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CL-84 TILT WING APPLICATIONS

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ABSTRACT

A review of tilt wing characteristics and flight test experience with the Canadair CL-84 prototype is presented. Included are results on handling qualities, performance, vibration, noise and downwash characteristics.

The paper presents results of design studies on three tilt wing variants based on the prototype configuration. These are; a multi-mission variant for light military roles such as utility transport, close support, and search and rescue; a higher performance close support aircraft; and a short haul commercial transport.

Alternate tilt wing design configurations providing higher wing loading for cruise and cyclic pitch control for hovering and transition are discussed. The effect of advanced technology in the propeller, engine and structures field on the tilt wing transport payload is assessed.

FIG. 1 CL-84 PROTOTYPE IN HOVERING FLIGHT

INTRODUCTION

The CL-84 tilt wing V/STOL prototype was developed by Canadair as a shared cost program with the Department of Industry of the Canadian Government. The contract was awarded in August 1963 and the first flight took place in May 1965. Fig. 1 shows the prototype in hovering flight and a description of the aircraft and its development history is given in Ref. 1. The prototype was lost in an accident on September 12, 1967 which was attributed to an uncontrollable yawing moment that developed in conventional flights at 130 knots due to a malfunction in the control system to the propellers. The pilot and test observer ejected successfully.

In February 1968 an order was received from the Canadian Government for three follow-on CL-84-1 aircraft for military evaluation by the Canadian Armed Forces. These aircraft are similar to the prototype but incorporate many detail improvements and have added operational capability. The first aircraft will be on test status early next year, and all three will be engaged in military evaluation by the latter half of 1970. This will encompass roles such as utility transport, helicopter escort, close support, reconnaissance, search and rescue and anti-submarine warfare.

TILT WING CHARACTERISTICS

The tilt wing V/STOL aircraft obtains vertical lift from rigid "airplane" type propellers mounted on the wing which tilts from a vertical attitude for hovering to a horizontal attitude for cruise. The same propellers then provide the propulsion. Several configurations have been used for tilt wing aircraft, namely: the two propeller single wing type characterized by the Hiller X-18, the Vertol VZ-2 and the Canadair CL-84; the four propeller single wing type characterized by the LTV, XC-142A; and the four propeller tandem wing VC-400 being developed in Germany by VFW.

The propeller disc loading for this class of aircraft can vary between approximately 20 to 80 pounds per square foot. This places it in a range between the helicopter on one hand and the fan or jet lift types on the other hand, and indicates an operationally more flexible vehicle

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well suited for applications where range, endurance, high speed and a moderate amount of hovering are required.

In hovering flight the moderate disc loading of the tilt wing contributes to operational characteristics such as good hovering efficiency, downwash low enough for operation from unprepared surfaces, low noise levels and no exhaust temperature problems.

In flight at intermediate tilt angles, between hovering and cruise, the tilt wing benefits from the powerful lift augmentation on the wing at low speed produced by the propeller slipstream. This brings about a rapid reduction with speed in power required to sustain level flight as illustrated in Fig. 4. The large excess power is thus available to enhance low speed performance such as short take-off, acceleration, rate of climb and turning capability. On the other hand the ability to readily tilt the resultant of the thrust and lift vectors aft enables high deceleration and rates of descent to be achieved at low speed. The rapid reduction in power with speed also results in good fuel economy for loiter and shrinks the "Dead Man's Curve". The latter is important because, unlike the helicopter, the tilt wing has no autorotative capability.

In cruise or high speed flight, with the wing locked down, the tilt wing exhibits the same general characteristics as conventional turbo prop aircraft with respect to propulsive efficiency, lift/drag ratio and handling qualities. Good cruise performance over a wide range of speed and altitude is obtained by using the combination of a propeller for thrust and a wing for lift. The compromises in propeller efficiency and lift/drag ratio for most applications can be surprisingly small in a well designed tilt wing aircraft.

Unlike stowed rotor or other convertiplane concepts, the tilt wing makes use of the same main components for vertical lift in hovering and propulsion in cruise. This avoids the weight, cost and complexity of providing separate systems, and for transferring the power from one system for hovering to another for cruise. The pilot's work load is also less with the tilt wing as he does not have to concern himself with changing over from one system to another during a critical phase of the flight. The transition from one mode of flight to the other is smooth, continuous and rapid without abrupt changes in flight characteristics.

The ability to tilt the lifting system independently of the rest of the aircraft allows the pilot to maintain the fuselage level during short take-offs, climbs, low speed flight, descents and short landing. This is particularly important in short take-offs, where the full performance potential of some deflected slipstream aircraft could not be utilized because of pilot disorientation at the high nose-up angles.

PROTYTYPE FLIGHT TESTS

The CL-84 prototype flight tests extended over a period of more than two years with 305 flights totaling 145 hours. In addition to the two Canadair test pilots, fourteen other pilots representing the Canadian Armed Forces, Royal Air Force, US Airforce, Army and Navy, NASA and the NAE flew the aircraft and commented on its characteristics. The following summarizes the handling qualities, performance and other characteristics which are relevant to the variants and missions discussed in this paper.

Handling Qualities

Hovering Flight. For vertical take-offs the aircraft was headed into wind with wing tilt adjusted to maintain position. The lift-off was smooth and positive with little control activity required to maintain a level attitude and position over the ground. Vertical landings were accomplished by reducing power from stabilized hover out of ground effect and allowing the aircraft to descend until the positive ground effect at about 2 to 5 feet wheel height arrested the descent. Setting the aircraft smoothly on the ground from that point required a little pilot familiarization because of random disturbances in ground effect, but the technique was easily mastered.

Longitudinal control response and sensitivity by the tail propeller were rated good with the Stability Augmentation System (SAS) on. With the "attitude hold" mode of the pitch SAS disengaged the response was better, but with all pitch SAS off there was a tendency for pitch divergence which increased the pilot's work load. For forward and aft translation the pilots preferred to use wing tilt while holding the fuselage level. This was smoother, easier and more natural than tilting the whole aircraft.

Lateral control power by means of differential pitch on the main propellers was satisfactory, but most pilots felt that increased sensitivity with the SAS on would be more desirable. This is being provided in the follow-on aircraft. With roll SAS off the control response improved, but oscillations were present which increased the pilot effort. Lateral translations, with speed controlled by bank angle, were easy to accomplish.

Directional control by means of the flap-ailerons in the propeller slipstream was judged marginal by most pilots with yaw SAS on, particularly when turning the aircraft out of wind. With the yaw SAS off directional control was satisfactory and most pilots preferred to operate the aircraft in this way.

The flight testing indicated that a means of attenuating the SAS signal so that it does not oppose pilot input would be desirable about all axes. As an interim measure a dual mode system, which allows the pilot to select either a maneuvering or stabilized flight mode, is being provided in the follow-on aircraft.

Height control by means of the conventional airplane type power lever was easily mastered, even by helicopter pilots. The height control system provided good response and sensitivity although height damping may be desirable for IFR operations. A thrust-to-weight ratio of 1.02 was adequate for take-off, 1.05 for all normal hovering maneuvers and 1.07 for landing under the conditions tested.

The vertical take-off, landing and hovering characteristics were evaluated in winds up to 40 mph. The pilot's work load incrased with increasing gustiness, but no particular problems were encountered.

Transition Flight. The conversion from hover to cruise flight, up to the maximum rate, was smooth and easily accomplished. No significant trim changes were apparent as a result of the programmed flap, horizontal tail and tail propeller blade angle with wing tilt. The reconversion from cruise to hover was also easy if performed at moderate rates of deceleration, but became more difficult at the maximum rates. This was to a large part due to hardware deficiencies in the wing tilt system, and thrust control system at the low power levels. Modifications to these systems in the follow-on aircraft are expected to result in improvements in this area.

Flight at intermediate tilt angles presented no difficulty. Desired speed was trimmed by means of wing tilt rather than stick position, with the latter being used to maintain fuselage level. Fig. 2 shows trimmed wing tilt angle versus speed, and also indicates the excellent agreement between estimates and flight test data. Control response and sensitivity about all axes were generally rated as good, and maneuvers, including tight turns up to 2g load factor, were performed. Some improvement in attitude stability at the lower wing tilt angles may be required for IFR operation.

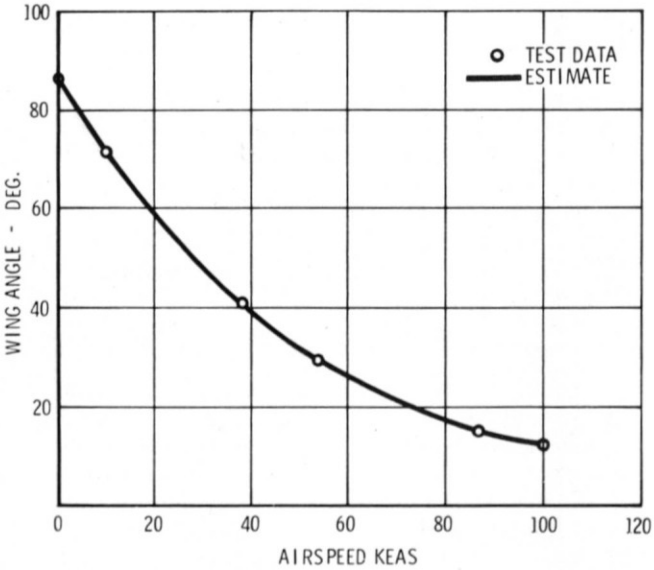

FIG. 2 TRIMMED WING ANGLE VS SPEED - PROTOTYPE

The triple fin configuration provided positive directional stability at all wing angles, and the lateral-directional characteristics met the proposed AGARD requirements. Control cross-coupling was small as a result of the control system programming. The dynamic stability about all axes with SAS on was satisfactory, with the motions following a control pulse either deadbeat or damped out in little over one cycle.

As in hovering flight initial control response was better with SAS off but the instabilities present, particularly in pitch, increased the pilot's work load.

Short Take-Off and Landing. Short take-offs and landings were performed at all wing tilt angles between 15 and 90 degrees. The technique for take-off was to hold the fuselage approximately level during the ground roll and climb-out. All pilots found this a natural and comfortable procedure which was easy to perform. Similarly for landing the fuselage was held level during the approach at a descent angle of about 10 degrees and a stabilized rate of descent of about 700 feet per minute. Power was applied just prior to touchdown to reduce the rate of descent. There was a mild nose-down trim change in ground effect, but touchdown was firm and ground effect did not cause deterioration in handling qualities at any tilt angle.

The boundary for buffet onset during descents was investigated and the results are shown in Fig. 3. Buffet was mild, there was no handling qualities problem and recovery was immediate on application of power. Although this boundary is generally satisfactory, it is less than estimated, and further wind tunnel testing is planned to improve on it.

Cruise Flight. The flight envelope up to 300 knots TAS and 2g load factor was explored. The maximum level flight speed attained was 265 knots TAS at 8000 feet and the maximum load factor was 3g at 188 knots.

Less attention was devoted to handling qualities in the cruise flight regime compared to the hovering and transition regimes. These were generally satisfactory, although there was a problem with insufficient elevator effectiveness at low speed, and most pilots reported weak directional stability at small sideslip angles. The main pilot complaints in cruise however were related to detail hardware deficiences of the prototype control system. These included

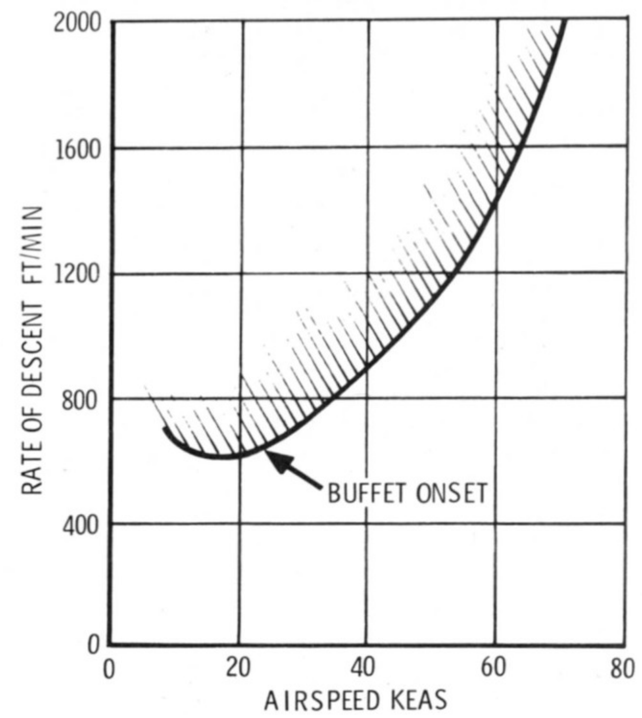

FIG. 3 RATE OF DESCENT VS SPEED - PROTOTYPE

lack of artificial feel, low trim rates combined with hysterisis and friction in the control system which made trimming the aircraft difficult, inadequate propeller governing, and small spurious control inputs due to backlash or deformations. Modifications to the control systems on the follow-on aircraft should eliminate these problems.

Performance

Power required for level flight was measured over the range of airspeed from hover to the maximum attained. Figure 4 shows flight test data for the hover and transition regime compared with estimates based on wind tunnel and model propeller tests. There was a deficiency at hover amounting to about 4% of thrust, which is apparently due to an adverse airframe-propeller interference, and model testing is underway in an attempt to resolve this. However the thrust-to-weight ratio initially assumed to meet AGARD requirements for thrust margin and control power was 1.07, which, as previously indicated, was found to be conservative by about 2% for hovering. The net thrust deficiency was therefore abount 2%, which is still significant as far as hovering payload is concerned. However experimental work on propeller static thrust at Canadair has evolved a new blade design that more than makes up this deficiency.

Above 40 knots the measured power required becomes equal to that estimated at the corresponding RPM, indicating somewhat better aerodynamic efficiency than predicted from the wind tunnel tests. Although flight tests to confirm the variation of power with speed at optimum propeller RPM were not completed, the existing test data confirms the estimated transition and STOL performance.

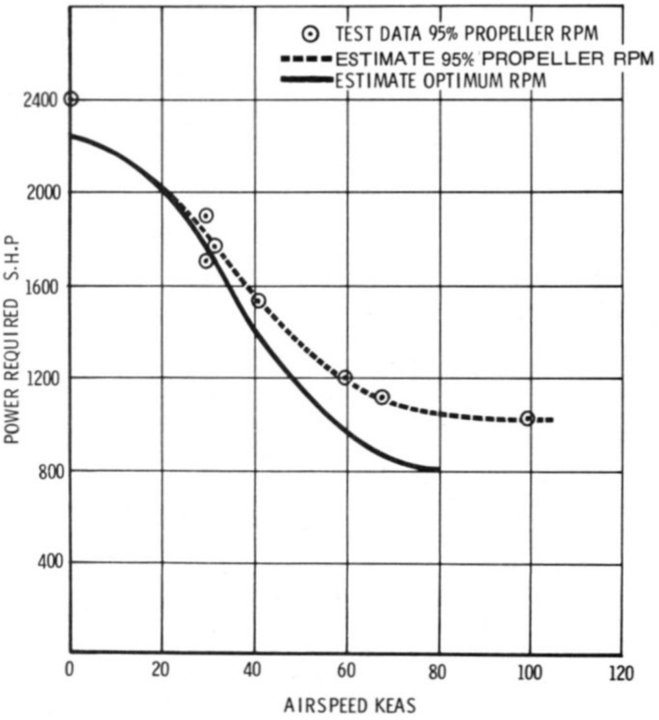

FIG. 4 POWER REQUIRED VS SPEED - PROTOTYPE

In cruise flight the aircraft drag was higher than estimated. This was due to the usual prototype problems such as gaps, leaks, protuberances and instrumentation. The sources of major drag increase have been identified and measures taken to eliminate them in the follow-on aircraft.

Vibration

The CL-84 prototype vibration levels were normally very low, particularly in cruise flight at reduced power and propeller speed, and pilot comment under these conditions was very favorable. There was an increase in vibration during hover and transition due to the higher power, but this was well within limits. However careful static and aerodynamic balancing of the propellers, using special procedures developed in the course of the test program, was necessary in order to achieve this, and relatively small unbalance produced large vibrations at the "once per propeller revolution" frequency.

No resonances were identified in the propellers or transmission system components over the full RPM range for all flight conditions, and no operating restrictions were necessary. Fig. 5 shows bands of vibration level versus RPM measured on the propeller and other gearboxes of the transmission system.

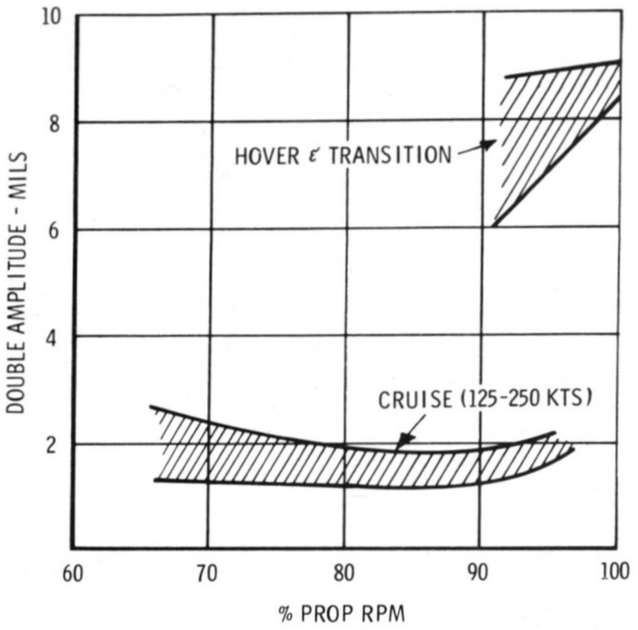

FIG. 5 GEAR BOX VIBRATION LEVELS - PROTOTYPE

A considerable amount of vibratory stress data was also collected on the main and tail propellers, gearboxes and attachment structure. Typical results are shown in Fig. 6, which indicates variation of propeller blade shank vibratory bending stress with airspeed and tilt angle for steady flight condition. The highest stress levels shown occur at very low speed during deceleration immediately prior to coming to a hover, and are probably due to some form of recirculation. However these are well within the design allowables and of about the same magnitude as extrapolated for the maximum design case in conventional flight.

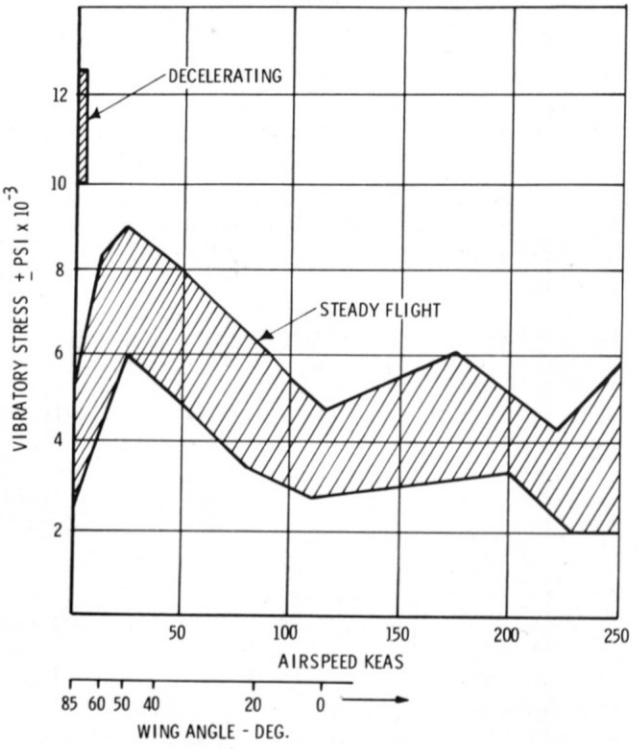

FIG. 6 PROPELLER BLADE SHANK VIBRATORY BENDING STRESSES - PROTOTYPE

Fatigue problems due to vibratory stresses were discovered in the tail propeller hub during the ground test phase, in the main propeller control unit late in the flight test program, and in the engine exhaust system. Except for the last item, these were satisfactorily corrected during the test program and the prototype propellers and transmission system components did not have any life limitations due to fatigue. A modification to overcome the enigine problem is being incorporated in the follow-on aircraft.

Noise

External noise measurements were taken with the aircraft hovering at a height of 50 feet, and the sound pressure levels are shown in Fig. 7. No external measurements were taken in cruise flight, but the aircraft impressed observers on the ground with its quietness.

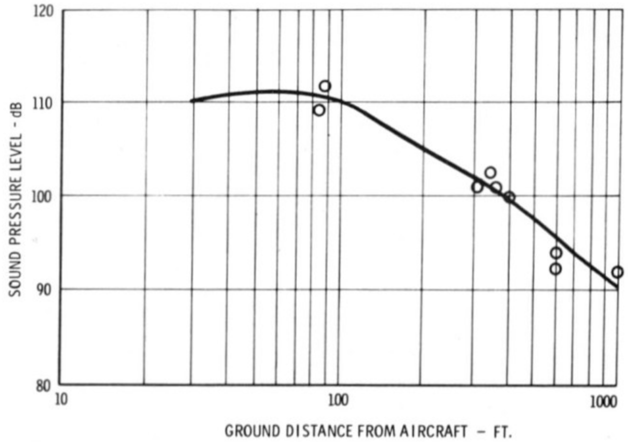

FIG. 7 EXTERNAL NOISE LEVELS IN HOVER - PROTOTYPE

Internal noise was also measured in hover, transition and cruise, and in only a few cases the limits for unprotected ears were exceeded slightly, even though no soundproofing was used on the prototype.

Downwash

Probably no other characteristic of V/STOL aircraft has aroused more controversy than the question of downwash. The limited operational suitability testing carried out with the prototype was directed primarily towards obtaining answers to these questions.

The prototype testing included simulated rescues with live subjects from land and water, and of a dummy through 60 foot trees. In addition the aircraft was hovered 20 feet above water and 5 feet above trees, and on many occasions in close proximity to unprotected personnel. No problems were encountered in any of the above operations. It should also be mentioned that both the LTV XC-142A tilt wing and the Ryan XV-5A fan-in-wing aircraft underwent more extensive testing of this nature and again, as far as is known, no serious problems were encountered. Downwash velocity measurements were also made with the CL-84 prototype and the data is given in Ref. 2.

It is difficult to make meaningful quantitative comparisons of downwash between different V/STOL concepts. A general observation based on several comparative tests on tilt wing aircraft and helicopters of equal gross weight is that, when close to the ground, the tilt wing generates a more concentrated, higher velocity region directly beneath the aircraft than does the helicopter, but at approximately a wing span or rotor diameter from the center there is very little noticeable difference between the two. Further away, the tilt wing produces less disturbance than the helicopter. It thus appears that different operational techniques will have to be developed for each type, but so far the evidence indicates that the tilt wing should be able to perform all missions presently carried out by the helicopter. Further, more extensive testing is required to develop the best techniques for each mission, and the forthcoming evaluations of the follow-on CL-84-1 aircraft by the Canadian Armed Forces will generate much useful data on this subject for a variety of operational roles and conditions.

OPERATIONAL VARIANTS

Variants of the CL-84 prototype have been investigated for a wide range of operational roles. Of these, three aircraft, representative of the complete spectrum have been selected as examples of the broad application of the tilt wing concept. Leading particulars of these aircraft, which will be described in this paper, are given in Table 1.

Variant A is a direct derivative of the prototype for a light utility, multi-mission role. Variant B is a larger, higher performance armed version for close air support of ground troops, and Variant C is a considerably larger aircraft for short-haul commercial transport. All these aircraft are similar in geometry and close to the prototype in wing loading and propeller disc loading. Their handling qualities and other flight characteristics should therefore also be similar.

Variant A

This version is a logical first stage growth of the evaluation aircraft presently under construction for the Canadian Armed Forces. It makes use of essentially the same systems and airframe but has uprated engines to increase the hot day power by about 25%. The engines are torque limited under standard conditions to avoid dynamic component development. The only significant external change is an increased cabin length to provide a volume of 280 cubic feet and room for 16 wall type troop seats.

The size, layout and performance of this aircraft appear ideally suited for a wide variety of light military roles, such as utility transport, close support, reconnaissance and search and rescue. This multi-mission capability with the same aircraft should greatly enhance its cost effectiveness, specially for a small self-contained mobile force.

TABLE I
TILT WING APPLICATIONS

VARIANT	A	B	C
Application	Multi-Mission Light Utility	Close Air Support	Commercial Transport
Design Gross Weight Lb.	13,200	22,000	52,600
Engines No.	2	2	4
Rated SHP	1,800	4,800	4,800
Hover Design Point	SL 95°F	6000 Ft. 95°F	SL 95°F
No. Engines Operating	2	2	3
Prop. Disc Loading Lb/Sq Ft	38	44	38
Wing Loading. Lb/Sq Ft	56	65	56
Operation Wt. Empty Lb	9,025	14,050	34,800
VTOL Payload Lb	2,575	4,000	13,600
Range NM	300	400	175
Cruise Speed Kts	250	370	350
Max Speed Kts	290	420	-
Wt. Empty/Gross Wt.	.69	.67	.66

Figure 8 shows typical interior arrangements for the above roles. In the transport role the most effective employment would be a short take-off at the base, wherever possible, to utilize the overload capability with a very short ground run. A vertical landing can be made at the destination after sufficient fuel is used up. In a mission of this nature 2000 pounds of cargo can be carried over a radius of 240 nautical miles.

In the air rescue role, the combination of high speed and hovering capability at the destination are of vital importance. On a typical rescue mission the aircraft can cruise out 225 nautical miles at 280 knots, pick up 4 men while hovering for 20 minutes and return to base.

For close air support and reconnaissance, emphasis would be on the ability to fly nap-of-the-earth, loiter economically and quietly at low speed and, where necessary, make use of the high dash speed for survivability. Ref. 2 describes the agility

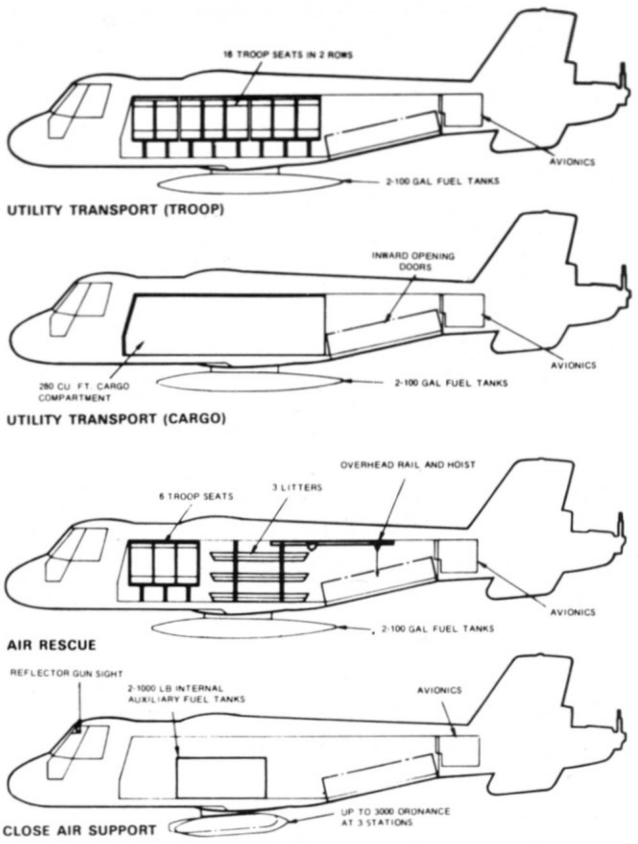

FIG. 8 MULTI MISSION LAYOUTS - VARIANT A

and other characteristics of this aircraft in the role of detecting and attacking small, well concealed targets in close support of ground troops. For a close support mission, the aircraft can cruise out 100 nautical miles, loiter on station for 2 hours, deliver 2000 pounds of ordnance and return to base.

Another important consideration, particularly in the reconnaissance role, is the aircrafts' detectability from the ground. Fig. 9 shows the estimated low noise levels at minimum power and propeller speed versus height above ground.

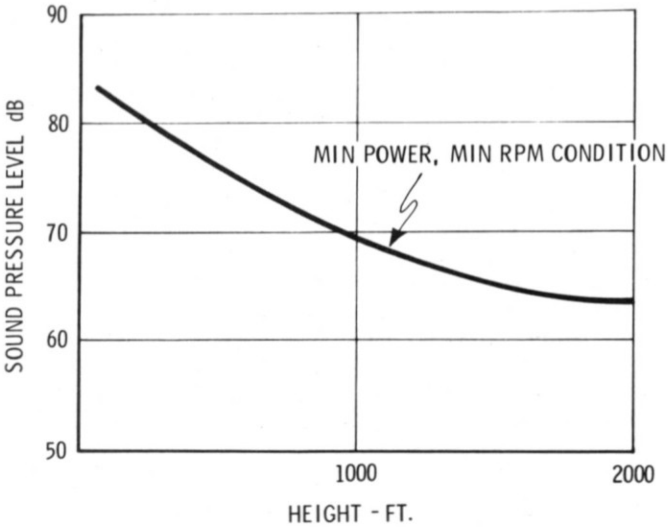

FIG. 9 ESTIMATED NOISE LEVELS ON GROUND - VARIANT A

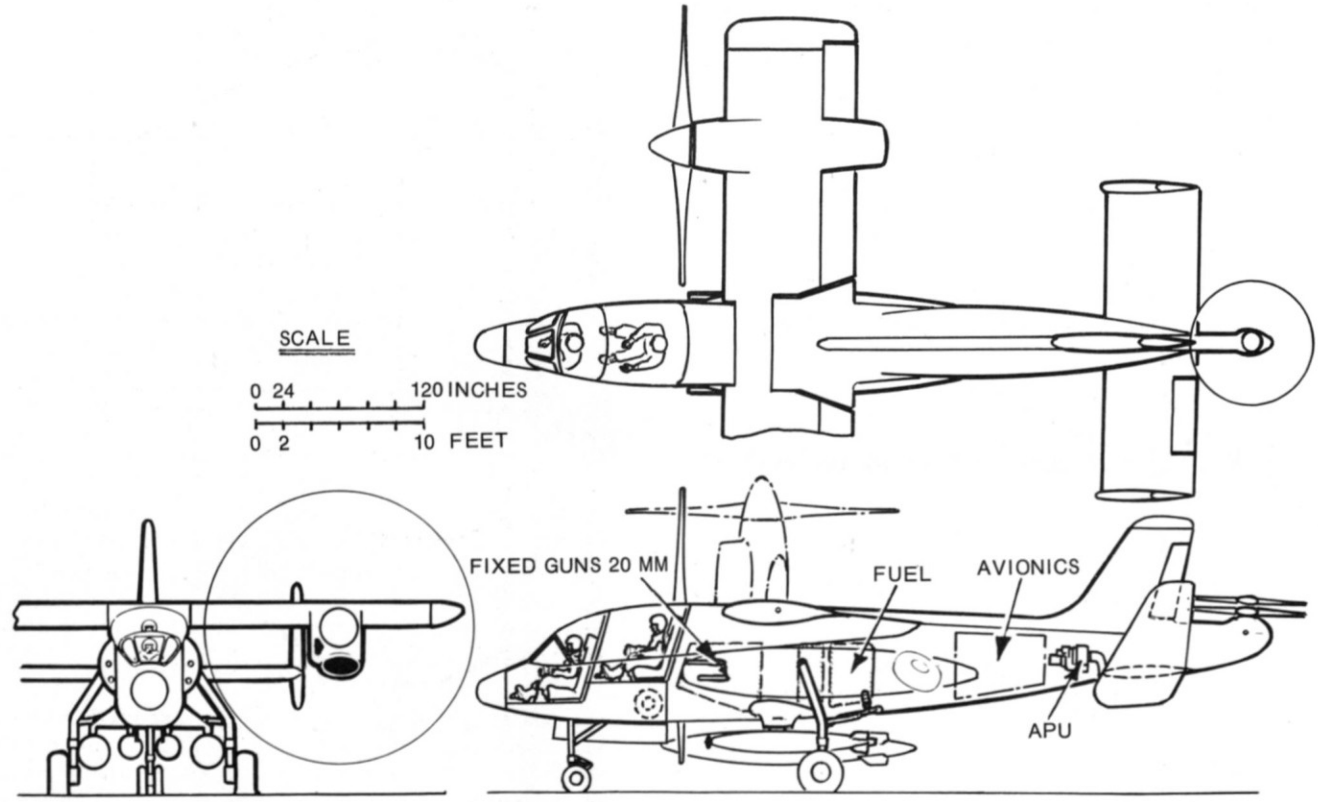

FIG. 10 CLOSE SUPPORT VARIANT

With the installation of fuel tanks in the fuselage, the aircraft becomes self deployable with a still air ferry range of 2300 nautical miles.

Variant B

Where a higher level of performance for the close support role than available with the previous version is required, the multi-mission concept involves more compromise, and a higher degree of specialization may be more cost effective.

Variant B, shown in Fig. 10, is typical of the more specialized types that have been studied. This aircraft is designed to hover under much more severe ambient conditions, carry a bigger payload, and have a considerably higher speed than the previous light close support version. It is powered by two growth General Electric T64 or Lycoming T-55 engines and accommodates a pilot and co-pilot/gunner seated in tandem in a minimum cross section fuselage. Full military equipment is carried, including armor, self-sealing fuel tanks, fixed 20 mm guns and external stores on a small stub-wing. The installation of flexible turret mounted weapons aimed by the co-pilot has also been investigated as a means of enhancing the effectiveness of the total system. In a typical mission the aircraft can cruise out 150 nautical miles at 350 knots, loiter for 2 hours, deliver 4000 pounds of ordnance and return to base. The maximum dash speed in the clean configuration is 420 knots.

Because of the requirement to hover at 6000 feet and 95°F the installed power is high, and therefore under more average conditions the maneuverability and agility in low speed flight are enhanced. Fig. 11 shows rate of climb and descent, Fig. 12 the sustained load factor that can be held in level turns versus speed, and Fig. 13 the acceleration and deceleration performance versus speed for standard conditions at the combat weight of 20,000 pounds. The above parameters can be illustrated in a more meaningful manner if one considers the problem of turning around in minimum time and distance after attacking a target, in order to deliver a second attack. The time and distance for this type of turn-around maneuver is shown in Fig. 14 versus initial speed. This data has been obtained by simulation and includes allowances for turn entry and pilot reactions.

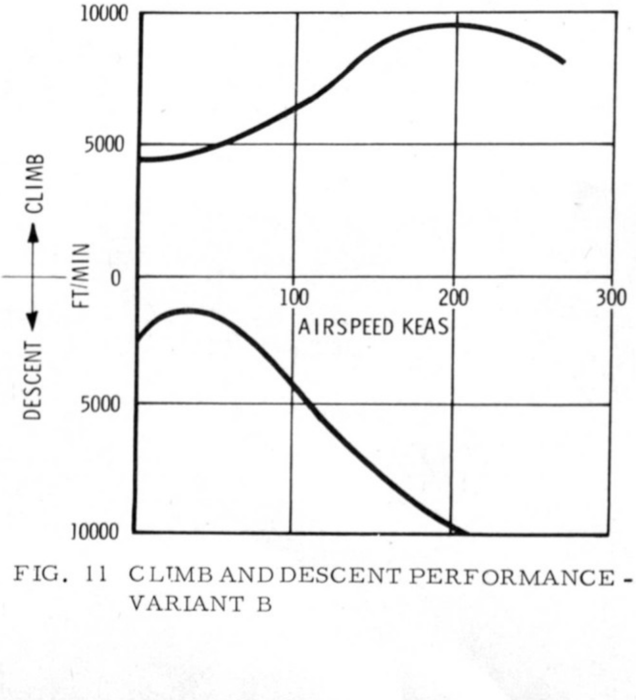

FIG. 11 CLIMB AND DESCENT PERFORMANCE - VARIANT B

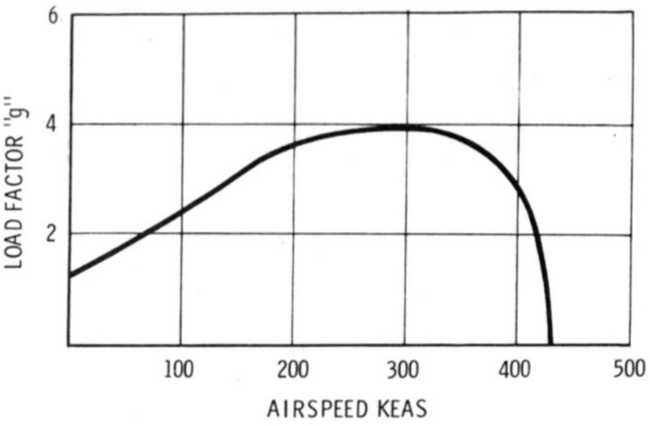

FIG. 12 SUSTAINED LOAD FACTOR - VARIANT B

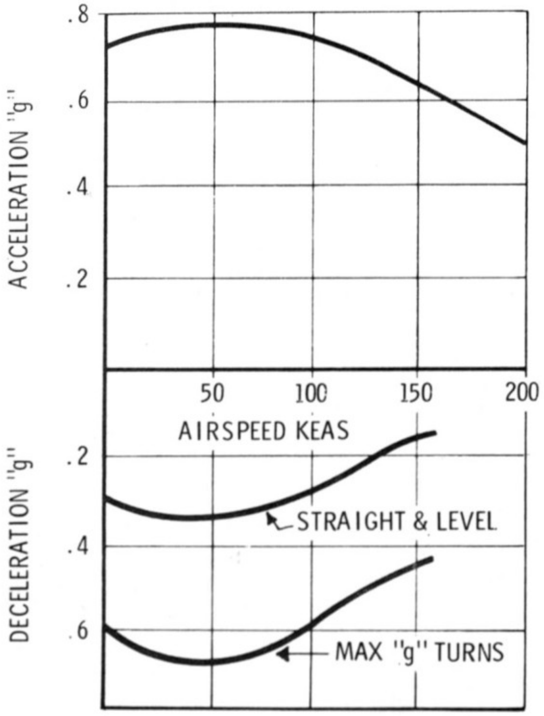

FIG. 13 ACCELERATION AND DECELERATION - VARIANT B

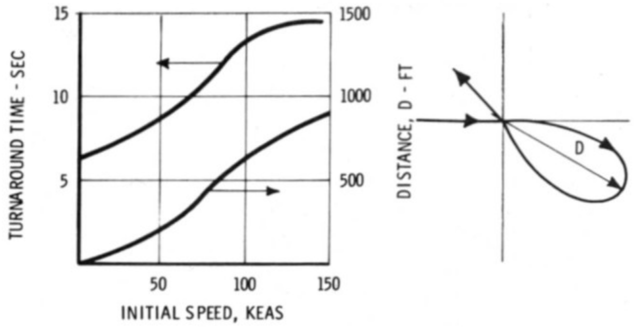

FIG. 14 TURNAROUND MANEUVER - VARIANT B

The unique agility described above, combined with a maximum speed of over 400 knots and the VTOL capability, introduces a new flexibility to air support in close proximity to ground troops, and invites a comparison of overall effectiveness with supersonic aircraft presently used for this purpose.

Search and rescue and utility transport variants based on the dynamic components of this aircraft have also been studied, and again these show important performance advantages over helicopters and fixed wing aircraft currently in use.

Variant C

In order to examine the tilt wing concept in larger size aircraft, a short haul inter-city V/STOL commercial passenger transport was selected as an example. This aircraft, shown in Fig. 15, is powered by four growth General Electric T64 or Lycoming T55 engines each rated at 4800 SHP, and carries 70 passengers in a pressurized cabin at the design range of 200 statute miles. It is designed for hover with three engines at the design gross weight of 52,600 pounds at an ambient temperature of 95°F at sea level. The aircraft is virtually

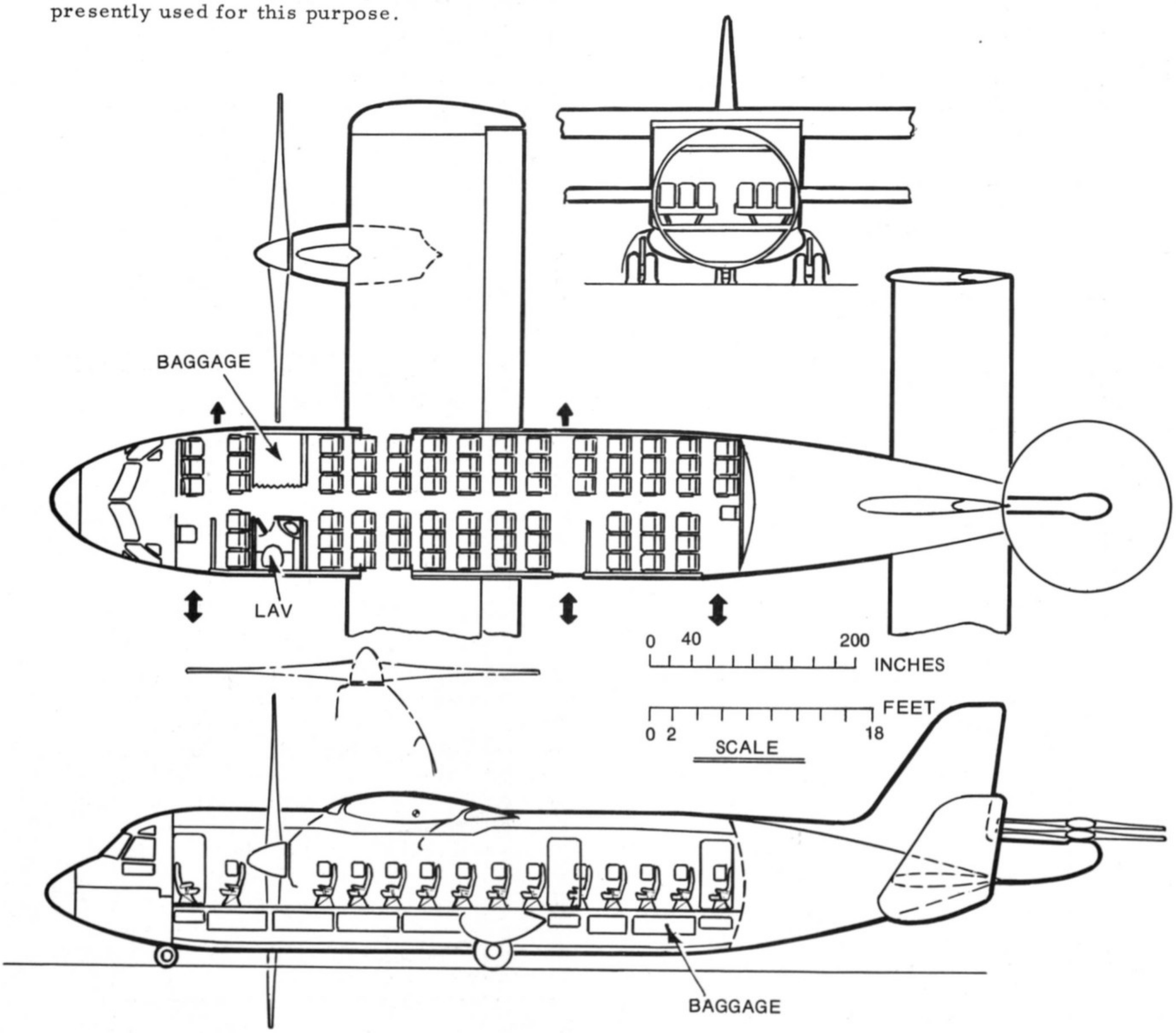

FIG. 15 COMMERCIAL TRANSPORT VARIANT

a scaled up version of the prototype with the same configuration, disc loading and wing loading. The aerodynamic development of the prototype is therefore directly applicable to this variant, in spite of its size.

The payload-range characteristics for this variant are given in Fig. 16 and the block times versus stage length in Fig. 17. The high acceleration, rate of climb, cruise speed and the steep descent angle contribute to low block times, even though current regulations in the United States which limit the speed to 250 knots EAS below 10,000 feet have been taken into consideration.

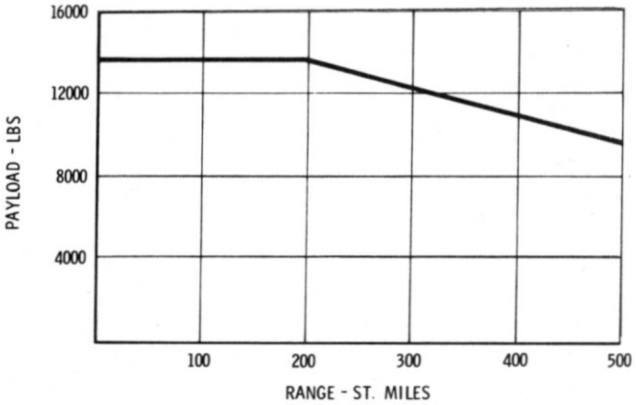

FIG. 16 PAYLOAD-RANGE - VARIANT C

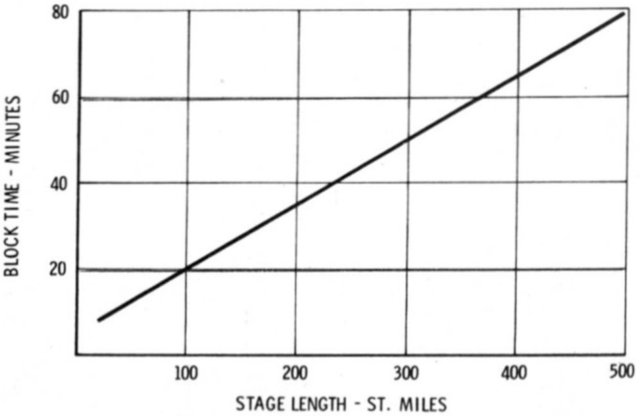

FIG. 17 BLOCK TIME VS STAGE LENGTH - VARIANT C

Of primary importance to an application of this nature is the safety aspect. The advantages of the very low approach speed and landing at zero speed are obvious, and should facilitate the development of blind landing systems. Although government airworthiness regulations for V/STOL aircraft are still being debated, the basic considerations assumed here, in addition to hovering with one engine out, are the ability to make a safe landing from cruise with one propeller feathered, or after complete loss of power.

Much concern has been expressed regarding safety problems with V/STOL aircraft because of their complexity, and indeed the record with prototypes has not been good. However the design requirements for propellers, drive trains and control systems to meet the necessary safety standards for aircraft of this type are now much more clearly identified, and work in this direction is proceeding.

Another very important consideration for civil V/STOL transports is public acceptance of the noise levels when operating from "Vertiports" located in city centers or other heavily populated areas. Fig. 18, shows estimated perceived noise level contours on the ground along the take-off path for the tilt wing aircraft. A vertical take-off, transition to 65 knots and climb at maximum rate was assumed. Other take-off profiles involving shorter exposure to somewhat higher noise levels are possible, but more information is required on criteria for public acceptance in this type of operation.

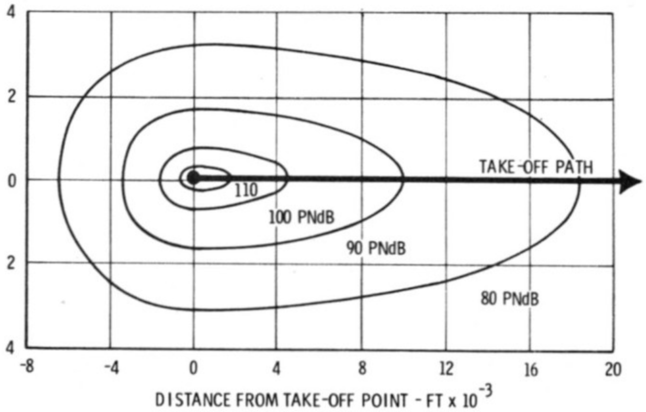

FIG. 18 NOISE LEVEL CONTOURS FOR TAKE-OFF - VARIANT C

The direct operating cost versus stage length for the aircraft described here is shown in Fig. 19. The method used for computing the cost follows that suggested in Ref. 3 for VTOL aircraft. Among other things, it takes into account the number of flight cycles and engine shutdowns, and is therefore more realistic for short-haul operations than present standard methods. It was assumed that the initial cost for the airframe is $4 million, the engines cost $400,000, and the annual utilization ia 2000 hours. The direct operating cost reaches a minimum of 1.85 cents per available seat statute mile at the design stage length of 200 statute miles. This is probably a good average stage length, however the operating costs are still attractive for distances as low as 50 miles and as high as 500 miles.

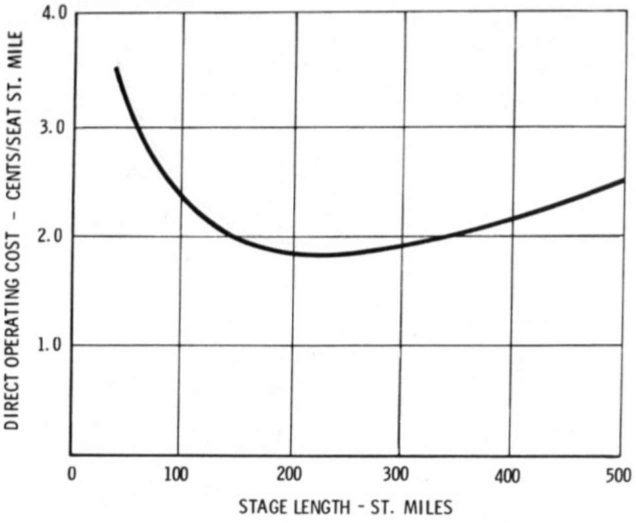

FIG. 19 DIRECT OPERATING COSTS - VARIANT C

The main competition for the tilt wing in short-haul passenger operation will be the advanced helicopter and the short range conventional jet transport. Studies have shown that the operating costs for the helicopter will be higher for stage lengths of more than about 25 miles, basically because of its lower cruise speed. On the other hand beyond stage lengths of about 500 miles the conventional jet transport becomes more economical and faster, even on an overall basis including ground transportation. Between these distances the tilt wing appears to be the most suitable aircraft. Its operating cost is about half that of advanced helicopters, and compared to conventional jet service, the tilt wing offers for the average traveller considerable overall saving in time and cost due to reduced ground transportation, without real sacrifice in block speeds. The heavy and growing concentration of people in the downtown city areas might provide a large potential market for a city-center to city-center service that will permit a traveller to leave his downtown office for a destination several hundred miles away, and return to this office the same day.

Many problems must still be overcome before a viable service of this type can become a reality, but it is believed that the combination of a high speed VTOL vehicle with advanced air traffic control, navigation and automatic flight control systems for operation under zero-zero conditions, could provide a solution to present day short haul transportation problems.

An aircraft of the type described here would also make a very effective V/STOL military transport. A new fuselage with rear loading, a more rugged, lower flotation landing gear and other changes of this nature would be required, but the dynamic components and other basic systems could be similar.

ALTERNATE CONFIGURATIONS

The CL-84 prototype, and the derivatives described in this paper, were designed on a conservative basis with respect to transition aerodynamics and control means. The wing area in the propeller slipstream is ample, and as a result sophisticated high lift systems were not required. A simple 10% chord leading edge Kruger flap and a 30% single slotted trailing edge flap were used.

For some applications a higher wing loading in cruise, than obtained by using the prototype wing - propeller proportions, may be advantageous from the drag and/or gust response aspects. This requires more elaborate flap systems than on the prototype in order to retain the same transition performance, and several such systems, as shown in Fig. 20 have been designed and tested in the wind tunnel. The weight, cost and complexity of these systems must be evaluated for each application, together with the advantages from the higher wing loading in cruise, in order to select the best combination.

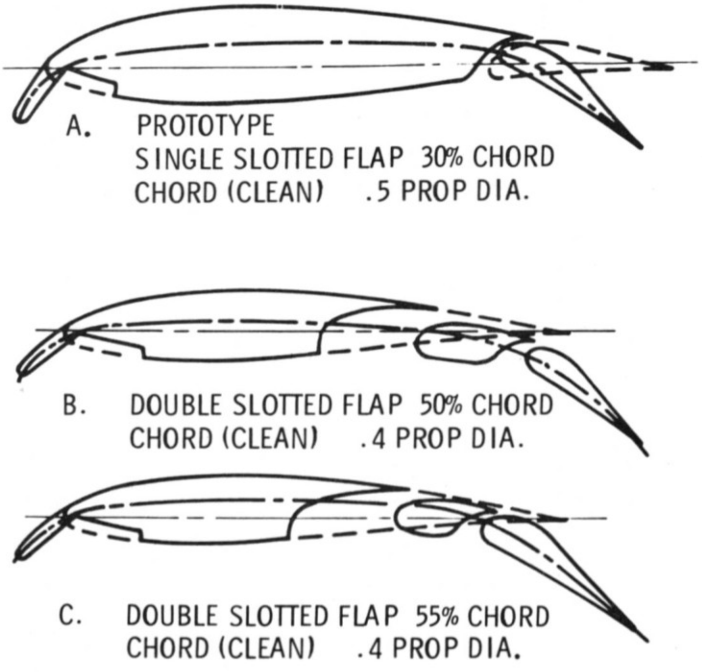

FIG. 20 HIGH LIFT SYSTEMS TESTED

Another alternate tilt wing configuration is the use of cyclic pitch on the main propellers for longitudinal control in hover and transition, in place of the tail propeller. This scheme was considered for the prototype, but the tail propeller approach was selected on the grounds that it provides a powerful, easily predicted control moment and avoids difficult mechanical and structural development problems on the main propeller. Potential propeller-wing interaction problems in transition are also reduced. However the potential advantages of reduced system complexity, cost and maintainability with cyclic pitch control are very attractive, and again a careful trade-off study is required for each specific application.

In order to obtain the necessary performance and aerodynamic data for such trade-offs, Canadair is presently conducting a model test program on the cyclic pitch propeller concept. Fig. 21 shows the model propeller and nacelle to be tested separately under static and forward speed conditions, and then mounted on the wing of a reflection plane model for overall wind tunnel tests.

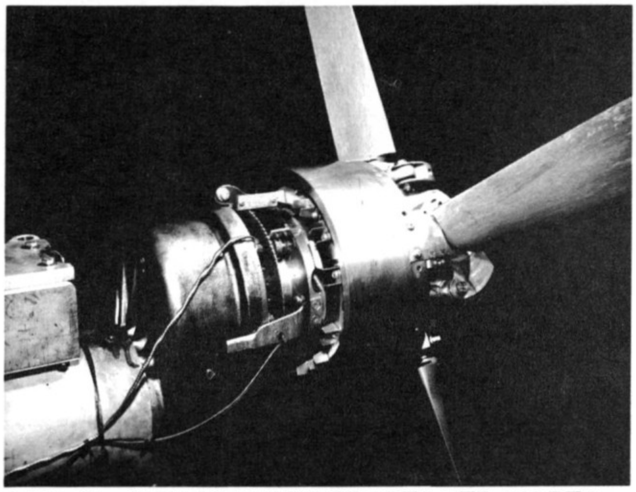

FIG. 21 CYCLIC PITCH PROPELLER MODEL

Another interesting propeller development that should be considered is the variable camber concept developed by Hamilton Standard. For some applications, particularly where the disc loadings are towards the higher end of the range for tilt wing aircraft, the variable camber propeller offers advantages in hover payload, maximum speed and noise. These can become significant when the mission requires high speed, long range or a combination of both.

ADVANCED MATERIALS & ENGINE TECHNOLOGY

In the same way that the advent of the turbine engine made non-rotary wing V/STOL aircraft technically and economically feasible, the advanced materials and engine technology projected for the next decade will make them competitive with conventional aircraft on the basis of weight empty and payload to gross weight ratios.

The most important improvements in sight appear to be in the propeller and mechanical transmission systems, and Ref. 4 gives a picture of the potential gains in this area. These constitute, for the 1970-75 time period, a 40-50% improvement in propeller and gearbox weight, a 2-3% improvement in static thrust, a 5-7% improvement in installed cruise efficiency and a 6-10 db reduction in take-off noise.

Since the installed power in V/STOL aircraft is relatively high, major benefits will also accrue from advanced engine technology. A 30-40% improvement in weight and a 20-30% improvement in specific fuel consumption are being predicted for the 1975 time period. Studies on the application of new composite structural materials to V/STOL aircraft are still in the early stages, and the potential weight reductions in this case are at present more difficult to define. However it is quite clear that major improvements in weight will be achieved.

In order to project the net effect on payload of the potential advances in technology discussed above, a study was carried out on the tilt wing commercial transport variant described in this paper. For this study the gross weight, installed power, disc loading, wing loading, range and speed were held constant, while the payload (or number of passengers) and fuselage length to accommodate the payload were varied. Fig. 22 shows a comparison of major system and fuel weights and indicates approximately a 30 percent net increase in payload. A corresponding improvement in direct operating cost can be expected.

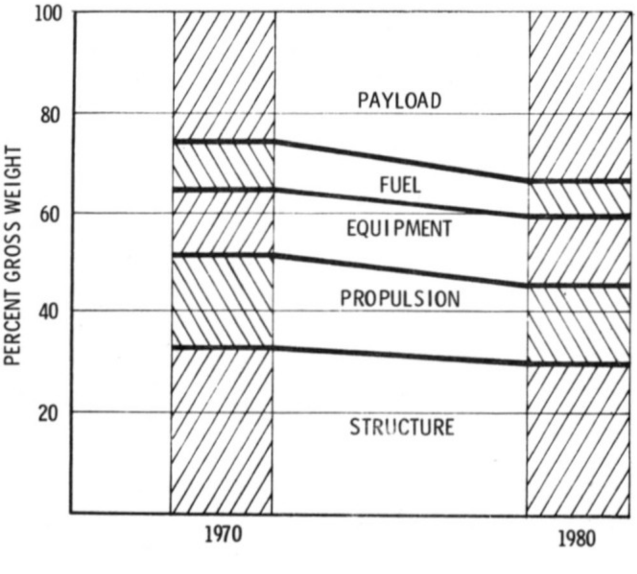

FIG. 22 ADVANCED TECHNOLOGY WEIGHT COMPARISON - VARIANT C

CONCLUDING REMARKS

Flight testing of the CL-84 tilt wing V/STOL prototype, together with design studies on variants up to over 50,000 pounds gross weight, have demonstrated the feasibility of this type for operational roles. The roles studied include utility transport, close air support, search and rescue and short-haul commercial transport operation. The tilt wing characteristics that contribute to effectiveness in these roles are the excellent STOL capability, low speed flight agility, high cruise speed, good hovering efficiency and economical operation.

Departures from the prototype configuration, that are being examined as potential improvements for some applications, provide higher wing loadings for cruise and cyclic pitch for longitudinal control in hover and low speed.

Advanced material and engine technology projected for the next decade will make important improvements to the tilt wing payload.

ACKNOWLEDGEMENTS

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