The Story of the Douglas D.C.'s

by LAWTON TINSLEY

A story of how a giant airliner is designed, built and tested. Beginning with simply an idea, the work is carried through the wind-tunnel tests, a "mock-up" is made and then the design is actually started. Then come the shop operations and the final test flights.

FLASHING across the continent in the amazing time of thirteen hours and two minutes, the Douglas Transport literally hurled itself to the front in the annals of Commercial Aviation history.

At a rate of speed excelled only by highly sensitive speed planes, the D.C.I., carrying its designed load of twelve passengers and over fifteen hundred pounds of cargo, established a new transcontinental transport record and set a mark for transport manufacturers to shoot at in the years to come.

That rival manufacturers are not losing any time in speeding up their ships is exemplified by the recent great change in aerodynamic style on all types of planes, both military and commercial. The deep fuselage-to-wing-fillets and the exceptionally clean areodynamic designs, characteristic of the Douglas which are coming out on all the new ships, lead one to wonder how long the present record will stand.

The true top speed of the Douglas Transport is known by very few people and they refuse to talk. Under such circumstances it is impossible to make a near-accurate estimate of the cruising speed. However, it is safe to assume that the ship is much faster than the published reports would lead one to believe.

To substantiate this assumption, it is said that the ship was not extended on the record breaking run and that when it is necessary, the record can be further reduced. This tends to make the record breaking future of passenger planes a little more complicated but a great deal more interesting to watch.

Anthony Fokker, when purchasing the rights to manufacture the Douglas Transport in Europe, is credited with saying that it would be useless for him to spend time and money in an effort to build a ship capable of favorably competing with the Douglas due to the time element involved in tests and experiments and the uncertainty of results.

It may be true that the transport startled the world because of its tremendous speed, but a study of its development from an idea to a record breaker will prove that it wasn't designed for speed alone.

The "idea," in the form of a one-eleventh scale model of the transport, was taken to the 200 m.p.h. tunnel at the California Institute of Technology where an extensive series of tests (approximately 200 test-runs) were made.

Every item of the plane affecting aerodynamic operation was considered in the wind-tunnel. The investigation covered tests on three complete wings, wing-to-fuselage-fillets of which a number were tested before the correct contour was determined, and tests on numerous combinations of tail surfaces, ailerons and wing flaps.

A Douglas D.C. passenger transport belonging to the Transcontinental and Western Air. When in flight, the landing-gear is retracted into the interior of the ship.

Tests of controllability and stability were made with different sets of control surfaces, both fixed and free. This was probably the first time that a model was allowed to demonstrate its ability to fly "hands off." The high speed of the tests and the large scale of the model were invaluable in perfecting the final areodynamic design.

A particularly interesting fact is that some of the early models tested were unstable and that it was necessary for satisfactory stability to incorporate a new arrangement of center-of-gravity, wing sweepback and general external appearance. The actual plane was built according to this heretofore untried plan of arrangement and its performance in flight carried out the predictions of the wind-tunnel tests.

Something of the value of these wind-tunnel tests may be gathered from the fact that the transport is so clean, areodynamically speaking, that the total resistance of the complete plane is less than twice the resistance of the wing alone.

Upon completion of the wind-tunnel tests a full scale model, called a "mock-up," was built to determine the location and the proportion of all structural details. The external design or streamline form of the mock-up was drawn up from the results of the wind-tunnel tests. The model itself was made with wooden frames and was covered with stiff paper to represent the metal skin of the actual plane.

The interior arrangement of the cabin was worked out to the smallest detail in the mock-up. The cabin floor was installed completely above the wing, thereby doing away with structural members within the cabin. The arrangement of passenger chairs placed each 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.

Different materials for the interior cabin trim were tried, including various wall coverings, curtains, floor covering and chair upholstery, until a neat, light, durable and easily maintained set-up was determined.

After much consideration, the final location of the lavatory and rear baggage compartment allows one to pass through the lavatory to the rear baggage compartment and into the tail portion of the fuselage where the radio apparatus is located, while the ship is in flight.

A great deal of effort was put into the development of the pilots' compartment. A complete system of controls, full size and in working order, was installed. The control handles and levers were placed in a great number of positions to determine their most practical arrangement. An instrument panel was built with full scale dummies of the instruments in place. A satisfactory allocation was made after numerous installations by means of which all related instruments were grouped together.

Light reflection and instrument board lighting were thoroughly investigated. Mirrors were first installed in the mock-up pilots' compartment in place of windshield glass. The angles of the mirrors were varied and their reflections noted until a setting was made which would not reflect light from the instrument board. A complete lighting system was then installed with actual windows in place and the results were checked at night. Ground light reflections were determined and eliminated by moving lights around the outside of the mock-up. The full scale model was complete down to inspection openings to all control cables.

In addition to the mock-up, a number of full scale working set-ups were built for test purposes. A complete fuel system was built with all lines and fittings of actual size and length. An accurate measurement of fuel flow and output was then obtained by driving the fuel pump with an electric motor.

The hydraulic-retracting mechanism for the landing-gear and wing-flaps, complete with cylinders, oil lines and controls, was reproduced to determine the arrangement of the component parts. The hydraulic-brake system was built up complete to the pedals, enabling an accurate measurement of the oil line pressure at the wheel with various pedal pressures.

To avoid the possibility of tail-wheel shimmy, the tail-wheel was mounted below a frame carrying a weight box to which different loads were applied and the complete apparatus was towed behind a truck at varying speeds. From these experiments the best trail and castor dimensions of the tail-wheel were determined and shimmy was eliminated. With the location and proportion of the structural details completed from the mock-up, the design for structural members of the actual plane was begun.

It was necessary to construct a wing having small unsupported surfaces and with the material so distributed that there would be no great stress variation in the component parts. At the same time, the wing must have negligible torsional deflection and a minimum of vertical deflection. In selecting the wing construction for the transport, single, two, three and multi-spar designs were considered as well as the shell type and multi-cellular designs.

The Northrup multi-cellular wing construction was finally chosen, due a great deal to its success on the "Alpha" mail carrying model, which has been operating for several years, each plane averaging over 5,000 hours in the air with no structural overhaul required.

This type of construction consists of a flat skin reinforced by numerous longitudinals and ribs. The combination of flat skin and full length stringers takes care of the bending while the shear loads are carried by three main webs. Indirect stress is carried by the skin with frequent ribs preserving the contour of the wing. This combination of webs, ribs and skin divides the entire wing up into a number of small rigid boxes or "cells," from which this type of construction derives its name.

The completed wing is extremely light for its strength and rigidity, is easily constructed and kept in repair. 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 problem in fuselage construction was basically the same. The ex-

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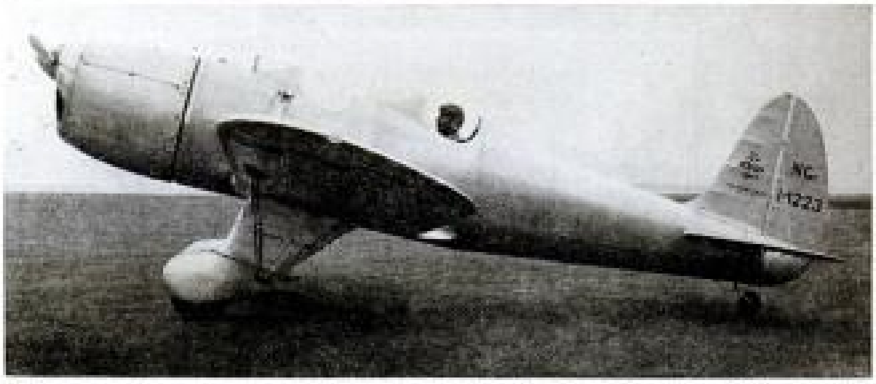
The Ryan S-T Monoplane is a New Departure

(See front cover drawing)



Side elevation showing the clean lithe lines of the new Ryan S-T monoplane. It is designed for the use of the private flyer.

THE RYAN low-wing monoplane, known as Model S-T, is a two-seater intended primarily for the use of the private owner and sportsman flyer.

It is highly efficient, the mark of 18 miles per gallon of gasoline is said to be attained at cruising speed, a fuel consumption rivaled by few automobiles. It is provided with the Menasco Pirate engine as standard equipment, installed in the inverted position. Either the Menasco B4-95 h.p. engine or the C4-125 h.p. engine is approved by the Bureau of Air Commerce.

The construction of the Ryan S-T is largely of metal. The fuselage is built up in true monocoque form with plates of Alclad 17 ST alloy, riveted as sturdily as a tank. The wing spars, of spruce, are the only wood parts in the ship. Both the wing and tail are duralumin structures, fabric covered.

Wing flaps (air brakes) are standard equipment, and are said to reduce the normal landing speed by 10 m.p.h. Tab trimming control, controlled from the cockpit, makes it possible to employ a fixed stabilizer, and in addition, the tabs make more accurate adjustment possible.

Long stroke oleo hydraulic shock-absorbers are used on the landing-gear, which with full airwheels makes landing soft and feathery, even on rough ground. The tail wheel is also provided with a shock-absorber which reduces stresses on the machine.

The "Tilbury Flash" is Smallest Racing Plane

THE TILBURY FLASH was by far the smallest racing plane at the Cleveland races. So far as size goes, it is the realization of the amateur's dreams. However, from a practical standpoint, such extremely small planes have disadvantages all their own for the amateur flyer and are not recommended for such purposes, although they may look "cute."

Its low monoplane wing is hardly more than ten feet in span, with a length that is less than the span. Its principal drawback is its extremely small landing wheels which can be used only on the smoothest of runways. During its flights, it was piloted by Clarence MacArthur, shown seated in cockpit. Mr. Tilbury, the constructor, is shown standing beside his creation.

Here's the "Tilbury Flash," one of the smallest planes to enter a real race. It was piloted at the Cleveland races by Clarence MacArthur.

Douglas D. C.'s

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perience of the Douglas Company in building metal monocoque fuselages combined with that of the Northrop Company resulted in the present semi-monocoque construction. This construction consists of a smooth stressed skin in contact with closely spaced bulkheads and numerous longitudinal stringers. All parts are securely attached together leaving the skin with very little unsupported area.

Following the acceptance of the type of construction for the plane, the determination of the detailed arrangement and dimensions necessitated approximately 215 individual static and dynamic tests, 100 preliminary tests on specimens of structural elements and well over 100 tests of wing ribs, fittings and small parts.

A great number of destruction tests were made on wing attachment joints and the more important structural details in which these parts were subjected to increasing loads until failure was noted. In this way an accurate check was made on the ultimate strength of the most important structural elements of the ship.

An example of the thoroughness of these loading tests is shown in the analysis of the landing-gear truss. As this truss is an indeterminate structure, the loads in the various members were analyzed 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.

The completed landing-gear and tail-wheel were subjected to drop tests in which the assemblies were loaded with weight proportional to the weight of the actual plane under full load and dropped from different heights traveling the entire range from the slight shock of a three-point landing to the destructive jolt of a crash landing. The ruggedness and the shock absorbing qualities of these parts at the present time are due to the results obtained in the torture chamber.

After more than eighteen months of experiment and test, the construction of the actual plane was begun. The fuselage was assembled on one jig. The general procedure consisted of clamping the bulkheads or frames to their respective stations and riveting the longitudinal stringers to the frames. The skin was then riveted to both frames and stringers.

The wing was constructed in five major sections: the center-section and the leading and trailing-edge sections of both port and starboard outer wing panels. The wing-tips and the motor nacelle shells complete with firewall installation were constructed on separate jigs.

The completed fuselage and center wing-section were removed from their jigs upon completion and assembled preparatory to a proof-test. The flanged bolt joints on the outer edges of the center-section, to which the outer wing panels are bolted, were securely attached to rigid steel-test jigs with the fuselage acting as a cantilever beam. Weight was then applied to all points of load concentration, namely: the forward mail compartment, passengers' cabin, rear baggage compartment and the horizontal tail surfaces.

This set-up closely approximated the attitude of the ship in actual flight and the affect of weight upon the structure suspended between the test jigs resembled the affect that weight would have upon the completed ship in the air. The variation under this stress was noted, but upon removal of the load, no permanent set or strain was in evidence. The results of this test showed that the fuselage possessed strength and rigidity to withstand a great overload with safety.

In conjunction with this test, the torsional strength of the fuselage was tested by applying the full design loads to the vertical fin with the fuselage still cantilevered from the test jigs at the ends of the center wing section.

A wooden frame was built around the vertical fin and connected to a system of pulleys and weights so placed as to impart a twisting or torsional load to the entire rear portion of the fuselage. Not only did this test fail to distort the fuselage, but the deflections across the main openings, such as doors and windows, were so small that even the close fitting cabin door could be opened and closed under full load.

To demonstrate the strength of the engine mount, the entire nacelle structure was tested by applying loads with a hydraulic jack attached to a steel plate on the engine ring. This test showed small deflection under maximum load.

To eliminate all possibility of control flutter at the high speeds obtained by the transport, all control surfaces and their supporting structures were vibrated by means of a specially designed electrically driven oscillation machine. The respective frequencies of the control surfaces and their supporting members were determined, enabling these parts to be designed far enough out of phase with each other so that flutter was eliminated and vibration dampened to a minimum.

Static tests were made on the control surfaces, both metal and fabric covered types, by loading them to the maximum loads expected in flight as suggested by the results of the wind-tunnel tests in conjunction with the new Department of Commerce regulations. Supporting 40 percent of the ultimate load, each control surface was moved through its entire range to determine that there was no binding due to excessive deflection.

The wing flaps or "air brakes" were tested to 100 percent load when depressed to 30 degrees, although the maximum load occurs only when the flaps are full down.

At the conclusion of the ground tests, the ship was taken into the air where every known method of flight test, including a few new ones invented for the tests, was used in an effort to locate weaknesses not discovered in the loading tests. Every maneuver from screaming power-dives and brutal pullouts to hard pancake landings was tried but the ship refused to shed its wings in the air or fold up on the ground.

It may be said that this ship was subjected to more thorough flight tests than any other known type of passenger transport or even military plane. Over two hundred flying hours and fifteen thousand gallons of fuel were used in making these tests, which resulted in several new conceptions in flight testing.

After satisfactorily demonstrating the structural strength of the ship in flight, it was necessary to check the design and wind-tunnel data with mathematical precision. Longitudinal, lateral and directional stability were determined under changing conditions of load, power-output and lift-coefficient with various wing and control surface flap positions and changes in cowling. 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.

The correct adaptation of ship to engines and accessories required several months to complete. Test runs were made on five different combinations of cowling, oil-cooling and carburetor-air intake systems. Engines from two manufacturers and three types of propeller blades were used in these tests. The object of these flights was to determine the performance which could be maintained from day to day under airline operating conditions and not the peak performance under ideal test conditions.

Performance and controllability under all conditions of engine failure were studied in flight. Single-engine operation was tested with overload and partially dumped fuel load. The final single-engine demonstration was made at Winslow, Arizona, which is at an altitude of 4,200 feet above sea-level.

One engine was cut when the plane had traveled just half of the take-off runway. The plane continued the take-off, climbed over the Continental Divide and flew to Albequerque, 240 miles away, on the remaining engine. An altitude of 1,000 feet was maintained above the ground which necessitated a climb to 8,300 feet when passing over the divide. At no time during this test was the engine allowed to exceed its rated horsepower output.

Landing and take-off tests with and without "air brakes" at different engine speeds were made to establish accurate landing speeds, landing-run, take-off distance, take-off time and the initial climbing angle.

The results obtained from these test flights enabled the Douglas test staff to develop a set of engine curves which made possible for the first time the continual determination of engine horsepower while in flight.

It is interesting to note that these engine curves have since been adopted as standard by the engine manufacturers. Cruising speed charts for the guidance of transport pilots were developed to cover the entire range of cruising powers and atmospheric conditions, changing the usual conception of the most favorable cruising altitudes and increasing the cruising speed at constant power by 18 miles-an-hour at ordinary cruising power.

Aided by acoustical engineers from the Sperry Corporation, the Douglas staff then attacked the problem of sound-proofing the transport with the result that the ship is as quiet and free from vibration as possible.

The primary sources of noise in an airplane are the exhaust, propellers, engine chatter and vibration. The first step in sound-proofing the transport was to reduce these noises as much as possible at their origin. The engines were mounted on special rubber insulators and the exhaust noises were reduced by carrying the exhaust below the wing, allowing the wing to blanket the noise away from the cabin. Each exhaust stack was designed differently to combat resonance. Stress carrying members, leading from wing and engines, were designed to pass beneath the cabin to prevent direct transmission of vibration into the passenger compartment.

The heating and ventilation systems were treated with a sound deadening cement and sound filters were provided at critical points. All furnishings of the cabin were designed to contribute their share to the absorption of sound. Even the metal hand-rails were stuffed with sound-proofing material. There was an assortment of eleven different sound-proofing materials used in the final installation, the weight of which was approximately two hundred pounds.

The thorough sound-proofing of the Douglas lowered the noise level from 98 decibels before treatment to 68 decibels which enables one to carry on conversation in ordinary tones.

The thermostatically controlled heating and ventilation system developed in the transport provides the cabin with a complete change of air every sixty seconds and will maintain an inside temperature of 70 degrees with an outside air temperature as low as 30 degrees below zero. There are additional cool air outlets at each seat so that any passenger can direct a stream of cold air on his face, if so desired.

Completed, the D.C.I. represents over two years of experiment and labor, and a total expenditure of approximately $325,000. That the money and time have been well spent is made evident by the fact that the Douglas Company is swamped with inquiries from all parts of the world. Incidentally, a large stack of orders has trickled in.

The immediate success of the D.C.I., in early test flights, resulted in the plans for the D.C.2. The successor of the D.C.I. is twenty-two inches longer in the fuselage, which with small additional space borrowed from the forward and rear cargo compartments, provides sufficient accommodation for two extra passenger chairs, thereby increasing the passenger carrying capacity of the transport to fourteen persons and permitting a total payload of over 4,250 pounds to be carried.

With the exception of an additional two degrees dihedral and larger area in the tail surfaces, the D.C.2. is structurally the same as the D.C.I. All the outstanding characteristics of performance and comfort of the D.C.I. are embodied in the D.C.2. to an even higher degree of perfection. This fleet of transports is aptly termed "the luxury liners of the airways."

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