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DEVELOPMENT AND IMPLEMENTATION OF NASA'S LEAD CENTER FOR ROCKET PROPULSION TESTING

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ABSTRACT

With the new millennium, NASA's John C. Stennis Space Center (SSC) continues to develop and refine its role as rocket test service provider for NASA and the Nation. As Lead Center for Rocket Propulsion Testing (LCRPT), significant progress has been made under SSC's leadership to consolidate and streamline NASA's rocket test infrastructure and make this vital capability truly world class. NASA's Rocket Propulsion Test (RPT) capability consists of 32 test positions with a replacement value in excess of $2B. It is dispersed at Marshall Space Flight Center (MSFC), Johnson Space Center (JSC) - White Sands Test Facility (WSTF), Glenn Research Center (GRC) - Plum Brook (PB), and SSC and is sized appropriately to minimize duplication and infrastructure costs. The LCRPT also provides a single integrated point of entry into NASA's rocket test services.

The RPT capability is managed through the Rocket Propulsion Test Management Board (RPTMB), chaired by SSC with representatives from each center identified above. The Board is highly active, meeting weekly, and is key to providing responsive test services for ongoing operational and developmental NASA and commercial programs including Shuttle, Evolved Expendable Launch Vehicle, and 2nd and 3rd Generation Reusable Launch Vehicles.

The relationship between SSC, the test provider, and the hardware developers, like MSFC, is critical to the implementation of the LCRPT. Much effort has been expended to develop and refine these relationships with SSC customers. These efforts have met with success and will continue to be a high priority to SSC for the future.

To date in the exercise of its role, the LCRPT has made 22 test assignments and saved or avoided ~$51M. The LCRPT directly manages approximately $30M annually in test infrastructure costs including facility maintenance and upgrades, direct test support, and test technology development. This annual budget supports rocket propulsion test programs which have an annual budget in excess of $150M.

As the LCRPT continues to develop, customer responsiveness and lower cost test services will be major themes. In that light, SSC is embarking on major test technology development activities ensuring long range goals of safer, more responsive, and more cost effective test services are realized. The LCRPT is also focusing on the testing requirements for advanced propulsion systems. This future planning is key to defining and fielding the ability to test these new technologies in support of the hardware developers.

BACKGROUND

In 1995, NASA Administrator Dan Goldin commissioned a bottoms up review of all NASA activity. This effort called the Zero Based Review (ZBR) resulted in significant streamlining and focusing of roles and missions within NASA. During the ZBR, SSC recommended establishment of the LCRPT. At the time, multiple NASA centers were sustaining test infrastructure which was not needed. NASA rocket test centers were also competing for the same limited number of test projects and were leveraging multiple funding sources to add to facilities and systems to make them more competitive. As the capabilities grew across the Agency, they had to be maintained and were incentives for future growth; "with a little modification here or there we can do almost any type of testing real cheap" was the common response to inquiries for test services.

The funding sources for the support and maintenance of the rocket test infrastructure were scattered across many institutional and project budget items within the NASA

budget, so NASA really didn't know how much it was spending to maintain a critical capability.

As added emphasis, several General Accounting Office (GAO) inquiries were initiated to investigate what was perceived to be excess test capability across the Nation. The GAO basically criticized the Air Force and NASA for competing for the same testing, unnecessary duplication of test stands, and for not convening the working groups. The formation of the LCRPT specifically addressed the GAO's concerns and was the conduit for cooperation with the DoD in regards to rocket propulsion testing. The National Rocket Propulsion Test Alliance (NRPTA) was formed with NASA and DoD sharing co-chair duties. This Alliance has become very productive. Beneficial cost savings have been achieved through sharing of equipment and personnel.

As the ZBR activity continued, in 1996 SSC was officially designated as the LCRPT by Mr. Wilbur Trafton, Associate Administrator for the Office of Space Flight.

As Lead Center, SSC was responsible for:

- Managing NASA's Rocket Propulsion Test Assets, Activities, and Resources at MSFC, JSC-WSTF, GRC-PB, and SSC
- Developing Test and Facility Investments
- Consolidating Capabilities and Assets
- Assigning Testing Across all Test Locations

The objectives of the LCRPT were stated as:

- Establish and Maintain World Class Propulsion Testing
- Reduce Duplication of Facilities and Supporting Infrastructure
- Reduce Cost of Testing

Implementation and consolidation plans were drawn up to carry out the direction received from NASA's senior management. The consolidation of testing originally expected and desired was not achievable for several reasons. First, SSC lacked the facilities and experienced test crews; therefore, was not in a position to take on all of the Agency's testing. This was recognized by SSC and was taken into account with the consolidation actions. Secondly, the more the testing at other NASA centers was analyzed, the more it was realized that unique capabilities and experience existed and were operational at MSFC, WSTF, and PB.

What resulted was a series of baseline roles negotiated by the RPTMB at a Summit meeting held at SSC in October 1997. The inherent strength in the facilities and test teams at all NASA test sites was recognized. Also, key to these baseline roles was the recognition for MSFC (the Lead Center for Space Propulsion Development) to retain sufficient test capability, managed under the RPTMB, to accommodate low Technology Readiness Level (TRL), advanced component testing. With the evolution of the LCRPT, these roles have recently been updated and are shown below:

MSFC:

Primary NASA site for:

- MSFC designed/developed component level test articles
- Technology development test articles with substantial MSFC engineering involvement
- Propulsion component research and technology (low TRL)
- Cryo structural test articles (tanks, ducts, etc.)

Alternate NASA site for:

- Non-hypergolic, ambient testing

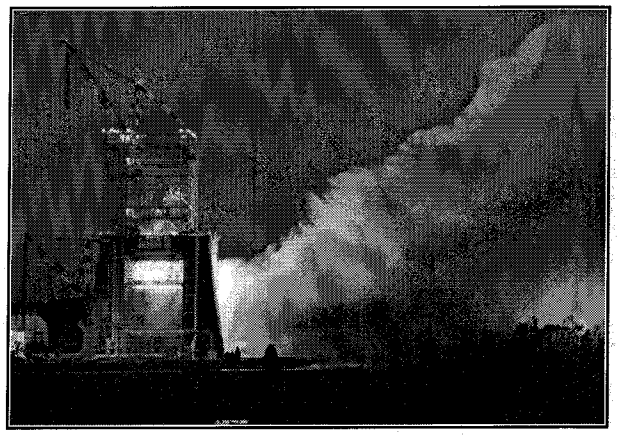

Figure 1 - Test Stand 4670 at MSFC

JSC - WSTF:

Primary NASA site for:

- Altitude testing of small/medium test articles up to 15K lb thrust, excluding LOX/LH2; includes all hypergolic testing

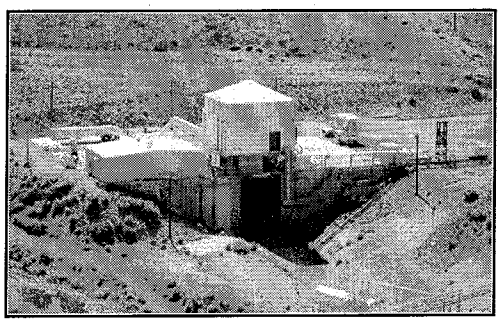

Figure 2 - Test Stand 301 at WSTF

GRC - PB:
Primary NASA site for:

- Altitude testing of medium/large test articles in the 1K to 400K lb thrust range, excluding hypergolics; includes all LOX/LH2 testing

Alternate NASA site for:

- Cryo structural test articles (tanks, ducts, etc.)

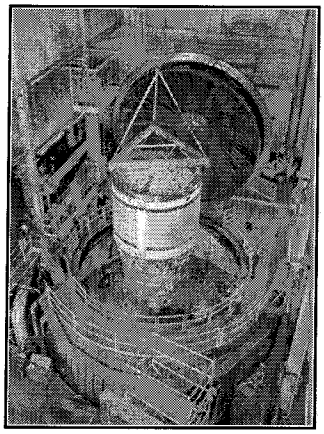

Figure 3 - B-2 Test Stand at PB

SSC:
Primary NASA site for:

- Non-hypergolic, ambient/low altitude testing
- Excludes other centers' baseline test assignments

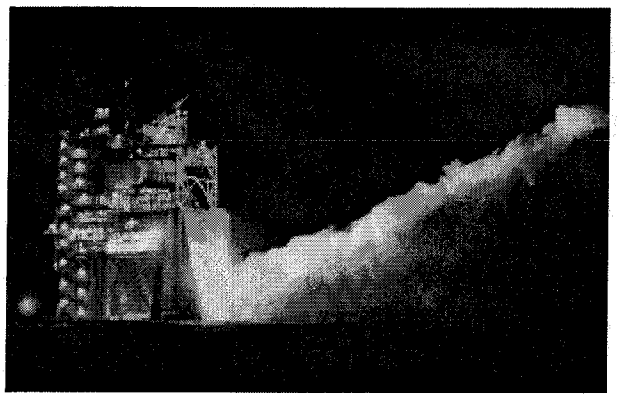

Figure 4 - A-1 Test Stand at SSC

SCOPE/CONTENT/STRUCTURE PROCESS

The facilities under the auspices of the LCRPT are located at MSFC, WSTF, PB, and SSC and continue to demonstrate the ability to support a wide range of component, engine, and system testing at sea level and at altitude. The operational tempo for these facilities is unmatched, supporting research through production testing for NASA, DoD, and commercial industry. They have a combined replacement value of over $2B. Each of the facilities is characterized in a Facility Capability Database. Each facility is assigned a status of active, inactive, or mothballed. Reference Figure 5 below for current inventory.

	Current Facility Inventory			
	TOTAL	Active	Inactive	Mothballed
	32	26	3	3
SSC	13	12	0	1
GRC	1	1	0	0
MSFC	10	7	3	0
WSTF	8	6	0	2

Figure 5 - Current Facility Inventory

The RPTMB was established to conduct the daily activity of the LCRPT. It is composed of members from each NASA test site as shown in Figure 6 with the Chairman being the Propulsion Test Program Office Manager at SSC. Members are selected based on their knowledge of test facilities at their centers and their ability to commit to actions determined by the Board.

Normally, the RPTMB meets weekly or as required. The Board Executive Secretary and Chairman set the weekly agenda based on issues needing attention. Test assignments, facility upgrades and modernization, consolidation activity, budget development, test technology, and lessons learned are typical discussion items. Minutes of the meetings as well as Action Requests and Directives are issued and maintained. The Board process is ISO 9000 certified and is described in the "Rocket Propulsion Test Management Board Operating Procedure" (Reference Document Number SOI-8080-0045-LC).

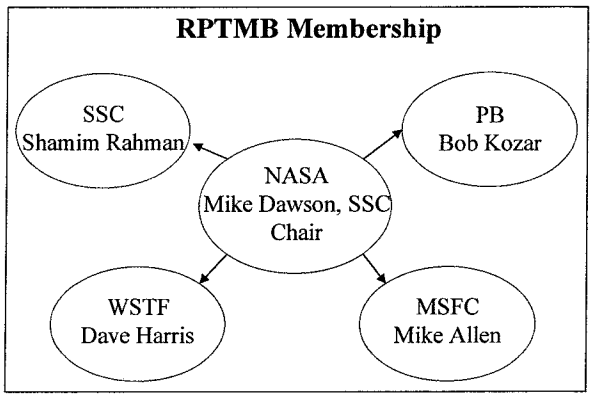

Figure 6 - RPTMB Membership

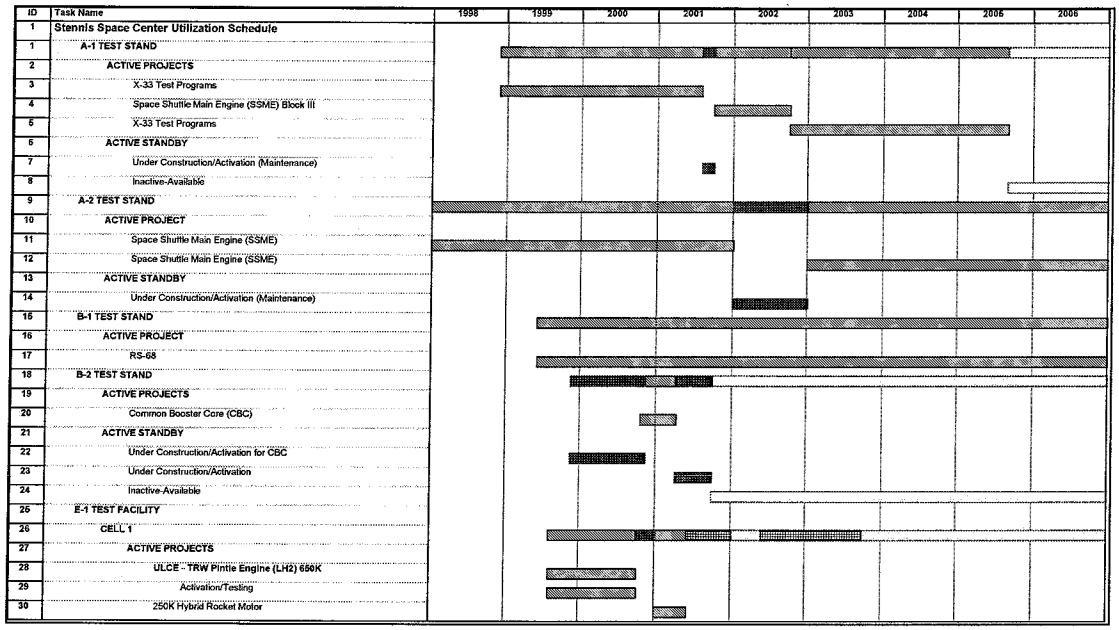

Figure 7 - Sample of a SSC Utilization Schedule

As test projects and customers come into NASA rocket testing they are assigned to a test facility through the RPTMB. Integrated schedules are maintained at each test site, in addition to an overall NASA utilization schedule. These schedules are developed and maintained at several levels of detail to support daily build up and test activity and also to ensure conflicts for test stand space are identified early and resolved. Until the LCRPT developed and mandated this integrated approach, test scheduling was fragmented at a single center not to mention across the Agency. Figure 7 is a sample of a SSC utilization schedule. These schedules are also accessible through the LCRPT web site at http://sscgemini.ssc.nasa.gov/schedules/index.htm.

The flow chart in Figure 8 shows the guidelines for what actually comes before the Board. Basically, upgrades will be addressed by the Board if they are not in a center's baseline or they exceed $500K or they require a test stand status being changed (i.e. from mothballed to active). This process has been effective over the last two years in the execution of the LCRPT.

For FY2001, NASA has established a Rocket Propulsion Test Budget Line Item (RPTBLI) in its annual budget. This has been a major development for the LCRPT because it puts financial authority behind the responsibilities assigned earlier. This budget is used for test infrastructure, test stand maintenance, test technology development, and direct test support at all four test centers.

The Board members propose and justify their respective portions of this budget before it is entered into the annual NASA budget process. The line item does not cover the marginal, recurring costs of labor and materials to conduct tests. Those costs are covered in the specific test project budgets. This budget is composed of the consolidation of numerous previously existing budget items as well as the newly added Facility Modernization category. Facility Modernization helps to ensure obsolete systems and components can be replaced and current technology is being infused into test systems to improve safety and reduce costs. The current RPTBLI level for the four centers is approximately $30M annually. The test project budgets vary, but typically are around $150M annually.

RESULTS

Consolidations – The major overlap in test capability that existed when the LCRPT was formed was between MSFC and SSC. According to the roles that were negotiated and in order to avoid further duplication of expensive test facility assets, two major and several minor equipment moves were made from MSFC to SSC. The first of the two major moves consisted of the 5,000 gal, 8,500 psi liquid hydrogen tank and two 15,000 psi gaseous nitrogen bottles along with connecting piping, valves and miscellaneous equipment located at MSFC TS 116. The second move consisted of the thrust structure, piping and valves from the 750K position at TS 116 and a 500 gal, 8,500 psi liquid oxygen tank, also from TS 116.

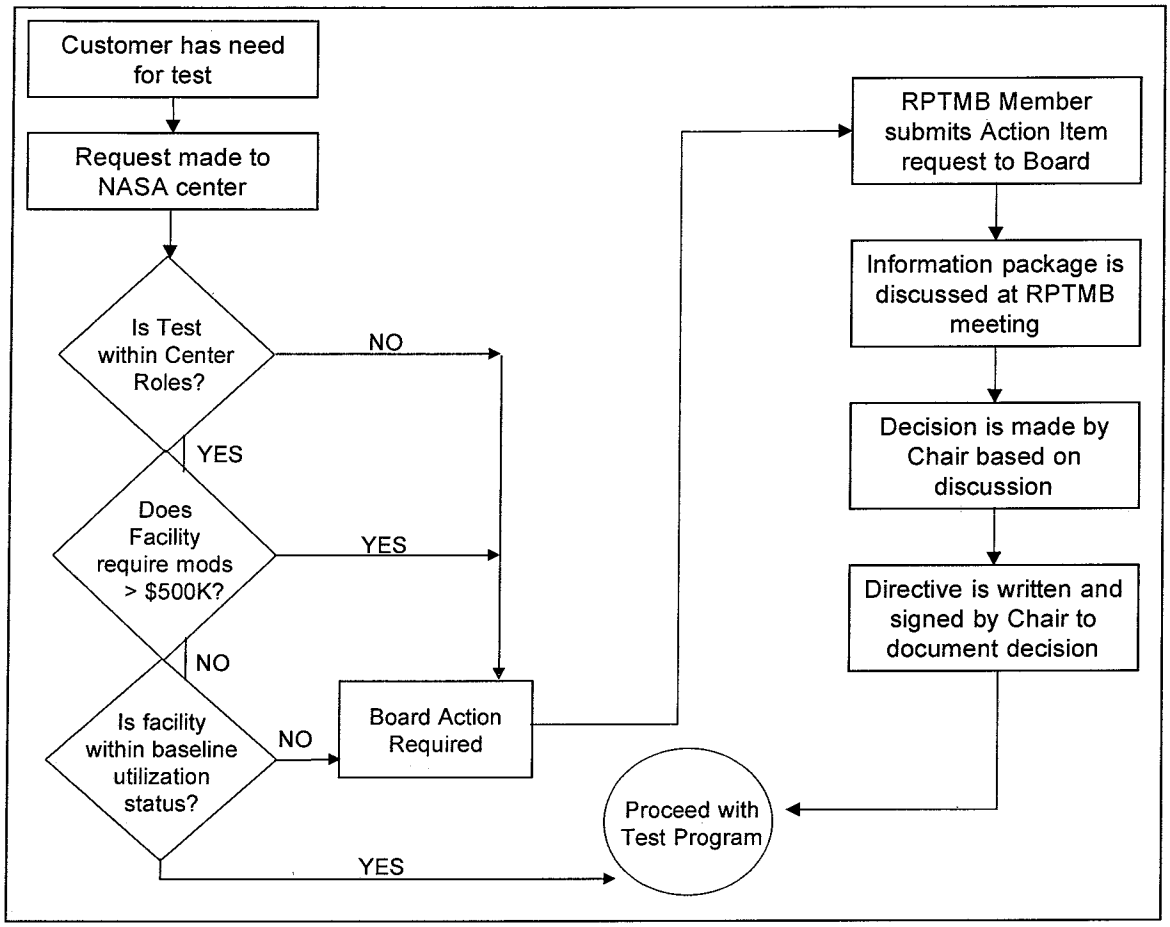

Figure 8 - RPTMB Process Flow

In addition, several lower pressure cryogenic storage vessels were transferred from MSFC to SSC and are now in service as liquid nitrogen and liquid oxygen storage vessels in SSC's E-complex. SSC, working with MSFC, transferred a significant amount of NASA owned hardware from commercial facilities to SSC. Assets in this relocation included additional high and low pressure cryogenic vessels, high pressure piping and various components such as valves and filters.

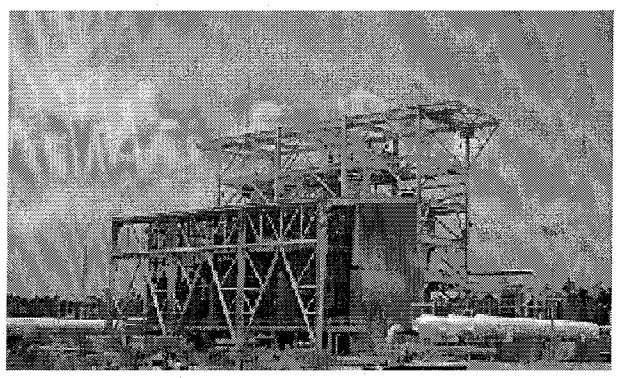

Figure 9 - E-1 Test Stand at SSC

As assets were consolidated, they have been and are being utilized in the facilities at SSC. Use of these assets have added significantly to the capability, while avoiding costly and long lead procurements. To date, it is estimated that $24M in savings or cost avoidance has been realized by equipment consolidation. Some might argue that it would have cost less to leave the assets in place. Doing so was contrary to NASA management direction to consolidate and the aggregate capability resulting from the relocated assets is significantly greater.

Assignments – To date 22 test assignments have been made by the RPTMB. These assignments are shown in Figure 10. As the operations of the LCRPT become more routine, the assignment process is almost always handled by the baseline role for each center. In other words, the Board does not have to assign a program that is clearly in the baseline of a center. The Board then processes, by exception, those assignments that can not be accommodated by the baseline center due to schedule conflict or other complications. In some cases, because of the minor overlap in baseline roles or

the workload, the Board will act as the integrator and sort out cost and technical capabilities between two or more centers and recommend to the customer where the testing should be located.

In making test project assignments, the RPTMB has learned the importance of including the customer in the assignment process. Assignments had been processed with little or no customer interaction. This is not the preferred method. Learning from several difficult assignments, extra effort is taken to keep the customer informed and involved in the assignment process and found that there is generally good agreement between where the Board recommends and the customer's ultimate preference.

22 Tests Assigned	
GRC	X-33 RCS Thruster Qualification
SSC	Pratt & Whitney Injector Test
SSC	Rocketdyne Injector and Chamber
MSFC	RS-68 Gas Generator
SSC	Fastrac Engine Program 60-80 klb
MSFC	RD-180 Propulsion System Tests
MSFC	Single F-1 Engine
MSFC	RSRM 48 Inch Motor Testing
GRC	Delta IV Heavy Cryogenic Upper Stage
GRC	X-33 Densified Propellent Tests
SSC	TRW Engine Test
MSFC	Bantam Workhorse Thrust Chamber
SSC	Bantam Thrust Chamber
SSC	Rocket Development Company Testing
GRC	RLV Multi Lobe Tank Thermal Cycles
MSFC	24" Hybrid Motor Firings
WSTF	JPS Warm Gas Pressurizaiton Testing
RTTC	Solid Rocket Motor Testing
GRC	RDC Altitude Testing on 40K Second Stage
WSTF	RDC RCS Qualification Testing
SSC	60K Fastrac re-assigned to SSFL
WSTF	ISSPM Testing

Figure 10 - Test Assignments

Numerous specific examples of test assignments that required Board action and resulted in lower cost and/or faster schedule to the customer are described below. In retrospect some of the assignments turned out to be more successful than others. In all cases however, it was learned how to serve customers more effectively.

In 1999, the Re-designed Solid Rocket Motor Project office at MSFC requested the Board assess and recommend the best location to conduct a test series on a 100K thrust solid rocket test motor. This type of test was within SSC's baseline, but the required environmental permits could not be obtained in time, so the Board looked at MSFC, which is SSC's backup for these types of test, and also looked at DoD facilities at Naval Air Warfare Center (NAWC) - China Lake, Air Force Research Lab (AFRL) – Edwards Air Force Base, and the Army's Redstone Technical Test Center (RTTC). Each site prepared ROM cost estimates and participated in technical discussions with the Board. Based on a $80K savings and an available stand requiring almost no modifications, the Board recommended the NASA Project Office conduct these tests at RTTC.

In the fall of 1999, the Board relocated the Fastrac (now known as MC-1) engine testing from SSC to a NASA owned, contractor operated facility. This move was necessitated by the Fastrac engine development extending well beyond estimated time frames and the previous commitment of the test stand to a commercial program. The Board looked at numerous options and determined, primarily on schedule, to continue with the move. The move caused concern with the customer (Fastrac Project Office at MSFC) and is a good example of how the Board needs to continuously strive to keep the customer's concerns foremost in the assignment process. As it turns out the move did not result in the amount of testing anticipated for reasons this paper will not discuss. It did, however result in some excellent engine performance data (i.e. thrust measurement and propellant flow measurement) which has helped significantly with engine calibration.

In the early spring of 2000, it was apparent that SSC could not conduct the Hydrogen Mitigation Project for a commercial customer as planned due to other test activity which had come on Board between the time the proposal was submitted and when the customer was ready to proceed. As a result the project was transferred to PB where a vacant facility and experienced personnel were available. This transition helped the customer by minimizing the schedule impact and allowed PB to retain skilled workers.

In 2000, both WSTF and PB received Request for Quotes for the testing of an Upper Stage Peroxide Engine. This was another overlap in the baseline roles and both PB and WSTF were capable of conducting the testing. They both submitted a ROM estimate with assumptions to the board. Discussions revealed that while both sites were very capable and experienced, there was a distinct cost advantage to one. The Board baselined the lowest cost site and relayed a recommendation to the customer accordingly. In almost all cases, the Board will review and integrate the four center responses and submit only one to the customer.

NRA 8-30 process – The Board made over 50 preliminary assignments in support of the NASA Research Announcement (NRA 8-30) process recently. The assignments were again made along baseline roles. However, because of the volume of proposed work, the Board reviewed the NASA test stand utilization schedule to ensure stands were not overloaded. Each assigned center would then work directly with the customer to provide estimates for the test services. As the NRA 8-30 process continues, down selects by MSFC will necessitate adjustments in the assignment process to ensure the testing is accomplished most responsively for the customer.

Savings – The overall savings and cost avoidances to date are shown in Figure 11. The bulk of the cost avoidances involve the transfer or relocation of expensive test stand equipment from one facility to another, such as the tanks from MSFC to SSC. In addition, equipment is loaned from one facility to another. The RPTMB process has established an excellent avenue to request equipment from sister sites. An example of how this worked is the Hydrogen Mitigation Project at PB that had to install some high pressure cryogenic run systems and some high speed data systems. Through the RPTMB, PB made a request for high pressure cryogenic valves and for high speed data system components. SSC was able to loan PB over $500K worth of equipment that was critical to a successful test project, the cost of which did not have to be passed on to the customer.

Cost Savings / Avoidance	
$ 500,000	Cancellation of MSFC 10" Valve Procurement
$ 8,542,890	Relocate LH2 run tank from MSFC TS116 to SSC E-1
$ 4,500,000	Relocate 3 high pressure bottles from MSFC TS116 to SSC E-1
$ 400,000	Relocation of Lockheed-martin LOX tank to SSC
$ 900,000	Relocation of 28,000 gal MSFC LOX tanks to SSC
$ 300,000	Relocation of 10,162 gal MSFC LOX tank to SSC
$ 100,000	SSC loan of POGO Pulser System to MSFC
$ 9,307,000	MSFC TS116 750K Equipment Transfer to SSC
$ 10,000,000	LOX/LN Direct Contract $2M/Yr for 5 yrs
$ 350,000	Relocation of 15,000 psi IH pump from MSFC to SSC
$ 2,000,000	(3 month savings) Fastrac relocation to SSFL
$ 90,000	temporary relocation of GRC technicians to SSC
$ 136,000	SSC E-2 table for changing parameter set points for testing
$ 464,250	H2 Mitigation project equipment loan from SSC to GRC-PB
$ 14,100,000	PTA1 Relocation
$ 51,690,140	TOTAL SAVINGS / AVOIDANCE

Figure 11 - RPTMB Cost Savings / Avoidance

Risk reduction – The operation of the LCRPT has also helped to reduce project and facility risks through the Operational Readiness Inspection (ORI) process. As a member center approaches an ORI, the Board is made aware and has the opportunity to designate individuals from other centers to serve as independent reviewers. This process has been used for test activity at all four NASA centers over the last two years. The independent reviewers add to the credibility and impact of the ORI and are then able to bring back information to their center relative to hazardous test operations.

Lessons learned – The RPTMB also serves as a clearing house for lessons learned from rocket propulsion testing. Each center uses the Board meetings as a forum to inform other centers of incidents and the results of investigations which might be applicable to them. Some examples of discussion topics are: LOX fires, triethyl aluminum vessel rupture, steam line rupture, H202 exposure, and the gaseous nitrogen system contamination. Since the test stands and support systems at all centers have a large number of similar systems and technology, the transfer of information between centers is invaluable, helping us to avoid costly occurrences.

FUTURE PLANS

The LCRPT is operational and resulting in integrated, responsive test services across NASA. As the process matures, continued positive trends are expected relative to lower test costs and ever-improving capability to test the components, engines, and systems being developed. NASA will continue to improve the fidelity in cost and schedule estimating and all business systems. In addition, modern, world class test facilities which are highly flexible and staffed by experienced testers continue to be a major priority. As such, NASA will continue to invest in test technology, advanced data acquisition and controls, and other key test system elements to ensure facilities and processes are available to meet the challenges of rocket propulsion development in the future.

Test technology development will be a major focus of future activity. It will include advanced sensors to better understand the physical parameters of the test article and the test systems, which are more rugged and have better response and resolution. It will also include data and controls systems that are easier to set up, reducing time and labor required to conduct a test. Real time measurements will be more useful in determining article performance and will aid in real time decision-making relative to hardware performance. Remote access to the test activity by customers and engineers will be an integral part of testing in the future. Advanced computer modeling of the test environment and systems will allow for safer and less costly build up and testing, cutting down time lines and simplifying designs.

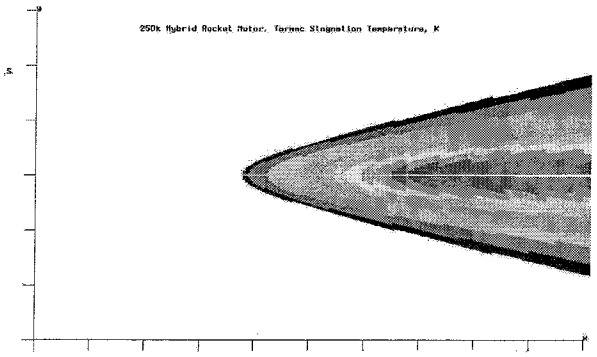

Figure 12 - Tarmac Heating from Motor Plum Impingement

NASA will work more closely with hardware developers to provide a "rocket tester's" perspective on the design and operation of the test article. We will also provide insight and recommendations to the customer on test plan content to improve the chance of success by testing more thoroughly.

SSC, working with the other centers, is in the process of identifying the testing requirements for the future generations of NASA, DoD, and commercial propulsion technology. The unique propulsion systems of the future will require different and unique facilities from the test stands operational today. Pressures, flow rates, power requirements, and isolation will be driven by higher performance requirements and different propulsion cycles. Identifying these requirements will enable us to plan the capability needed to perform testing and to have it available when needed by developers.

SSC will continue to develop and improve the performance of all four test centers. This unique relationship between NASA's rocket test centers will continue to provide critical support to Shuttle while supporting developments in propulsion for future systems. As a group, NASA will continue to work with DoD on opportunities for sharing and exchange. In addition, emphasis will be placed on working more closely with industry to ensure their propulsion test requirements can be met with minimum costs.

REFERENCES

[1] "Rocket Propulsion Test Management Board Operating Procedure," Doc. No. SOI-8080-0045-LC, October 2000.

[2] "National Rocket Propulsion Test Alliance 2000 Annual Report/Master Plan," September 2000.

[3] Virtual Management Information System web site, content http://sscgemini.ssc.nasa.gov/vmis.