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Paper Session III-A - The Advanced Solid Rocket Motor Project

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THE ADVANCED SOLID ROCKET MOTOR PROJECT

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On April 21, 1989, NASA informed Lockheed CEO Dan Tellep that Lockheed Missiles & Space Company had been selected for negotiations of the Advanced Solid Rocket Motor (ASRM). Lockheed Missiles & Space Company, specifically the Missile Systems Division, is the prime contractor to the Marshall Space Flight Center for the ASRM. Teamed with Lockheed as major subcontractors are Aerojet Space Boosters and Rust International as shown in Figure 1. Lockheed Missiles Systems Division's primary function for more than thirty years has been the systems management of major Fleet Ballistic Missile programs for the United States Navy. In those projects, Lockheed subcontractors have been all of the major solid propellant contractors in the United States. Lockheed's role resulting from this experience base is that of project manager, where Lockheed provides systems engineering and integration of the entire project.

Figure 1. The ASRM Project Team

Lockheed's association with Aerojet as subcontractor on the Polaris program, dates back to the mid-1950's; thus the ASRM project represents a continuation of a long and productive association between the two major corporations. Aerojet, the major participant in the project, is responsible for the design, analysis and engineering of the rocket motor, as well as the manufacturing, quality assurance and testing. The other major subcontractor to Lockheed is Rust International, headquartered in Birmingham, Alabama. Rust is one of the largest domestic construction companies in the United States and will be responsible for the design and engineering of the facility, procurement and installation of equipment, and managing the construction activities.

This paper will provide information on the ASRM and facility design and on the development program now underway at Lockheed, Aerojet and Rust. It will be an update on ASRM activities since last year's Space Congress, where Ken Jones and Lowell Zoller of the Marshall Space Flight Center described the project as it existed at that time. In their paper, Jones and Zoller described the primary goals and objectives of the ASRM project. These are shown in Figure 2 and remain unchanged.
NASA's paramount goal for the ASRM is to enhance Shuttle System safety and performance. This goal is supported by the four objectives shown in the figure. The first is to improve safety by improving system reliability through enhanced quality techniques and enhanced reproducibility. Enhanced quality techniques help to assure that the product is made exactly as it was designed and that each successive unit is identical.

The increased size and higher performance propellant of the ASRM will provide increased performance for the Shuttle System by achieving the goal of an additional 12,000 lbs. of payload to a 110 nautical mile, 28.5 degree orbit. The increased performance and the tailored time thrust profile as described in the Zoller/Jones paper, significantly enhance system safety by eliminating the requirement to throttle back the Space Shuttle Main Engines during the period of peak dynamic pressure.

No matter how much safer and how much the performance is improved, if the nation cannot afford the ASRM, then these attributes will never become available. The program is tailored to provide cost efficiency through a dedicated production facility. Also, all levels of the project are established with future recompetition as an available option. The establishment of a Government Owned Contractor Operated (GOCO) production facility at Yellow Creek, Mississippi, will minimize future investment for successor contractors. The proposed rocket motor design and the proposed production process have been totally focused to satisfy NASA's objectives for the ASRM project.
Figure 3 delineates the key features of the Lockheed/Aerojet proposed Advanced Solid Rocket Motor. These features combine to satisfy the aforementioned objectives, with each individual feature satisfying one or more of them. Perhaps the most unique feature of the ASRM is the three segment design which eliminates one complete field joint, eight factory joints and reduces failure modes by 18%. In addition, the two joints connecting the three segments are bolted flange designs which are designed to stay closed under pressure and provide a more positive and inspectable closure system for the solid rocket motor. Within each segment, the factory joints are welded instead of bolted. Welded joints are possible because of the excellent weldability attribute of the high strength HP 9Ni-4Co-0.30C steel used in the ASRM design.

The propellant for ASRM is hydroxy-terminated polybutadiene (HTPB), a well characterized propellant used in several military programs. It is a class 1.3 propellant. Also, ASRM processing safety is enhanced and compliance with current environmental requirements is assured, through the use of non-asbestos insulator, specifically Kevlar-filled EPDM. The nozzle design proposed also incorporates the latest technology through the use of a 3D carbon-carbon integrated throat entrance (ITE) with a lightweight carbon phenolic exit cone, both well characterized in military programs.

The key to reproducible performance is achieved through another unique feature of the ASRM; the processing of the propellant using a continuous mix and direct cast technique. This technique was first used on the Polaris program in the 1950’s and was also demonstrated by Aerojet in their 260 inch solid rocket motor program. Also unique to the ASRM project, is the ASRM production facility itself which is an automated, state-of-the-art, dedicated GOCO production facility. Each of the above features will be discussed in more detail in the following paragraphs.
The pictorial in Figure 4 reiterates and shows in more detail some of the unique features of the ASRM. One of the requirements of ASRM is that the impact on NSTS interfaces be minimized, so consequently, the length is exactly the same as the RSRM, the diameter just 4 inches larger at 150 inches. Overall, this loaded motor weighs 1.3 million pounds and has a burn time of about 130 seconds and produces a peak sea level thrust of 3.5 million pounds.

The bolted flange field joints and the welded factory joints are not the only unique features of this high strength steel case. The aft segment features integral stiffener rings which are machined directly from the basic segment forging. Likewise, the External Tank Attach (ETA) ring is integral to the aft segment case. The integral design significantly reduces the assembly and processing time at Kennedy Space Center (KSC). The more robust design provides a significant enhancement to the water impact survivability. The case will be welded, heat treated and machined by Babcock & Wilcox Corporation (B&W). B&W will be using technology and capabilities developed in their Naval reactor business.

Figure 5 shows additional details of the nozzle including the single piece Carbon-Carbon ITE and the improved flex bearing. Carbon-Carbon ITE's have been used extensively in the Peacekeeper and Trident II ICBM programs, although in smaller sizes. Scale-up to the larger size of the ASRM has been assessed as a risk area, requiring dedicated attention and a back-up solution. The back-up is an ablative throat concept similar to the RSRM. Both solutions will be carried in the development program until the Carbon-Carbon ITE has been demonstrated in full scale tests. The nozzle to case joint provides reduced leak paths and was designed for optimum assembly technique.
Most of the metal parts of the nozzle have been designed for reuse and were also designed for flexibility to incorporate the prime Carbon-Carbon ITE and the back-up ablative throat. The exit cone liner uses a low density carbon phenolic which provides significant weight reduction, and consequently, an increase in payload capability. Thiokol Corporation, a subcontractor to Aerojet, will design and fabricate the nozzle at the Michoud Assembly Facility (MAF), using the latest state-of-the-art assembly equipment.

The key to the repeatability in performance is the continuous mix direct cast process, one of the most unique features of the ASRM project. The process relies on a horizontal screw mixing technique used extensively in the food, chemical and pharmaceutical industries. This process is shown schematically in Figure 6. Basically, the ammonium perchlorate oxidizer and the fuel are fed in precisely controlled quantities and at precisely controlled rates into the UK400 mixer. About 1,000 lbs. of propellant are in the mixer at any time as it traverses the mixing action. The propellant is de-aerated through the rotofeed and then pumped out of the mixing room, where its characteristics are continuously checked. The propellant is pumped in pipes past the Fourier Transfer Infrared (FTIR) station directly to the cast pits where four segments are cast in succession. As shown in the figure, key portions of the process are isolated through a damage control system to isolate damage and direct the results of any incident away from other portions of the process.
A prototype continuous mixer and rototorp feed have been in operation at Sacramento for over two years. HTPB propellant mixed in the prototype has shown very repeatable properties, more repeatable than were previously available in batch mix processes. The UK400 mixer, two of which will be installed at Yellow Creek in duplicate propellant production processing lines, has a capacity of 20,000 lbs. of propellant per hour. Inert propellant was mixed in an existing UK400 during the proposal period at another facility to validate the scale-up to the larger size. The properties of the mixed propellant will be continuously assessed through the on-line FTIR equipment which will check for variations in constituent parts of the propellant. Early in the development program and during the production program, on-stream analysis will be augmented through wet chemistry tests with samples taken in parallel with the FTIR. Density measurements will also be made. A knowledge based system is being designed by Lockheed's Artificial Intelligence Laboratory to provide, in the future, direct feedback control to the raw material input using the results of the FTIR analysis to provide even further reduction in the variation in the characteristics of the propellant. If at any time the on-line sensing equipment detects propellant characteristics out of specification, the propellant can be diverted from the cast pits to a waste area until the propellant can be brought back into specification by adjustments in the mixing or raw material input. The ASRM team is convinced that the continuous mix process provides a significant improvement over batch processing for large quantities of propellant production.

The ASRM will be produced at the Yellow Creek site (Figure 7), at the headwaters of the Tennessee-Tombigbee Waterway. The nozzles for the ASRM will be produced for Aerojet by Thiokol at the Michoud Assembly Facility, just outside of New Orleans. Static firings for the ASRM, both in development and production, will be conducted at the Stennis Space Center in Bay St. Louis, Mississippi. The customer and the NASA center responsible for the development is the Marshall Space Flight Center in Huntsville, Alabama. Major structural testing of the ASRM will be conducted at Marshall during the development program. Final utilization of the ASRM, of course, will be at KSC on the eastern shore of Florida.
Locations of the key facilities allow for extensive use of water transportation using dedicated barges and eliminating many of the risks attendant to rail transportation as used currently. The development team is now located in Sacramento, California, and will transition to the Yellow Creek site in the summer of 1990. The Yellow Creek site itself (Figure 8), located in northeast Mississippi, was initially proposed as the site of a TVA nuclear power plant. This nearly 1200 acres has extensive infrastructure in existence, with twenty-two of the existing facilities to be completed and utilized in a modified form for ASRM production. Thirty-one new buildings will be constructed to complete the remaining process locations.

Figure 7. ASRM Project locations

Figure 8. ASRM GOCO Facility at Yellow Creek, MS

Lockheed was announced as the contractor selected for negotiation of the ASRM in April of 1989. Full Authority To Proceed (ATP) was given December 1 of that year. The development schedule, shown in Figure 9, outlines in broad terms the overall facility

YELLOW CREEK SITE

- ACRES: 1,168
- 22 EXISTING FACILITIES
  534,000 SQ FT
- 31 NEW FACILITIES
  740,000 SQ FT
- HIGHLY AUTOMATED PLANT
  WILL PROVIDE IMPROVED:
  - FLIGHT SAFETY
  - INDUSTRIAL SAFETY
  - ENVIRONMENTAL SAFETY
construction and activation, and the ASRM design and development activities leading to the delivery of the first flight articles to KSC early in calendar year 1995. At this writing, discussions are underway concerning the delay in the project resulting from budget reductions in fiscal 1990 and 1991. This delay could be approximately six to twelve months. Facility design started initially during the proposal, continued immediately after ATP, and at mid-1990, initial construction activities will start at Yellow Creek. Equipment installation will begin in the Fall of 1990 in the earliest activated building, the case preparation building, and will continue until all buildings at the Yellow Creek site are completed and activated by mid-1993. Maintaining this construction, equipment installation and activation schedule is highly critical to the overall pace of the program. Each critical process building must be completed in order to support the overall delivery schedule. Rocket motor design itself, also begun during the proposal, has continued since the issuance of Authority To Proceed.

![Graphical representation of the ASRM Master Project Schedule]

Figure 9. The ASRM Master Project Schedule

The first major milestone, the Project Requirements Review, conducted in January of 1990, was successfully completed. The first manufacturing activity at Yellow Creek will be the processing of the Pathfinder unit. This inert rocket motor will be used to validate each step of the production and assembly process at Yellow Creek, Stennis and later at Kennedy Space Center. The first of seven static firings prior to first flight of the ASRM will occur at the Stennis Space Center in 1993. Three development motors and four qualification motors are currently planned, to be followed during production by four firings a year to assess the performance of the production articles. As stated earlier, deliveries to KSC will commence in early 1995 with the first six flight sets heavily instrumented as development units to be followed at a production rate of fourteen flight sets per year through the 1990's. The transition from RSRM to ASRM at Kennedy will cover a span of two years, at the completion of which all subsequent shuttle flights will be utilizing the ASRM.

The Advanced Solid Rocket Motor will fully satisfy NASA's goal of enhancement of the Shuttle System safety and performance. It will provide improved system reliability and increased performance for a more economical boost to orbit of future NASA payloads. The Yellow Creek site will provide a national asset for the production of high quality, cost efficient, solid rocket motors.