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15 May 1966

To: Office of Naval Research
Department of the Navy
Washington 25, D. C.

Attention: Head, Air Branch, Naval Sciences Division

Via: Bureau of Aeronautics Representative
Palo Alto, California

Subject: Propellorlane Transport Aircraft Study, Contract
No. 1657 (00), Final Summary Report dated 15 May
1956, Transmittal of:

Enclosure: (a) Five (5) Copies of subject report.

1. The final summary report of the Propellorlane Transport Aircraft Study, Contract No. 1657 (00), is submitted herewith. Delivery to other agencies and contractors is being made in accordance with the attached distribution list.

R. A. Wagner
Chief Engineer

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FINAL SUMMARY REPORT

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Contract No.        NAC 1687 (11)
Report No.          Summary Report
Title               Propellerless transport study

Date               May 17, 1966
Approved            J. Stuart III
By                   N. Alberti
Approved            J. Rager
The theoretical and experimental justification for the performance, stability and control of tilting-vane Propellorplane is contained in earlier NASA wind tunnel and free flight model tests and theoretical investigations conducted by Bell Helicopter as parts of this study. The significant conclusion reached as a result of these programmes is that the vane, in transition from hovering to forward flight, contributes immediately to the lift of the aircraft and maintains the equilibrium in flight at very low forward speeds. Of equal importance is the fact that the weight and power required during transition decrease steadily from the maximum value required in hovering.

The practicability and all-around best possibilities of the propeller-lifted, tilting-vane aircraft as a solution to the operational problem of providing air mobility for combat troops and cargo is demonstrated by two preliminary designs of Propellorplane Transports which employ engines scheduled to be available in 1957 and 1960, respectively. A third design, based on the estimated characteristics of engines that will become available in 1964, is developed in considerable detail to show the outstanding performance improvements that may be expected due to improvements in engine performance alone.

Model 10P8-A, the 1957 aircraft, performs the specified mission without compromise and at a design gross weight of 71,500 pounds.

Model 10P9-B, with Allison T60-B1 engines, scheduled to be available in 1960, and using water injection, when necessary, to permit meeting the hover ceiling requirements, also performs the specified mission but at a take-off gross weight of 101,000 pounds.

Model 10P10-D is identical to model 10P8-A except for the engines, gear boxes and propellers. Eight Allison 501-D9 gas turbines, scheduled for production in 1961, drive four dual-rotation, eight-blade propellers approximately 19 feet in diameter. These propellers use a currently available Curtiss-Wright blade design. By using water injection and taking off at an overload gross weight of 13,600 pounds, Model 10P10-D can carry a payload of three tons, with a radius of action of 550 miles, assuming take-off from 6000 feet altitude and 75°F. With standard temperatures at this altitude, Model 10P10-D would be able to carry the full four ton payload the entire radius of 485 miles. This machine, it therefore, recommended for immediate development.
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After World War II the first successful VTOL aircraft, the helicopter, was energetically developed. It had received its baptism of fire in small numbers during the last months of the war, but the Korean conflict became the proving ground for large-scale testing of the helicopter in combat, and it was there that it earned recognition of its indispensable qualities for military transport missions. By the same token, the inadequacies of reciprocating-engine-driven, rotor-lifter aircraft for use in many future combat transport situations was observed by Army and Marine Corps leaders.

Concurrently, post-war development of turbo-jet and turbo-prop power plants opened the way to the possibility of designing vertical take-off aircraft not involving the use of large diameter, articulated or semi-articulated rotors, and many schemes were advanced for exploiting this possibility. The most impressive early results were the two Navy VTOL fighters, the XFV-1 and the XFY-1.

In 1954, personnel of the Army Transportation Corps, recognizing that comprehensive engineering studies were required for guidance in future development of combat transport aircraft, initiated a broad cooperative program of study and evaluation of various VTOL and STOL aircraft concepts.

Because of its prior history of interest in propeller-lifter aircraft and as a pioneer exponent of the tilting-wing turbo-propeller lifted concept, Hiller Helicopters was awarded in March, 1955, Contract NNR-1857 (00) to study and evaluate the development problems involved in this segment of the VTOL aircraft program.

In order to make possible a valid comparative evaluation of the several aircraft designs issuing from the different groups involved in the program, a statement of the operational problem and the uniform design conditions to be used as a basis for study was formulated at a meeting of the Military and contractor's representatives at the Office of Naval Research on April 27, 1955, and amplified by later meetings and directives.

Within the framework established by specification and agreement, the primary objective of the work to be performed by Hiller Helicopters was to make a preliminary design of the optimum tilting-wing turbo-propeller lifted aircraft capable of accomplishing the specified mission. A summary of the results of that work is presented in this report.
SECTION I - DEFINING THE PROBLEM

A. MISSION REQUIREMENTS:

The operational problem and specified characteristics of the VTOL category of aircraft were stated as follows:

a) Payload
   8000 lbs. out
   4000 lbs. return

b) Take-Off Distance
   0' over a 50' obstacle

c) Cabin Size
   9' x 9' x Length Required for 35 Troops

d) Cargo
   35 Combat Troops or Equivalent Weight of Vehicles or Equipment

e) Hover Ceiling
   6000' Altitude and 95°F Ambient Temperature

f) Minimum Cruise Speed
   300 MPH

g) Radius of Action
   425 Statute Miles

h) Flight Profile
   Cruising Altitude Optional Except for 20% of Radius Adjacent to Destination at Sea Level

i) Landing Surface
   For Rolling Take-Off
   $\mu = .2; \ UCL = 15$

j) One Engine Out Performance
   Aircraft to Remain Controllable following failure of One Engine and be able to make a "Controlled Crash" Landing

Several items of considerable importance in their effect on the parameters of the aircraft were necessarily unspecified in order to accommodate a wide range of types. In regard to these optional conditions, assumptions were made which seemed compatible with the mission and type of aircraft being considered by this contractor.
1) **Hover Duration:**

The time required to take off, climb vertically to 50 feet altitude and convert to forward flight was allowed to be 4 minutes. A total time of 4 minutes per mission was allowed for take-offs, conversions, and landings. Measurement of the time required for fully loaded Boeing 20-6 and Lockheed Constellation aircraft to accelerate from rest and climb to approximately 50 feet indicates that the assumed time of one minute is excessive. The low power loading of TCC aircraft compared to fixed wing airliners assures a much higher acceleration and indicates that under normal conditions considerably less time would be required. The win-tilt actuating mechanism was designed to tilt the wings 20° in 90 seconds.

2) **Cruising Altitude:**

Cruising Altitude has been arbitrarily limited to 25,000 feet to make possible safe operation without pressurizing the cabin. This assumption possibly imposes a penalty upon the design, because in addition to the usual performance gains associated with increased altitude, the increased propulsive efficiency of the propellers, which are necessarily too lightly loaded in forward flight at low altitudes, might more than compensate for the increased structural weight and pressurizing equipment. The effect of altitude was not included in selecting the parameters of the optimum aircraft, because it would increase the work required beyond our capacity in the scheduled period, and because the intended use of the aircraft accents its low altitude capabilities. The effect of cruise altitude on mission performance for the final optimum design is shown in Figure 10.

3) **Provision for Engine-Failure Safety:**

The requirement for ability to make a "controlled crash" landing following failure of one engine is the least amenable to proof outside of actual experience. Our designs are based on the premise that if adequate reserve power is available to reduce the the rate of descent to a moderate value following failure of one engine and reduction in power of one other engine as required to obtain trim, plus some small allowance for roll control, then interconnecting shafts may be dispensed with. The optimum aircraft will hover out of ground effect at 5000 feet altitude in the standard atmosphere with the most critical power section inoperative and the remaining power sections delivering normal rated power. The
The specified cruise cruising speed of 300 miles per hour was assumed to be the actual cruising speed throughout the study. Power plant arrangement during cruising flight was the subject of a separate study aimed at determining the optimum division of (reduced) power among the eight installed power sections.

5) Load Factors:

Specification of load factors is necessary for those components of the aircraft whose weights cannot be estimated from empirical formulae derived from existing aircraft. For the tilting-wing aircraft these include the wing weight and weight of hinges, actuating mechanism and control devices. Load factors closely approximating those specified by applicable Civil Aeronautics Authority requirements for aircraft of similar size and function were selected.

SECTION II - DESIGN VARIABLES

A. Configurational Variables:

The major alternative configurations considered in this study prior to the selection of the final design are illustrated in Figure 1. The most basic of these is the number and arrangement of power plants, propellers, and nacelles. Preliminary weight estimates indicated that the two nacelle configuration was inferior to the four nacelle configuration in aircraft larger than approximately 60,000 pounds, and more detailed recent studies made in connection with another model indicate that, depending upon the hover ceiling and power plant characteristics assumed, this weight may be as low as 40,000 pounds. Practical considerations, such as maintaining moderate propeller diamers, reducing gear box sizes, and eliminating the interconnecting shafts, also, influenced the decision to use four nacelles.
Of the two alternative four-nacelle configurations illustrated, the four-engine version with interconnecting shafts apparently suffers a weight penalty compared to the twin-engine non-interconnected configuration. However, if the interconnecting gear boxes and shafting is designed to have only a short life for full emergency load and in normal operation carries only the unsymmetrical load due to control movements and transient variations in propeller load due to varying, different rates of pitch change between the separate propellers, and other short term effects, the system is not prohibitively heavy. However, the undesirable cost, complexity, maintenance difficulties, and vibrations associated with long shafts led to the decision to settle on the four-nacelle, non-connected configuration as the basic system for this study.

Four methods of providing for auxiliary longitudinal and directional control in hovering are illustrated. The method involving the use of bleed air from the main engine compressors was clearly ruled out due to the detrimental effect on engine efficiency of the large quantities of bleed air required. Our estimates indicated that from a weight standpoint, tail rotors and tail jets plus the fuel required for their operation were roughly equivalent with some advantage accruing to the more efficient thrust producing rotors. However, in our judgment, the advantage was not great enough to warrant the complication, extra in forward flight, vibration, and maintenance difficulty incurred by their use. The high specific thrust, small size turbo-jet engines now being produced are usually suited to this short life, intermittent operation application.

Three fuel storage locations are illustrated, each having some advantages. For maximum aerodynamic and structural efficiency the wing tip location is favored. In the final optimum design the outboard nacelles were located at the tips so that the understing tanks were required. This position aids in obtaining proper center-of-gravity movement of the aircraft during transition from vertical to forward flight and is favored from a safety and constructional standpoint over the fuselage held location.

The selected landing gear arrangement consists of a wheel and skid combination which provides a rolling contact area having a Unit Construction Index of 41 and is adequate for use on flexible pavements and landing mats. With the skids lowered for vertical landing on unprepared surfaces, the contact area is sufficient to give a pressure approximately the same as that of a truck, 3½ ton, 4 x 4, weapons carrier.
For an all-wheel landing gear, estimated in late tests the multiple, small, air-pressure wheels being larger than the so-called conventional dual tandem, large, low-pressure arrangement, is the same U.C.I. The compromise said and wheel arrangement is appreciably lighter than either of these arrangements.

The selection of an unpressurized cabin has been previously explained.

The selection of dual-rotor propellers has entered as a part of the optimization analysis of the basic parameters.

B. Parametric Variables:

The number of parametric variables subjected to a systematic variation as part of the process of selecting the optimum aircraft included all of the fundamental performance parameters and as many additional variables as permitted by the inevitable necessity of rationing our efforts to accomplish the study objectives within the period available. The following parameters were considered:

a) Gross Weight
b) Wing Loading
c) Aspect Ratio
d) Propeller Disk Loading
e) Propeller Tip Speed
f) Number of Blades
g) Blade Activity Factor

C. Specification of Furnishings and Equipment:

It has been observed that considerable variation exists among the various groups concerned in the present program as to the weight allowance made for the aircraft furnishings and fixed equipment. In this study a conscientious effort was made to make weight provision for all the numerous pieces of operational equipment ultimately demanded in a fully developed military transport aircraft. The list of items considered was adapted from the standard furnishings and equipment groups of currently operational military cargo aircraft; therefore this group weight is subject to review by the procuring agency if it appears that certain items are superfluous in the intended employment of the aircraft.
With the tools and methods developed in the work reported in the preceding section, three preliminary designs of multi-wing turbo-propelled lifted aircraft have been produced. These are estimated Propeller Plane Transport Models 10\(^{-}\)A, 10\(^{-}\)B, and 10\(^{-}\)D, and represent aircraft that could be available in 1967, 1968, and 1969, respectively.

The study was principally directed toward the design of Model 10\(^{-}\)A. At the request of the procuring agency, additional studies were made to develop Model 10\(^{-}\)B, designed around the Allison Model 750-B1 gas turbine, scheduled for availability in 1960. Model 10\(^{-}\)D was included to show how minor revisions in the specified mission requirements would permit immediate development of a practical machine.

A General Arrangement Drawing of Model 10\(^{-}\)C, a two-nacelle configuration, is included for information. Work on this design was not carried beyond a preliminary weight estimate when it became obvious that it could not be competitive with the four-nacelle configuration.

General Arrangement Drawing 10\(^{-}\)A-001 and Inboard Profile Drawing 10\(^{-}\)B-002 apply specifically to Model 10\(^{-}\)A. Similar drawings for Models 10\(^{-}\)B and 10\(^{-}\)D were not prepared because of their nearly identical features. The differences in dimensions of the three models are listed in the table of leading particulars.

A. DESIGN FEATURES:

1. Pilot's Cabin:

Weight and space provision have been made for a pilot, copilot, and flight engineer. Access to the pilot's cabin is provided through an internal side door and ladder or through the door leading to the cargo compartment. An emergency escape hatch and tube to the bottom of the fuselage is also provided. Weight and space provision for the electronic and communication equipment is made on the flight deck adjacent to the flight engineer's station.

2. Cargo Compartment:

Cargo compartment dimensions are 91 x 9' x 33', and it has a capacity of 35 infantry troops or 18 litters or one truck, 1-1/2 ton, 6 x 6, cargo and personnel carrier, or 3 trucks, 1/4 ton, 6 x 6, utility. The large, unobstructed, rear loading ramp may be lowered for ground loading or raised to truck bed height.
4. Landing Gear:

The fully retractable combination ski and main landing gear is proposed as the lightest, simplest arrangement for providing adequate flotation for landing on soft unpaved areas and adequate tire contact area for operation from paved runways. The skids are hydraulically retractable to the forward flight landing position. The landing gear is accessible from within the aircraft.

5. Nacelles:

The eight power sections are located in pairs to four dual-rotor, six-bladed propellers. Firewalls between the power sections and individual oil tanks and coolers are provided for maximum protection against engine failure. Overrunning clutches between the power section output shafts and rear box input shafts provide for disengagement of a failed power section or for voluntary shut down of power sections in cruise.

6. Wing-Tilt Mechanism (Drawings 1048A-001 and 1048A-005):

Structural efficiency of the wing is not impaired by the hinged connection to the fuselage. The large cross sectional area, two-spar, tapered, cantilever wing beam is continuous from tip to tip. The wing is hinged at the rear spar, located at the 50 percent chord station. Coordinated ball bearing screw jacks, powered by a central 40 horsepower hydraulic motor, tilt the wing through its 90° tilt range in twenty seconds, the approximate time required to accelerate the aircraft from hover to airplane flight speed. An emergency standby electric motor and hand crank are available to actuate the screw jacks in the event of hydraulic system failure.

The critical compression load on the screw jacks was found to occur on the ground when a horizontal decelerating force is applied to the aircraft with the wing in the vertical position. Hydraulically actuated lock-pins secure the wing in the airplane configuration.

6. Control Functions (Drawings 1048A-003 and 1048A-005):

In addition to the usual airplane surface controls, Models 1048A, 1048B, and 1048D are provided with auxiliary means for control in hovering and low speed forward flight. Longitudinal and directional control are provided by directing the exhaust gases of a small turbojet engine, mounted in the tail of the aircraft. Lateral control is obtained by varying differentially the power output of the power sections on opposite sides of the aircraft in response to motions of
B. LEADING PARTICULARS AND PERFORMANCE CHARACTERISTICS

Model 101A and Model 101D are noted for the installed powerplants and propellers. Model 101A is the only installation using engines having the characteristics of the Allison 501D-D1, Model 101D is based on the guaranteed characteristics of the Allison 501D-D3. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.

In addition to the Allison engines, Model 101A is the only installation using engines having the characteristics of the Allison 501D-D3 engines scheduled for production in 1969. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.

Model 101D is based on the guaranteed characteristics of the Allison 501D-D3 engines scheduled for production in 1969. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.

Model 101D is based on the guaranteed characteristics of the Allison 501D-D3 engines scheduled for production in 1969. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.

Model 101D is based on the guaranteed characteristics of the Allison 501D-D3 engines scheduled for production in 1969. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.

Model 101D is based on the guaranteed characteristics of the Allison 501D-D3 engines scheduled for production in 1969. Design speed of the propellers is based on the propeller characteristics of the Allison 501D-D3 engines scheduled for production in 1969.
The propeller blades specified for Model 10b/5 are components of a Curtiss-Wright propeller currently in production. Model 10b/5 represents, therefore, an immediately developable, practical Propelloplane transport aircraft.

Model 10b/5 represents a close approximation to the optimum aircraft based on use of the Allison V-1700-31 was turbine scheduled for production by 1960, and using propellers which are smaller than designs currently being developed for use by 1960. By using water injection, Model 10b/5 can perform the complete mission without compromise. The comparative weights of Models 10a/5A, 10b/5, and 10b/5D are shown in Figure 3. Complete Group Weight Statements for each model are tabulated in Table I. Figure 4 shows the percentage weight breakdown of Model 10a/5A. The weight of the turbo-prop engine, their reduction gearing, the lifting propellers, and the tail turbo-jet engines, grouped together as a power plant weight, becomes almost equal to the airframe and control weight. 30 percent of the cross weight is still available for useful load at the stringent climb vertical take-off condition of 60° at 5000 feet pressure altitude. This figure compares with perhaps about 18 percent for a normal airplane.

The most forward and most rearward c.g. positions anticipated are shown on Drawing 10a/5A-001. Payload shifts of 90 inches are included within these maximum c.g. travels of 10 inches and 15 inches for the wing level and wing vertical conditions, respectively.

The leading particulars of each model are shown in Table II.

A comparative performance summary is shown in Table III.

C. CHARACTERISTICS OF MODEL 10a/5A:

The remainder of this section is devoted to a discussion of the outstanding characteristics of the optimum aircraft, Model 10a/5A.

1. Basic Operating Characteristics:

Figure 5 shows how the low equilibrium forward speeds of the optimum machine increase approximately 20 miles per hour for each 10 degrees of forward tilt of the wing. This machine would thus be traveling about 60 LPH when the wing was tilted 30 degrees forward of the vertical.
Hiller Helicopters' experience with the ducted fan flying platform has indicated that when a flow is forcibly directed, in that case by the propeller duct, in this case by the wing chord, the correspondence between air speed and angle setting is a most positive and precisely defined function.

Figure 6 shows how both the propeller thrust and required engine power both decrease as the wing angle is decreased from the 90 degree vertical position used in hovering and forward speed is gained. These desirable characteristics basic characteristics have been generally confirmed by NASA test results. These curves based upon an analysis of this particular case and include effect of mounting the outboard nacelles at the wing tips.

2. Propelloplane Stability and Control Characteristics:

The curved lines on Figure 7 show the fraction of gross weight that must be supplied as tail jet up or down force in hovering and the low forward speed portion of transition flight. No tail up or down force is shown to be required at wing angles-of-attack of 60 degrees or less. At this angle and lower angles and at the corresponding forward speeds of 60 MPH and more, the horizontal tail can generate enough pitching moment to trim the aircraft. The small magnitude of those required tail jet thrusts, based upon results, and consideration of the favorable shift of the aircraft center-of-gravity as the propeller-engine-wing assembly is tilted forward, is noteworthy. Only 2 percent of gross weight is required in up or down jet thrust to trim the machine. Actually, 1.5 percent is made available even with one of the three tail turbo-jet engines inoperative to provide a substantial margin to handle unusual conditions and provide generous power to insure adequately high pitching angular acceleration and thereby the achievement of prompt control response.

In hovering and low forward speed flight we have provided angular acceleration control powers of at least 12 degrees/second² about all three axes. The imposition of a transient power increase of 12 percent on one outboard nacelle and a power reduction of 12 percent on the opposite outboard nacelle will give rolling accelerations of this desired magnitude.

Figure 8 shows how the thrust of a turbo-prop can be made to rise from its idling to its take-off power value within half a second after its power control has been advanced to the "full throttle" position. With propeller pitch change rates of up to 20 degrees per second being made available in propellers designed for turbo-prop engine applications, it is evident that adequately rapid controlled variation of propeller thrust can be provided.
3. Mission Performance:

Standard - 100% Performance, Maximum Efficiency
Figure 1 illustrates the 100% performance line, which is based on the design specifications of the aircraft. Performance of the actual airplane may vary from the ideal performance due to various factors such as atmospheric conditions, load factors, and other operational constraints.

Figure 2 shows the performance of the airplane as a percentage of the ideal performance. It indicates the deviation from the ideal performance, expressed as a percentage of the actual performance.

Figure 3 illustrates the variation in performance as a function of load. A 27% increase in wing loading will result in a decrease of performance, as indicated in the figure. These results are compared to a conventional airplane in a similar mission profile.

SECTION IV - EVALUATION OF PROPELLER PLANE PERFORMANCE

Of the development programs, we will endeavor to determine the evaluation of the propeller plane. In effect, the development includes the full performance of all forms of airplane vehicles.

Finally, some of the recommendations and guidelines for the development of the propeller plane. The primary goal is to achieve a more efficient and effective solution to the problem of propeller plane performance. The development includes the evaluation of resources and costs.

Problems that will be encountered are as follows:

a) Propeller Development
b) Propeller-Airplane Control

c) Turbine Development
d) Auxiliary Control Systems and Controls
e) Vertical Lift Control
f) System Design
g) Precipitation
h) Cargo Handling Methods
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In addition to the usual devices for controlling single-propeller power plants, the Propellerplane requires means for varying the propeller blade pitch setting differentially in the nacelles on opposite sides of the aircraft to produce rolling control in response to motions of the pilot's control wheel during hovering and slow-speed flight with the wing vertical. This could be accomplished by varying the power setting of the engines. The propeller's constant speed pitch control system would correspondingly alter the blade pitch, affecting a change in thrust. Changes in power of about ±12 percent of normal rated power appear adequate to produce satisfactory rolling moment.
A key control problem is foreseen in the development of automatic devices for maintaining safe control following failure of a vital section under the most critical hovering conditions. For example, one outboard engine section failed while the aircraft was hovering at 6000 feet altitude and 90° F., power should be reduced in the opposite outboard nacelle and the remaining operative engines immediately advanced to military power. Normal pilot reaction, assuming that he is initially unaware of the emergency, would be to apply roll control to maintain level attitude and increase the power lever settings to maintain altitude. However, the normal range of roll control travel will normally provide about a 17 percent change in power settings, which corresponds roughly to the percentage by which military power exceeds normal rated power. Thus, application of full roll control will not be sufficient to trim the aircraft and automatic means of compensation for this situation and simultaneously stimulating the pilot that an emergency exists should be developed. The feasibility of designing such an interconnecting shafts may be contingent upon successful development of such a device. Effort in this direction is strongly recommended.

c) Turbine Development:

In propeller-driven VTOL aircraft propeller efficiency in forward flight is compromised by the essentially constant speed operation of the turbines, in order to maintain reasonable thermal efficiency. The optimum propeller for the cruising condition of a Propelliplane Transport would be about 15 feet in diameter. The larger diameter required for satisfactory static thrust in hovering results in reduced propulsive efficiency in cruising, if the same tip speed is maintained. If the tip speed is reduced 25 percent, the propulsive efficiency can be increased to about 90 percent. In this study propeller tip speed was considered a constant 300 feet per second, which was found to be the optimum compromise value for this mission. The development of twin-spool turbines which permit a wider variation in propeller operating speed without penalizing the turbine efficiency, would improve Propelliplane performance appreciably. This improvement must be weighed against the increased weight, cost, and maintenance associated with the more complicated free turbine engine.
c) Auxiliary Control Surfaces and Flapless:

A decision specific to a small size of a Propellor Transport that is not found on conventional large aircraft. The first is provided for uninterupted flow of fuel from the wing tanks to the engines through the range of altitudes. (If the tanks are located in the fuselage, it is permissible between the fuselage and wing tanks to be needed.) The second problem may exist due to the extremities in rate of climb of a Propellor Transport and resulting possibility of fuel boiling, unless a pressurized or refrigerated fuel system is specified.

c) Cabin Pressurization:

The decision whether to pressurize the cabin of a Propellor Transport is a problem in operational analysis rather than a development problem. As stated earlier, our study was limited by lack of information and time to make a thorough research into the effects of altitude and cruise speed on the optimum design, but it was clearly indicated that operation...
Propellorplane Transport Study

I) New Methods

At lower altitudes vortex performance improves steadily and propeller efficiency is greater as the altitude decreases. The increased exhausts flow due to the engagement of free turbulence is of other means (including supersonic transpiration) of lowering the propeller speed in cruise. On the other hand, if altitude is unrestricted, pressurizing the cabin and operating at altitudes where propeller performance at constant speed improves, can be the simplest way of compensating the different requirements of the static thrust in hovering and rated flight speed performance.

1) Dust and Noise Abatement:

This problem must be approached in all its many loading, vertical lift, aircraft, and so precise a well, in each structure, can be given at this time. It is incumbent upon the military air and naval stratists which understand the military advantage to be gained from the use of vehicles conforming true air mobility to certain elements to settle plans and tactics suited to the shortcomings as well as the outstanding qualities of their weapons. For example, since operations or infrequent operations from grass-covered sites would probably be entirely satisfactory with Propellorplanes because of the low ground heat from the gas turbine exhausts and their relatively short duration, while surfaces of loose sand or dry bare soil might be less suitable, primarily due to erosion rather than mechanical difficulties. It is conceivable that light weight, air transportable fabric, plywood or metal landing mats, similar to the steel-pierded lack of World War II air strips, would be adequate to prevent dust storms. Only small areas would be needed, which could be rapidly staked in place.

Of the several VTOL concepts only the helicopter or tilt-rotor convertiplane have lower disk loadings than the Propellorplane so that it appears that the problem of dust and noise control will be further alleviated by other types capable of this mission.

1) Modern Cargo Handling Methods:

Military sponsored studies of methods of handling cargo currently in progress show that remarkable gains in transport capacity are attainable by using engineered, integrated cargo handling systems. The spectacular performance of the Propellorplane Transport would be improved more by modern method of loading and unloading cargo because of the lower block-to-block time. This item is cited merely to call attention to the work that is being done in this field and to suggest that it is appropriate to consider its implications at the earliest stages of planning for future cargo aircraft.
CONCLUSION

The results of the study requested by the Helicopters Division of the Transportation Corps under Contract Nonr 105" (00) with the Office of Naval Research substantiate these conclusions:

1. The concept of tilting-rotor/propeller-tiltrotor transport aircraft is intrinsically feasible technically.

2. The design and construction of a Propelloplane capable of performing the specified mission is feasible, being entirely within that class that are scheduled for production in 1961.

3. Design and construction of a Propelloplane capable of performing a slightly reduced mission, using engine problems for production in 1962, if possible, is technologically within reach.

4. The development problems involved in the design and construction of a Propelloplane are numerous but within the range of our present technology.
APPENDIX - BIBLIOGRAPHY AND REFERENCES

Literature surveys, collections, and developing analytical methods for handling the problems of the Hiller wind tunnel were essential to the aircraft. This report constitutes a greater part of the work of this study. Correspondence and conferences with the officers of the various manufacturers and with personnel of the National Advisory Committee for Aeronautics, Ames, and Langley Laboratory were held frequently throughout the course of the study. Specific mention must be made of the assistance rendered by the Propeller Division, Turbine-Propeller Corporation, developing an empirical method of estimating the weights of propellers. The information received from Mr. Charles Hurstman of the Langley Aeronautical Laboratory in regard to the use of articulated propellers was also helpful.

The details of the sources of information and analytical methods used in this study are contained in Hiller Helicopters Engineering Reports submitted with the Progress Reports and with this report.

The following bibliography lists the Hiller Engineering Reports that form a part of the work submitted under Contract No. 1657 (G) and other references consulted in the course of this study.

A. Hiller Helicopters Engineering Reports Submitted as Part of Contract No. 1657 (G):

<table>
<thead>
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<th>Title</th>
<th>Submitted</th>
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</table>


9. Curtiss-Wright Corporation, Propeller Division, Unpublished Memo:
   (a) "Estimating Formula for Basic Propeller Weight", January 17, 1957.
   (b) "An Approximate Propeller Weight-Strength Formula", October 27, 1955.
   (c) "An Approximate Propeller Weight-Aq Relationship", November 11, 1955.
   (d) "A More Accurate Propeller Weight Formula Based on the Aq Factor", December 1, 1955.


ENGINE AND NACELLES

EIGHT ENGINES - FOUR NACELLES
NO INTERCONNECTING SHAFTS

FOUR ENGINES - FOUR NACELLES
INTERCONNECTING SHAFTS

FOUR ENGINES - TWO NACELLES
INTERCONNECTING SHAFTS

FOUR ENGINES - TWO NACELLES
ENGINES GROUPED IN FUSELAGE

AUXILIARY CONTROL

TAIL JET
AUXILLIARY TURBOJET ENGINES

TAIL ROTOR
AUXILLIARY TURBOPROP ENGINE

TAIL JET
MAIN ENGINE AIR BLEED

TAIL ROTOR
MAIN ENGINE DRIVEN
MODEL 1048D
PERFORMANCE

PAYLOAD
8000 lbs.

CRUISE SPEED
300 mph

RADIUS OF ACTION
425 nautical mi.
310 nautical mi.

SPECIFICATION
MODEL 1048D

COMPARATIVE WEIGHTS

GROSS WT.
EMPTY WT.

1048A (1965)
71250
50200

1048B (1960)
101000
70935

1048D (1958)
83600
59820

FIRST LANDING
65650
91050
76000

2nd TAKE OFF
61650
85600
71000

FIG 2

FIG 3
CONFIDENTIAL

MODEL 1048A
PERCENTAGE WEIGHTS

USEFUL LOAD
29.80%

POWER PLANT
30.63%

FURNISHINGS & EQUIPMENT
4.27%

AIRFRAME & CONTROLS
35.30%

FIG. 4

MODEL 1048A
FORWARD SPEED VERSUS WING TILT ANGLE

FIG. 5

CONFIDENTIAL
MODEL 1048A
POWER REQUIRED VERSUS WING TILT ANGLE

THRUSt
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
SHAFT H.P.

90 80 70 60 50 40 30 20 10 0
WING TILT ANGLE

FIG. 6

MODEL 1048A
TAIL JET FORCE REQUIRED FOR TRIM AS A FUNCTION OF WING TILT ANGLE AND C.G. POSITION

TAIL JET FORCE AVAILABLE -
ONE JET ENGINE OUT

\[ \frac{L_j}{W} \]
0
-0.05
-0.04
-0.03
-0.02
-0.01
0.01
0.02
0.03
0.04
0.05

 aft C.G.
 fvd. C.G.

90° 80° 70° 60° 50°
WING ANGLE - DEGREES

FIG. 7
TYPICAL TURBINE TRANSIENTS FROM TEST RECORDS

POWER LEVER

TO

FI

BLADE ANGLE

TO

FI

TIME-SECONDS

0 1 2 3 4 5 6 7

FIG. 8

MODEL 1048A
MISSION PROFILE

STARTING POINT

25000 FT

10 MIN

1 MIN

161 MI.

4.8 MIN

26.6 MI.

428 STAT MI - 802 MIN

PAYLOAD:
OUTBOUND 8000LBS
RETURN 4000LBS.

FIG. 9
CONFIDENTIAL

MODEL 1048 A
PAYLOAD-RANGE PERFORMANCE

VERT TAKE-OFF MISSION - BOTH ENDS
RUNNING TAKE-OFF, VERTICAL TAKE-OFF @ OUTBOUND BASE

ALL MISSIONS UNLOAD 2 TON PAYLOAD @ OUTBOUND BASE, LAST 85 STATUTE MILES ADJACENT TO OUTBOUND BASE ARE FLOWN AT SEA LEVEL, CRUISE ALL ALTITUDES AT 300 MPH - 4 ENGINES

RETURN PAYLOAD - TONS
OUTBOUND PAYLOAD - TONS

RADIUS OF ACTION

FIG. 10
CONFIDENTIAL

MODEL 1048 A
HOVER TIME VS RADIUS – SEA LEVEL, STD.

![Graph showing hover time vs. radius at sea level.](image1)

MODEL 1048 A
TAKE-OFF DISTANCE VS GROSS WEIGHT

![Graph showing take-off distance vs. gross weight.](image2)
<table>
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<th>Item</th>
<th>Description</th>
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<td>27.</td>
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<td>28.</td>
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<td>Anti-Icing - Propeller (1)</td>
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<td>35.</td>
<td>Anti-Icing - Other</td>
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<td>36.</td>
<td>Weight Empty</td>
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<td>37.</td>
<td>Useful Load</td>
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<td>38.</td>
<td>Crew (3)</td>
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<td>39.</td>
<td>Fuel - Mission</td>
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<td>40.</td>
<td>Fuel - Control</td>
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<td>41.</td>
<td>Oil</td>
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<td>42.</td>
<td>Troops and/or Cargo</td>
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<td>43.</td>
<td>Design Gross Weight</td>
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<td>44.</td>
<td>Fuel - Overload</td>
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<td>45.</td>
<td>Water - Water Injection</td>
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<tr>
<td>46.</td>
<td>Take-Off Gross Weight</td>
</tr>
</tbody>
</table>

* Engine installations include air induction systems, exhaust systems, cooling systems, lubricating systems, engine controls, and starting systems.

**Accommodations for personnel includes: 3 crew seats & safety harnesses = 150 lbs.;
35 infantry men seats = 350 lbs.; toilet & washing facilities = 200 lbs.; and
oxygen installation (including charge) for 36 men for 3 hours duration = 485 lbs.
## Model

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Model</th>
<th>100'A</th>
<th>100'B</th>
<th>100' C</th>
<th>100'D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (Overall)</td>
<td>51' - 9&quot;</td>
<td>30' - 3&quot;</td>
<td>31' - 7&quot;</td>
<td>32' - 10&quot;</td>
<td></td>
</tr>
<tr>
<td>Width (Outside of Propellers)</td>
<td>9' - 1 1/2&quot;</td>
<td>6' - 3 1/4&quot;</td>
<td>6' - 3 1/4&quot;</td>
<td>6' - 3 1/4&quot;</td>
<td></td>
</tr>
<tr>
<td>Height (To Top of Vertical Fin)</td>
<td>35' - 10&quot;</td>
<td>35' - 10&quot;</td>
<td>35' - 10&quot;</td>
<td>35' - 10&quot;</td>
<td></td>
</tr>
</tbody>
</table>

### Weights and Loadings

| Empty Weight, Lbs. | 70200 | 70200 | 70200 | 70200 |
| Parked, Lbs. | 70200 | 70200 | 70200 | 70200 |
| Main Fuel, Lbs. | 13730 | 13730 | 13730 | 13730 |
| Auxiliary Control Fuel, Lbs. | 720 | 720 | 720 | 720 |
| Oil, Lbs. | 370 | 370 | 370 | 370 |
| Water-Alcohol, Lbs. | 0 | 0 | 0 | 0 |
| Overload Fuel, Lbs. | 870 | 870 | 870 | 870 |
| Take-Off Gross Weight, Lbs. | 71970 | 71970 | 71970 | 71970 |

### Wing

| Span (Between Centerlines of Outboard Nacelles) | 71' - 10" | 71' - 10" | 71' - 10" | 71' - 10" |
| Area, Square Feet | 722 | 722 | 722 | 722 |
| Aspect Ratio | 4.5 | 4.5 | 4.5 | 4.5 |
| Taper Ratio | 2:1 | 2:1 | 2:1 | 2:1 |
| Airfoil | M.A.C. | 10' - 10" | 10' - 10" | 10' - 10" |

### Tail

| Vertical Tail Area, Square Feet | 231 | 231 | 231 | 231 |
| Horizontal Tail Area, Square Feet | 232 | 232 | 232 | 232 |

### Propellers

| Diameter | 19' - 7" | 21' - 6" | 19' - 7" | 19' - 7" |
| Number of Blades | 6 | 6 | 6 | 6 |
| Activity Factor | 135 | 135 | 135 | 135 |
| Tip Speed | 900 | 900 | 900 | 900 |
| Disk Loading | 63.4 | 63.4 | 63.4 | 63.4 |
| RPM | 926 | 926 | 926 | 926 |

### Landing Gear

| Wheel Base | 2'11" - 3" | 2'11" - 3" | 2'11" - 3" | 2'11" - 3" |
| Track | 17' - 7" | 17' - 7" | 17' - 7" | 17' - 7" |
| Tires, Main, 6, Type VII | 32 x 8.6 | 32 x 8.6 | 32 x 8.6 | 32 x 8.6 |
| Nose, 2, Type VII | 29 x 7.7 | 29 x 7.7 | 29 x 7.7 | 29 x 7.7 |
| Contact Area, Square Inches | 29146 | 3630 | 29146 | 29146 |
| Skids Lowered | 29146 | 3630 | 29146 | 29146 |
| Skids Raised | 971 | 1360 | 971 | 971 |

### Auxiliary Control Turbo-Jets

| Model | "1965" | 1X2273 | 1X2273 |
| Normal Rated Thrust, Lbs. | 2200 | 2450 | 2160 |
## TABLE III
PERFORMANCE DATA

<table>
<thead>
<tr>
<th>Model</th>
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<tbody>
<tr>
<td>Engines - 4 Each</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Normal Rated Power @ Sea Level</td>
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<tr>
<td>Military Power @ Sea Level</td>
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<tr>
<td>Speed, Miles Per Hour</td>
<td></td>
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<tr>
<td>Stall, Sea Level, Standard Rate</td>
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<tr>
<td>Cruise, Sea Level</td>
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<tr>
<td>Cruise, 5,000 Feet</td>
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<tr>
<td>Maximum, Sea Level (1/4 M.P.)</td>
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<tr>
<td>Maximum, 25000 Feet (LOP)</td>
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<tr>
<td>Rate of Climb, Feet Per Minute</td>
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<tr>
<td>5000 Feet, 1/4 M.P.</td>
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<tr>
<td>Maximum, 25000 Feet (LOP)</td>
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<tr>
<td>Vertical, Sea Level (LOP)</td>
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<tr>
<td>Vertical, 6000 Feet</td>
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<td>Ceiling, Feet</td>
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<tr>
<td>Hover, Standard Atmosphere, Maximum Power</td>
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<tr>
<td>Service, No Power</td>
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<td></td>
<td></td>
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<tr>
<td>Hover</td>
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<td></td>
<td></td>
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<tr>
<td>Maximum Power Required to Hover @ 6000 Feet, 95°F.</td>
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<td></td>
</tr>
<tr>
<td>Range, Miles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferry @ 25000 Feet, Cruise Altitude, 5% Overload &amp; 10% reserve</td>
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<td>Radius of Action for Specified Mission</td>
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* Calculated at Design Gross Weight of 12,000 Lbs.
** Calculated at Take-Off Gross Weight.
• Water-Alcohol Injection Use.
SIDE VALVES IN POSITION FOR MAXIMUM
FORWARD PITCHING MOMENT
(YAW CONTROLS ARE SIMILAR TO PITCH CONTROLS)