Return to

C. T. REID

DEVELOPMENT
OF THE
DOUGLAS
TRANSPORT

BY C.T. REID

ENGINEERING DEPT.
TECHNICAL DATA SW-157A

DEVELOPMENT
OF
THE DOUGLAS TRANSPORT

DOUGLAS AIRCRAFT CO. INC.
SANTA MONICA CALIF. U.S.A.

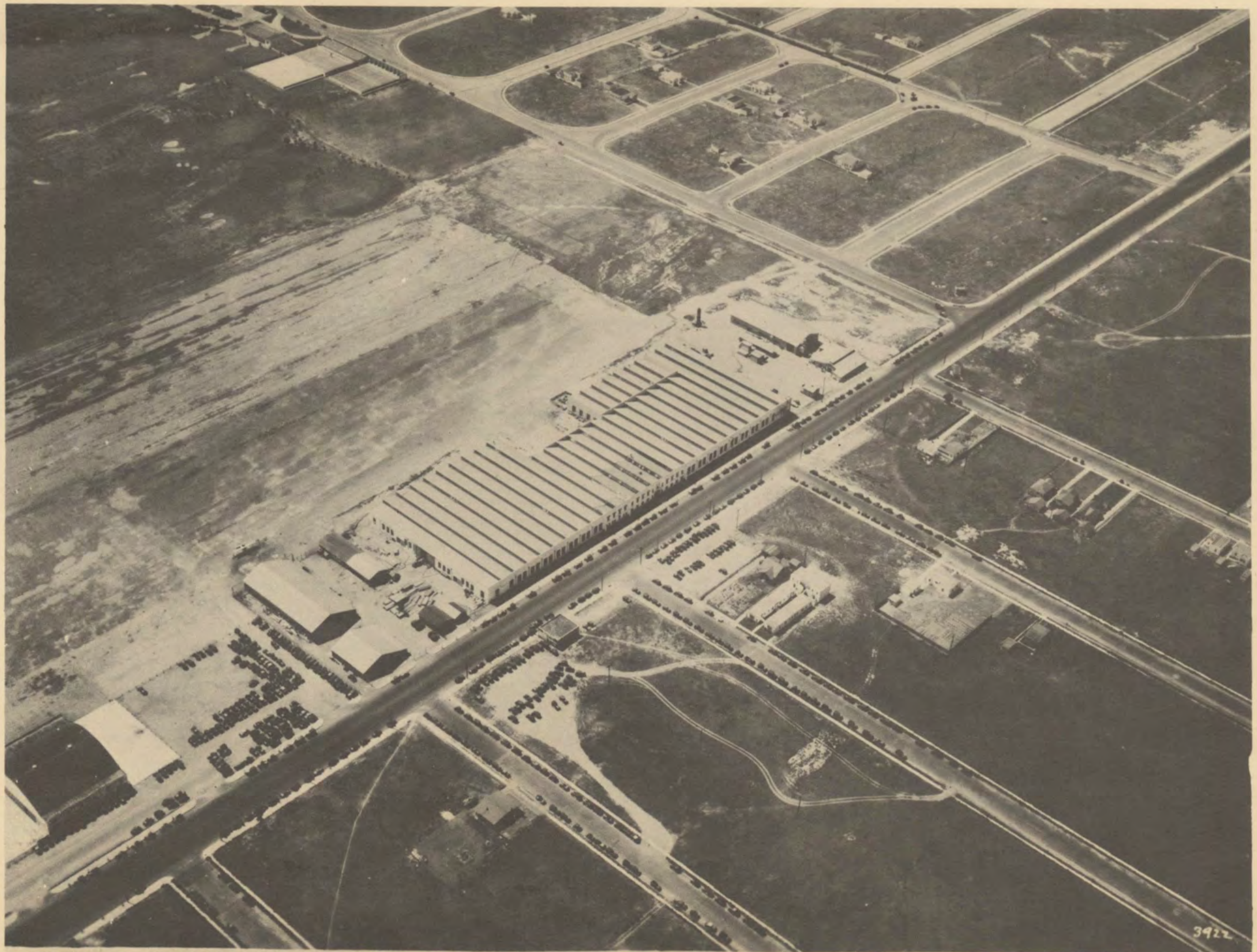
The Douglas Aircraft Company, Inc.

The Douglas Aircraft Company has, since 1928, occupied the present factory site at Clover Field, Santa Monica, California. The plant has been repeatedly enlarged and now comprises eight acres of land with 350,000 square feet of floor space in buildings and adjoins an excellent all paved surface flying field.

At the present time, the Douglas Company employs 2500 people at its plant in Santa Monica. In addition to the DC transports, a number of two-engined amphibions for military and commercial use are being produced. Army observation airplanes in quantity and a great variety of experimental land planes, amphibions and flying boats for the United States Government are also under construction.

The Company has, in the past, produced large quantities of advanced training planes, bombers, fighters, patrol boats and transports in addition to its standard line of torpedo and observation planes. The success of these airplanes, most of which have been of metal construction, has been evidenced by repeated orders from the United States and foreign governments. The Douglas general utility amphibion originally produced for the commercial field has been adopted as a standard type by the United States Army, Navy and Coast Guard.

A Douglas subsidiary interest, the Northrop Corporation, employing 1000 people, has at the present a factory of 140,209 square feet floor space at Los Angeles Municipal Airport, where much valuable pioneering in high speed airplane building is being carried on. The reliability of the Northrop all-metal, multi-cellular construction is exemplified by the "Alpha" mail carrying model, of which a fleet has been operating for several years with running time on each airplane aggregating over 5000 hours and no structural overhaul as yet required.



AERIAL VIEW OF THE DOUGLAS FACTORY. (THE FACTORY HAS RECENTLY BEEN ENLARGED SINCE THIS PICTURE WAS TAKEN.)

DEVELOPMENT

of the

DOUGLAS TRANSPORT

Introduction

After fourteen years of continuous, successful experience in building airplanes of all types for the United States Army, Navy, Post Office Department and Coast Guard and for private persons and foreign governments, the Douglas Aircraft Company started plans for the design and development of a high performance passenger airplane for airline use. Profiting by extensive experience in the design and production of aircraft, the Company decided to make an extremely thorough investigation of all factors, however minor, that might affect performance and passenger comfort. Before construction was started, hundreds of wind tunnel and structural tests were made in addition to an intensive mock-up investigation and studies and tests of special items, such as fuel systems, control mechanisms, heating, lighting and ventilating systems and sound control. When the various parts of the airplane were ready, they were each tested to show their static strength and freedom from vibration or flutter.

The finished airplane was, in all probability, subjected to more thorough flight tests than any other known type of passenger transport or even military airplane. Over two hundred flying hours and fifteen thousand gallons of fuel were used in making these flight tests. Not only were the usual tests for speed, stability and general performance made but also tests subjecting the airplane to dynamic loads in flight to prove its structural strength, to determine the best soundproofing practical, to eliminate vibration and to determine the effect of certain variables, such as different engine cowls, fairings, oil temperature regulators, propellers, wing and control surface flaps, engine cooling and power. In conjunction with these tests, several entirely new conceptions in flight testing were put into practice and a new technique for airline cruising operation was developed.

The development cost of the first airplane, including all research directly connected with the project, was approximately $325,000. In addition, the airplane incorporates a great amount of the experience obtained during airline operation of the highly successful single-engined Northrop transports, which represent an engineering and development cost of approximately $290,000.

It is desired to outline briefly in the following pages some of the work done in the development of the Douglas DC-1 and its successor, the DC-2. Tests are still being carried on daily, both on the ground and in flight, to improve and refine this airplane and make it a still more superior product, both from a manufacturing and an operating viewpoint.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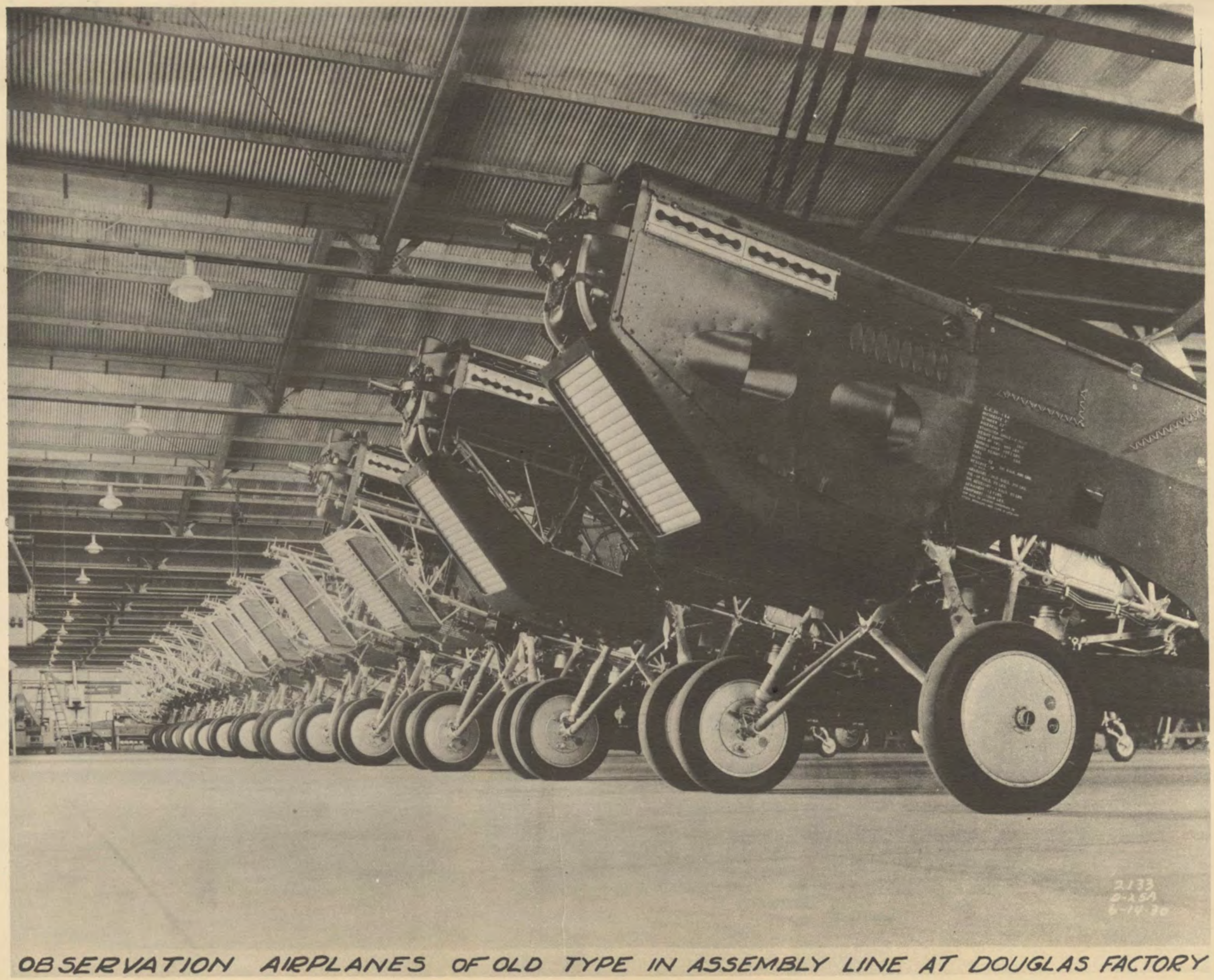

OBSERVATION AIRPLANES OF OLD TYPE IN ASSEMBLY LINE AT DOUGLAS FACTORY

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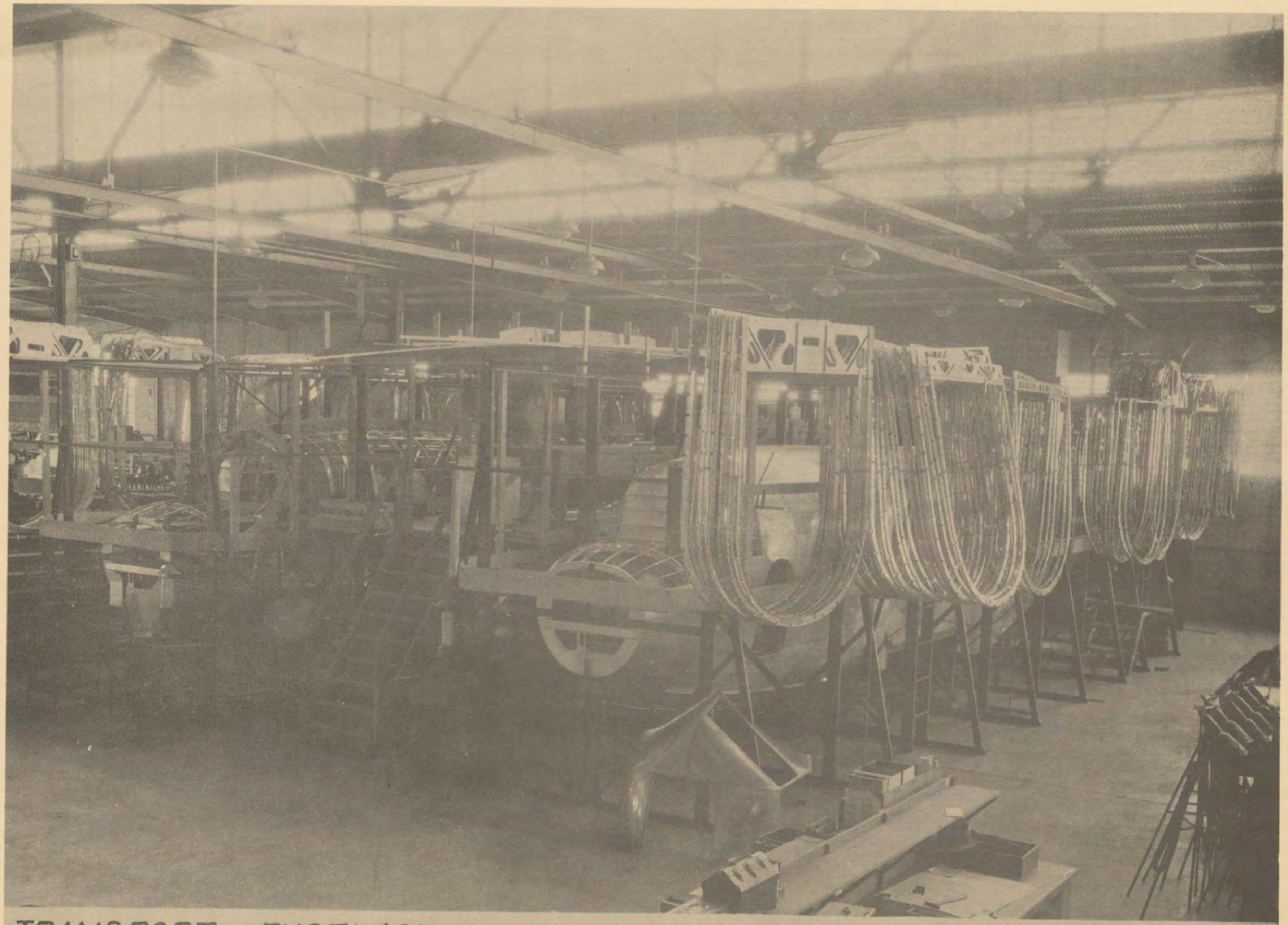
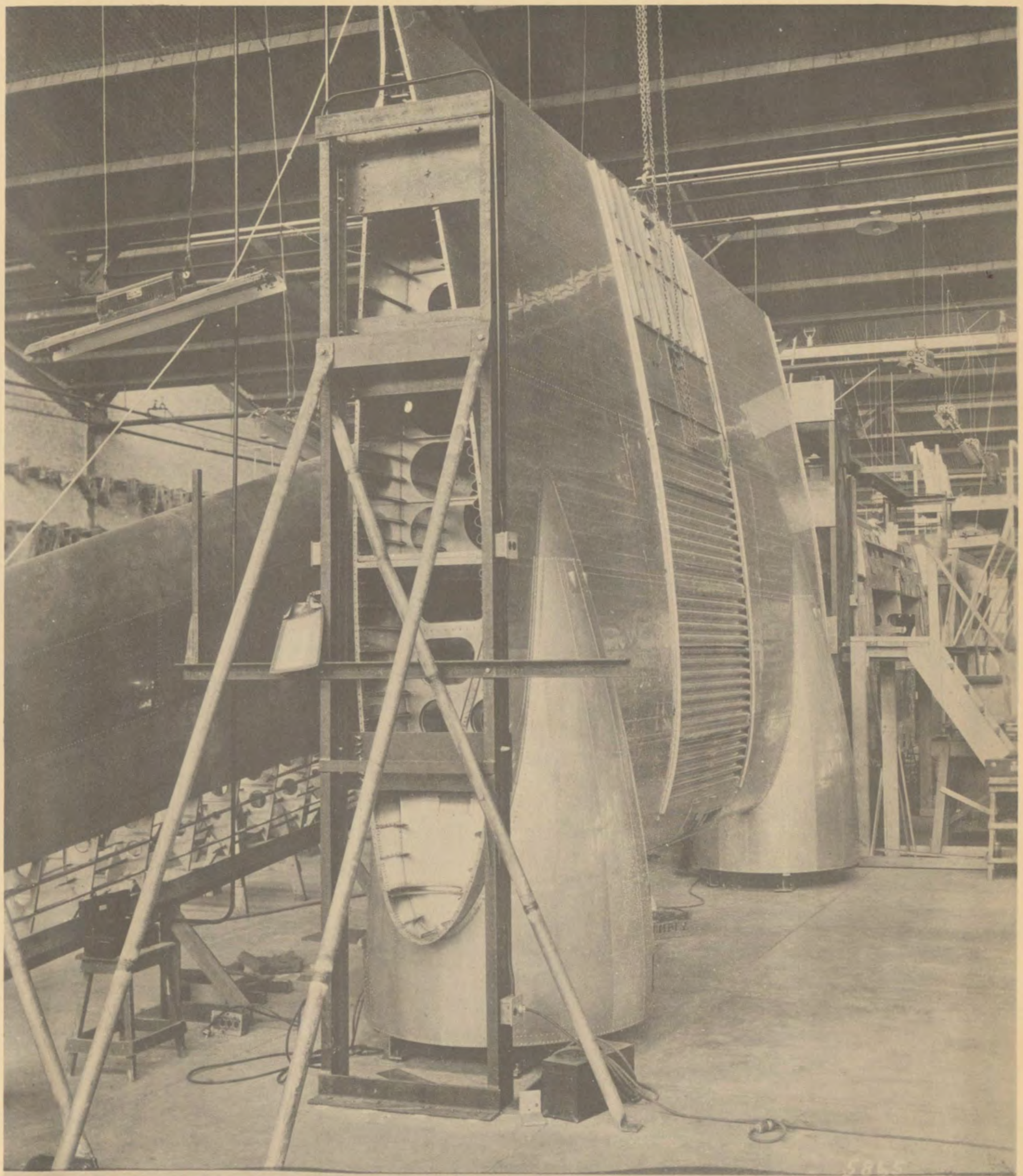
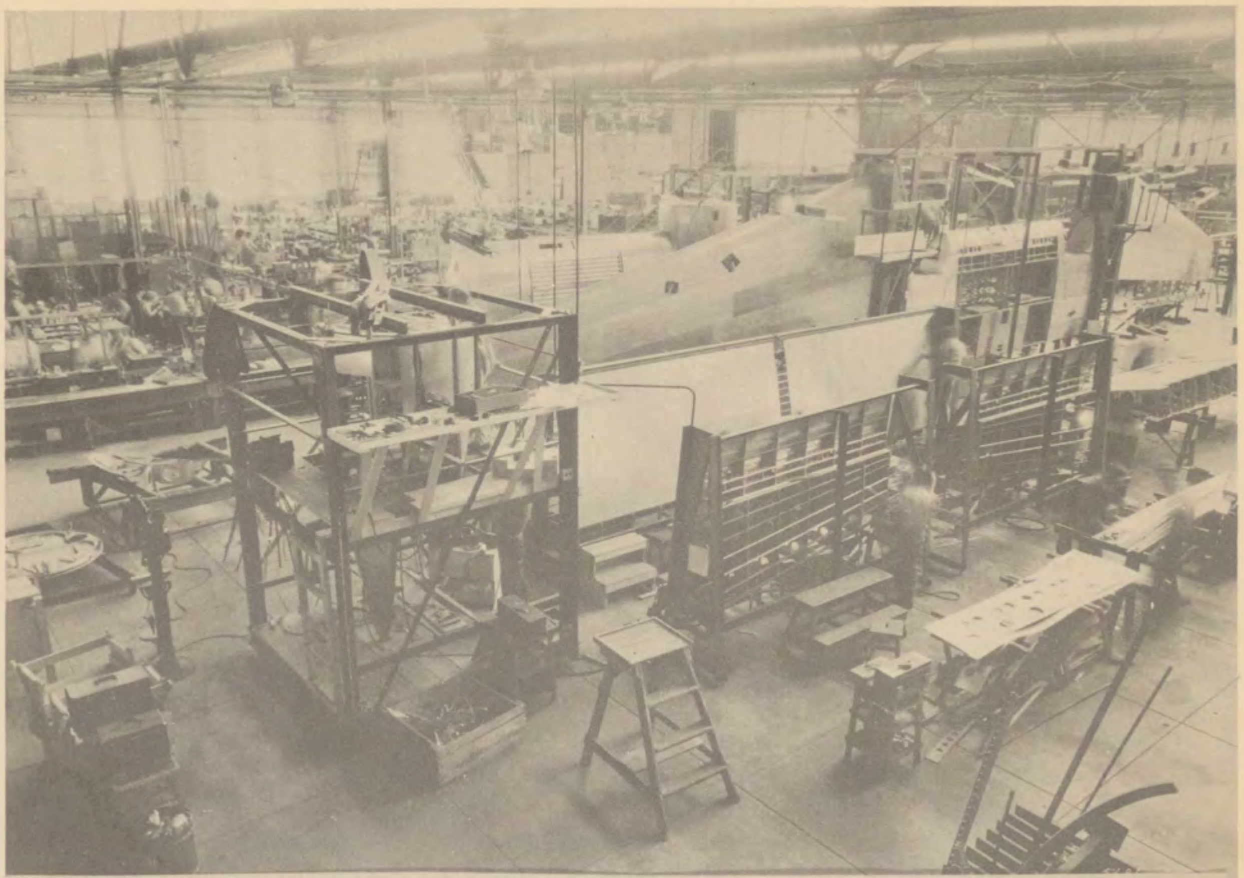


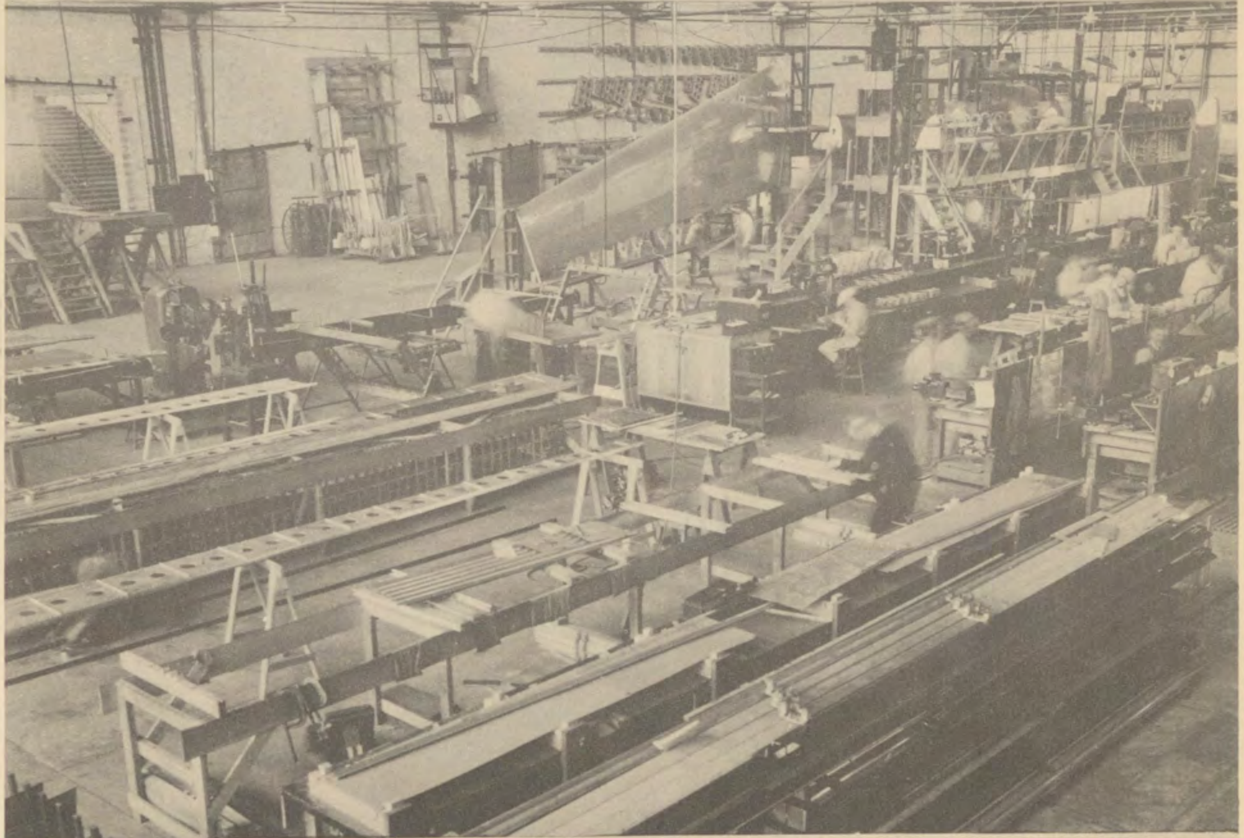
TRANSPORT FUSELAGE ASSEMBLY JIGS. IT REQUIRES ONLY FIFTEEN MINUTES TO REMOVE THE COMPLETE FUSELAGE AND PLACE IT ON THE ASSEMBLY FLOOR.



THE TRANSPORT CENTER WING PANEL IS CONSTRUCTED IN TWO SECTIONS, THE FRONT ONE CARRYING THE NACELLES. IN THE JIG SHOWN HERE THE FRONT AND REAR SECTIONS OF THE WING ARE JOINED TOGETHER.

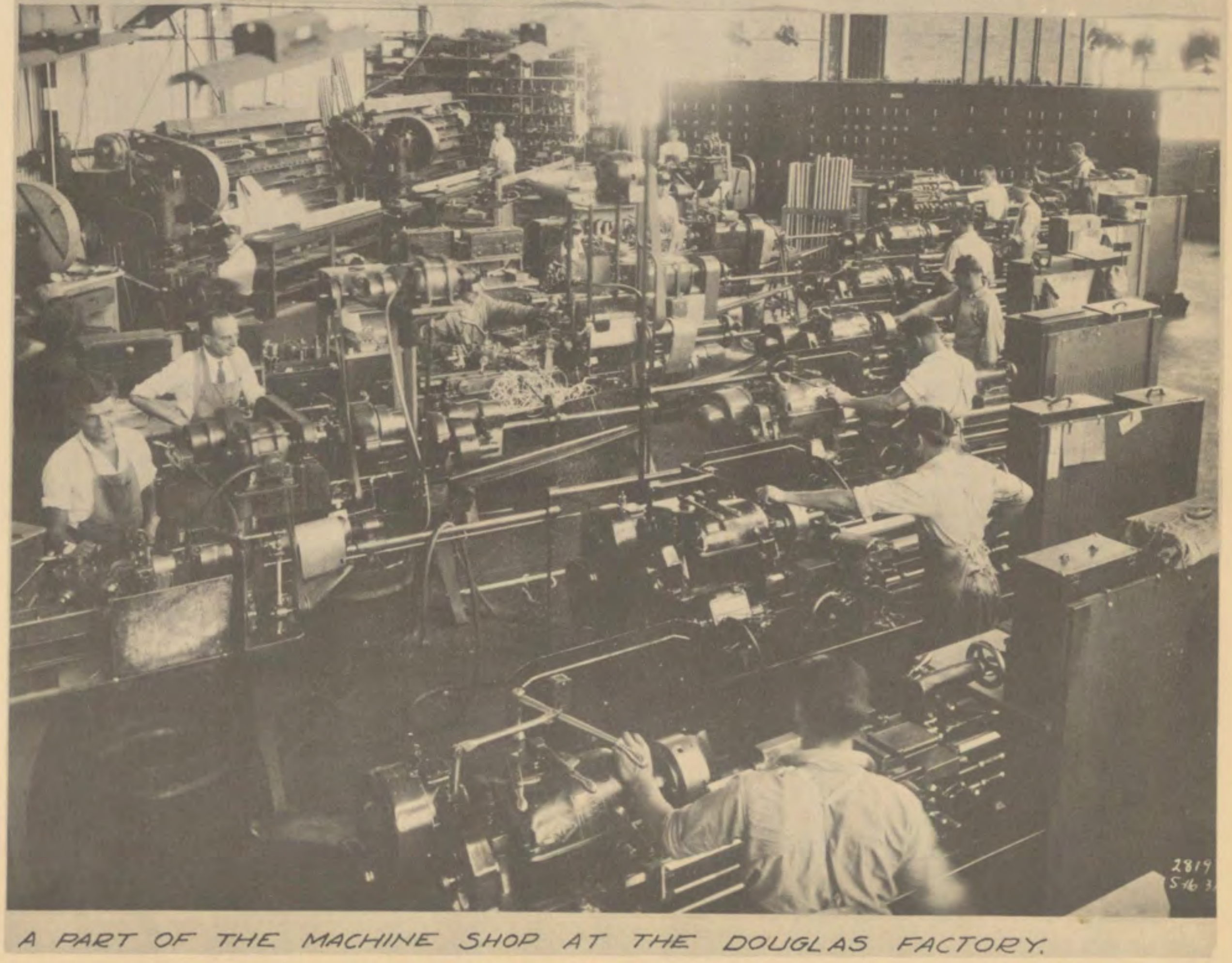


A PORTION OF THE WING DEPARTMENT AT THE DOUGLAS FACTORY. IN THE LEFT FOREGROUND IS AN ENGINE NACELLE ASSEMBLY JIG AND IN THE RIGHT FOREGROUND JIGS FOR ASSEMBLY OF WING TRAILING EDGE SECTIONS. BEHIND THESE A JIG FOR ASSEMBLY OF CENTER WING PANELS WITH OUTER WING PANEL JIGS AT EITHER SIDE.

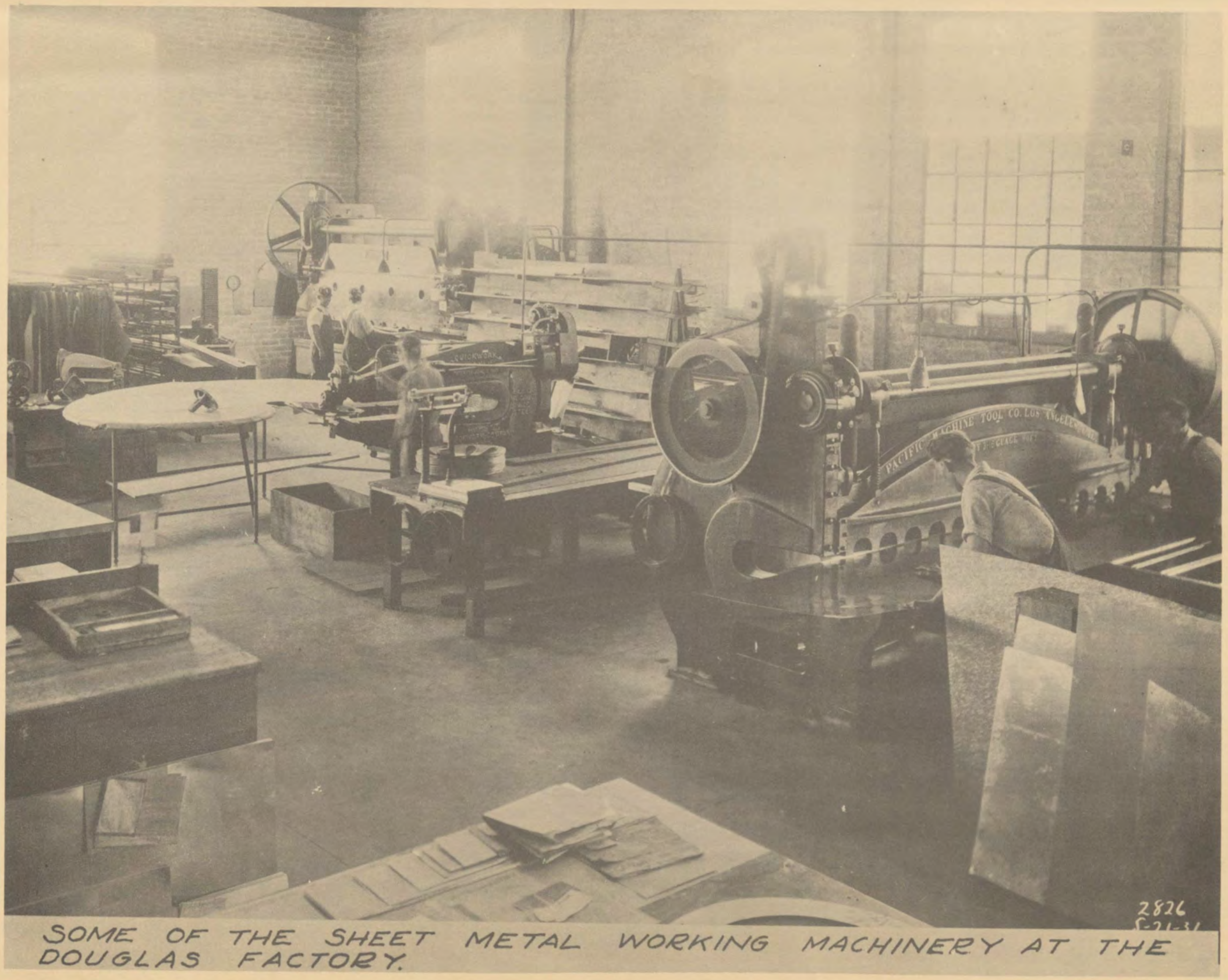


ANOTHER VIEW IN THE WING DEPARTMENT. IN THE FOREGROUND IS THE WING SPAR ASSEMBLY DEPARTMENT. NOTE THE AUTOMATIC RIVETING MACHINE AT THE LEFT. THE OUTER WING PANEL JIG SHOWN IN THE BACKGROUND IS USED FOR ATTACHING THE TRAILING EDGE SECTION, AILERON HINGES, AND WING ATTACHMENT PROFILES.

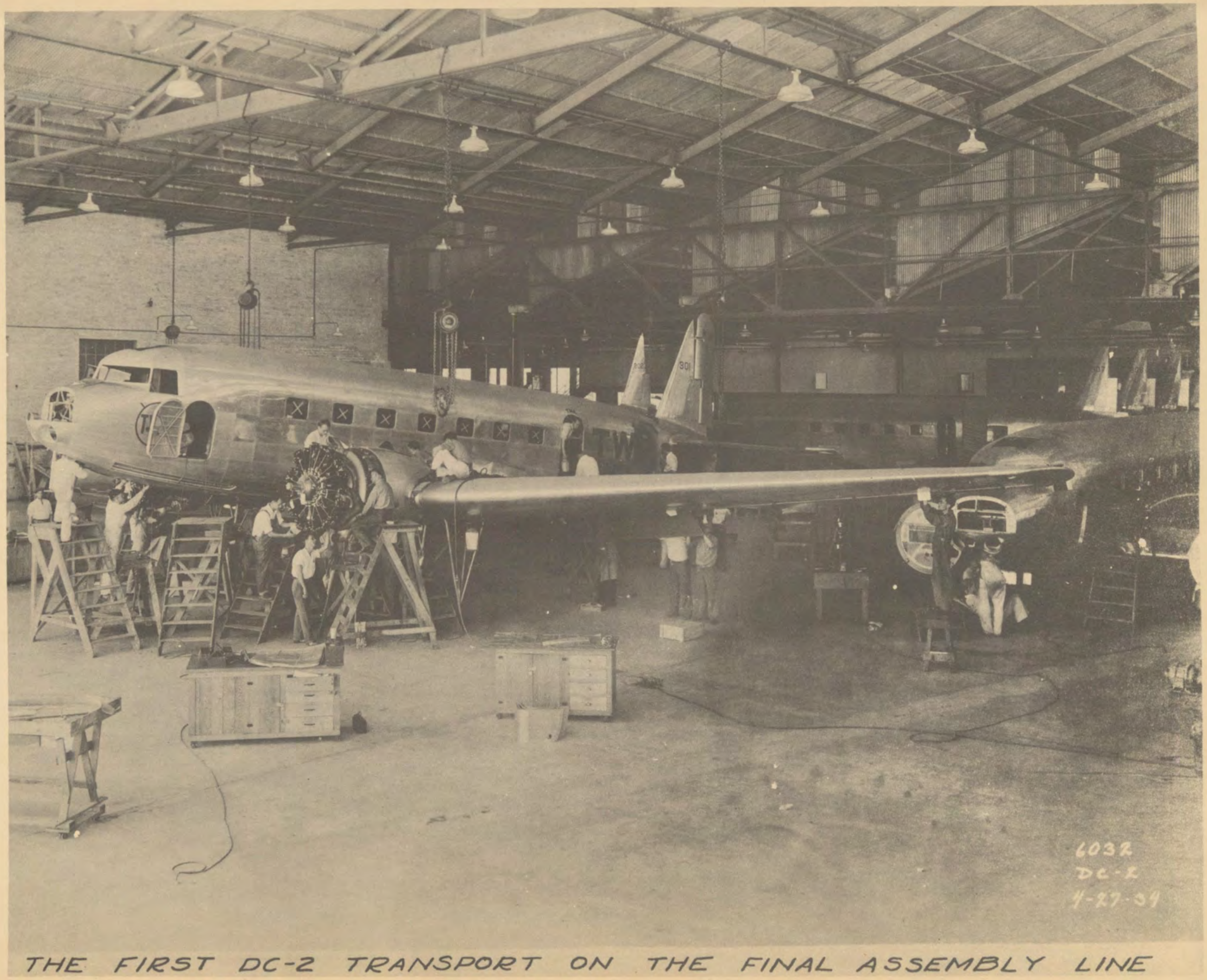
VIEW OF THE METAL FITTINGS DEPARTMENT AT THE DOUGLAS FACTORY THE SCREENED SECTION IN THE LEFT BACKGROUND IS AN INSPECTION BOOTH.



A PART OF THE MACHINE SHOP AT THE DOUGLAS FACTORY.



SOME OF THE SHEET METAL WORKING MACHINERY AT THE DOUGLAS FACTORY.



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DC-2
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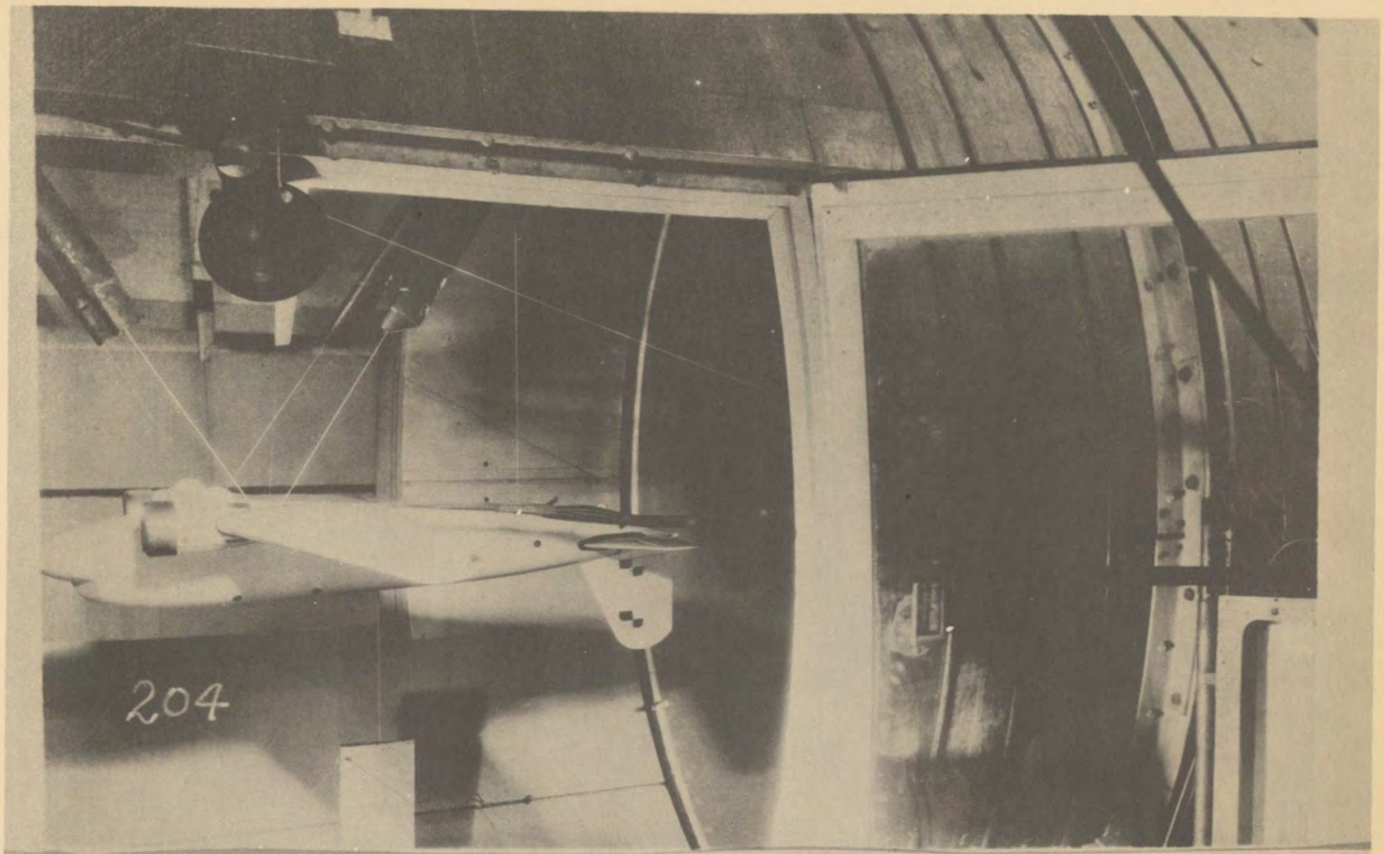
THE FIRST DC-2 TRANSPORT ON THE FINAL ASSEMBLY LINE

Aerodynamic Development

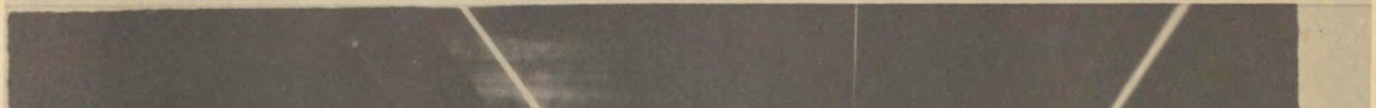
The aerodynamic design of the Douglas Transport was the subject of exhaustive study for a period of more than eighteen months. This study included aerodynamic calculations and wind tunnel and flight tests, which were carried out in a scientific and comprehensive manner. Through the correlation of these calculations and data, it was possible to predict and analyze the actual aerodynamic characteristics which were later obtained in service. The high degree of performance and safety offered by the Transport is the realization of features that have been thoroughly studied and tested in the wind tunnel and in flight.

The aerodynamic calculations were particularly concerned with performance and control at all attitudes of flight, both in normal and single-engine operating conditions. Special design of the controls, wing and fairing makes possible continued single-engine operation at high altitudes with sufficient controllability to insure safety for meeting emergency conditions. The performance studies for obtaining the desired velocity, range and climb led to the choice of the bi-motor type with controllable-pitch propellers and high-lift wing flaps being adopted as best meeting the requirements of the high-performance airliner. The flaps give a gain in lift of 35% and a drag increase of 300%.

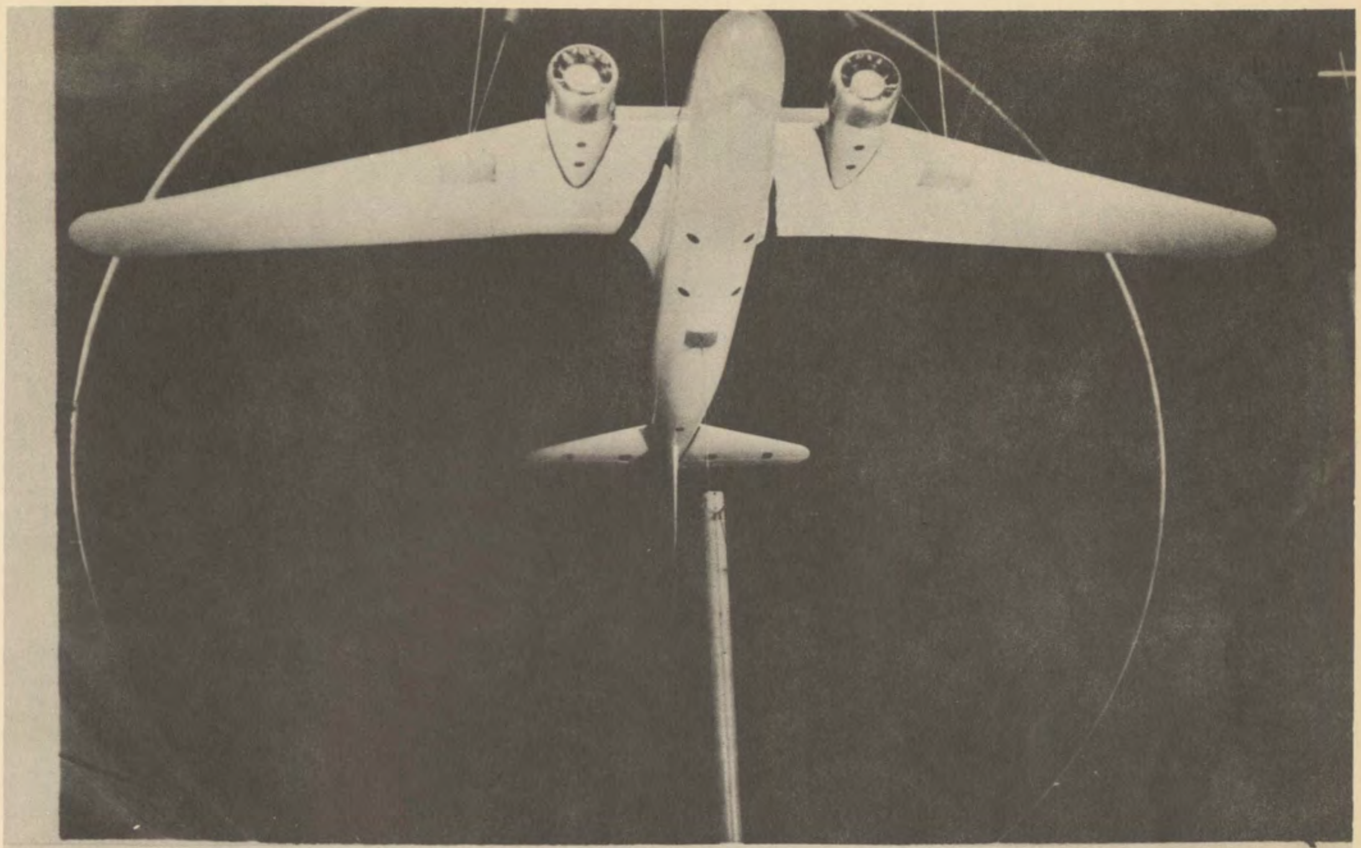
An extensive series of wind tunnel tests, including approximately 200 test runs, were carried out on a one-eleventh scale model of the Transport in the 200 mile-an-hour wind tunnel at the California Institute of Technology. The large scale of the model and high speed of the tests were particularly valuable for this work. All items of the airplane affecting aerodynamic operation were tested with the view not only of obtaining the desired performance, stability and controllability, but also of perfecting each item to the greatest practical degree. Briefly, the investigation included tests on three complete wings with various modifications, various wing to fuselage fillets, tail surfaces, landing gears and tail wheels, several sets of ailerons,



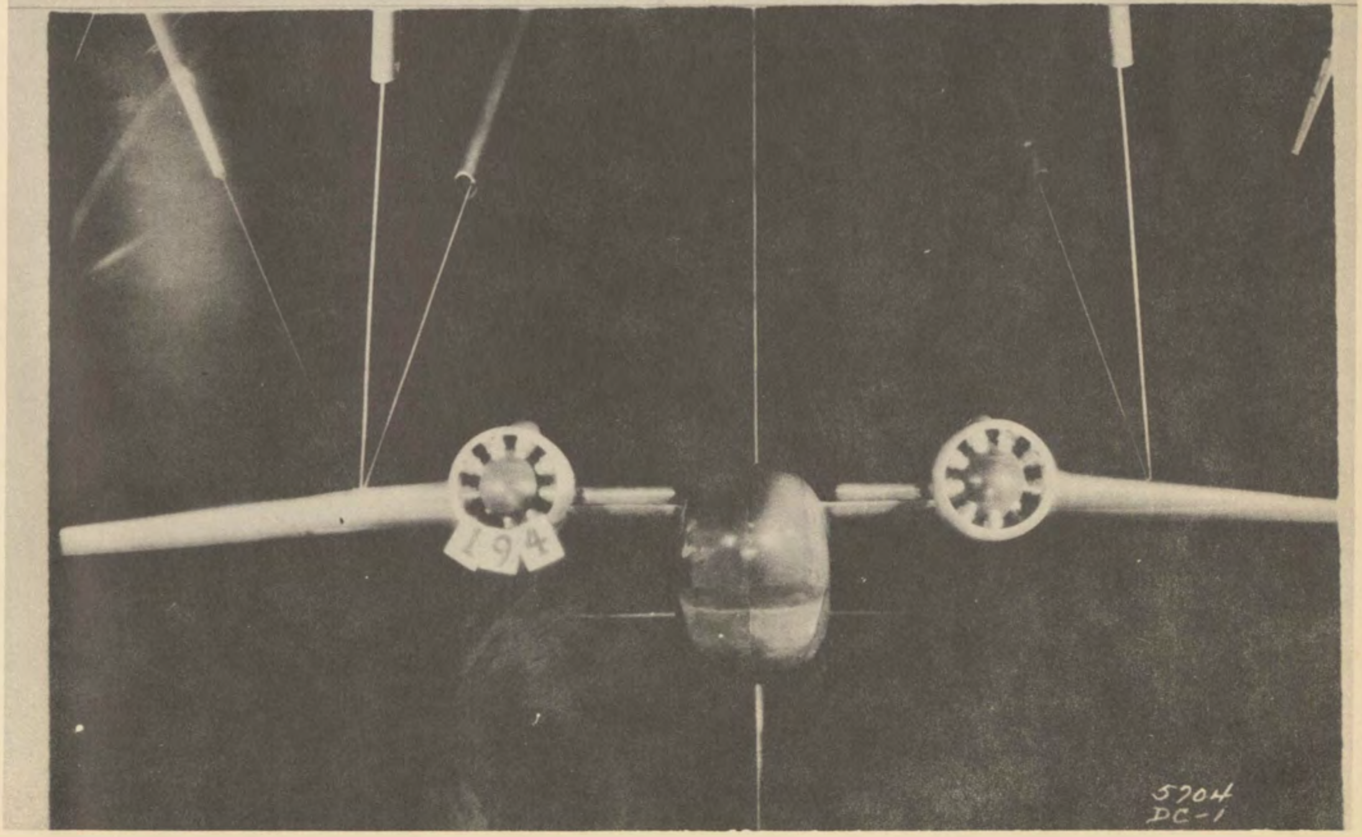
ONE ELEVENTH SCALE MODEL OF THE DOUGLAS TRANSPORT IN THE 200 M.P.H. WIND TUNNEL AT THE CALIF. INSTITUTE OF TECHNOLOGY.



ENGINE NACELLE WIND TUNNEL TEST. THE SCALE IS SHOWN IN INCHES



MODEL MOUNTED IN WIND TUNNEL FOR TEST WITH AUXILIARY WING BETWEEN FUSELAGE AND NACELLES



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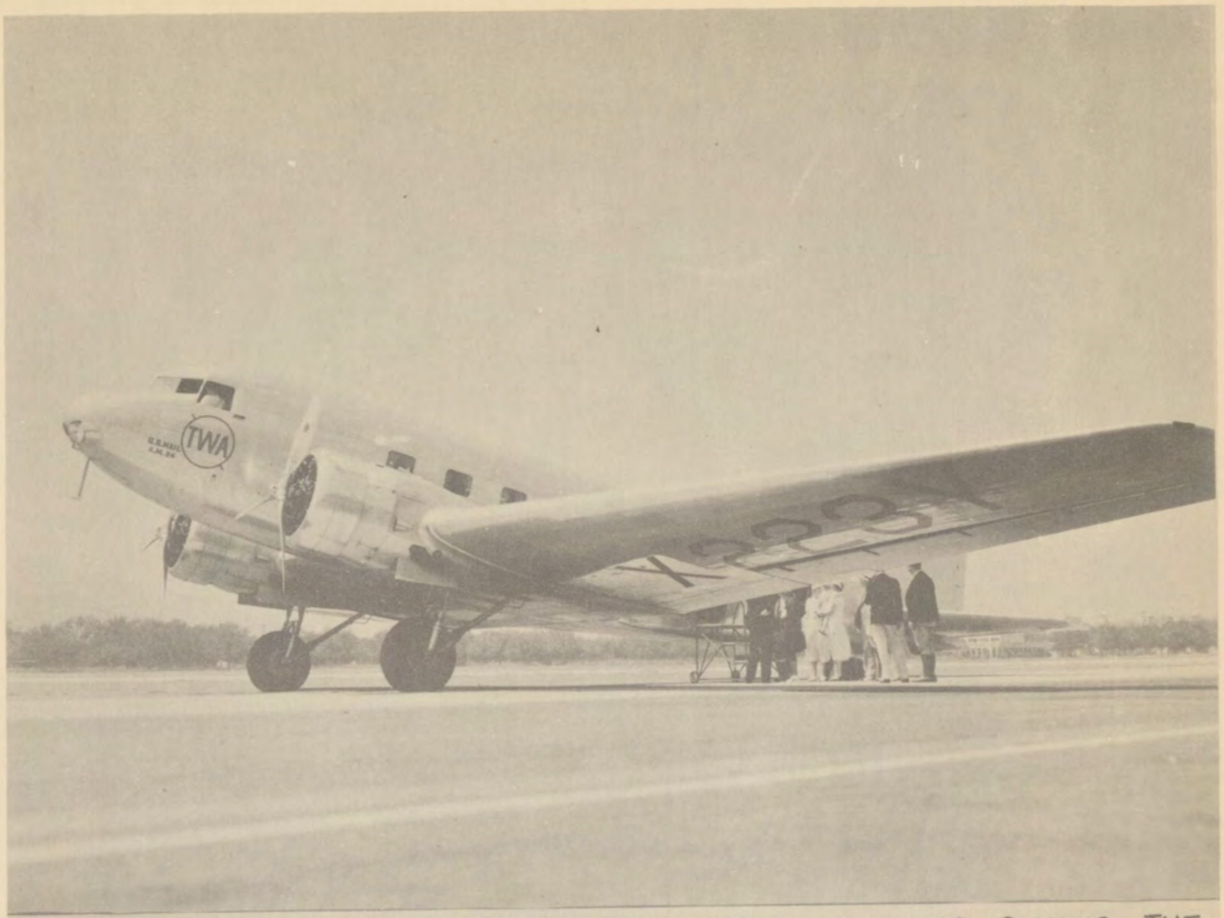
DC-1

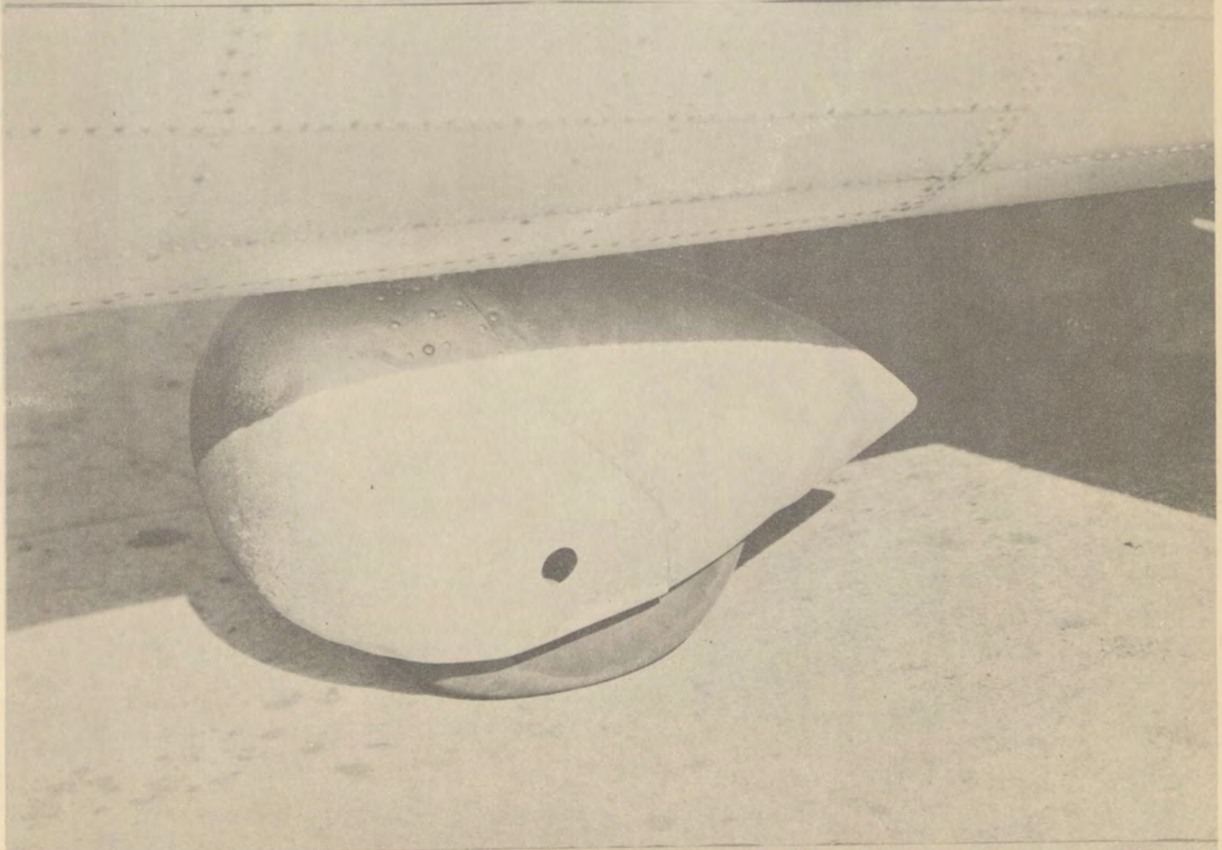
of normal and special types, six arrangements of high-lift wing flap devices, and other special arrangements. Tests on controllability and stability were made with controls both fixed and free. The lift and drag of the final model were tested at various Reynolds numbers in order to indicate the trend in passing to full-scale. The wind tunnel tests resulted in the final erodynamic design providing an increased degree of performance with satisfactory stability and ample controllability for all normal and emergency conditions of flight.

It is interesting to note that some of the early models tested in the wind tunnel showed instability and that the tests revealed that it was necessary for satisfactory stability to have a hitherto untried arrangement of center of gravity, wing sweepback and general configuration. The actual airplane was built in accordance with this new plan of arrangement and the stability in flight proved to be exactly as predicted. If the wind tunnel tests had not been made, it is very possible that the airplane would have been unstable because ordinary investigation had indicated that the original arrangement was satisfactory.

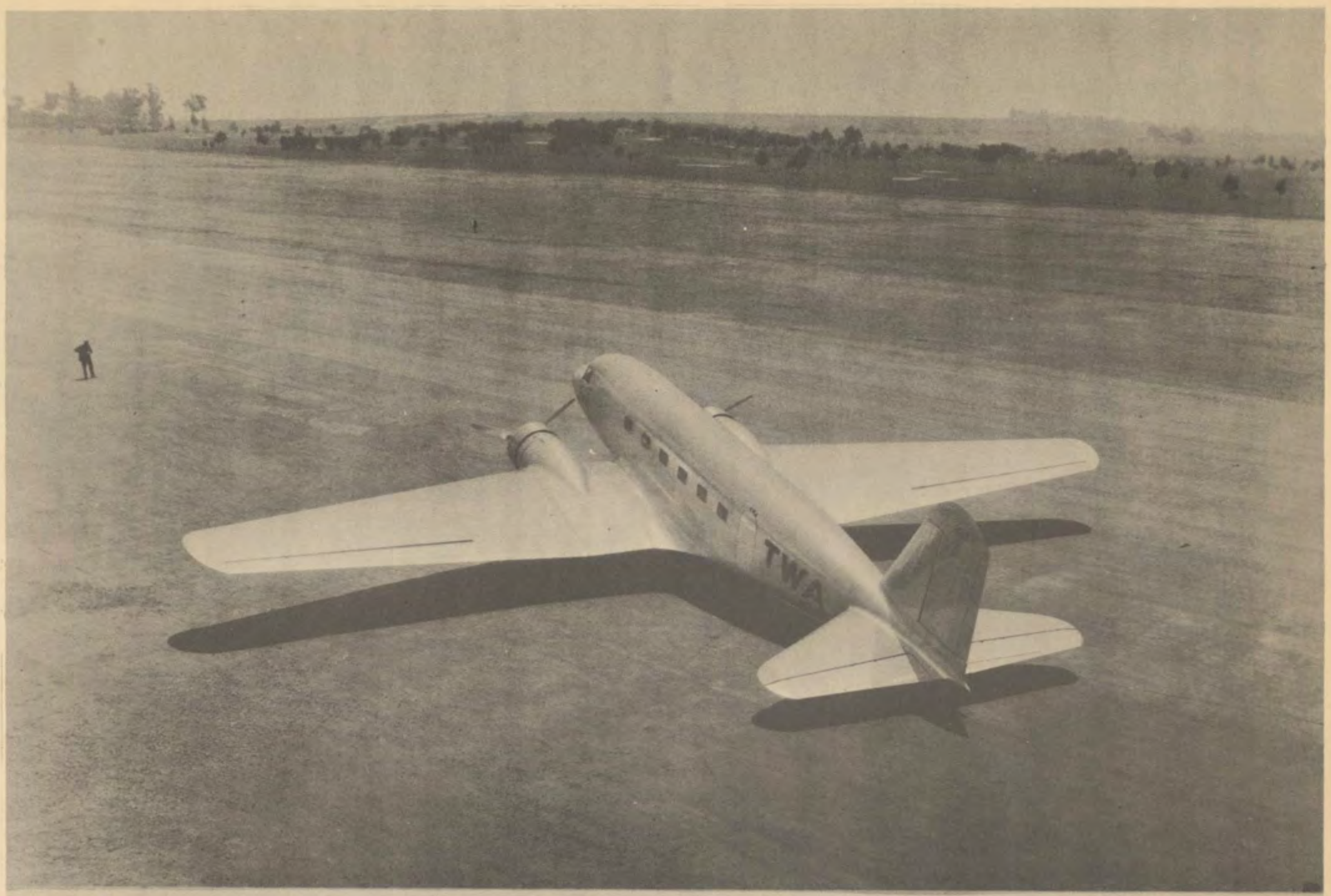
The actual measured flight test results showed an excellent agreement with predicted performance in all phases and fully justified the extensive aerodynamic study and wind tunnel investigation. These flight data have further been used to modify aerodynamic features that indicated possible improvement, so that the final aerodynamic characteristics of the Douglas Transport are extremely satisfactory and very advanced for a transport airplane. In fact, the total resistance of the complete airplane is less than twice the resistance of the wing alone.



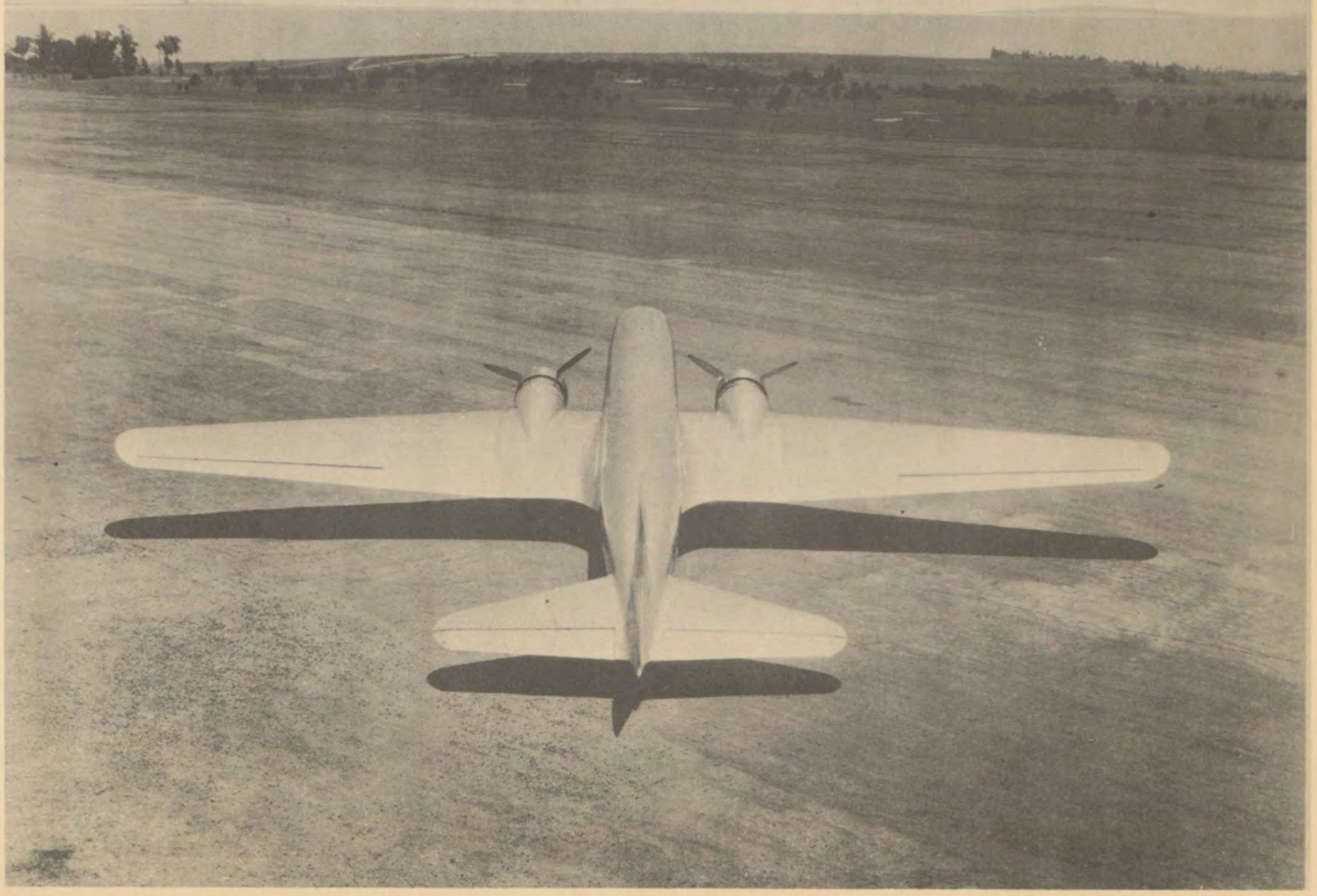
THIS PHOTOGRAPH, TAKEN DURING TEST FLIGHTS, SHOWS THE DOORS WHICH COVERED THE WHEEL OPENINGS IN THE NACELLES WHEN THE GEAR WAS IN THE RETRACTED POSITION. SINCE THE REDUCTION IN DRAG DERIVED FROM THESE WAS NEGLIGIBLE THEY WERE DISCARDED.

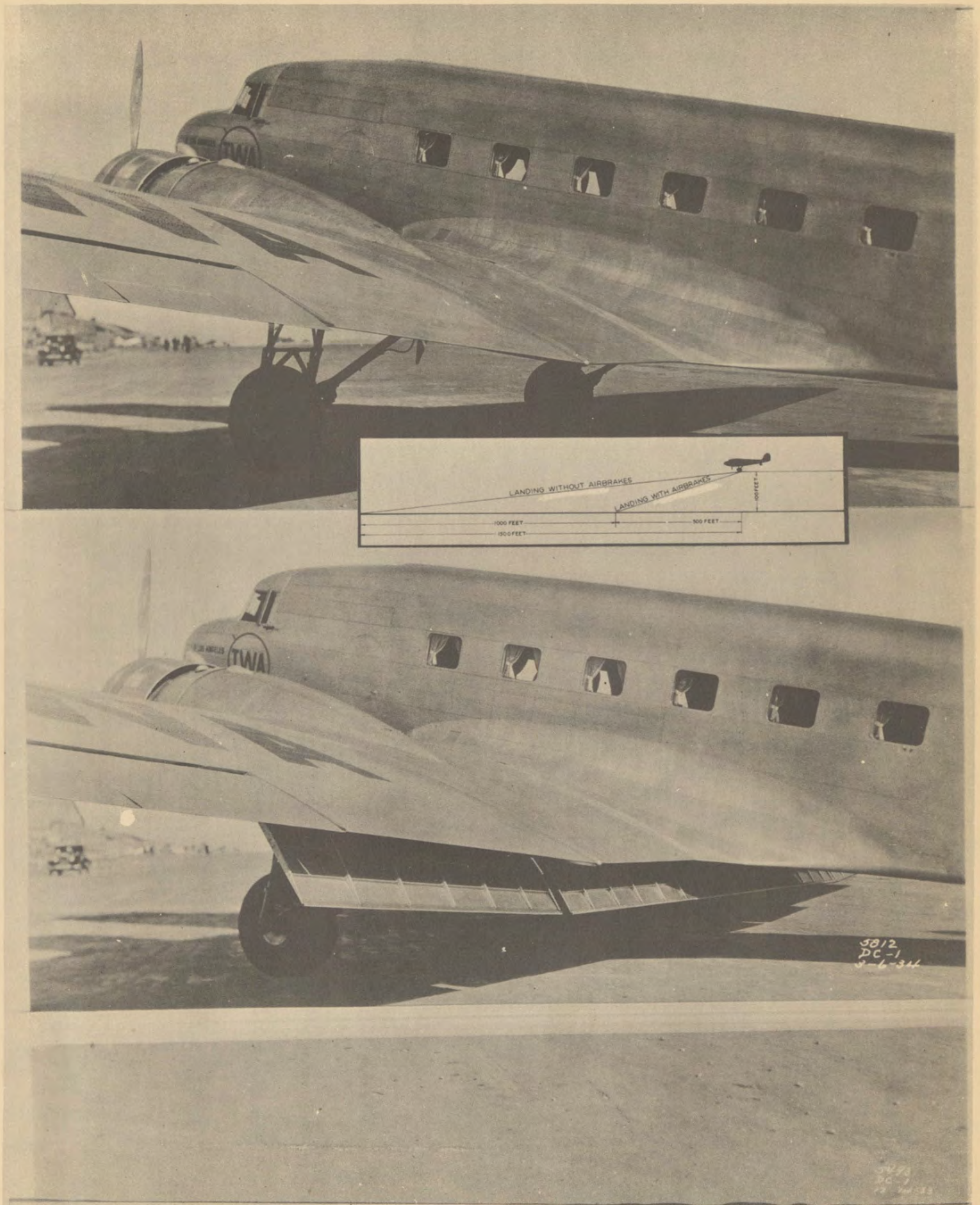


VIEW OF TAIL WHEEL FAIRING WHICH WAS EXTENSIVELY TESTED BUT DISCARDED BECAUSE ITS REDUCTION IN DRAG PROVED TO BE VERY SMALL AND IT WAS UNDESIRABLE FROM THE STANDPOINT OF MAINTENANCE.



THE DC-1 COMPLETE. NOTE THE AERODYNAMICALLY CLEAN DESIGN





VIEW SHOWING THE WING FLAP AIR BRAKES IN THE "UP" AND "FULL DOWN" POSITIONS.

Mock-up and General Arrangement

After the wind tunnel tests had indicated the best aerodynamic arrangement of the component parts of the airplane, a mock-up or model in full size was made to determine the best location and proportions of all structural details. This mock-up was made with wooden frames and covered with heavy paper to simulate the metal sheet covering. All frames were made in the exact sizes and locations of those in the actual airplane.

A complete floor was installed and various seating arrangements were tried in order to determine the combination that would give maximum roominess and comfort. The final arrangement was so worked out that it placed each passenger chair opposite a window, gave ample leg room, wide and unobstructed aisles and allowed a passenger over six feet tall to walk erect in the cabin.

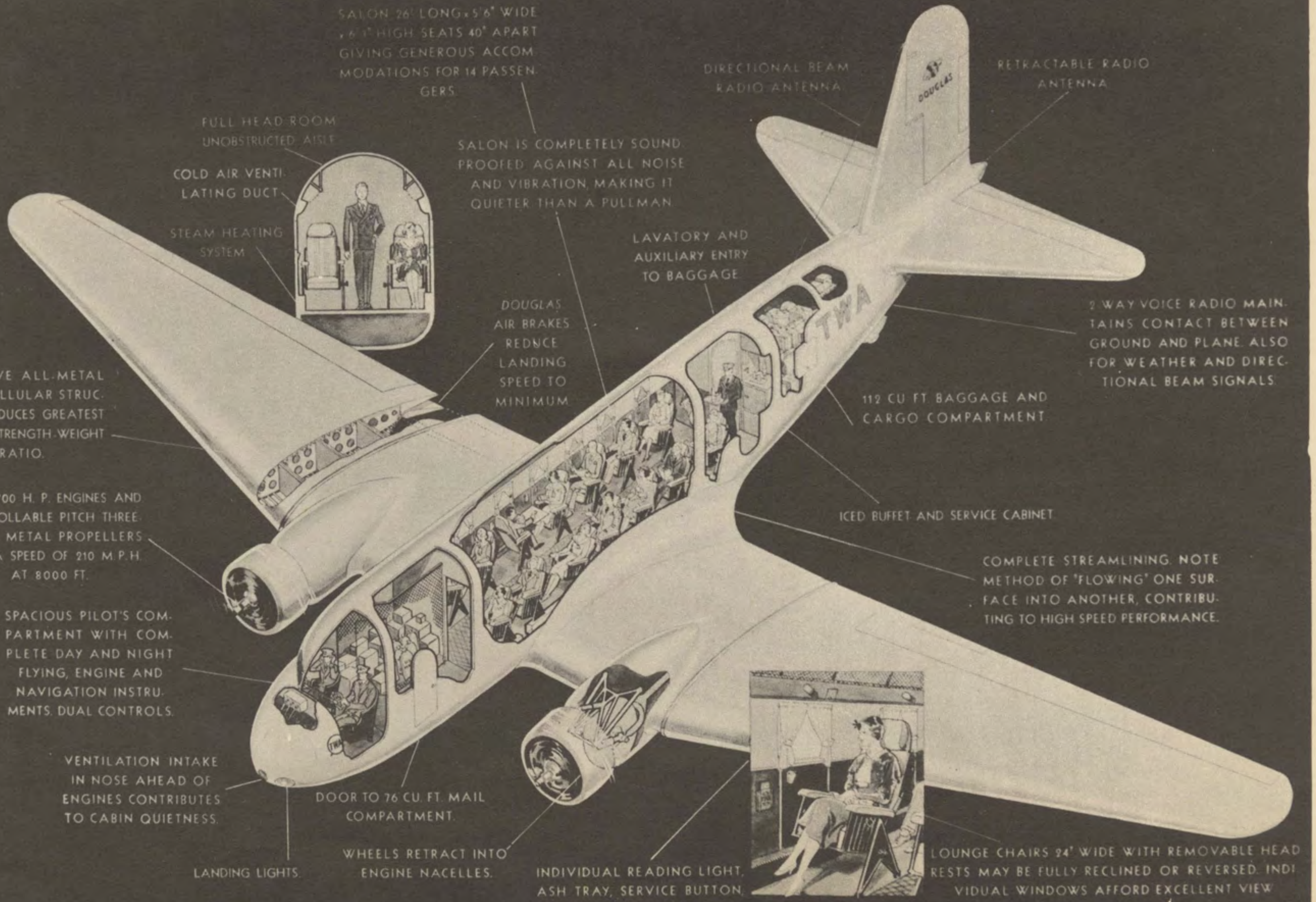
The cabin floor was installed completely above the wing so that there would be no structural members whatever in the cabin. It will be noticed that the level of the passenger windows is considerably higher in relation to the low wing than in most airplanes, thus allowing excellent vision and, as the wing has a very pronounced taper, passenger vision downward is improved still more.

Numerous different designs of passenger chairs of wood with tubular steel frames were tried and finally replaced by an aluminum alloy structure of the best model, which was so designed that the angle of inclination of the entire seat could be changed in addition to having the back adjustable for sleeping. It was also made reversible so that passengers could face forward or rearward, as desired. A safety belt adjustment was provided in the chair frame and the entire chair assembly was then mounted in rubber to absorb vibration.

Various arrangements of the lavatory and baggage compartments were tried in order to use the space available most economically and still have them conveniently accessible. The final arrangement was worked out with doors and all component parts so located that one could conveniently pass through the

INTERIOR VIEW OF THE DOUGLAS TRANSPORT ILLUSTRATING ROOMINESS AND PASSENGER COMFORT.

The New Douglas 14-Passenger Airliner



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lavatory to the rear baggage compartment and on into the tail portion of the fuselage while in flight.

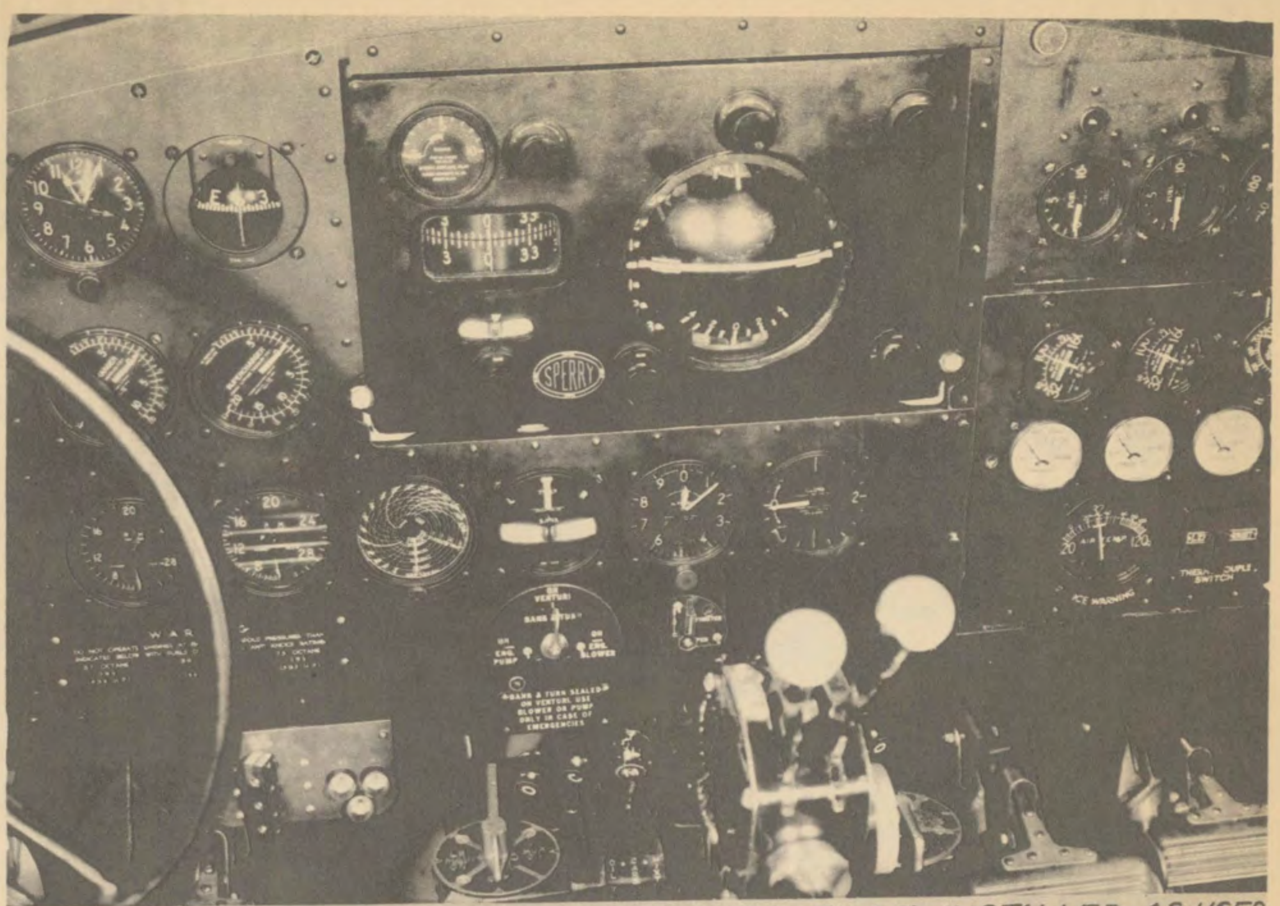
In a similar manner, a number of arrangements were tried for the door in the front of the cabin and that of the forward cargo and mail compartment, the resulting arrangement allowing a spacious section for stowing mail bags yet leaving an ample sized passageway from the cabin to the pilots' compartment.

Different materials for the interior cabin trim were tried in the mock-up, including various wall coverings, curtains, floor covering and chair upholstery, until a light, neat appearing, durable and easily maintained arrangement was determined. This resulted in the cabin walls and flooring being washable and entire panels quickly removable and replaceable. After a number of experiments and arrangements for individual reading lights for each passenger chair, an installation was developed whereby a beam of light was so directed to each chair as not to disturb any other passenger.

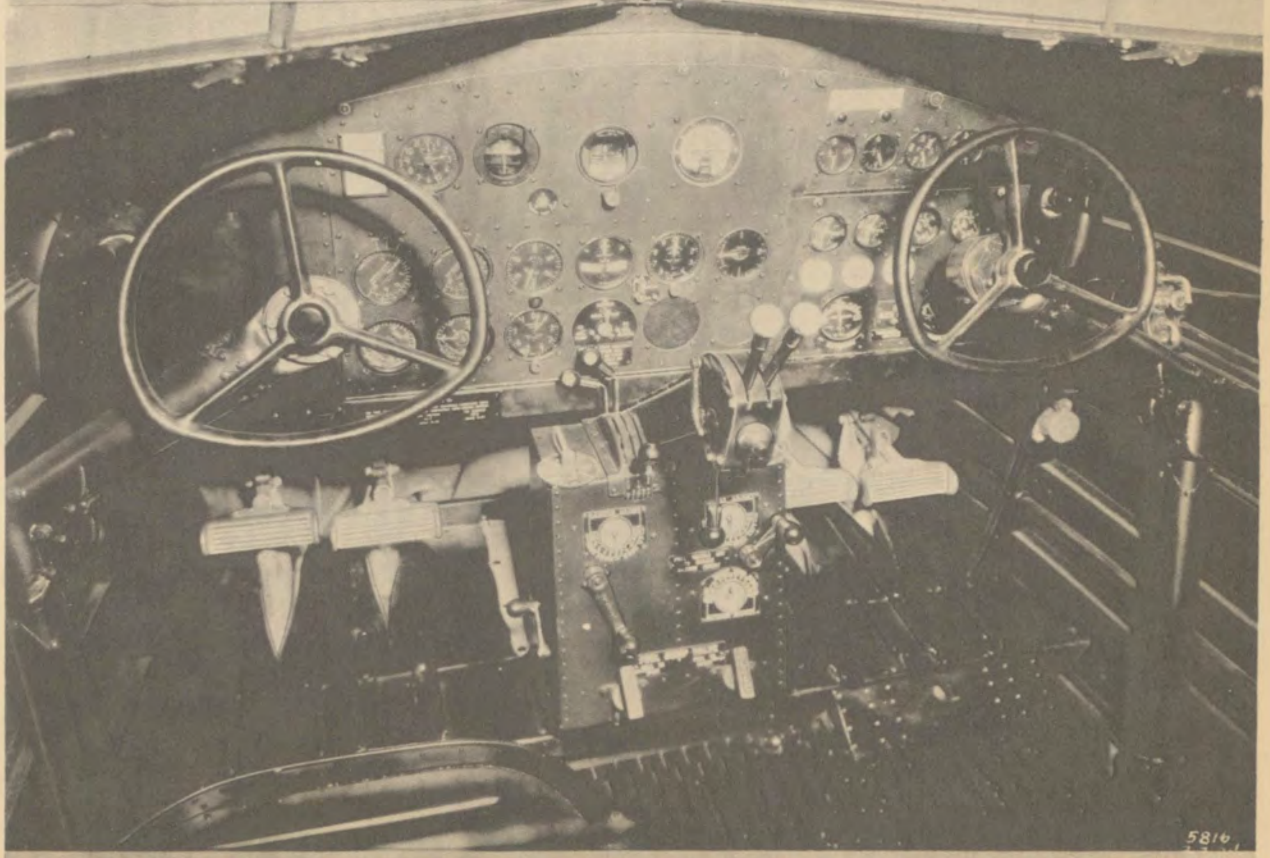
A great deal of effort was put into the development of the pilots' compartment and many weeks were spent in trying every possible arrangement of the various items. A complete control system with wooden members made to exact size and in working order was installed with strings in place of cables. Every lever, knob and handle, even such minor ones as the remote control handle for the radio and the auxiliary heat control for the cabin were actually installed in a countless variety of positions to determine the most practical arrangement. The brake controls and hydraulic mechanism, including dummy cylinders as well as oil lines were included to insure that they were located in the most efficient manner.

An instrument board was installed with full scale dummies of the instruments in place. After numerous instrument installations were tried, a satisfactory placing was determined whereby all related instruments were grouped together with all the electrical instruments on one portion of the panel so that they could be removed without disturbing the rest of the board.

An elaborate investigation of light reflection and instrument board lighting for night flying was made. At first, mirrors were installed in the mock-up of the pilots' compartment in place of the windshield glass panels and the reflections noted when angles and locations of the various mirrors were varied. After a satisfactory arrangement, which



INSTRUMENT BOARD WITH AUTOMATIC PILOT INSTALLED AS USED DURING TEST FLIGHTS OF THE TRANSPORT. THE THIRD INSTRUMENT FROM THE LEFT IS AN AIRSPEED INDICATOR CALIBRATED TO READ TRUE AIRSPEED WHICH WAS DEVELOPED BY THE DOUGLAS FLIGHT TESTING STAFF. THE THREE SMALL ELECTRIC LIGHTS AND SWITCH MOUNTED AT THE BASE OF THE INSTRUMENT BOARD INDICATE THE STATE OF ENGINE SYNCHRONIZATION.



INSTRUMENT BOARD AND CONTROLS WHEN AUTOMATIC PILOT IS NOT PROVIDED FOR.

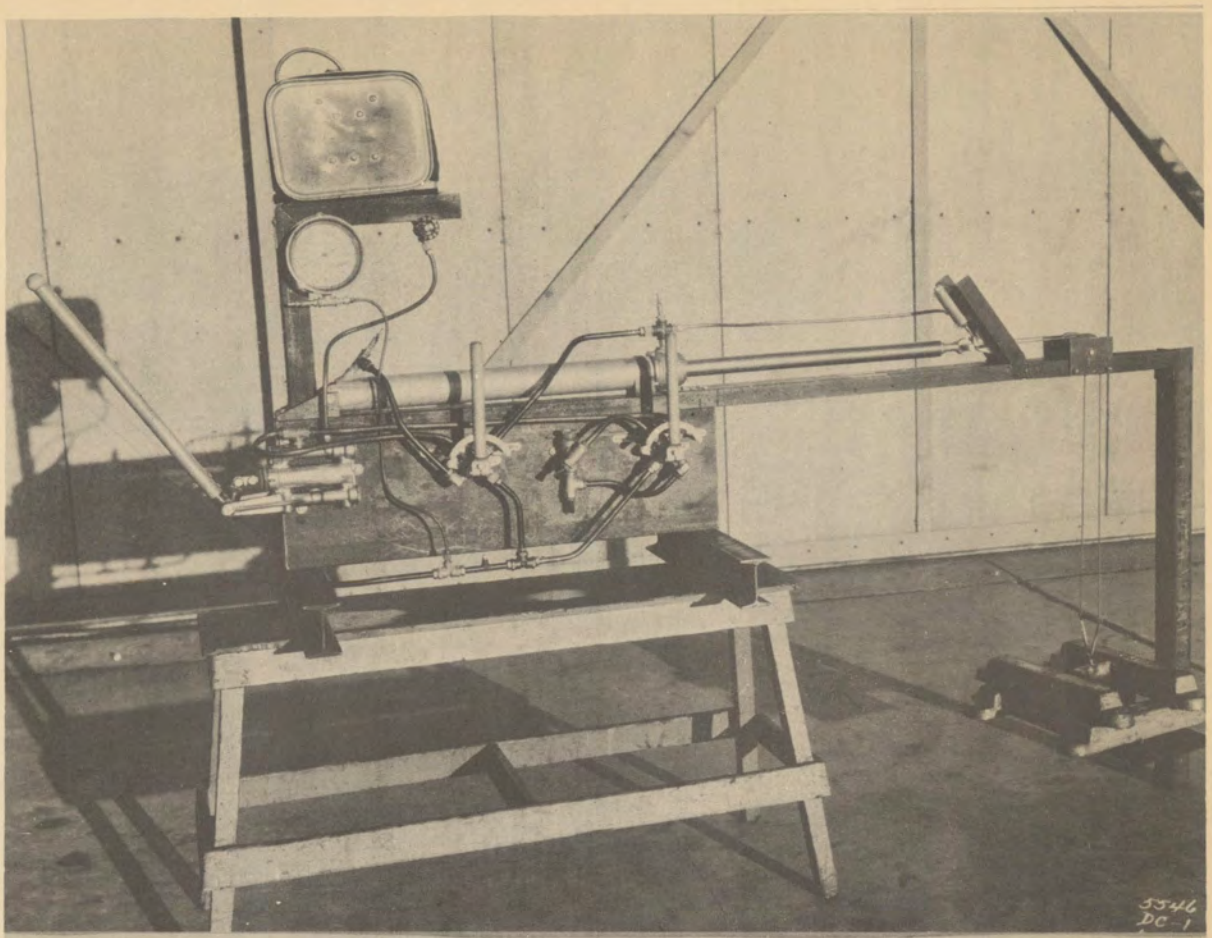
would not reflect the light from the instrument board, was determined, a complete lighting system was installed with actual windows in place and this was checked at night to show the effect of interior lights in the cockpit. All possible reflections from ground lights were determined and eliminated by moving lights around the outside of the mock-up.

Even inspection openings to all the control cables were located to determine best access for assembly, adjustment, inspection and replacement. Every possible location for the various cables was tried before it was finally determined to have them under the floor of the cabin where the quickly removable center panels expose the entire system for inspection or repair.

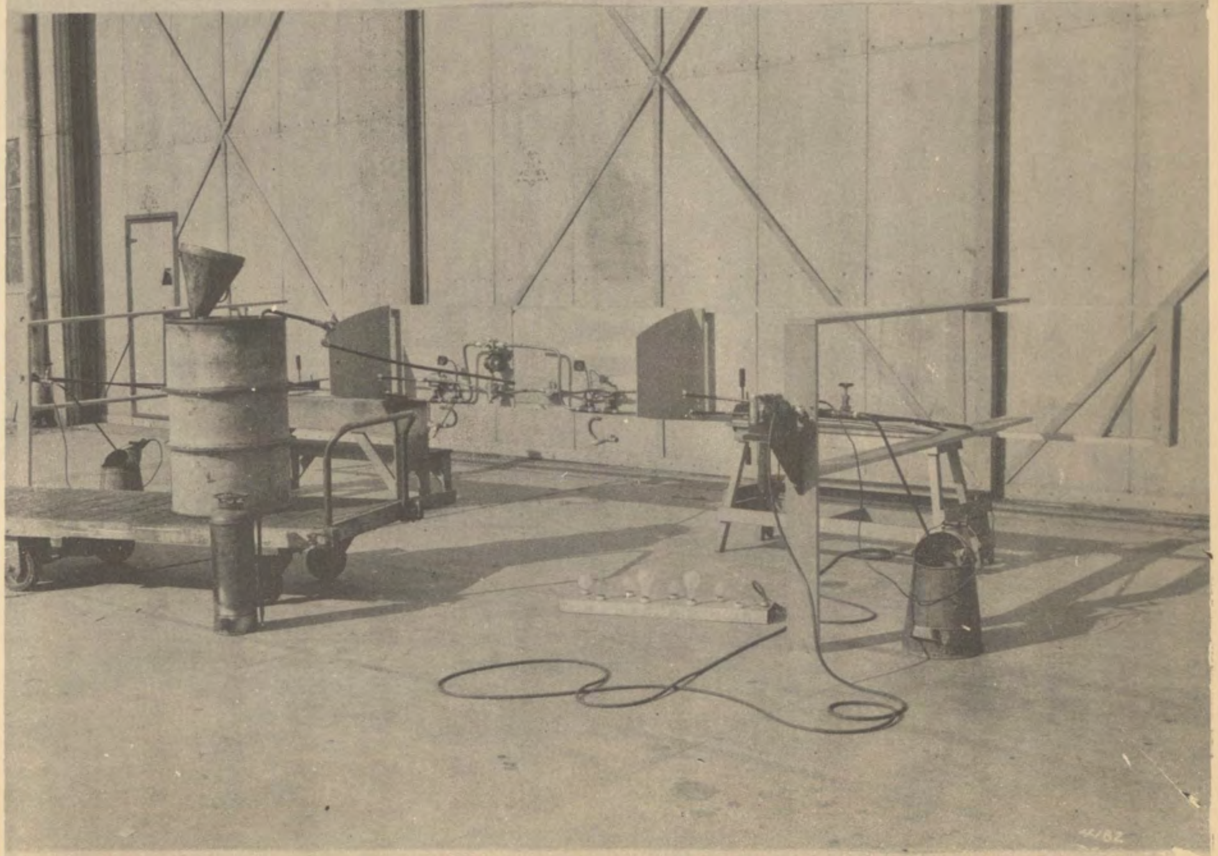
The pilot's seat was a subject of considerable experimentation before an arrangement was finally determined whereby there would be arm rests on both seats and it would be easy to get in and out without having to straddle the control column. In the final arrangement, one arm of each pilot's chair folds out of the way but is quickly locked into position once the pilot is seated. The problem of the control column resulted in a wheel type control mounted on a "U" frame, thereby giving dual control with no interference whatever in the cockpit.

In addition to the mock-up, a number of model setups were made for test purposes. A complete brake system was built up with cylinders, oil lines, handles, rudder pedals and all component parts and the oil line pressure at the wheel was then measured with the various pedal forces and positions. Similarly, a complete hydraulic retracting system for the landing gear and wing flaps was reproduced and tested to determine the most efficient arrangement. A complete fuel system was reproduced with all lines of actual size and length and all valves and controls installed. Then, by driving the fuel pump with an electric motor, fuel output and flow was very accurately measured.

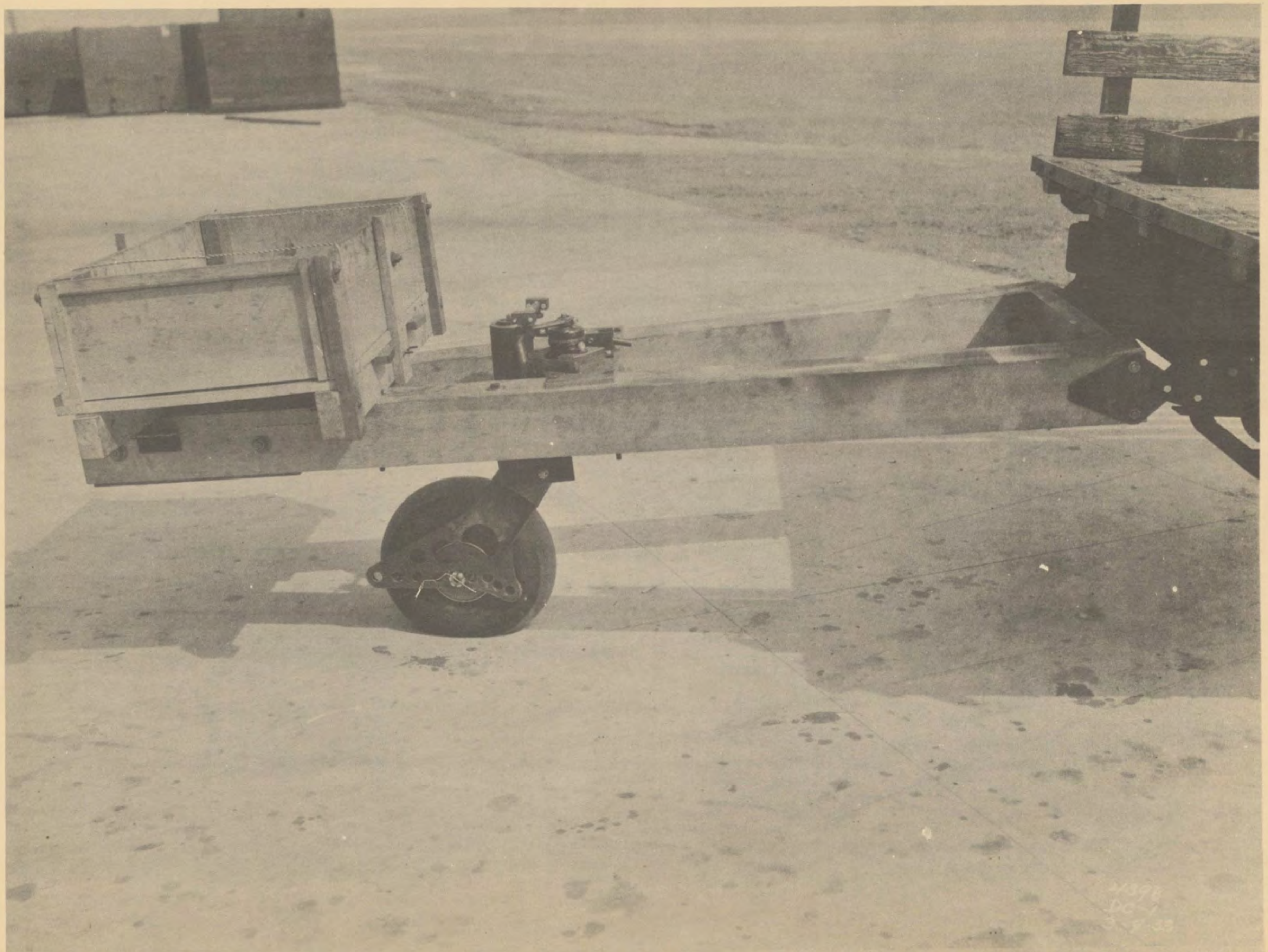
Tests were made to determine the best trail and caster dimensions of the tail wheel to avoid any possibility of tail wheel shimmy. In these tests, an adjustable wheel mechanism was mounted below a special frame to which varying loads could be applied, and was towed behind a truck at various speeds.



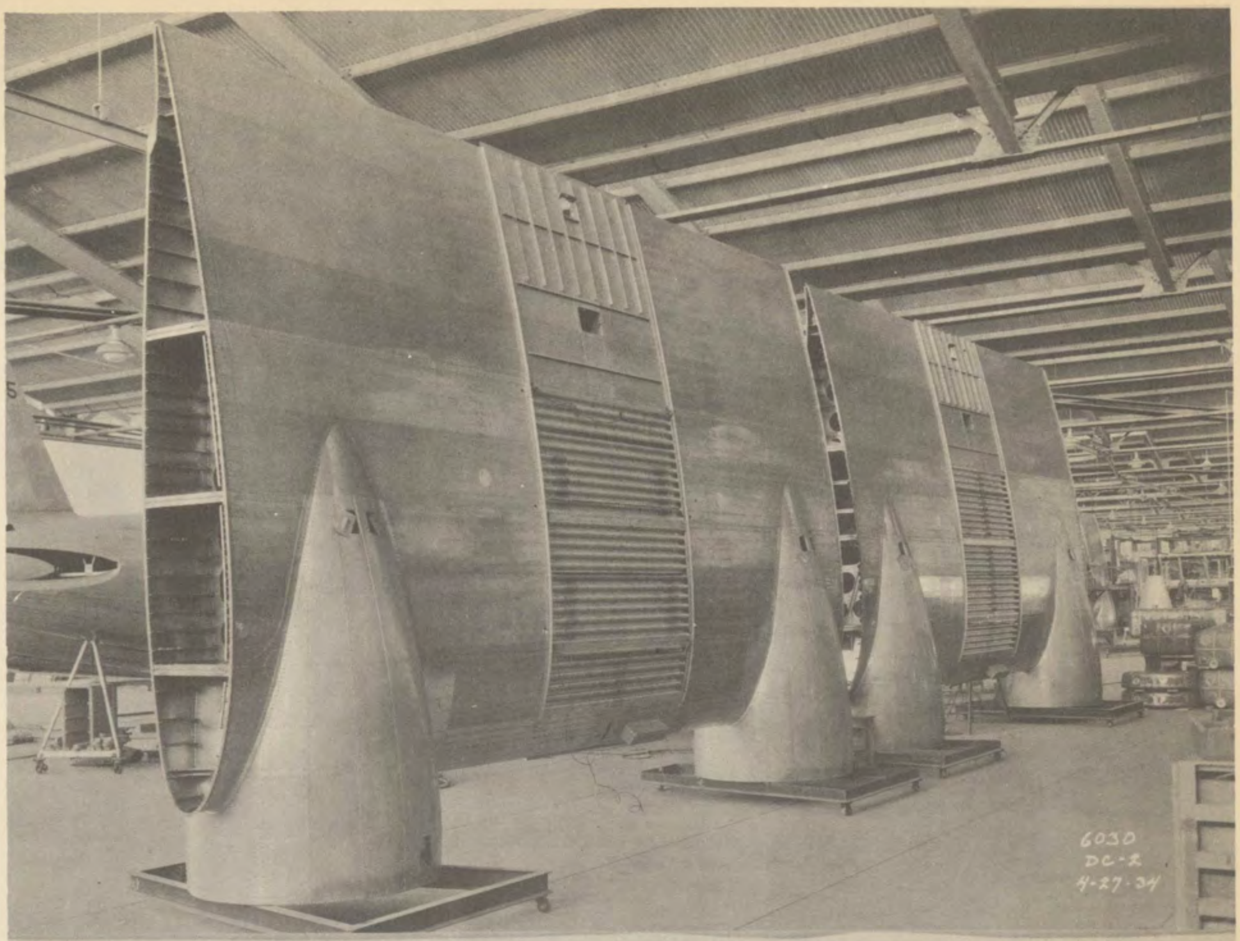
TEST SET UP FOR LANDING GEAR HYDRAULIC SYSTEM



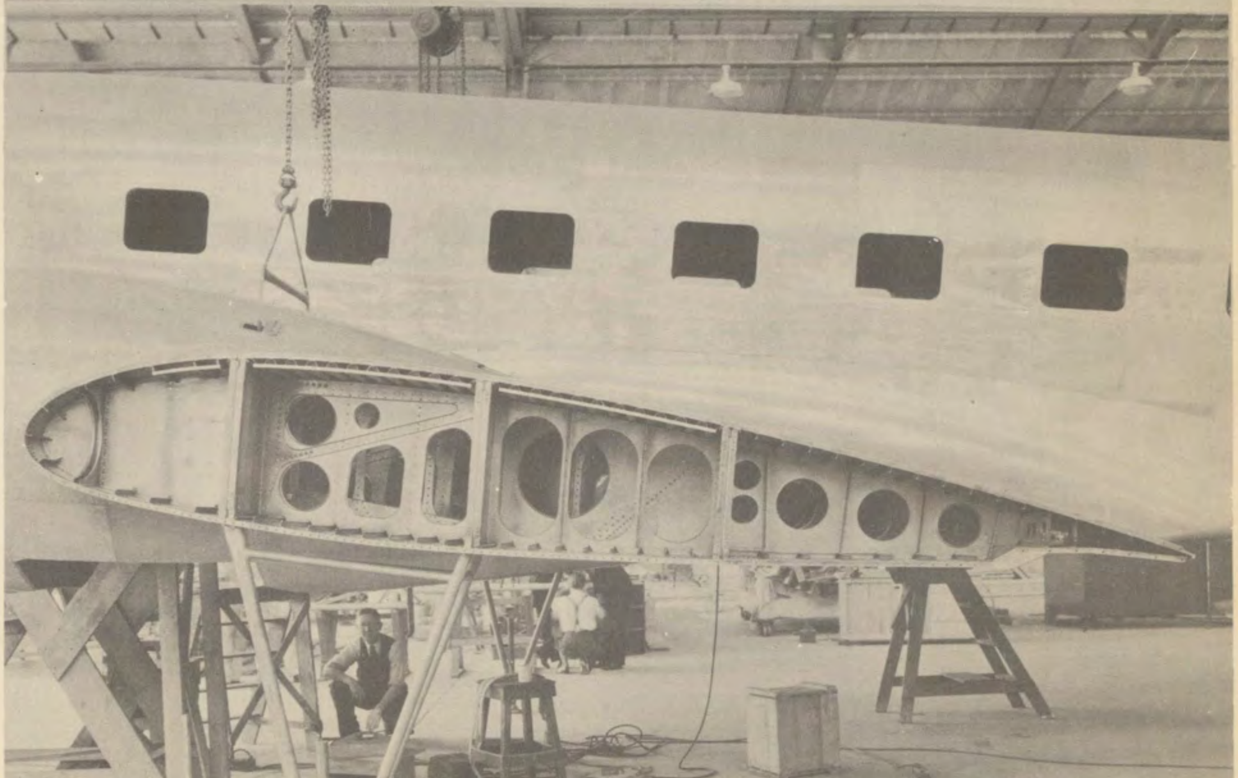
FUEL SYSTEM TEST. IN THIS TEST ALL TUBING WAS THE SAME SIZE AND LENGTH AS THAT USED IN THE ACTUAL AIRPLANE.



TEST SETUP FOR DETERMINATION OF BEST CASTER ANGLE AND TRAIL DISTANCE FOR THE TAIL WHEEL INSTALLATION.



TRANSPORT CENTER WING PANELS ON ASSEMBLY FLOOR READY FOR INSTALLATION.



FUSELAGE AND CENTER WING PANEL READY FOR INSTALLATION OF LANDING GEAR

Structural Development

The studies of aerodynamics and general arrangement showed the desirability of having the engine nacelles well ahead of the wing leading edge. It was also found desirable to house the retractable landing gear within the nacelles. Sweeping back the outer part of the wing offered the advantages of getting the landing gear well forward of the center of gravity and having the center of gravity come well forward on the wing for stability. With these points in mind and recognizing the fact that the size and performance desired for this machine presented an entirely new problem, an exhaustive study of the various possible types of construction was made.

In developing a structure having the maximum strength and rigidity with a minimum of weight, it is preferable to design a wing with the material so distributed that there is no great variation in the stresses in the various parts. Such variation is apt to be caused by rigidly attaching very thin members, such as the skin, to very heavy members, such as spars or beams with heavy stresses, if very thorough and careful investigation of the distribution of loads, deflections, local stresses, etc., is not made. At the same time, the wing must have little or no torsional deflection, a minimum of vertical deflection, and no excessively large unsupported flat metal surfaces.

A first investigation showed that most metal wings were merely an adaptation of wooden designs in other material. However, the characteristics of wood and metal are quite different and, therefore, the design principles of one do not apply to the other. In a metal wing, having a thin skin rigidly attached to a heavy spar, sudden changes in cross section are apt to cause very objectionable stress concentrations. If precisely the proper proportions of material are not made, or if the designs of the various attachments are not exactly correct, there are apt to be cracks in the skin and popping of rivet heads due to the deflecting spars pulling against the skin.

In the Douglas and Northrop types of multi-cellular wing construction, there are a multiplicity of full length span-wise stiffeners, and the fact that they have no abrupt changes or "breaks" results in no concentration of stresses. With the centroids of the stiffeners located at the maximum distances from the neutral axis of the section, a most efficient structure for absorbing the bending load is obtained.

In a highly stressed airplane, torsional rigidity of the wing is of paramount importance in the prevention of wing flutter at high speeds and torsional deflection of the structure must therefore be kept to an absolute minimum. When under load, there will always be some vertical deflection but this must not be excessive since a wing with large vertical deflections might cause jamming of aileron controls and by no means inspires confidence in the passengers or pilots.

If unsupported flat metal surfaces are even moderately large, there is always a tendency for the middle of the surface to vibrate in flight even when there is no stress. This is termed "oil canning" and will, in time, cause fatigue in the sheet metal and in the rivets and cause rivet heads to work and to pop off. These unsupported flat surfaces continually drum and cause a noise that cannot be completely eliminated in a cabin because part is carried as vibration through the structure. Even when on the ground with the engines running, this "oil can" action and drumming is apparent. "Oil can" action should be differentiated from wrinkling in the skin. Wrinkling of the skin will be present in every metal wing with a flat metal covering taking stress. These wrinkles are deflections of the skin under load and ordinarily do not have any tendency to vibrate.

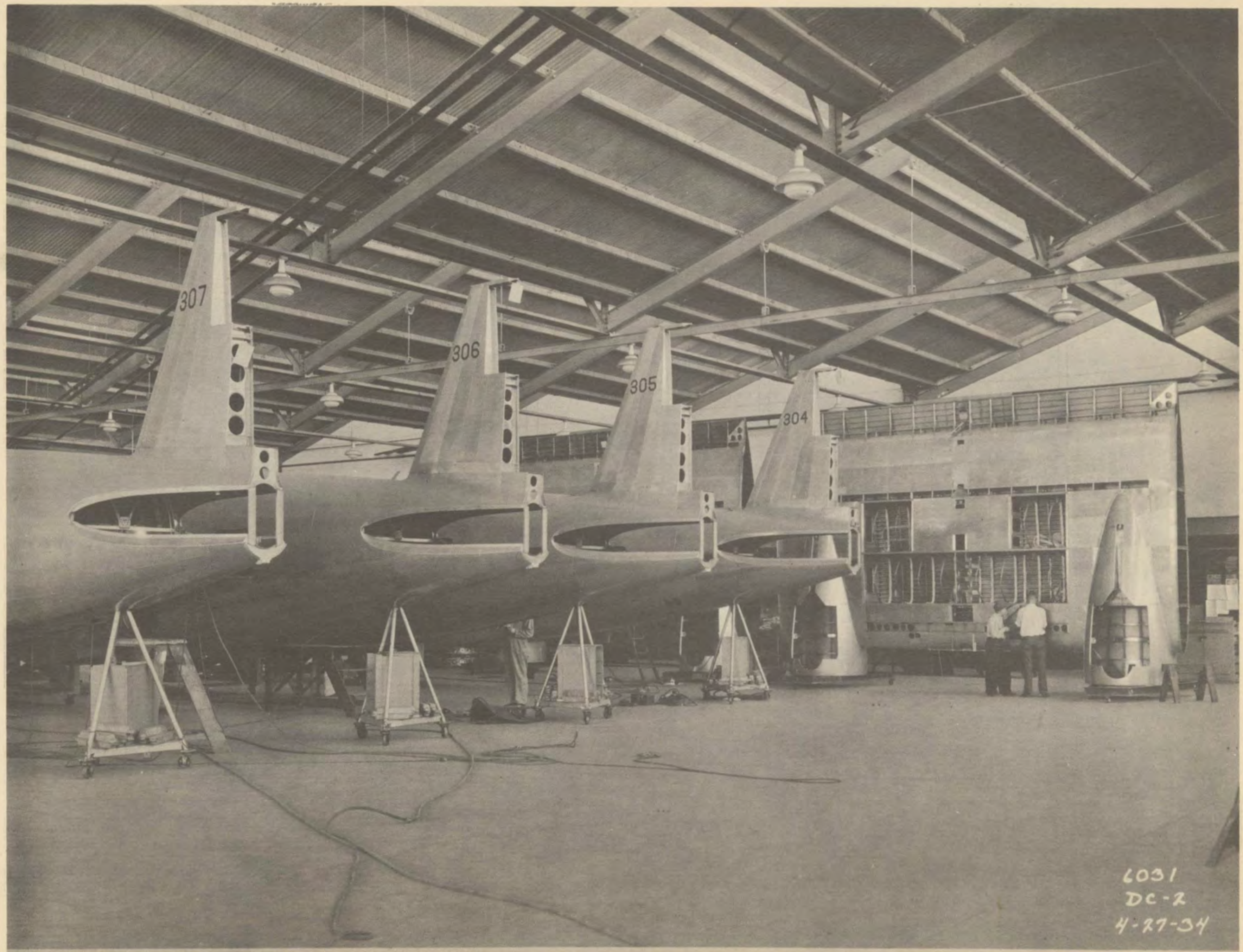
In determining the wing construction of the Douglas Transport, single, two, three and multi spar designs were considered as well as shell type and multi-cellular designs.

After a thorough investigation of all types, the Northrop multi-cellular wing construction was finally decided upon. This type of structure consists of a flat skin reinforced by numerous longitudinals and ribs. The bending is taken by the combination of flat skin and full length stringers. Three main flat sheets or webs carry the shear loads and torsion and indirect stress are carried by the skin with frequent ribs preserving the contour and dividing the structure up into a number of small rigid boxes or cells. Since the major loads are carried in the outer surface of the wing as well as in the internal structure, an inspection of the exterior gives a ready indication of the structural condition. The unit stresses in the material are low and therefore the deflections are at a minimum giving a maximum in rigidity. This construction has proven to be a happy medium of those considered since it combines practically all of the advantages of each; namely, very small unsupported areas, extreme lightness for its strength and rigidity, also ease of construction, inspection, maintenance and repair. The Northrop wing being comparatively small, it is economical to have many of the stringers run from the top to the bottom of the wing as shear webs or spars. However, when the principle is carried out on a larger scale, as in the Douglas Transport with its deeper wing, it is more efficient to have only three shear webs or spars. Thus it was not necessary to evolve a new type of structure but merely to adapt a time-proven type to the dimensions of the Douglas Transport.

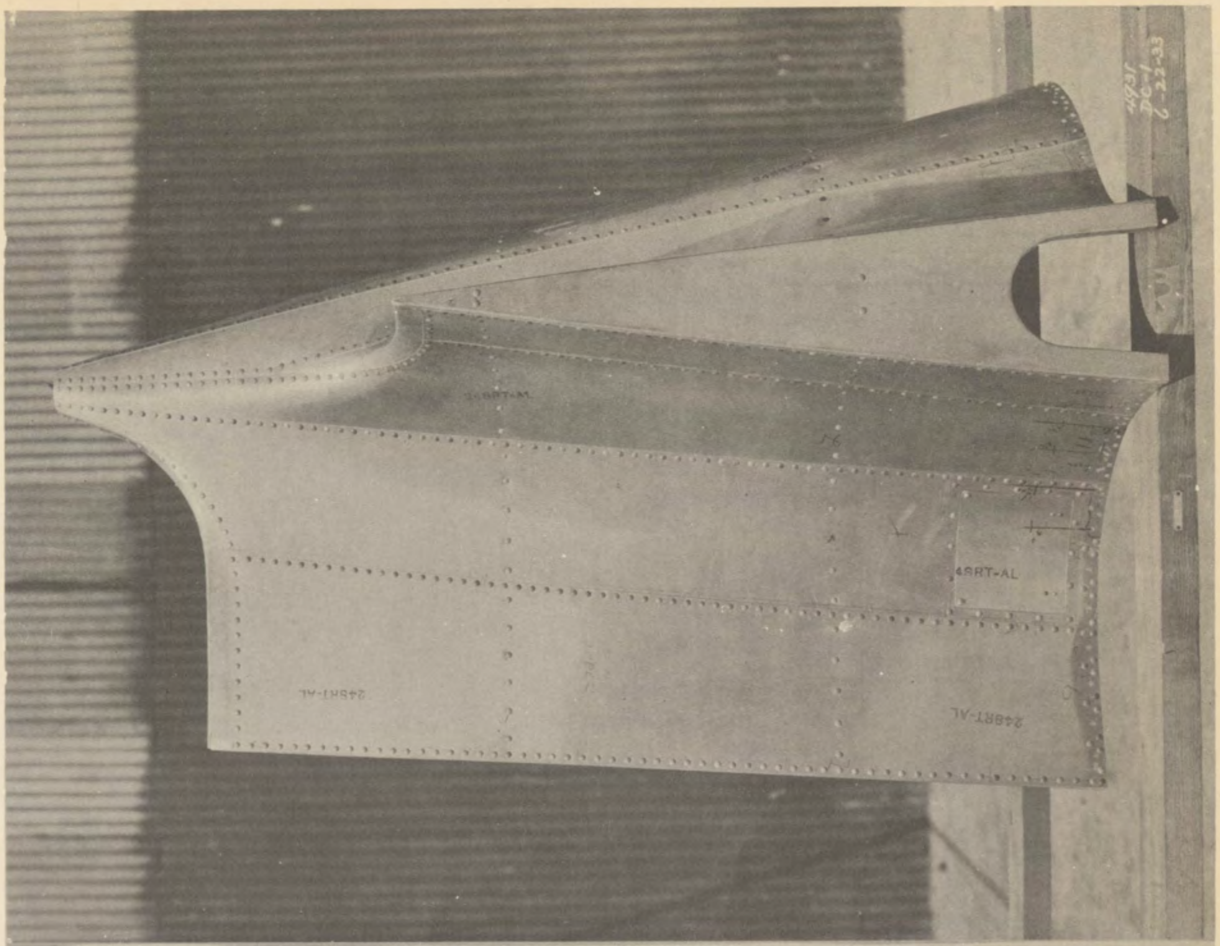
In the fuselage, the structural problem was basically the same. However, the Douglas Company had had extensive experience in building metal monocoque fuselages. This experience, combined with that of the Northrop Company, resulted in the present fuselage construction. This construction consists of a smooth, stressed skin in contact with closely spaced over-strength bulkheads and numerous longitudinal stringers (either flanged members or extruded angles) as a rigid part of the skin passing through the bulkheads, thus all parts are securely attached together and the skin has very small unsupported areas.

The coast to coast airline, Transcontinental and Western Air, Inc., which has been using a fleet of Northrop mail planes in daily service with notable satisfaction, advised on the design of the Douglas Transport from an operator's viewpoint. The airline encouraged this type of wing, fuselage and tail construction principally because their actual experience of many thousands of flying hours in hard service with the Northrop mail planes showed that the maintenance costs of this type of construction are negligible.

THE FUSELAGE STRUCTURE IS CALLED "SEMI-MONOCOQUE." SIMPLE BULKHEADS AND STRINGERS REINFORCE THE STRESSED SKIN.



TRANSPORT FUSELAGES AND CENTER WING PANELS ON ASSEMBLY FLOOR. NOTE THE CONVENIENT HANDLING DOLLIES



FUSELAGE TAIL CONE. THIS UNIT AGAIN EMPHASIZES THE CLEANLINESS OF DESIGN.

WING-TO-FUSELAGE FILLET. A SIMPLE BUT RIGIDLY CONSTRUCTED SUB ASSEMBLY UNIT.

Structural Tests

After the type of construction was decided upon the detailed arrangements and dimensions had to be worked out. This involved approximately 215 individual static and dynamic tests, approximately 100 preliminary tests on specimens of structural elements and well over 100 tests of wing ribs, fittings and various small parts in addition to the countless number of tests previously made by both the Northrop and Douglas Companies in their development of metal airplane structures for the United States Army and Navy, and civil use.

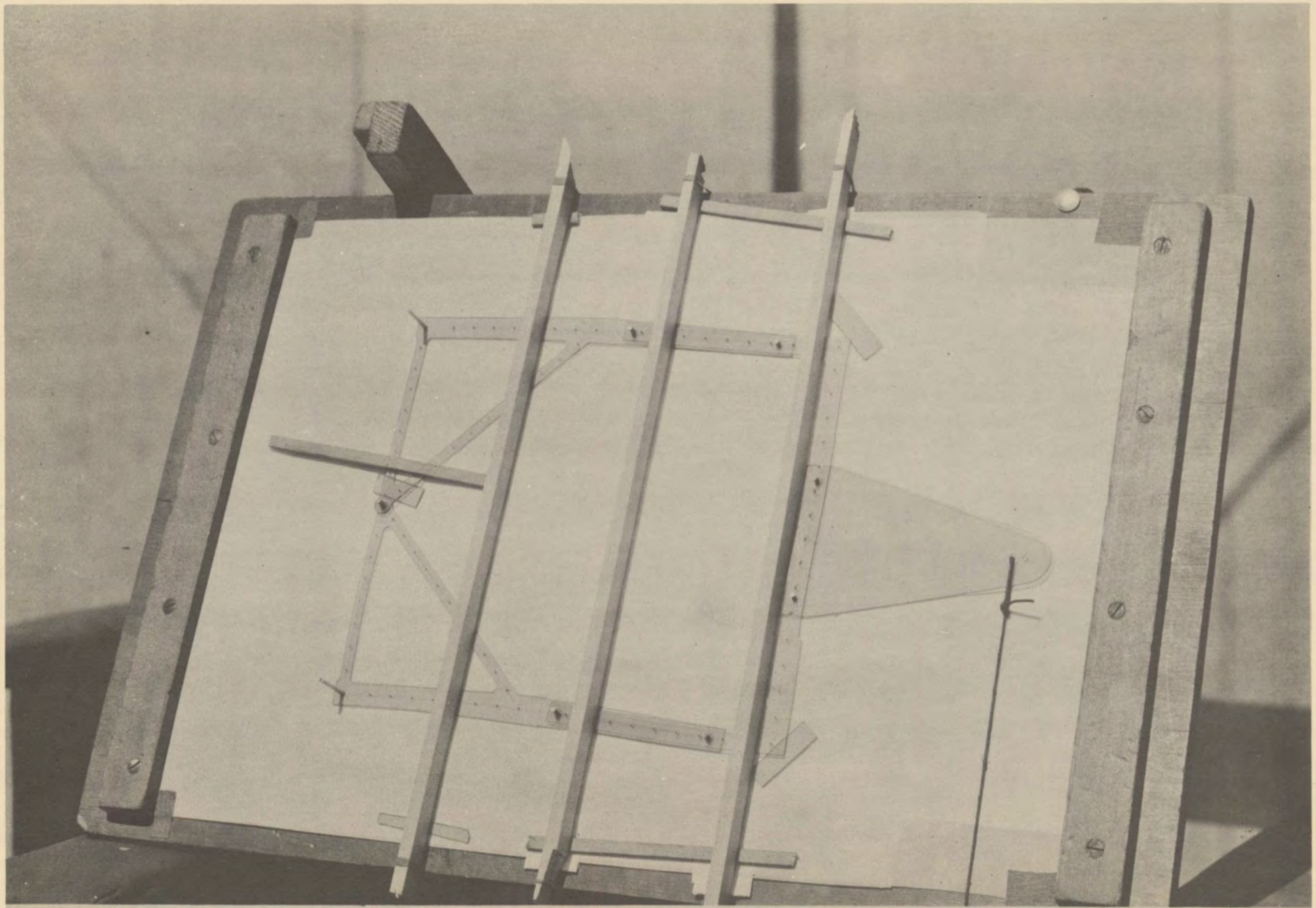
As a result of the preliminary tests on combinations of sheet covering and stiffeners, a structural arrangement giving a high unit strength with ease of attachment to wing ribs or fuselage frames was determined. By a judicious placing and construction of bulkheads and frames in the wing and fuselage, this shell type structure has very low unit stresses with small flexural deflections and is extremely rigid torsionally.

How well this was achieved is a matter of record on an N.A.C.A. velocity-acceleration (V-G) recorder and on motion picture records which were taken in flight through a 35 mm motion picture camera. This camera, with a built-in cross hair for use as a horizontal reference line, was set up in the cabin and focused on two vertical scales mounted on the wing tip. In addition, a 16 mm motion picture camera was mounted in the cabin and sighted on the top surface of the outer and center wing panels and a United States Navy type visual accelerometer was installed in the pilots' cockpit. The recorded pictures showed that with a measured acceleration of 3.25 times gravity (thus producing a load on the airplane equal to 3.25 times its gross weight or about 30 tons) the vertical deflection of the wing tip was four-tenths of an inch less than the computed deflection. Less than three-tenths of an inch difference between front and rear scale readings was recorded, showing that even with the large sweepback and overhanging engine the torsional deflection of the wing was negligible, being only half of one degree. This indicated a very rigid connection between the wing and fuselage and a very satisfactory structure in spite of the fact that the fuel tanks occupy a large part of the inner section of the wing. Although the entire airplane was loaded by this high acceleration no permanent deflections or indications of minor weaknesses were evident.

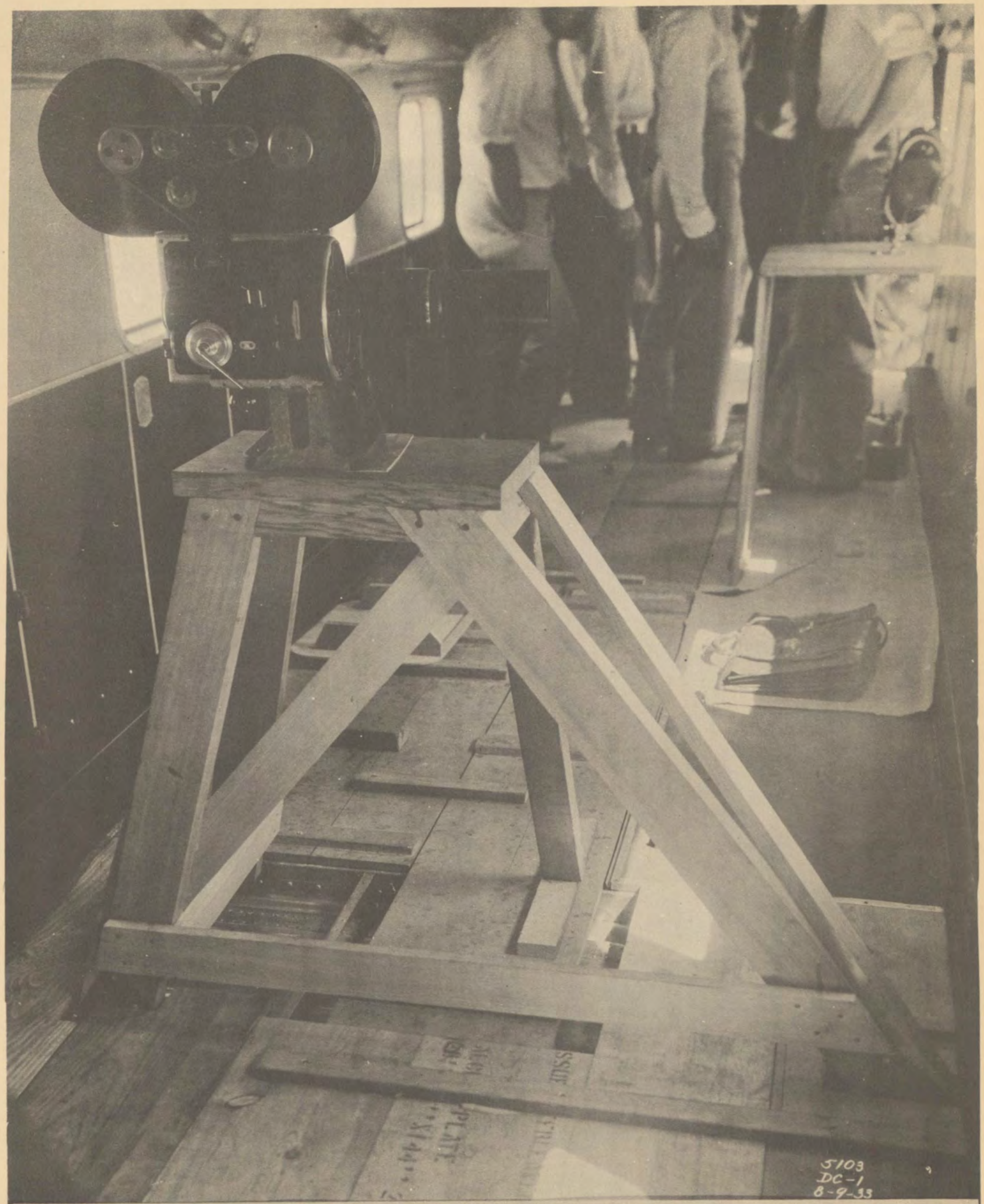
Furthermore, the wing was vibrated torsionally on the ground with the vibrating force applied at various points by means of a specially designed electrically driven oscillation machine. These tests showed the wing to have an extremely high natural frequency in torsion again indicating a very high torsional rigidity. In addition, all control surfaces and systems and their supporting structures were vibrated to determine their natural frequencies in order to be sure that no condition conducive to flutter existed. The structure was so designed that all supporting members were far enough out of phase with the surfaces they carry that flutter could not develop at the high speeds which are attained by this airplane. The structures investigated include the elevator control system, stabilizer (in bending), elevator torque tube, rudder control systems, rudder (in torsion), vertical stabilizer (in bending), fuselage (in side bend, vertical bending and torsion), aileron control system and the wing (in bending and torsion).

Besides these, static tests were made on the control surfaces, both fabric and metal covered types, by loading them to the maximum loads expected in flight as based on the wind tunnel tests and the new Department of Commerce regulations. When 40% of the ultimate load was applied, each control surface was moved through its entire range to ascertain that there was no binding due to excessive deflections. The wing flaps were tested to 100% load when deflected to 30 degrees although the wind tunnel tests indicated that this maximum load occurs only when the flaps are full down. This latter test was undertaken to ascertain the ability of the flap control to carry the maximum possible loads throughout a considerable range of flap travel.

The fuselage and center wing panel were proof tested together by supporting the outer ends of the center wing panel on rigid steel jigs with the fuselage acting as a cantilever beam. Load was then applied at all points of weight concentration in the mail compartment, passengers' cabin, rear baggage compartment and on the horizontal tail surfaces. This test took ten men more than twelve hours to complete and all portions of the fuselage were demonstrated to have sufficient strength and rigidity before the design was accepted. The torsional strength of the fuselage was tested by applying the full design loads to the vertical stabilizer with the airplane cantilevered from jigs at the ends of the center wing



AS THE LANDING GEAR TRUSS IS AN INDETERMINATE STRUCTURE, THE LOADS IN THE VARIOUS MEMBERS WERE ANALIZED BY LOADING A CELLULOID MODEL HAVING PARTS MADE WITH WIDTHS PROPORTIONAL TO THE MOMENTS OF INERTIA OF THE CORRESPONDING MEMBERS OF THE ACTUAL LANDING GEAR AND MEASURING THE DEFLECTIONS.



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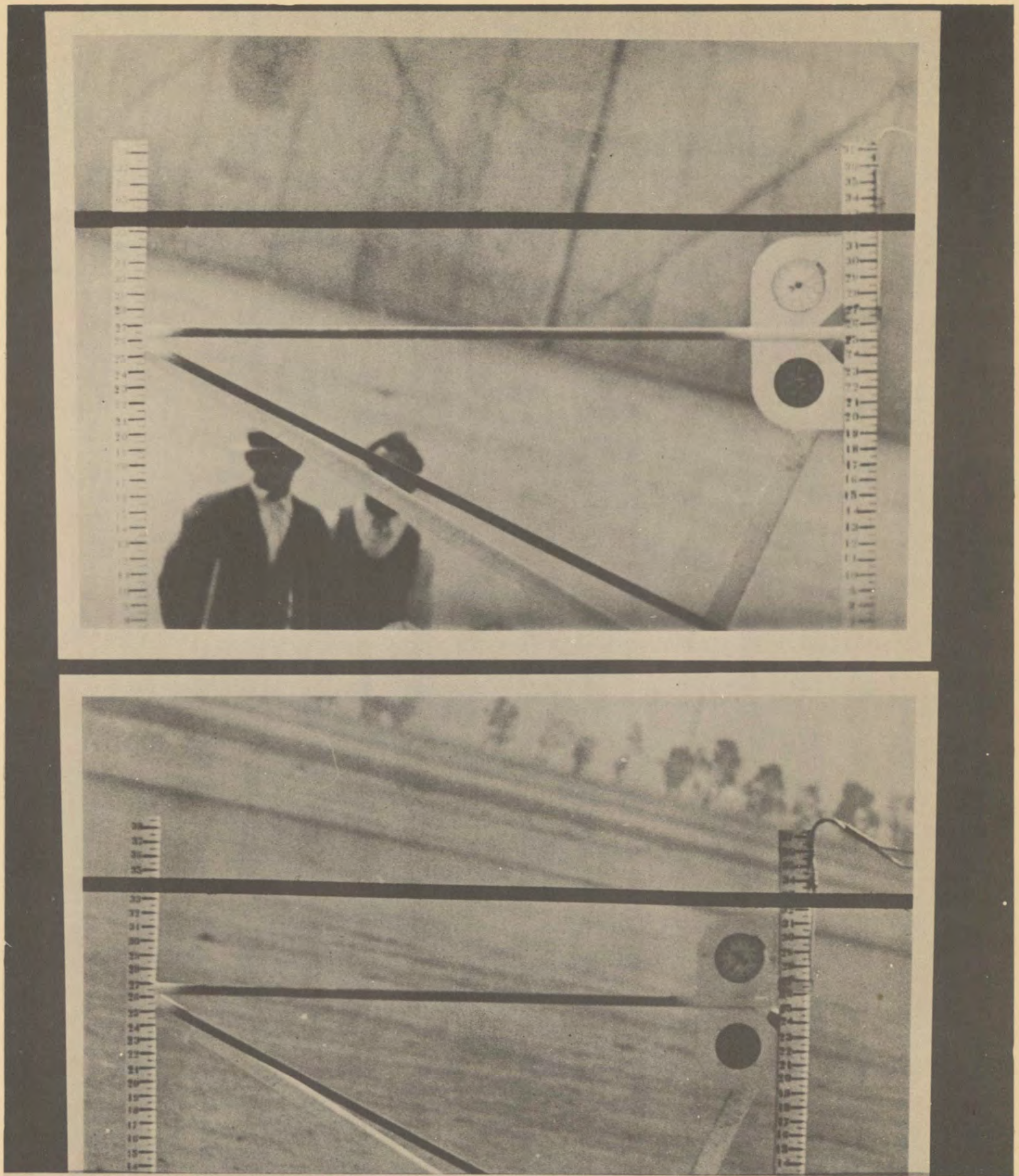
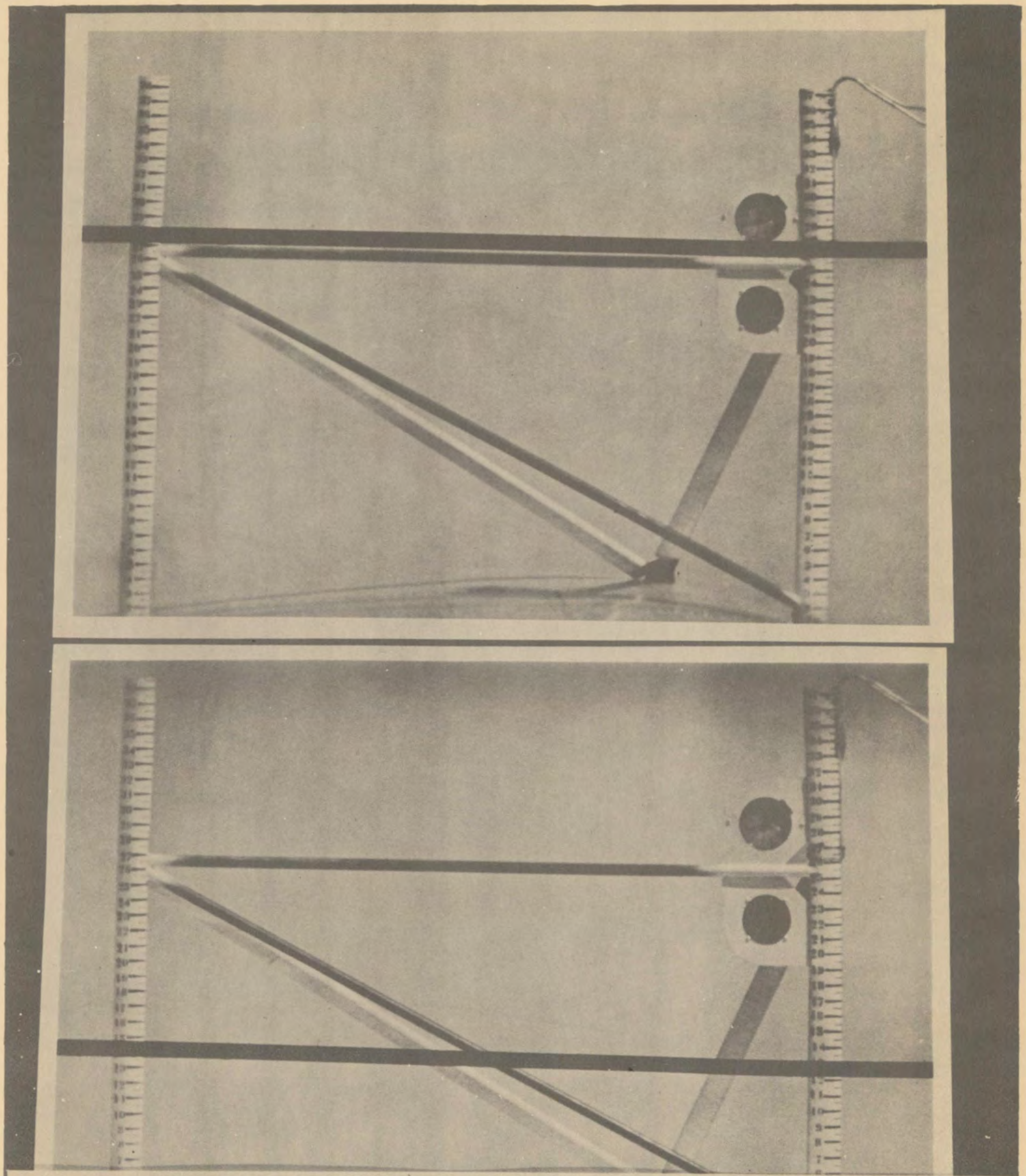
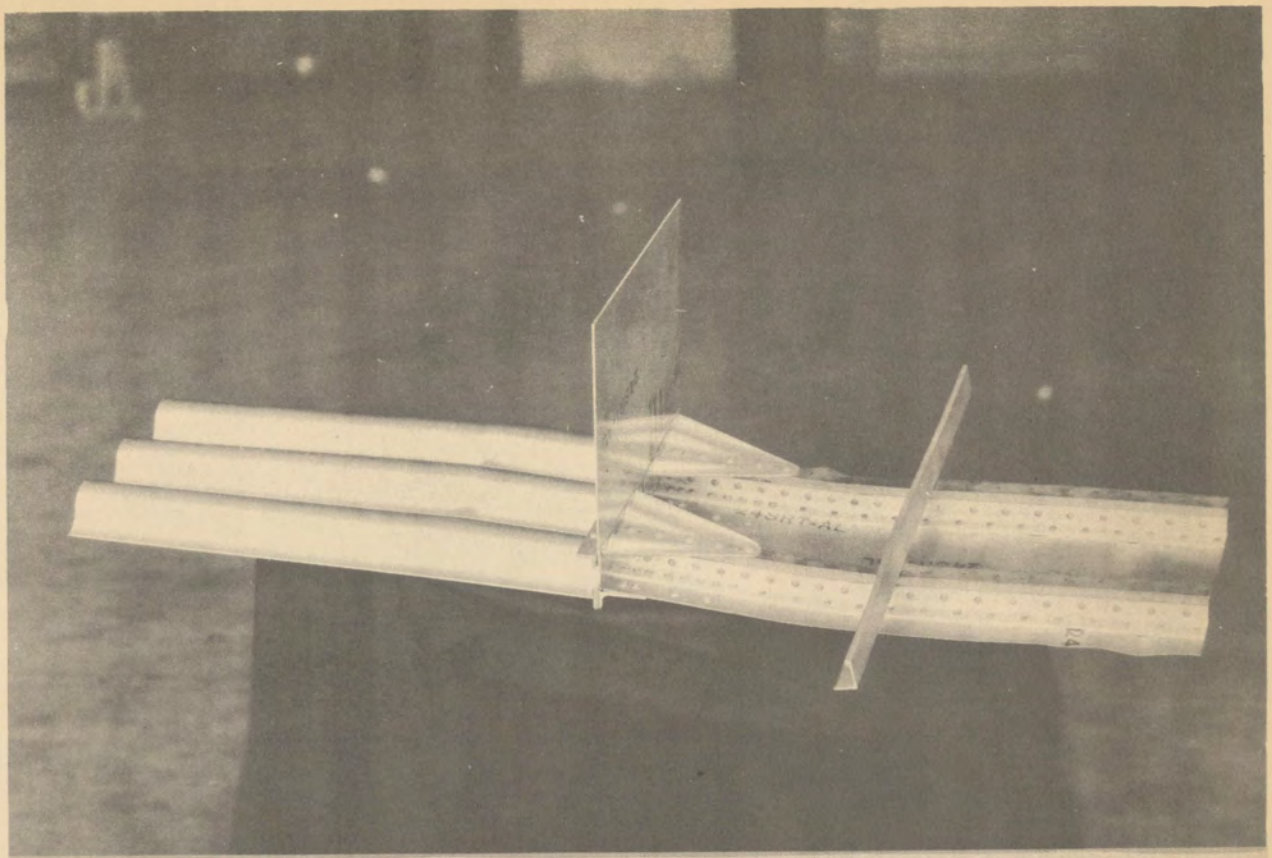
SPECIAL MOTION PICTURE CAMERAS MOUNTED IN CABIN TO MEASURE WING DEFLECTIONS.



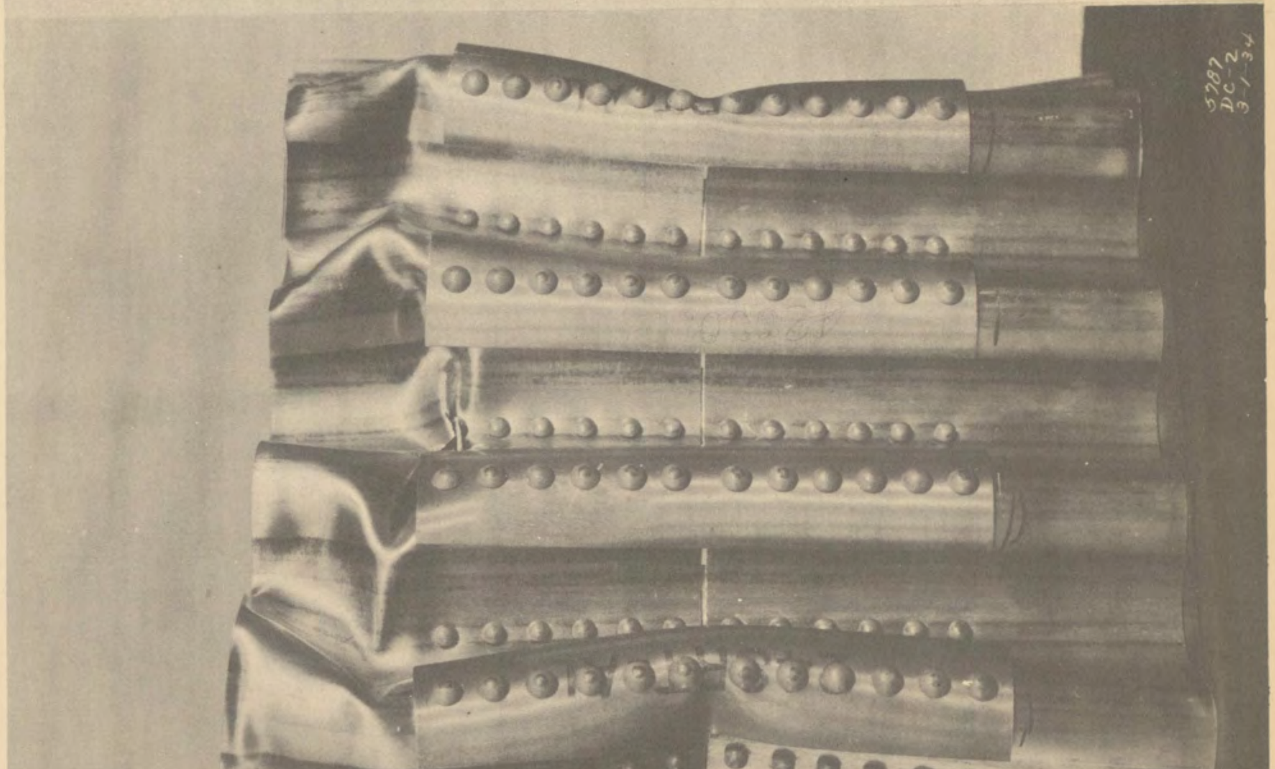
SCALE MOUNTED ON WING TIP FOR MEASURING WING DEFLECTIONS. THE GRADUATIONS ARE IN INCHES AND THE BLACK LINE IS THE REFERENCE HAIR. THE DIFFERENCE IN THE ZERO READINGS SHOWN HERE WITH THE AIRPLANE AT REST WAS CAUSED BY MOVING THE AIRPLANE BETWEEN RECORDINGS.



WING DEFLECTION RECORDINGS. THE UPPER VIEW WAS TAKEN IN NORMAL LEVEL FLIGHT AND THE LOWER VIEW DURING A "PULL-UP" ACCELERATION OF 3.25 G MEASURED ON THE N.A.C.A. "V-G" RECORDER. IT CAN BE SEEN THAT THE TORSIONAL DEFLECTION OF THE WING IS NEGLIGIBLE.



SPECIMEN OF ONE OF MANY WING ATTACHMENT JOINTS TESTED, VIEWED AFTER DESTRUCTION TEST



SPECIMEN OF CENTER WING PANEL CORRUGATED SECTION AFTER DESTRUCTION TEST.

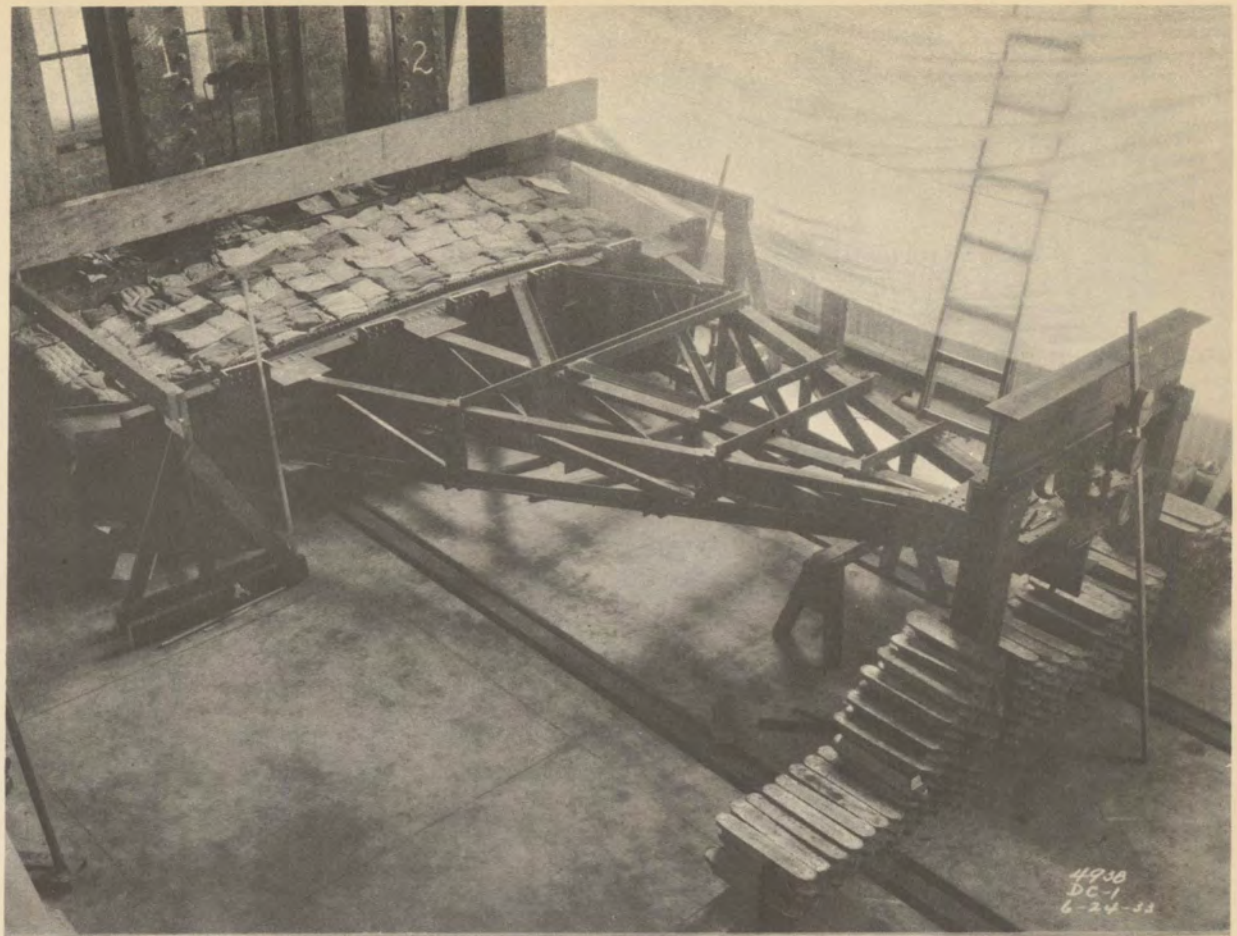
panel. This test showed the deflections across the main openings, such as doors and windows, to be so small that even the close fitting cabin door could be opened and closed under full load.

In order to demonstrate the adequate strength of the monocoque structure supporting the engine mount, the entire nacelle structure was proof tested on the ground by applying loads with a hydraulic jack attached to a plate on the engine ring. This test showed small deflections under maximum load, with no set whatever in the structure. Further, the cutout for the landing gear wheel had less than one-thirty-second of an inch deflection under 60% of the full breaking load and showed no permanent set whatever.

The ruggedness and shock absorbing qualities of this type of construction were demonstrated by repeatedly driving a tractor over a test wing without crushing or impairing the strength of the wing.

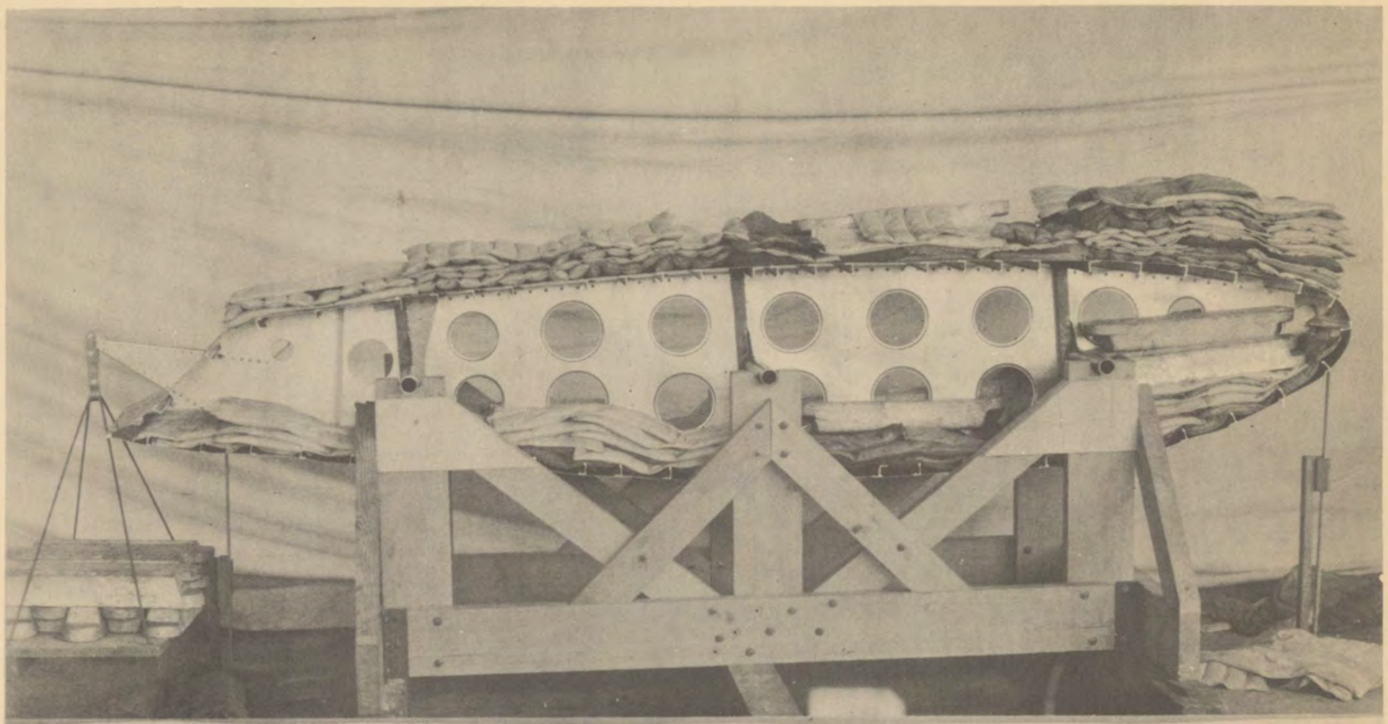
The landing gear chassis was subjected to extensive dynamic testing in order to prove its strength and shock absorbing qualities. The tail wheel unit was also tested dynamically both for the shock absorbing strut and tire and its efficiency has been highly developed by the collaboration of the Bendix and Douglas companies.

In addition, all typical joints, component parts, completed units and final assemblies were tested to prove their strength and safety. A variety of tests are still being made from day to day to simplify design and improve the airplane from a standpoint of manufacturing and maintenance.

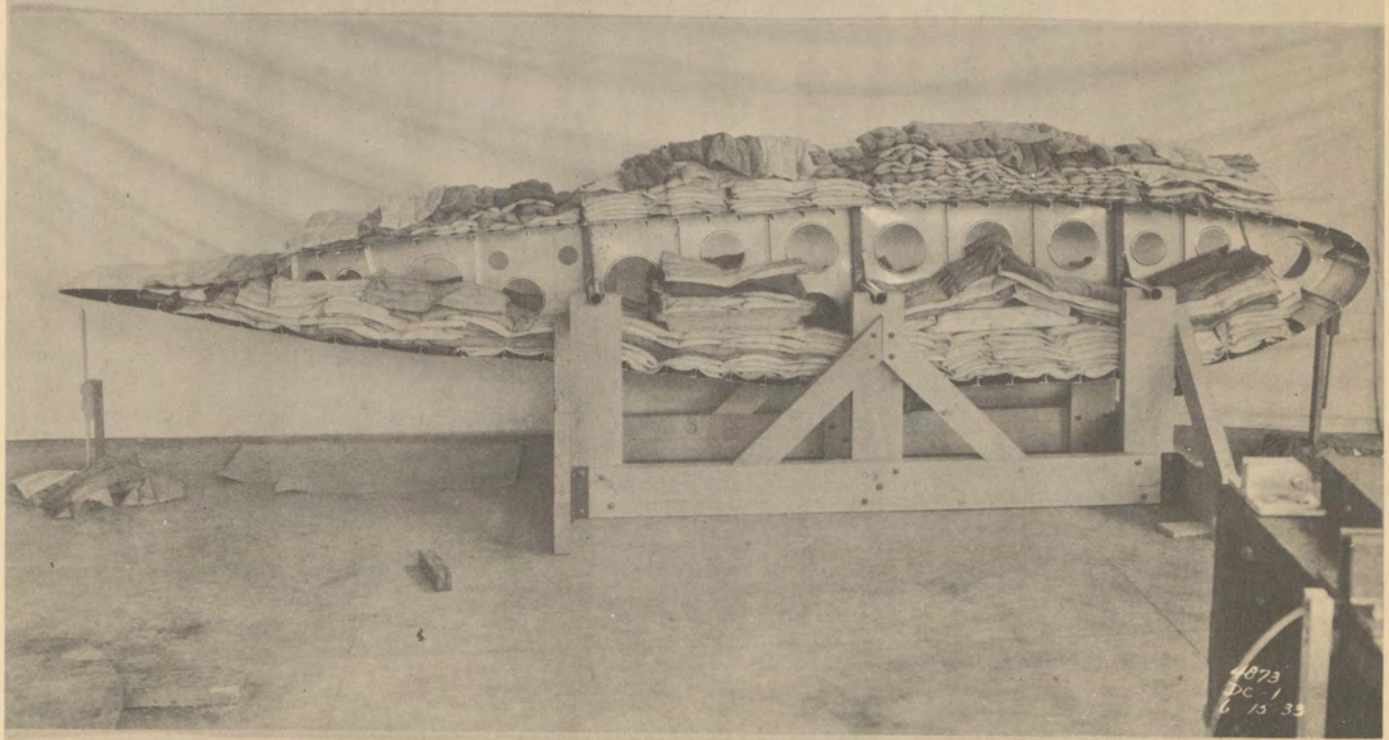


STATIC TEST OF WING ROOT. IN THIS TEST THE BENDING LOAD WAS APPLIED HYDRAULICALLY UPON A TRUSS BUILT OUT TO GIVE THE EFFECT OF A COMPLETE WING.

SETUP FOR PRELIMINARY TEST ON SHORT SECTION OF WING ROOT, AND WING ATTACHMENT TO CENTER PANEL.

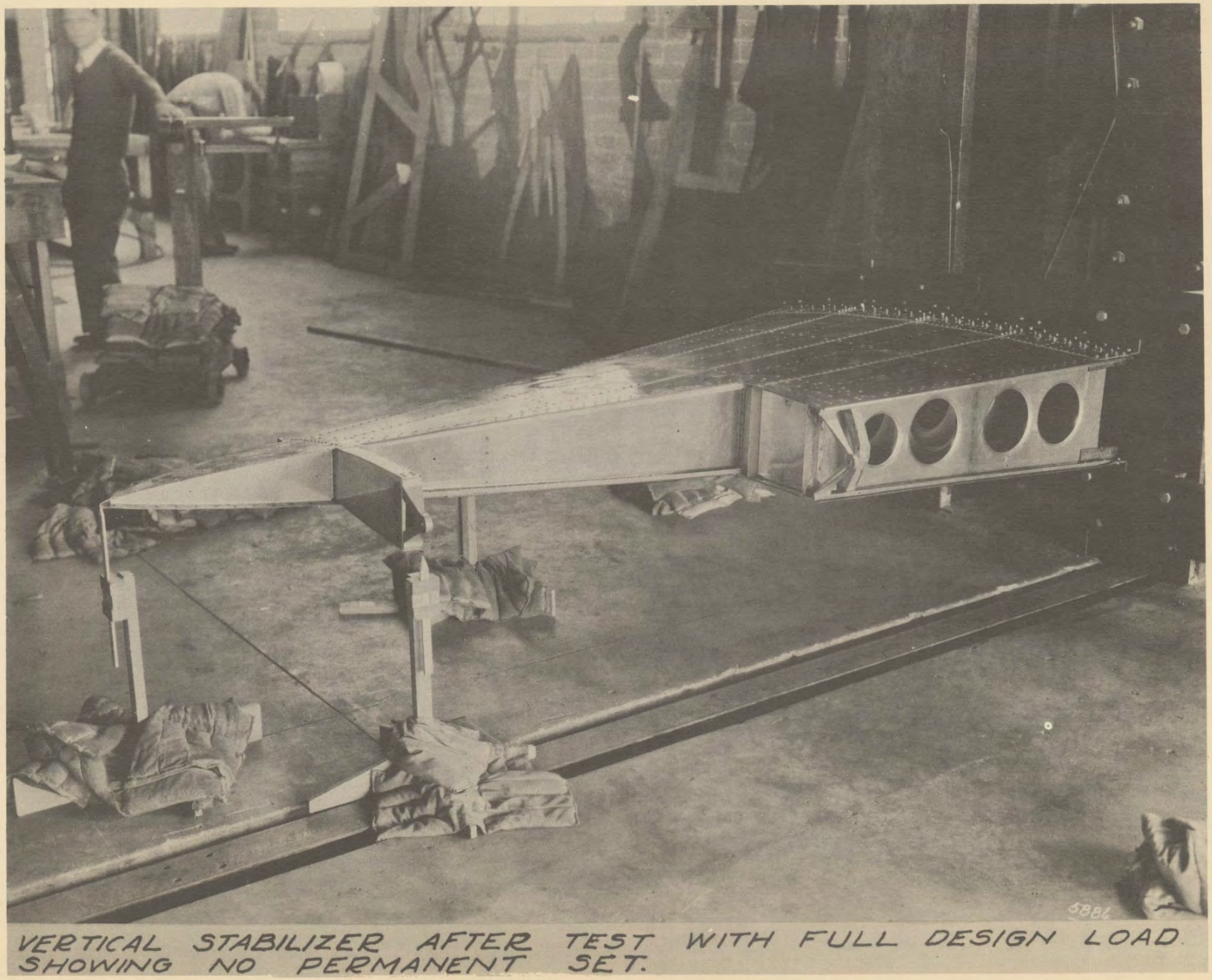


STATIC TEST ON WING RIB WITH AILERON HINGE. HIGH ANGLE OF ATTACK CONDITION WITH STATIC LOAD ON AILERON HINGE EQUAL TO DOUBLE THE ACTUAL DESIGN AILERON LOAD.



STATIC TEST OF TYPICAL WING RIB. MEDIUM ANGLE OF ATTACK CONDITION.

VERTICAL STABILIZER UNDER FULL DESIGN LOAD.



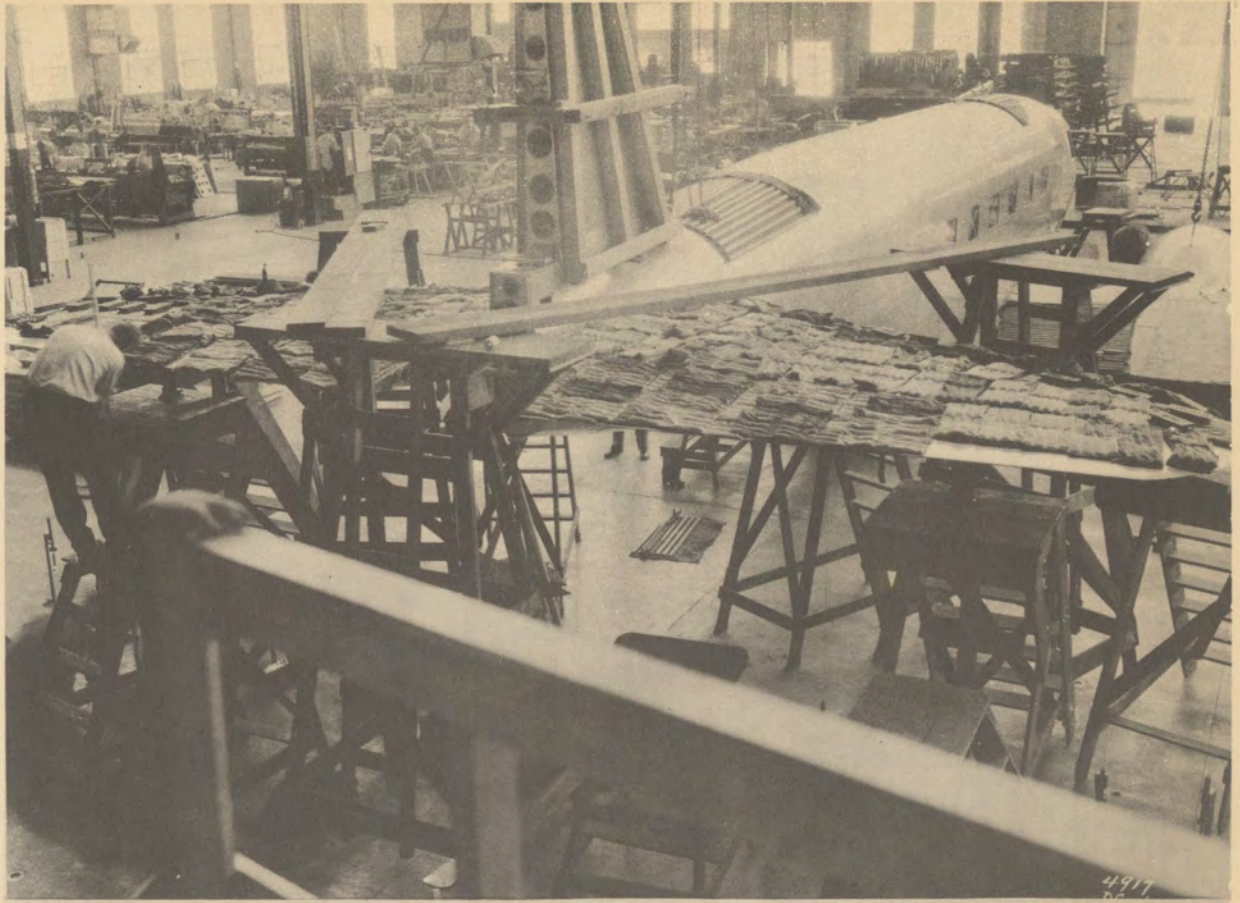
VERTICAL STABILIZER AFTER TEST WITH FULL DESIGN LOAD SHOWING NO PERMANENT SET.

METAL COVERED RUDDER, STATIC TEST TO FULL DESIGN LOAD.

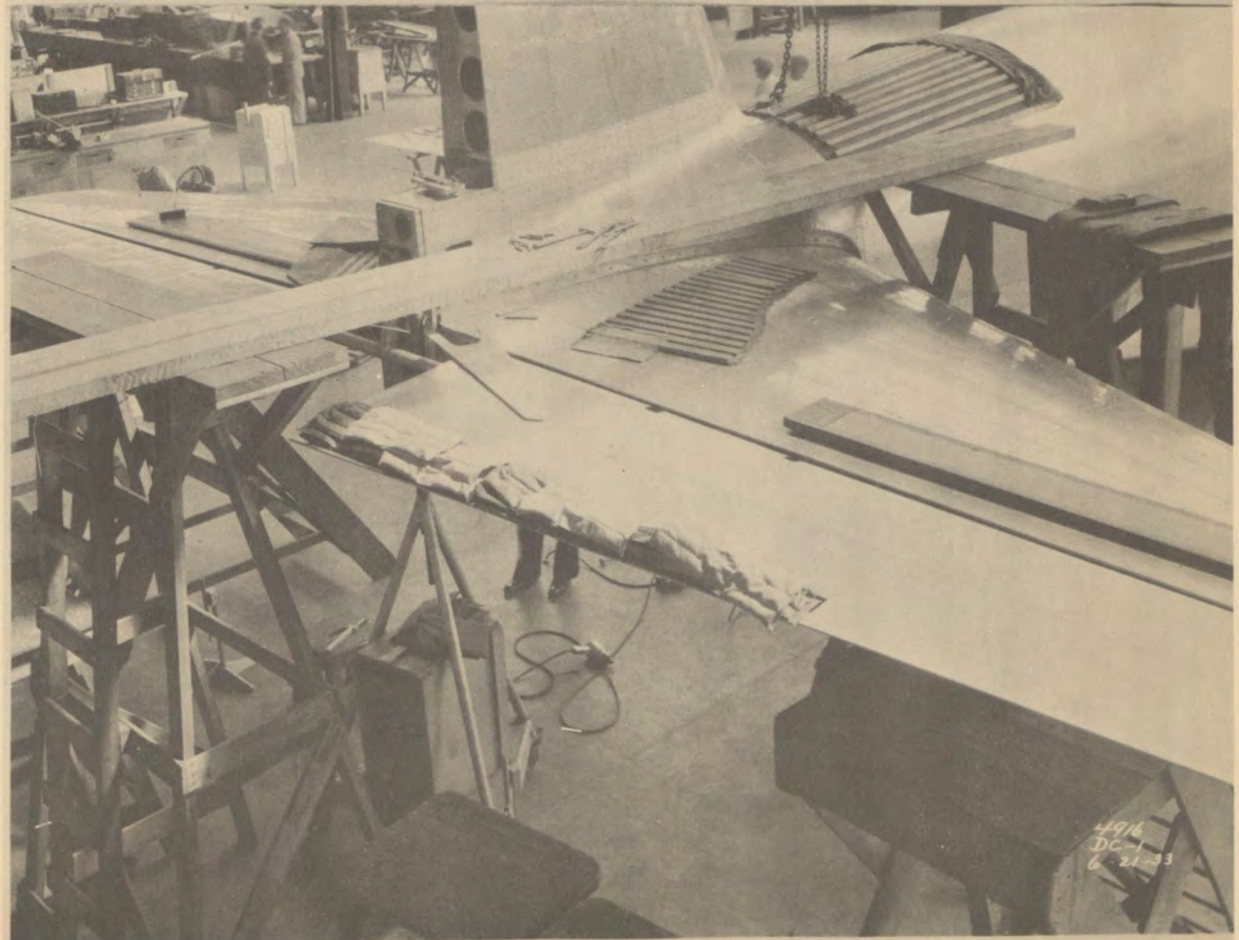
FABRIC COVERED RUDDER STATIC TEST TO FULL DESIGN LOAD.

STATIC TEST TO FULL BREAKING LOAD OF ELEVATOR CONTROL SYSTEM. NOTE THE ACCESSIBILITY WHEN THE FUSELAGE TAIL CONE IS REMOVED.

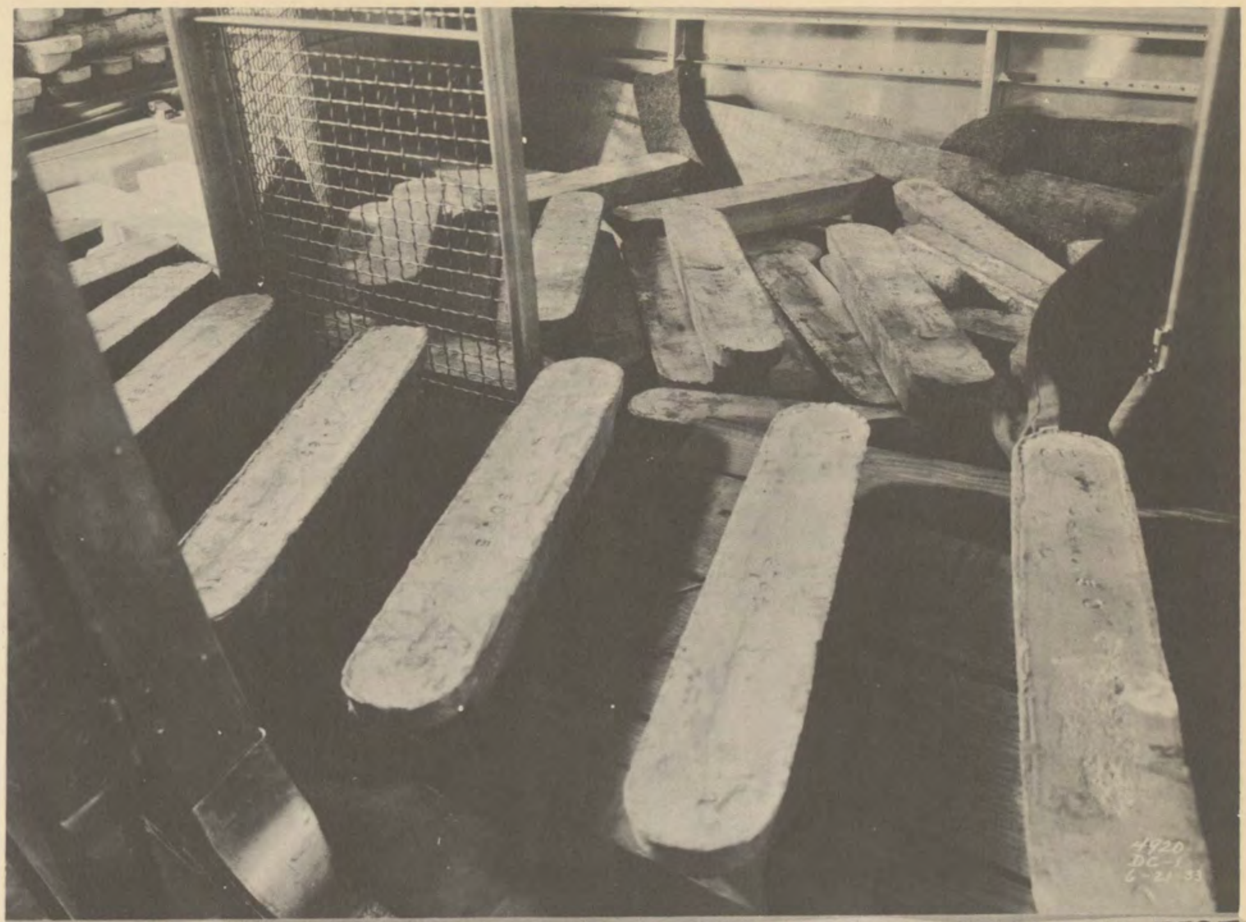
FUSELAGE TORSIONAL TEST. IN THIS TEST SIDE LOADS WERE APPLIED TO THE VERTICAL STABILIZER THROUGH A SYSTEM OF CABLES, PULLEYS AND WEIGHTS.



STATIC TEST OF HORIZONTAL STABILIZER, ELEVATORS, ELEVATOR FLAPS, FUSELAGE IN BENDING AND CENTER WING PANEL. THE CABIN, CARGO AND BAGGAGE COMPARTMENT ARE ALSO LOADED. THE FRAME ON THE VERTICAL STABILIZER IS FOR DISTRIBUTING THE SIDE LOADS.

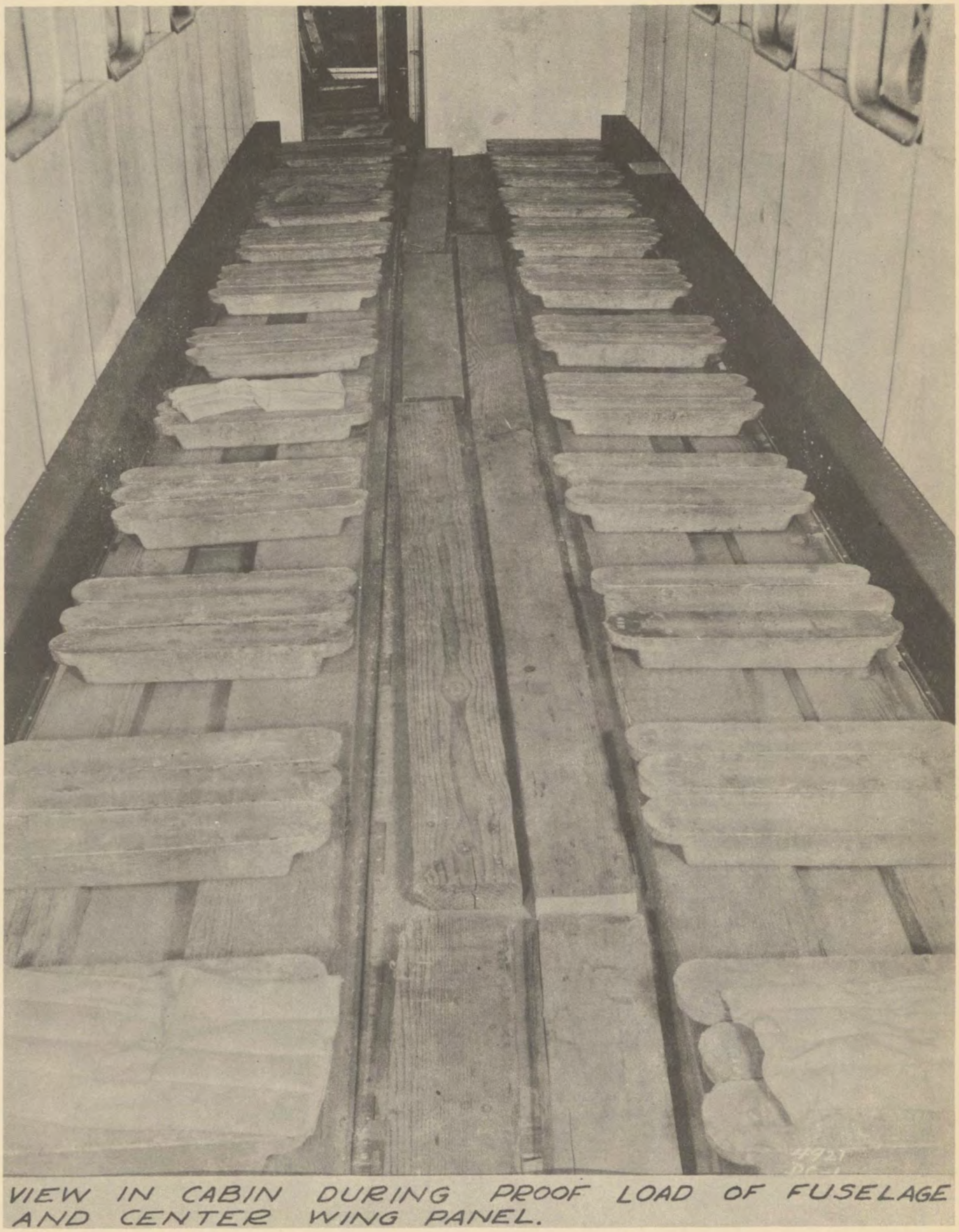


STATIC TEST OF ELEVATOR FLAP AND CONTROL MECHANISM

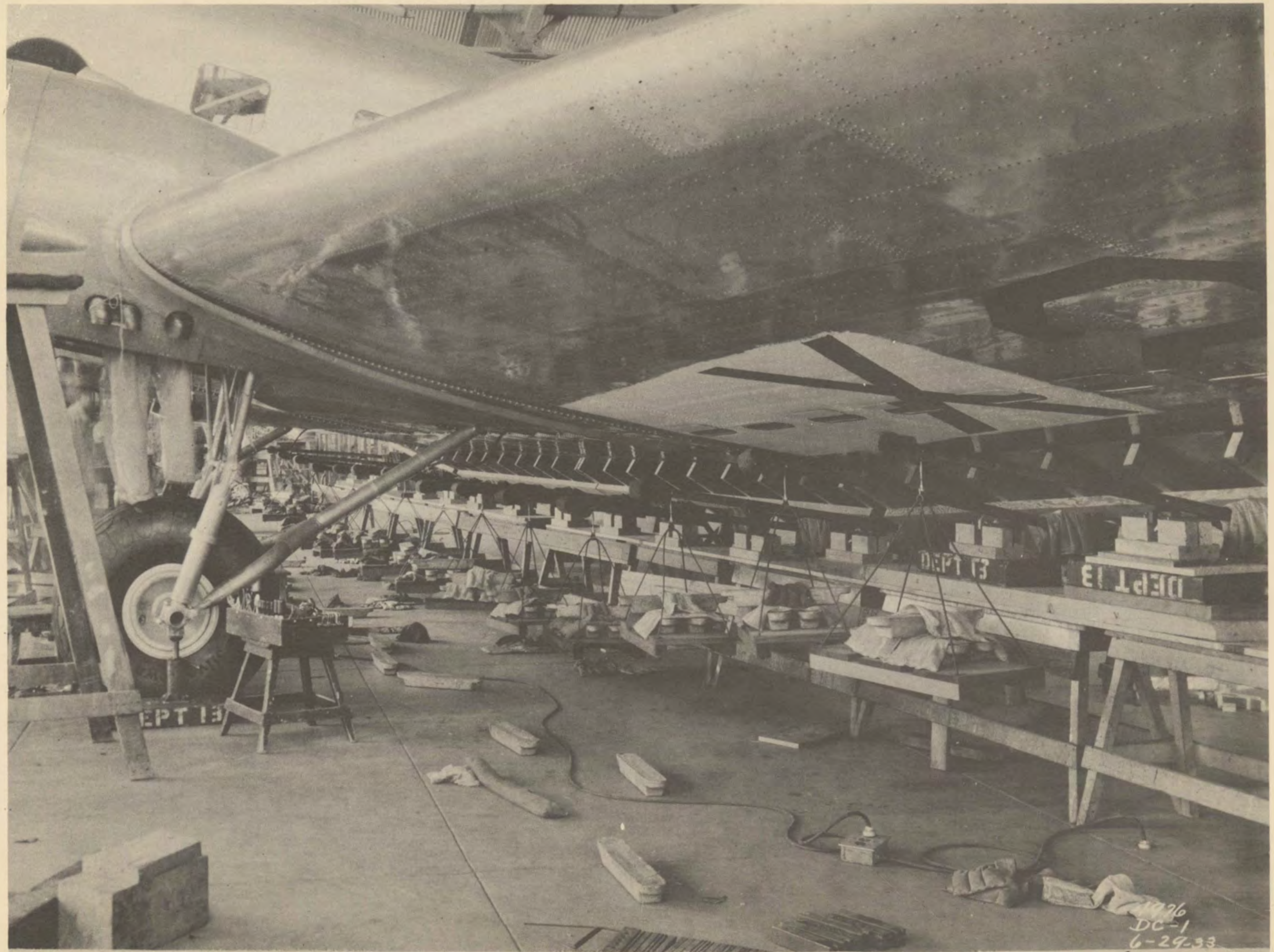


LOAD IN FORWARD MAIL COMPARTMENT DURING PROOF LOAD TEST OF THE FUSELAGE AND CENTER WING PANEL. THE WEIGHTS IN THE UPPER LEFT CORNER ARE IN THE PILOT'S COMPARTMENT.

LOAD IN REAR BAGGAGE COMPARTMENT DURING PROOF TEST OF FUSELAGE AND CENTER WING PANEL.



VIEW IN CABIN DURING PROOF LOAD OF FUSELAGE AND CENTER WING PANEL.



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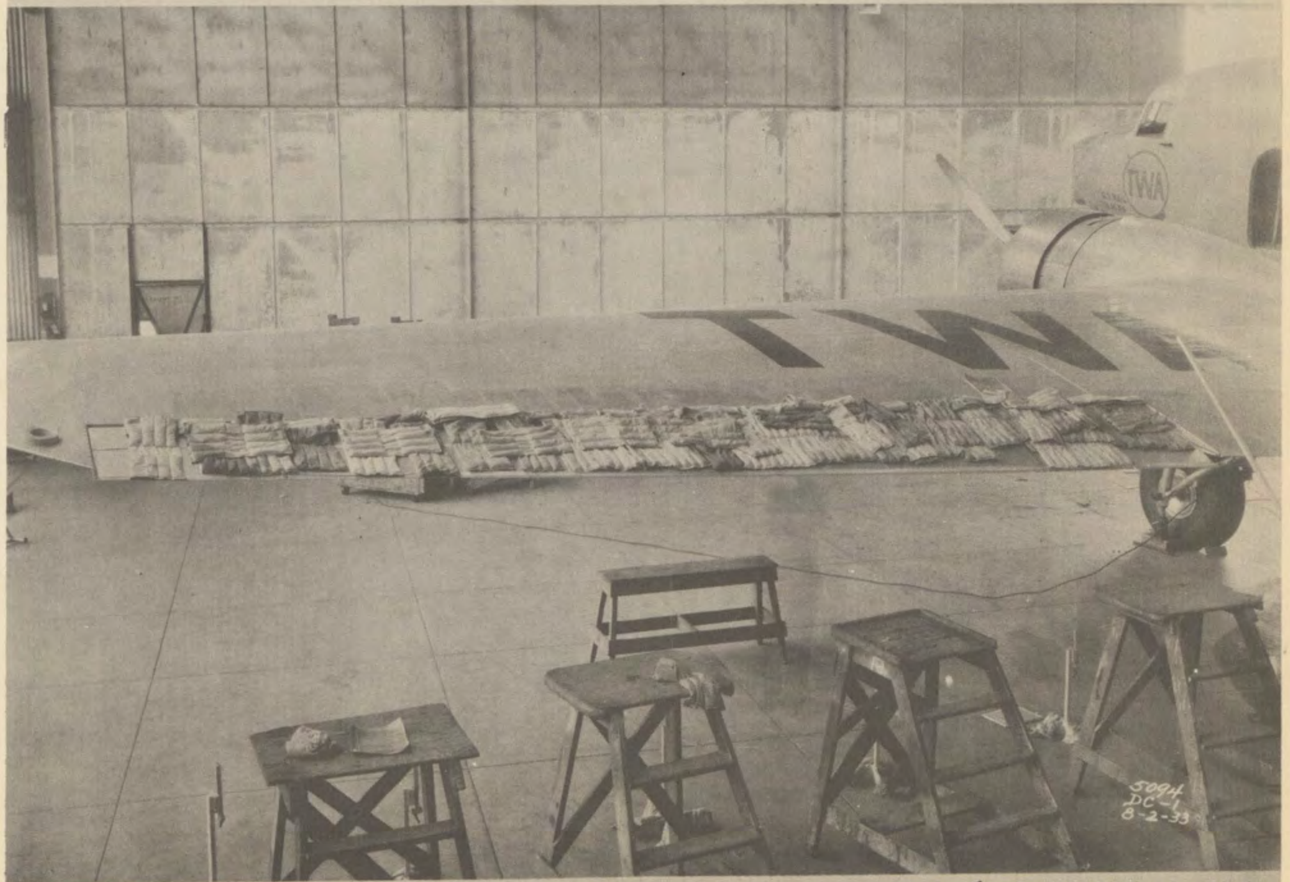
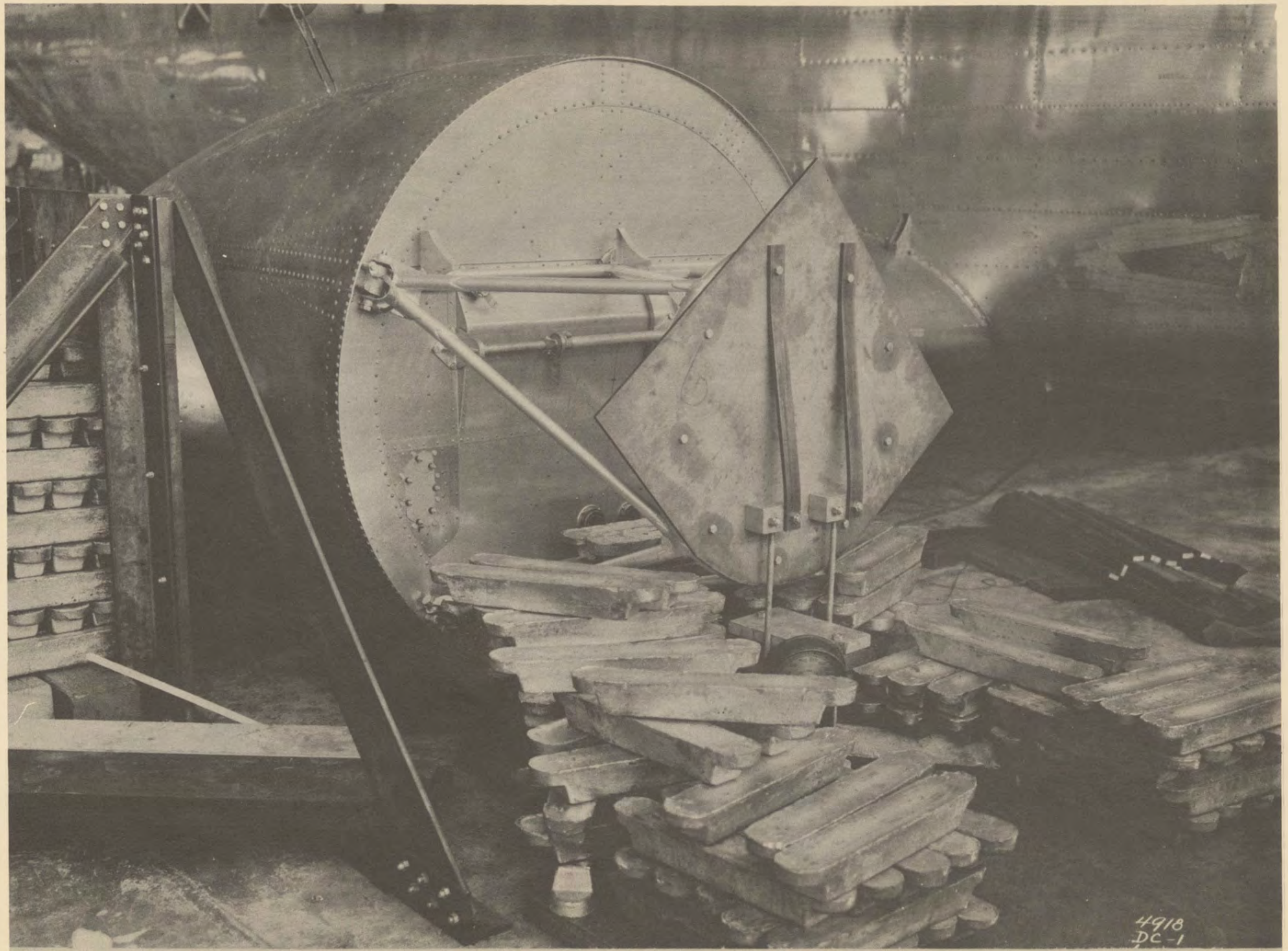
STATIC TEST OF WING FLAP AND CONTROL MECHANISM. (NOTE ACCESSIBILITY OF ENGINE NACELLE INTERIOR).

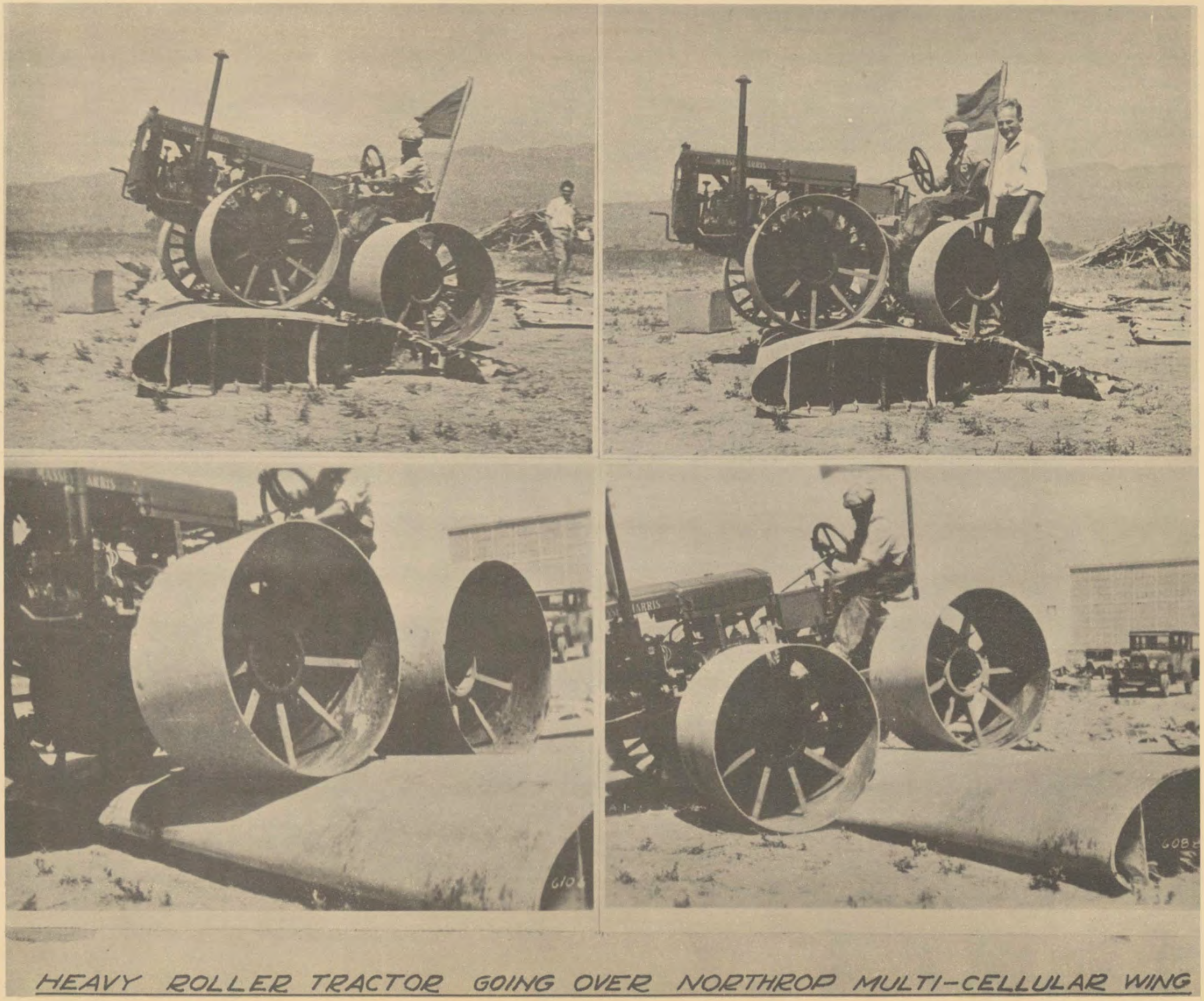
AILERON UNDER FULL STATIC LOAD.



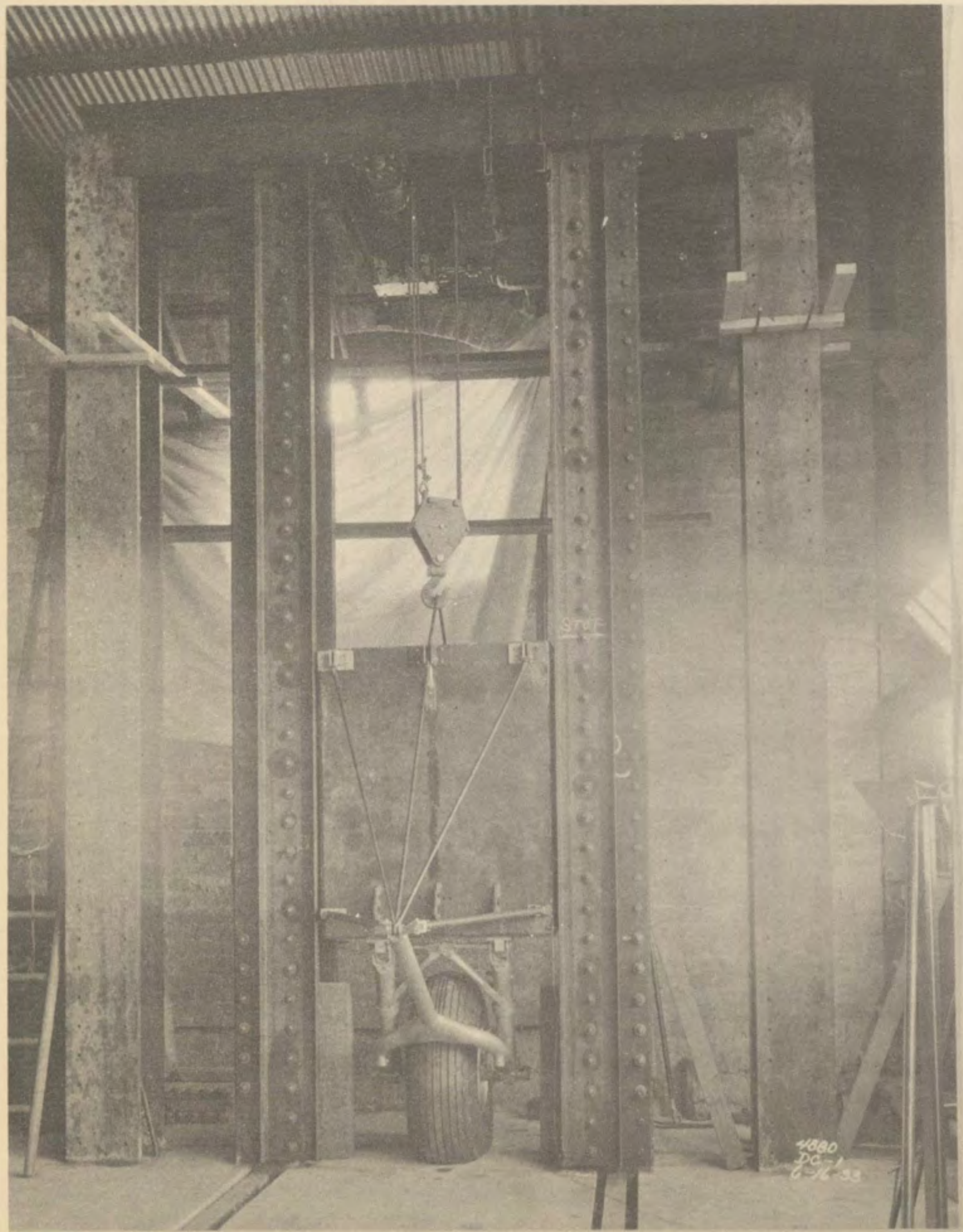
AILERON STATIC TEST TO FULL DESIGN LOAD. (MAXIMUM CALCULATED LOAD TIMES SAFETY FACTOR).



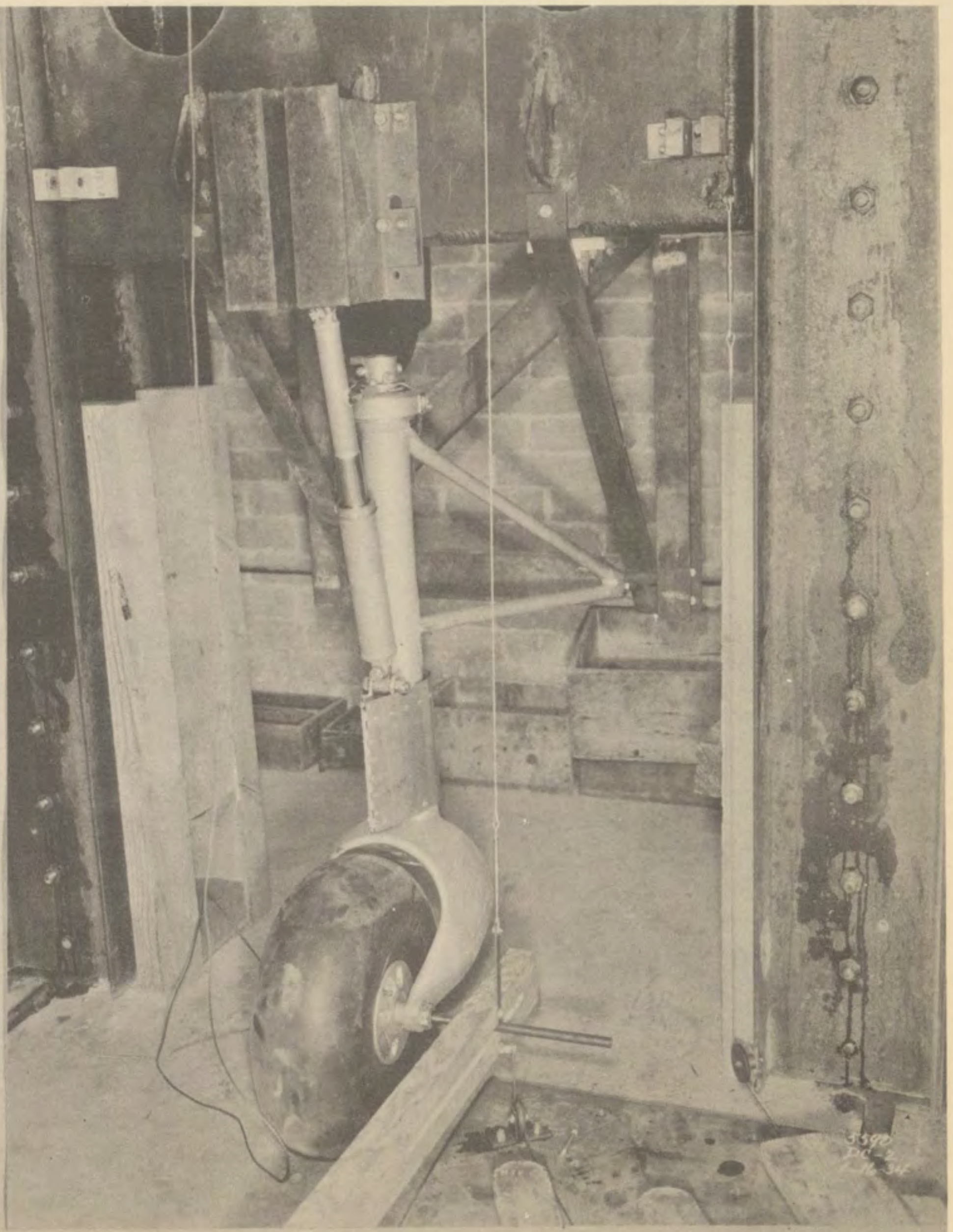
STATIC TEST OF ENGINE NACELLE STRUCTURE TO 60% BREAKING LOAD. THIS TEST SHOWED LESS THAN 1/32 OF AN INCH DEFLECTION IN THE WHEEL OPENING.



HEAVY ROLLER TRACTOR GOING OVER NORTHROP MULTI-CELLULAR WING



DYNAMIC DROP TEST OF LANDING GEAR.



DYNAMIC DROP TEST OF TAIL WHEEL ASSEMBLY.

Soundproofing and Elimination of Vibration

Realizing the complexity of the problem of soundproofing and vibration, the Douglas Company determined to add to its own experience and development everything that would aid in making the Transport as quiet and free from vibration as possible. The Sperry Corporation was engaged for research work because of its extensive experience along the line of these problems. Engineers from the Sperry Corporation were consulted while the airplane was still in the design stage so that their recommendations could be incorporated in the structure.

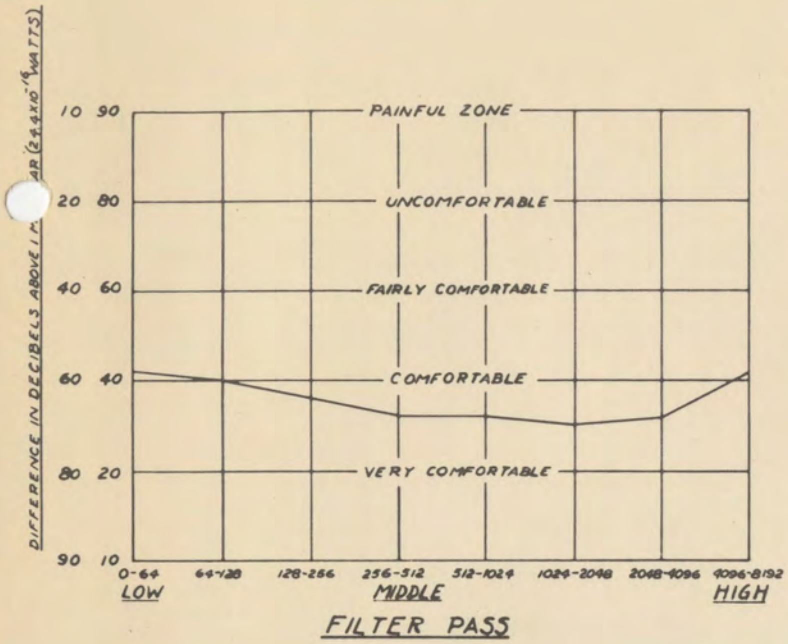
As the primary sources of noise in an airplane are the exhaust, propellers, engine clatter and vibration, the first step in soundproofing of the Douglas Transport was to reduce each of these noises as much as possible at its origin, to prevent vibration of cabin walls and panels, to seal the cabin so that sound entering it would be at an absolute minimum, to absorb all sounds that might enter the cabin, and to make such a pitch (frequency) distribution as to render it agreeable to the human ear.

An acoustical engineer of the Sperry Corporation accompanied the Douglas Transport on its first test flights, which were made before the upholstering or soundproofing had been installed in the airplane. A complete analysis was then made of the frequencies (pitch), and of the sounds at various points in the cabin while flying at various speeds. Under these conditions, at cruising speed, the average noise level was about the same as that in an open cockpit airplane and conversation was only possible by shouting. By studying the data thus obtained, it was possible to determine the best means of soundproofing the cabin. An assortment of eleven different soundproofing materials were used in the final installation. Each material was chosen after a thorough study had been made of its properties and the materials were then judiciously placed in the airplane so as to be the most effective without causing excessive weight. Stiff materials were eliminated as they reflect sounds back into the cabin very readily. Coarse art sacking or other soft deadening materials, such as are sometimes used, were eliminated because they are poor absorbers of low frequency sounds (although they are efficient for high frequencies) and because they are not easily washable. The material selected for the interior cabin finish is washable, paintable, light in weight and has a high coefficient of sound absorption over the low frequency end of the range of the noises encountered. Behind the cabin finish special compressed Kapok fiber sheets were placed to absorb the high frequency sounds. A sound deadening bulkhead 2-1/2 inches thick was built up to separate the forward mail and baggage compartment from the cabin. The effectiveness of this bulkhead is appreciated on opening the door leading through the bulkhead into the pilots' and mail compartments. With the door closed, the cabin is 12 to 14 decibels quieter than the pilots' compartment. To prevent noises from entering the cabin through the ventilating or heating systems, the interior walls of the ventilators and the intake ducts were treated with a special sound deadening cement and sound filters were provided at critical points. At all points where the cabin encounters members of the fuselage structure, flexible felt or rubber spacers that have a high damping effect were used for insulation. In the cabin all fittings and furniture were designed so that each piece would contribute its part to the absorption of sound. The passenger chairs were mounted on rubber supports and the metal hand rail on each wall was stuffed with soundproofing material.

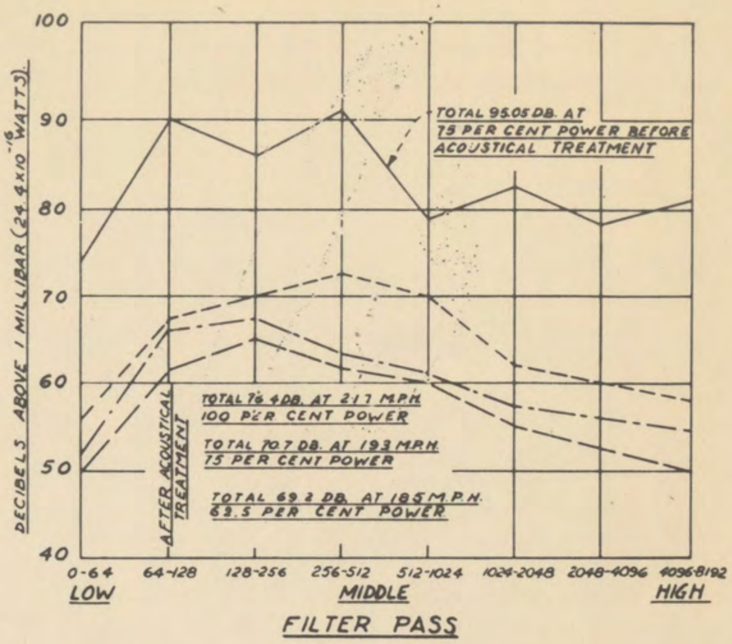
Further, the engines were mounted flexibly on special rubber insulators, exhaust noises were reduced by carrying the exhaust below the wing with the wing blanketing the noise away from the cabin. Each exhaust stack was designed to a different shape and diameter to prevent resonance effects. Stress carrying members leading from the wings and engines were prohibited from entering the cabin in order to prevent direct transmission of vibration.

The airplane was then flown with all soundproofing and upholstering installed and analyses were again made of the sound and frequency distribution in the cabin. A number of minor adjustments were then made until the noise level and distribution were satisfactory.

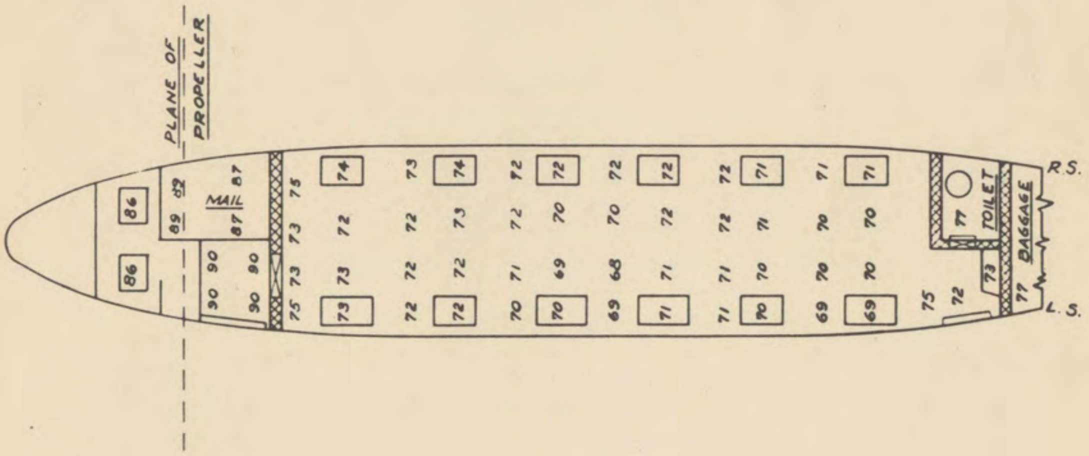
Noise level is measured by a scale of decibels ranging from dead silence at zero decibels to a painful roar, such as a wide open aircraft engine on the ground, equivalent to 120 decibels. On this scale, noise inside the Transport fuselage before soundproofing was begun, mounted to 98 decibels. After completion, the noise level was reduced to 72 decibels at 185 m.p.h. Comparisons made with some airplanes cruising at 90 m.p.h. and having a noise level of 66 to 68 decibels, have shown that at this speed the Douglas Transport would have a noise level of 60 decibels or less. Thus it was for the first time in aeronautics and perhaps in any moving vehicle that the principle of balanced acoustics has been successfully tried with the results that this airplane is not only the most quiet airplane flying but also has a noise spectrum which seems to be less fatiguing to passengers.



DIFFERENCE BETWEEN THE UPPER THRESHOLD AND NOISE LEVEL OF THE DC-1



SPECTRUM OF NOISE WITH DOUGLAS TRANSPORT MODEL DC-1 AT DIFFERENT SPEEDS AND BEFORE AND AFTER ACOUSTICAL TREATMENT (CENTER OF CABIN). CURVES 1 AND 3 GIVE A DIRECT COMPARISON AS TO THE EFFECTIVENESS OF ACOUSTICAL TREATMENT.



NOISE LEVEL DISTRIBUTION OF THE DC-1 AT 75 PER CENT TO 80 PER CENT POWER (12 PASSENGERS; NO MAIL OR BAGGAGE).

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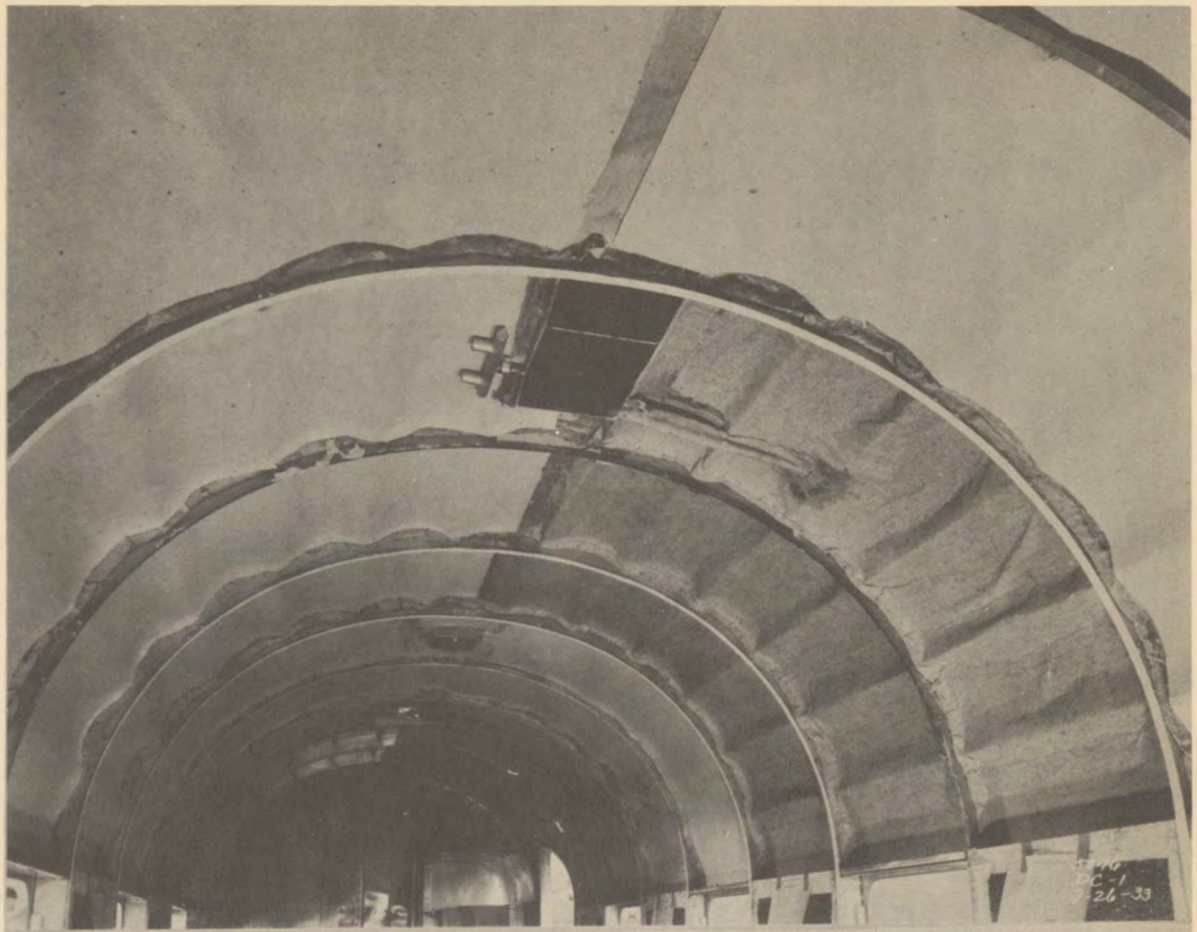
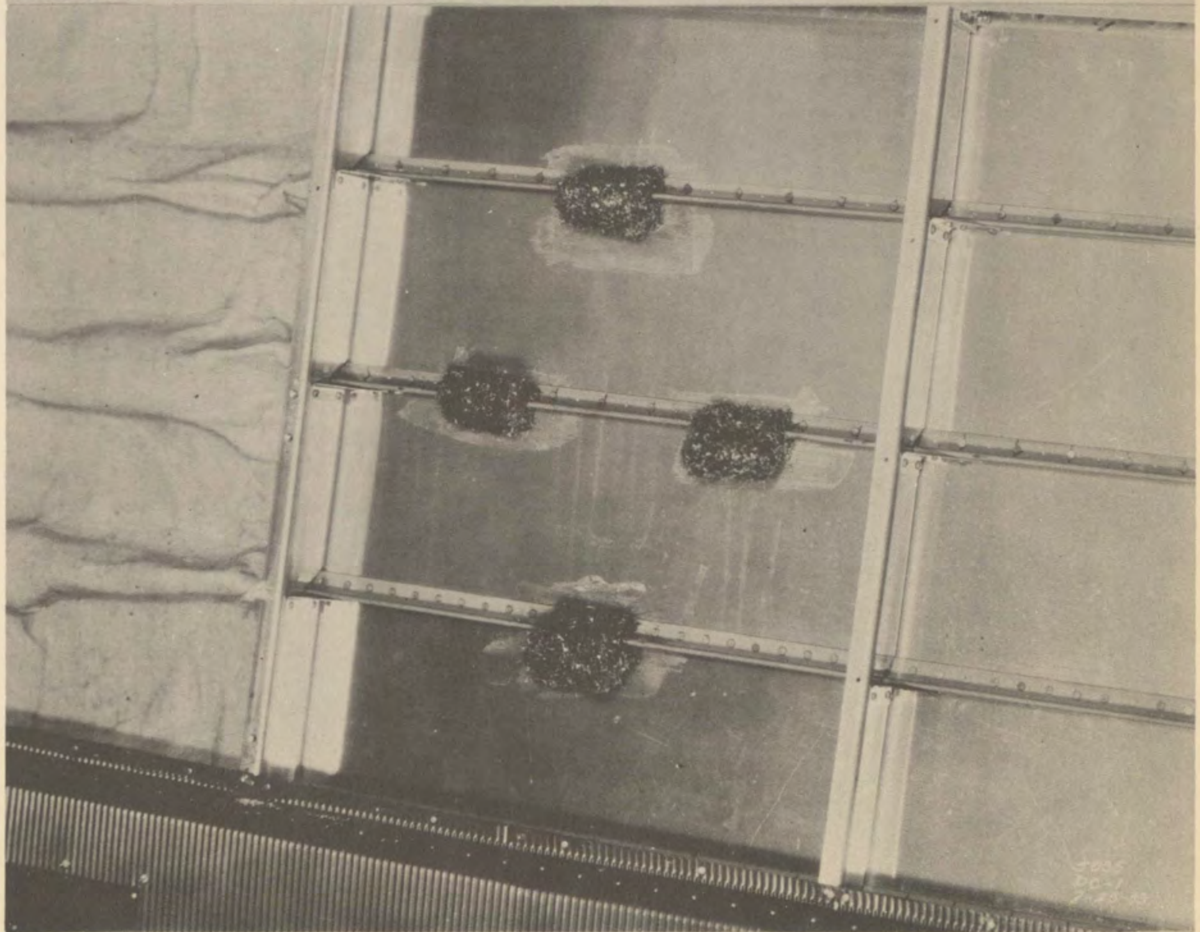
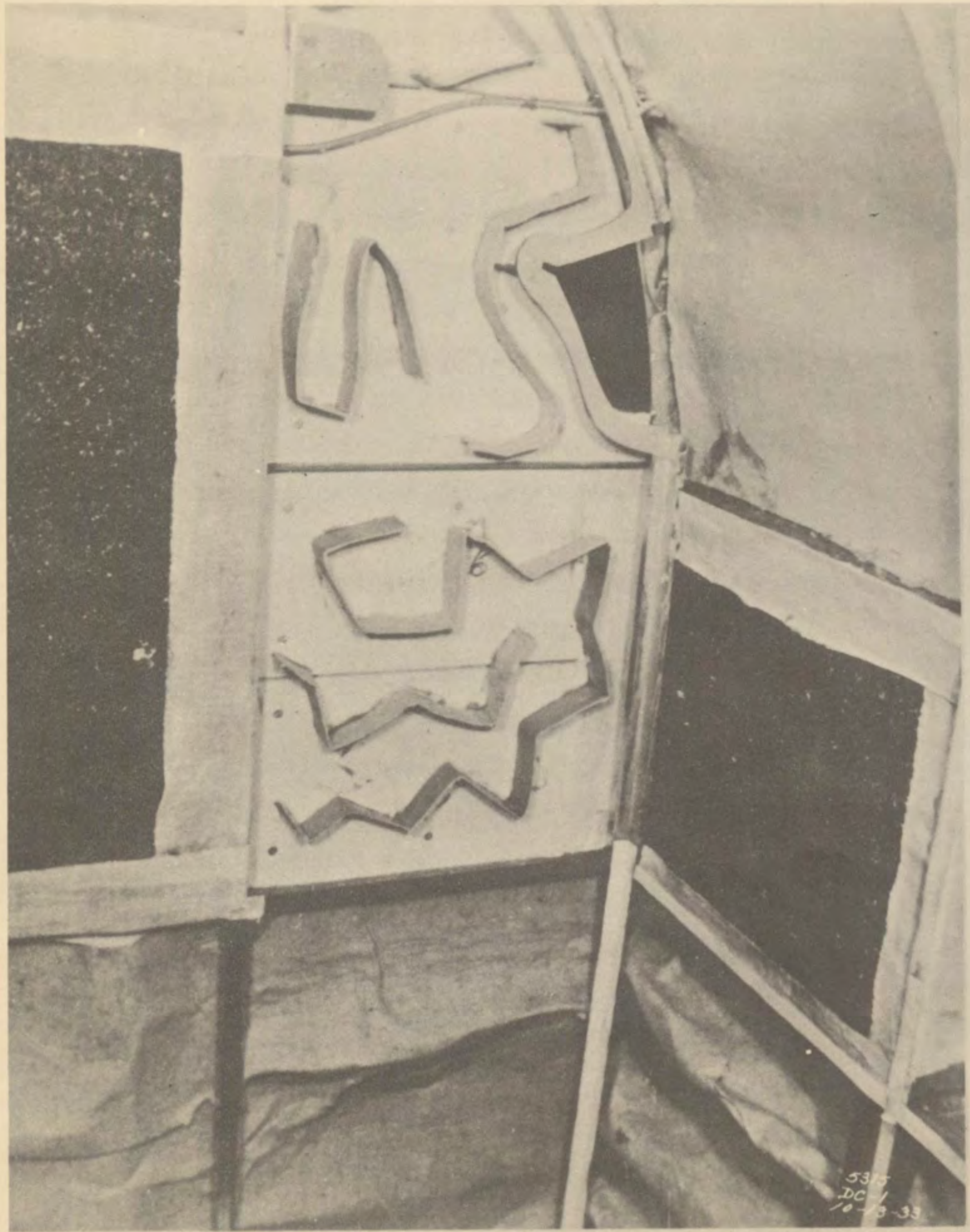
ACOUSTICAL ENGINEER MEASURING SOUND IN THE CABIN OF THE DOUGLAS TRANSPORT.



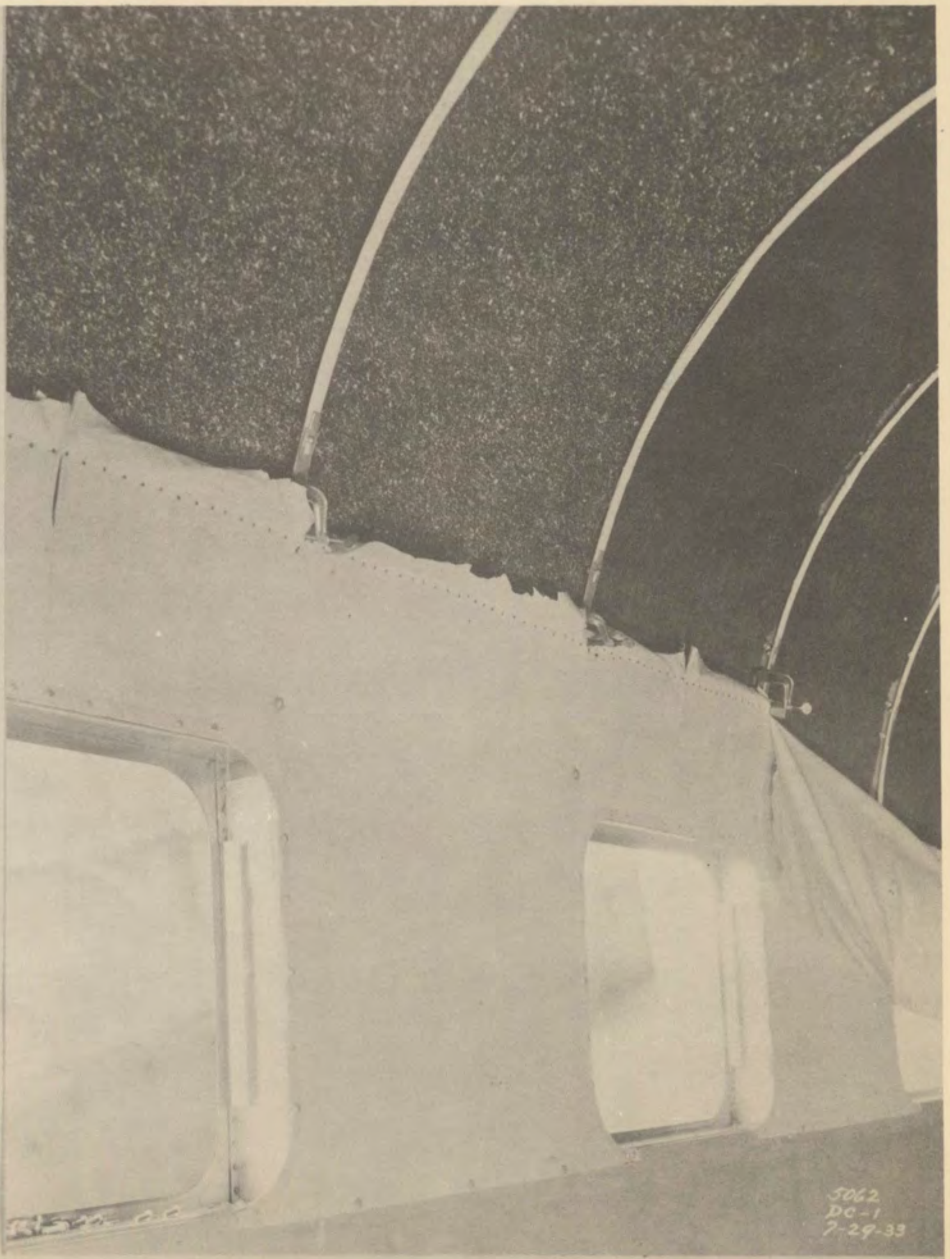
TWO STAGES OF THE SOUNDPROOFING INSTALLATION IN THE CEILING. NOTE THE SOUND TRAP ON THE LEFT SIDE OF THE AIR OUTLET



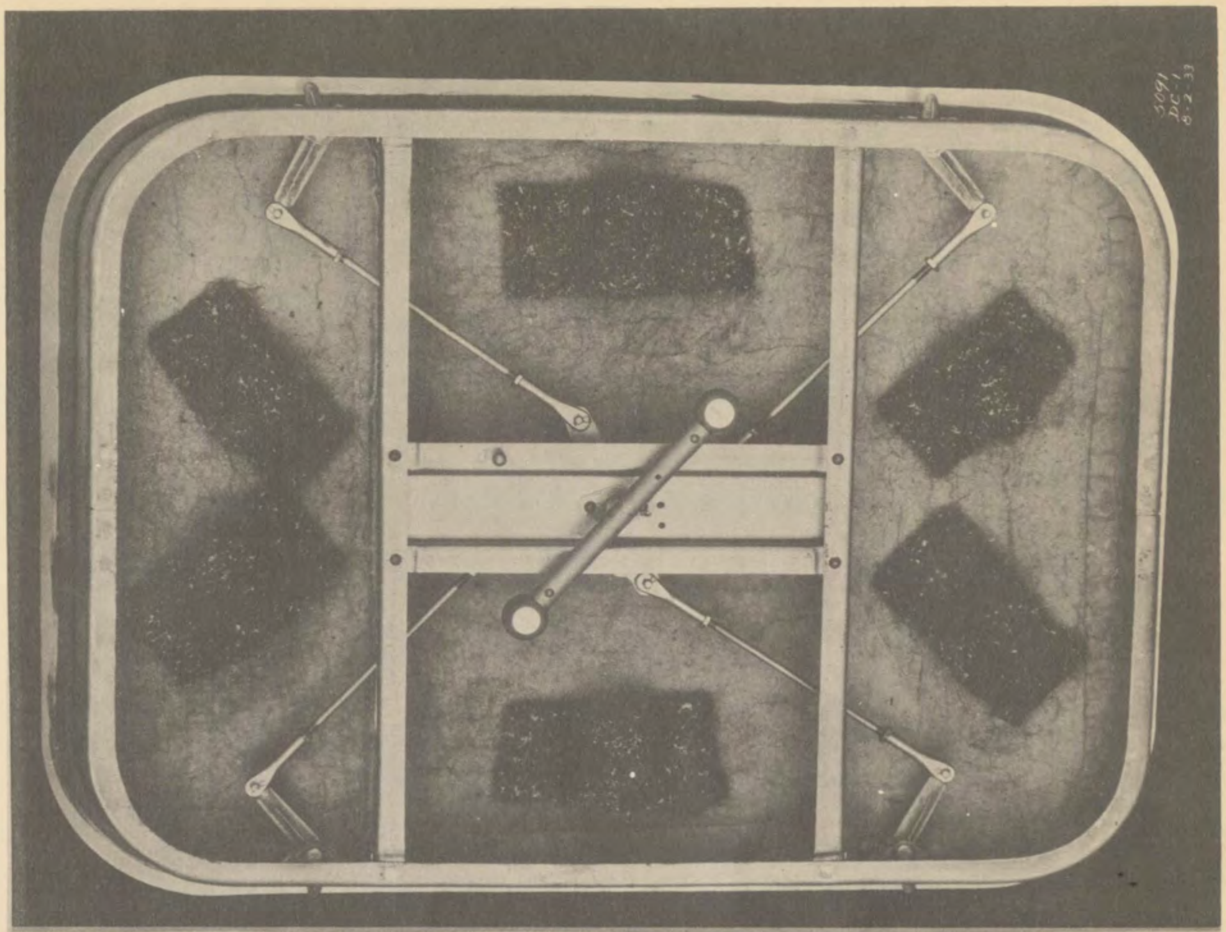
TWO STAGES OF THE SOUNDPROOFING INSTALLATION IN THE CABIN WALL BELOW THE WINDOWS.



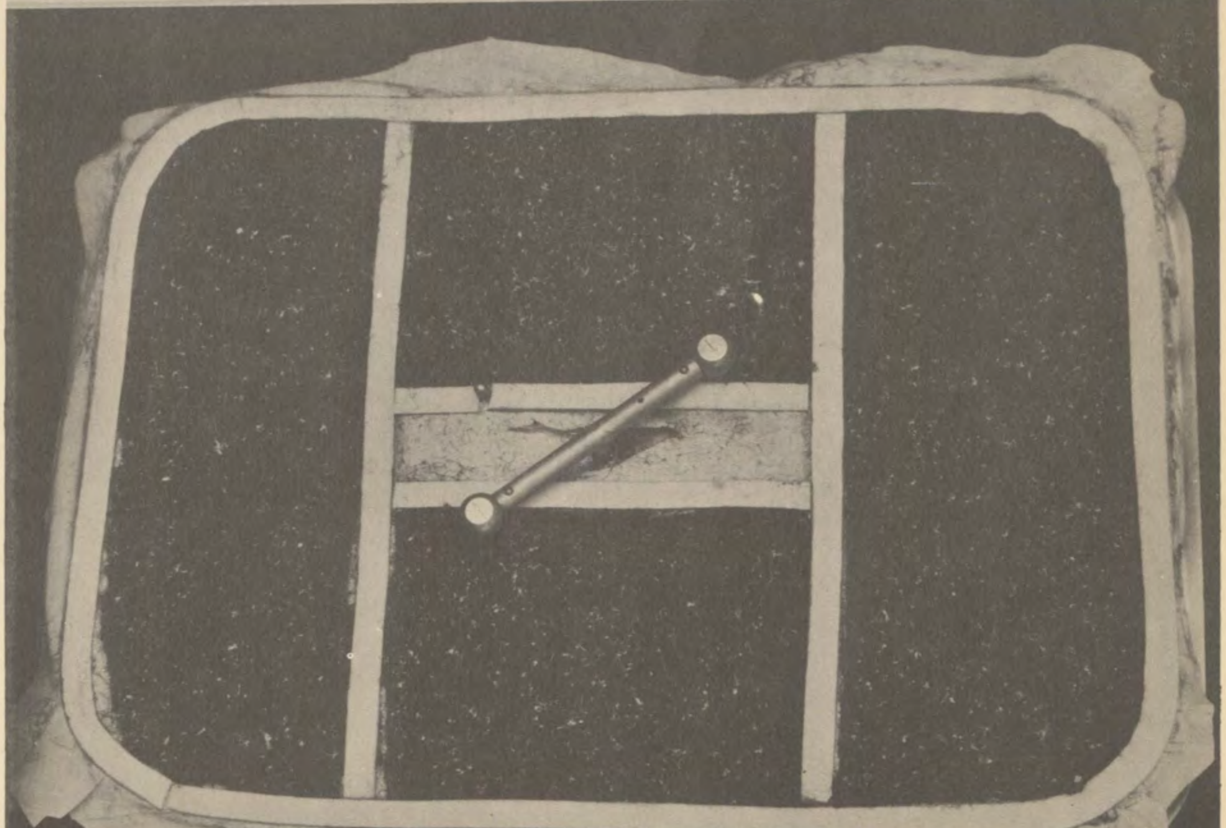
VARIOUS STAGES OF THE SOUNDPROOFING INSTALLATION IN THE FORWARD CABIN WALL.



SOUNDPROOFING INSTALLATION COMPLETE AND FABRIC COVERING OF CABIN IN FIRST STAGES OF APPLICATION.



EMERGENCY EXIT DOOR WITH FIRST LAYERS OF SOUND-PROOFING MATERIALS INSTALLED.



EMERGENCY EXIT DOOR, WITH ALL SOUNDPROOFING INSTALLED, READY FOR INSTALLATION OF FINISHING MATERIAL.

Heating and Ventilating

To further insure passenger comfort under all conditions, a very thorough study of the heating and ventilating system was made. In developing the heating system, it was resolved to eliminte every possibility of gases entering the ventilating system and after considerable experimentation a satisfactory steam heating system was evolved.

This system provides the cabin with a complete change of air every sixty seconds and will maintain a temperature of 70 degrees with an outside air temperature as low as 30 degrees below zero. Further, there are additional cool air inlets adjacent to each seat so that each passenger can direct a stream of cold air in his face, if desired. The entire heating system is thermostatically controlled.

Because of the excellent ventilation and the absence of noise and vibration, air sickness in the Douglas Transport is practically unknown.

Flight Testing

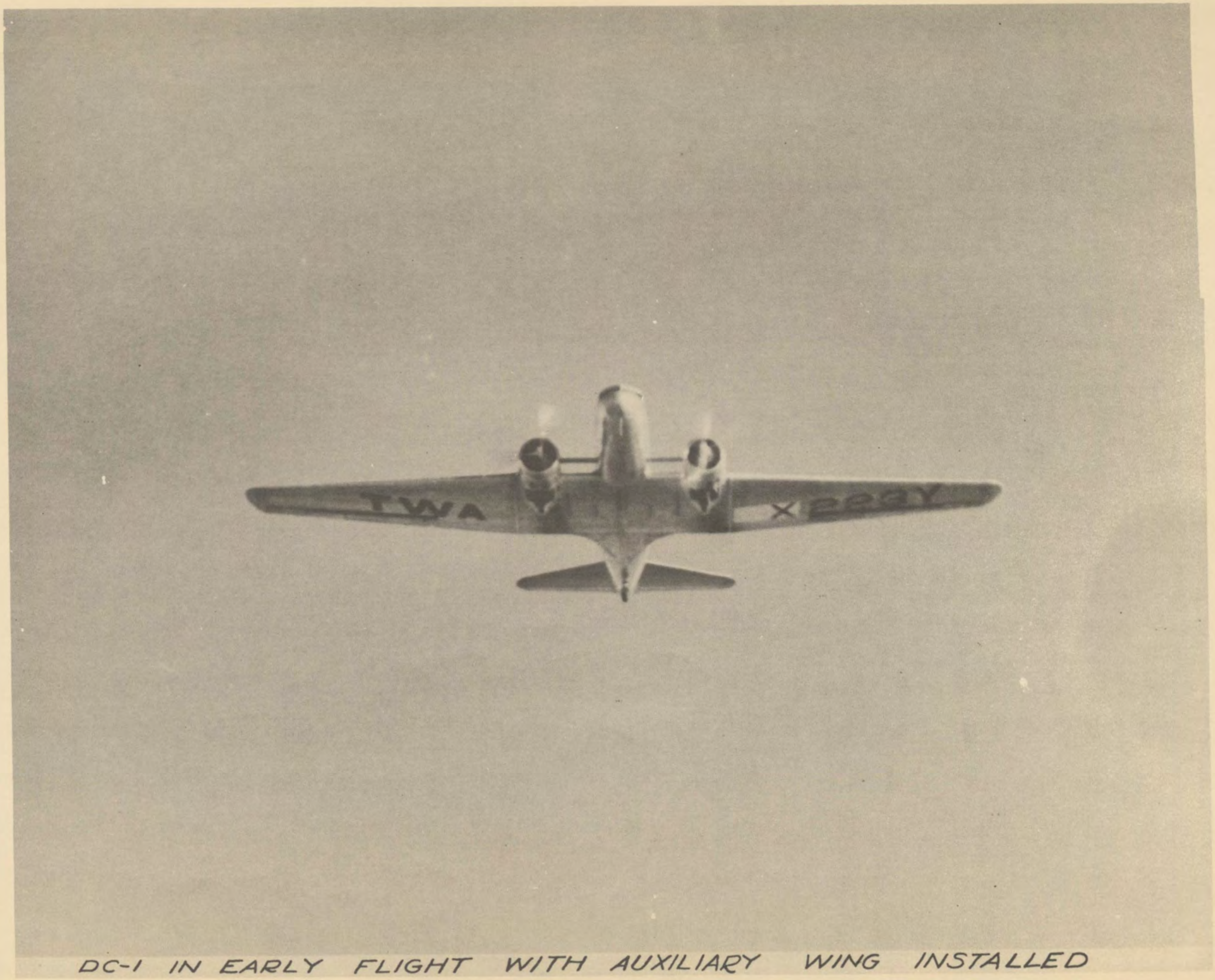
The flight testing of the Douglas Transport initiated a new conception and precision into flight methods and technique. With the high degree of accuracy of the design data and the elaborate care and precision of the wind tunnel tests, it was vital that the flight tests do more than merely measure performance by the old methods. It was necessary to check the design and wind tunnel data quantitatively and with mathematical exactness. Another object of the flight test program was to determine the cruising performance of the airplane under airline operating conditions.

The thoroughness with which these flight tests were conducted is exemplified in the fact that approximately 200 test flights were made, requiring over eight months to complete and using over fifteen thousand gallons of fuel.

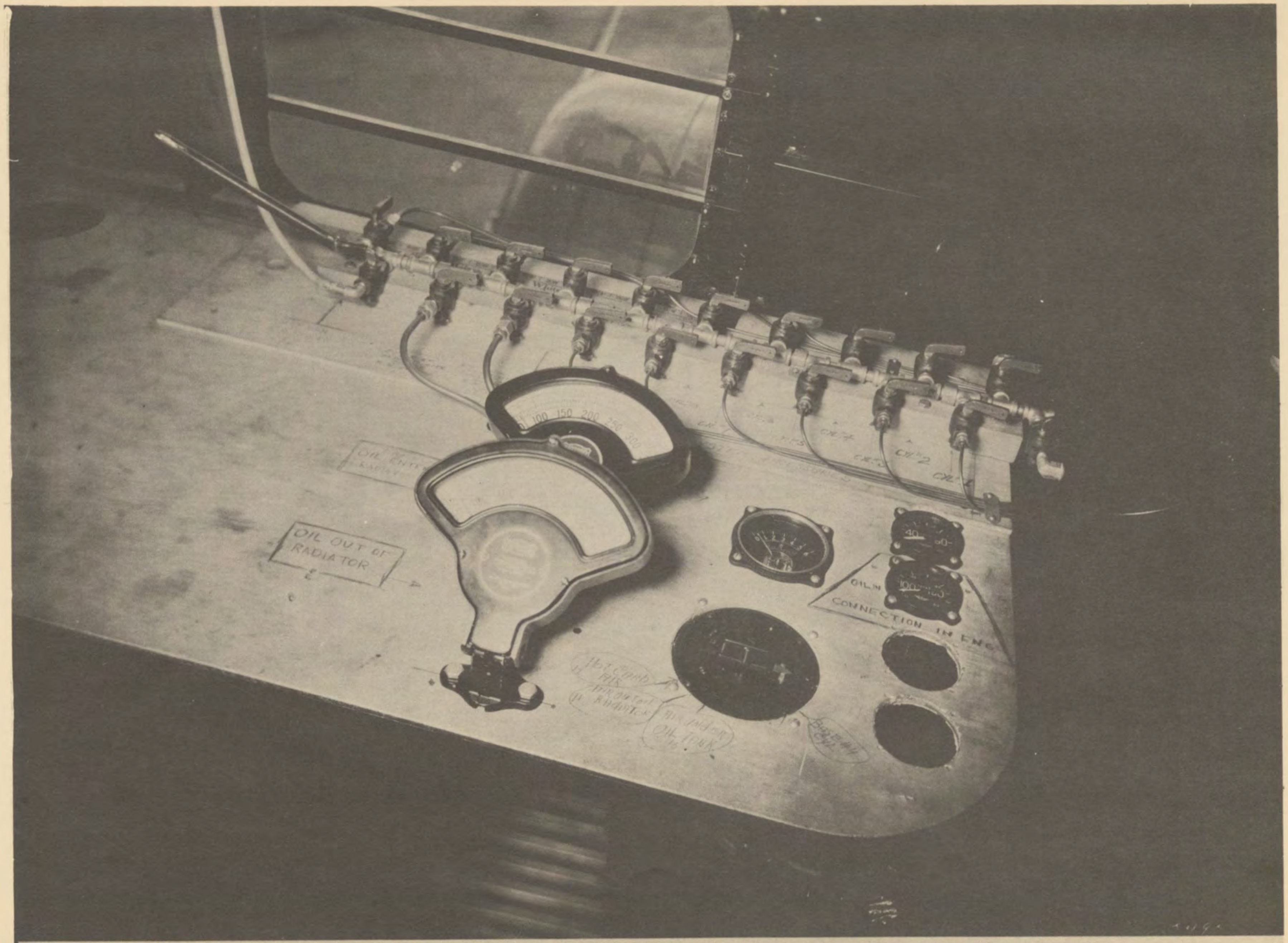
These tests included quantitative determination of stability (longitudinal, lateral and directional) under varying conditions of load, power output and lift coefficient and with various wing and control surface flap positions and changes in cowling and wing arrangement to check the wind tunnel stability determination. Also quantitative measurement was made of controllability and maneuverability with the three sets of control surfaces until the correct proportion of control effectiveness and control heaviness with proper aerodynamic balance was obtained.

Tests for loading the structure in the air were made, in which pull-outs were recorded on velocity-acceleration (V-G) and visual accelerometer instruments. This data was then correlated with deflections recorded by telephoto motion picture cameras.

The power plant development part of the flight testing occupied several months in the effort to obtain exactly the right installation and adaptation of airplane to engines and accessories, such as oil radiators, steam heating plants, vacuum system, hydraulic and electrical systems. Flight tests were run for five different combinations of cowling, oil cooling and carburetor air intake systems.



DC-1 IN EARLY FLIGHT WITH AUXILIARY WING INSTALLED



INSTRUMENTS AND CONTROLS SETUP IN FORWARD CARGO COMPARTMENT FOR RECORDING ENGINE DATA. DURING TEST FLIGHTS.

Landing and takeoff tests with and without flaps and with varying powers were made to establish accurate landing speeds, takeoff distance, landing run, takeoff run, takeoff time and initial climbing angle. These were all carefully checked and correlated through motion picture records.

The automatic pilot installation was developed with the designer from the Sperry Gyroscope Corporation in constant attendance and many cross-country flights were made until the final development was pronounced to be the most successful automatic pilot installation to date.

The landing gear has received unusual development to obtain excellent ground handling properties with high taxiing speeds and ease of maneuverability, quick retraction and extension of the gear with fool-proof warning and locking mechanisms.

On one of the first test flights, a landing was made with the landing gear fully retracted. As the wheels are well forward of the center of gravity and project slightly below the nacelle structure and the axles rest in rigidly supported sockets and full brake control is available, no damage was incurred other than that to the propeller tips. In fact, after installing new propellers, the airplane was flown away.

Tests were run for two-engine and single-engine flight with engines from two manufacturers and testswere also run with three different designs of propeller blades.

In the actual performance determination many of the hitherto neglected variables and uncertainties of flight testing were eliminated and there was kept clearly in mind from the first the object of determining, not the peak performance under ideal test conditions, but that performance which could be maintained from day to day under airline operating conditions. In order to perform such a flight test, it was necessary to define cruising in terms of allowable engine operation and allowable airplane operation and then to map the entire field of cruising power required, altitude and atmospheric temperature, engine revolutions, super-charger pressure and true velocity. This was all done in flight.

The Douglas Company test staff developed a set of engine curves which made possible for the first time the continual determination of engine horsepower while in flight. These curves have since been adopted as standard by the engine manufacturers. To check further the power output during flight, a propeller calibration was made in flight for each engine-propeller combination.

Cruising speed charts for guidance of transport pilots were developed to cover the entire range of cruising powers and atmospheric conditions. The conception of optimum cruising altitudes was developed which increased the cruising speed at constant power by 18 m.p.h. at ordinary cruising power (63%). A great number of cross-country flights were made to confirm the accuracy of the cruising speeds developed.

Emergency operations were exhaustively studied in flight to determine performance and controllability under all conditions of engine failure. Single-engine operation was tested with over-load and partially dumped fuel load, including single-engined takoff from airports at altitudes up to 5,000 feet and in flight up to and above 12,000 feet. The final single-engined demonstration was made by cutting one engine when the airplane had traversed just half of the takeoff runway on a field 4,200 feet above sea level. The airplane continued the takeoff, climbed over the continental divide and flew to the next regular airport 240 miles away on the remaining engine. An altitude of 1,000 feet above the ground was attained shortly after the takeoff and maintained throughout the flight, which necessitated climbing to 8,300 feet when passing over the peak of the divide, which is 7,300 feet above sea level. At no time during this test was the operating engine allowed to exceed its rated horsepower output.

VIEW OF AIRPLANE AFTER LANDING WITH WHEELS RETRACTED. NEW PROPELLERS WERE INSTALLED AND THE AIRPLANE WAS FLOWN AWAY.

Conclusion

It is gratifying to note that the time and expense of all the preliminary aerodynamic, wind tunnel, mock-up and design studies were more than justified by the results obtained. The performance, stability characteristics and wing deflections, as determined in flight, conformed almost exactly with the predicted results. In fact, no major changes were necessary in the arrangement of the various parts of the airplane. Similarly, other wind tunnel predictions were proven in flight to be accurate.

The superior strength and rigidity of the Douglas multi-cellular wing and all-metal fuselage construction has been proven in both static and dynamic tests as well as in service to more than justify the time and expense of the thorough investigation made of the structure. There is no doubt left regarding the strength and reliability of any part.

From the viewpoint of passenger and pilot comfort, the mock-up, soundproofing, heating and ventilating investigations have more than proven their value as shown in the quietness and comfort of this multi-engined transport.

To add further to the completeness and excellence of this airplane, carefully worked out maintenance aids have been so constructed and mounted as to provide for servicing and replacement with a minimum of time and expense. In fact, the complete power plant section, including the engine, propeller, oil tank and all cowling, may be completely removed in seventeen minutes.

In general, this airplane is the product of a painstaking study of all the problems concerned and a thorough and methodical investigation of every possible solution, combined with the extensive experience of the Douglas Company in producing a great quantity of experimental and production airplanes. The Douglas Transport takes the air fourfold in supremacy - in comfort, performance, safety and service - the luxury liner of the airways.