The N-1M with 'Jack' Northrop (standing) and Moye Stephens (in cockpit) at Muroc Dry Lake, circa December 1941, during its press debut.

Initial configuration of the N-1M. Light-colored bands in the wing semi-span and near the tips are fairings for variable geometry joints.

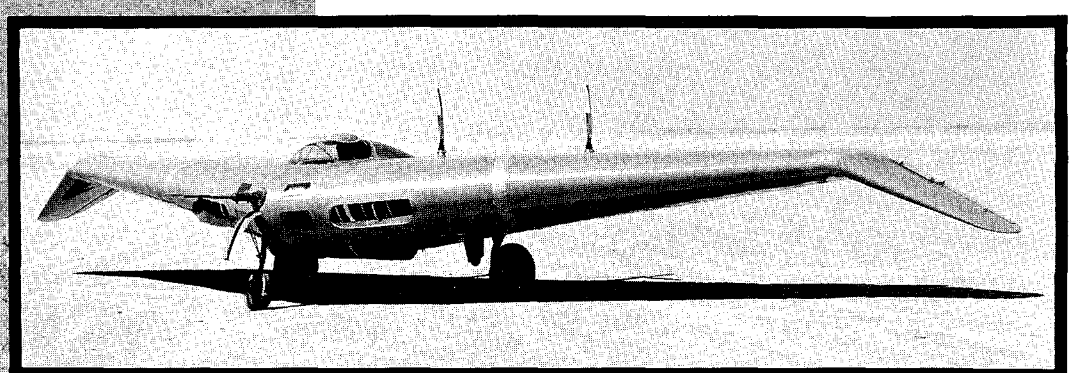
NORTHROP N-9M FLYING WING

Part I Description

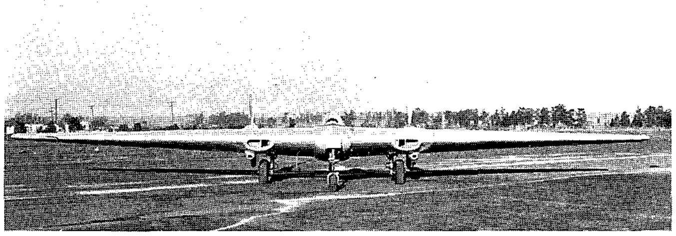
By Bill Young and Gerald Balzer

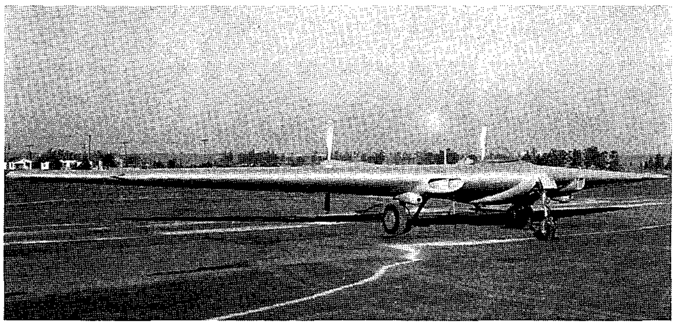
THE STORY OF THE NORTHROP N-9M FLYING WINGS IS the story of four piloted scale models used to develop a much larger and, for its time, a massive development program with little or no usable technical precedent. That program was John K. Northrop's lifelong fulfillment for maximum aerodynamic efficiency, the XB-35 Flying Wing intercontinental bomber. The N-9Ms validated the design concept, provided the necessary research and development for control system configuration/systems and provided essential pilot training for flying the larger aircraft.

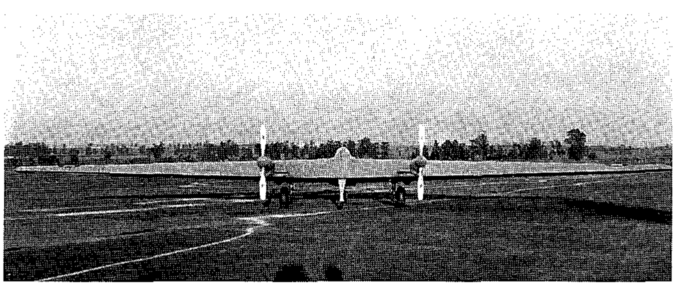
Background—On March 7, 1939, Northrop Aircraft, Incorporated, was formed as a company under the laws of the State of California. On August 1, 1939, John K. (Jack) Northrop opened the doors to his fourth and final venture into the design and manufacture of aircraft, the features of which were invariably dedicated to advancing the state-of-the-art.



His first objective, pursuing the elusive lifelong goal of maximum aerodynamic efficiency, was Project N-1. Project N-1 was studied in a number of configurations, varying principally in wing span. One configuration, with negative dihedral at the wing tips, was studied as a medium bomber, and is described in United States Patent 2,406,506. It was configured as a twin-engined pusher, 85-foot-span flying wing with a crew of five. The noted patent laid out the basic parameters and ideas that would baseline future Northrop 'wing' developments. Project N-1 was embodied in a 38.72-foot-span







Photographed at Northrop Field, Hawthorne, California, circa January 1943, these photos present a walkaround inspection of the first N-9M. In spite of the cooling air and carburetor inlets, the clean configuration of the flying wing is quite evident. (Northrop/Balzer)

Top view of the first N-9M; diagonal lines at the wing tips are the hinge lines for the forward-opening speed brakes. Engine cooling air exits are clearly shown. (Northrop/Balzer)

(.45 scale of the patent version) developmental prototype, the N-1M (Northrop Model 1, Flying Mockup), which was the essence of a true flying wing.

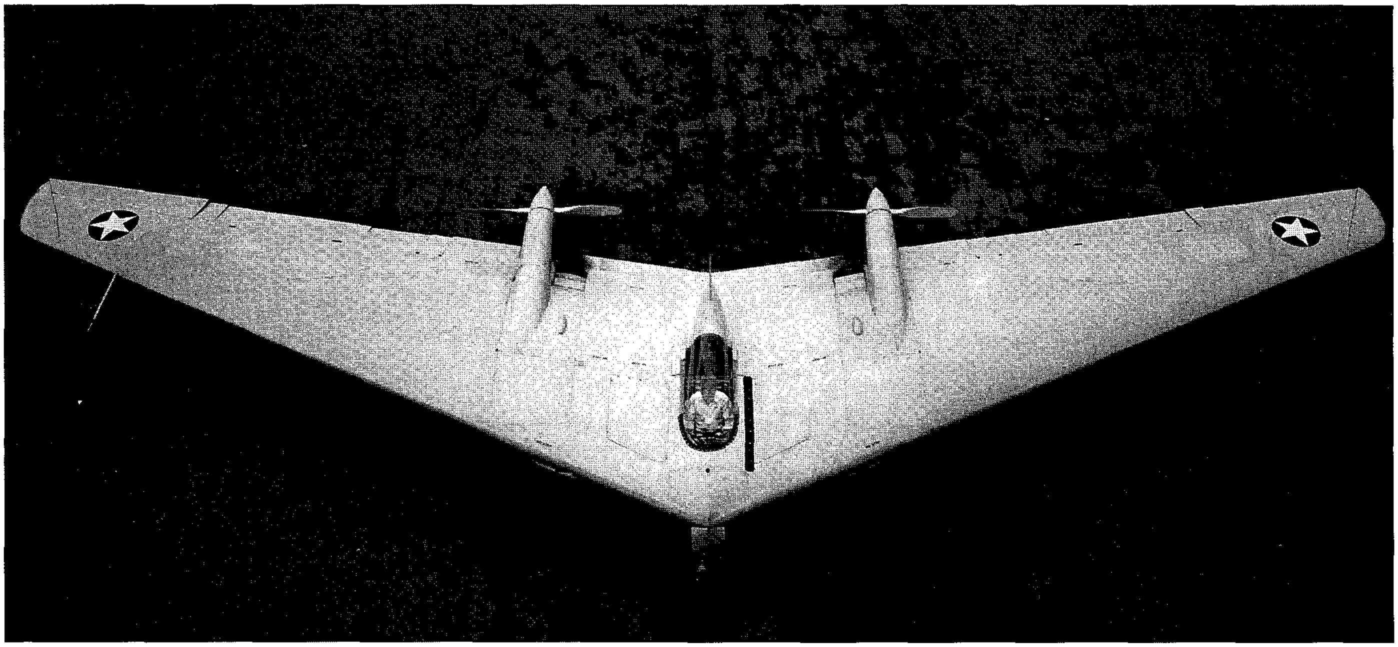
After carrying out wind tunnel tests of various sizes, taper ratios and sweepback, it was decided to configure the N-1M as a variable geometry airplane, with an adjustable center of gravity (CG). Configuration changes could be made on the ground only and consisted of adjustable dihedral (outer wing panel only) from 6° to 12° from the horizontal reference plane, sweepback from 26°46′ to 41°46′ and wing tip dihedral from 0° to −30°, from the wing reference plane. Though seriously underpowered, particularly with the initial engine installation (initially two 65-hp Lycoming Model O-145 engines, later replaced with 117-hp six-cylinder Franklin, Model 6AC264F2 engines), the airplane proved to be an excellent testbed, and never exhibited any serious difficulties in any flight attempt or in any of the flight configurations tested.

One of the primary differences of the Flying Wing configuration from a conventional tailed aircraft is the placement of all aerodynamic controls on the trailing edge of the wing structure. Roll and pitch control of the N-1M was combined into control surfaces located approximately at the mid-semispan of the wing. Called "elevon," a word coined from their dual functions, these control surfaces operated together, as elevators, for pitch control, and differentially as ailerons for roll control. Directional control was provided by drag-producing elements at or near the wing tip, as were pitch trim controls. Early in the flight test program, when it was found that the airplane exhibited satisfactory two-control characteristics, the engineers often considered eliminating rudder controls entirely.

The N-1M completed its flight test work and after stops at several Air Force storage facilities, ultimately went into many years (approximately 25) of storage at the Smithsonian's Silver Hill facility. In May of 1979 the aircraft was uncrated for a lengthy restoration effort lasting nearly four years and some 11,500 manhours of work, being completed on March 4, 1983. The N-1M is now on display at the National Air and Space Museum in Washington, D.C.

Project N-9—The development of the N-1M was watched with interest by the Air Corps. After several successful flights, Jack Northrop made his friend General H.H. Arnold aware of the potential of the flying wing configuration. In the following months Mr. Northrop, on his occasional trips to Wright Field, kept Colonel Howard Z. Bogert, Chief, Technical Staff, Materiel Division, informed of the progress with the N-1M. On May 21, 1941, Mr. Robert Lovett, Assistant Secretary of War for Air, was briefed on the N-1M at the Northrop plant in Hawthorne, California. Two days later, General Oliver P. Echols, Chief, Materiel Division, visited the plant and was shown movies and other N-1M data, discussing performance potentialities at length. As the result of these various discussions on the possibilities of a military version of the flying wing, Northrop was requested, on May 27, 1941, by Lt. Col. A.E. Jones, Chief, Contract Section, to submit a study based on certain general requirements, with possible excess performance to be traded off for maximum range.

At the time of the request, performance requirements were



very vague and changed repeatedly depending who was being contacted. A preliminary design (under the designation N-9), responding to suggested performance parameters which included a 5,333- to 8,000-mile range with a 2,000-pound bomb load at an average cruising speed of 250 to 300 mph, was submitted in person by Jack Northrop on July 2, 1941.

The final thrust of the performance requirements was communicated to Northrop in a telephone conversation between Walt Cerny and Lt. Col. F.O. Carroll on August 20, 1941; this conversation first identified the desire for a 10,000-pound bomb load and a 10,000-mile range and a minimum cruising and top speed of 240 mph and 350 mph, respectively. Also requested was a critical altitude of 35,000 feet and a service ceiling of 40,000. What ultimately evolved was a specification for a very heavy bomber with a transatlantic combat radius; these requirements became the baseline specification for the development of the Northrop XB-35 and the Consolidated XB-36.

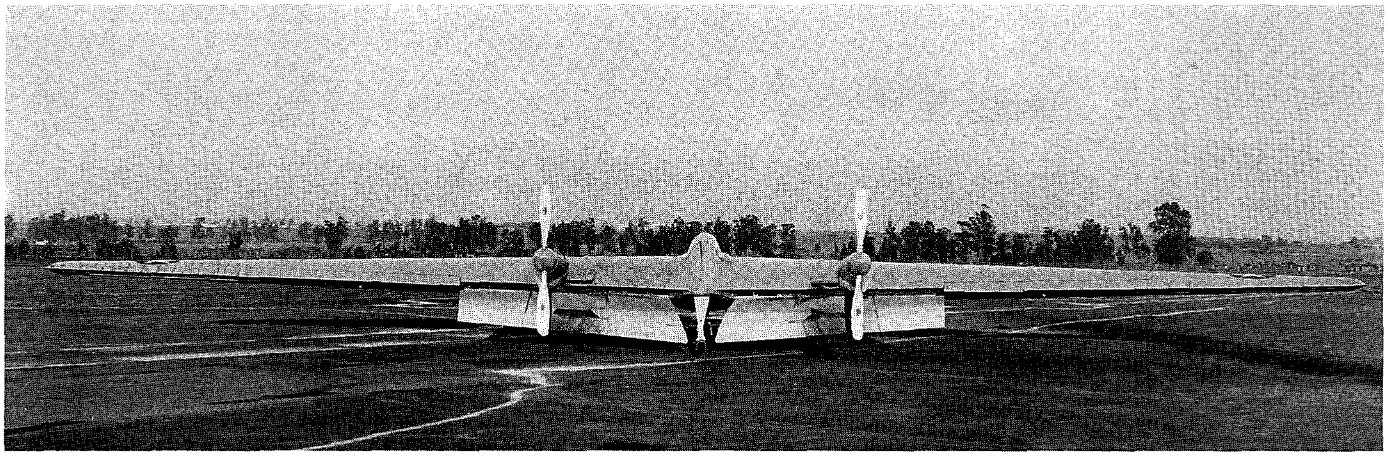
N-9M—Following evaluation of the proposed N-9 design, a number of parallel, seemingly independent, actions took place. Procurement of the XB-35 was authorized in a conference in Brigadier General Oliver P. Echols' (Chief, Materiel Division) office with General Hap Arnold and Lt. Col. F.O. Carroll on September 9, 1941. Purchase Order 42-2552 was approved on October 3, 1941, for engineering data and wind tunnel models (8 feet and 14 feet), two or more mock-ups, and the construction of a .3 to .4 scale flying model (later designated the N-9M) with delivery in 360 days. On October 30, contract W535 ac-21341 was approved to cover this work.

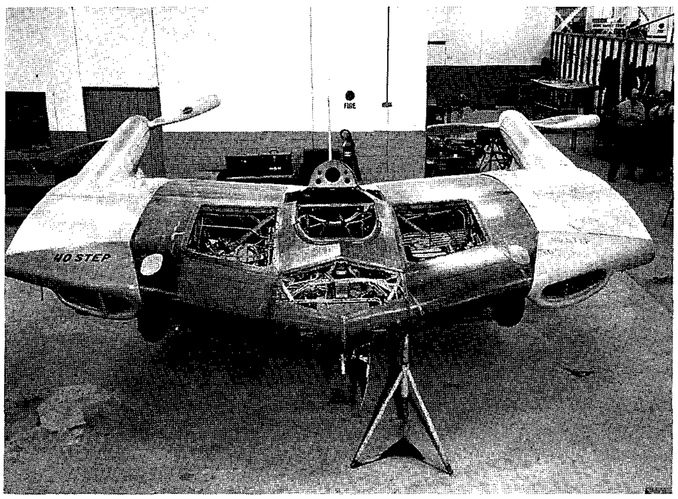
Concurrently with the purchase order activity, contract W535 ac-21920 for one XB-35 was drafted on August 6, 1941, and finally approved on November 22, 1941. Change Order No. 1, dated November 1, 1941, and approved January 2, 1942, ordered a second XB-35. Ultimately, a total of 15 XB-35/YB-35/YB-35As were ordered.

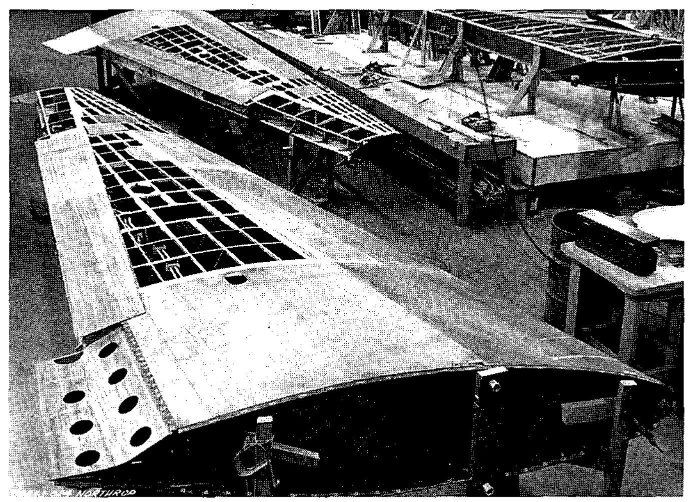
The specified .3 to .4 flying scale model materialized as a .35 scale aircraft, which was an aerodynamic equivalent of the XB-35. Overall dimensions of the N-9M included a wing span of 60 feet, with a length of 213.48 inches and a height of 79 inches measured over the canopy; wheel base and wheel tread were 103 inches and 140 inches, respectively. It should be noted that contractually the N-9M aircraft were engineering development 'tools'; in effect, the equivalent of large size, sophisticated wind tunnel models. As such, they were produced and flown without the usual military serial numbers or CAA registration numbers. The primary mission of the N-9M was to provide flight test information from which the maneuverability, controllability and performance characteristics of the XB-35 could be predicted. Maneuverability and controllability solutions for the flying wing configuration were not available from contemporary design solutions. As the result of this situation, the design of the N-9M(s) gave rise to various control configurations which represented a dynamic controls system evolution.

Change Order No. 3, dated September 10, 1942, to contract W535 ac-21920 authorized the construction of two additional N-9M aircraft, designated N-9M2 and N-9MA. The reasons for this additional procurement were to accelerate testing and clarify the design features of flying wing airplanes, thus providing a stop gap in case of an accident to the first N-9M, and to provide for additional pilot evaluation and simultaneous flight testing. Contract estimate for the N-9M2 was $111,871.77 with a fixed fee of $5,034.23 (4½%), and a delivery date of January 15, 1943. Estimated contract cost for the N-9MA was $92,751.20 with a fixed fee of $4,175.80 (4½%), and a delivery date of March 15, 1943. In mid-1943, the prospects of purchasing a fourth N-9M, to replace the first N-9M which was lost in a crash, was under consideration. It was felt that it would be needed to support the extended flight test program contemplated for the flying wing program. This airplane was later purchased on Change Order No. 9 (AFP #381601), dated July 24, 1943, to contract W535 ac-21920 for a total cost of $199,339.92 (estimated at $191,693) and designated N-9MB.

It was evident from the very beginning of the N-9 (XB-35) project that manually-operated controls, based on the size







and projected speed of the full-scale aircraft, would be beyond reasonable human physical capabilities; control power boosting or some equivalent approach was needed. Control system details, by N-9M model, are discussed later in this treatise. In addition to its primary mission, the various NB-9M models served well as pilot training aircraft for both Northrop and Army Air Force personnel. As a matter of reference, the aircraft was on the drawing boards a month or more before Pearl Harbor, striking a definitive prewar technology baseline. Airplane operating requirements were ultimately established in Model Specification NS-99, initially dated February 15, 1942.

The airfoils used on the N-9Ms were the same as those used on the XB-35, i.e., 65_3-019 (root chord) and 65_3-018 (tip chord). Use of the NACA laminar flow section on the XB-35 reflected Jack Northrop's toying with the idea of converting the N-1M to a laminar flow section and their subsequent use on the XP-56 (Project N-2). A driving concern was the reversal of control stick forces, at high angles of attack, experienced on the N-1M. Use of a thick, four-digit standard (not laminar flow) NACA airfoil—NACA 0025 (25%) at the N-1M's centerline—experienced either a very thick boundary layer or flow separation along the wing's trailing edge, depending on the flight angle of attack. Such a phenomenon is related to early air flow transition from laminar to turbulent (not separated) along the wing chord. Turbulent flow, as it moves aft on the airfoil chord, creates a thickening boundary layer, ultimately transitioning to a separated flow, adding significantly to wing drag, particularly at high angles of attack. Sufficient foresight existed at this time to envision the use/need for suction laminar flow control. Laminar flow control was postulated in the early Northrop flying wing patents and was demonstrated many years later (circa 1963) with the Northrop X-21A.

Laminar flow airfoil sections, because of their shape and their rearward location of maximum section thickness, substantially delay the transition from laminar to turbulent flow, hence providing a better airfoil-conforming flow on the aft portion of the wing chord and lower drag coefficients. A certain amount of serendipity aided and abetted this process; according to Bill Raikes, crew chief, the N-9Ms were waxed and polished frequently as a 'keep busy' effort, all of which contributed to overall drag reduction when compared to dust-laden surfaces so typical of a desert environment.

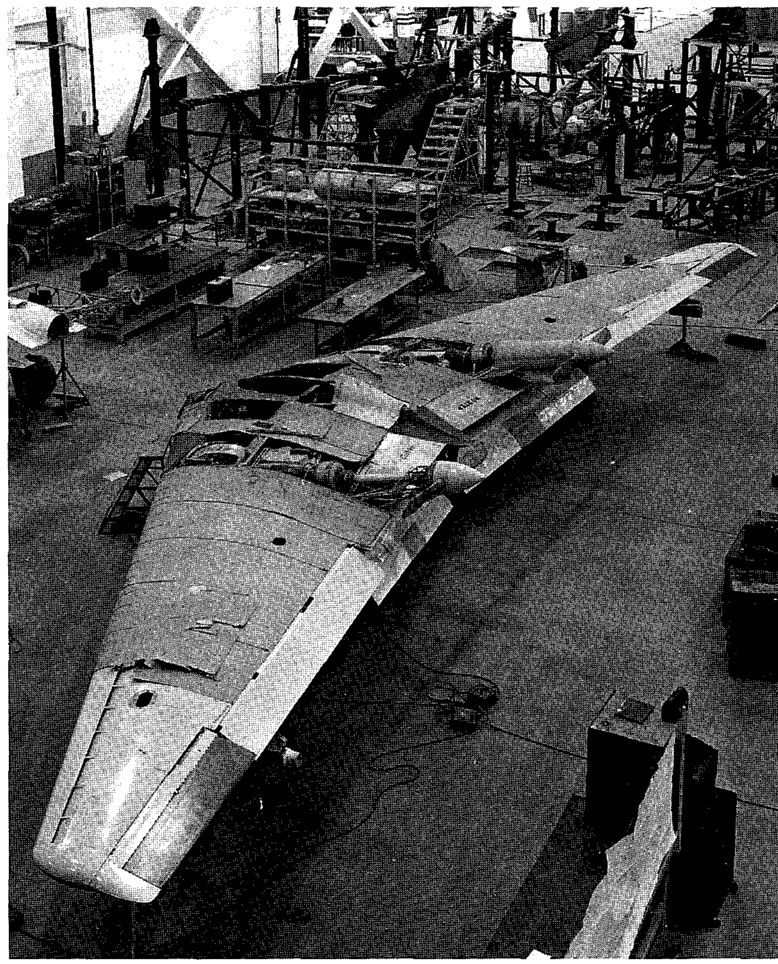
Cleaning up the airflow in this manner provided better control response for wing trailing edge control surfaces, but did not completely eliminate airflow problems. The fact that the selected airfoils were symmetrical about their chord plane was another significant feature. Symmetrical airfoils exhibit a stable zero pitching moment which directly correlates to control surface size and aerodynamic response. The use of zero pitching moment airfoils was a patented design feature of all of Jack Northrop's flying wings. This approach was not generally used by Lippisch and the Horten brothers in their flying wing efforts; they favored a cambered airfoil with a reflexed trailing edge for pitching moment control. These

Aft view of the first N-9M with flaps extended. Flap span is approximately 39 percent of the total wing span. (Northrop/Balzer)

The N-9MA center section nearing completion in February 1944. Note the drive shafts located at one side of the engine bays. This is to accommodate the Menasco 6-cylinder inline engines. (Northrop/Balzer)

Outer wing panels of the N-9MA during assembly on February 18, 1944. (Northrop/Balzer)

N-9MA in final assembly as of April 3, 1944; the structure in the background is the N-9MB center section. (Northrop/Balzer)



airfoils were penalized by a lower lift-to-drag ratio and were rejected by Northrop for this reason.

The N-9Ms were fabricated in three major subassemblies; a center section and left and right outer wing panels. They were essentially wooden aircraft with mixed wood and metal construction in the center section. The choice of wood as the basic structural material was driven by a number of reasons. Contract schedule constraints and the shortage of skilled manpower required that the aircraft be designed and developed off-line from the factory production line activities. Time and cost limits required expedient and inexpensive tooling, which militated against the use of sheet metal construction. Also at this time, incipient worldwide hostilities created an anticipated shortage of critical war materials, with aircraft grade aluminum alloys high on the list; the use of wood for the limited mission of the N-9Ms was an obvious and realistic choice. Furthermore, the use of wood made the structure easy to build and later modify during flight testing, if needed; also non-critical model maker and woodworking skills could be used to advantage.

Design of the center section incorporated the principal equipment installations. These included the pilot's compartment, including flight instruments and flight/engine controls, the engine installations (two), the fuel tanks/fuel system, and the landing gear. The instrument panels contained a complete assortment of normal flight instruments, plus others appropriate to a research aircraft. To accommodate these installations, the structure was deepened on the airplane centerline, by the localized use of a 24 percent thick airfoil which faired out to the basic 19 percent root airfoil some 18 inches each side of the wing's centerline.

To provide the space and the load-carrying capability for this equipment, the center section utilized a steel tube, welded truss configuration, producing a simple, low-cost (material, tooling and manhours) structure. The truss structure carried all of the primary flight loads on, as well as those introduced into the center section; this differed from the contemporary practice of loading the skin or shell structure, typical of metal, semi-monocoque airframes. Wing coverings and support/contour framing materials for the center section were wood products. Removable panels and compound shapes were formed from sheet aluminum alloy.

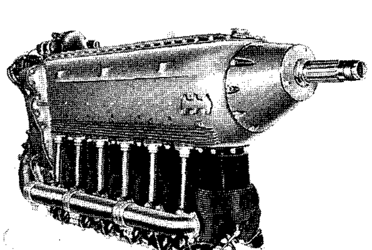
The outer wing panels were subassemblies extending outboard from wing station 99, approximately a 22-foot-long structure, attaching to the center section through bolted joints. With the exception of the landing flaps, the outer panels contained all of the aerodynamic controls for roll, pitch, pitch trim, and yaw (rudder effect). The outer wing panel structure was of a wooden, semi-monocoque design, not materially different from the cantilever wing of the Lockheed *Vega*, also designed by Jack Northrop. It consisted of a two-spar layout, with ribs and stringers completing the structural framework. Wing skins were stressed mahogany plywood with decreasing thicknesses towards the tip. Pregwood, a material made by impregnating maple plywood with resin and then compressing to one half of the original thickness, was used to reinforce bolted connections to the wooden structure. The entire structure was glued together with weldwood glue. The wing tips were formed from aluminum and many smaller metal fittings were fabricated from magnesium.

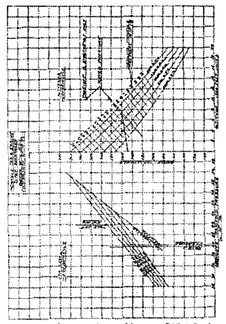
Gene Bogges, a woodworker on the N-9M wings, described the process of assembling the wing skins. First, the various thicknesses of plywood were scarfed 10:1. Then each panel was placed on the frame and marked from the underside. The cap strips on the ribs were then reduced in thickness to compensate for the thickness of the plywood. As a manufacturing aid or disposable tool, small strips of pine were prepared with small nails every inch. After the nail strips were prepared, weldwood glue was applied to the ribs and the plywood, then the plywood was placed in its final position on the structure assembly. The plywood was then tacked to the substructure by the use of the pine nail strips. Finally, weights were placed to ensure that everything stayed in place and that intimate contact of the glued components was main-

MENASCO

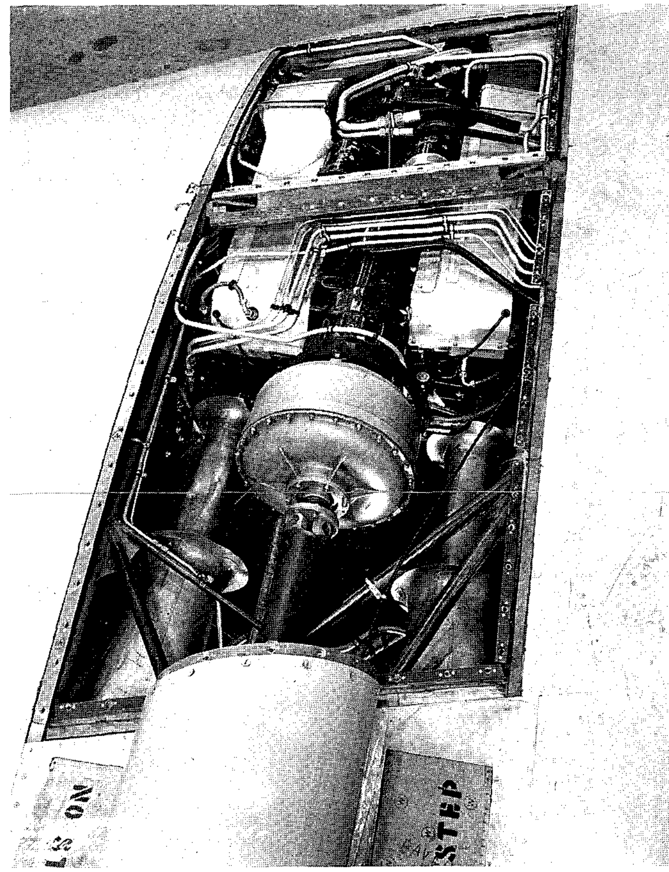
C6S-4 260 h.p.

SUPERCHARGED





Altitude and Power Curve, Menasco C6S-4 Engine



SPECIFICATIONS

of the Menasco "SUPER BUCCANEER" Model C6S-4

Type.....6 cylinder, air cooled, inverted in-line
A. T. C.....Pending
Bore.....4¾ in. Stroke.....5⅛ in.
Displacement.....544.9 cu. in.
Compression Ratio.....5.5 to 1
Supercharger Ratio.....10.9 to 1
H.P.....(Dept. of Commerce Rating) 260 @ 7500 ft., @ 2300 r.p.m.
Crankshaft Propeller End.....No. 20 S.A.E. Spline
Ignition.....2 Scintilla
Carburetion.....1 NA-R9A Stromberg
Fuel Consumption at Rated Power.....55 lb./H.P. Hr.
Oil Consumption at Rated Power.....025 lbs./H.P. Hr.
Dry Weight (without Air Scoop, Fuel Pump or Propeller Hub).....535 lbs.

Weight of Fuel Pump.....2½ lbs.
Weight of Side Air Scoop & Head Scoop.....11 lbs.
Weight of Hub for Wooden Propeller.....12½ lbs.
Average Weight of Wooden Propeller.....30 lbs.
Average Weight of Controllable Pitch Propeller.....95 lbs.
Weight of Engine Crated for Shipment.....870 lbs.
Size of Shipping Crate.....23x40x70 in.—32½ cu. ft.

Equipment furnished with engine—Side air scoop, lifting eye bolts, tool kit, steel exhaust flanges, instruction manual, propeller hub cones and nut.

Extra equipment furnished on order—Electric or hand starter, fuel pump, battery ignition, electric generator, hub for wooden propeller.

tained at the bond joints. This tacking and weighting task was time critical, and usually involved the use of about 30 people so that the glue would not set-up before the assembly was completed.

Competing with the pilot's compartment for space in the enlarged center section was the fuel supply of 100 gallons, contained in two 50-gallon tanks. Control of the fuel supply was by a cross-feed feature of the fuel system plumbing using shutoff valves. Proper sequencing of the shutoff valves made the fuel in either tank available to either engine. One tank, located immediately behind the pilot, could be removed and replaced with a seat for an observer. Seating of the observer was a cramped affair, with accommodations being a sideways seating position. On several occasions, Jack Northrop or Dr. William Sears, Chief Aerodynamicist, were passengers in the observer's position. In support of the test objectives of the N-9Ms, the fuel system was designed to be functional during all maneuvers performed by bombardment class aircraft.

Each of the first three N-9Ms were powered by two Menasco C6S4 *Super Buccaneer* engines, each engine being incorporated into a sophisticated propulsion system by contemporary standards. To achieve aerodynamic equivalence, these engines were chosen to effectively underpower the N-9M by normal standards. Spanwise locations of the engine thrust lines were midway between the scaled positions of the thrust lines of the inboard and outboard engines of the XB-35. These engines were ex-racing engines scavenged from all over the United States and rebuilt for installation in these aircraft. Impending hostilities had created a wartime atmosphere in certain key industries, especially aircraft engines. Massive pilot training programs demanded all available engine production, allowing little or no priority for providing the engines needed for the N-9Ms, hence the use of available rebuilt racing engines.

The *Super Buccaneer,* as rebuilt, produced 260 horsepower at 7,000 feet altitude and 2,600 rpm; takeoff rating was 290 horsepower at sea level at 2,600 rpm. The engine was basically designed for production aircraft and converted for use in the racing circuit, with mounting to be in a normal inverted position. The N-9M engine installation proved to be a challenge. As demanding as air racing was, the installation placed additional requirements on the handiwork of Al Menasco; submerged mounting had its associated cooling problems and the horizontal orientation of the engine installation necessitated redesign of the oil scavenging system. As it turned out, engine development, installation and maintenance problems effectively negated the flight test mission of the first N-9M.

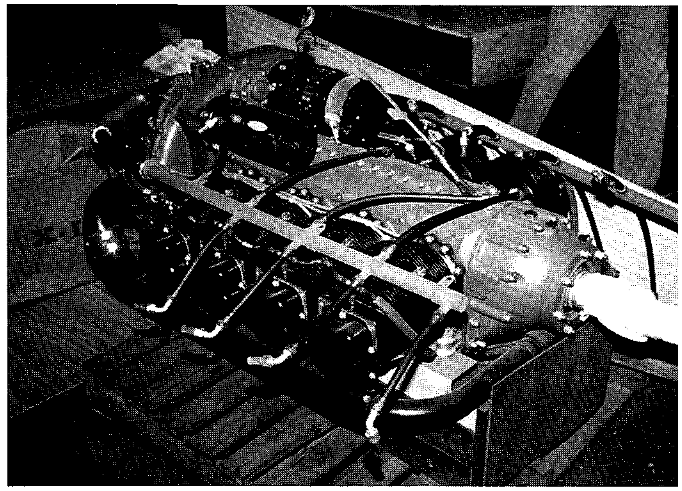
Crew chief Bill Raikes stated that the engines in the N-9MA ultimately needed replacement. No production engines were available, but replacement engines, Menasco *Super Buccaneer* racing engines, were obtained from Harry Crosby's and Tony LeVier's racing planes. They were rebuilt and de-rated, resulting in engines of improved reliability and increased power.

With the later decision to produce the N-9MB, engine selection once again became an issue. The solution was to use specially built Franklin 8ACSA-538 (Air Corps designation X0-540-7), flat, eight-cylinder engines. They provided approximately 40 hp more per engine, but on the negative side, each engine was approximately 65 pounds heavier. Six of these engines were built for the N-9MB. The Franklins were normally rated at 300 hp at 2,700 feet altitude at 2,600

An original Menasco advertising brochure for the inline 6-cylinder engines used in the N-9M1, 2 and A. (Menasco)

Close-up of the fluid drive installation, a feature unique to the N-9M series, circa October 1945. (Northrop/Balzer)

A rebuilt Franklin flat-eight engine. June 1991. (Young)



rpm; takeoff power was 320 hp at sea level and 2,600 rpm. Use of the Franklin flat-eights required considerable redesign of the center section structure, including engine mounts, drive shaft location, exhaust doors, and air intake shapes. The engine geometry of four opposed cylinders required that the thrust centerlines be moved closer together to a distance between engines of 162.50 inches, compared to the 178.00 inches for the Menasco engine installations. This change also required the redesign of the removable engine access panels.

According to John Myers, he experienced many engine failures during initial flight testing, due to the unusual installation of the Menasco engines. With the exception of four or five flights, most of the N-9M's 45 flights were terminated because of problems with the engines and their installation. One particularly disconcerting experience, not found in conventional aircraft, was the flight attitude with one engine out. Upon failure of an engine, the aircraft would assume a rather large, but stable, yawed condition. Control of the aircraft was not significantly affected. The problems with these temperamental engines were eventually solved, but it was left to the N-9M2 to provide the first usable flight test data. The remaining N-9Ms continued in use as pilot trainers for several years after their test programs were completed.

The propulsion system in the N-9Ms was unusual in several ways, other than the horizontal orientation of the engines. Engine mounts were of tubular steel integrated into the primary truss structure of the center section. Design of the engine mounts was such that the engines were completely accessible through quickly removable panels. Overall, the propulsion system included the engines, each with a unique fluid coupling-flywheel combination attached, a universal joint, a drive shaft and a propeller bearing housing with a built-in thrust meter (thrust meter installations were apparently limited to the N-9M and the N-9M2 airplanes). Completing the propulsion equipment were the seven-foot-diameter, two-bladed, constant-speed, Hamilton Standard propellers.

The fluid drive units were incorporated into the design of the N-9Ms to provide a way to stop the propellers in case of a pilot bailout situation. An emergency brake was installed on each of the propellers to stop them. The brakes were designed to stop the propellers in a near horizontal position, to avoid pilot injury during a bailout or damage to the propellers in the event of a wheels-up landing. Application of the propeller brake was accomplished by a pull-control for each propeller, located forward of the control column and below the instrument panel.

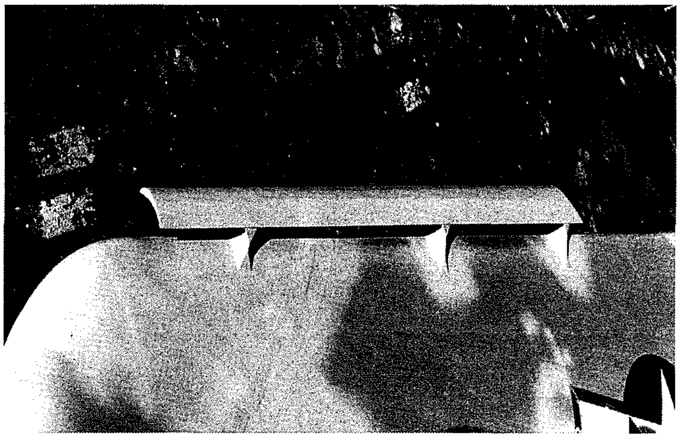
To ensure workability of the propulsion system concept, the flywheel was required on the engine side of the fluid coupling to replace the flywheel effect of the propeller, necessary for smooth engine operation. Because of the fluid link in the coupling, the propeller inertia could not be transmitted back to the engine through the device. The universal joint was employed to accommodate assembly misalignment and airframe deflections due to thrust and air loads. While the special propeller thrust bearing was needed to transmit thrust loads to the airframe, the thrust calibration unit measured engine/propeller thrust, giving a direct readout of airplane drag.

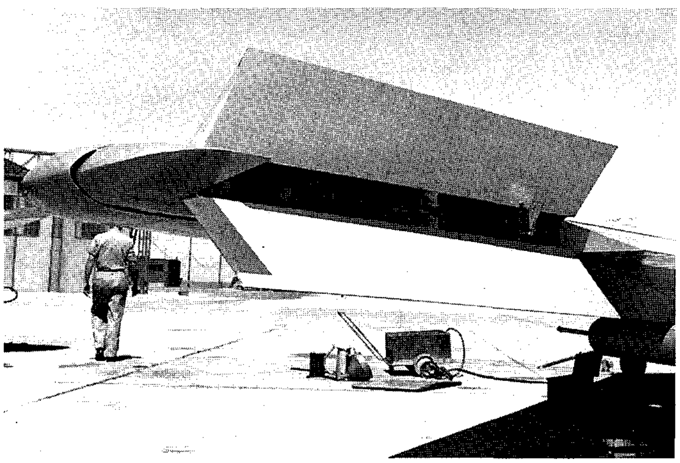
The fluid drive units were designed and produced in-house at Northrop. Herb Blinn was the engineer charged with the actual design of these units, which was based upon a patent held by another Northrop employee, Vladimir Pavlecka (Pavlecka had established a substantial reputation at Northrop for advanced work on numerous development projects). As an added benefit, these units also served as shock absorbers for engine startup loads, thus allowing a minimum-weight extension shaft, which would not be susceptible to twisting out of shape.

The exhaust system was more sophisticated than the design of contemporary exhaust collectors, with a simple gas release into the atmosphere. Exhaust collectors designed into the N-9Ms terminated into augmentors in the aft end of the engine compartment; they served as air pumps ensuring cooling air circulation around the engines on the ground and in flight. Controllable doors at augmentor outlets controlled the cooling air flow, maintaining proper engine cylinder head temperatures.

The landing gear was a fully retractable, self-locking, hydraulically operated tricycle gear supplemented with an anti-rotation gear; when retracted it was completely enclosed within the wing airfoil. Hydraulic power was supplied by engine-driven hydraulic pumps, with an emergency extension backup consisting of bungee cords. An emergency hydraulic hand pump was also provided on the left side of the cockpit.

The nose gear assembly was a single strut, cantilever design, without an oleo shock-absorbing unit. Limited shock-absorbing capability was provided by tire deflection upon touchdown. Nose wheel travel normally used by an oleo unit, was utilized by an auxiliary retractor that shortened the gear seven inches during retraction, to clear the forward edge of the pilot's seat. Typical gear anti-rotation scissor links were incorporated. Wheel size was a 16-inch-diameter magnesium





Close-up view of the slats retrofitted to each wing tip. (Northrop/Balzer)

Close-up of the N-9MA split rudder incorporated into the pitch flap at each wing tip. This was a major control configuration change; ultimately to be incorporated in the XB-35 design. Seen to the right of the split rudder is the temporary spin chute installation. (Northrop/Balzer)

The N-9M2 in the full-sized wind tunnel at Ames Research center. Bill Raikes sat in the cockpit during the runs. (NACA)

alloy air wheel.

The main gears of the N-9Ms were single cantilever oleo struts with the pivot axis integrated into the truss structure of the center section. Retraction was simple rotation into the wing. Wheel size was a 27-inch-diameter, smooth contour, Type II, magnesium wheel with hydraulic brakes, manually operated by toe pedals. The main gear doors were normally closed with the gear both extended and retracted. Closed doors, with the gear extended, provided a minimum drag configuration, especially desirable during takeoff acceleration.

The fourth element of the N-9M landing gear was the anti-rotation gear located on the centerline trailing edge of the wing and rotating forward for retraction. This gear had the singular function of limiting airplane pitch-up rotation, protecting the propeller during takeoff and landing. Using an eight-inch-diameter, smooth contour, aluminum wheel, it provided a five-inch propeller ground clearance for the N-9M, N-9M2 and N-9MA, and a six-inch clearance for the N-9MB.

In order to support the evolving XB-35 design, the N-9M aircraft tested variations in control system configuration; the N-9MB, the last of the N-9M series, incorporated the final XB-35 flight control design. In spite of the work done on tailless aircraft since the first flight of the Wright brothers, flight control systems for true flying wing designs were in need of much research and development, being critically dependent upon shape, size and speed range of the wing.

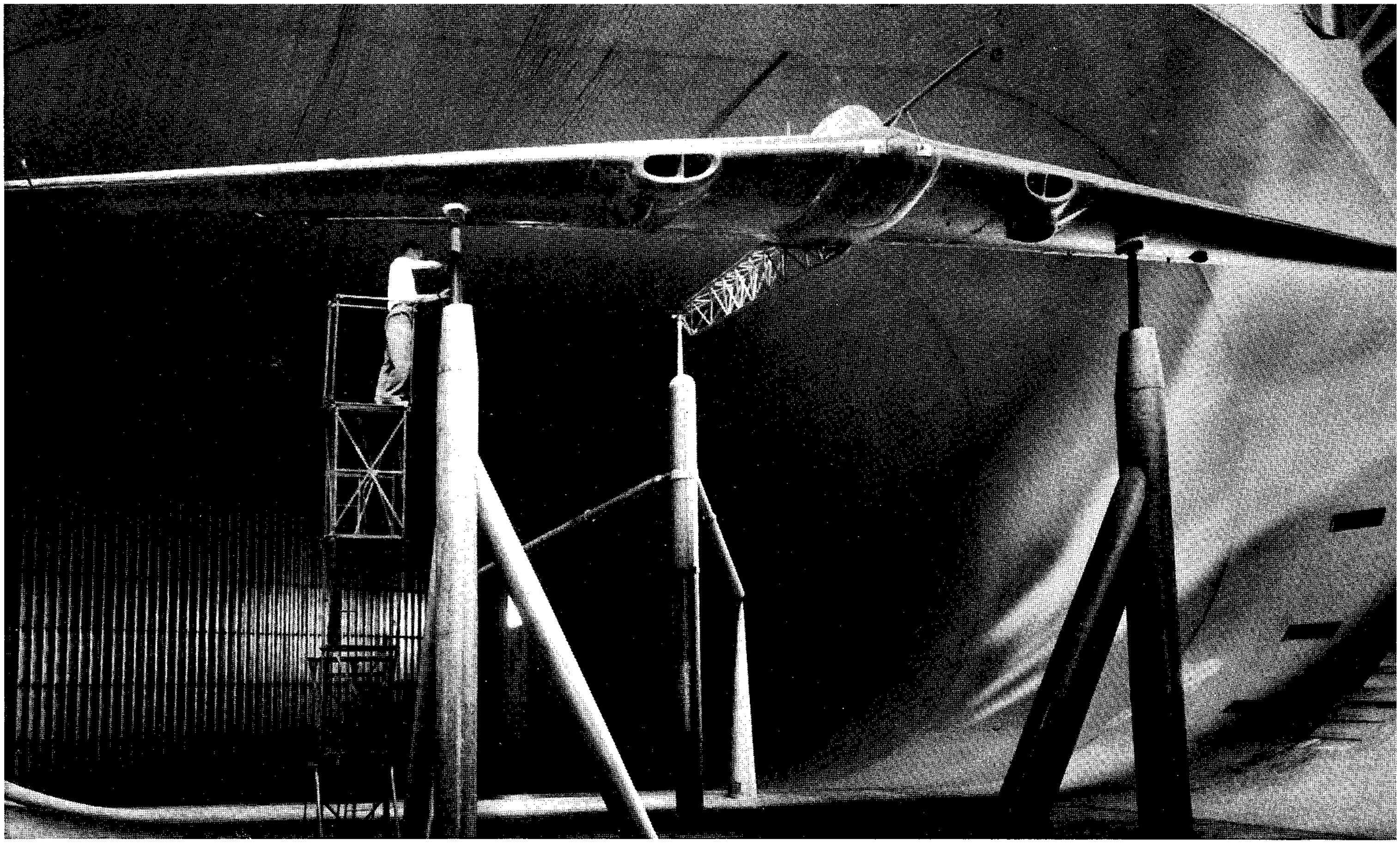
The initial design of the first N-9M incorporated several unique aerodynamic controls, all of which were operated in a manual mode. Flight control was provided by movable trailing edge surfaces. The inboard surfaces were split flaps which could be deflected down 46° ; construction was of wood and encompassed a portion of the upper wing surface. They were used primarily for landing, to reduce the L/D ratio of the airplane, thus steepening the approach angle, and increasing the rate of descent. They were, however, troublesome during takeoff, when applied in conjunction with elevon deflection, the combination tending to hold the airplane on the ground.

The controls outboard of the split flaps were the elevons, also fabricated from wood. Operation of the elevons was by means of a conventional control wheel mounted on a column, which was connected to the elevons by a system of cables. They were dual-function controls, providing the function of elevators and ailerons, independently or in combination; trim tabs controlled from the cockpit were included in the design. The elevons were 100 percent static mass balanced inside the wing contour and possessed zero dynamic balance. Movement of the elevon was ± 15° in the aileron mode and up 20° and down 10° in the elevator mode.

The outboard portion of each wing (approximately 100 inches) contained a speed brake, a pitch flap, a scoop-type drag rudder, and an 'ailerudder' spoiler-type control for trimming the aileron and drag rudder functions. Initial application of the ailerudder concept was on the first XP-56. By January 1943, the ailerudder had been deleted from the airframe; whether this happened before or immediately after the first flight is unknown at this time.

The pitch flap and the drag rudder were located immediately outboard of the elevons, both occupying the same general spanwise location. Constructed of wood, the pitch flap was hinged to the rear spar, with the aluminum, scoop-type drag rudder installed just forward of the rear spar. The concept of the pitch flap/drag rudder had been tested on the N-1M and was featured on the number one XP-56, then under construction. In a manner similar to the elevon, these surfaces were dual-function controls. The pitch flap could be used independently from the drag rudder. It could be moved up 30° and down 5°, to trim out flight pitching moments resulting from C.G. locations and power settings. The rudder function was provided by additional pitch flap deflection interconnected with the 74° (max.) deflection of the drag rudder which rotated down out of the lower wing surface. In addition to these functions, the pitch flaps were interconnected with the split landing flaps. Upon lowering the split flaps (and the landing gear), automatic pitch compensation was afforded the pilot, thus simplifying his landing procedure.

Design of the speed brakes was truly unique; the wing tip split open facing into the airstream, looking somewhat like an opening clam shell. The hinge line was approximately 63°



aft, relative to the vertical longitudinal reference plane. With typical flight line humor, no doubt fired by the war with Japan, the flight crew dubbed these speed brakes as 'Jap Snappers.' They were subsequently embellished with fanciful teeth to emphasize the sobriquet, when the brakes were open. The speed brakes did not work as well as envisioned and according to Bill Raikes, they were taped closed for the flight test program.

The overall control system design of the N-9M2 was essentially the same as the final configuration of the N-9M. As with the N-9M, the wing tip speed brakes were fixed in the closed position. Flight test results during the first two to three months demonstrated the continued need for improved airflow over the wing tips. Up to this time the N-9Ms flying had displayed unsatisfactory tip stall characteristics, resulting in lateral control that was not adequate in a stall allowing a wing to drop sharply. It was believed that fixed slats/slots would correct this condition (at this point in time fixed slots were being planned for the XB-35). During the October timeframe, fixed "eyebrow" slats were added externally to the leading edge of the wing to control tip stalling characteristics typically encountered on swept wings at high angles of attack; testing was continued subsequent to the installation of spin chutes. The slats reestablished the airflow over the pitch flaps for improved response. The overall value of the slat installation was questioned in one pilot's report, dated December 9, 1943; in it he stated that control reversal seemed to come in more abruptly with more force than before the installation. Whether the in-flight characteristics were bad or not was not definitely determined.

On November 1, 1944, after some 16 months of flight testing, the N-9M2 was placed in the 40x80 foot wind tunnel at Moffett Field to evaluate the airplane efficiency factor and investigate the characteristics of Northrop's newly designed elevon aeroboost system. Analysis of the control requirements for the XB-35 established that elevon movement would require control column forces beyond reasonable human capability. The aeroboost control system that was conceived would reduce control system forces proportional to the airspeed of the airplane, and was scheduled to be flown on the N-9M2. Before committing a pilot and the airplane to actual flight, wind tunnel tests were desired to check out the safety and adequacy of the aeroboost system and identify possible improvements.

Test speeds were limited to 100 mph, being dictated by the strength limitations of the tunnel support attachments to the rear spar of the airplane. The airplane was painted and sanded to give an aerodynamically clean surface, but not a polished surface. No attempt was made to seal inspection hole covers in order to maintain a normal flight configuration for drag assessment. For the tests evaluating the airplane efficiency factor, the airplane was cleaned up; no slats were installed and the aeroboost scoops were removed and sealed. These temporary modifications were made to correspond to previous flight configurations.

Basic design of the aeroboost system featured a baffle or 'balance board' extending forward of the leading edge of the elevon, which in turn was sealed to the wing structure. The sealed balance board, in effect, created an upper and a lower balance chamber. Elevon boost forces were aerodynamically created by external ram air, supplied by an air scoop on the lower surface of the wing (approximately 40 percent of the chord) and directed into the appropriate balance chamber. Control of the airflow in the aeroboost system was by means

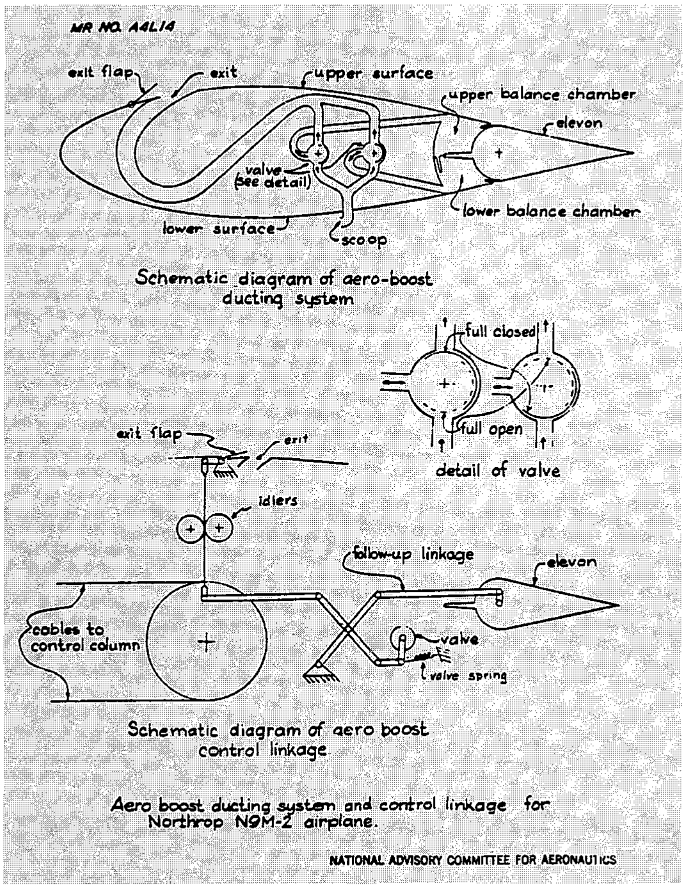
Schematic of the aeroboost control system installed on the N-9M2 and tested in the 40- by 80-foot wind tunnel at Moffett Field. (Northrop/Balzer)

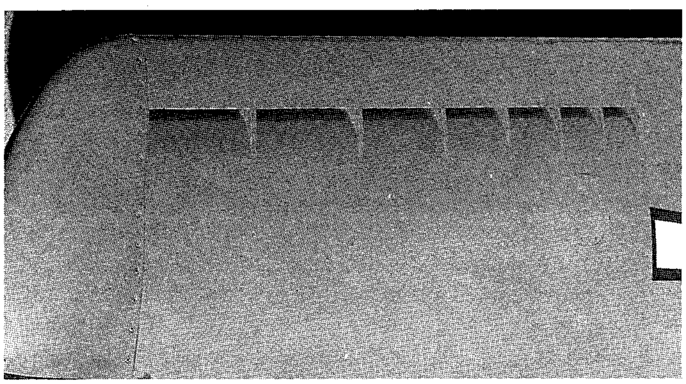
Close-up view of the wing slot installation on the N-9MA, as opposed to the slat on the N-9M2. (Northrop/Balzer)

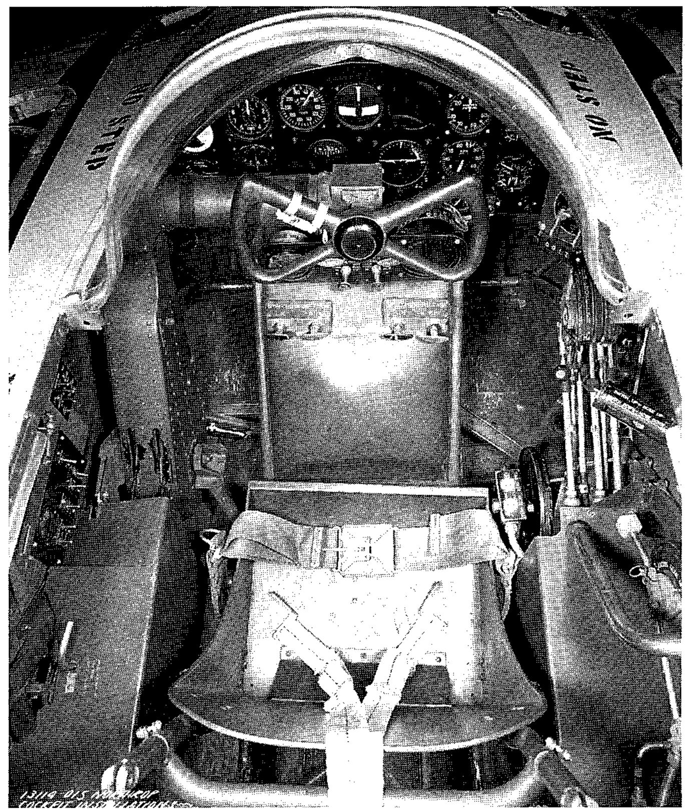
Cockpit installation of the N-9MB, circa January 1945. (Northrop/Balzer)

The N-9MB in final assembly, circa October 1944. Clearly evident are the generous maintenance access areas covered by removable panels. (Northrop/Balzer)

N-9M2 photographed in the desert around Muroc AAB, circa April 1944. Evident are the slats on the wing tip(s), the movie camera installed in the cockpit (not a Mickey Mouse hat), and the fittings on the propeller extension shaft fairings for the installation of temporary fins for test purposes. (Northrop/Balzer)



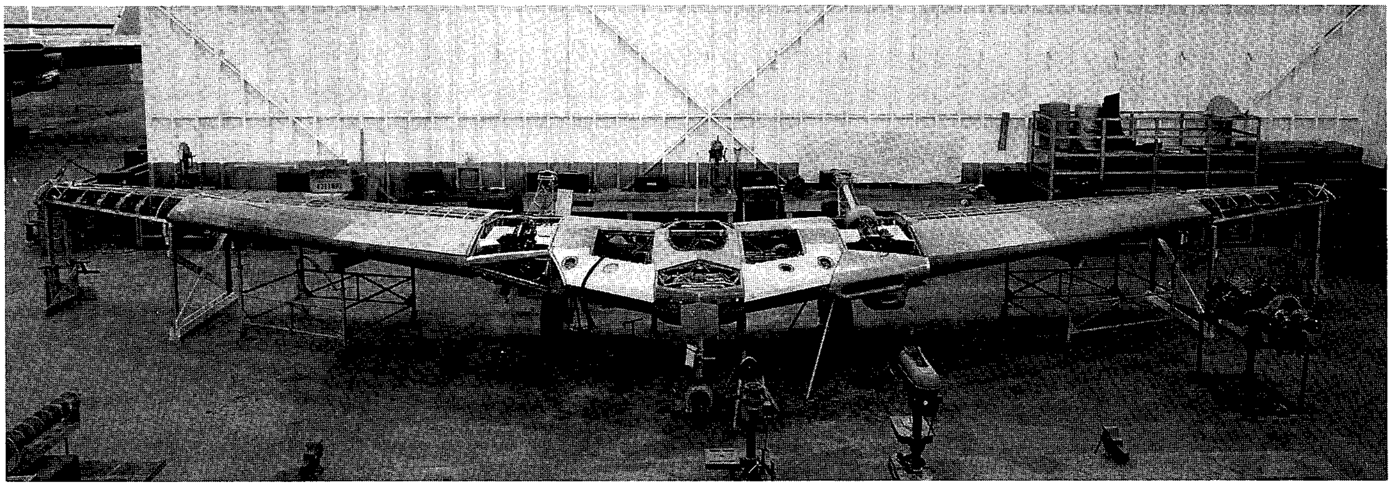


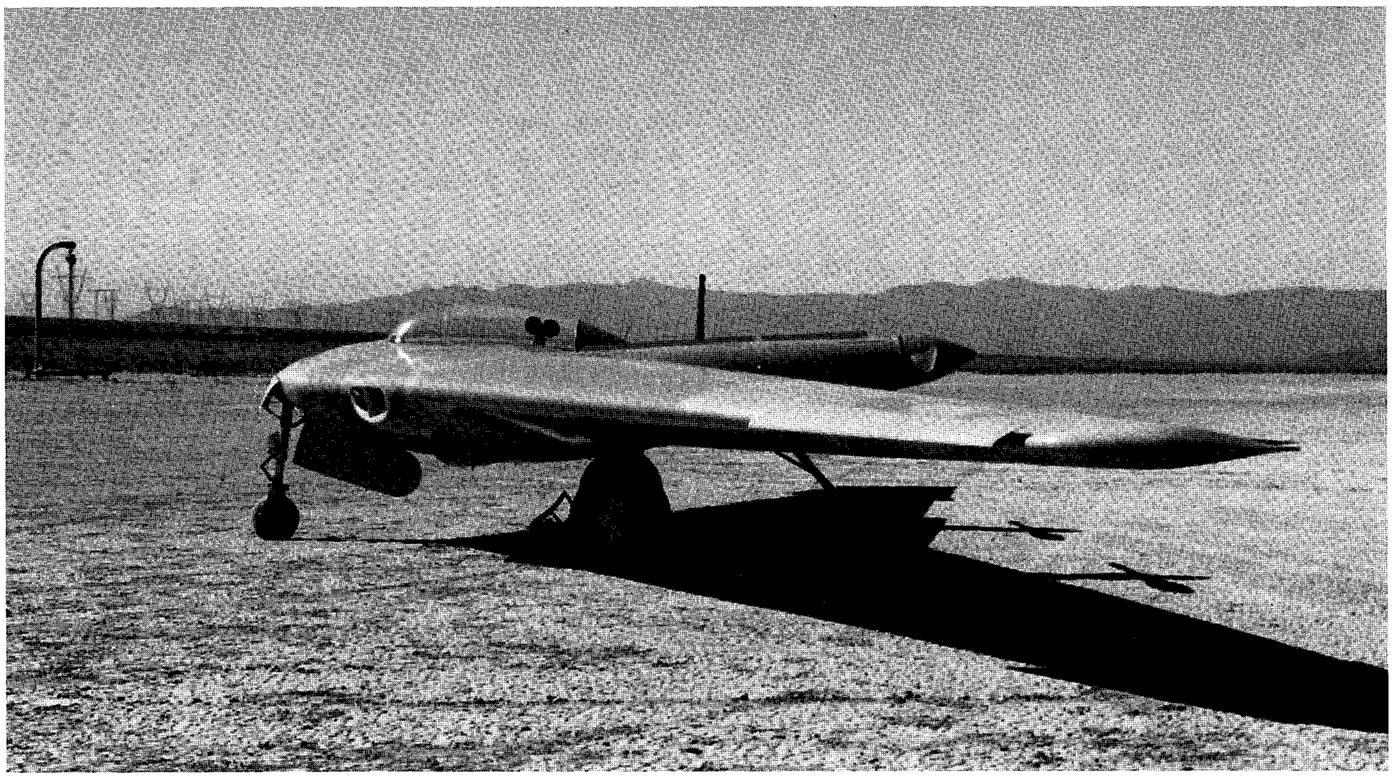


of a dual valve design, which allowed ram air to be directed into a balance chamber, and at the same time allow the air in the opposite balance chamber to be vented overboard. Venting was assisted by locating the vent exit on the upper surface of the wing (approximately 21 percent of the chord), in the suction portion of the flow over the wing. The air scoop and the vent were located 16 feet outboard of the wing centerline.

Elevon boost forces, generated by differential air pressure on the balance boards, acted in a direction consistent with the movement of the control column, reducing the control force needed by the pilot. By using ram air, boost forces were proportional to the speed of the airplane, as generally were the control column forces on the airplane. Dynamic characteristics of the aeroboost system were obtained in the wind tunnel with a pilot, Lt. Col. H.E. Warden (Bill Raikes sometimes filling in), at the controls to obtain his reactions to control movements. Wind tunnel tests concluded that the aeroboost system was safe to fly, but the boost efficiency was low due to leakage in the dual valve and some of the ducting. A manual override system was also recommended and incorporated. The aeroboost system was not developed further, being scheduled for replacement by a redesigned, irreversible hydraulic control system.

The flight control system on the N-9MA was a significant departure from the preceding N-9Ms, the result of the earlier N-9M flight tests and their impact on the evolving XB-35 design. Flight controls on the N-9MA were configured to be as nearly identical to the XB-35 as circumstances would allow. At a glance, the most readily apparent physical change was the incorporation of a fixed (open) slot in the outer wing structure, as opposed to the externally applied slat on the N-9M2; it served the same purpose but with less drag. In addition to the landing gear and the split flap, hydraulic power was applied to all flight surfaces, creating an irreversible control system, i.e., a control system wherein flight loads could not move the control surfaces. As part of the design, an



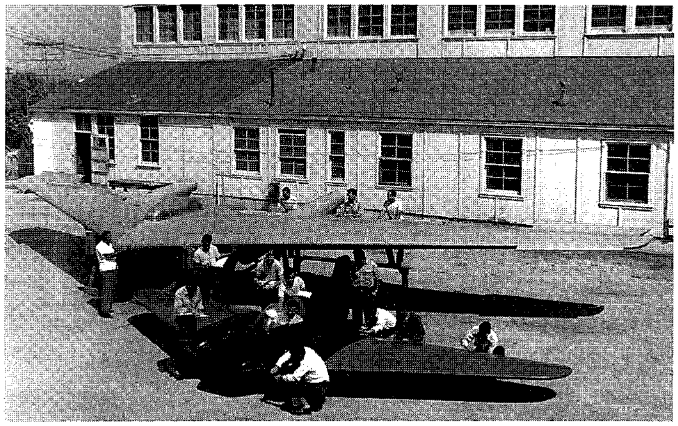


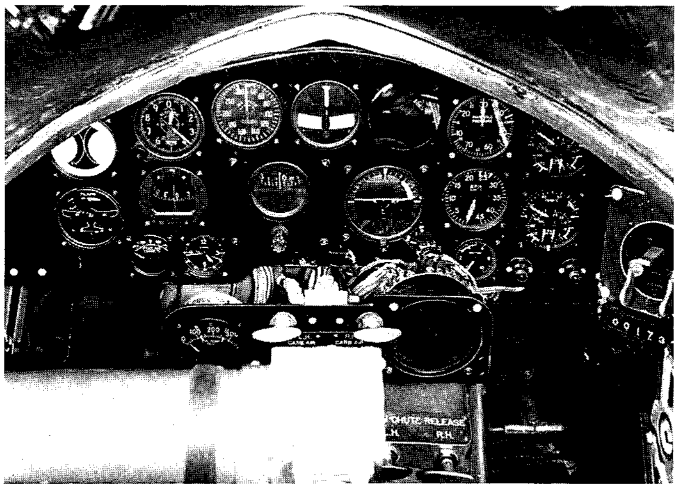
artificial feedback system was provided for the pilot. Northrop claims an 'engineering first' for the irreversible hydraulic control system on the XB-35 and so it must be for the N-9MA, which flew before the XB-35. Hydraulic operating pressures were 1,000 psi for the landing gear, split flap and the pitch flaps, and 1,500 psi for the elevons and rudder controls. Manual backup controls were provided for the elevons and the pitch flap.

Elevon design underwent considerable change, though not readily apparent; externally the trim tabs were deleted and replaced by electrically trimming the entire control surface. Actuation of the elevon was now provided by a 1,500 psi hydraulic cylinder. The manual override provided for the elevons was at the pilot's discretion and controlled by a switch in the cockpit.

While the split flap and the elevon surfaces were essentially unchanged, the pitch flap and rudder functions were completely redesigned to reflect the controls being designed for the XB-35. Although the pitch flap was still hinged to the rear spar, the scoop rudder function was now incorporated as a split flap type of drag rudder comprising the aft 70 percent of the pitch flap. The upper and lower drag rudder surfaces were attached to the pitch flap by full-length 'piano' hinges. Movement of the rudder surfaces was $\pm 60°$ relative to the pitch flap chord plane; when the pitch flap was moved, the rudders moved with them, without changing their settings. This whole assembly was both statically and dynamically balanced. As with the earlier N-9Ms, the pitch flaps were interconnected to the main flaps and to the landing gear to achieve a degree of automatic pitch compensation.

The drag rudders could be operated simultaneously to function as speed brakes. In one aspect, the drag rudder operation differed significantly from the rudder functions of a more conventional airplane. Each rudder was operated by an individual rudder pedal, i.e., no interconnection. Inadvertent pressure on both pedals at the same time (from body





The N-9M2 serving as a training instrument at Northrop Aeronautical Institute, in the company of the Northrop JB-1a, piloted glider version of the JB-1 guided missile. (Northrop/Balzer)

The instrument panel of the N-9MB. The empty space is for the rate-of-climb indicator. January 1945. (Northrop/Balzer)

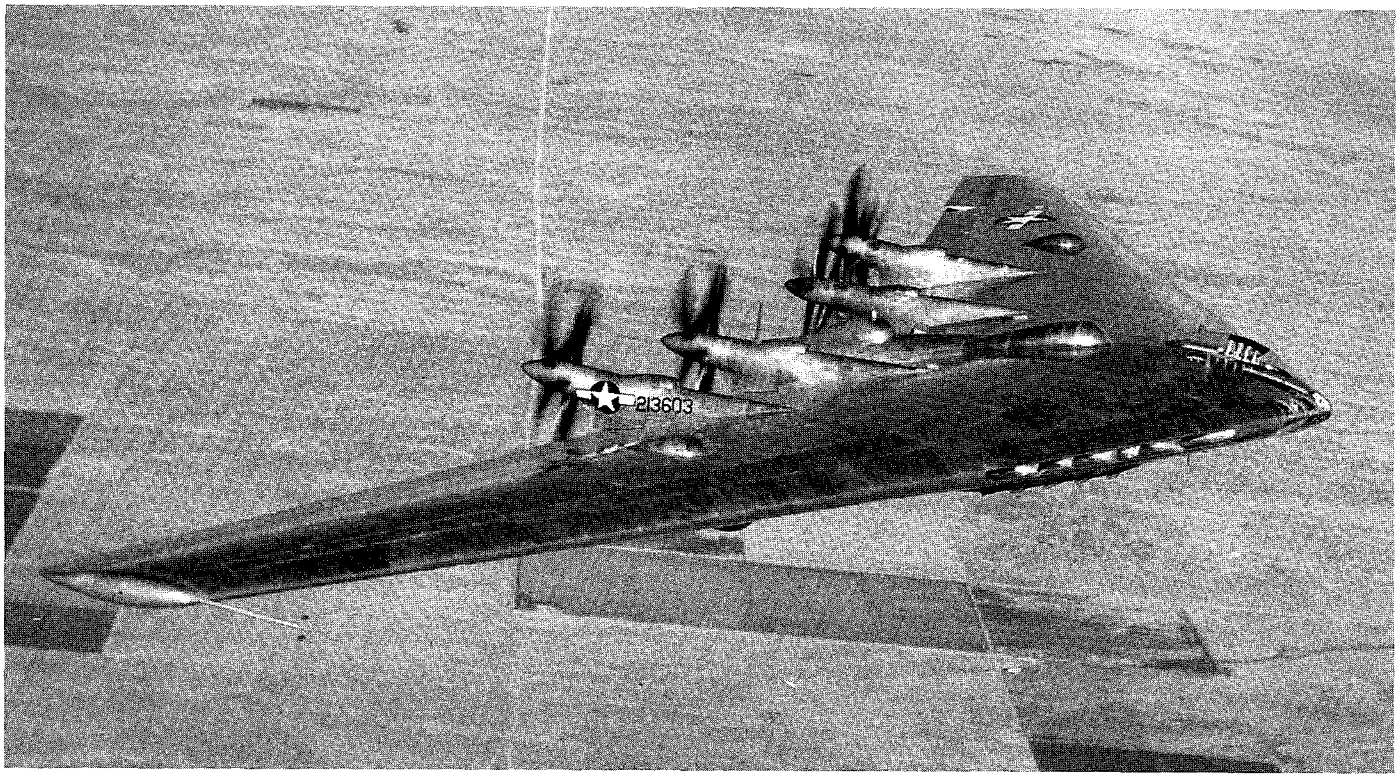
Fred Bretcher, Northrop test pilot in the N-9MB with Bill Raikes, Northrop crew chief, circa September 1946. Fred was a member of Northrop's XB-35 flight test crew. (Northrop/Balzer)

The XB-35 on its maiden flight, June 25, 1946. Aerodynamic validation and control system research for this aircraft were the prime functions of the N-9M series aircraft.

movement or heavy feet) provided the pilot with an instant and unexpected speed brake action.

In the light of control system variations and persistent mechanical and electrical difficulties, the flying wing development program was still considered immature by the AAF, as late as December 1943. Ongoing investigations to improve directional stability/damping and correct the force reversal problem at high lift coefficients were the reason for this perception. The N-9Ms were constantly undergoing modification to improve flying qualities, leading to the conclusion that a suitable "fix" for the XB/B-35 was not yet in hand. However, all problems were considered amenable to eventual solution.

The control systems on the N-9MB, while nearly identical to the N-9MA, had some additional differences/design upgrades incorporated, to make the airplane the functional



equivalent of the XB-35. Among the changes was a new slot design, which now had automatic doors that opened at high angles of attack and low speeds. This was done to clean up the wing in normal flying attitudes. The hydraulic system was essentially the same as the N-9MA, modified only as required to maintain functional equivalence to the XB-35. As with the N-9MA, the pitch flaps were interconnected to the main flaps and the landing gear to achieve a degree of automatic pitch compensation.

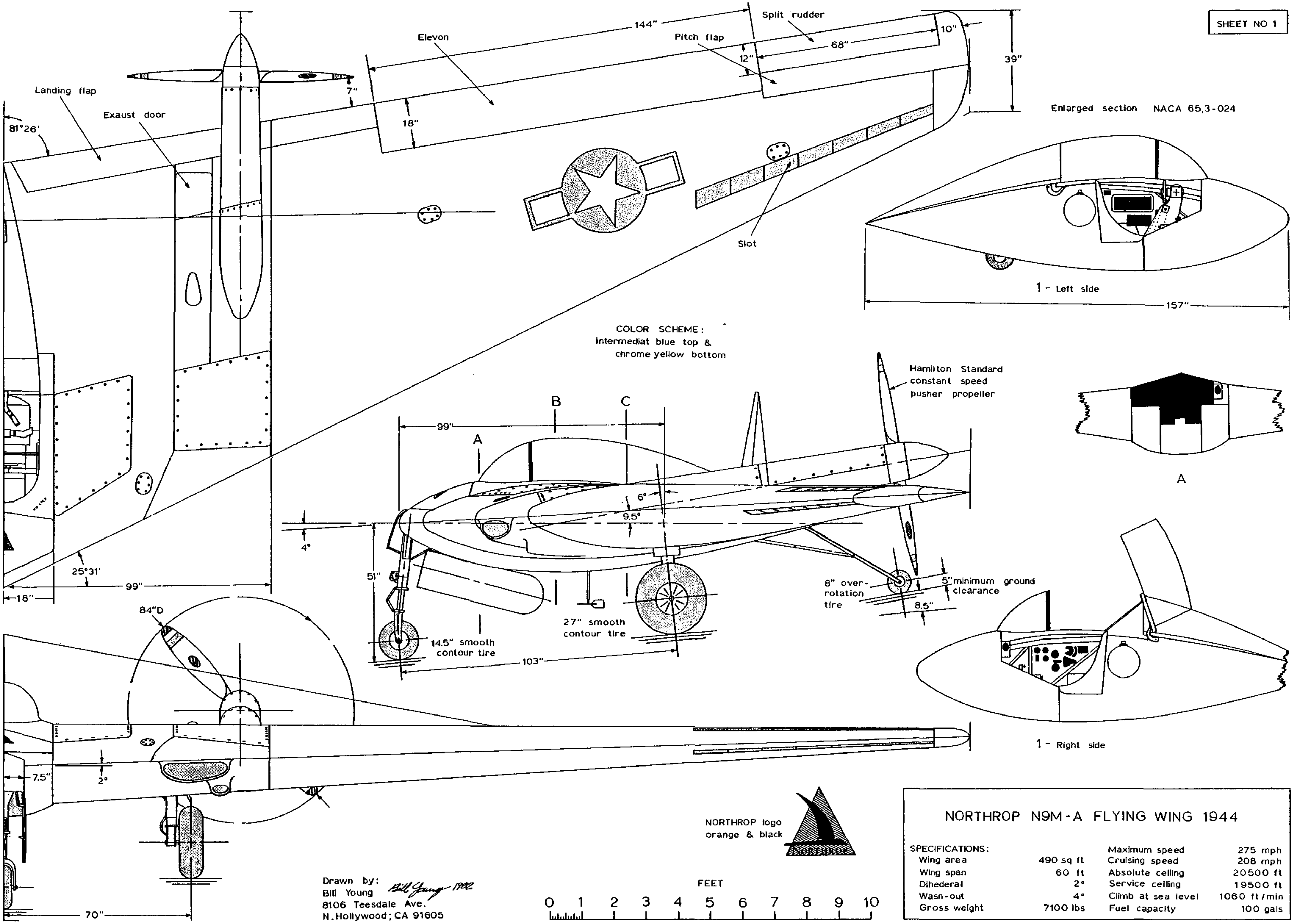
Distribution of the N-9M's weight laterally along the wing span established a very low moment of inertia about the pitch axis. This in turn created a control sensitivity that most pilots found troublesome initially, but it could be readily accommodated after a few minutes of familiarization flight.

Northrop test pilot, Chuck Tucker, who flew the N-9Ms extensively for flight experience, stated that in calm air the N-9M had excellent overall stability. However, flying in rough air and encountering a gust would cause the nose to bob up and then down, setting up a 'low-grade' oscillation; he did not consider this oscillation dangerous—just different. It was a damping problem. Flying the N-9M according to Tucker was totally different from flying the YB-49 (a B-35 conversion). Pitch 'bobbing' was not experienced due to the much greater size and weight of the YB-49 and its corresponding higher mass inertia.

Yaw damping was another matter from a technical point of view; it was low as designed and not troublesome in the N-9Ms because their handling characteristics were more like a fighter than a bomber. Dr. William Sears, in his paper on the "Evolution of Aircraft Wing Design," presented to the Air Force Museum and the University of Dayton (AIAA), March 18 and 19, 1980, said: "The performance and flying characteristics of the N-9M were good enough to contribute a great deal of confidence to the XB-35 program. Its flight tests, however, revealed that the lateral-directional oscillation, which was lightly damped, as expected, was sufficiently annoying in turbulent air, to cast some doubts on the success of the airplane as a bombing platform. The period of this oscillation in the full-scale airplane would be ≈ 3 times as great—10 to 12 sec."

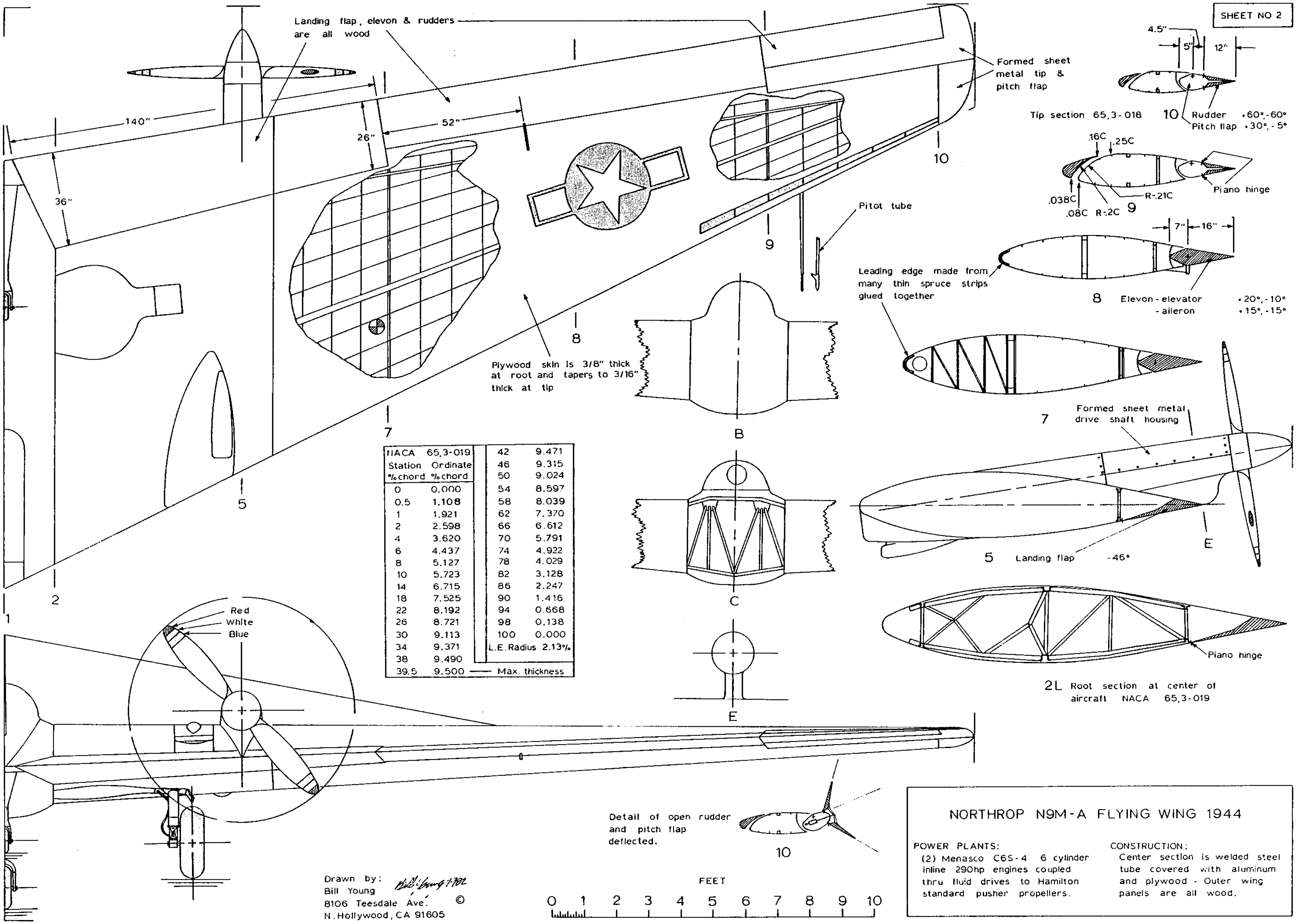
Flight characteristics of the N-9Ms were similar to well-designed conventional aircraft, once the appropriate control modifications were incorporated and some of their unique properties became familiar. An attribute of Northrop's flying wings, not included in available publications, is that the basic concept envisioned positive stability about all axes, but at a reduced level, one-tenth to one-fifth of what were considered orthodox standards. Reduced stability levels were thought to be appropriate because of the elimination of destabilizing conditions, such as propeller slipstream, fuselage influence, forward projection engine nacelles and so on. This in turn would allow smaller control surfaces in spite of the close coupling of the controls (in pitch) to the C.G.; smaller controls are desirable, having a lesser impact on total wing lift, which improves takeoff, maneuver and landing performance. In fact, the N-9Ms, as well as the XB-35/YB-49, were stable about all axes, but what materialized were reduced damping characteristics that were considered unacceptable by contemporary Army Air Force standards. Flying Wing literature, in a somewhat subjective manner, emphasizes "stability when damping is the issue." Damping requirements could readily be handled by properly designed autopilots, however, autopilot evolution lagged the evolving flying wing. □

CONCLUDED NEXT ISSUE



NORTHROP N9M-A FLYING WING 1944

SPECIFICATIONS:			
Wing area	490 sq ft	Maximum speed	275 mph
Wing span	60 ft	Cruising speed	208 mph
Dihederal	2°	Absolute ceiling	20500 ft
Wasn-out	4°	Service ceiling	19500 ft
Gross weight	7100 lbs	Climb at sea level	1060 ft/min
		Fuel capacity	100 gals



NACA 65,3-019 Station %chord	Ordinate %chord	Station %chord	Ordinate %chord
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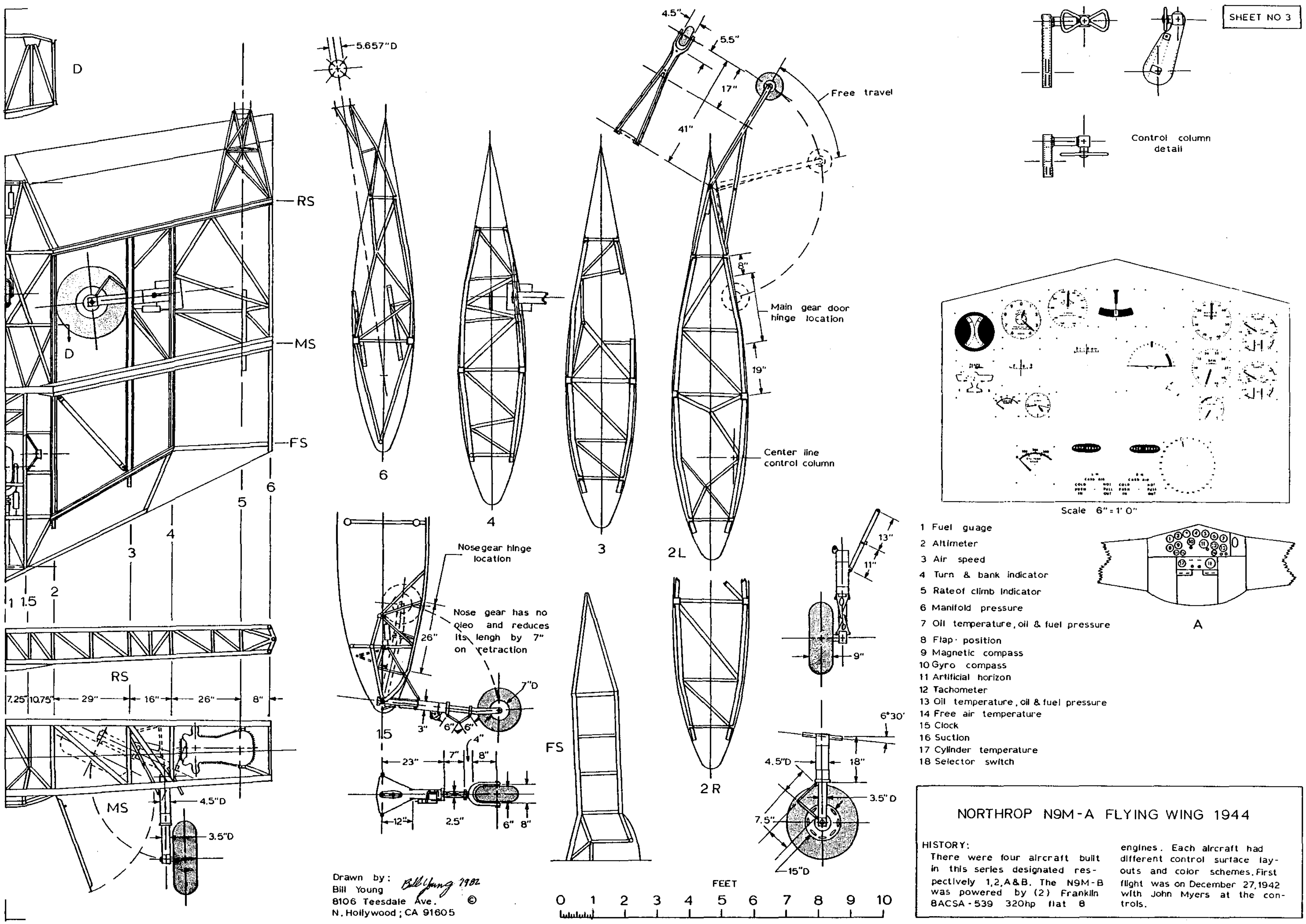
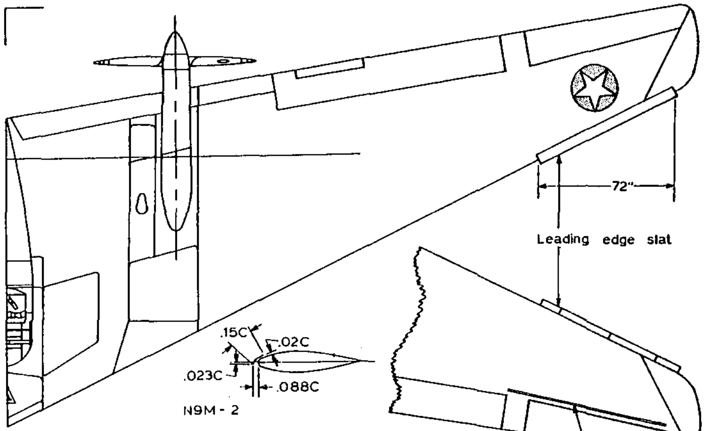
0.5	1.108	46	9.315
1	1.921	50	9.024
2	2.598	54	8.597
4	3.620	58	8.039
6	4.437	62	7.370
8	5.127	66	6.612
10	5.723	70	5.791
14	6.715	74	4.922
18	7.525	78	4.029
22	8.192	82	3.128
26	8.721	86	2.247
30	9.113	90	1.416
34	9.371	94	0.668
38	9.490	98	0.138
39.5	9.500 — Max. thickness	100	0.000
		L.E. Radius	2.13%

NORTHROP N9M-A FLYING WING 1944

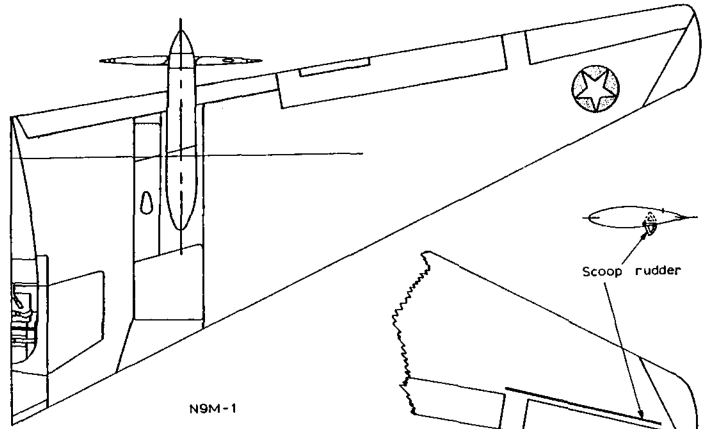
POWER PLANTS:
(2) Menasco C6S-4 6 cylinder inline 290hp engines coupled thru fluid drives to Hamilton standard pusher propellers.

CONSTRUCTION:
Center section is welded steel tube covered with aluminum and plywood - Outer wing panels are all wood.

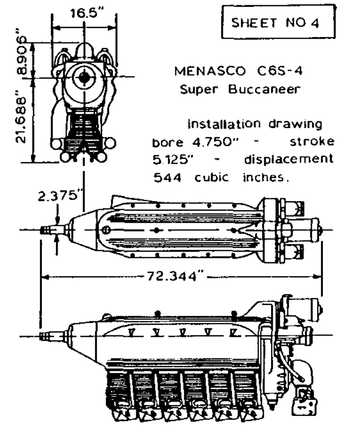

SHEET NO 3
Control column detail
Free travel
Main gear door hinge location
Center line control column
Nosegear hinge location
Nose gear has no oleo and reduces its lengh by 7" on retraction
RS
MS
FS
Scale 6" = 1' 0"
1 Fuel guage
2 Altimeter
3 Air speed
4 Turn & bank indicator
5 Rateof climb indicator
6 Manifold pressure
7 Oil temperature, oil & fuel pressure
8 Flap position
9 Magnetic compass
10 Gyro compass
11 Artificial horizon
12 Tachometer
13 Oil temperature, oil & fuel pressure
14 Free air temperature
15 Clock
16 Suction
17 Cylinder temperature
18 Selector switch
A
Drawn by:
Bill Young
8106 Teesdale Ave.
N. Hollywood; CA 91605
Bill Young 1982 ©
FEET
0 1 2 3 4 5 6 7 8 9 10
NORTHROP N9M-A FLYING WING 1944
HISTORY:
There were four aircraft built in this series designated respectively 1, 2, A & B. The N9M-B was powered by (2) Franklin 8ACSA-539 320hp flat 8 engines. Each aircraft had different control surface layouts and color schemes. First flight was on December 27, 1942 with John Myers at the controls.



Color scheme : orange yellow top & intermediat blue bottom, differences from N9M - A : elevons 24" shorter and include a trim tab , a slat on the leading edge , the pitch flap is hingeded on the top leading edge , and a scoop rudder is installed on the bottom of the wing , the dihederal was 1/2°.



Color scheme : orange yellow all over ; other differences same as the N9M - 2 except for no leading edge slat.



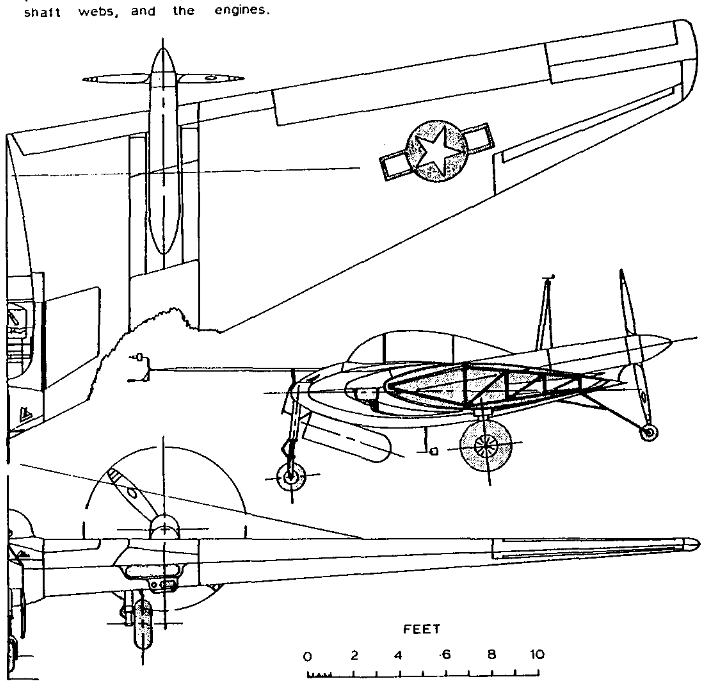
SHEET NO 4

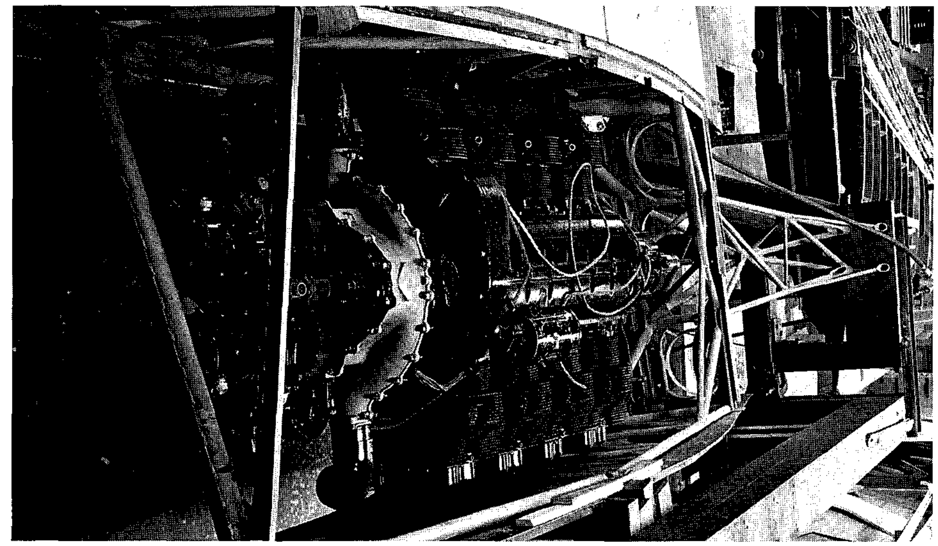
MENASCO C6S-4
Super Buccaneer

Installation drawing
bore 4.750" - stroke 5.125" - displacement 544 cubic inches.

N9M - B

Color scheme : intermediat blue bottom & orange yellow top , differences from N9M - A : drive shaft center to center distance is 162.5", air intake, pitot tube location, radio antenna, automatic doors on slots, drive shaft webs, and the engines.





Close-up of the Franklin XO-540-7 engine installation in the N-9MB on February 18, 1944. (Northrop/Balzer)

NORTHROP N9M - A FLYING WING 1944

Overall length	17.78 ft.
Overall height	8.58 ft.
Max. forward cg	27.5% mac.
Max. rearward cg.	28.6% mac.

History: The N9M's were true 1/3 scale models of the XB-35 bomber. They went through many changes to prove which configuration was most viable.

Drawn by : Bill Young 1982
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