

RESEARCH ON VTOL AND STOL AIRCRAFT IN THE UNITED STATES

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INTRODUCTION

DURING the past few years there has been a rapidly increasing interest in the United States in VTOL and STOL aircraft, that is aircraft capable of performing either vertical or short take-off and landing. Because of the number and variety of research projects that have been undertaken and the number of organizations involved it has become difficult, even for those working in the VTOL-STOL field, to keep abreast of all the research being done in this field. It appeared, therefore, that a summary of this work might be appropriate for presentation at this First International Congress of the Aeronautical Sciences.

Before proceeding with this summary, it is first necessary to establish the boundaries of the VTOL-STOL field which will limit the discussion. As for VTOL aircraft, this paper will not cover helicopters or rocket ships but will cover all those VTOL aircraft falling in between that are propelled by rotors, propellers, ducted fans, or turbojets. Helicopters are not covered because they constitute in themselves a large separate field of VTOL aircraft that would more than double the scope of this paper. STOL aircraft to be covered include only those in which all or most of the power available is used for producing high lift. For example, the paper will cover the jet flap but will not cover boundary-layer control applications which make use of only a small portion of the power available.

In order that a logical and systematic presentation can be made covering a wide variety of aircraft, the VTOL and STOL configurations to be considered have been classified in two different ways as shown in Table 1. First, the configurations are classified on the basis of their propulsive means for hovering and low-speed flight as Rotor, Propeller, Ducted Fan, and Turbojet types. In addition, the configurations are classified as follows on the basis of their means of accomplishing the transition or conversion from hovering to forward flight:

- (a) Dual propulsion
- (b) Thrust redirection
 1. Tilting of thrust unit
 2. Deflection of thrust vector

TABLE 1
VTOL-STOL aircraft types under study in the United States

	Rotor	Propeller	Ducted fan	Turbojet
A. Dual Propulsion :	McDonnell XV-1 (AF-A) [Sikorsky] (AF-A) NACA		[Vertol Vertodyne] (N-A) [Ryan Vertifan] (U) NACA	NACA
B. Thrust Redirection 1. Thrust tilting	Bell XV-3 (AF-A) Transcendental (AF-A) [Kellett K-25] (A) NACA	Vertol 76 (N-A) Hiller X-18 (AF) NACA	Doak 16 (A) [Bell transport] (U) [Hiller transport] (N) NACA	Bell air test vehicle (U) Bell Fighter (N, AF) [Bell transports] (U) NACA
2. Thrust deflection	[Kaman K-16] (N)	Ryan 92 (N-A) Fairchild M-224I (A) Robertson (U) NACA	[Piasecki Ring Wing] (N) [Collins Aerodyne] (N-A) [Goodyear Convoplane] (A)	VTOL : Bell X-14 (AF) [Collins Aerodyne] (U) NACA
C. Aircraft Tilting : 1. Tail-sitter airplane		Convair XFY-1 (N) Lockheed XFY-1 (N) NACA	[Hiller Coleopter] (U) [Flechaire Coleopter] (U) NACA	STOL (jet flap) : [Martin, Fairchild] NACA (N-A)
2. Flying platform	Delackner Aerocycle (A) NACA		Hillierflying platform (N-A) NACA	Ryan X-13 (AF) NACA
3. Aerial jeep		Aerophysics jeep (A) NACA	Piasecki jeep (A) Chrysler jeep (A) Aerophysics jeep (A) NACA	

The following letters in table indicate contracting agency :

A, Army (Transportation Research and Engineering Command (TRECOM)) ; AF, Air Force ; N, Navy (Office of Naval Research (ONR) or Bureau of Aeronautics) ; AF-A, Air Force for Army ; N-A, Navy (ONR) for Army ; U, Unsponsored
 The letters NACA within block indicate NACA research on this type.
 Projects shown enclosed in brackets have not yet involved construction of a flight article.

- (c) Aircraft tilting
1. Tail-sitter airplane
 2. Flying platform
 3. Aerial jeep

Dual propulsion refers to configurations which use two different means of propulsion for hovering and forward flight. Thrust redirection configurations are those which have a single means of propulsion, with provisions for either tilting the thrust unit itself or deflecting the slipstream or jet exhaust in order to perform the transition with the fuselage remaining essentially horizontal at all times. Aircraft tilting configurations are those in which the thrust axis remains essentially fixed in the aircraft, and the aircraft itself tilts to perform the transition from hovering to forward flight.

Use of both means of classification shown in Table 1 results in a total of twenty-four possible VTOL-STOL aircraft types, eighteen of which have been the subject of research in the United States by industry, the armed services, or the National Advisory Committee for Aeronautics. The specific aircraft of the various types are listed in Table 1 along with a notation of the contracting agency sponsoring the work in each case. In addition to the research aircraft that have been built and tested or are now under construction, Table 1 lists in brackets certain other research projects which might eventually lead to some form of VTOL or STOL aircraft. The initials NACA shown in certain blocks of the table indicate research on this type of aircraft has been or is being conducted by the National Advisory Committee for Aeronautics.

Since the discussion of work on individual types or configurations in this paper will necessarily be quite brief, a fairly comprehensive list of references is provided for those who desire additional information. After a listing of general references⁽¹⁻¹¹⁾ the remaining references are grouped according to aircraft configuration type as follows:

- Rotor configurations—Refs. 12 to 19;
- Propeller configurations—Refs. 20 to 60;
- Ducted fan configurations—Refs. 61 to 75;
- Turbojet configurations—Refs. 76 to 89.

A significant feature of VTOL-STOL research programs undertaken recently in the United States has been the use of flying test-bed aircraft which are simple and relatively inexpensive research machines. The use of such aircraft has made it possible to obtain research results much more quickly and at much lower cost than would have been possible with operational prototypes or more sophisticated research aircraft. Some good examples of flying test-bed aircraft covered in this paper are the VERTOL 76, RYAN 92, FAIRCHILD M-224I, and DOAK 16 machines.

ROTOR CONFIGURATIONS

In classifying VTOL aircraft types on the basis of propulsive means, questions often arise as to the distinction between rotor and propeller

configurations. In this paper, rotor configurations are considered to be those which have helicopter-type disk loadings and/or use cyclic pitch control in hovering flight. The term rotor-propeller, which has been aptly used by some manufacturers in describing the propulsive system of their machines, will not be used in this paper in order that the classification shown in Table 1 be maintained.

Dual Propulsion Types

Two examples of dual propulsion rotor VTOL configurations are the XV-1 unloaded-rotor convertiplane of McDonnell Aircraft Corporation and the stowed-rotor convertiplane type studied by Sikorsky Aircraft. This work has been sponsored by the Army and administered by the Air Force. The Sikorsky study has involved analysis and force-testing of small wind-tunnel models to study the stowed-rotor principle but no aircraft have been built. On the other hand, the McDonnell work has included extensive research with the XV-1 aircraft.

The McDONNELL XV-1 is a two-place convertiplane of the unloaded-rotor type designed to determine the feasibility of applying this principle to larger aircraft⁽¹²⁻¹⁴⁾ (see Fig. 1). In hovering and low-speed flight a relatively small freewheeling-rotor is driven by pressure jet units at the blade tips which are supplied with compressed air ducted through the



FIG. 1. McDONNELL XV-1 unloaded-rotor convertiplane in NACA Ames 40 by 80 ft. tunnel.

hub and rotor blades. In cruising flight the rotor autorotates and supplies about 15% of the total lift. A Continental R975 reciprocating engine powers a pair of radial compressors during helicopter flight and a pusher propeller between the tail booms in forward flight.

The development of the XV-1 was started in 1949 with a wind-tunnel research program. The first successful conversion to airplane flight was accomplished in April 1955 and a maximum speed of 200 miles per hour was reached in the Air Force evaluation program in 1956. The contractual work has now been completed and the two XV-1 aircraft have been bailed to McDonnell for further studies of the rotor system. McDonnell feels that the problems encountered with the XV-1 can be traced to the specific configuration of the machine which resulted from the use of a single reciprocating engine with a pusher propeller, and they conclude that an unloaded-rotor type convertiplane of multi-propeller, tractor configuration, powered by gas turbine engines would be an excellent VTOL aircraft for certain operations. Although no work on such a machine is being done in the United States at this time, the success to date of the Fairey ROTODYNE in England does seem to indicate promise for aircraft of this type.

The only NACA work on configurations of this type was an investigation of the full-scale XV-1 machine in the Ames 40 by 80 ft wind tunnel^(1,2) (see Fig. 1).

Thrust Redirection Types

Thrust tilting. Convertiplane configurations of the tilting-rotor type have been built and flown by two companies in the United States: Transcendental Aircraft Corporation and Bell Helicopter Corporation (see Figs. 2 and 3). A third convertiplane of the thrust-tilting type was the



FIG. 2. Transcendental model 2 tilting-rotor convertiplane.

Kellett Aircraft Company K-25, a tilt wing and rotor type with all controls in the rotors. This configuration was developed under a study contract but was not built. Most of this convertiplane work has been done under joint Army-Air Force sponsorship.

The Transcendental Aircraft Corporation was founded about twelve years ago for the purpose of designing and building tilting-rotor type convertiplanes and did produce four research vehicles of this type before ceasing operations last year. The third of these research vehicles was the Model 1-G, a small single-place aircraft which made its first flight in 1954 and later performed over 120 flights, including transitions, up to about 115 miles per hour with the rotors tilted forward 70° and with the wings sustaining over 90% of the weight of the machine. A larger and more advanced convertiplane, the Model 2 (Fig. 2) was built in 1956, but the contract for this work was terminated and the machine has not been flown.

The Bell XV-3 is a four-place tilting-rotor type convertiplane which was designed for observation-reconnaissance and rescue missions and was also intended to provide design and test data for the development of larger, higher-performance machines of this type^(15, 16). The XV-3 is powered by a single reciprocating engine (Pratt and Whitney R985) which drives the rotors through a two-speed transmission that permits the rotor to be operated at lower rotational speeds for better performance in cruising flight. The first XV-3 aircraft, which was built in 1955, had three-bladed rotors and relatively high rotor masts (Fig. 3). Following



FIG. 3. Bell XV-3 tilting-rotor convertiplane. Original configuration.

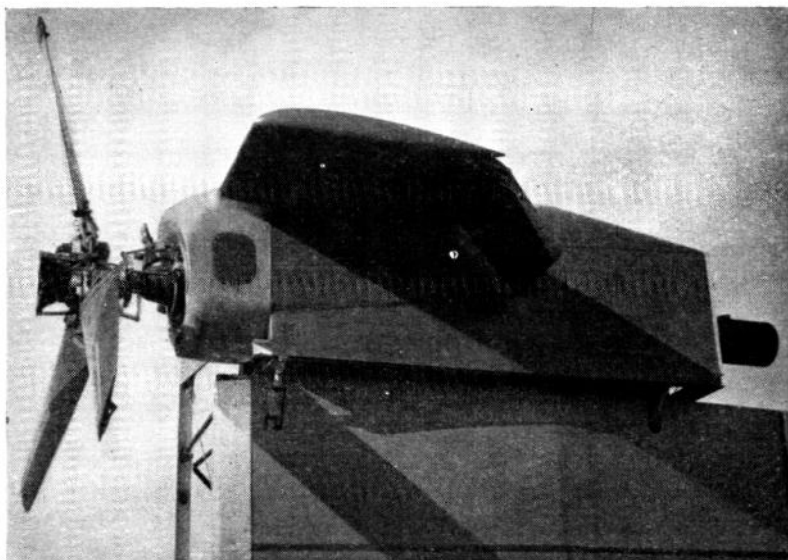


FIG. 4. Static-test setup of Kaman deflected-slipstream configuration (K-16).

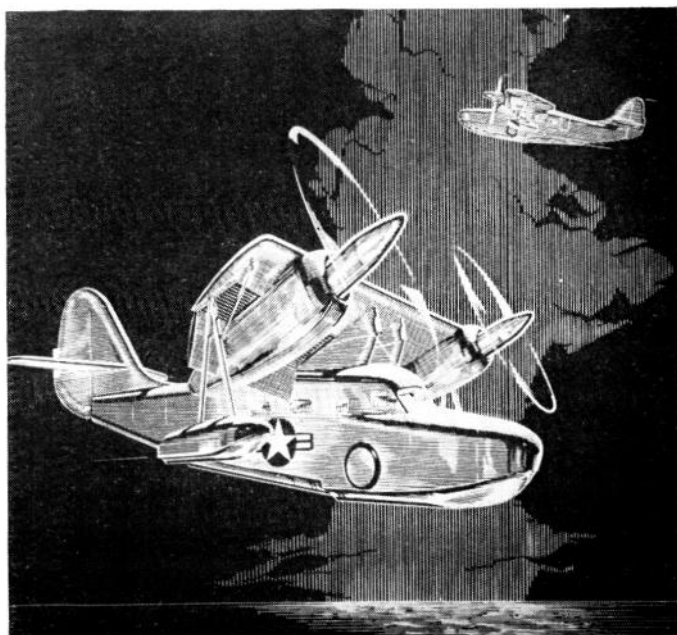


FIG. 5. Example of rotor-type VTOL aircraft under study in Kaman K-16 program.

an accident to this aircraft during flight testing, which was attributed to a combination of rotor mechanical instability and wing flexibility, a second aircraft was built with "sea-saw" type two-blade rotors and a shorter rotor mast. This machine is now being flight tested and has made conversions up to a rotor angle of about 55° without experiencing major difficulties.

NACA research on tilting-rotor convertiplanes has been limited to one investigation—a comprehensive study of the full-scale BELL XV-3 convertiplane in the Ames 40 by 80 ft wind tunnel⁽¹⁶⁾.

Thrust deflection. The Kaman Aircraft Corporation has been studying, under Navy sponsorship, rotor-type VTOL configurations that make use of the deflected slipstream principle in combination with either a partially tilted wing or partial aircraft tilting. One basic feature of the configurations covered in this program (designated K-16 by Kaman) is the use of helicopter-type cyclic pitch control in hovering and low-speed flight. A photograph of a large-scale static test setup used by Kaman in studies of their configurations is shown in Fig. 4. It consists of a 14 ft dia. fully-articulated propeller with a flap for cyclic and collective pitch control, mounted beneath a flapped wing. A sketch showing the type of configuration to which the research and development work performed by Kaman could be applied is shown in Fig. 5.

Aircraft Tilting Types

Most rotor-type VTOL aircraft that involve tilting of the entire aircraft for forward flight are helicopters. As pointed out previously, helicopters will not be covered in this paper, but one unique rotor-type VTOL aircraft of the aircraft tilting type that will be covered is the flying platform or stand-on type aircraft.

Flying platforms. The flying platform or stand-on type VTOL aircraft was conceived by Charles Zimmerman about fifteen years ago as a machine that would be flown by kinesthetic control. That is, a person would make use of his natural sense of balance and would shift his weight instinctively to provide the moments necessary for stability and control of the aircraft on which he would stand. This principle has been utilized in several machines making use of various means of propulsion. The NACA Langley Laboratory has done basic research with three such machines: one in which the hovering thrust was provided by a compressed air jet⁽¹⁷⁾, one in which an air-driven rotor was used⁽¹⁸⁾, and one in which a ducted fan was the propulsive means. Once the soundness of the principle had been established, two VTOL aircraft of this type were built under sponsorship of the services with the aim of developing operational machines: a ducted-fan type developed by Hiller Helicopters (which will be covered later) and a rotor type developed by deLackner Helicopters.

The deLackner flying platform, an Army project called the AEROCYCLE, is shown in Fig. 6. It has two counter-rotating 15 ft dia. rotors mounted

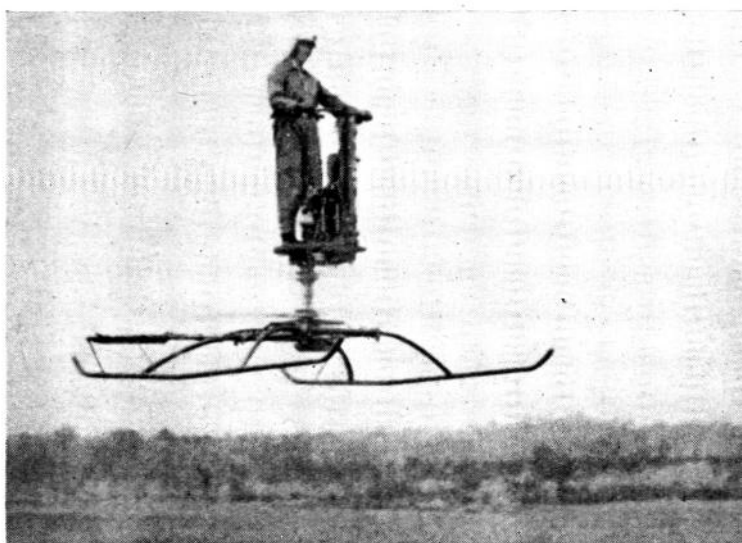


FIG. 6. The deLackner AEROCYCLE, a rotor-type flying platform.

below the platform. In the first machine, the rotors were powered by a 25 horsepower, two-cycle engine, but in later models a 40 horsepower engine has been used. Yaw or steering control is accomplished by turning the handlebars in the desired direction which varies the torque differentially on the two rotors. Pitch and roll control are obtained by leaning in the proper direction. The AEROCYCLE has been flight tested extensively by the contractor and the Army and also at Princeton University⁽¹⁹⁾. A force test investigation of a full-scale AEROCYCLE has been carried out in the NACA Langley full-scale tunnel.

PROPELLER CONFIGURATIONS

Thrust Redirection Types

Extensive research has been undertaken in the United States in connection with propeller configurations that make use of the thrust redirection principle. In addition to the numerous NACA studies of such configurations⁽²⁰⁻⁵⁷⁾, research with four flying test-beds is being sponsored by the services and at least one aircraft of this type is being developed with private capital.

Thrust tilting. Two of the configurations being sponsored by the services are tilting-wing-and-propeller VTOL configurations. The Vertol Model 76 is being financed by the Army Transportation Corps and was built under the technical cognizance of the Office of Naval Research (ONR), while the HILLER X-18 is an Air Force project.

The VERTOL Model 76 (Fig. 7) is a small two-place aircraft designed to explore the tilt-wing principle within a very short time and at low cost^(58, 59). It is powered by a single Lycoming T-53 free turbine engine



FIG. 7. VERTOL model 76 tilt-wing research airplane.

mounted externally on top of the fuselage. Power is transmitted by mechanical shafting to two three-blade propellers and two tail control fans. In the original configuration the propellers incorporate flapping hinges, but some tests with rigid propellers are planned. The Model 76 has accumulated several hours of hovering time since its first hovering flight in August 1957 and has been flown in normal airplane flight. Flight testing is now in progress to study the transition range.

Vertol has been assisted by the NACA in the development of the Model 76. An extensive investigation was carried out at the NACA Langley Laboratory with a quarter-scale flying model. The investigation included hovering flight tests, slow transition flights in the Langley full-scale tunnel, and rapid transitions on the Langley Control-Line Facility. A comprehensive force test program was also conducted with the model. A full-scale propeller assembly of the airplane has been tested in the NACA Ames 40 by 80 ft wind tunnel (see Fig. 8). Upon completion of a 25 hr flight test program by VERTOL, the Model 76 is to be turned over to the NACA Langley Laboratory for flight research to investigate flying and handling qualities and to gain some insight into the flying and handling qualities, requirements which should be established for such airplanes.

The HILLER X-18 (Fig. 9) is a large tilt-wing VTOL research airplane that is being constructed largely from existing components of other airplanes. The airplane has a design gross weight of about 32,000 lb and is powered by two of the engine-propeller units used by the CONVAIR

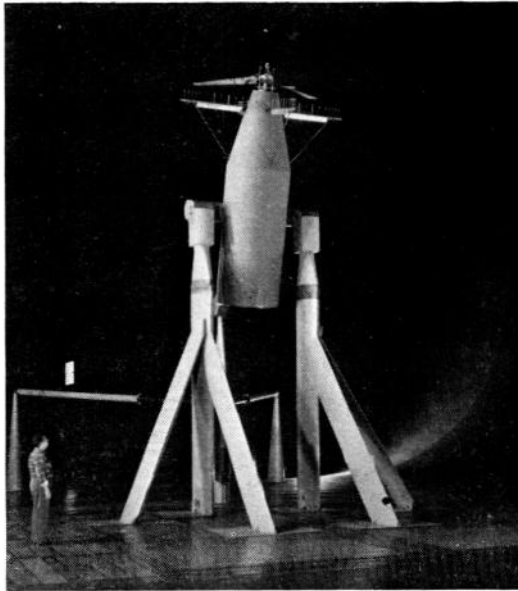


FIG. 8. Propeller assembly of VERTOL model 76 mounted for tests in NACA Ames 40 by 80 ft. tunnel.

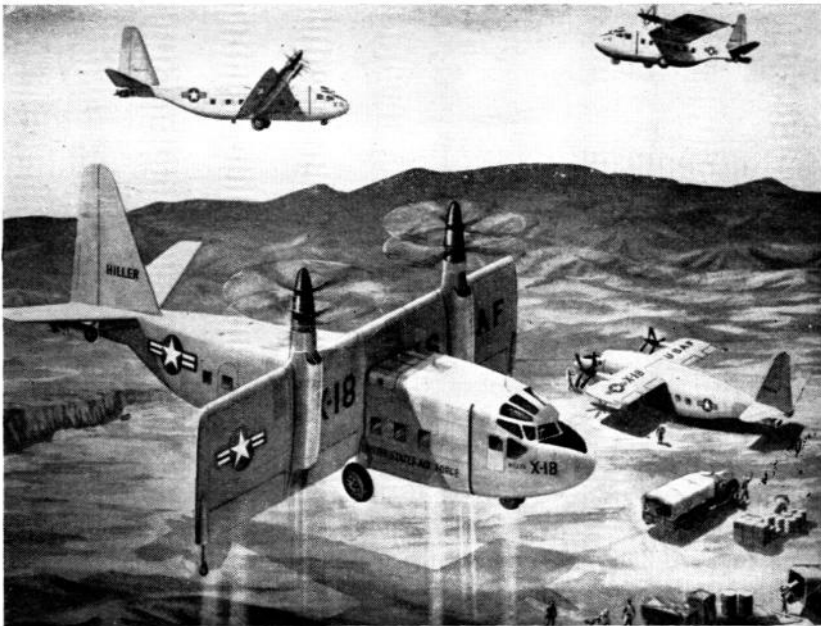


FIG. 9. HILLER X-18 tilt-wing research airplane.

XFY-1 and LOCKHEED XFV-1 VTOL airplanes (YT-40A turboprop engines driving 16 ft counter-rotating propellers). The fuselage and tail assembly are modified components of a C-122 airplane. The wing, which is being constructed by Hiller, has a span of 48 ft but provisions have been made for wing-tip extensions which will increase the span to 60 ft if desired. A J-34 jet engine is mounted at the tail of the airplane to provide thrust for pitch control moments in hovering and low-speed flight. The airplane is now under construction and is scheduled for completion in the fall of 1958. Although the X-18 is not intended to represent an operational VTOL machine, it is expected to provide useful research information regarding the probable operating problems of such machines.

In order to assist Hiller and the Air Force with the development of the X-18, the NACA Langley Laboratory has made extensive force and flight

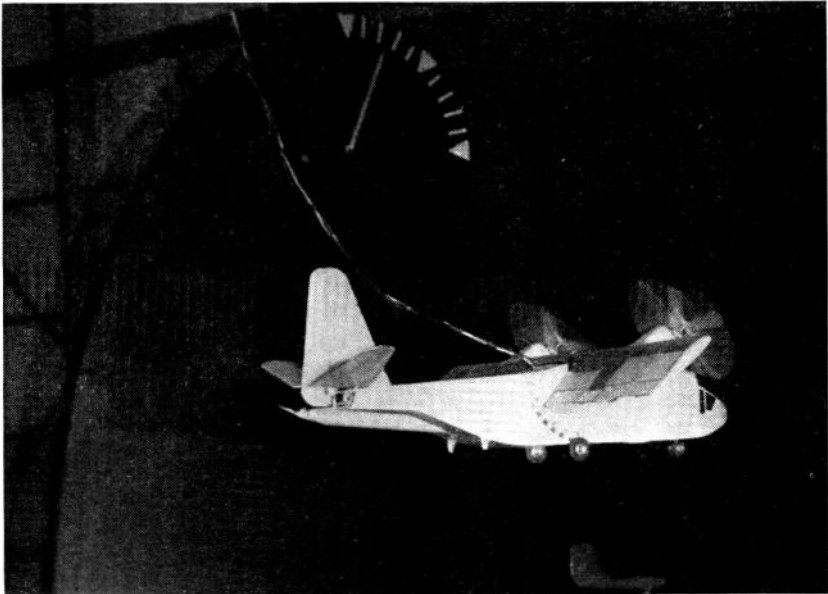


FIG. 10. Flying model of HILLER X-18 airplane performing transition in NACA Langley full-scale tunnel.

test studies with a one-eighth-scale model of the airplane. Figure 10 is a photograph of the model taken during the transition from hovering to normal forward flight in a flight test made in the Langley full-scale tunnel. Note the slack cable coming into the model from above, which supplies the power for the electric motors and compressed air for the pneumatic control servos in the model.

During the past five years the NACA Langley Laboratory has carried out a fairly comprehensive program of research on the tilting-wing-and-propeller type VTOL-STOL airplane with particular emphasis on the stability and control problems⁽²³⁻²⁹⁾. This program has included flight investigations with models of three different transport configurations, the

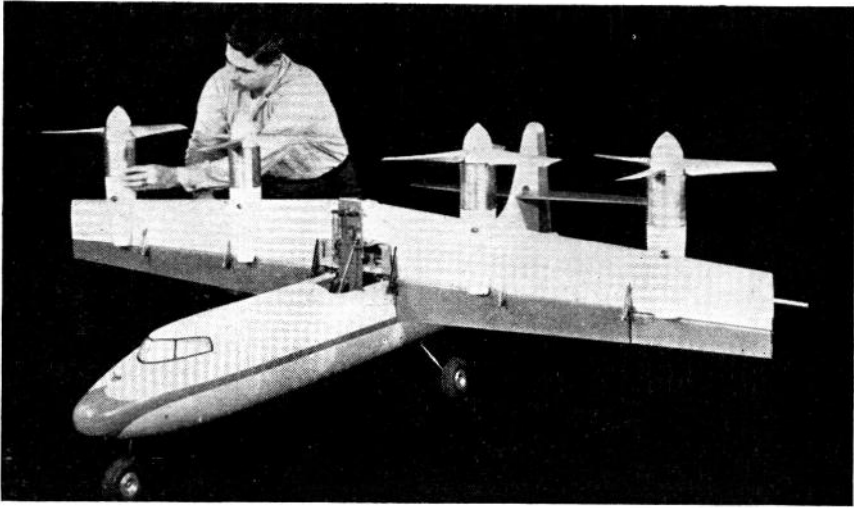


FIG. 11. NACA flying model used in research on tilt-wing VTOL principle.

latest of which is shown in Fig. 11. This model configuration, which was designed on the basis of results obtained in previous NACA studies, represents what is felt to be a promising VTOL-STOL type. The wing is equipped with a 35% chord slotted flap for improved performance in STOL operation. The nacelles are underslung and the wing pivot is located well aft on the wing to minimize longitudinal trim changes during the transition and to minimize the wing structural problem. In hovering flight, roll control is provided by differential thrust of the outboard propellers, pitch control by a tail jet, and yaw control by either a tail jet or the aileron surfaces.

Another research project recently undertaken at the NACA Langley Laboratory involves the use of a large model of the tilting wing and slipstream deflection type which will be used to obtain experimental data at fairly high Reynolds numbers. The model, which will be supplied by the Army, will have a span of 35 ft and will be equipped with six 5 ft dia. propellers. Force tests of the model will be conducted in the Langley full-scale tunnel which has a test section 30 ft high by 60 ft wide.

Thrust deflection. Two VTOL-STOL airplanes of the deflected-slipstream type are now undergoing tests in the United States and a third is under construction. The RYAN Model 92 Vertiplane, an Army-ONR

project, and the Robertson Aircraft Corporation airplane, a private venture being sponsored by Aero Design and Engineering Company, are both being flight tested. Construction of the FAIRCHILD M-224I airplane, an Army project, is now nearing completion and flight tests should start within a few months.



FIG. 12. RYAN model 92 Vertiplane, a deflected-slipstream research airplane.

The RYAN Model 92 Vertiplane (Fig. 12) is a small single-place machine powered by a single T-53 free turbine engine which drives two 9 ft dia. propellers⁽⁶⁰⁾. Slipstream deflection for hovering and low-speed flight is accomplished by a large-chord, two-segment flap on a high wing with underslung nacelles. For hovering flight, a swivelling turbine exhaust nozzle at the tail provides pitch and yaw control and differential propeller pitch is used for roll control. The machine has been hovered and flown in normal forward flight, and tests to study the transition from hovering to forward flight are now in progress. A force test investigation has been carried out with the airplane in the NACA Ames Laboratory 40 by 80 ft wind tunnel. Upon completion of the preliminary flight test program by Ryan it is planned to turn the airplane over to the NACA Ames Laboratory for research use.

The FAIRCHILD M-224I airplane (Fig. 13) is a two-place machine powered by a single YT58-GE-2 free turbine engine which drives four propellers through a system of shafting and gear boxes and furnishes hydraulic power for the operation of the flaps and the single tail control fan. The airplane has a strut-braced high wing equipped with a 50% chord, full-span sliding flap of the type developed by the NACA. Vertical take-off is to be achieved by using a ground attitude angle of about 25° with a slipstream turning angle of about 65°. In hovering flight, roll control is obtained by differential pitch of the outboard propellers, pitch control by changes in speed of the tail fan, and yaw control by tilting the



FIG. 13. FAIRCHILD M-224I deflected-slipstream research airplane.

plane of the tail fan. A one-fifth-scale powered wind-tunnel model of the M-224I has been force tested in the 17 ft test section of the NACA Langley 300 m.p.h. 7×10 ft tunnel. Following preliminary flight testing by Fairchild, it is expected that the airplane will be turned over to the NACA Langley Laboratory for a flight research program.

The Robertson Aircraft Corporation deflected-slipstream type VTOL airplane (Fig. 14) was designed and built not as a flying test bed but as a

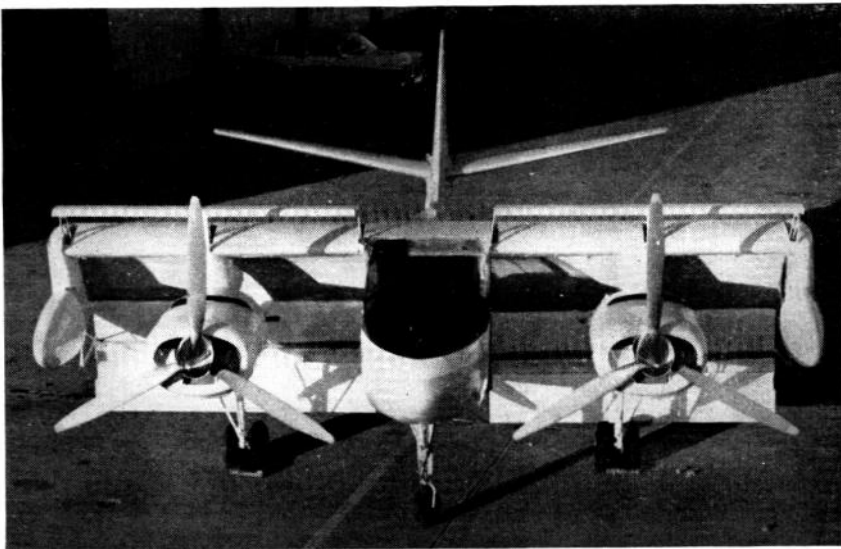


FIG. 14. ROBERTSON deflected-slipstream prototype airplane.

prototype of an operational airplane. It is a four-place, high-wing airplane powered by two 340 horsepower LYCOMING GSO-480 reciprocating engines, each driving a three-blade propeller. It is equipped with a large-chord sliding flap, a leading-edge slat, and wing tip fuel tanks which also serve as end plates. The airplane has been flown in tethered hovering flight and work is continuing toward achievement of free hovering flight and transition flight.

The NACA Langley Laboratory started a basic research program on deflected-slipstream type VTOL-STOL airplanes in 1951 and since that time has conducted numerous investigations in this field⁽³⁰⁻⁴⁴⁾. This work is continuing with studies involving models such as those shown in Figs. 15 and 16. Figure 15 shows a six-engine research model equipped with a large-chord sliding flap. The model is shown mounted on a ground board force-test setup in the 17 ft test section of the Langley 300 m.p.h. 7 by 10 ft tunnel. This large test section has been recently built into the tunnel especially for the testing of large VTOL-STOL airplane models. Figure 16 shows a four-engine flying model equipped with a sliding flap. This model will be used in VTOL and STOL flight studies in the Langley full-scale tunnel and on the Langley Control Line Facility.

NACA research to date on the two basic propeller VTOL types that make use of the thrust redirection principle has indicated that the deflected slipstream machine is superior for STOL operation while the tilt-wing machine is superior for VTOL operation. These tentative conclusions are based on results which show that the deflected-slipstream type has lower power requirements for low-speed flight but suffers a substantial thrust loss in hovering flight and has a generally more severe longitudinal trim problem and a more detrimental ground effect than the tilt-wing type. Perhaps some combination of the deflected-slipstream and tilt-wing principle, similar to that incorporated in the model shown in Fig. 11, will prove to be the best propeller-driven aircraft for overall VTOL-STOL operation. A more complete discussion of these points is presented in Ref. 6.

Aircraft Tilting Types

All of the work that has been done in the United States to date with propeller-driven configurations of the aircraft tilting type has involved tail-sitter type VTOL airplanes such as the CONVAIR XFY-1 and the LOCKHEED XFV-1. Some work is planned, however, with aerial jeep type aircraft having unshrouded propellers, and this work will be covered later in the discussion of ducted-fan type aerial jeeps.

Tail-sitter airplanes. Much of the earlier effort on VTOL airplanes in the United States was put on propeller-driven tail-sitter types, but there is little, if any, interest in such configurations today. The vertical attitude of the fuselage for take-off and landing appears to rule out non-military applications and the services apparently feel that there are no promising

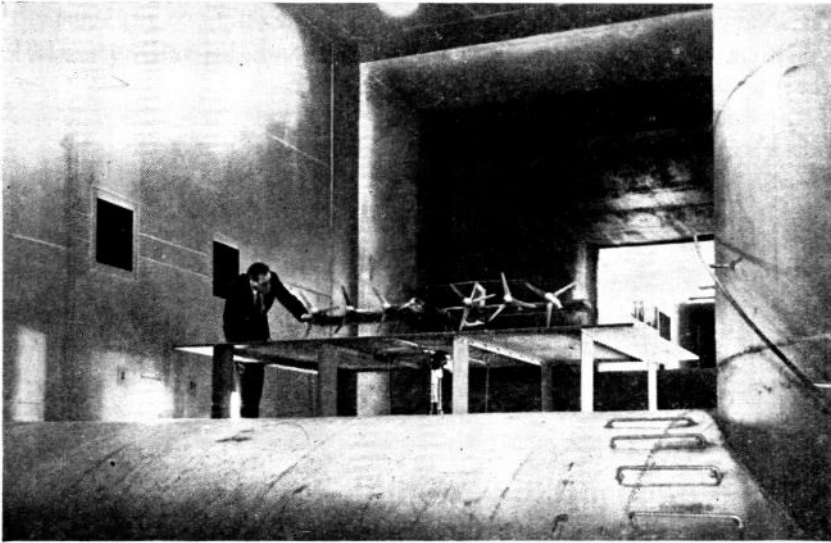


FIG. 15. Deflected-slipstream research model on ground-board setup in 17 ft test section of NACA Langley 300 m.p.h. 7 × 10 ft tunnel.

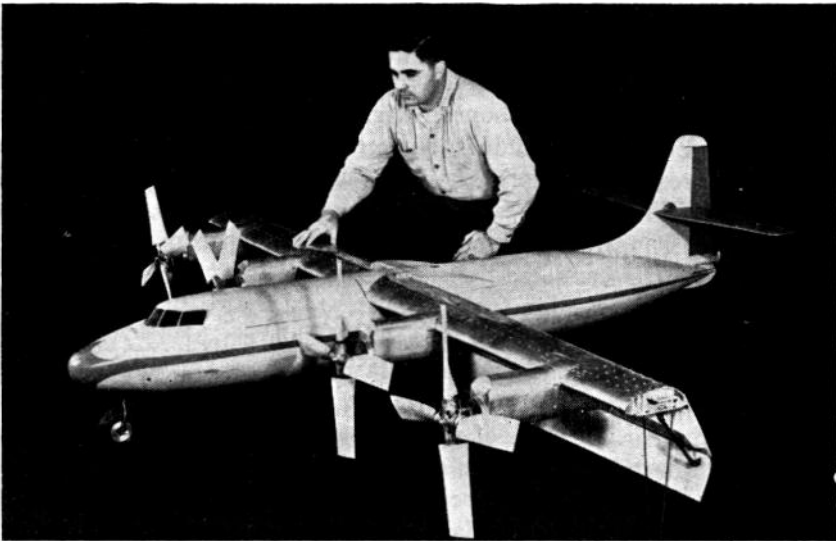


FIG. 16. NACA flying model used in research on deflected-slipstream principle.

military applications for propeller-powered VTOL airplanes of this type. The Navy Bureau of Aeronautics sponsored the only two airplanes of this type that were built: the CONVAIR XFY-1 and the LOCKHEED XFV-1 (see Fig. 17).

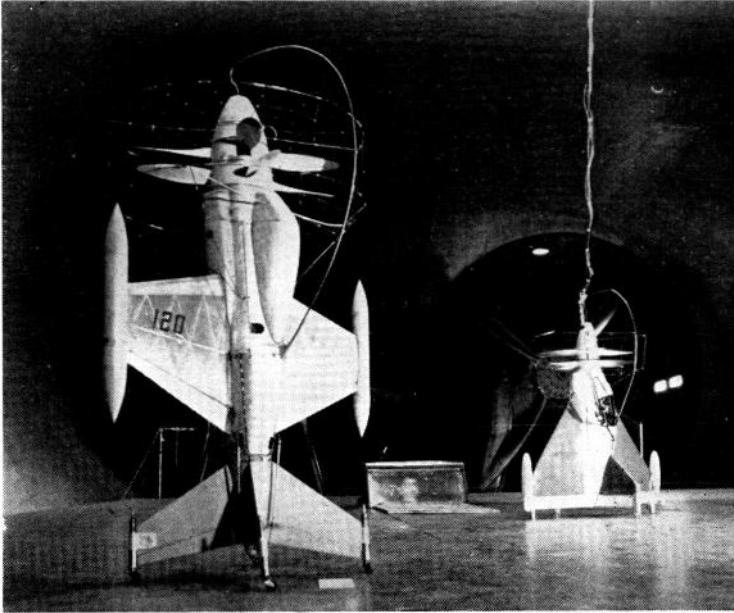


FIG. 17. Flying models of LOCKHEED XFV-1 and CONVAIR XFY-1 tail-sitter airplanes in NACA Langley full-scale tunnel.

The CONVAIR XFY-1 was a 14,000 lb delta-wing configuration powered by an Allison YT-40A turboprop engine driving 16 ft counter-rotating propellers. Elevon and rudder surfaces located within the propeller slipstream provided control in hovering as well as forward flight. Flight tests of the XFY-1 started in 1954 in a special tethered flight rig installed in an airship hangar. Free hovering flights were then made outside and later a total of six complete transition flights were made which included vertical take-off, transition from hovering to forward flight and back to hovering, and vertical landing. Much valuable experience with VTOL operation was obtained in this program but, because of engine and propeller problems, the project was terminated in 1956 and the airplane was moved to the Air Museum of the Smithsonian Institution in 1957.

The LOCKHEED XFV-1 was a configuration with an unswept wing and cruciform tail surfaces equipped with the same engine and propeller combination as the XFY-1. Tail control surfaces operating in the propeller slipstream provided roll, yaw, and pitch control in hovering and forward, flight. The airplane was equipped with a special fixed landing

gear to permit conventional take-off and landing. Flight testing, which started in 1954, included many transitions made at altitude; but no vertical take-offs or landings were ever attempted. As in the case of the XFY-1 the XFV-1 project was terminated in 1956 because of engine and propeller problems.

NACA work on the propeller-driven tail-sitter type was started in 1949 to assist the Navy in their VTOL program prior to the XFY-1 and XFV-1 projects. In addition to several investigations with research models^(45 - 48) the NACA carried out extensive investigations with flying models of the XFY-1 and XFV-1 (Fig. 17) before these airplanes were flown^(49 - 55). During the last few years, however, no research work at all has been done by the NACA on this VTOL type because there appears to be little or no general interest in such configurations.

Aerial jeeps. The work with aerial jeeps will be discussed later under Ducted Fan Configurations, since most of the jeeps under consideration are ducted-fan types. As will be brought out in later discussion, however, some work with unshrouded-propeller jeep configurations is planned by the NACA and by Aerophysics Development Corporation under Army sponsorship.

DUCTED FAN CONFIGURATIONS

Considerable interest is now being shown in VTOL configurations involving the use of ducted fans. Table 1 indicates that work is being done on all of the six different types of ducted fan VTOL aircraft, but much of the work at this time involves studies rather than flight research with full-scale aircraft. In addition to work on the various types of ducted fan VTOL aircraft, research on the ducted fan itself is being carried out by the NACA, the University of Wichita, Mississippi State College, and others^(61 - 64).

Dual Propulsion Types

Although some interest is being shown in dual propulsion VTOL aircraft which use ducted fans for hovering and turbojets for forward flight, no machines of this type are being built at the present time.

The Vertol Aircraft Corporation, under sponsorship of the Army and Navy, is conducting a research study on a machine of this type which they call a Vertodyne. It has shaft-driven ducted fans submerged in the wing with provisions for covering the ducts in forward flight. A photograph of a model being used by Vertol in a force test investigation in the University of Detroit 7×10 ft wind tunnel is shown in Fig. 18, and a sketch illustrating the type of configuration to which the Vertol research may apply is shown in Fig. 19.

The Ryan Aeronautical Company has undertaken studies on its own of VTOL aircraft of this general type which they call Vertifan configurations. The Ryan studies involve the use of a ducted fan driven by turbine

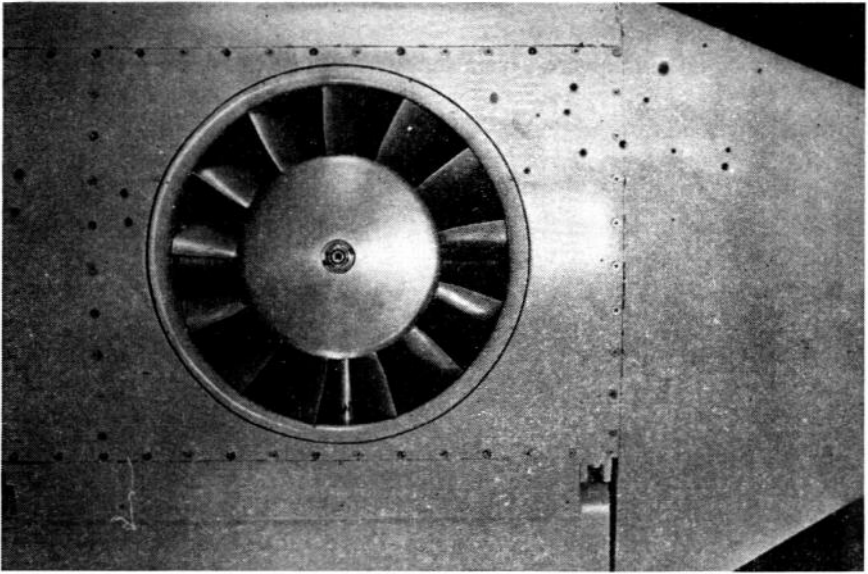


FIG. 18. Force-test model of Vertol ducted fan submerged in wing (Vertodyne).

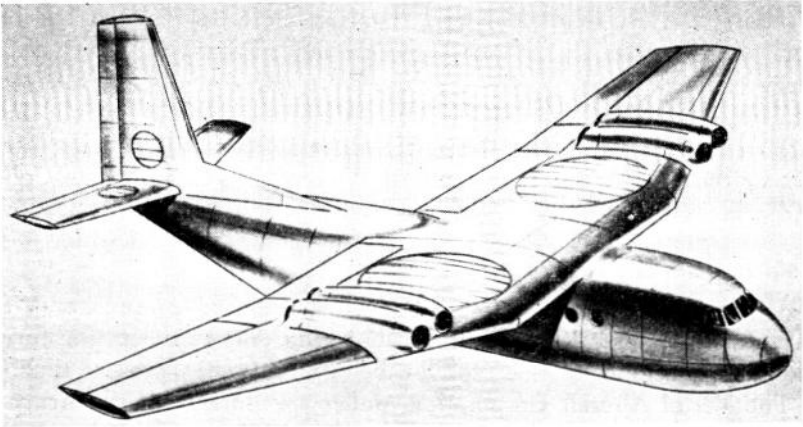


FIG. 19. Example of submerged ducted-fan airplane under study in Vertol Vertodyne program.

blades on the periphery of the fan rather than by shafting as in the case of the Vertol Vertodyne. A sketch of a possible Vertifan configuration that Ryan has considered in its study is shown in Fig. 20.

Some basic research on the characteristics of a ducted fan submerged in a wing is being done by the NACA^(65, 66), the Massachusetts Institute of Technology⁽⁶⁷⁾, and others. In addition, studies have been made by

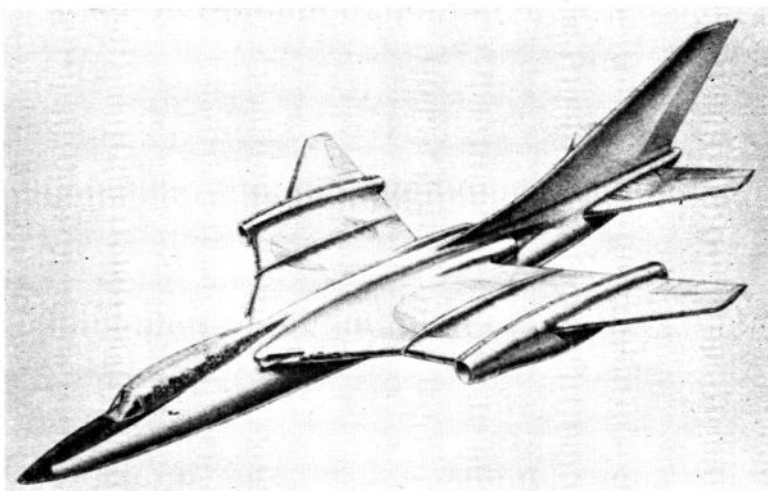


FIG. 20. Example of submerged ducted-fan airplane under study in Ryan Vertifan program.

Vertol⁽⁷⁾ and the General Electric Company⁽⁶⁸⁾ to compare the dual-propulsion ducted-fan configuration with other types of VTOL aircraft. One basic problem of this type appears to be the difficulty of integrating within the wing a ducted fan of the size required for hovering without compromising the performance of the airplane in forward flight.

Thrust Redirection Types

Several research studies involving ducted-fan VTOL configurations which make use of the thrust redirection principle are being sponsored by the services. Work is being done on both the thrust tilting and thrust deflection types but the only machine that has been built is the Doak Aircraft Company Model 16, a flying test bed with tilting ducted fans at the wing tips.

Thrust tilting. The Doak Aircraft Company, Bell Aircraft Corporation, and Hiller Helicopters have all been advocates of tilting ducted fan VTOL aircraft for some time and all are continuing to do work in this field.

The DOAK 16 VTOL flying test bed (Figs. 21 and 22) is an Army project handled by its Transportation Research and Engineering Command (TRECOCM). It is a 2600 lb, two-place machine powered by a single Lycoming T-53 free turbine engine which drives 4 ft dia. ducted fans at the wing tips. The ducted fans rotate about a transverse axis to perform the transition from hovering to forward flight. In hovering flight, pitch and yaw control are provided by vanes in the turbine exhaust, and roll control is provided by differential thrust of the ducted fans. The airplane has completed a 50 hr ground test program and has been flown in tethered hovering flight. A flight program is now under way in which transitions

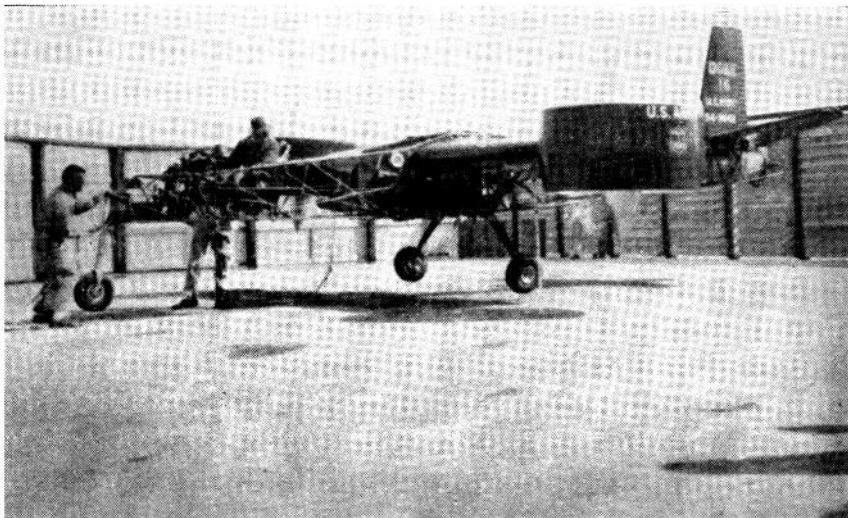


FIG. 21. DOAK 16 ducted-fan research airplane in tethered hovering flight.

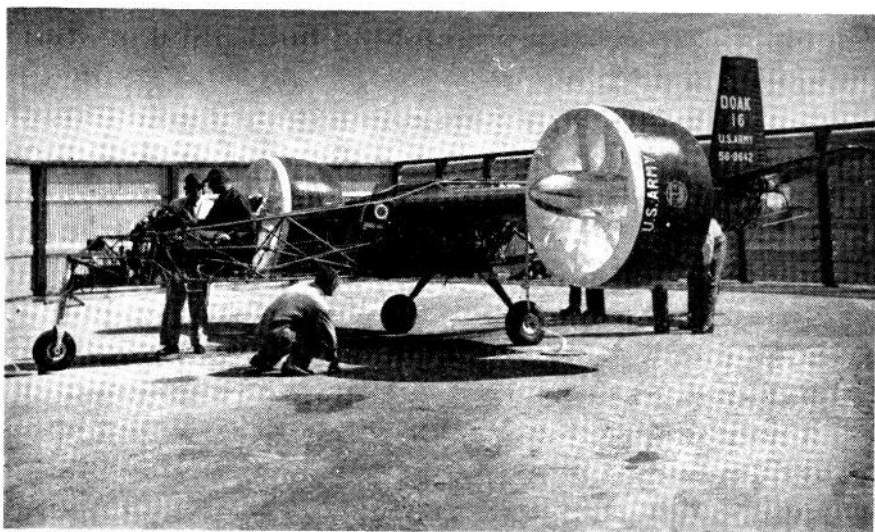


FIG. 22. DOAK 16 airplane with ducted fans rotated to position for cruising flight.

from hovering to forward flight should be made in the near future. Later, the airplane may be turned over to the NACA for a flight research program. In a research investigation that has direct application to the DOAK 16, a ducted fan exactly like the two used on this machine is to be tested in the NACA Ames 40 by 80 ft wind tunnel.

Bell Aircraft Corporation has made numerous studies involving the use of tilting ducted fans⁽⁶⁹⁾ but has built no machines of this type. A drawing illustrating a military transport configuration of this type which they have studied is shown in Fig. 23.

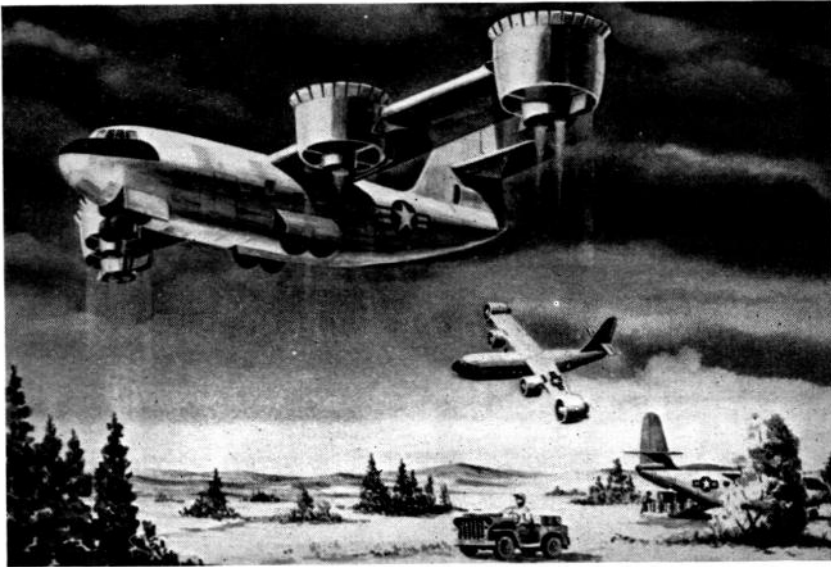


FIG. 23. Example of tilting ducted-fan airplane under study by Bell.

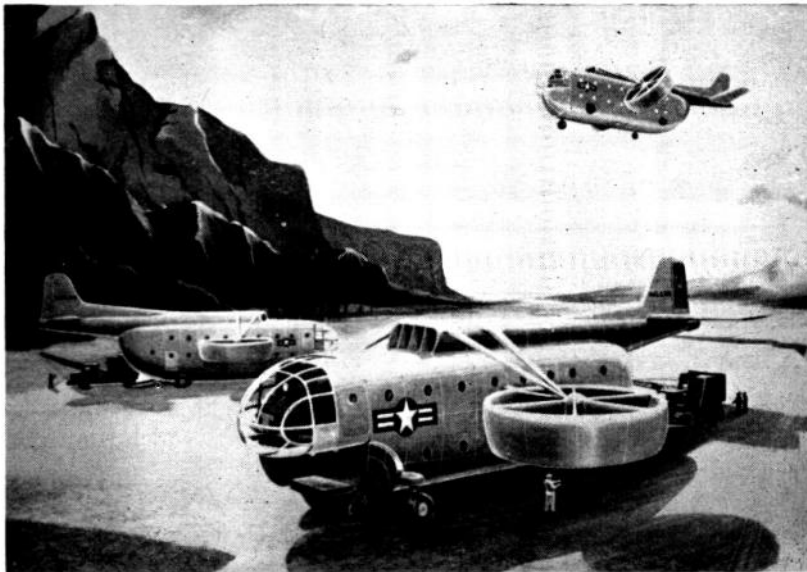


FIG. 24. Example of tilting ducted-fan airplane under study by Hiller.

Hiller Helicopters, which has been working with ducted-fan VTOL configurations since 1954, has recently completed a Navy-sponsored preliminary design study considering ducted fans for specialized heavy-weight-lifter VTOL aircraft. One of the configurations resulting from this study was the tilting-ducted fan machine shown in Fig. 24.

Thrust deflection. Three different ducted-fan VTOL configurations of the thrust-deflection type are being studied under sponsorship of the services. Piasecki Aircraft Corporation has a Navy contract, Goodyear Aircraft Company is performing a study for the Army, and Collins Radio Company has done work under joint sponsorship of the Army and Navy.

Piasecki has been studying a VTOL machine, called a RING WING CONFIGURATION, which has a large ducted fan on each side of the fuselage with vanes in the ducts to deflect the slipstream downward for hovering flight. A photograph showing a static test of one of the ducts is presented

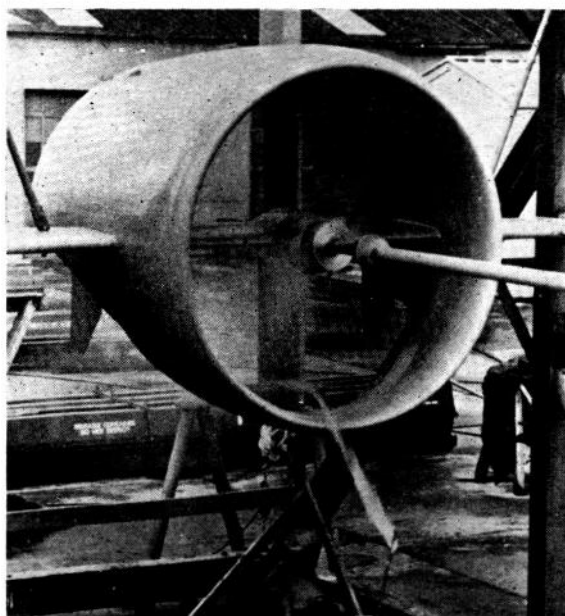


FIG. 25. Static test setup used by Piasecki in study of ducted-fan deflected-slipstream configuration.

in Fig. 25. Control of this machine in hovering flight would be accomplished by trailing-edge control surfaces on the struts which support the propeller shaft.

Collins Radio Company has done extensive research on a deflected-slipstream ducted-fan VTOL type called an AERODYNE⁽⁷⁰⁾. This work has included analytical studies, model flight investigations, and force testing of models, including the large machine shown in Fig. 26. This

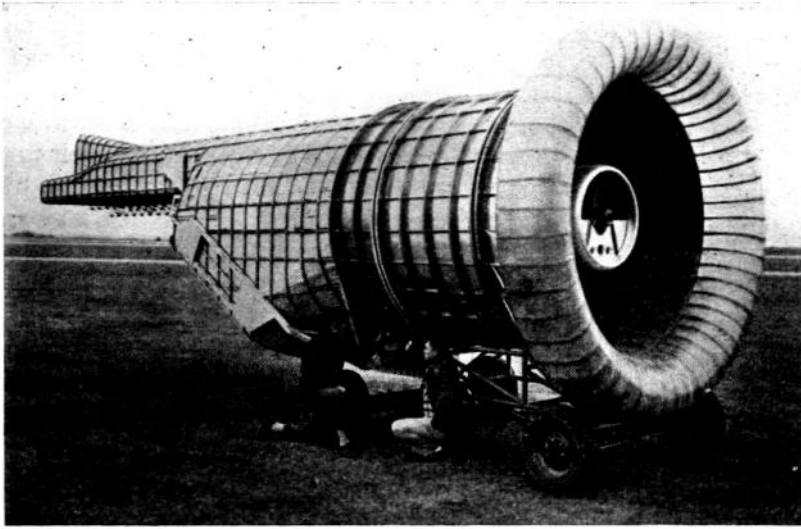


FIG. 26. Large-scale test model used by Collins Radio Company in ducted-fan AERODYNE study.

large AERODYNE is 42 ft long, has two 7.5 ft propellers each driven by a Continental 213 h.p. engine, and has vanes at the duct exit to deflect the slipstream downward. It has already been used to obtain forces and moments in hovering flight and information on internal air flow, and

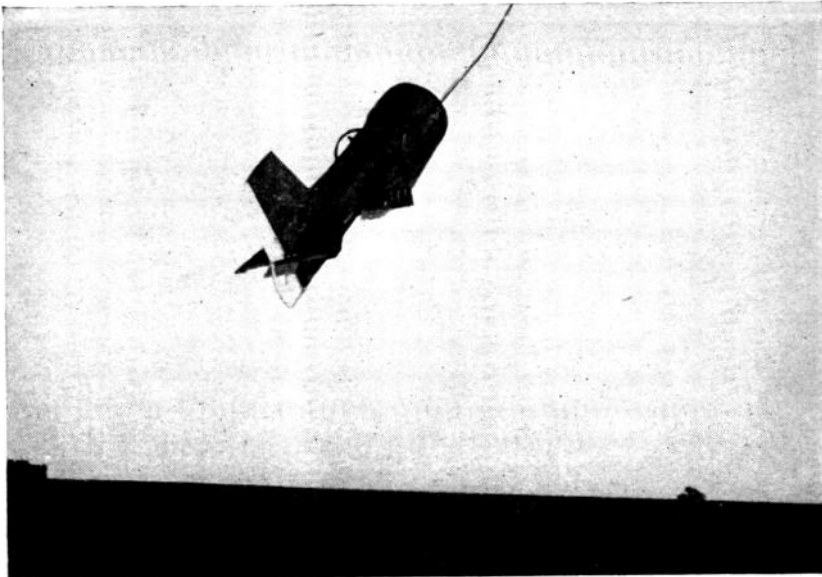


FIG. 27. Flying model of ducted-fan Aerodyne being tested by Collins Radio Company.

it is to be tested soon in the NACA Ames 40 by 80 ft wind tunnel, Although no full-scale machines have been built and flown, the flight characteristics of such machines have been demonstrated by means of flying models such as the one shown in Fig 27.

Goodyear Aircraft Company is studying a third ducted-fan deflected-slipstream VTOL type which they call a CONVOPLANE. It is similar to the Vertol Vertodyne and Ryan Vertifan types in that it has a ducted fan submerged in the wing for hovering flight. Instead of having a separate propulsion means for forward flight, however, it has provisions for diverting the slipstream of the ducted fan rearward. Research on this configuration has included a wind-tunnel force test program.

Aircraft Tilting Types

Research is being done on all three of the ducted-fan VTOL types that involve tilting of the entire aircraft for forward flight.

Tail-sitter airplanes. The tail-sitter ducted-fan VTOL type, better known by the name coleopter, has not received as much attention in the United States as it has in France, but some work directly applicable to this type has been done by the NACA⁽⁷¹⁻⁷³⁾, and some studies have been made by Hiller, Fletchaire, and others of possible coleopter configurations. One of the Hiller configurations of this type which is essentially an adaptation of their ducted-fan flying platform configuration is shown in Fig. 28.

Flying platform. As pointed out earlier in the paper, a ducted-fan type flying platform has been developed by Hiller Helicopters for the



FIG. 28. Example of ducted-fan coleopter configuration under study by Hiller.



FIG. 29. Hiller ducted-fan flying platform. Original design with 5 ft dia. duct.

Army Transportation Corps under the technical supervision of the Office of Naval Research. Work on the flying platform was started by Hiller in 1953 and the first flights were made in January 1955 with the machine shown in Fig. 29. This machine had two, two-blade, counter-rotating propellers in a 5 ft dia. duct and was powered by two 40 h.p. engines mounted above the propellers. It was test flown extensively and was also force tested by means of a special setup mounted on a truck⁽⁷⁴⁾. Hiller's work with this machine indicated the feasibility of using kinesthetic control on this type of aircraft but also revealed some of the basic problems involved, such as the difficulty of obtaining adequate longitudinal trim for moderately high forward speeds by means of only a shift of the pilot's center of gravity. As a follow-up on their work with this first machine, Hiller received a contract for two 8 ft dia. machines, one of which is shown in Fig. 30. These larger machines are three-engine experimental prototypes which are to be delivered to the Army for field evaluation.

The NACA Langley Laboratory is conducting some basic research with a ducted-fan flying platform generally similar to, but smaller than, the Hiller configurations⁽⁷⁵⁾ (see Fig. 31). This machine is a simplified research vehicle that is powered by an electric motor. One purpose of the research with this machine is to make a direct comparison of kinesthetic control with conventional control that involves the use of a control



FIG. 30. Hiller ducted-fan flying platform. Revised design with 8 ft dia. duct.

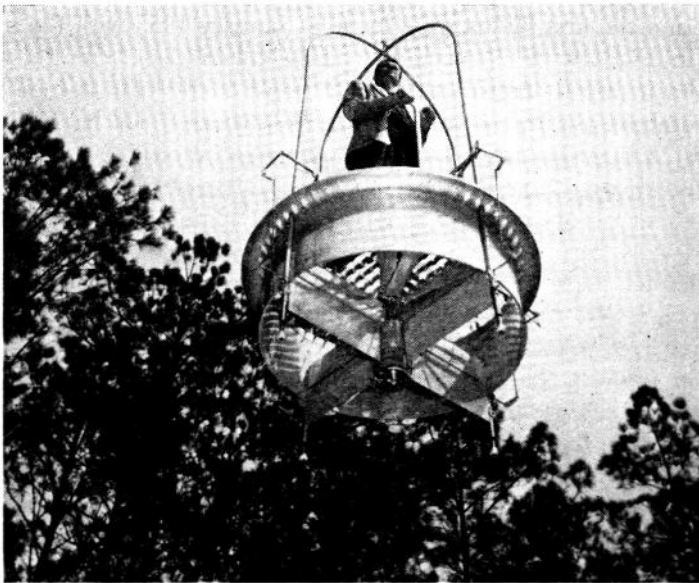


FIG. 31. NACA ducted-fan flying platform research vehicle.

stick linked to vanes in the slipstream. Preliminary results indicate that the machine can be flown fairly easily in hovering flight with either means of control.

Aerial jeeps. The aerial jeep is classified here as an aircraft-tilting-type VTOL machine even though aircraft of this type are likely to include some form of slipstream deflection.

The work on aerial jeeps is being sponsored by the Army Transportation Corps which has long desired to possess a compact vehicle having the versatility of the ground jeep combined with the ability to hover and fly forward at moderately high speeds a few feet off the ground. As a result of a design competition for a machine of this type, contracts have been awarded by the Army to Aerophysics Development Corporation, Chrysler Corporation, and Piasecki Aircraft Corporation for the design, construction, and testing of flying research vehicles to be utilized in the development of the aerial jeep concept.

The Aerophysics aerial jeep as originally conceived had four 6 ft dia. ducted fans driven by a single 400 h.p. Artouste gas turbine (see Fig. 32). It was designed for a gross weight of 1850 lb with a useful load of

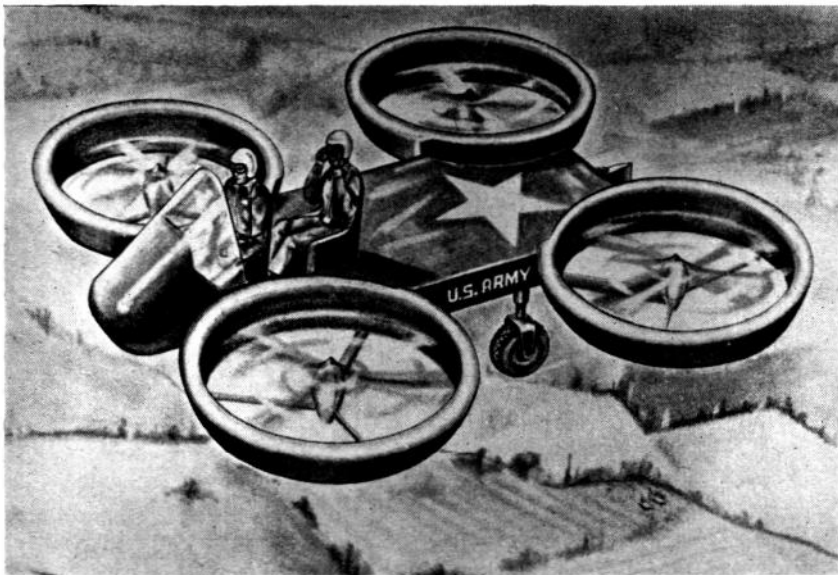


FIG. 32. Original design of Aerophysics aerial jeep. Ducted-fan configuration.

1000 lb, and control about all three axes was obtained by varying the collective pitch on the four ducted propellers differentially in various combinations. After some preliminary study of this ducted-fan jeep, Aerophysics is now working on an unducted version of the machine as

a first flight test vehicle. Flight tests are scheduled for September 1958, after completion of shakedown and tether tests.

The CHRYSLER aerial jeep is a tandem two-shroud configuration with 8.5 ft dia. propellers driven by a 500 h.p. reciprocating engine. It is designed for a gross weight of 2300 lb with a useful load of 600 lb. Control will be provided by vanes in the slipstream and differential propeller pitch. Preliminary work is being done by Chrysler with the flying test bed shown in Fig. 33.

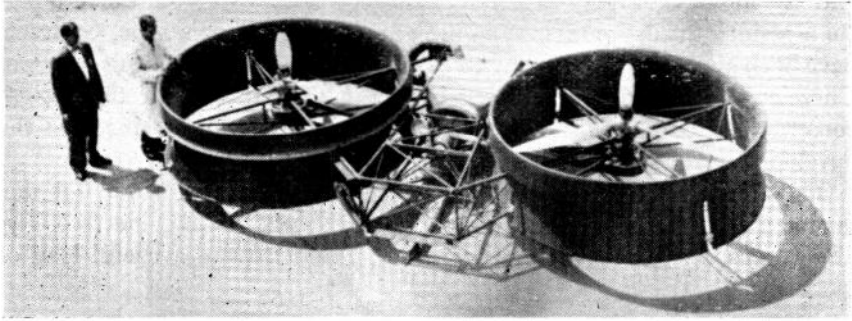


FIG. 33. Flying test bed used in development of CHRYSLER aerial jeep.

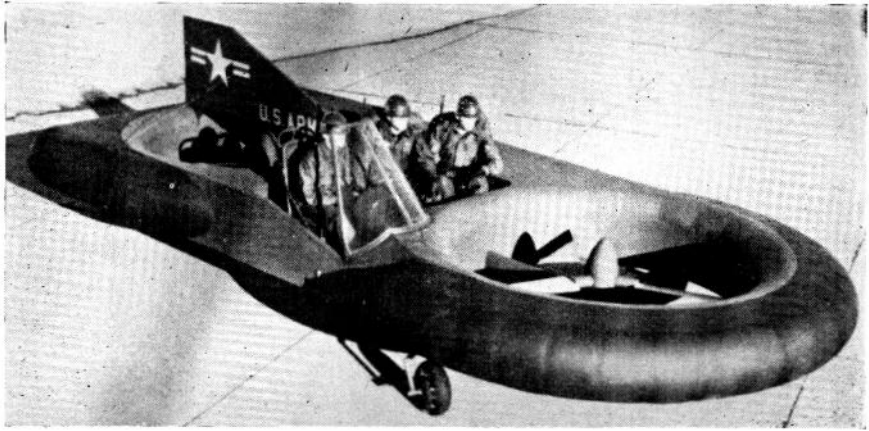


FIG. 34. Mockup of PIASECKI aerial jeep.

The Piasecki aerial jeep (Fig. 34) is a tandem two-shroud configuration with 7.5 ft articulated fans driven by two interconnected 180 h.p. reciprocating engines. It is designed for a gross weight of about 1900 lb with a useful load of about 500 lb. Control is provided by collective and cyclic pitch of the fan blades and by duct exit vanes. Preliminary flight testing of the PIASECKI aerial jeep is now in progress.

The NACA Langley Laboratory has undertaken a research investigation of VTOL configurations of the aerial jeep type to assist the Army in its program. This work will include flight investigations with models of the two-shroud and four-shroud types and also models with two and four unshrouded propellers. The two-shroud model, shown in Fig. 35,

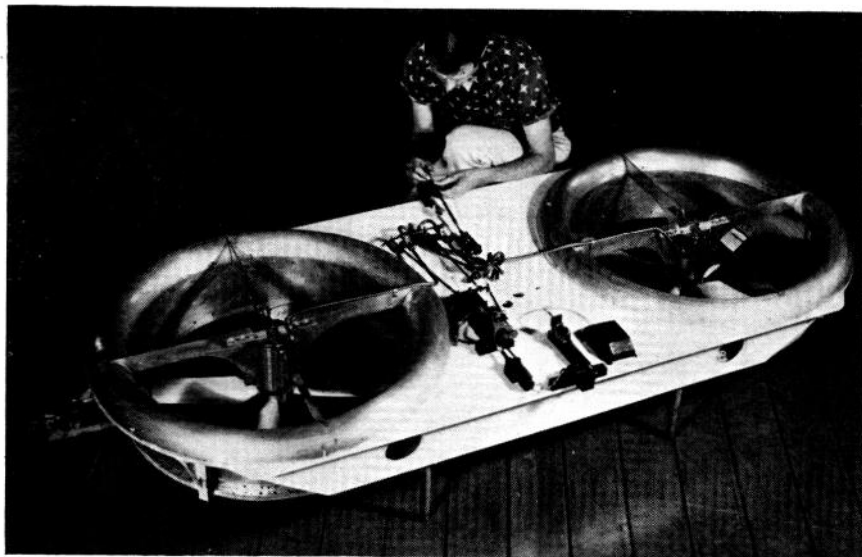


FIG. 35. NACA flying model used in research on aerial jeep.

has already been flown to afford a preliminary indication of the flying characteristics of this general type when used either as a tandem or a side-by-side arrangement. This investigation has indicated the feasibility of the aerial jeep from the stability and control standpoint but has revealed some basic stability and control problems for such machines.

TURBOJET CONFIGURATIONS

Considerable progress has been made in the turbojet VTOL field during the last few years, principally because of the pioneering work carried out by Bell Aircraft Corporation and Ryan Aeronautical Company in this field. The NACA has conducted some basic and supporting research in the turbojet VTOL field^(76 - 78) and has, in addition, carried out during the last three years a comprehensive research program on the turbojet STOL type known as the jet flap, jet-augmented flap, or jet wing.

Dual Propulsion Types

The dual propulsion type turbojet VTOL airplane, usually referred to as the lifting-engine type, has not received as much attention in the

United States as it has in England but interest in such configurations now seems to be increasing. The NACA has undertaken a research investigation on supersonic VTOL transport airplanes making use of this principle. This investigation will include studies with flying models of some of the more promising configurations, one of which is shown in

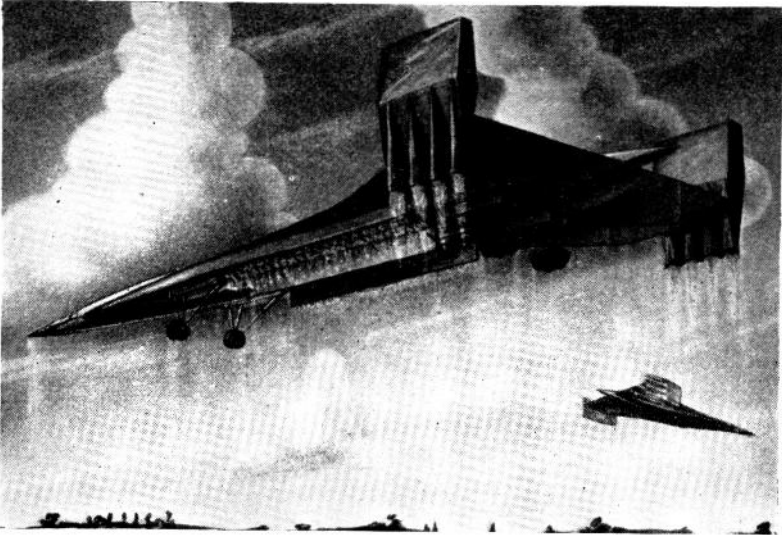


FIG. 36. Sketch of NACA flying model to be used in research on lifting-engine-type jet VTOL transports.

Fig. 36. This model, which is quite similar to the interesting configuration being studied in England by Rolls-Royce, is now under construction and will be flown soon. It is intended to represent a 400,000 lb, 150-passenger, Mach 3.5 transport with 90 small lifting engines along the fuselage and two packs of four larger engines at the wing tips. Unlike the Rolls-Royce configuration, this model has provision for tilting the engine packs to permit use of the large engines for hovering as well as forward flight.

Thrust Redirection Types

Thrust tilting. Most of the work on jet VTOL airplanes making use of the thrust-tilting principle has been done by Bell Aircraft Corporation and the NACA. Bell has studied configurations that involve tilting only the engine while the NACA work has covered, in addition, the tilting-wing-and-engine type.

Bell's first work with this jet VTOL type was started in 1954 with their so-called Air Test Vehicle shown in Fig. 37. This machine was constructed from parts of existing airframes and had two J-44 engines which were in the vertical position for hovering flight and could be

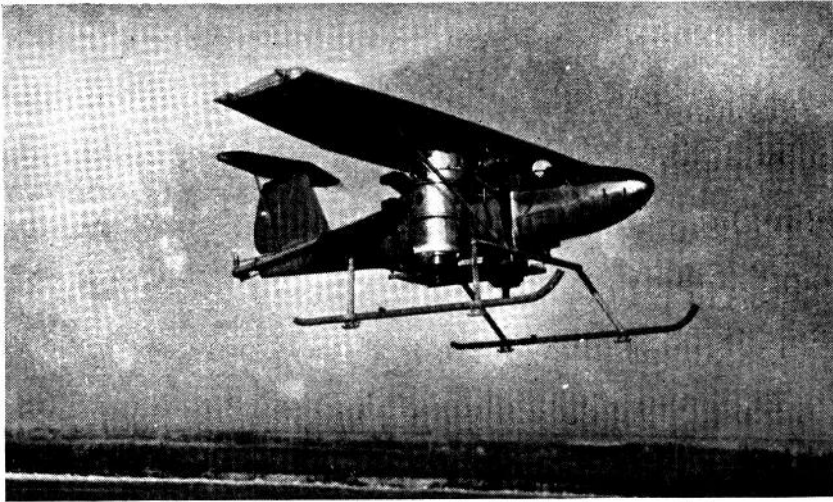


FIG. 37. Bell tilting-engine-type jet VTOL air test vehicle.

rotated to a horizontal position for forward flight. Control in hovering flight was provided by compressed-air jets at the wing tips and tail. Although this was a rather crude machine, it served the purpose of providing some early flight experience with jet VTOL aircraft. It is now in the Air Museum of the Smithsonian Institution.



FIG. 38. Example of jet VTOL fighter-type airplane considered in studies by Bell.

Bell's latest work in this field involves a fighter-type jet VTOL airplane, the development of which was initiated by the Navy and which is now being sponsored jointly by the Navy and Air Force. Specific data regarding configuration details and performance of the airplane are classified, but the Navy has revealed that the airplane is a multi-engine, horizontal-attitude type which incorporates both the tilting engine and thrust deflection principles. No sketches or drawings of this airplane are available, but some indication of Bell's thinking in the past on jet VTOL fighter-type airplanes might be obtained from Fig. 38 which shows an artist's conception of a VTOL fighter that has been used in Bell advertising.

Studies of jet VTOL transports of the thrust tilting type have also been made by Bell⁽⁷⁹⁾. Two configurations considered in these studies are shown in Figs. 39 and 40.

The NACA Langley Laboratory is conducting an investigation of jet VTOL airplane configurations in which both the wing and engines are tilted to perform the transition from hovering to forward flight⁽⁶⁾. This investigation includes flight studies with models having either conventional or canard-type tail surfaces. The NACA is also assisting the Navy and Bell Aircraft Corporation in the development of the VTOL fighter by performing force and flight tests on scaled models of the airplane.

The NACA Langley Laboratory is also conducting an investigation of jet VTOL configurations of the flying fuselage type. These configurations are wingless but do have conventional stabilizing surfaces which provide some lift to supplement the lift of the fuselage. Although this type of machine may seem at first glance to be entirely unrelated to winged jet VTOL configurations, there is a basic relationship between the two types. Since they are VTOL aircraft, their wing areas are determined from considerations other than take-off and landing. If the wing is designed for optimum efficiency in cruising flight, the wing area will decrease with either an increase in cruise airspeed or a decrease in cruise altitude, so that for some low-altitude high-speed missions all the effective wing area required might well be provided by the fuselage and stabilizing surfaces. The first wingless configuration being studied by the NACA is a jet transport type with tilting engines at the side of the fuselage. Some of the engines are used only for take-off and landing and are faired into the fuselage for cruising flight. Analysis has indicated that a configuration of this type has some promise for short-range missions that involve flying at low altitude at high subsonic speeds.

Thrust deflection. Table 1 shows the turbojet thrust deflection type subdivided into VTOL and STOL configurations. This subdivision appeared to be desirable since jet flap aircraft are usually considered to be limited to STOL operation and are basically different from most of the thrust deflection VTOL types.

In the thrust deflection VTOL field, Bell Aircraft Corporation has

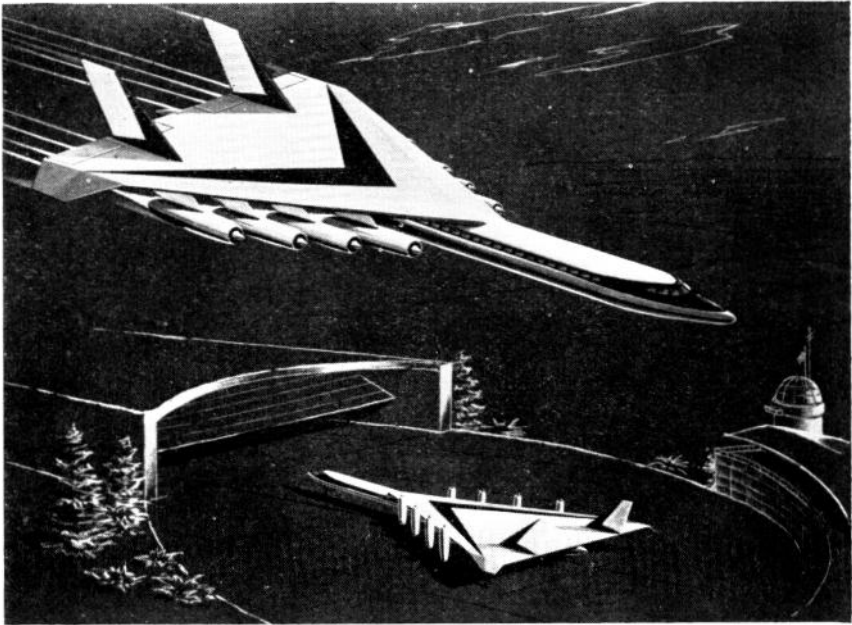


FIG. 39. Example of tilting-engine-type jet VTOL transport studied by Bell.

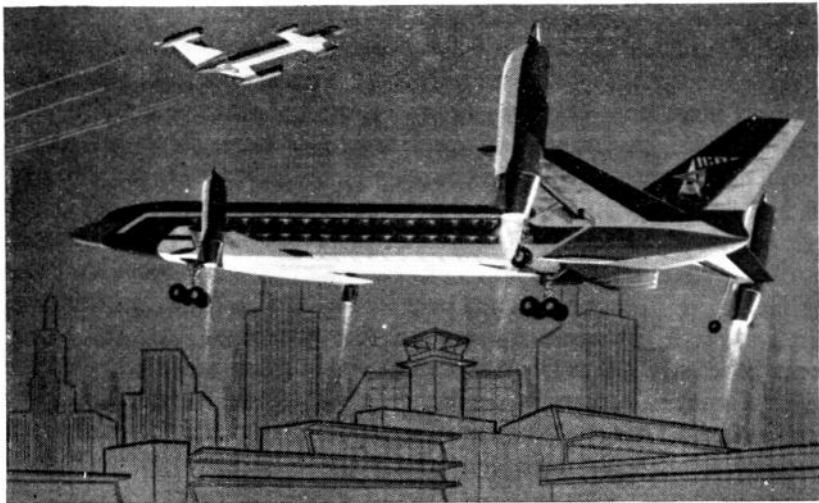


FIG. 40. Example of canard-type tilting-engine jet VTOL transport studied by Bell.

studied configurations that are more or less conventional airplanes except for the jet deflection feature, while Collins Radio Company has worked for several years with the Aerodyne, a wingless VTOL aircraft which is similar in principle to the wingless jet VTOL type discussed in the previous section, but which makes use of thrust deflection rather than thrust tilting.

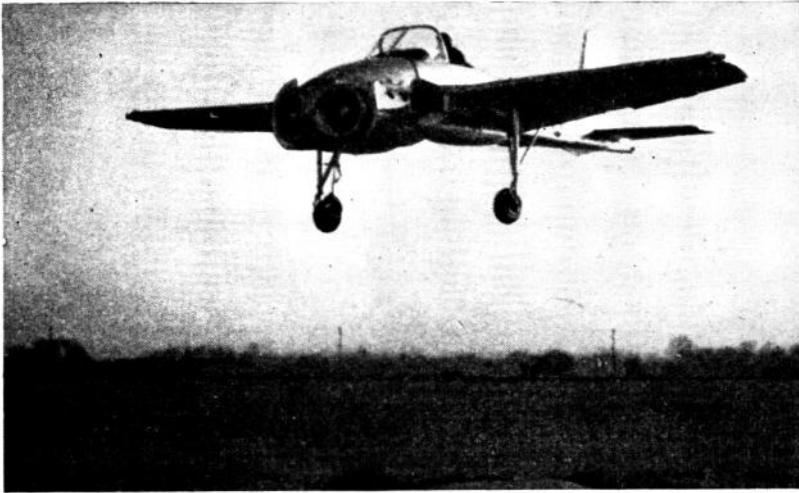


FIG. 41. BELL X-14 deflected-jet research airplane.

The BELL X-14 airplane (Fig. 41), an Air Force project, is the only deflected-jet type VTOL airplane that has been flown to date in the United States. It is a small research machine having a span of 34 ft and a take-off weight of about 3500 lb, and it is powered by two Armstrong-Siddely Viper turbojet engines. Thrust director vanes at the engine tailpipes direct the jet exhaust downward for hovering and backward for forward flight. Control in hovering and low-speed forward flight is provided by air jets at the wing tips and tail. The X-14 has been test flown in hovering and in normal forward flight by Bell and has recently been equipped with a later model of the Viper engine to provide a greater thrust margin. Following some additional flight testing by Bell with this engine, the X-14 will be turned over to the NACA Ames Laboratory for an extensive flight research program. Some research has already been done at the NACA Langley Laboratory with a flying model of a deflected-jet configuration generally similar to the X-14⁽⁶⁾. In addition to the work with the X-14, Bell Aircraft Corporation has made studies of possible applications of the jet deflection principle to VTOL transports⁽⁷⁹⁾.

Although the experimental work on the Aerodyne concept that has been done at Collins Radio Company has involved only ducted-fan configurations, studies have also been made at Collins of the jet Aerodyne⁽⁷⁰⁾. A

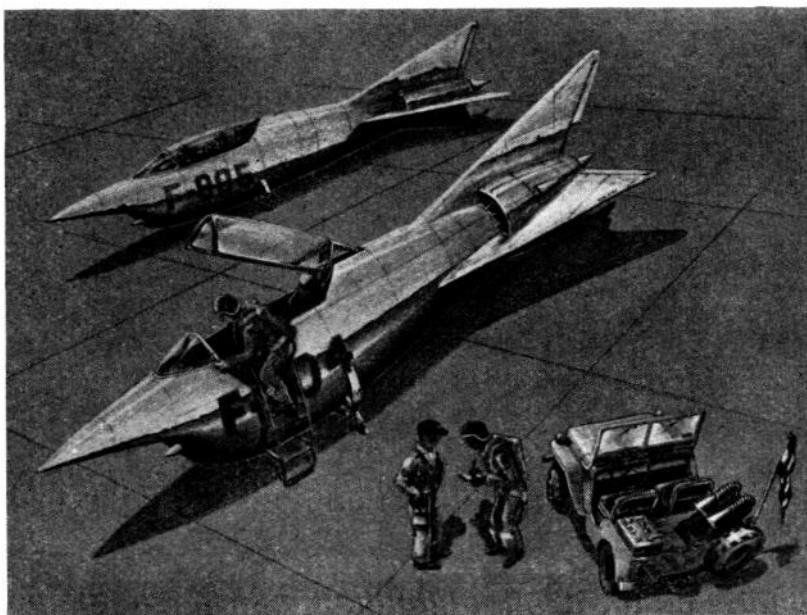


FIG. 42. Configuration illustrating jet Aerodyne concept under study by Collins Radio Company.

sketch of a wingless configuration that illustrates the jet Aerodyne concept is shown in Fig. 42.

Jet flaps. About three years ago, interest in the United States in the jet flap (or jet-augmented flap) was stimulated by the work being done in England and France, and this interest has now increased to the point where research aircraft equipped with jet flaps are being considered. During this time the NACA Langley Laboratory has been conducting a comprehensive research program on the jet flap^(80 - 89) and this work is continuing with models and test setups such as those shown in Figs. 43-45. Figure 43 shows a large-scale static test setup of an external flow jet-flap arrangement consisting of a J-69 engine with a flat nozzle which directs a flattened jet sheet through a slotted flap. The equipment was set up inverted as shown in order to eliminate the effect of the ground in these tests. A large swept-wing transport model using the same engine-nozzle and flap arrangement is being constructed for tests in the Langley full-scale tunnel. The model shown in Fig. 44 is a flying model equipped with a double-slotted external-flow type jet flap and a canard surface that is also equipped with a jet flap. The analysis presented in Ref. 83 indicated that a canard configuration of this type is promising from the standpoint of longitudinal stability and trim. In addition to work on the internal-flow and external-flow jet flap types, the NACA is also studying another type that involves blowing over flaps from flattened

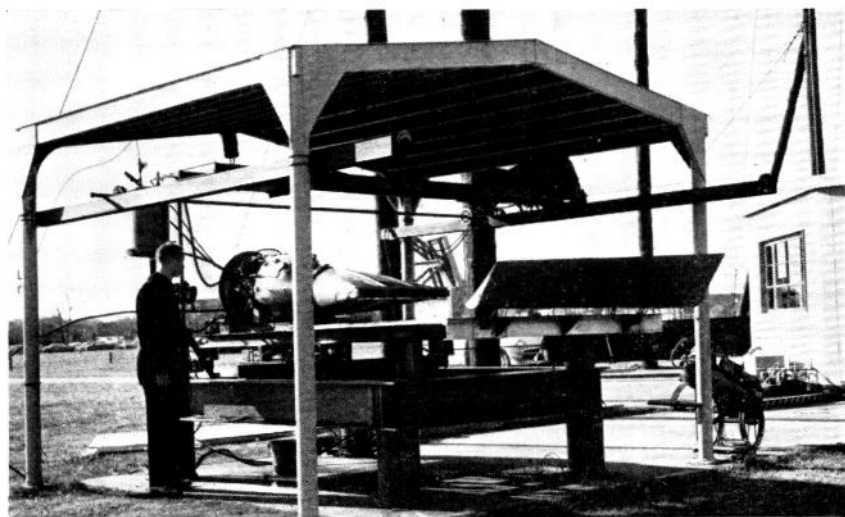


FIG. 43. Large-scale, hot-jet static-test setup used by NACA in study of external-flow jet-augmented flap.

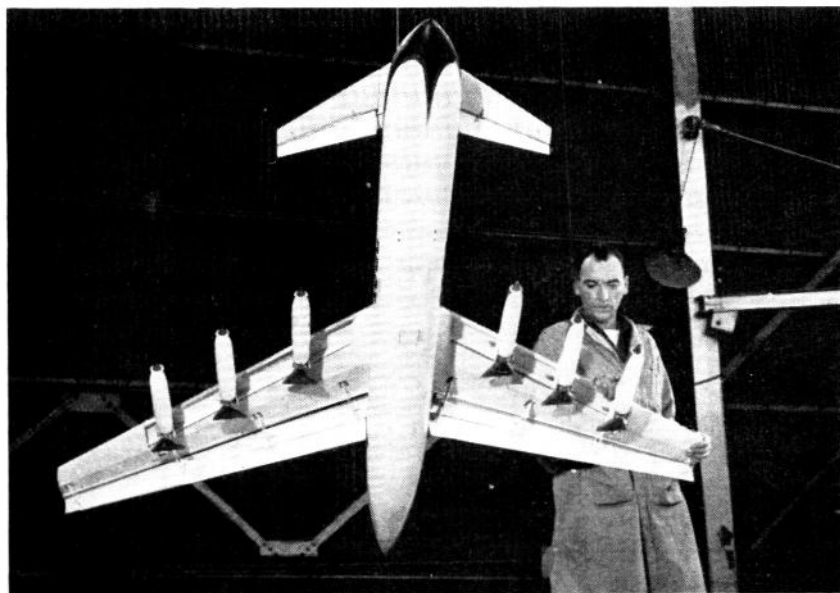


FIG. 44. Canard-type flying model used by NACA in jet-augmented-flap research.

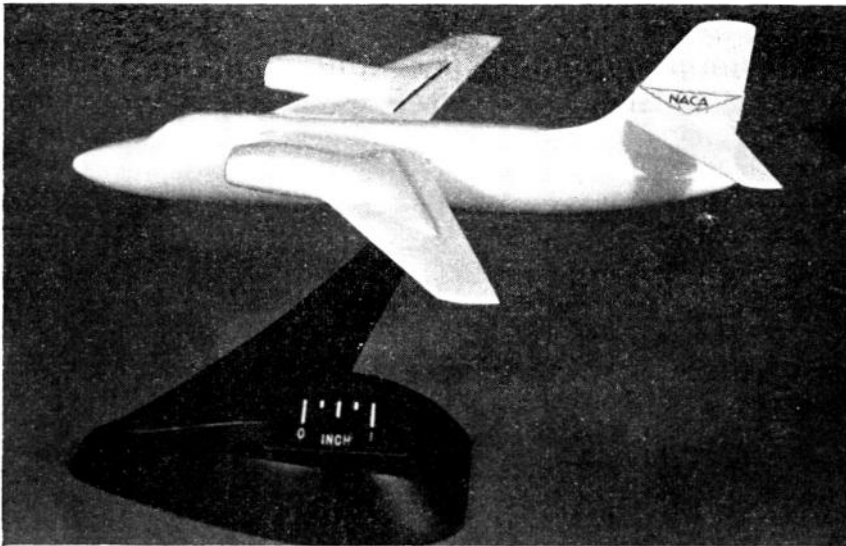


FIG. 45. Research configuration used by NACA in study of upper-surface blowing-type jet-augmented flap.

nacelles mounted above the wing⁽⁸⁸⁾ (see Fig. 45). A jet flap configuration of this type appears to afford very desirable noise reduction characteristics⁽⁸⁹⁾. Other NACA jet flap research includes studies of high-speed configurations at transonic and supersonic speeds; basic research studies to obtain information on such items as partial-span



FIG. 46. Large-scale, hot-jet, static-test setup used by Martin on jet-flap studies.

blowing and optimum nozzle location; and investigations of possible favorable combinations of the jet flap and slipstream deflection principles.

In addition to the NACA research with the jet flap, work along this line is also being done by a number of companies. Among the companies which have contracts from the Army and Navy for jet flap studies are the Martin Company and Fairchild Aircraft. Shown in Fig. 46 is a photograph of a Martin test facility which is being used to determine the flow and pressure distribution of jet-engine exhaust gases over the full-scale flap section of a large seaplane. This facility will also be used to develop the hardware that would be required for the installation of such a system in an airplane. Fairchild is engaged in a jet flap program that involves wind-tunnel force testing, static tests on a large-scale setup, and analysis and performance studies of various jet flap airplane configurations. They feel that the next logical step in jet flap research is a small research airplane similar to the configuration shown in Fig. 47 which they have

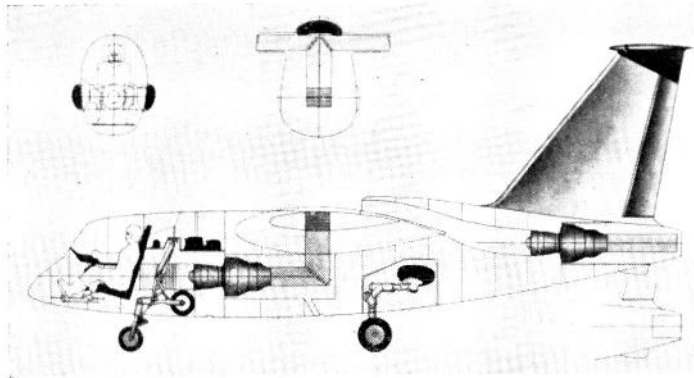


FIG. 47. Jet flap research airplane design considered in studies by Fairchild.

considered in their studies. The machine shown is an unswept configuration with a span of about 40 ft and a gross weight of about 7000 lb, and it is powered by two J-69 engines, one for propulsion and one for jet flap use.

Aircraft Tilting Types

Tail-sitter airplanes. Perhaps the most impressive VTOL aircraft flown in the United States to date is the X-13 airplane, a jet tail-sitter type designed and built by Ryan Aeronautical Company for the Air Force (see Fig. 48). The successful flight testing of the X-13 culminated ten years of jet VTOL research by Ryan that started in 1947 with a Navy contract to investigate jet reaction control. This early jet reaction control work led to the development of a vertical-attitude engine test rig which

in 1950 lifted off the ground under its own power and was controlled remotely by a pilot on the ground. Later, a pilot seat and controls were mounted on top of the test rig, and in 1953 this vehicle made the first piloted hovering jet flight. At about this time Ryan received an Air Force contract for construction of the X-13 airplane. The first hovering and transition flights of the X-13 were made in 1956 using special landing gear, and finally in 1957 the complete operation of the machine was demonstrated, using the nose hook for take-off and landing on the special ground-service trailer (Fig. 48)

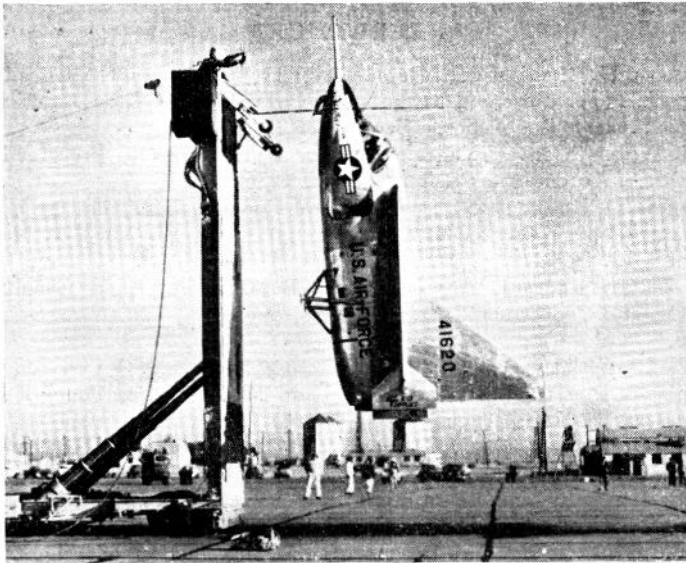


FIG. 48. RYAN X-13 tail-sitter-type jet VTOL research airplane to land on ground-service trailer preparing.

The X-13 is 24 ft long, has a wing span of 21 ft and is powered by a Rolls-Royce Avon turbojet engine. Pitch and yaw control in hovering flight is provided by a swivelling tail pipe, while roll control is obtained from wing-tip nozzles. A rather elaborate automatic stabilization system is used to provide adequate stability in all flight conditions.

The NACA Langley Laboratory carried out a fairly extensive study of the tail-sitter jet VTOL type to assist the Air Force and Ryan in the development of the X-13. Preliminary work was done with flying research models powered by a ducted fan within the fuselage^(72, 73). Later, a scaled model of the X-13 powered by a hydrogen-peroxide motor was flown on the Langley Control Line Facility and the same model, powered by compressed-air jets, was flown in the Langley full-scale tunnel.

CONCLUDING REMARKS

The foregoing summary indicates that a large number of widely different VTOL and STOL aircraft types are receiving attention in the United States at this time. In some respects it probably appears that the effort is being spread too thin to accomplish very much with anyone type. It should be emphasized, therefore, that the present approach was chosen for the express purpose of providing a limited amount of information on a large number of configurations in a short time, in order to determine at an early date the proper direction for our major efforts in the VTOL-STOL field.

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DISCUSSION

J. W. DRINKWATER*: Since one of the major characteristics of VTOL aircraft is to be able to go from one city center to another, and bearing in mind our discussion on aircraft and engine noise on Wednesday morning, what does the author feel should be done about the noise problem on these VTOL aircraft?

J. P. CAMPBELL: First, of course, the noise produced during take-off, climb, and landing should be minimized at its source by the selection of power plants of a given type that are inherently the quietest. For example, bypass and turbofan engines are quieter than turbojets, and fortunately these engines are very well suited to use on VTOL airplanes since they have a much higher ratio of static thrust to cruise thrust than turbojets. Similarly, in the case of turboprop VTOL configurations, the use of very large diameter propellers is advantageous from the standpoint of noise reduction as well as static thrust. While the VTOL aircraft is being made as quiet as possible, consistent with other design considerations, careful attention should also be given to the selection of take off and landing sites. It has been suggested that perhaps an optimum location for a VTOL airport which be a platform or pier along the shore of some large body of water such as a lake, river, or bay, so that climbouts and landing approaches could be made over water, away from heavily-populated areas. Many of our larger cities are situated so that such an airport location could be fairly near the center of the city. Other suggestions that have been made for reducing the noise problem of VTOL aircraft include the use of very steep take-off and climbout patterns and the use of high-walled enclosures around the take-off and landing areas.

H. WITTENBERG†: 1. Is there any fundamental difference between the air vehicles called "flying platform" and "aerial jeep" in the paper?

2. Is anything to be gained in take-off and landing performance by using the jet-augmented flap for subsonic jet aircraft with thrust-weight ratios in the order of 0.2 - 0.3?

J. P. CAMPBELL: 1. The principal fundamental difference between the flying platform and the aerial jeep is that the flying platform as originally conceived is flown by kinesthetic, or natural, balancing control, while the aerial jeep is flown by conventional control methods. Another difference is that the aerial jeep is a

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larger machine designed to do the same job in the air that a ground jeep does on the ground, while the flying platform is a one-man machine that might be considered an aerial motorcycle.

2. Analytical studies such as the one covered in Ref. 83 of the subject paper have indicated that the jet-augmented flap would provide little improvement in take-off and landing performance for aircraft having thrust weight ratios of 0.2 or less, but could provide very large gains for aircraft having thrust-weight ratios of 0.3 or more. Even for thrust-weight ratios as low as 0.25, worthwhile gains appear possible in some applications of the jet flap.

P. RADEN*: 1. During the landing maneuver of VTOL aircraft with tilting turbojet engines when changing from hovering flight to the descending path, the engines are blown across the axis of the inlet. Have you had some difficulties like a blow-out of the engines?

2. Is the thrust regulation of turbojet engines with fuel throttle sufficient and quick enough?

3. Did the turbojet engines have afterburners? What is the possibility of a deflected jet machine with afterburner on?

J. P. CAMPBELL: 1. To my knowledge, no engine blow-out difficulties have yet been experienced by turbojet VTOL aircraft during transition flight.

2. This form of thrust regulation has appeared to be generally satisfactory on the three turbojet VTOL configurations flown to date (X-13, X-14 and Bell Air Test Vehicle). The vertical motions of the X-13 in hovering flight are stabilized by automatic throttle control.

3. None of the turbojet VTOL machines tested to date has been equipped with afterburners. At this time, no one appears to be considering configurations which involve deflecting the extremely hot jet exhaust of engines with afterburners. Some consideration is being given, however, to arrangements which involve the use of an afterburner for high-speed flight with provisions for deflecting the jet downward for hovering flight by means of a by-pass valve ahead of the afterburner.

J. DESCHAMPS†: 1. In the films that were presented, we have seen numerous models, tested either in a wind tunnel or suspending from a turning crane. I would like to know the type of control system used in testing these models, particularly during transition flight. Is it a question of automatic control? Or is it rather a human visual control with a direct command?

2. Do the models contain instruments for indicating attitude or motions?

J. P. CAMPBELL: 1. The VTOL models flown in the Langley Full-Scale Tunnel and on the Langley Control Line Facility are not equipped with automatic control but are flown manually by the multiple-pilot technique described in Ref. 5 of the subject paper. In this technique, there is a separate pilot for roll, yaw, and pitch control, and another operator for the model power control. Experience has indicated that the use of multiple pilots in dynamic-model flight testing tends to compensate for the difficulties resulting from the higher angular velocities and shorter periods of the models and the lack of acceleration sensing or "feel" that aids the airplane pilot. Although the models are flown by manual control they are sometimes equipped with rate-type roll, yaw, or pitch dampers to improve the dynamic stability.

2. The models do not contain instruments for indicating attitude or motions but do, in some cases, contain instruments for indicating control deflection angles. All information regarding attitude or motions of the model is obtained from film records taken with motion picture cameras located at the side and rear of the tunnel test section or, in the case of the Control Line Facility, on the cab of the rotating crane.

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