N78-16083

OPERATIONAL EXPE[illegible]

POWERED-LIFT [illegible]

Robert C. Innis and [illegible]
NASA [illegible]

SUMMARY

The experience gained in over four [illegible] with the Augmentor Wing Research Aircraft and the [illegible] of other STOL powered-lift aircraft have identified [illegible] that will be basic to most STOL aircraft designs. The [illegible] the use and percent of lift achieved by powered lift [illegible] the operational characteristics of STOL aircraft and [illegible] the performance that can be achieved. A brief de[illegible] including the means by which it achieves its [illegible] ted. Specific problem areas relating to the [illegible] path are discussed as well as the consequences [illegible] the design and operation of this class of aircraft

INTRODUCTION

This paper reviews the experience gain[illegible] years of operation of a powered-lift jet STOL airplane, [illegible] Wing Research Aircraft. It reflects some 330 flight hours [illegible] STOL approaches and landings. While the concept for achieving pow[illegible] with this airplane is perhaps unique, the design is such that it allo[illegible]derable flexibility to the pilot in the means by which he controls the aircraft. With the incorporation of an advanced digital flight control system, designed and built by Sperry Flight Systems, it is possible to [illegible] a wide range of handling qualities and flight control concepts. [illegible] for this reason we feel that the conclusions presented here apply in general to those aircraft which derive a subs[illegible]ntial portion of their lift from the [illegible] propulsion system. The contents of this paper address pri[illegible] the approach and landing phase of flight where the consequences of the powered lift are most pronounced, and the resultant characteristics most different from those of conventional aircraft.

DESCRIPTION OF AIRCRAFT

The augmentor wing was designed as a low-cost, low-speed research vehicle that could be used to investigate the operational characteristics of a powered-lift jet STOL aircraft in the environment of the terminal area including takeoff, transition, approach, and landing. The aircraft, shown in figures 1, 2, and 3, was modified from a deHavilland C-8A Buffalo which was donated by the USAF. The G. E., T-64 turboprop engines were replaced by R. R. Spey turbofans. The wing area was reduced by removing about 2 m from each wing tip, and fixed, full-span slats were installed on the leading edge. The landing gear was fixed in the down position and modified to accommodate a higher gross weight. The spring tab controlled elevator system was changed to a hydraulic powered unit, and the conventional double slotted flaps were replaced with an entirely new augmented jet flap system. This flap, illustrated in figure 4, consists of two nearly parallel surfaces with a continuous double slot nozzle located between them which acts as an ejector pump with air drawn in from both the upper and lower surface of the wing.

Air for the flap nozzles is provided by the fan section of the Spey compressors. The lower nozzle is supplied by air from the engine on the same side of the airplane, while air for the upper nozzle is cross ducted from the opposite engine. This arrangement reduces the asymmetry which would occur should an engine fail during takeoff, approach, or landing. The purpose of all this is to augment the thrust from the ejector nozzle and also to induce airflow over the surface of the wing which increases its lift. The aft portion of the lower surface of the flap is hinged so that it can be closed thereby choking the augmentor and spoiling the lift. The outboard chokes are used for lateral control while the inboard chokes are modulated for direct lift control. Additional lateral control is obtained from drooped ailerons provided with BLC and from spoilers located in front of the ailerons.

The hot gases from the Spey engines are exhausted through Pegasus-type swiveling nozzles which are located on both sides of each engine nacelle. They can be positioned from nearly straight aft to slightly forward of the vertical and are controlled by levers located adjacent to the overhead throttles in the cockpit. During the approach where the nozzles are deflected nearly normal to the flight path, they contribute about 1800 newtons (8000 lb) of direct lift to the airplane. However, this is only a small part of the powered lift that is achieved by the augmentor wing as shown in figure 5. This bar graph compares the airspeed that corresponds to a given angle of attack with varying amounts of thrust. The center bar represents our nominal approach conditions, 65 knots at 4° angle of attack, utilizing about 2/3 of the available thrust. If there were no thrust, the airspeed corresponding to this angle of attack would increase to 100 knots. The thrust from the swiveling nozzles would account for only about 7 knots of this difference. Applying maximum thrust, which might occur during a wave off, would decrease the airspeed by about 10 knots.

Following the initial documentation and proof-of-concept flight testing, the aircraft was equipped with STOLAND. This is an experimental digital avionics system which, through its computer, sensors and servos, can drive any or all of the primary and secondary controls. This allows us to independently vary the lift, drag and stability characteristics of the augmentor wing so as to represent the response characteristics of a wide range of aircraft of this class. Subsequent flight testing has emphasized the examination of STOL handling qualities over as broad a range of these characteristics as is practical.

Most of these flight tests were conducted at a Naval Auxiliary Landing Facility called Crows Landing, located in the San Joaquin Valley of California. The approaches were conducted on a 7-1/2° glide slope with guidance provided by an experimental microwave landing system called MODILS. Some of these approaches were hooded to simulate instrument meteorological conditions. The landings were made to a 518 m × 30 m (1700 × 100 ft) STOL strip marked out on one of the main runways.

DISCUSSION OF RESULTS

The environment in which the airplane has operated, in terms of wind and turbulence, is indicated in figure 6. The points represent the maximum wind velocities and direction relative to the landing runway. The lines extending from the points indicate the gust factor. The grid resolves them into their headwind and crosswind components. These are tower reported winds which do not accurately depict the conditions at the touchdown zone but are at least representative. Approaches with headwinds of 30 to 40 knots and 10- to 15-knot gusts were negotiated without great difficulty although they did take a considerable length of time and were sometimes subject to large flight path excursions. Landings with crosswind components in excess of 20 knots were relatively easy even though the decrab maneuver of some 20° required full rudder. The most critical condition in terms of both safety and performance was approach and landing with a tailwind component. The higher descent rates tax the capabilities of both the aircraft and the pilot, and landing distance increases dramatically. This is illustrated in figure 7 which depicts the results of some landing performance tests. These landings were performed on two back-to-back flights, the first of which was made with a light tail wind which steadily increased to about 10 knots as the flight progressed. The second set of landings was made into the wind. It is apparent that as the wind velocity approaches 10 knots, landing with the wind rather than into it effectively doubles the stopping distance.

It was recognized early in the design of the augmentor wing that stability augmentation would be required to achieve satisfactory handling qualities. This is typical of those aircraft which operate at high lift coefficients and low dynamic pressure. The initial flight tests were made with a lateral-directional SAS which provided positive spiral stability, increased roll and yaw damping, and improved turn coordination. Later in the program, more advanced augmentation schemes were examined. Attitude command and rate-command attitude hold were evaluated in both the pitch and roll axis. With attitude command, the ability to return the aircraft to wings level and trimmed pitch attitude was appreciated by the pilots; however, the sustained control forces and deflections required when maneuvering in either pitch or roll were objectionable. With those configurations which required pitching the aircraft for flight path control, the trim button which was used to change the reference pitch attitude became a primary but somewhat awkward controller. Because of this the pilots settled on rate command attitude hold as the basic SCAS configuration. It should be pointed out that acceptable STOL approaches and landings were performed without any SAS or SCAS in light to moderate turbulence, but only under visual flight conditions.

Having arrived at an acceptable stability and control augmentation scheme, we proceeded to examine those characteristics which are peculiar to powered lift. These, of course, occur primarily in the longitudinal axis as shown in figure 8. With conventional aircraft, the thrust exerts a force along this axis which in steady flight balances the drag force. Changes in thrust produce a longitudinal acceleration.

The concept of powered lift implies that the lift produced by the wing is dependent upon the amount of thrust applied. In order to achieve a low approach speed and maintain a steep descent angle, the thrust must be also deflected or turned so as to properly balance the longitudinal and normal forces. In this example, the thrust vector includes the contribution of both the cold air from the flap nozzle and the hot gases from the swiveling nozzles. Changes in thrust now increase the lift which produces more change in normal force than longitudinal acceleration and in some cases may even cause the aircraft to decelerate when thrust is increased. This provides the pilot with a powerful means by which he can change flight path angle but leaves him somewhat at a loss as to how to manage airspeed control. In the case of the augmentor wing, the swiveling nozzles which divert the hot gases from the Spey engines provide an effective means of changing airspeed. As the pilots gained experience and familiarity with the airplane, they learned to use the nozzles in conjunction with the throttles to adequately control the flight path (and airspeed). However, in the presence of turbulence and wind shears, the pilot workload became quite high and there was sometimes confusion as to which set of levers to move first. In an IFR environment, glide slope tracking was poor, therefore the pilots concluded that the use of three different controllers for the management of the longitudinal task was too much to cope with for everyday operation.

Leaving the nozzles fixed at some predetermined value requires the pilot to control airspeed by changing pitch attitude. If the effective thrust turning exceeds about 80°, adverse coupling can occur between thrust and longitudinal acceleration which will compound the control problem. As thrust is increased at constant attitude, airspeed decays, which puts the aircraft further on the backside of the thrust required curve. As this occurs, the flight path response diminishes and the pilot is forced to add still more power. The problem is illustrated in figure 9 which is a time history of an approach with a configuration which has substantial adverse thrust-airspeed coupling.

Glide slope intercept is from above and is initiated by a change in pitch. Tracking is accomplished with thrust while attitude is held relatively constant. At about 80 sec the aircraft starts to descend below the glide slope which prompts the pilot to add thrust. Airspeed decays though, and the aircraft descends still lower until the thrust is at the maximum allowable and the airspeed is well below the desired value.

The obvious solution to this problem, to everyone but the pilot, is to lower the nose to gain airspeed. However, to be effective, this requires a fairly large change in attitude — at least 5°, and the initial response of the airplane is to descend even steeper. Furthermore, the recovery time to regain airspeed is such that the approach had best be abandoned.

One question which the pilot must address with a powered-lift aircraft is how much power can be used in the approach. Assuming he has the option of changing the inclination of the effective thrust vector by either flap or nozzle deflection or by some other means, he can increase the amount of thrust used and thereby reduce the approach speed while maintaining the low effective lift to drag required for the steep flight path angle. In other words, the approach speed depends upon the amount of thrust used; but the margins in terms of flight path capability depend on the excess thrust available.

Our pilots felt that they would like to have the capability of achieving level flight without requiring a change in configuration. Assuming that this performance is available under standard conditions, the pilot must also concern himself with what adjustments must be made to accommodate temperatures above standard and higher altitudes. Figure 10 presents a chart which was used for this purpose with the augmentor wing. It allows the pilot to determine what rpm is required to achieve the thrust that would be realized on a standard day. For example, our approach speed was predicated on a nominal 93 percent rpm for standard day conditions. For a day on which the temperature was 10 degrees above standard, 94.5 percent rpm would be required, and if in addition, the field elevation was 1000 m (3280 ft), about 97 percent would be needed. Under these conditions, there would be insufficient thrust remaining to allow adequate flight path corrections. In this case our pilots would select a lesser nozzle deflection and accept a higher approach speed with its reduced thrust requirement.

SUMMARY OF OPERATING PROBLEMS AND CONSEQUENCES

Perhaps the greatest asset of a STOL airplane in terms of safety is its low closure rate to the intended touchdown point. It allows the pilot time in which he can observe, react, and make corrections. Powered lift is an attractive means of achieving this performance while still maintaining the high speed cruise and efficiency of a jet airplane. There are, however, certain operating problems which are inherent to the concept. Some of these are listed in table I along with the implications they might have on either the design or operation of the aircraft. They are divided into two categories, the first of which includes those problems which are brought about by operating at low dynamic pressures and high lift coefficients. Our experience has shown that the low aerodynamic stability and damping associated with this condition will require some form of augmentation in order to provide satisfactory handling qualities. The effect of wind naturally becomes more pronounced as its velocity becomes greater relative to the approach speed. More directional control is required to accommodate the higher sideslip or crab angles associated with a given crosswind component. In addition, turbulence or gustiness will probably dictate a requirement for increased flight path control. Runways whose length is determined by no-wind stopping distance are comfortable to land on in a head wind but suddenly become too short with a light tailwind component.

The second category includes operating problems which are the direct result of powered lift. The first three of these are the subject of discussion in reference 1. I would like to comment on them from the viewpoint of a pilot. The first two items should actually go together, since the adverse effects of speed variations are due in part to the poor ability to control airspeed. Because of the operation on the backside of the thrust required curve, these aircraft will probably experience greater flight path excursions when encountering wind shears. Airspeed management through the use of an additional controller to be operated by the pilot seems impractical, so some form of automatic speed stabilization may be required. Adverse coupling can, of course, be minimized by design, but if the full performance benefits of the powered lift system are to be realized, some form of control augmentation may be required. The final item is a fact of life which must be accounted for in the day-to-day operation of this type of aircraft. The use of flat-rated engines will alleviate the situation because takeoff thrust will be available under all conditions up to the rating limits. However, charts will still have to be used to determine proper thrust settings, and operation outside these limits will sometimes require a configuration change if adequate safety margins are to be preserved.

REFERENCE

1. Franklin, James A.; Smith, Donald W.; Watson, De Lamar M.; Warner, David N., Jr.; Innis, Robert C.; and Hardy, Gordon H.: Flight Evaluation of Advanced Flight Control Systems and Cockpit Displays for Powered-Lift STOL Aircraft. Aircraft Safety and Operating Problems, NASA SP-416, 1976. (Paper no. 4 of this compilation.)

TABLE I.- SUMMARY

Operating problems	Consequences
Due to low speed	
Reduced stability and damping	SAS or SCAS required
Effects of wind and turbulence	Increased control required
	Field length more sensitive to wind
Due to powered lift	
Poor ability to control airspeed	More sensitive to wind shear
Adverse effects of speed variation	May require speed stabilization
Possible adverse coupling between thrust and airspeed	Can be minimized by powered-lift system design
	May require SCAS
Increased effect of temperature and altitude on landing performance	Landing performance must be computed like takeoff performance

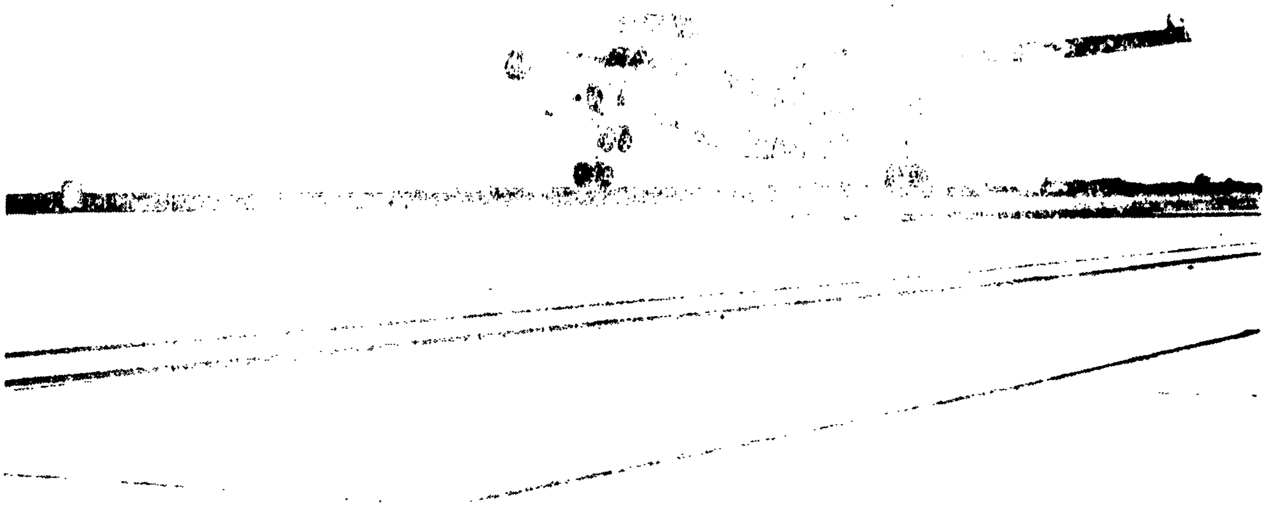
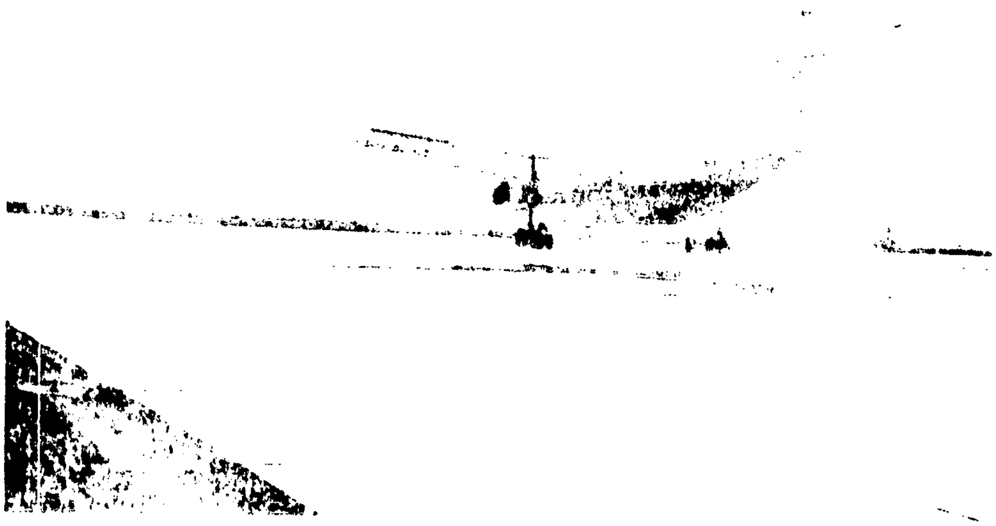


Figure 1.- Operational experience ... aircraft.



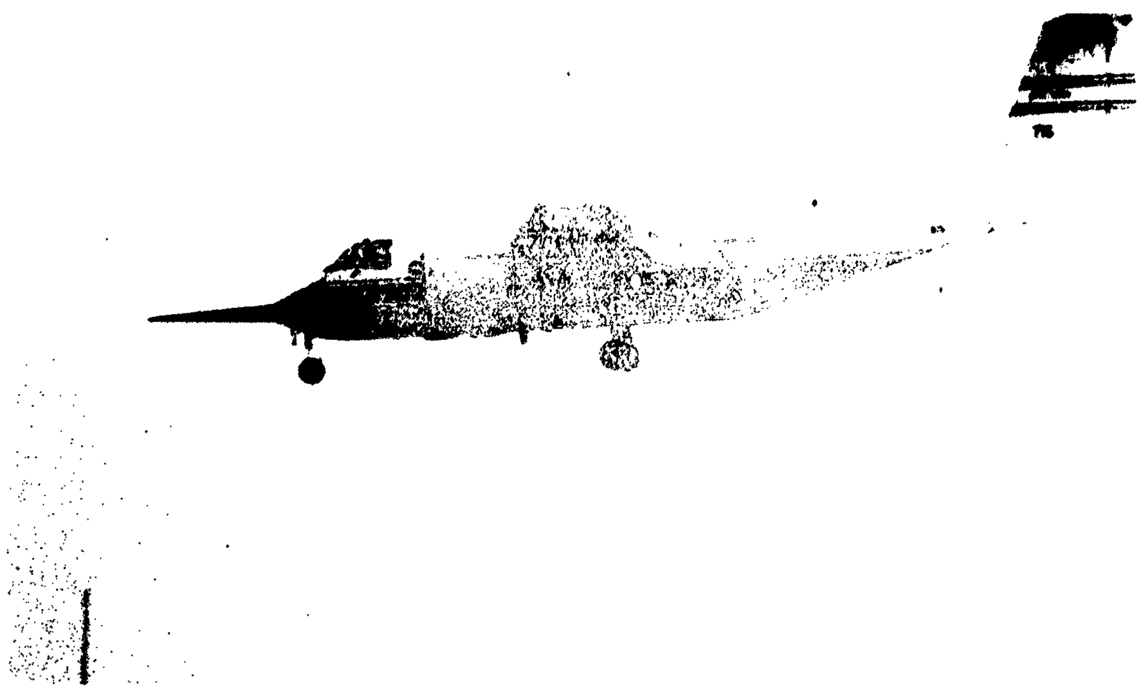


Figure 3.- Augmentor wing research aircraft approach.

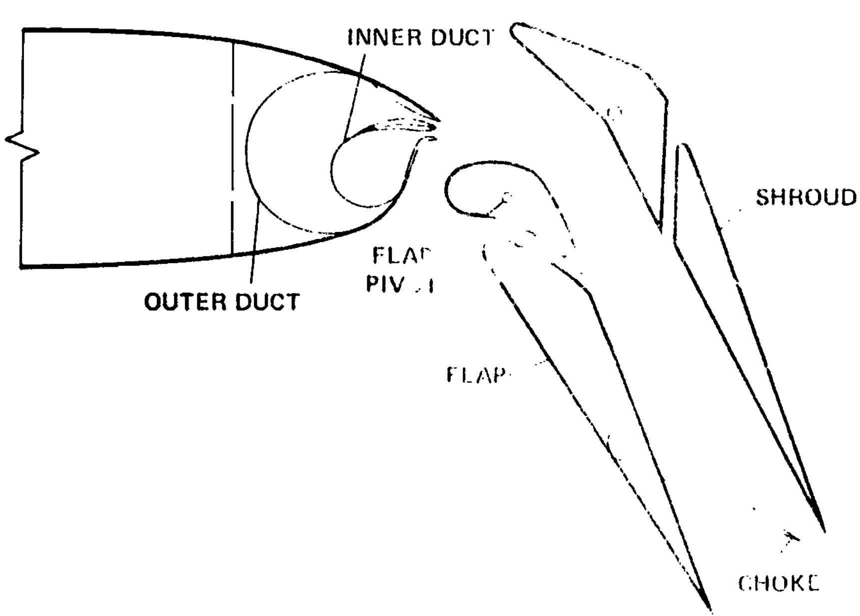


Figure 4.- Augmented jet flap.

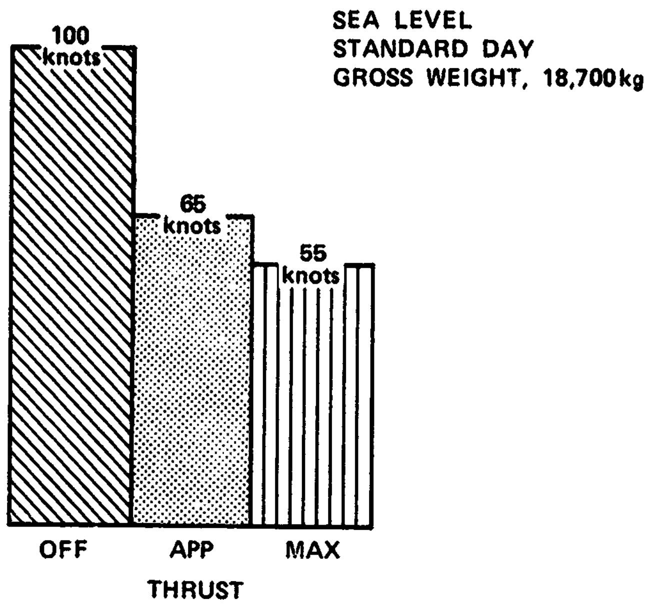


Figure 5.- Effect of thrust on approach airspeed constant angle of attack (4°).

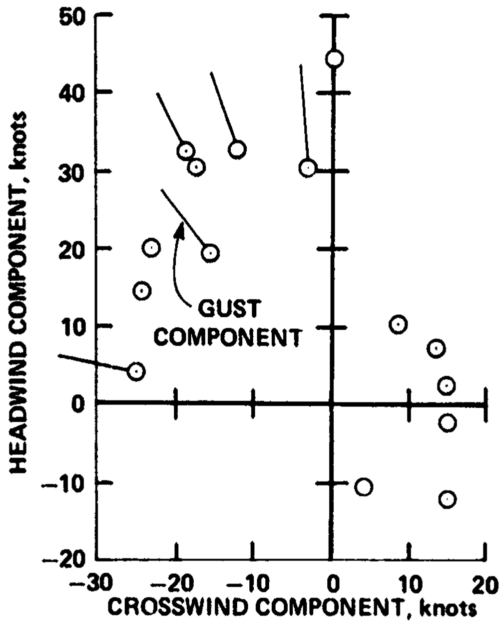


Figure 6.- Maximum wind conditions encountered in flight tests.

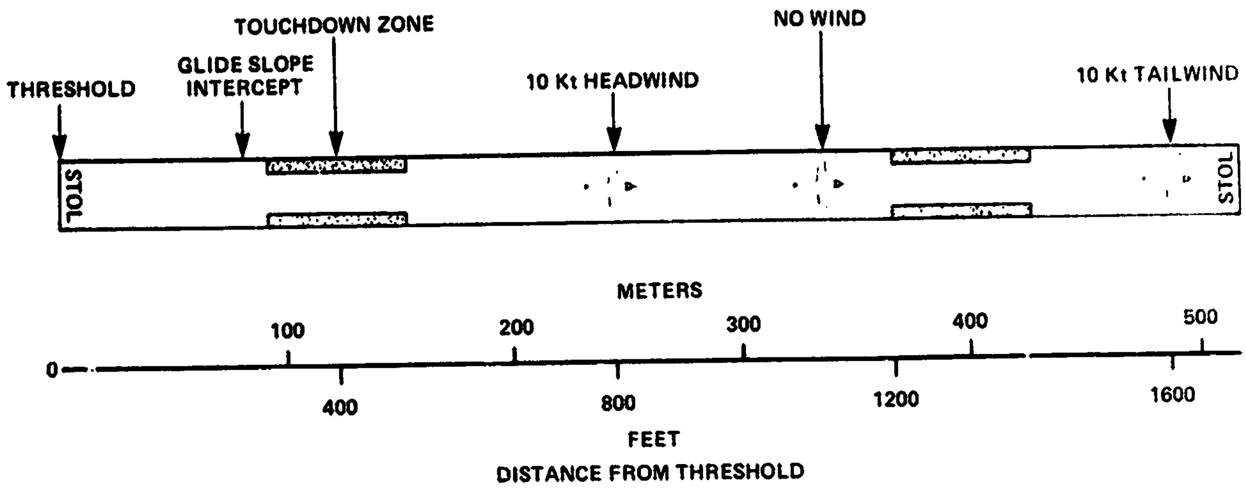


Figure 7.- Effect of wind on landing distance.

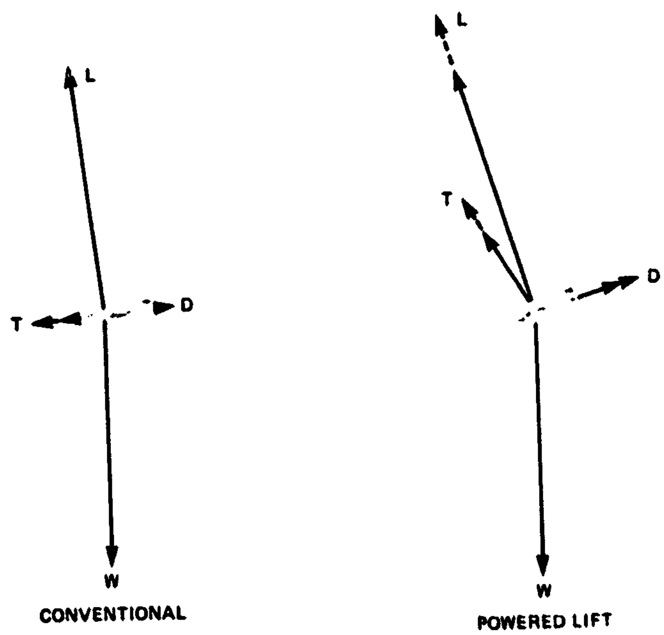


Figure 8.- Effect of thrust variation.

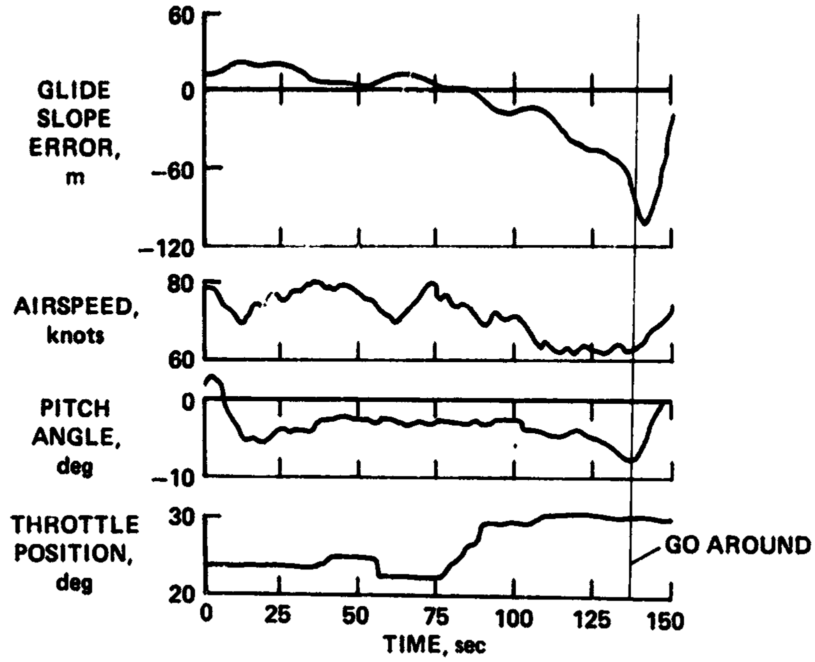


Figure 9.- Effect of thrust-airspeed coupling.

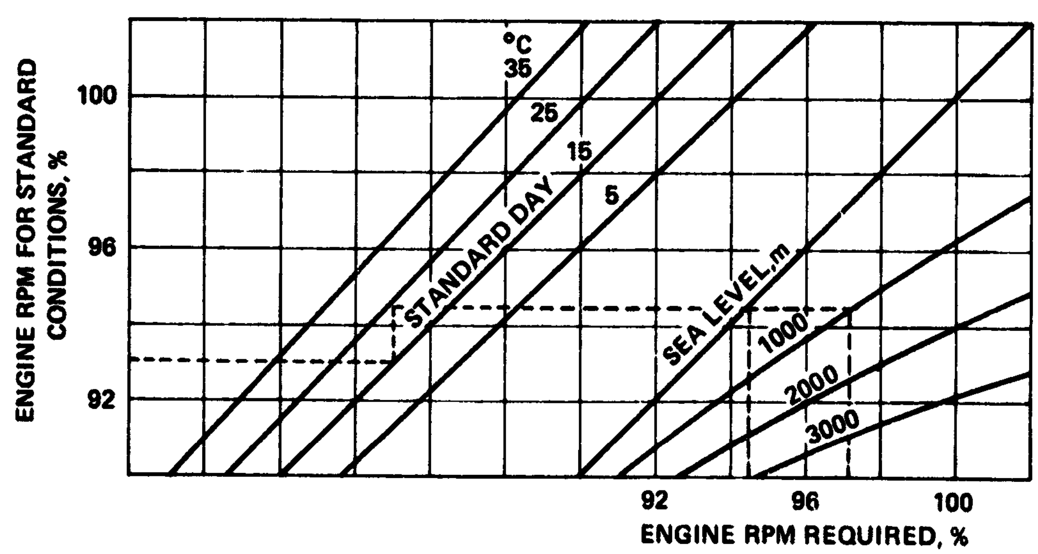


Figure 10.- Effect of temperature and altitude on approach thrust.