READINESS REPORT: AEROSPACE / HYDROSPACE

"Could it be done?" There were scores of doubting Thomases when a solid-propellent rocket with a thrust equal to today's largest liquid-fueled rockets was first proposed. The biggest stumbling block was the fabrication of a case large enough from a metal strong enough. It's history now: The job is done. Two cases were built by Sun Ship and successfully test fired. This report tells you about the company that is ready now . . . as it was then . . . to handle the "never before" projects.

Why Sun Shipbuilding is prepared to help you cope with the big challenges of Aerospace and Hydrospace

As men began, probing the frontiers of aerospace, and later hydrospace, Sun Ship recognized its capabilities for building rocket cases, deep submersibles, and other large, precision structures that required high reliability. A half century of shipbuilding experience had provided excellent background.

But Sun also realized that these new fields presented several distinct challenges that required different approaches from its shipbuilding and manufacturing activities:

- A majority of assignments would involve first-of-a-kind structures with unprecedented performance specifications.
- Many projects would demand the development of new alloys or the use of existing metals in entirely new roles.
- Closer tolerances and new materials would require new fabricating techniques.
- Often, the design of new tooling would call for the same kind of resourcefulness that went into the design of the proposed vehicle or structure itself.
- Fabricating new metals in thicknesses never before joined would require basic advances in the state of the welding art.

To meet these special requirements, Sun Ship established its Aero/Hydro Space Division. It is a separate entity with its own administrative, engineering, and metallurgical staffs, as well as its own manufacturing facilities. It is geared up to approach new, unique, and challenging projects as they should be approached—step-by-step, without reliance on pat answers and traditional procedures.

What the Aero/Hydro Space Division can do is best shown by what it has already done. When the challenges of the aerospace and hydrospace frontiers came along, Sun Ship was ready. . . .

. . . Ready to Encase the World's Largest Solid-Propellent Rocket

A few years ago, 18% nickel maraging steel was a laboratory curiosity. It showed promise as a material that could withstand the high pressures of a rocket-motor inferno—or of the ocean depths — in thicknesses light enough to allow for a substantial payload. Its tensile strength range was 200,000 to 300,000 psi—five times stronger than the advanced metals used in aircraft construction.

But no large structure had ever been built from the material.

Sun Ship launched a company-funded study of the properties and workability of 18% nickel maraging steel. Sun engineers tested its strength, fracture toughness, response to cold working, aging effects, corrosion resistance, and other properties. After evaluating many specimens, they developed promising welding, machining, and heat-treating techniques.

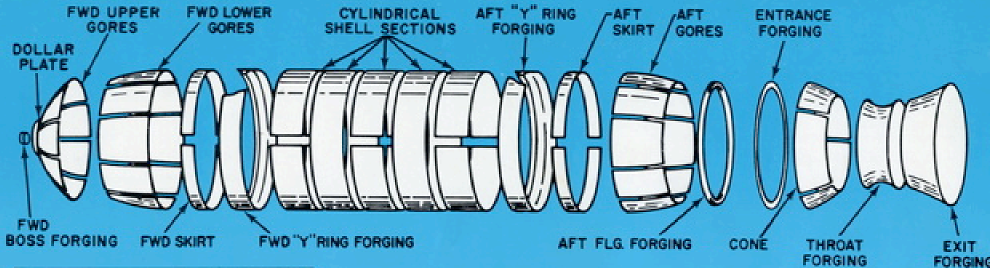
And when Aerojet-General Corporation sought a material—and a builder—for the largest solid-propellent rocket ever designed, Sun Ship was ready . . .

PROJECT:

260″ SOLID-PROPELLENT ROCKET MOTORS

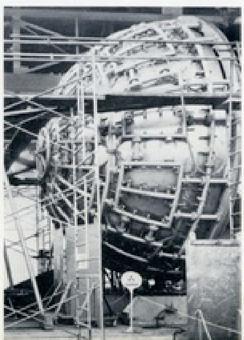
Aerojet-General Corporation won a USAF/NASA contract to build two giant solid-propellent rocket motors, the largest ever attempted. Each measured 260″ in diameter x 60 feet long, and weighed 70 tons. The motors were crucial to the future of large solid-propellent boosters in the nation's space program. Though solid propulsion had been thoroughly proven in the smaller Minuteman and Polaris missiles, many engineers were not convinced that the technology could be expanded to the giant boosters.

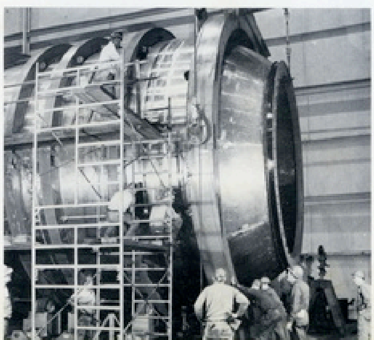
Fabricating the huge cases and nozzles called for a company who could machine, weld, and handle huge structures . . . with the precision required in making a fine watch. Aerojet selected Sun Ship.



MATERIAL
18% NICKEL MARAGING STEEL
PRINCIPAL THICKNESSES

FORWARD HEAD	.400"
CYLINDER	.600"
AFT HEAD	.600"
NOZZLE SHELL	.750"-1.00"





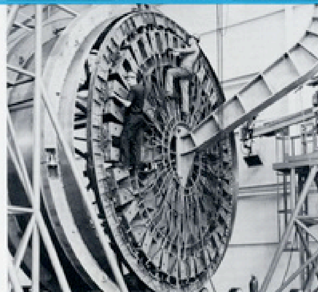
PROBLEM:

Select a material to contain the pressure created by 1.6 million pounds of solid propellent burning at 6000°F.

SUN SHIP'S SOLUTION:

Sun Ship's research with 18% nickel maraging steel had shown that the metal was equal to the job. Working with Aerojet-General and the steel producers, Sun engineers developed a modified chemistry that produced a tensile strength in the 200,000 psi range, and gave increased toughness. Sun shops then built and hydroburst-tested two 36" scale-model cases. Evaluation of test results confirmed the material choice.

Weld five 260" diameter shell sections together to form the complete rocket case—maintaining tolerances more often associated with small-scale precision manufacturing operations.



A specially built hydraulic expansion fixture applied uniform pressure along each 68-foot weld seam to maintain roundness and control weld shrinkage. The same fixture also supplied the gas atmosphere for the tungsten-inert-gas welding procedure.

Specified roundness requirements of ±0.060" were maintained or bettered in the finished 260" diameter case; misalignment of cylinders was held within an average of 0.008".

Heat-treat the welded case in one piece—holding a 900°F. temperature for eight hours—to develop the full tensile strength of the maraging steel.

Sun built a giant maraging furnace twelve stories high, sectionalized into 14-foot high rings so its size could be varied to treat different structures. (The rocket nozzle, for example, required only two sections, while the motor case used the entire height.) Control circuits held the maraging temperature of the motor case within the required 30°F. range.

PROBLEM:

Match-machine the aft nozzle flange on the case to mate with a corresponding flange on the nozzle—a critical step in the rocket motor assembly.

SUN SHIP'S SOLUTION:

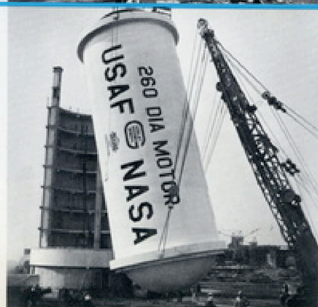
Sun Ship engineers adapted the stand that would later hydrotest the rocket as a giant lathe for the nozzle-flange machining. They built a milling head atop the stand, twelve stories above the ground. This tool was used to finish the 180" diameter flange to an accuracy of ±0.007".

Simulate the stresses encountered in flight by subjecting the finished motor case to both internal pressure and thrust loading.

A giant hydrotest stand was erected with a huge piston at its top which fit into the nozzle. The stand subjected the case to an internal pressure of 738 psig . . . exceeding the pressure of actual firing . . . and simultaneously imposed thrust loadings of more than six million pounds.

Before the case successfully passed this final test, ultrasonic, x-ray, dye penetrant and magnetic particle inspections had already certified weld soundness.

Handle and deliver the finished 70-ton cases to Aerojet's test facility south of Miami, Florida.



Giant cranes moved the completed case from shop to maraging furnace . . . then inverted it into the hydrotest stand . . . and finally moved it to a pier for shipment.

Sun Ship's waterfront location on the Delaware River in the Port of Philadelphia simplified delivery. The cases were loaded on barges right at the plant and shipped via the Intercoastal Waterway—eliminating the many problems of land shipment such as bridges, tunnels and road clearances.

RESULT:

At Aerojet's test facility in Florida, the largest solid-propellent rocket ever built delivered 3½ million pounds of thrust in 126 seconds of flawless test firing. An equally successful firing of the second motor confirmed that large solid-propellent rockets were not only mechanically simple, but also eminently practical. Both cases came through static firing completely undamaged. The first case has now been successfully hydrotested for the second time . . . a key step toward further development on large solid-propellent rocket motors.

Successful construction, testing, and firing of the 260″ rocket motors also proved something more: Sun's ability to adapt and extend its knowledge of giant fabrications to meet the challenges of the aerospace frontier.

Building the 260″ rocket motors developed Sun Ship's capability in maraging steel fabrication still further.
And Sun was ready to apply the metal's unique properties to the conquest of today's other frontier . . . hydrospace. . . .

PROJECT:

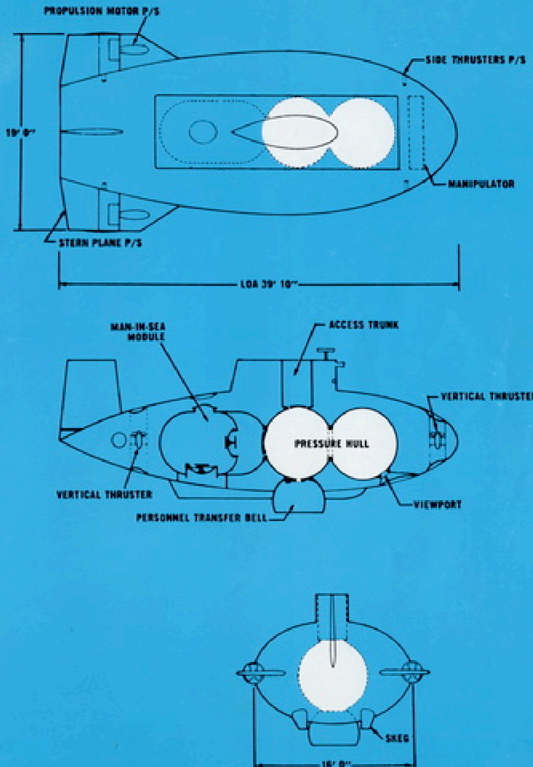
"DEEP QUEST" MANNED SUBMERSIBLE

In a privately funded effort to develop its undersea capability, Lockheed Missiles & Space Co. conceived the "Deep Quest" manned submersible vehicle. Carrying a four-man crew, the submersible is designed to descend to 6000-foot depths and maneuver for 24 hours at speeds up to 4 knots.

In addition to its crew, Deep Quest can carry two divers or a 7000-pound instrument payload. Standard equipment includes external TV cameras, sonar, remotely controlled manipulators, and a viewport. Lockheed plans the vehicle as a test platform for undersea sensors, instruments, and communications equipment, as well as a training craft for undersea rescue and exploration.

A critical part of the program is the bisphere pressure hull that holds the crew. The two 7-foot diameter spheres that form this hull provide maximum usable space with lowest total weight. But they must be precisely joined so that the potential of the high strength material and light weight design may be fully realized. The final design climaxed months of detailed analysis by Lockheed. Transforming it into a practical structure would require equal care.

To build the bisphere, Lockheed selected Sun.



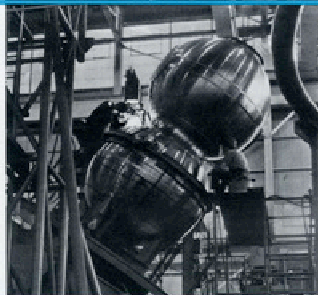
PROBLEM:

Find a metal that could withstand the pressure of 12,000-foot depths (allowing a substantial safety factor over the designed 6000-foot operating depth) yet was light enough to allow for a sizeable payload in the submersible.

SUN SHIP'S SOLUTION:

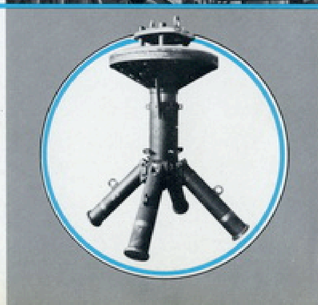
Drawing on their experience with 18% nickel maraging steel, Sun Ship engineers worked with Lockheed to modify the chemistry of the metal into a 175,000-psi formulation with the toughness needed for the bisphere. They tested their ideas by fabricating a ⅛-size model of the bisphere. The model successfully withstood the pressure of 12,000-foot depths and endured pressure cycling over 10,000 times.

Fabricate four hot-spun hemispheres and a "Y" connecting ring into the bisphere, maintaining near-perfect roundness over the two 7-foot diameter spheres. Exact control of the hull geometry was vital to realizing the full potential of the bisphere design.



Sphere seams were tungsten-inert-gas welded entirely from the outside, with argon gas backup on the inside. Extra metal was left on the spheres in the seam area, and machined off after welding. This procedure eliminated weld distortion and produced finished spheres within ±0.015" of round over their 84" I.D. Weld strength matched base-plate strength. All welding and machining operations were done without handling attachments to the spheres, to prevent scars that might later weaken the structure.

Weld several forged fittings—like hatches, viewports, and electrical connectors—into the spheres without distorting their near-perfect sphericity.



Sun Ship engineers developed a special hydraulic expansion fixture that fit inside the spheres and exerted forces as high as 85 tons on weldment areas. The force created a plastic stress in the first weld bead, preventing distortion and controlling weld sinkage.

RESULT:

On May 6, 1966, the bisphere pressure hull successfully withstood testing at 8500-foot depths . . . 2500 feet more than its designed operating depth of 6000 feet.

Sun's success in meeting the specified geometric tolerances was a contributing factor in Lockheed Missiles & Space Company's uprating of the operating depth of the Deep Quest vehicle to 8000 feet.

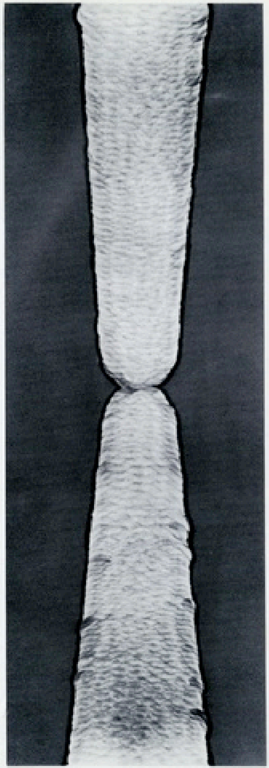
The pressure hull was then shipped to Lockheed's Sunnyvale facility for installation into the aluminum outer hull. Early in 1967, Deep Quest will be launched into the waters of the Pacific at Lockheed's San Diego Marine Terminal to begin its mission of developing new techniques for exploiting the ocean's depths.

...Ready to Bring the Sea into the Lab

HY-100, another advanced high-strength alloy, was a strong contender for the walls of ultra-high-pressure vessels. But the metal had never been welded in the extreme thicknesses required—up to 16". Sun Ship engineers developed special butt-welding techniques and groove configurations for the thick sections.

At the same time, they adapted metallic-inert-gas techniques for coating the base metal with monel and nickel weld overlays. The result was a metal combination that could contain high pressures and resist sea-water corrosion.

And when the Navy needed pressure chambers to simulate conditions 26,000 feet beneath the sea, Sun Ship was ready . . .



Cross section of butt weld in 16" HY-100 test section.

PROJECT:

DEEP SUBMERGENCE TEST CHAMBERS

The U. S. Navy Marine Engineering Laboratory is constructing a new Ocean Pressure Laboratory that will provide complete facilities for developing and testing undersea equipment. Key components of the laboratory are the deep submergence test chambers. These giant pressure vessels will be filled with high-pressure sea water to simulate conditions in the deepest parts of the ocean. They will give scientists a powerful new tool for testing propulsion machinery, pressure hulls, control techniques, life-support systems, and instrumentation in a realistic deep-sea environment.

The large and medium chambers can be statically pressurized to 12,000 psi, and pressure-cycled from 0 to 4000 psi at 1-minute intervals for fatigue studies. They will be equipped with a 500-channel digital data acquisition system and closed-circuit TV camera for continuous monitoring of the equipment under test.

To build the complex chambers to their exacting design, the Marine Engineering Laboratory selected Sun Ship . . .

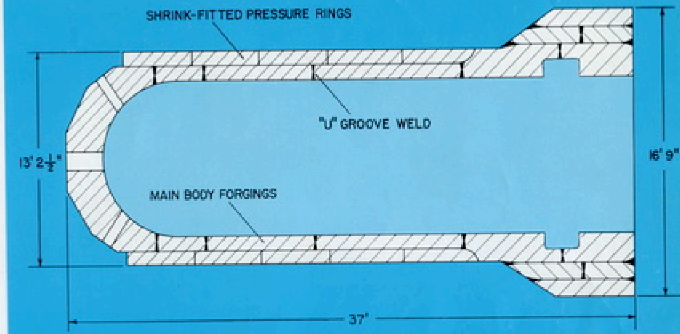
The larger of the two chambers being built by Sun will measure 37 feet long and 10 feet inside diameter, and will weigh 750 tons. Individual subassemblies, later to be combined into the finished chamber, will weigh as much as 150 tons.

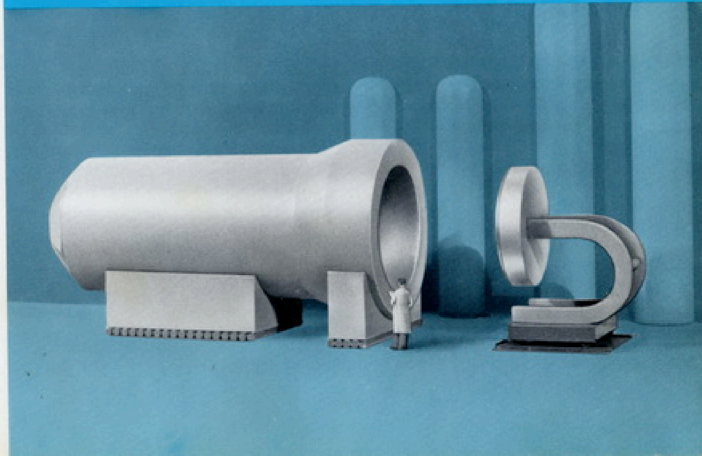
The chamber will be built by welding together nine individual forgings by the submerged arc process to form the body. Special "U" welding grooves will be used to insure perfect welds in material up to 16" thick. The body will then be surrounded with five shrink-fitted pressure rings.

After fabrication, the chamber will be fully lined with a layer of nickel overlayed with two layers of monel, all applied by metallic-inert-gas welding. The interior of the chamber will be finish-machined after completion of the overlays. Complicating construction is the fact that three machinery nozzles, two piping nozzles, and four instrumentation nozzles must be bored through some of the thickest parts of the chamber wall.

The smaller chamber will be similar in construction. It will measure 12 feet long and 4 feet inside diameter, and will weigh 80 tons.

Sun's experience in handling heavy structures, and their waterfront location, will prove invaluable in assembling—and finally transporting—the massive chambers.





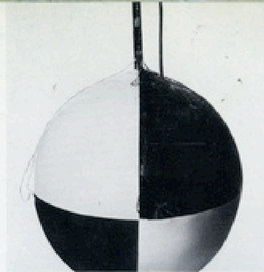
. . . Ready to Put an Escape Hatch Beneath the Sea

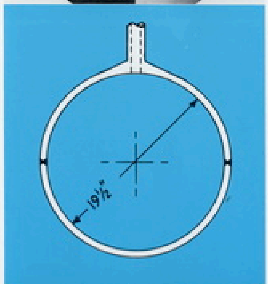
In 1965, Sun Ship built a small metal sphere by hot-pressing, austenitizing, quenching and tempering, and welding together two 19½" diameter hemispheres. Then the sphere was hydraulically pressurized until it burst at 15,800 psi.

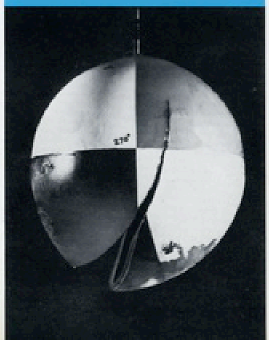
The project represented a major step toward the development of an undersea rescue capability to match man's undersea exploration capability. The sphere — built on Sun's own initiative — was the first structure ever made from HY-140 high-strength steel. And the burst test proved that special tungsten-inert-gas welding techniques could produce a seam whose strength equalled the strength of the metal itself.

The successful burst test climaxed months of research into the properties and practicality of HY-140 steel. Sun Ship engineers evaluated strength, toughness, fatigue effects, formability, machinability, and weldability. They demonstrated that the high strength-to-weight ratio of HY-140 could be utilized to increase the payload capacity of deep submersible vessels.

And when Lockheed Missiles & Space Company needed a complex three-sphere pressure hull for the U. S. Navy's first deep-sea rescue vehicle, Sun Ship was ready . . .







PROJECT:

DEEP SUBMERGENCE RESCUE VEHICLE

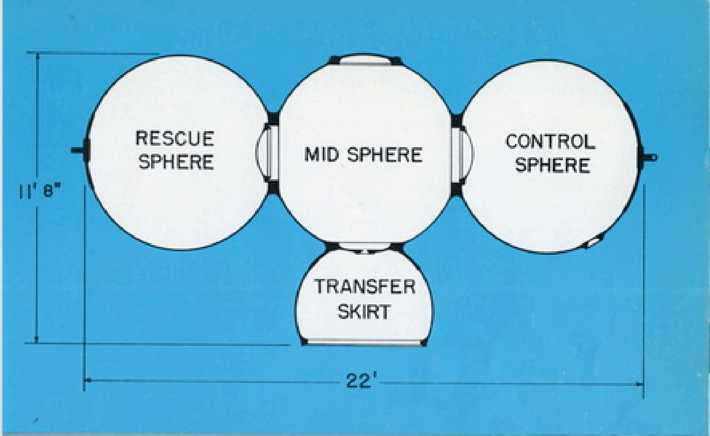
After their success with the privately funded Deep Quest submersible, Lockheed Missiles & Space Co. won the contract for the first vehicle in the U. S. Navy's Deep Submergence Systems Project. This was DSRV—the Deep Submergence Rescue Vehicle.

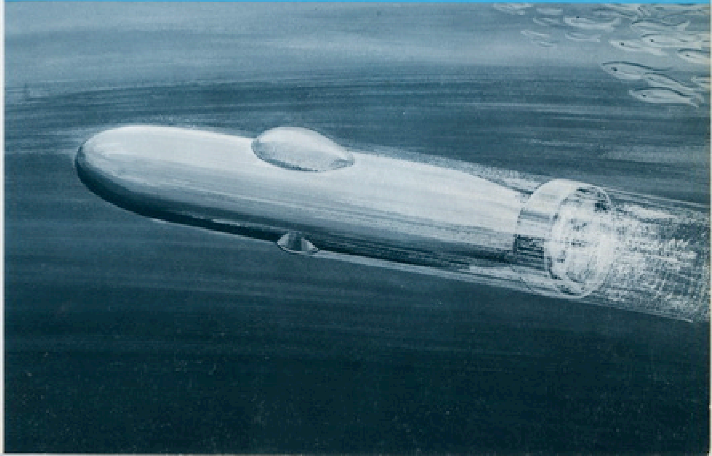
DSRV will provide the Navy with a fast-reaction undersea rescue capability anywhere in the world. It will be light and compact enough to be air-transported to a submarine emergency within 24 hours. Yet it will be capable of operating at 3500-foot depths for as long as twelve hours. It will carry a crew of three, and have capacity to remove 24 survivors at a time from a stricken submarine.

The pressure hull for DSRV will consist of three identical, inter-connected spheres, each 90" in diameter. A forward sphere will house crew and controls. An identical aft sphere will house survivors. A third "passage" sphere will connect the two.

Lockheed will need two such hulls—one for the prototype DSRV, and one for testing. The hulls will be built of HY-140 steel to provide high strength with light weight.

To build them, Lockheed selected Sun. Construction is now underway . . . Sun Ship's latest answer to the challenges of hydrospace.





. . . Ready to House a Twentieth-Century Titan

Another untried material studied by Sun Ship engineers was HP 9-4-25 steel. The metal exhibited yield strengths up to 190,000 psi. Standard tungsten-inert-gas welding procedures, however, often produced porous welds. Another difficulty was the tendency of the metal to harden in the weld area. Special welding and retempering processes eliminated these drawbacks.

As interest in this new material developed Sun Ship was ready . . .

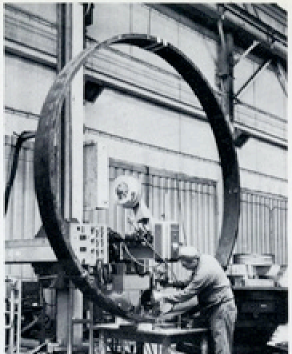
PROJECT:

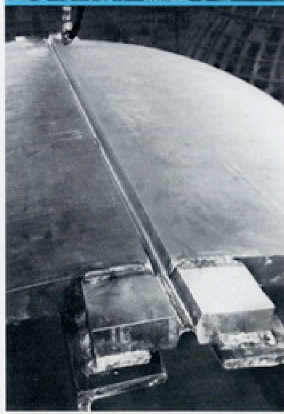
EXPERIMENTAL TITAN III MISSILE CASE

As part of the Air Force Materials Laboratory R & D program on the Titan III missile, United Technology Center of Sunnyvale, California had to build a 122" diameter, 5'-10" long rocket case preform from HP9-4-25 steel.

Plans called for first rolling a cylinder, then welding together the longitudinal seam. After welding, this cylindrical preform would be shear-formed into a longer cylinder with one-fifth its original wall thickness. The seam weld would virtually disappear in the process. This meant that the weld had to have full penetration, be free of porosity, and exhibit the same tensile strength and hardness as the base metal.

On the basis of Sun Ship's research on welding HP9-4-25, UTC selected Sun to weld the crucial seam.





PROBLEM:

Prove that HP 9-4-25 steel can be successfully welded in the thicknesses required for the Titan case.

SUN SHIP'S SOLUTION:

Working with the procedures developed by R&D, Sun Ship welders test-welded 1" thick qualification plates of HP 9-4-25 that were accepted by UTC before the contract proceeded. To further prove the technique, they built and welded a scale-model ring.

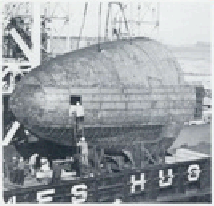
PROBLEM:

Weld the 120" diameter rolled-plate cylinder into the completed case segment, achieving full weld strength and hardness with no porosity.

SUN SHIP'S SOLUTION:

A special Sun Ship procedure that gave full weld penetration of the 1⅜" material without back grinding produced a smooth, non-porous weld that retained the full tensile strength of the steel. The weld and heat-affected area around it both exhibited the same hardness as the parent metal.

Ready to solve many Aerospace/Hydrospace problems...

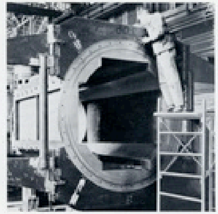


Bow section of a Polaris submarine built by Sun Ship for Portsmouth Naval Shipyard. This unit includes both the pressure hull and the outer hull and weighs 115 tons. The forward end of the pressure hull is a fabricated segmented head.

Four other pressure hull sections were also built using special techniques and fixtures developed by Sun to insure high-quality welds. The HY-80 hulls were 1½" thick and 22 feet in diameter. All sections were shipped by barge to Portsmouth.

Cylindrical test chamber will become part of "Launch Phase Simulator" at Goddard Space Flight Center. Actually a giant centrifuge, simulator can subject full-size satellites to accelerations up to 23 G's, as well as random vibration and acoustical shock. Besides withstanding these stresses, chamber must hold vacuum of 3×10^{-1} torr, used to simulate 200,000-foot altitude.

Built of A441 structural steel, chamber measures 154" outside diameter by 28 feet long, and was vacuum leak-tested with a mass spectrometer before delivery.



Sun Ship helped to design, fabricated, and supervised erection of two alloy steel tubes for the helium-blowdown jet wind tunnel at Langley AFB.

The shorter tube, 152 feet long and tapering from 100" to 4" in diameter, will provide gas flows up to Mach 10. The longer tube, 156 feet long and tapering from 84" to 2", will provide flows as high as Mach 20. Both will be used to simulate re-entry conditions for testing of nose cones and similar structures. Nozzle jets and chambers are 17-4 PH stainless steel.

Conical shock tube for Naval Weapons Test Laboratory, Dahlgren, West Virginia will simulate effect of 20-kiloton nuclear blasts. Four 16" naval guns coupled in series form small end of tube, which enlarges to 24-foot I.D. at open end. Overall length is 2447 feet.

Sun Ship's prime contract includes site preparation, utility installation, and railroad spur construction as well as fabrication of the tube itself. Metal composition and thickness varies throughout length to suit pressures encountered: Small end is HY-80 steel 1½" thick, while large end is ⅜" carbon steel. Tube was fabricated in 27 sub-sections at Sun's plant and barge-shipped to site.

Ready for your next project . . .

As you've seen in these pages, the goal of Sun Ship research is to keep ahead of your needs in aerospace/hydrospace. Studies of new materials, new welding techniques, and new fabrication methods continue. For example, Sun Ship engineers are currently evaluating alloys such as 8-1-1 and 6-4 titanium in thicknesses suitable for the next generation of deep submersibles because of their high strength-to-weight ratio.

But research is only part of the story. The tools to turn your advanced designs into practical structures are the other part. At Sun Ship they include:

- an Aero/Hydro Space Division established specifically to meet your new challenges with new approaches
- a manufacturing complex of 200 acres in the Port of Philadelphia
- an organization of 5000 skilled craftsmen and engineers
- a total of fifty years' experience in on-time, on-spec fabrication of large precision structures

Sun Ship engineers are applying this background in the exploration of both aerospace and hydrospace; in offshore petroleum recovery and undersea mineral mining; in deep sea salvage and rescue missions; and in missile components and support.

Sun's research with new metals and manufacturing methods may already hold the technology required for your next project. When your needs for large, precision structures push metallurgical and manufacturing technology into uncharted areas . . . Sun Ship can help bring your project off the drawing board into reality.

Your big challenges will meet big thinking at Sun.

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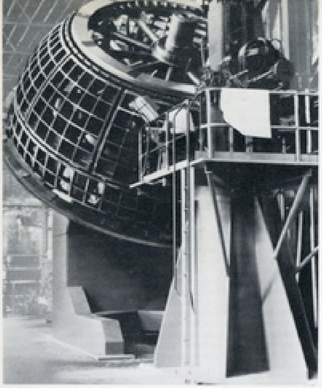
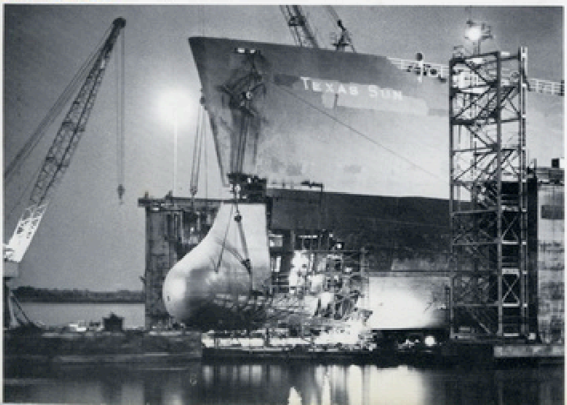


AERO/HYDRO SPACE

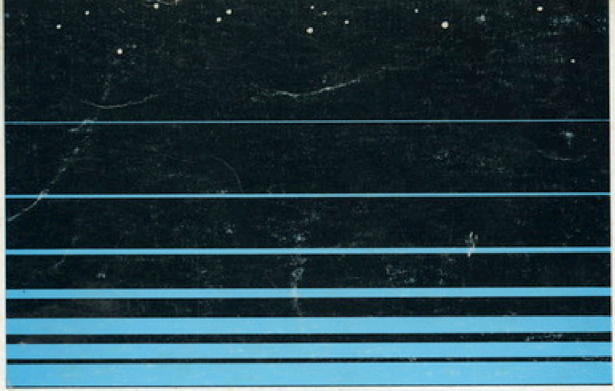
INDUSTRIAL PRODUCTS

SUN SHIPBUILDING AND DRY DOCK COMPANY

SHIP REPAIR

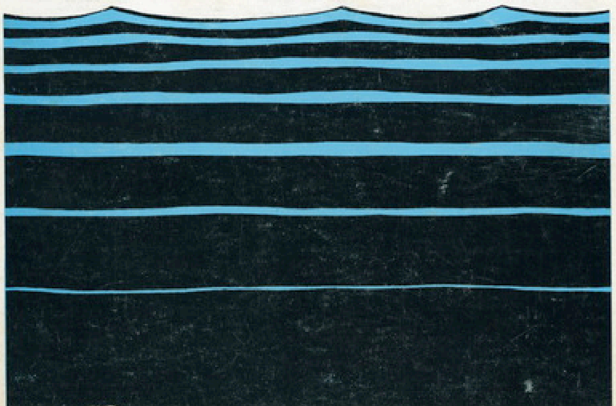


SHIPBUILDING



SUN SHIPBUILDING AND DRY DOCK COMPANY

Chester, Pennsylvania 19013 / (215) 876-9121



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