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Sacramento, CA

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Abstract

Aerojet in the mid 1960s, under contract to NASA, built and static hot fire tested the largest solid rocket motor (SRM) in history for the purpose of demonstrating the feasibility of utilizing large SRMs for space exploration. This program successfully fabricated two high strength steel chambers, loaded each with approximately 1.68 million pounds of propellant, and static test fired these giants with their nozzles up from an underground silo located adjacent to the Florida everglades. Maximum thrust and total impulse in excess of 5,000,000 lbf and 3,470,000,000 lbf-sec were achieved. Flames from the second firing, conducted at night, were seen over eighty miles away. For comparative purposes: the thrust developed was nearly 100 times that of a Minuteman III second stage and the 260 in.-dia cross-section was over 3 times that of the Space Shuttle SRM.

Although many difficult technical challenges confronted the NASA/Aerojet team, the space race demanded success. The team motto was "get it right the first time". The bottom line for the program: any catastrophic failures would lead to project termination.

This paper focuses on the various challenging aspects of the program and how these were successfully addressed. The challenges included:

1. Chamber material and heat treatment selection to achieve both high strength and toughness
2. Method of fabricating a 6 story high, 22 foot dia chamber that would be compatible with tight tolerances, rigorous inspections and handling
3. Transporting the 60 ton chamber over 1000 miles
4. Development of a propellant having the desired manufacturing, ballistic and structural properties
5. Development of propellant processing capable of reliably producing large quantities in a short time
6. The mixing and casting process for the propellant into the chamber
7. Motor Ignition
8. Engineering the project over 3000 miles away from the fabrication, casting and inspection activities

This program was highly successful and NASA used some the technology that was derived to develop the Space Shuttle SRM Boosters. This program was conducted in the infancy of solid rocketry and represented a very large undertaking as well as significant forward thinking and risk management on NASA's part.

Motor Description

The 260-in. motor configurations for SL-1 and SL-2 are illustrated in Figure 1. The following list describes the attributes of these motors.

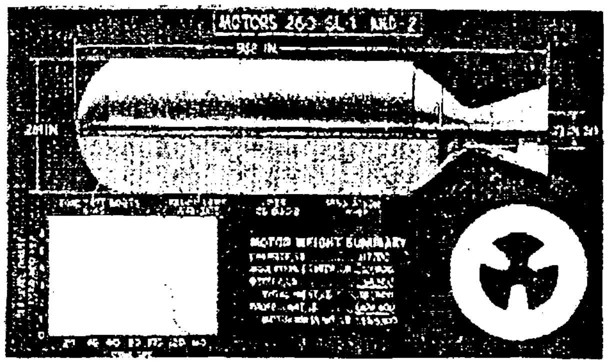

Figure 1. 260 SL-1 and SL-2 Motor Configuration

- Chamber – grade 200, 18% nickel maraging steel having a diameter of 260 in. and length of 61 ft.
- Nozzle – shell made from maraging steel with a length of 9.5 ft.

  Non-metallic flame liner parts molded from impregnated silica and carbon fabrics.
- Exit cone – type 3003 aluminum shell with an overall length of 10 ft.

  Non-metallic flame liner parts molded from impregnated silica and carbon fabrics.

- Nozzle/exit cone expansion ratio of 6:1.
- Internal insulation – V-44 (asbestos and silica filled nitrile rubber).
- Forward and aft boots made from V-45 (silica filled nitrile rubber).
- Propellant – PBAN; bore configuration was wagon wheel.
- Motor Assembly – length of 80.7 ft. and weight of 1,858,300 pounds.
- Ignition system –30 in. dia rocket motor placed in 260 in.-dia nozzle
- No TVC

Initial Effort

Initial effort (circa 1963) on the 260 in. dia rocket motor program was under the cognizance of the U. S. Air Force (AFRPL) and consisted of design and analysis studies and laboratory testing to obtain data that would be useful in the building of the 260. The 1965 modification to the DoD/NASA agreement granted full responsibility to NASA Lewis Research (contract NAS3-6284). Despite the early changes, the 260 program is usually thought of as an all NASA development effort.

Early in the program the Air Force specified that Aerojet use 18% nickel maraging steel, which was an excellent material, but one for which manufacturing experience was somewhat limited. Consequently much of the 1963 – 1965 laboratory testing was directed to its characterization (strength, toughness, weldability, cold rolling, etc.) and scale up of prior materials and processes to the components and assembly sizes required for the 260 in. dia rocket motor program.

Studies leading to the use of grade 200, 18% nickel maraging steel for the rocket motor were initiated at Aerojet under Air Force contract AF 33(657)-8740. During 1962, Aerojet reviewed a number of different alloy steels for chamber fabrication including D6AC, AISI 4335V, 18% nickel maraging steel (3 grades), 9Ni-4Co, 12% nickel maraging steel and HY 150 materials. The low alloy steels were discarded because of the need to develop and construct very large protective atmosphere gantry furnace-quench and temper facilities to heat-treat the 260 in-dia chambers. The 9 Ni-4Co and 12% maraging steel were new developments while the HY 150 steel, an advanced submarine hull steel, did not meet the strength –weight requirements. Consequently 18% nickel maraging steel was selected as the best candidate and the 3 major grades, 200, 250 and 300 KSI nominal yield strength, were evaluated with regard to melting practice, material properties, welding, heat treating, forging and forming. The three nominal strength levels produced by air melt, air melt plus vacuum degas and vacuum arc remelt were evaluated for strength, ductility, fracture toughness, stress corrosion resistance, weldability, etc. Various solution treating temperatures (1500–1675°F) and aging cycles (850–950°F for 2–16 hours) were investigated. Weld processes evaluated included the inert gas shielded tungsten arc (TIG); inert gas shielded metal (MIG) and submerged arc process. Typical mechanical properties obtained for parent material and weldments are shown in Figure 2. Based on the results of the program, the grade 200, 18% nickel maraging steel produced by vacuum arc remelting, welded by the TIG process and post weld aging at 900°F for 4-8 hours were selected.

These materials and process studies were expanded and applied directly to the 260 in. dia chamber fabrication at Sun Ship. The technology developed at Aerojet was transferred to Sun Ship through extensive materials and process development and manufacture of subscale pressure vessels using the processes, tooling and equipment to be used in the manufacture of the 260 in. dia chambers. This program assured the complete controllability and understanding of the materials and fabrication techniques.

Tests were conducted to determine the effects of temperature variations within the large aging furnace used for post weld maraging of the monolithic 260 in.dia chambers. Weldments produced using the production equipment, processes and weld wire were evaluated. Stress corrosion tests using various hydrotest fluids were performed and a solution of 1.5% sodium dichromate with pH adjustment to 7.4 using sodium hydroxide was selected. Extensive machinability tests were performed to develop acceptable process parameters and fluids for all anticipated processes, e. g. turning, milling, drilling, tapping, etc., used for manufacture. Weld repair tests to establish process parameters, number of permissible repair welds, post weld aging cycles and fixtures, etc., were conducted. Non-destructive inspection techniques were also evaluated and defect containing samples of plates, forgings and weldments were tested to insure that the critical flaw sizes and types, determined by fracture toughness tests and analyses could be readily detected on full scale hardware.

The parent metal required for this total development effort at Sun Ship was obtained from subscale and full-scale plates, bars and forgings produced by our suppliers.

Steel Grade	Ult. Strength, (Ksi)	0.2% Offset Yield Strength, (Ksi)	Elongation in 1" (percent)	Reduction in area (percent)	Fracture Toughness K_{IC} (Ksi$\sqrt{in}$)
Grade 200					
Parent Metal	225	215	12	55	135
Weldment (GTAW)	220	205	12	50	120
Grade 250					
Parent Metal	260	250	9	45	95
Weldment (GTAW)	255	245	8	40	80
Grade 300					
Parent Metal	307	300	6	30	N / A
Weldment[1]					

Note: 1) Welding by chamber manufacture processes not practical

Figure 2. 260 Typical Tensile Properties and Fracture Toughness of 18% Nickel Maraging Steels

Plate sizes of 431 x 104 x 0.61 in. and ring forgings 260 dia x 32 x 3.5 in. were successfully produced and used for hardware manufacture. Test material from each plate and forging was tested for chemistry, metallurgical, tensile and toughness properties for both parent and weldments over the full range of temperatures and times expected in the large aging furnace to ensure compatibility between plates, forging and weld wire. This total materials and process development program ended with the successful manufacture and hydroburst of two 36 in.dia process evaluation pressure vessels. The burst tests also provided biaxial properties that were used to verify the criteria and analyses used for hardware design. This extensive materials and process development over approximately 18 months served to verify the materials, processes and equipment to be used during hardware manufacture, inspection and testing. It also provided the main avenue to the technology required for manufacturing reliable rocket chambers in a sea coast shipbuilding environment.

Similar process and propellant development was conducted initially, and is described under Propellant and Casting sections of this paper.

Chamber Fabrication

The fabrication of a chamber of this magnitude exceeded the capabilities of Aerojet in terms of experience and facilities. Consequently Aerojet teamed with Sun Ship and Dry Dock Co. located in the Philadelphia area. This marriage proved beneficial in that each company brought technologies necessary for the success of the program. Aerojet's contributions lay in the areas of chamber design, chamber materials and processing technology, nondestructive inspection, structural testing of the finished chamber and overall rocket design experience. Sun Ship's contributions lay in the areas of handling large metal plates, fabricating large metallic structures and having facilities, including overhead cranes, big enough to accommodate the 22 foot dia chamber. Additionally, Sun's location on the Delaware River allowed ease of shipment via barge to the Aerojet facility in Florida.

Prior to building the first 260 in. dia chamber, a 280 in. dia chamber was fabricated using mild steel for purposes of identifying any problems relating to handling, welding, and the ability to maintain the required tight tolerances. The 280 in dia chamber was subsequently used as a water storage tank to support hydrotesting of the 260 in dia chambers.

A combination of cold formed segments for the dome areas, forgings for the Y-joint areas, and rolled plates for the cylinder were used in the chamber fabrication as shown in Figure 3.* All were made of grade 200, 18% nickel maraging steel. The Ladish Co. supplied the forgings. Sun Ship performed the cold forming and rolling operations. Plates used in fabricating the cylindrical sections were 408 x 102 x 0.60-in. (after extracting test coupons); two plates joined by longitudinal TIG welds were required for each cylindrical section.

*The terminology 260 SL is used in this figure and elswhere in this paper. The SL designation indicates a short length configuration, as the full length was not required for such a demonstration program. The short length motors were approximately 80 feet long and capable of 3.5 million pounds thrust for about two minutes. The first two SL motors fired used propellant burning rates and nozzle size appropriate for full-length design.

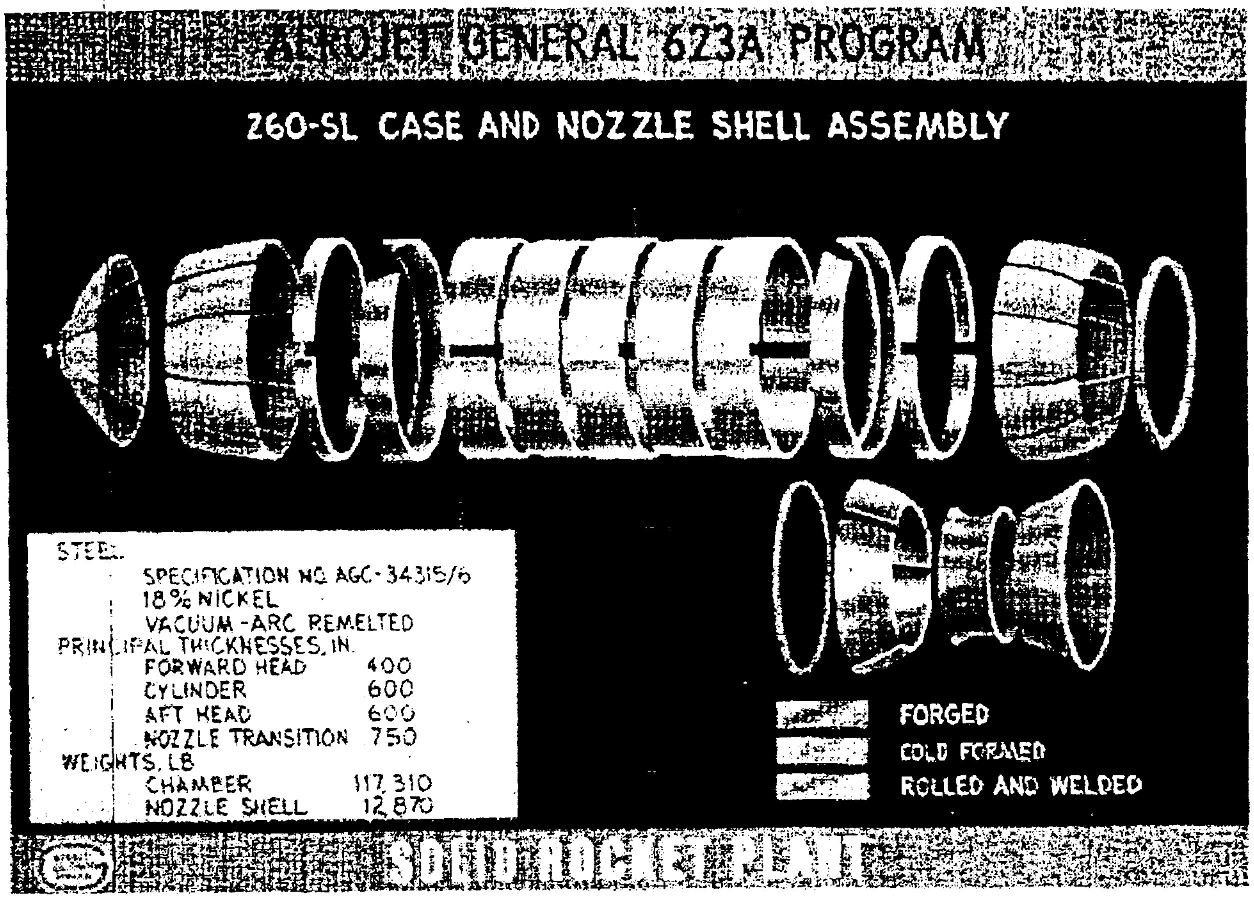

Figure 3. 260 Chamber Assembly and Materials

Seven cylindrical sections plus forward and aft Y rings and domes were required for each chamber.

Figure 4 shows special tooling used for holding tight tolerances for concentricity and weld mismatch during the welding of two cylindrical sections together. This tooling utilizes an array of hydraulic cylinders, each individually controlled, for the purpose of locally applying force (and deflection) to ensure that the two cylinders matched up for the welding operation and to maintain the chamber concentricity.

The actual welding of two cylinders is shown in Figure 5. "J" grooves were machined in the edges of the plate and welded together using the down hand gas-shielded tungsten inert gas (TIG) weld process. For the most part (except for tack welding), this was done with an automatic equipment setup and required 10-12 passes to join the 0.60-in. thick cylindrical sections. Manual TIG welding was done for repairs when necessary. In Figure 5 the automatic TIG welding equipment is located at the very top with the cylinders slowly rotating one revolution approximately every 72 minutes.

The chamber domes were welded assemblies comprised of cold formed plate gore sections and forged and machined forward dome apex and aft dome nozzle flanges. The forward and aft Y-ring transition sections between the domes and the cylinder sections were machined from seamless ring forgings. The dome gore sections were "bump" formed and welded into a subassembly at Sun Ship using a large welding positioner and very rigid tooling to insure accurate weldment fit up and the dimensional accuracy of the welded dome. The welding gun was stationary and oriented in the down-hand position; the assembled gore sections, weld tooling, etc., were rotated under the welding head using the welding positioner, illustrated in Figure 6. Inert cover gas was provided on both the top and backside surfaces of the weld joints to prevent excessive oxidation. The gore sections were welded to the forward and aft flanges followed by welding to the Y-rings and cylinder sections to complete the monolithic chamber. Final machining and drilling-tapping the dome flanges were performed following maraging of the welded chamber.

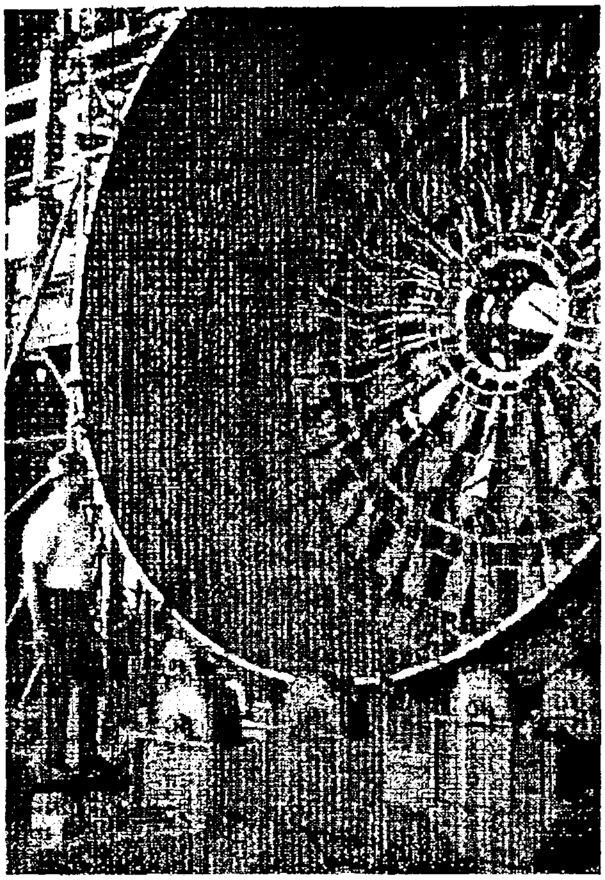

Figure 4. 260 Chamber Cylindrical Welding Tooling

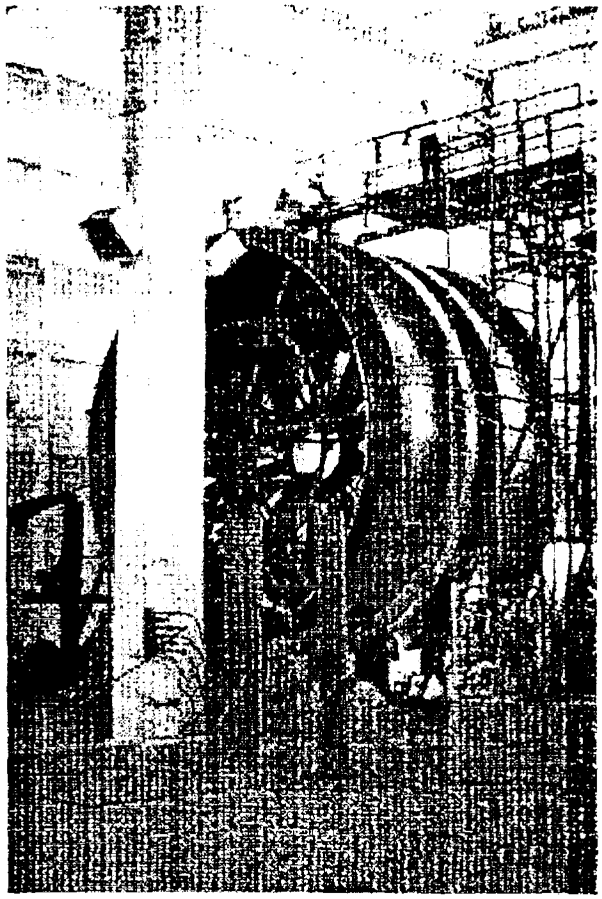

Figure 5. 260 Chamber Welding of Two Cylindrical Case Sections

All welds were radiographically inspected for porosity, flaws and foreign material. Weldment X-ray parameters and acceptance criteria for such were based on the fracture analysis and material toughness, e.g. what size flaw could be tolerated without detrimental propagation during hydrotest and motor firing. Over a quarter of a mile of welds were inspected for each chamber.

Heat treating of the chamber was accomplished by subjecting the chamber to 900°F for 8 hours. This was done by building a special structure to house the chamber. Gas furnaces and blowers were attached to the structure and provided the heating and its distribution through an enclosed ducting system (no direct flame impingement on the chamber). Thermocouples attached to the chamber wall provided the necessary information for controlling furnace heat and its distribution.

After aging, the chamber was placed vertically in the hydrotest stand and the aft boss and the threaded holes used for nozzle attachment were machined.

Nozzle Fabrication

The nozzle assembly consisted of a maraging steel nozzle shell and type 3003 aluminum exit cone structural components with flame liners. The nozzle shell had an entrance cap (welded gore sections) plus three forgings all welded together using the down-hand GTWA welding process to form the convergent-divergent nozzle shell. The nozzle shell was finished machined (bolt holes drilled, etc.) after the welded assembly was heat-treated at 900°F for 8 hours. The entrance throat and the flame liners were bonded internally to the nozzle shell. The exit cone external support system was machined from a single type 3003 aluminum forging. The exit cone flame liner was bonded internally to this support structure. All of the flame liners were tape wrapped using impregnated silica and/or carbon tape, which was autoclaved cured to achieve the required density and properties. Tape wrap angles were selected to optimize erosion resistance and minimize ply lifting during firing.

Structural Proof Testing

The chamber and nozzle were hydrostatic proof tested to a pressure of 737 psig (measured at the highest point) for purposes of verifying their structural integrity. The forward skirt was loaded concurrent with the pressure load.

The chamber was placed vertically, with the aft end up, in a special test stand, see Figure 7. The nozzle was then secured to the chamber using two hundred and twenty 1 1/4 in. bolts each torqued to 800ft-lbs. A floating piston was attached to the top of the nozzle. Four structural columns connected the base of the stand to a top platen for purposes of reacting the piston load back into the forward skirt. Corrugated siding for weather protection enclosed the structure. A steel mesh blanket was hung from the outside periphery of the top platen for energy absorption in the event of a failure. Energy at proof pressure was estimated to be equivalent to 15 pounds of TNT.

Approximately 125 channels of strain and 28 channels of acceleration were continuously recorded during the test with the most critical strains monitored directly. The location of the strain gages was based on stress analyses and the chamber manufacturing history (e.g. thin spots, weld porosity). Accelerometers were used to detect any flaw growth, and if a failure occurred to triangulate to the failure origin.[†] In the event of a warning signal, either strain or accelerometer, the test was to be terminated and the anomaly investigated.

Water containing a small percentage of sodium dichromate for corrosion protection was used as the pressurization medium.

Both chambers successfully passed proof pressure tests conducted at Sun Ship. One of the chambers was

[†]Dual contracts were awarded for the 260 program. The first chamber from the other contractor failed during hydrotest. That contract was subsequently terminated. Cause of that failure was a flaw growth from a weld defect produced during submerged arc welding of the chamber. NASA contracted with Aerojet to install accelerometers on that chamber for information only purposes. Triangulation of that data was successful in locating the origin of failure.

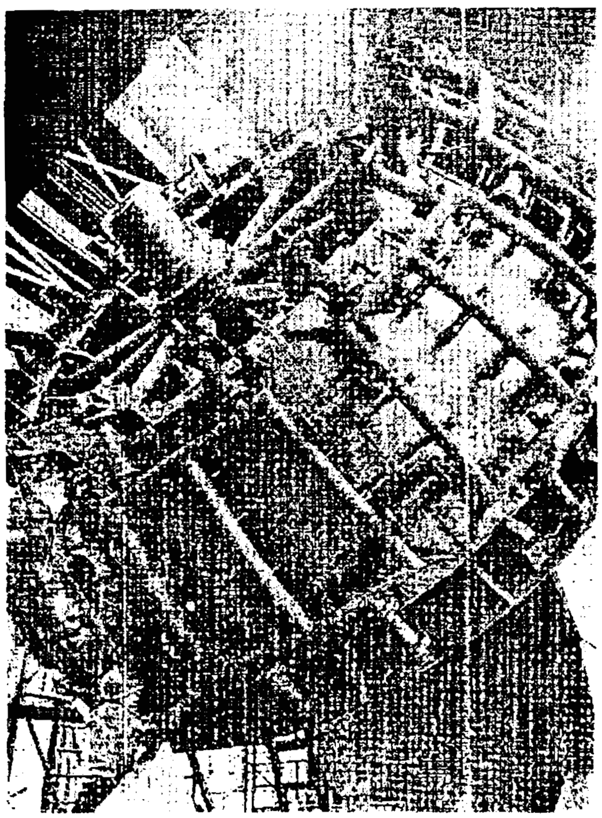

Figure 6. 260 Chamber Welding Head Gore Positioner

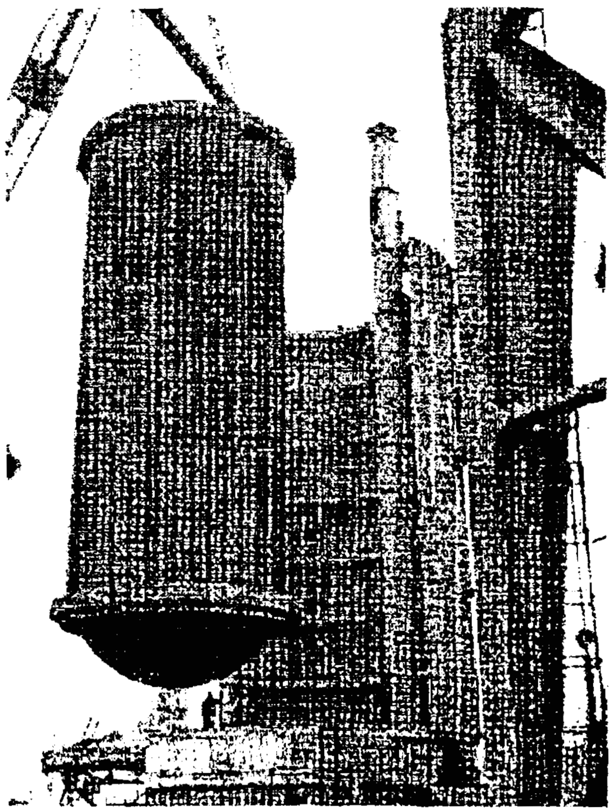

Figure 7. 260 Chamber Being Loaded Into Structural Proof Test Fixture

reused for the 260 SL-3 static firing. This chamber was hydrostatic tested at Dade County Florida in a slightly different manner. It was placed in the underground silo and the nozzle capped.

Transportation to Cast Site

Following hydrotest the chambers were painted and then placed on a barge, Figure 8, for transport down the inter coastal waterway to Florida. The transport for the final few miles from where the waterway ended was by truck and trailer. During the transport of the second chamber the barge encountered a hurricane and was beached. Fortunately the chamber support was designed to take out torsional loads and the chamber was undamaged.

Figure 8. 260 Chamber Being Transported to Aerojet's Florida Rocket Facility

The Florida Dade County Facility

In anticipation of the 260 program and future booster contracts Aerojet acquired a site south of Miami and adjacent to the everglades. This site (approximately 74,000 acres) was about 250 miles south of Cape Canaveral, and both were accessible by barges. In parallel with designing the motor, work began on the huge facilities required for the motor and propellant production, static test firings, and supporting activities. The overall concept was that the chamber would be insulated in the horizontal attitude and then lowered nose first into a below ground silo, illustrated in Figure 9, with the nozzle at ground level. Propellant casting and cure, core removal, nozzle assembly and test firing was done in this vertical nozzle up position in the underground silo. This silo was constructed to accommodate a full-length motor. There was a great deal of concern about the silo becoming flooded since the ground level was essentially sea level. The 150-ft. depth proved to be no problem for a competent caisson contractor.

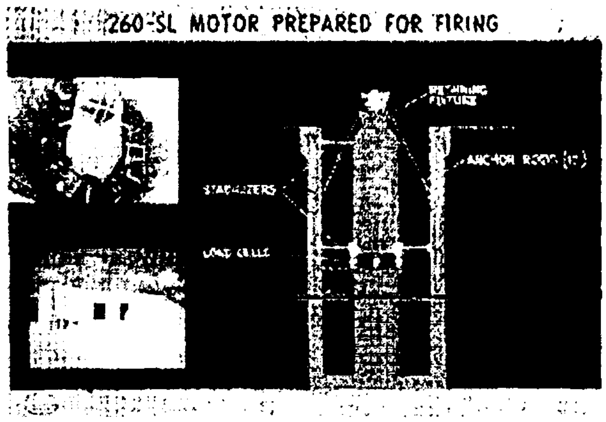

Figure 9. 260 Motor Cast Configuration

Other facilities included a general processing building, a quality control laboratory, a fuel preparation building, an oxidizer preparation building, a qualification motor building, continuous mix building, two vertical batch mix stations and a remote control house to support static testing.

Constructing roads throughout the plant required fill dirt, and the most convenient place to obtain this was adjacent to the road. Consequently there was a series of "canals" next to most roads. Some of the best bass fishing in Florida were at these "canals". However, bass were not the only inhabitants, and it came to pass that alligator crossing signs were required along certain stretches of the roadway.

An office building for the permanent staff was located in Homestead approximately 12 miles away.

Insulating the Chamber

V-44, an asbestos and silica filled nitrile rubber, was used to thermally insulate the chamber cylindrical and dome walls. Sheets of the insulation were bonded to the chamber interior using a room temperature curing bonding system. This was done in a series of steps with the chamber in the horizontal position. In the case of the domes the sheets of insulation were cut to form gore sections. V-45 silica filled nitrile rubber boots (also called flaps) were installed in the forward and aft ends in the area of the equators.

Propellant

Propellant and liner formulation and process development work conducted at the Sacramento facility led to the selection of an 86% solid PBAN propellant for the motor. Extensive processing and cured propellant testing was conducted on propellant from small and pilot scale batches and then full scale batches. Tests included pot life, viscosity, cure, chemical and physical properties of cured and uncured propellant, ballistics, mechanical and bond properties. Comprehensive mechanical and propellant-liner bond tests were performed to determine allowable properties and full scale motor structural margins. Many of the tests were repeated on the propellant produced at Dade County.

The size of the 260 in. dia motor and the processes selected for producing the motor imposed a number of unique requirements, some of which were time related on the propellant and liner bonding system. Among those requirements were: long propellant liner bonding life, low propellant viscosity, long propellant pot life and steady state cure of the propellant.

For the 260 SL motor a liner substrate was required to bond the propellant grain to the rubber thermal insulator. A liner bonding life‡ of several months was essential for the motor process. Typical liner bonding lives are in the order of days. The PBAN/epoxy developed for the motor satisfied all of the processes as well as all bond strength requirements.

The motor was cast using a bayonet cast process which involved forcing the propellant down a 6 in. dia hose from the cast pot into the motor. This process required a propellant having both a low viscosity and a long pot life.

Many solid propellants never reach a steady state-of-cure. When held at the cure temperature, they increase in modulus with an attendant decrease in elongation and strain bearing capability. Such behavior is highly undesirable for a large motor which requires 2-3 weeks to cast, since it would cause significant mechanical property gradients in the propellant grain. The 260 SL-1 and –2 propellant reached a steady state-of-cure after three weeks thus minimizing such gradients.

Casting

The Dade County mix facilities consisted of two 600-gal. Day vertical mixers and an UK-200 continuous mixer. All mixers were used in loading the 260 in. dia motors.

Propellant reproducibility and predictability were essential to a successful motor firing. These objectives were met by utilizing single propellant raw material lots (or master blends) for each of the motors and by conducting lot standardization tests with each new lot by testing the propellant produced in production mixes prior to each motor cast. Laboratory acceptance testing was performed on all raw materials before use and on all process intermediates and uncured propellant before casting. Mechanical property tests were performed on each batch after cure, and ballistic test motors were fired.

To prepare for cast after chamber placement in the underground silo, core tooling was installed, the roller mounted cast building moved over the silo, cast tooling set up and motor preheated to the cure temperature. When the loaded propellant pots arrived from the mix stations they were hoisted to one of three cast stands. 6-in. dia hoses, or bayonets, were attached to each pot and the propellant was forced down the hoses. The hoses were shortened as the propellant level rose. Two to three weeks were required to complete the casting process. The grain was then cured for approximately three weeks. The propellant grain as viewed from the top is shown in Figure 10.

After cure the motor was cooled to ambient temperature, the cast building moved and the core stripped. The bore of the grain was then visually inspected for defects; no significant ones were found for 260 SL-1 and –2 but were found for 260 SL-3.

A concern early in the program was whether during core stripping the propellant grain lobes would slump, thus binding against the core and making its removal difficult. Laboratory slump tests were not conclusive. A take-apart core was designed to avoid this possible problem. The core was easily removed in one piece so that this precaution was not needed.

Ignition System

A non-conventional ignition system was employed for the 260 demonstration firings and consisted of placing a 30 in. dia rocket motor in the nozzle of the 260. The 30 in. dia motor was attached to a sled, which in turn was mounted to a track so that when the igniter motor fired its thrust carried it and the sled up the track, and away from the 260 motor. Two long 2 ½ in cables, attached to the sled and secured to the ground, forced the sled/motor into a circular orbit once the sled/motor cleared the track. The igniter motor provided penetration of gases to approximately 70% of the motor bore length.

260 SL-1 and SL-2 Static Firings

The first and second static test firings were conducted on September 25, 1965 and February 23, 1966 (at night)

‡Liner bonding life is defined as the time interval between cure of the liner to contact with the propellant in the motor.

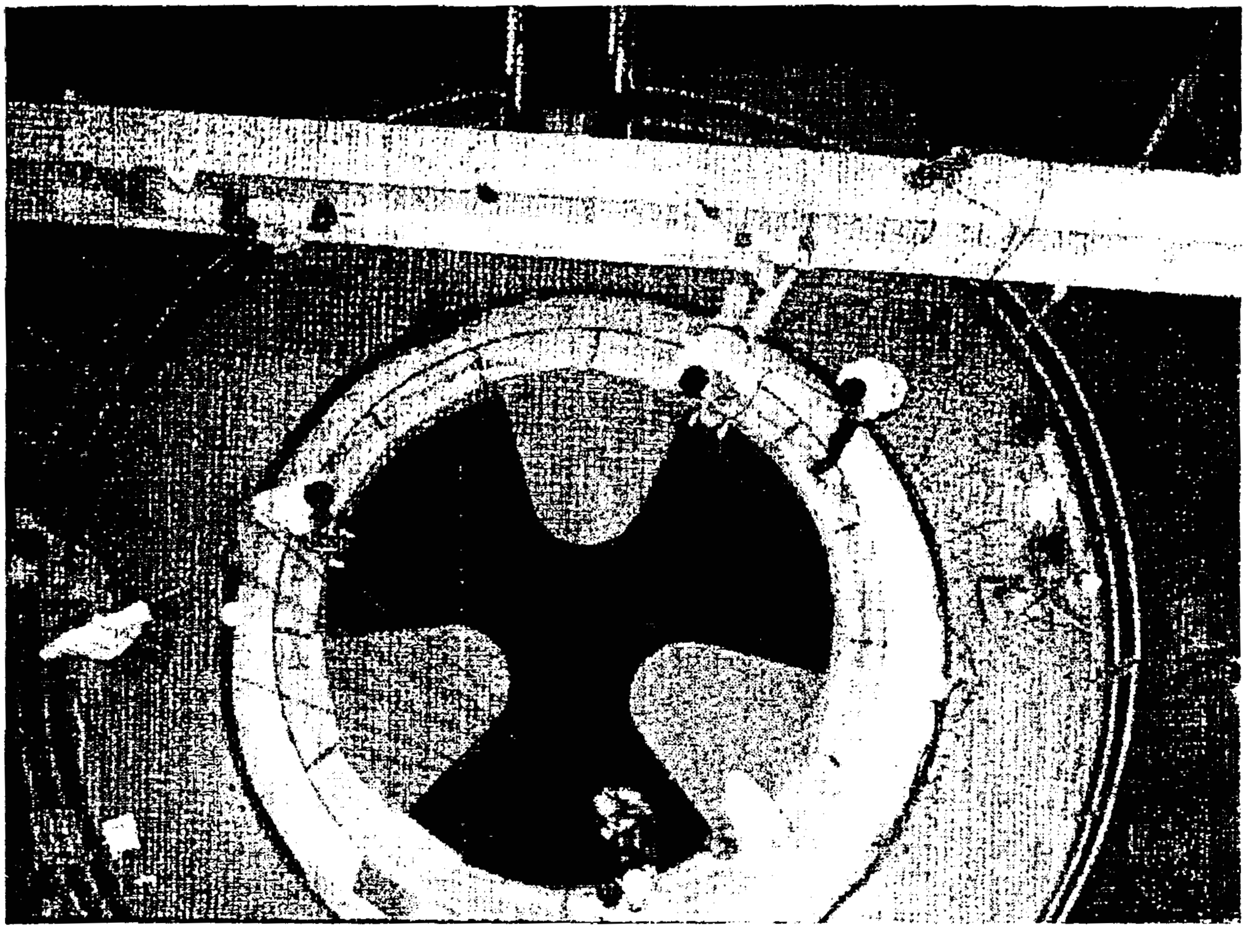

Figure 10. Top View of 260 Motor Grain Configuration

and were totally successful. Performance was nearly identical for the two firings with the maximum thrust and total impulse being 3.6 million pounds force and 375,000,000 pound seconds respectively. The thrust time curve is shown in Figure 11. Figure 12 shows the firing of 260 SL-1. As noted previously the propellant burning rate and nozzle sizing was similar to that which would be used in the full-length configuration.

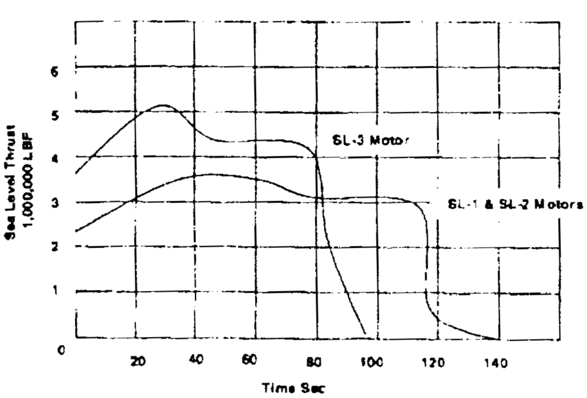

Figure 11. 260 SL Hot Fire Test Results

260 SL-3 Static Firing

NASA contracted with Aerojet for a third 260 static firing with the primary objectives of:

- Testing a large ablative nozzle using a submerged nozzle configuration similar to that proposed for use with thrust vector control systems
- Demonstrating a PBAN propellant formulation with an increased burn rate from 0.45 to 0.72 in/sec to duplicate full-length mass flow rates

The 260 SL-1 chamber was rehabilitated (including proof test) for the SL-3 firing.

The 260 SL-3 motor fired on June 17, 1967. A maximum thrust in excess of 5 million pounds thrust was achieved. However the test was not a total success in that chunks of propellant were ejected which caused the loss of the exit cone in the latter portion of the firing. Based on observations during casting and bore surface anomalies after core stripping, it was concluded that the

Figure 12. 260 SL-12 Hot Fire Motor Test

flow characteristics of the new propellant were not compatible with the casting process. Under a subsequent NASA program studies were conducted to develop a better understanding of propellant flow behavior during casting and to establish flow acceptance criteria. Flow behavior and defects like those observed in 260 SL-3 were demonstrated in a 60,000-lb casting of a mold designed as a 120 degree segment of the 260 motor. A similar sized mold which was essentially defect free was cast with an improved propellant (an HTPB formulation that met the 260 SL-3 burning rate requirement) and the newly established viscosity criteria. These criteria have become the base for an industry standard.

Three Work Sites

One of the challenges identified early in the program was that of doing the engineering and management of the program on the west coast a long distance from the two east coast sites where the physical work was being performed. As it turned out the problems associated with this concern were minimal. This was due primarily to the "skunk works" approach taken at Aerojet Sacramento and the competency and dedication of Sun Ship and Dade county plant personnel.

In Sacramento, Aerojet had a handful of engineers which performed most of the design and analyses as well as coordinating with Sun Ship and with the Dade county personnel. Aerojet had only 5 or 6 permanent representatives at Sun Ship. However weld engineers, metallurgists, chamber designers, etc were shuttled into Sun Ship on as required basis. A team of instrumentation technicians and test engineers spent 6 weeks per hydrotest at Sun Ship.

Dade County was staffed with about 45 permanent people. However during motor casting the plant population would increase to over 200 people in that it was a 3 shift, 7 days a week operation. Most of the additional work force was hired from the Miami area for a 3-4 week period and were given specific duties and accelerated training. The Aerojet Sacramento engineers and chemists were flown in for the motor casting and acted as supervisors, quality inspectors and MRB and ERB members.

Conclusion

In the late '60s, the 260 program was cancelled because there was no specific mission. Some of the technology developed on the program was later used on the Space Shuttle. The program put Aerojet in the lead for the highly coveted Space Shuttle booster contract. However, Aerojet championed a monolithic vs. segmented rocket motor design philosophy which produced a major misinterpretation by Aerojet of the
1 proposal requirements. This issue was believ[illegible]
2 a separation between the highly successful [illegible]
3 Aerojet team and was partially responsible in Aerojet [illegible] being selected for the Space Shuttle Solid Rocket Booster contract. The rest is space history.

1 "...was believed to cause"
2 "...successful NASA and"
3 "... in Aerojet not"