ASME International

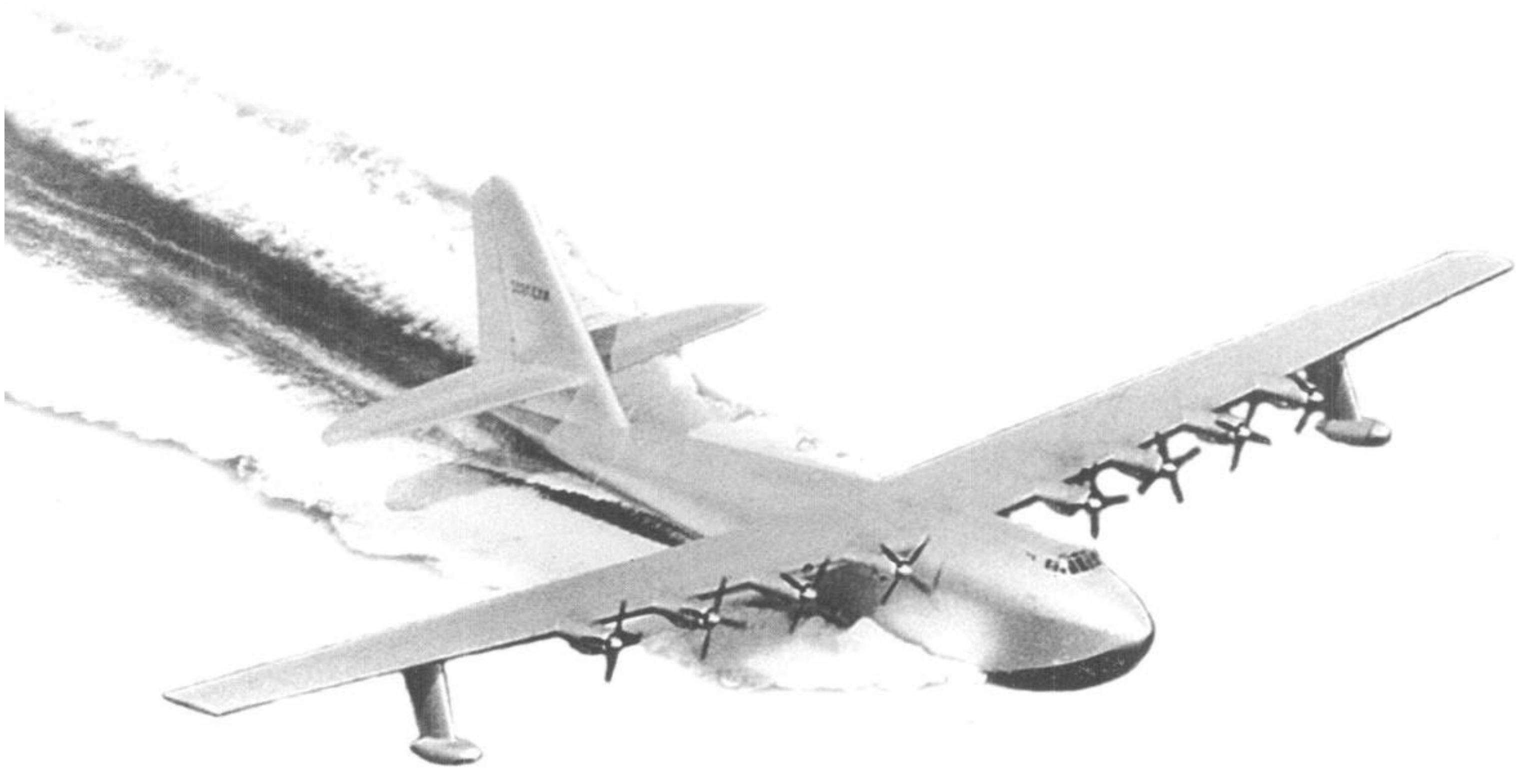
Howard Hughes'

Flying Boat

"Spruce Goose"

Historic Mechanical Engineering Landmark

July 20, 2002

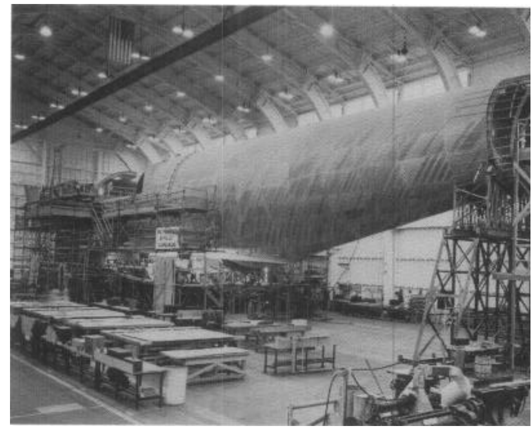


Evergreen Aviation Museum

The Captain Michael King Smith Educational Institute

In July 1942, the world was at war. America had just lost 800,000 tons of her supply ships to German U-boats. Henry Kaiser, famed industrialist and builder of “Liberty” ships, proposed a fleet of flying transports to safely move troops and materiel across the Atlantic. Kaiser approached Howard Hughes with his idea. Together they formed the Hughes Kaiser Corporation and obtained an $18,000,000 government contract to construct three flying boats.

Hughes and his team of skilled engineers designed a single hull flying boat capable of carrying 750 troops. The plans called for eight 3,000 horsepower engines, a mammoth fuel storage and supply system, and wings 20 feet longer than a football field. The aircraft was dubbed the HK-1, standing for the Hughes Kaiser design number 1.



The fuselage under construction

Adhering to the government mandate not to use materials critical to the war effort (such as steel and aluminum), the Hughes team constructed the Flying Boat out of wood. Testing new concepts for large-scale hulls and control surfaces, plus the incorporation of complex power boost systems, delayed the construction process.

In mid 1944, Henry Kaiser withdrew from the project, and Hughes renamed the seaplane H-4, representing his aircraft company’s fourth design.

After the war’s end in 1945 criticism of the project mounted. The Flying Boat prototype had exceeded the government’s funding allowance and the U.S. Senate formed an investigation committee to probe alleged misappropriation of funds. Hughes invested $7,000,000 of his own into the project to keep it going.

Meanwhile, the Hughes team assembled the Flying Boat in the Long Beach dry dock. Wishing to vindicate himself after a being interrogated by the Senate committee in Washington, D.C., Hughes returned to California and immediately ordered the Flying Boat readied for taxi tests.

On November 2, 1947, a crowd of expectant observers and newsmen gathered. With Hughes at the controls, the giant Flying Boat glided smoothly across a three-mile stretch of harbor. From 35 miles per hour, it cruised to 90 during the second taxi test when eager newsmen began filing their stories. During the third taxi test, catching the media and crowd unaware, Hughes lowered the wing flaps and lifted the seaplane off the water flying her a little over a mile at an altitude of 70 feet for approximately one minute. The short hop proved to skeptics that the gigantic machine could, indeed, fly!

Technical Aspects

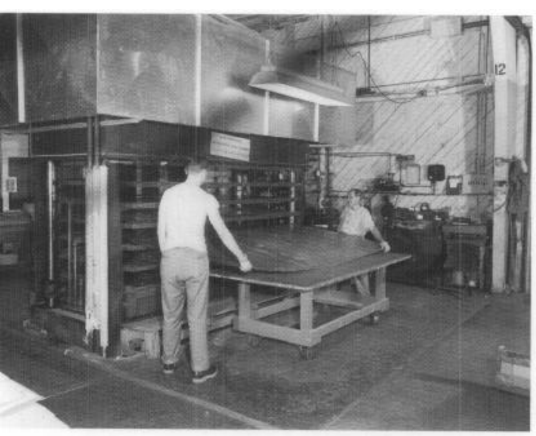
The creation of the Hughes Flying Boat involved many engineering disciplines. Not only did mechanical engineers participate in the numerous aspects of the aircraft project, but their efforts ranged in breadth from the models constructed for wind tunnel evaluation and towing basin tests through to the final launching details of the completed seaplane.

Mechanical engineering was involved in designing many elements of the Flying Boat: the jigs and fixtures for molding the aircraft parts; the fire suppression systems; multiple hydraulic components such as flareless tubing fittings and slip joints; the fuel and oil tanks; the pumps and piping for the fuel and oil supplies; the oil cooling system; and the cockpit instrumentation—not to mention the design of the massive engines and full feathering propellers with reversing capability.

Laminated wood Construction

The principal structural material used for the Hughes Flying Boat was birch veneer. Members were built up using several plies of thin veneer bonded together. When glued and steam heated, birch held up better than spruce, and it took the bolting stresses better. By laminating birch in multiple grain directions, the necessary grip for bolts proved practical. Birch was also superior in terms of weight reduction in high stress applications.

Duramold, a lamination bonding process, was originally created for molding parts for smaller aircraft. The contoured surfaces were very smooth and provided great aerodynamics. Originally developed by Fairchild Aircraft Company, Howard Hughes purchased the rights to use it in large aircraft. Because the pieces required were so big, and the materials for steel dies costly and in short supply, Hughes fabricated and experimented with "Gunite" dies. Gunite is a patented process for placing concrete mortar with compressed air. The Gunite process produced difficult shapes easily at a relatively low cost.



Workers making Duramold parts

Intensive research resulted in one of the earliest practical uses of epoxy resins. The main structural material for the huge craft was built up by bonding several plies of birch veneer with a ureaformaldehyde adhesive. In addition, some spruce, poplar, maple, and balsa were employed. Special corner angles were developed to replace glue blocks. Glue blocks were a serious problem for the aircraft builders because of differential expansion across and with the grain. Thousands (about eight tons) of small nails were used to provide pressure for attaching the hull and wing skin. After the adhesive had cured, they were removed with specially designed nail pullers. The result was an immense wooden airframe able to withstand the stresses of flight without being too heavy.

Fire Protection

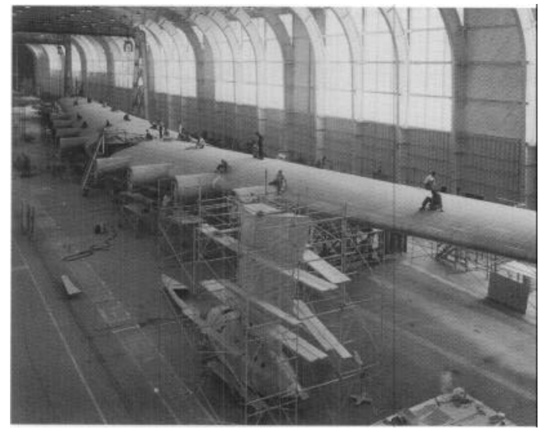
The wooden construction made fire protection a high priority. The amount of fire protection equipment aboard the Flying Boat is impressive. A total of 36 CO_2 (carbon dioxide) pressure containers are located on the cargo deck. They provided both primary and auxiliary fire control to the fourteen fuel tanks and to each of the eight engines. A complex manifold allowed the gas to be directed to the plane's various areas as needed. If required, all 36 bottles could be discharged into one area for maximum effectiveness.

Electrical System

Hughes and his team of engineers discarded the idea of using the conventional 24-volt direct current (D.C.) system for the aircraft, primarily because of weight, and designed a new 120-volt, three wire, redundant D.C. system, which brought about a weight reduction of 75 percent. Care also was taken to insure that all the electrical relays would perform at high altitudes. Two 30-kilowatt generators provided backup electrical power, and emergency battery power consisted of ten 12-volt batteries in two banks.

Fuel System

To attain a range of 3,000 miles, the Hughes Flying Boat was equipped with fourteen tanks, complete with baffles to minimize fuel sloshing. Each fuel tank had a 1,020-gallon capacity, but to allow for expansion each was filled to only 900 gallons. Fuel was transferred from the tanks, located below the cargo deck, to two 300-gallon wing tanks. One wing tank fed the four inboard engines, and the other wing tank fed the four outboard. The Flying Boat was also equipped with an emergency fuel transfer and supply system in case of leakage or pump failure.



Giant wings under construction

Engine Oil Supply System

Each of the seaplane's eight engines had a 31-gallon oil lubricating tank. Each of these tanks was replenished from a central 281-gallon tank located in the rear of the flight deck. The oil supply system operated automatically with a float in each individual tank or manually. The oil piping in each engine nacelle consisted of a main engine-oil pipe, reserve-oil supply lines, vent lines and propeller-feathering piping. Carburetor inlet scoops were placed below each engine nacelle, and oil coolers were placed in the inlets, which were enclosed by the air-scoop fairings and temperature regulating doors.

Propellers

Each of the eight Pratt and Whitney Wasp Major R-4360 air-cooled radial engines drove a Hamilton Standard four-bladed, hydromatic, full-feather propeller measuring 17 feet 2 inches in diameter. The four inboard propellers could provide reverse thrust. The thrust reversing capability would assist the Flying Boat back off the beachhead after loading or unloading its cargo.

Engine Controls

Originally designed with four throttles—one for each pair of engines, Hughes changed the design to eight after the flight, one for each individual engine. At first, all engines operated by Pneudyne's pneumatic system, or compressed air in place of hydraulic fluid. However, it was difficult to control them precisely, and no two valves would operate the same with identical pressure. After the flight, Hughes had electric throttles installed, along with servos for throttle control on all eight engines, which gave them a response time of 1/300 of a second.

Flight Controls

Hughes and his team of engineers developed the first "artificial feel system" in the control yoke, which gave the pilot the feeling he was flying a smaller aircraft, but with a force multiplied two hundred times. For example, for each pound of pressure exerted on the control yoke by the pilot, the elevator received 1,500 pounds of pressure to move it.

The Flying Boat required two auto-pilot systems but Howard Hughes' passion for safety required five hydraulic control systems, which included two main systems, two auxiliary systems, a hand pump system, plus an emergency flying-tab system in case of complete hydraulic failure. Conventional control cables directly connected cockpit controls to the control surfaces, however, they did not move the control surfaces. They only provided a follow-up to ensure the proper relationship between the pilot's control positions and the actual deflections of the control surfaces. The Hughes engineers used electrically driven, high-pressure hydraulic pumps that provided

Flying Boat assembly

the operating power for the systems. When the pilot moved the controls, he actuated sensitive relay valves that transmitted metered, pressurized hydraulic fluid into tubing that led to receiving relay valves located at the control surfaces. The receiving valves in turn permitted pressurized oil to flow to the power cylinders, which actually moved the control surfaces. To insure complete safety, each control surface was operated by two independent, self-contained telecontrol systems, which were supplied with electric power from two separate generators.

Control Surfaces

The enormous control areas (ailerons, flaps, elevators and rudder) cover 4,414 square feet, and all are fabric covered except the flaps.

Flareless Tubing Connectors

The Flying Boat was the first aircraft to utilize flareless tubing connectors in the hydraulic lines.

Wing Deflection

Fuel lines were equipped with "slip" joints and "floating" fairleads to allow for the deflection of the wings.

Flight Deck Layout:

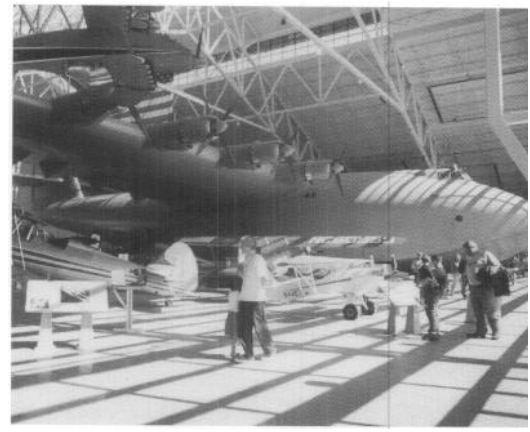
The pilot and co-pilot's cockpit flight controls are each equipped with a control column and wheel, pedal operated rudder control, and engine throttles between the two positions, plus essential engine and navigation instruments. A starboard-side flight engineer's station is immediately behind the co-pilot's seat and contains dials and gauges to monitor the eight engines, throttles, alarm annunciators, fuel indicators and hydraulic status gauges. The radio operator's console is located on the port side, directly behind the pilot's seat and the flight test temperature recorder's desk is behind it. Also on the port side is a table for the strain gauge calibration equipment. On the port side aft is the assistant flight engineer's station, complete with the more essential dials and gauges. The console for the propeller test equipment is located on the starboard side aft. In addition, a number of chairs are provided as a "crew rest area."

Bocking Elevator

A novel elevator equipped with guardrails, located in the rear of the flight deck, is designed to lift personnel through a top-opening hatch. Equipped with a microphone connected to the aircraft's communications network, the personnel could supervise docking and mooring of the Flying Boat from a vantage point atop the fuselage.

Today

Now commonly called the "Spruce Goose," the Hughes Flying Boat has endured to become a popular cultural icon of American history. She tells a story of wartime sacrifice, determination and technological development. She still is the largest wooden seaplane ever built, and she proved that jumbo flying aircraft and large lift capability were possible. She was decades ahead of her time in the early 1940s,



The Hughes Flying Boat at the Museum

and today, thanks to the many dedicated to her survival, she rests among other historic aircraft at the Evergreen Aviation Museum.

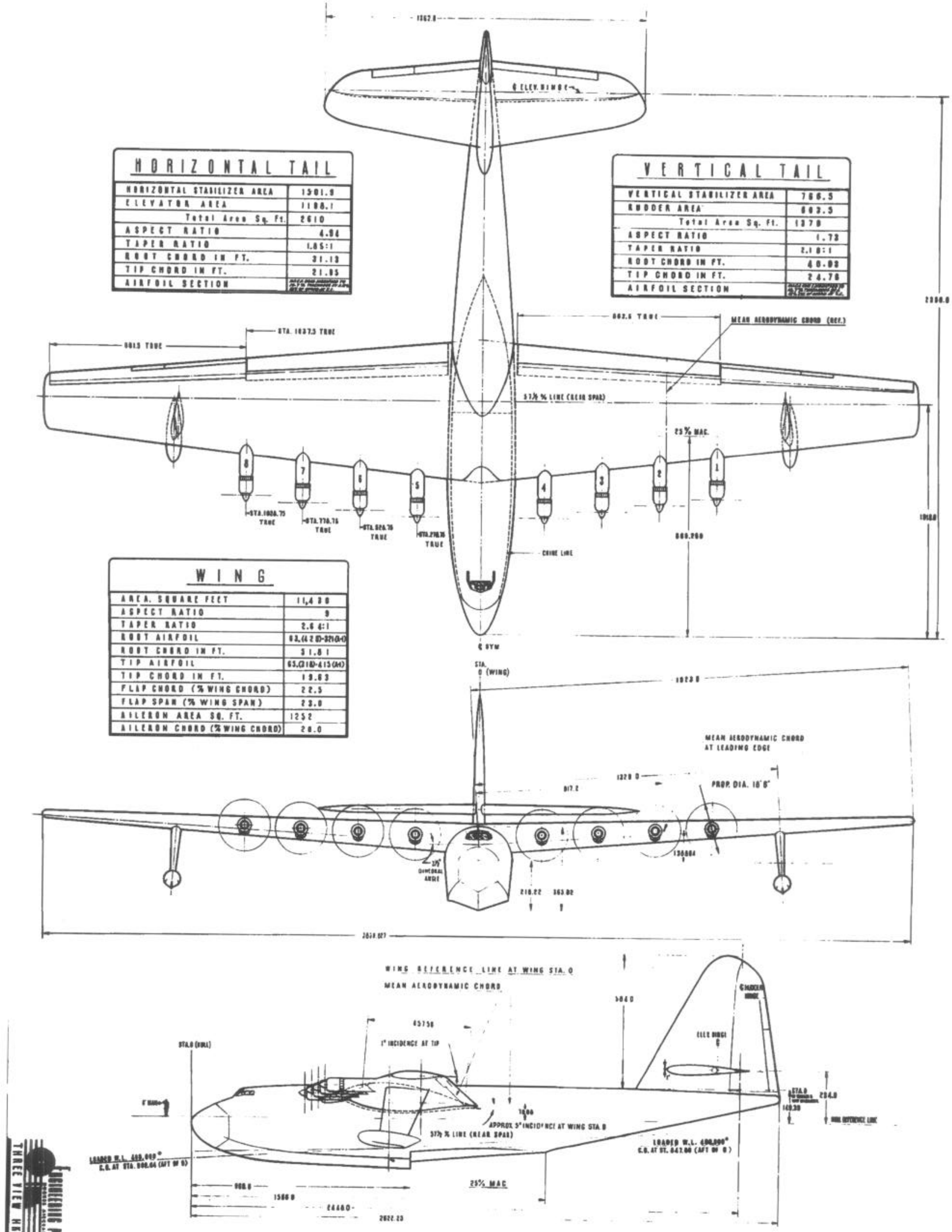
The History and Heritage Program of ASME International

The History and Heritage Landmarks Program of ASME International (the American Society of Mechanical Engineers) began in 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee initially composed of mechanical engineers, historians of technology and the curator (now emeritus) of mechanical engineering at the Smithsonian Institution, Washington, D.C. The History and Heritage Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. This Committee is part of ASME's Council on Public Affairs and Board on Public Information. For further information, please contact Public Information at ASME International, Three Park Avenue, New York, NY 10016-5990, (212) 591-7740.

Designation

Since the History and Heritage Program began in 1971, 218 landmarks have been designated as historic mechanical engineering landmarks, heritage collections or heritage sites. Each represents a progressive step in the evolution of mechanical engineering and its significance to society in general. Site designations note an event or development of clear historic importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The Landmarks Program illuminates our technological heritage and encourages the preservation of the physical remains of historically important works. It provides an



HORIZONTAL TAIL

HORIZONTAL STABILIZER AREA	1501.9
ELEVATOR AREA	1108.1
Total Area Sq. Ft.	2610
ASPECT RATIO	4.94
TAPER RATIO	1.85:1
ROOT CHORD IN FT.	31.13
TIP CHORD IN FT.	21.95
AIRFOIL SECTION	[illegible]

VERTICAL TAIL

VERTICAL STABILIZER AREA	766.5
RUDDER AREA	603.5
Total Area Sq. Ft.	1370
ASPECT RATIO	1.73
TAPER RATIO	2.18:1
ROOT CHORD IN FT.	40.03
TIP CHORD IN FT.	24.78
AIRFOIL SECTION	[illegible]

WING

AREA, SQUARE FEET	11,430
ASPECT RATIO	9
TAPER RATIO	2.64:1
ROOT AIRFOIL	63,(420)-321(a-1)
ROOT CHORD IN FT.	51.81
TIP AIRFOIL	65,(318)-415(a-1)
TIP CHORD IN FT.	19.63
FLAP CHORD (% WING CHORD)	22.5
FLAP SPAN (% WING SPAN)	23.0
AILERON AREA SQ. FT.	1252
AILERON CHORD (% WING CHORD)	20.0

THREE VIEW HK-1 Scale 1/120

Historic Mechanical Engineering Landmark

Hughes *Flying Boat*, "Spruce Goose"

Constructed: 1943–1946
Assembled: 1946–1947

Designed and built by Hughes Aircraft Company, this is the largest wood constructed and the largest wingspan airplane ever built.

Originally designated the HK-1 in 1942, the Flying Boat was designed to meet wartime troop and materiel transportation needs. Laminated wood (mostly birch) forms the airframe and surface structures of the seaplane, minimizing the use of critical war materials, such as aluminum. It was powered by eight Pratt and Whitney 3,000 horsepower engines.

Howard Hughes piloted the Flying Boat on its only flight, November 2, 1947, in Long Beach Harbor, Long Beach, California. The flight covered approximately one mile and reached an altitude of approximately 70 feet above the water's surface.

annotated roster for engineers, students, educators, historians and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

The 125,000-member ASME International is a worldwide engineering society focused on technical, educational and research issues. ASME conducts one of the world's largest publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards.

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The Hughes Flying Boat is owned by the Evergreen Aviation Museum, located at 3685 NE Three Mile Lane, McMinnville, Oregon 97128, USA, (503) 434-4180.

Acknowledgements

ASME thanks all those who have contributed to the designation of the Hughes Flying Boat. Special thanks to nominators of this landmark in 1986: Don Albrecht and Carson Dalzell of ASME; Ray Hesser, Jack Whitehead and George Stawniczy. In 2000: Diane Kaylor of ASME International; Brian W. Doyle, David P. Taylor, J.D. MacEwan and Dennis A. Armstrong of ASME Region VIII; Lyndon F. Davis of ASME Western Regional Office. Photographs provided by the Evergreen Aviation Museum. Brochure author Katherine Huit, Associate Curator, Evergreen Aviation Museum. Editorial assistance by Tracy Buckley, Curator, Evergreen Aviation Museum and Michael Wright, Restoration Manager, Evergreen Aviation Museum and museum staff. Brochure design by Christina Laliberté and Tyler Whitely, Evergreen Aviation Corporate Communications.

Notable Hughes Flying Boat Facts:

Cargo aircraft prototype

Largest wingspan: 319 feet, 11 inches with a wing area that covers 11,430 square feet

Features cantilever wing and tail surfaces

Tallest aircraft: 79 feet, 3 3/8 inches

Length: 218 feet 6 inches

Largest seaplane

Largest wooden aircraft—the entire airframe is composed of laminated wood

Primary control surfaces, except the flaps, are fabric-covered

The most reciprocating horsepower ever installed in an aircraft

Power: Eight Pratt & Whitney R-4360, 3,000 horsepower engines

Propellers: Eight, 17 feet, 2 inch diameter

Weight, empty: 284,000 pounds

Weight, loaded: 400,000 pounds (maximum take-off weight)

Capacity goals: 750 troops or two Sherman tanks

Normal crew: 11

First and only flight: November 2, 1947

Estimated Performance:

Cruise speed: 141 to 150 miles per hour at 5,000 feet

Top speed: 227 to 231 miles per hour at 5,000 feet

Range: 2,975 miles with 12,500 gallons of fuel

Service ceiling 17,400 to 20,900 feet

H219