Develop operational data for comparison with conventional stand alone engines. This approach represents a major departure from the conventional and implementation is dependent upon extensive coordination and cooperation with NASA and engine component manufacturers.

RLV Need (PL-9)

Provide a light weight source of electrical power during main engine operation when TVC EMA power demands are high. (TRL 4, Criticality 3)

Technical Rationale

Electromechanical actuators used for thrust vector control require high electrical power during main engine operation. If this electrical power can be supplied from the engines, significant reduction can be made in requirements for battery or other power sources.

State of the Art

Direct drive of electrical generators has been proven. Basic technology exists to power a turbo-generator from the autogenous hydrogen pressurization system.

IPTD Test Objective

System studies should explore power generation utilizing rocket engine fluids. System studies should also evaluate power transfer from ground power and other issues associated with power management. Once issues are determined to be solvable, power generating hardware can be developed and tested at the component level and on a single engine facility. IPTD can be the ideal single engine facility as it not only provides the engine but many other vehicle systems. The IPTD objective is to demonstrate the power generating system with the complete engine and TVC system. Develop operational data for comparison with conventional power operations will also be obtained.

RLV Need (PL-10)

Propulsion/engine system integration. (TRL 6-7, Criticality 2-3).

Technology Rationale

Many items of some importance to the RLV program and which the technology status may be marginal may be non-deserving of individual identification have been lumped within this task. Generally they can be combined with other technology objectives. A few examples are: 1) H_2 gas pressurization of the RP propellant tank; 2) vehicle located flow meters; 3) O_2 venting without vehicle ice formation; and 4) resolving problems leading to vehicle damaged hardware as has occurred on Orbiter.

State-of-Technology

Existing.

IPTD Test Objective

Resolve miscellaneous engineering issues for RLV/ELV improvement. Test activities to be piggy backed to other identified objectives.

RLV Need (PL-11)

Light weight reusable propellant tanks. (TRL 3, Criticality 1).

Technical Rationale

Reusable propellant tanks which can satisfy key RLV requirements do not exist. Light weight reusable tanks are essential for SSTO type vehicles to meet payload requirements.

State-of-the-Art

Advanced materials and manufacturing methods have matured sufficiently so that tanks can possibly be developed. NASA is developing a light weight external tank (not a reusable tank) for Shuttle. NASA has also recently initiated technology activity with contractors to develop technology for RLV tankage. Extensive component testing will be performed and scaled tanks will be designed, constructed and tested within the next approximately 2 1/2 years.

IPTD Test Objective

IPTD is not a reusable and light weight tank test facility at this time. Planned IPTD engine firings could provide test environments which will not be available in the planned tank test series.

Appendix B

Ground Rules and Assumptions

MSFC Reusable Launch Vehicle Concepts Studies

Ground Rules and Assumptions

	Ground Rule/Assumption*/Criteria*	CLS	GRP	Rationale
0	Cost - DDT&E S $12.6B - Annual S $1.4B	GR	C	ATS (Adjusted for Moorman Activity to include savings resulting from NWDB and technology maturation)
2	Initial operating capability: 2006	GR	G	ATS
3	Launch vehicle dry weight: S 250k lbs	GR	G	Minimize vehicle complexity
4	Abort capability from all mission phases	A	G	Increased mission reliability
5	Launch and landing at KSC day or night	GR	G	Reduce OPS cost
6	Fully reuseable rocket to LEO	GR	G	ATS, pushes technology
7	Payload = 25k up and down	A	G	ATS (satisfy ISS crew rotation/logistics resupply and Delta/Atlas class missions)
8	Veh performance includes 15% dry wt margin	GR	G	ATS
9	Minimize number of fluids required for launch system and ground processing with no hypergols	A	OP	Simplify systems, reduce OPS cost
10	On time launch = 0.95	A	OP	Operability
11	Standardized mission flight software	A	OP	Reduces OPS cost
12	Turnaround operations time and cost will be reduced, e.g., - Automated vehicle maintenance identification - Built-in-test - Automated checkout and diagnostics - Autonomous systems to minimize ground control requirements - Maximum use of existing facilities - Sustaining engineering and logistic support at launch site - No special facilities for "national security launch" processing - Normal 1-2 shifts, 5 days/wk - Hardware delivered ready for flight/component test at vendor	A	OP	Past experience, reduce costs
13	Payload processing will be off-line	GR	OP	Streamline OPS
14	Nominal pad stay time will be 12 hrs - No late payload access on pad - No vehicle maintenance on pad	A	OP	Reduce OPS costs
15	Fully autonomous flight control with no vehicle crew intervention	A	OP	Minimize system complexity, reduce OPS cost
16	Ground based sensors provide data on winds aloft and surface winds	A	OP	Cost reduction, pushes technology
17	Payload bay doors can be opened in 1g without GSE	A	OP	Streamline OPS
18	"Wave-off" can be initiated by Station flight crew	GR	OP	Station requirement
19	Isp used is guaranteed engine minimum	A	E	Guaranteed is min required to make mission
20	Engine operation verified before liftoff	GR	E	Increased mission reliability
21	NPSP - LOX = 38 psia - LH2 = 5 psia - RP = 18 psia	A	E	RD 704 characteristics
22	Pressurization methods - LOX = Autogenous - LH2 = Autogenous - RP = Helium	A	E	ATS
23	Engine characteristics (Mode 1/Mode 2) - Tvac = 466875/185629 lbs - Isp = 406.9, 452.2 - Flowrate (lbm) = LOX933.98/351.86, LH68.85/58.64, RP144.57 - MR = 4.38:1/6:1 - Pc = 4266/1762 psia - Exp ratio = 73.8:1 - Wt = 5822 lbs - Throttlability: max = 100% / min = ??? - TVC actuation via engine gimbal using self-contained hydraulics	 A A A A A A A A A	 E E E E E E E E E	WB 001 7 engines RF 704 type characteristics (scaled) ATS

* Subject to trade

Ground Rules and Assumptions

	Ground Rule/Assumption*/Criteria*	CLS	GRP	Rationale
24	Upper Stage - Upper stage provides required delta V to meet missions beyond LEO - Expendable - No suborbital starts - Orbital injection of US by launch veh for performance analysis is 100x100 n.mi. @ 28.5° - Max g level = Atlas/Delta levels - Rendezvous and docking capability not required - PL pre-integrated with standardized interfaces - ASE wt is 10% of injected weight on orbit (PL+US) - No US propellant dump required for abort landing - US fueled and vented through vehicle system if required	A GR GR A A GR GR A GR A	US US US US US US US US US US	Simplifies vehicle systems Reduce DDT&E and OPS cost, simplify systems NASA policy Consistency in performance analysis Simplify stage design Streamline OPS Initial estimate Simplify stage and vehicle design Simplify systems, clean pad approach
25	Reliability - Launch vehicle (LEO round-trip) 0.98 - Upper stage 0.99 - Safe vehicle return 0.995 - Passenger survivability 0.999	GR	V	ATS (modified to include upper stage)
26	Vehicle service life: airframe-100 flts, engine-60 flts, 500 press cycles, TPS-100 flts, components-20 flts min.	A	V	ATS
27	One time certification for each vehicle	GR	V	ATS
28	Cargo bay - Unpressurized - 15' dia x 30' length - Standardized 5 pt PL mounting (4 sill/keel) - Standard interfaces for power, data, fluids, etc. - No special PL bay environmental conditioning - Intertank to be purged per vehicle requirement	A A A A A A	V V V V V V	ATS, streamlined OPS ATS Simplified system and OPS Simplified system and OPS Simplified system and OPS Simplified system and OPS
29	System will not launch or land in rain but must be capable of withstanding rainstorm on launch pad	A	V	Increased OPS efficiency
30	Ascent/entry/landing loads will be compatible with ISS PL design parameters	GR	V	ATS
31	Satellite servicing will only be accommodated within the launch system's PL capability	GR	V	Minimize vehicle complexity, infrequent mission
32	Landing w/residuals for abort propellant dumped through engines)	A	V	Good engineering practice
33	Aft end support on pad - All ground/vehicle interfaces through rise-off umbilical - Vehicle fueled through rise-off - US fueled through vehicle fuel system	A	V	Clean pad approach
34	Structural design factors - MSFC 505A-manned launch vehicles - Verify by analysis and static test	A	V	Std design practices
35	materials database (EH43) is correct data base	A	V	Common documented data base
36	Empirical base heating methodology = SPF2/Gas Rad radiation heating; STS/Sat V convective heating	A	V	Best available within time frame
37	Ascent/entry aerothermal methodology = LANMIN code w/refinements from CFD solutions	A	V	Best available within time frame
38	Analytical ascent and entry aerodynamics based on APAS code w/some low subsonic and hypersonic test data	A	V	Best available within time frame
39	Airloads based on empirical techniques and CFD solutions	A	V	Best available within time frame
40	Ascent wind criteria - Annual winds (QA = ± 4200 psf°) - DOL winds (QA = ± 1960 psf°)	A	V	Evaluate effect of wind criteria (partials)

* Subject to trade

Ground Rules and Assumptions

	Ground Rule/Assumption*/Criteria*	CLS	GRP	Rationale
41	Ascent trajectory design - Dispersions - Dynamic responses	A	V	Establish sensitivity to uncertainties Evaluate effect/establish sensitivities
42	natural environments - KSC peak ground wind speed profile (10m-152.4m) from NASA TM 4511 - KSC annual enveloping vector wind profile model (336 winds) - KSC DOL Jimsphere wind pairs winter, summer and transition (2 hrs and ???	A	V	Past experience Only data available Past experience
43	Tank residuals (% of total) - Lox = 0.5% - LH2 = 0.5% - RP = 0.5%	A	V	ATS
44	Ullage volume (vol. of liquid) - Lox = 3% - LH2 = 3% - RP = 3%	A	V	ATS
45	Start-up propellant = 1.5% of ascent	A	V	ATS
46	Mission duration = 7 days max.	A	V	ATS
47	Off-the-shelf hardware will be used where possible on vehicle and GSE	A	V	Reduce cost
48	Avionics fault tolerance is FO/FO/FS at liftoff - One failure - mission completed - Two failures - safe vehicle return - Three failures - passengers survive	A	V	Increased reliability
49	Capability to launch w/certain, selected failures in critical systems	A	V	Increased reliability, operational efficiency
50	Depot maintenance - Event 20 missions for 3 mos duration - Performed at launch site - Vehicle engineering changes conducted during depot	A	V	ATS, reduce OPS costs
51	Rendezvous GN/C algorithms derived from AR&C program	A	V	Reduce dev cost
52	EMA's for aerosurface control	A	V	No hydraulics
53	Electro-mechanical gear deployment, braking, steering control, etc.	A	V	No pyrotechnic devices
54	RCS - Lox/LH2 liquid thruster system w/Isp = 422's - Dedicated storage of propellants w/He pressure fed system	 A A	 V V	NASA CR-185289 (IHOT Study); ATS; lowest wt; pushes technology
55	OMS - Lox/LHs liquid thruster system w/Isp = 462's - Dedicated storage of propellants w/He pump fed system	 A A	 V V	Minimize number of fluids
56	Electrical power - Fuel cells for subsystem power - Batteries for aerosurface EMA power	 A A	 V V	 ATS, reduce weight Simple system, reduces OPS cost
57	Communications - Direct link for ascent/landing - TDRSS for all other flight phases - UHF interface with station	 A A A	 V V V	 Good engineering practice Good engineering practice Good engineering practice
58	Feedlines - CRES and Al materials on Lox and LH2 - Composite for RP - Flanged connections minimized - BSTRA flex joints - Min feedline bend rad R/D 2.0 - Min 15° slope on cryogenic feedlines - Min straight section above eng inlet 2D	 A A A A GR GR GR	 V V V V V V V	 Good engineering practice Reduces weight Reduces wt., good engineering practice Good engineering practice Good design practice Good design practice Good design practice

* Subject to trade

Ground Rules and Assumptions

	Ground Rule/Assumption*/Criteria*	CLS	GRP	Rationale
59	Flight			ATS
	- OMS Delta V budget = 1100 fps	A	V	
	- OMS reserves = 40 fps	A	V	
	- RCS Delta V budget = 110 fps	A	V	
	- RCS reserves = 45 fps	A	V	
	- Cross range 1100 n.mi.	A	V	
	- Ascent and entry max accel = 3 g's	A	V	
	- Ascent prop reserves provide 1% of total delta V	A	V	
	- Launch window allowable = 5 minutes max for 51.6°/220 n.mi. mission	A	V	
	- Landing cross wind = 30 kts max	A	V	Good engineering practice
	- Qalpha/Qbeta span = 8400 psf°/annual wind criteria and 3920 psf°/day-of-launch winds	A	V	Ascent load indicator required for concept evaluation
	- Orbit at MECO = 50x100 n.mi.	A	V	ATS
60	Liftoff T/W = 1.2 (eng out = 1.02)	A	V	1.2 — Good design practice, 1.02 is resultant

* Subject to trade