Reliability with STOL

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The low-speed, high-lift characteristics that make the STOL type of aircraft uniquely suited for short-haul transport operation within relatively confined areas and on short runways introduce a requirement for increased pilot skill and proficiency in the takeoff, transition, and land ing phases of operation. A high degree of reliability in the man-machine systems and their supporting systems must therefore be available to insure confidence and maximum safety of the STOL mode. To provide the pilot with the capability of attaining this precision, many new and improved aids must be provided to the STOL pilot in order to achieve safe, daily operation. The necessity for a very rapid and precise response of the STOL aircraft in the low-speed regimes during landing and takeoff requires control system augmentation to develop high control power and rapid aircraft response. In order to utilize the peculiar capabilities of these airplanes to their fullest extent and thus increase their reliability of operational service, certain changes in air traffic control and airport operational control must be made. Different methods of using the presently installed navigational aids and/or specifically designed aids, as well as associated cockpit instrumentation, will be required.

Operational Requirements

FROM the operational standpoint, the low-speed landing approach portion of the flight regime has proved to be the most critical. It has been expressed that not many pilots operating STOL aircraft, or attempting to get maximum performance from conventional aircraft, can make good short landings without mistakes. These pilots point out that STOL operations require a very high pilot skill level. Some of the landing requirments of STOL in support of these views are as follows: 1) Accuracy in speed and glide angle control are more critical during the approach and landing of a STOL aircraft. 2) It is necessary to touch down on an exact spot on the runway and then rapidly come to a stop because of restricted runway length. 3) Precise judgment must be exercised before a landing is attempted, because a landing in a very short field will either be made properly or result in an accident.

The foregoing factors do not exist for VTOL type of aircraft. If a VTOL landing is not correct the first time, the pilot has the option to stop, get oriented, and then proceed to land. Since the VTOL aircraft has the ability to hover, it has a better reliability factor than the STOL aircraft. In-flight emergencies for a VTOL aircraft, in most cases, can be terminated in the time it takes to descend to the ground, whereas a runway or suitable surface is required for landing a STOL aircraft.

From the pilot's point of view, takeoffs are not as critical as landing because calculations can be made in advance. The effect of factors such as altitude, temperature, weight, and wind direction are available to the pilot prior to takeoff. Some of the take-off requirements of a STOL aircraft are as follows:

Pilot technique required at a high level: 1) Pilot must know exactly when he is at the proper rotation speed. 2) Because of the short runway, a pilot can not wait too long nor can he rotate too early; otherwise he will not get off.

Reliability is inversely proportional to the square of the landing speed; therefore, reliability increases as airspeed decreases for any given runway length. The slower the airplane approaches, the safer and more reliable the operation for STOL airplanes for any given runway length. Conversely, the shorter the runway, the greater the reduction in reliability for any given approach speed. Approach weather facilities must be much more accurate than they are at present. Much more precise and reliable factors would be required. Likewise, slow-speed accuracy of the instrumentation system must be more exact than what is presently available. From the pilot's point of view, the STOL may be less reliable than conventional aircraft because he will be pushing the aircraft to its maximum capability, i.e., engine, high-lift devices, landing aides, lighting, reversing techniques, and short runways. The effect of crosswind on STOL is much greater at slower speeds; hence, reliability is reduced as compared to conventional aircraft operating at higher speed. Pilot visibility is increased if high-lift devices permit the STOL aircraft to fly at low attitude angles in the approach. However, if the high-lift devices produce high attitude angles, then visibility and reliability during the steep approaches will be reduced. Devices that are used to compensate for losses in visibility have their own reliability factors.

The preceding discussion is given from the viewpoint of the pilot. Thus far, we have looked at those operational aspects that seem to reduce reliability and safety in very low airspeed operation, but there is another side to the coin. Much of the STOL operational experience to date has been with conventional aircraft; however, an aircraft of true STOL design in a STOL environment may not be too critical. In a study of commercial aircraft accidents, it has been shown that approximately 18% of the accidents occur during cruise operation; about 25% occur during takeoff; and the majority, about 57%, occur during the landing phase (Table 1).[1] The study further shows that a direct correlation exists between the takeoff and landing speed and the accident rate. These statistics are taken from a study of total U.S. carrier operations in both domestic and international flights for the period 1961–1965. Since the majority of accidents occur during landings and takeoffs, this becomes a significant phase of the flight operation for safety/reliability improvement.

Air carrier accidents per 100,000 landing operations, plotted against average landing speed, are given by the lower curve on Fig. 1. The curve of landing risk vs landing speed was deduced from only 174 landing accidents. Moreover, these were grouped into only three average-speed classes, and each class consisted of only one type of aircraft, i.e., piston, turboprop, and jet. The range of landing speeds occurring in the air

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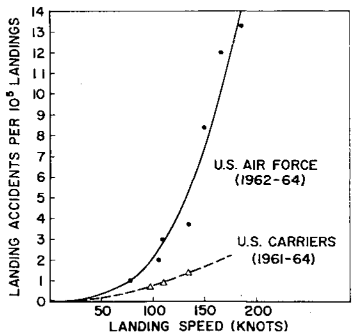

Fig. 1 Landing accidents vs landing speed.

carrier fleet is relatively narrow. Hence, there is a degree of uncertainty to the tentative conclusion that landing accidents vary as the square of the landing speed. To confirm (or deny) this conclusion, an independent method was sought with a higher confidence level. To achieve this, full data for all winged aircraft for the period 1962–64 were obtained on U.S. Air Force landing accidents. A curve was plotted from these data, as shown in the upper part of Fig. 1. The curve is based upon a very large number of landing accidents (i.e., many times greater than that of the air carrier record), upon a much wider range of landing speeds, and with different aircraft types represented in each speed range in most cases. This curve confirms that fewer landing accidents can be anticipated at the lower airspeeds. Although there are many variables not considered in the accident rate vs landing speed, there appears to be ample indication that reliability/safety can be enhanced by the low landing speeds of a STOL aircraft.

Low-Speed Performance Parameters

The STOL airplanes of the future will be required to operate out of small airfields and yet retain high cruise performance in order to satisfy both military missions and commercial operations. It is a well-known fact that short field landing distance depends on approach speed. The relation between the landing field length and the approach speed is given in Fig. 2.[2,3] To reduce the field length from 3500 to 1500 ft requires a reduction in approach speed from 90 to about 60 knots and an increase in thrust for takeoff. Since approach speed depends on both lift and wing loading, landing on very short fields requires either low wing loading or very high lift, or a combination of the two. Since some of the STOL airplanes of the future will require high wing loading for efficient cruise, the expected short field requirements can be met only by the use of high-lift devices. In addition, to realize maximum STOL performance, engine power must be used to augment aerodynamic lift. Since the STOL aircraft will be required to operate in an environment of low dynamic pressure where aerodynamic control power and damping are reduced, engine power effects on stability become more important.[3]

Though STOL aircraft performance data are proprietary, the data published by the Federal Aviation Agency (FAA)[4] provide a composite landing profile for a multiengine STOL aircraft. The ground run is approximately 330 ft with a total landing distance of 747 ft from a 50-ft height, as shown in Fig. 3. The approach speed is approximately 60 knots cruise

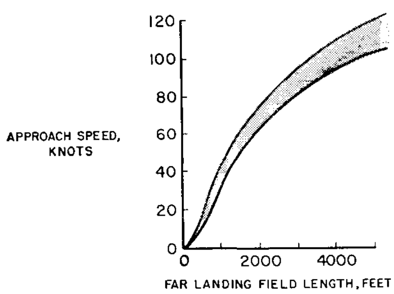

Fig. 2 Variation of landing field length with approach speed

Table 1 Number of aircraft accidents[a]

Phase of flight	Number of accidents	Percent of total
Total U. S. carrier operations, domestic and international, 1961 through 1964		
Takeoff	81	25.5
Cruise	56	17.6
Landing	181	56.9
Total	318	100.0

[a] Includes jets, turboprops, pistons, helicopters.

airspeed (CAS) with an approach angle of 8.6°. The takeoff profile for a multiengine STOL aircraft with a ground run of approximately 450 ft and a total takeoff distance of 740 ft, including climb to 50 ft, is shown in Fig. 4.

The ability of any aircraft to achieve short takeoff and landing is a function of wing loading, thrust-to-weight ratio, and aspect ratio as related to maximum lift coefficient. The maximum usable lift coefficient which may be obtained with complex mechanical systems is about 2.5. For high-gross-weight aircraft, this is hardly adequate in trying to obtain takeoff and landing runs of 1500 ft or less.[5] To exceed a lift coefficient of 2.5, not only additional complex systems are required, but also greater installed power. Figure 5 shows the effect of wing loading and thrust-to-weight ratio on takeoff distance over a 50-ft obstacle for a lift coefficient of 2.5. Today's intercontinental commercial jet transports would fall on the upper curve at a wing loading of approximately 100. To reduce the takeoff distance to 1500 ft or less requires an increase in aspect ratio (preferably with reduced wing loading), increased thrust-to-weight ratios, and a high C_L system such as boundary-layer control (BLC). The short stage transports of today would also fall on the upper curve whereas the STOL transports of the future would be spotted on the lower curve. The effect of thrust-to-weight ratio on takeoff distance over a 50-ft obstacle is shown in Fig. 6 for a wing loading of 50.

The Breguet 940 demonstrated experimentally the feasibility of the highly deflected triple-slotted flaps, interconnected propellers, and use of differential outboard propeller pitch for control to obtain acceptable STOL performance and handling qualities.[6] The Boeing 727 transport airplane is using a triple-slotted flap plus a drooped leading-edge flap to obtain high lift. Another approach to STOL is the use of high aspect ratios and low wing loading and a power control that provides full range from negative to positive thrust, such as provided by the Beta Control of the Fairchild Hiller Heli-Porter. This provides instant power response through the full range of propeller pitch, from forward through reverse thrust. It gives the aircraft immediate response for missed approaches, increases the angle of approach without the penalty of increased landing speed for nose-down descents, and reduces landing roll.

Need for Automatic Aids and Controls

The required number of tasks and decisions to be effected in a short period of time during a landing is large, whereas the amount of quantitative information available to the pilot to assist him in these tasks is quite limited. Coupled with the increase in pilot work load during this critical landing phase is a decrease in the handling qualities of contemporary aircraft in terms of reduced stability, particularly in the lateral direc-

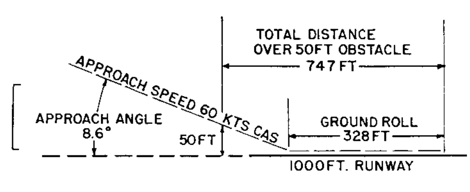

Fig. 3 Landing profile, multiengine STOL aircraft.

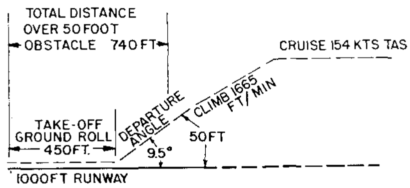

Fig. 4 Takeoff profile, multiengine STOL aircraft.

tional axis where control of sideslip angle is of primary concern for several reasons.[7,8] Proper and adequate control of sideslip angle is necessary to prevent loss of directional control due to the tendency of the vertical fins to stall at large values of sideslip angle.[9] Secondly, there is the problem of maintaining desired heading and turn rate, because sideslip excursions are directly transformed to heading errors in turn maneuvers. Finally, control of sideslip is needed during touchdown, particularly in crosswind landings.

The point of the foregoing discussion is that it is very likely that the pilot is going to be a very busy man during the STOL approach and landing phases. He is trying to effect a touchdown in a very limited runway length at a time when the aircraft's inherent stability characteristics are deteriorating.[3,6,10] Just as solutions were developed to cope with the transonic and supersonic aerodynamic problems of ten years ago (e.g., pitch-up, trim changes, etc.), it is anticipated that the advances in the state-of-the-art of low-speed aerodynamics will provide a solution to the low-speed problem in handling qualities as encountered by present-day aircraft. However, it still can be expected that automatic flight control systems will be relied on to take over a large portion of the pilot's tasks to assure the reliability of the control and stability of the airplane. Some form of control system will be provided to augment the aircraft's natural damping, to handle the critical lateral directional control problem, and to perform a completely automatic approach and let-down. Both yaw axis and lateral axis augmentation must be considered if handling qualities are to be satisfactory. Primary consideration must be given to the yaw axis, first in order to damp the Dutch-roll to a satisfactory level, and second, to improve turn coordination by eliminating the large sideslip excursions that develop with low stability and adverse yaw due to roll rate inherent at low airspeeds.[11] Secondary consideration must be given the lateral axis augmentation to increase roll-rate damping, to reduce dihedral effect, and to stabilize the roll spiral mode.[11]

The use of automatic systems for control of fuel to provide c.g. control is being investigated, and the automatic control of lift and cruise engine thrust modulation for providing aircraft pitching and turning moments is being developed. With the acceptance of automatic control of these basic safety-of-flight-type aircraft systems, it becomes feasible to assign added functions to automatic systems. This is especially true where the rapid response time of these systems is greater than that of the human pilot when his workload is at its peak.

A typical application would be in a STOL type of aircraft where multiple engines are used rather than a single power source.[7] With most designs the loss of one engine, in addition to reducing over-all lift, will cause a roll, pitch, or yaw angular rate, a highly undesirable condition in close proximity to the ground. To reduce this rate, either sufficient aerodynamic control must be present, or the thrust in the opposite engine must be reduced. However, under any circumstances the total engine thrust levels must be kept sufficiently high to control altitude. There are several methods of sensing engine failure and initiating proper action. If the pilot initiates the action, he must first detect which engine is malfunctioning and then throttle back the properly functioning engine(s). This delay in reaction time may be sufficient to allow the aircraft to reach a dangerous attitude before recovery can be accomplished. The type of failure may be difficult to determine

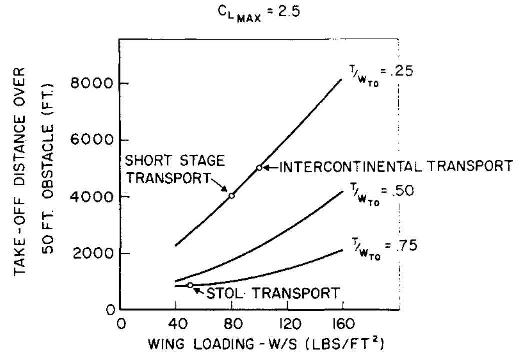

Fig. 5 Effect of wing loading and thrust-to-weight ratio on takeoff distance.

because it may be fuel, fuel control, compressor stall, or some type of mechanical failure. To instrument all possible sources of failure would require a multiplicity of sensors, each providing a high degree of reliability.

During the low-speed flight envelope in which these functions will be performed, the aerodynamic control surfaces are not as effective as at high speeds. Consequently, the automatic flight control system is required to utilize a large percentage of the available surface authority to do its job.[2] With large authorities entrusted to the automatic flight control system (AFCS) it is incumbent on systems designers to insure that failures in the AFCS will not result in large, rapid, or unexpected motions of the aircraft. Extreme reliability becomes a necessity, and guidelines for providing the required safety features must be established.

Designing Safety into the AFCS

Very early in the development of the AFCS for the V/STOL aircraft, the designer must determine whether a malfunction in the system shall be permitted to cause the entire system to shut down, or whether steps must be taken to keep the system functioning in the presence of one or more failures. In those cases where loss of the stability or control augmentation function of the AFCS would leave the pilot with a seriously degraded and undamped vehicle, it becomes necessary to provide fail-operational flight-control system performance. Redundancy of components, usually on a triplicated basis, coupled with voting logic circuits, can provide such fail-operational performance.[12]

Various monitor schemes are employed when fail-safe operation of the control system is to be provided.[13] One of these is the vertical gyro monitor. It consists of three redundant gyros used in a pair-and-spare technique as shown in Fig. 7. In this configuration, two gyros operate and furnish outputs to the monitor but only gyro A supplies signals to the control electronics. When the monitor detects a significant difference in the outputs of the two gyros A and B, gyro A is removed from the circuit and gyro C is switched in and supplies signals to the control electronics.

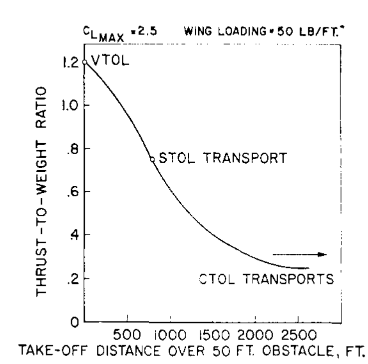

Fig. 6 Effect of thrust-to-weight ratio on takeoff distance.

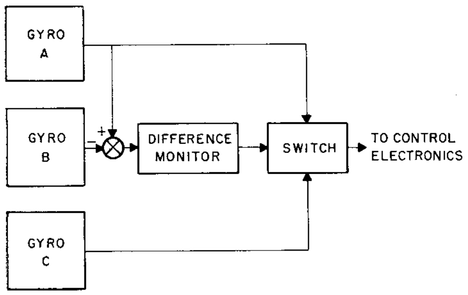

Fig. 7 Vertical gyro monitor.

Terminal Navigation and Approach Facilities

STOL aircraft differ from conventional aircraft only during the takeoff and transition to cruise, or during the transition from cruise to landing and touchdown. During these flight regimes, STOL aircraft can be easily separated because of their slow flight and steep ascent or descent capabilities. These characteristics can be used to ease air traffic control (ATC) work load in the terminal area.

Large Metropolitan Airports

At large airports, sufficient space is normally available to permit the construction of "porter patches" (Fig. 8) or short parallel runways located conveniently close to the loading point for the STOL aircraft. Separate approach and landing aids will be required to segregate this type of traffic during instrument weather conditions. These aids need not be complex but must insure that the transition from cruise to touchdown ends at the right place in a minimum amount of time.[14]

STOL aircraft have a very low airspeed, and thus approach patterns can be brought much closer to the airport boundary. From a traffic-control standpoint, approach control must therefore be capable of working on much smaller incremental time and distance factors. The precision and reliability of the approach control equipment must be assured to provide the controller with the intelligence required for the more rapid decisions that these shorter time/distance factors will dictate.

Terminal approach and landing aids normally in service at these major terminals can be used as part of the terminal air traffic control system for STOL aircraft. These, however, must be augmented with specific aids for close-in accurate guidance, control, and rapid handling of STOL aircraft.

Medium-Size Airports

The density of traffic operating in and out of these airports is usually much lower than that of the major terminals. At these sites the standard available navigational systems can be used for approach aids. However, special considerations should be given to the STOL aircraft's characteristics. Specifically, because of their lower operating airspeeds they should be able to operate to lower instrument flight rules (IFR) approach limits. If necessary, a special additional terminal guidance aid may be required. The size and complexity of this equipment is a secondary consideration at these terminals, whereas cost, accuracy, and reliability take on major importance.

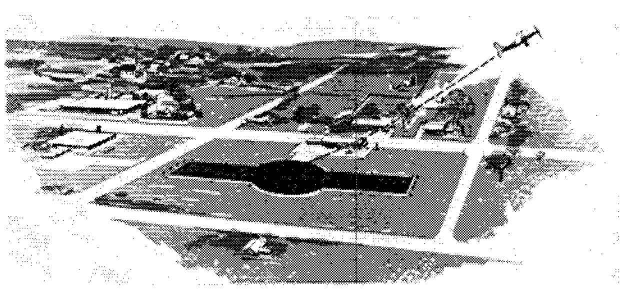

Fig. 8 Porter patch.

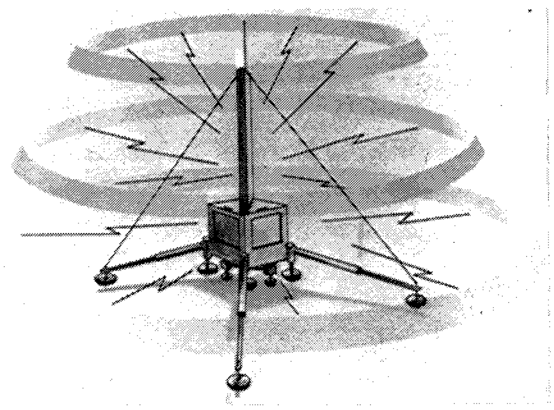

Fig. 9 Modils system.

Small/Private Airports

Little if any problem exists at small fields from a traffic viewpoint. However, most of these fields do not have approach aids or weather reporting facilities because of the low utilization rate and limited finances. Thus, all equipment must be simple, easily maintained, and relatively small in size, and should not require full time attendance.

At small or privately owned landing strips, physical obstructions may present a problem. A pilot performing an instrument approach to minimum limits must be given assurance that his safety is not compromised. Not only should the terminal facility be simple and reliable, but it must be accurate and relatively unaffected by local terrain and objects. In addition, weather condition information must be made available.

Problem Area Defined

It is therefore quite obvious that if the STOL type of terminal used at large metropolitan airports proves to be feasible, its supporting and control systems should be more than adequate for adaptation to other airports. Any system or combination of systems must be selected with the following requirements in mind: 1) instill a high degree of confidence in the pilot, 2) allow operation into an unfamiliar airport, 3) provide adequate obstacle clearance, 4) provide precise guidance along a desired approach path, 5) provide accurate information of position relative to the touchdown point, 6) ability to effect a landing from the aircraft's present position, using the presented data, without having to first correct back to previously assigned path, 7) automatically transmit weather information or allow operations to at least category III minimum, 8) allow easy transition to visual runway acquisition, 9) high inherent reliability, 10) simplicity, 11) low cost, 12) easy maintenance, 13) small size, 14) unattended automatic operation.

Evaluation of Terminal Systems

The boundary conditions previously stated fairly well eliminate possible systems such as: Decca; Loran; SPN 10, 41, and 42; PAR, ASR, and ILS because of either size or complexity.

The AILS, STATE, TALAR, and VAPS systems are similar to the standard instrument landing system (ILS) for azimuth and glide slope beam guidance. The azimuth beam is oriented along the runway. The glide slope beam is adjusted as required in elevation so as to provide a satisfactory obstacle clearance path.

Table 2 STOL terminal landing aids

AZIMUTH APPROACH PATH	GLIDE PATH APPROACH ANGLE: PRESET VALUE DETERMINED BY GROUND INSTALLATION	ELECTRONICALLY CALCULATED ON BOARD AIRCRAFT	ELECTRONICALLY SELECT DESIRED GROUND EMITTED GLIDE SLOPE BEAM	PILOT JUDGEMENT
PRESET VALUE DETERMINED BY GROUND INSTALLATION	AILS STATE TALAR VAPS / GAIL VASI			MICROVISION BEACON VISION
ELECTRONICALLY SELECTABLE ON BOARD AIRCRAFT		TACAN VOR-DME RATS TELECART	VORTAL MODILS	

Glide slope information is not available in the TACAN, VOR-DME, RATS, and Telecart systems and must be derived by calculation from the distance-measuring equipment (DME), the onboard altimeter, and a prior knowledge of the ground station's barometric altimeter setting. The use of a radar altimeter to derive altitude is not always practical since approach path to any runway has a different topographical cross section. At higher altitudes, i.e., several thousand feet, a 50-ft obstacle would cause a 50-ft jump which would normally be ignored. On the final approach at a 100-ft terrain clearance altitude, a 50-ft object would reflect a 50% drop in this altitude.

The use of an inertial and/or Doppler navigation system combination would satisfactorily serve as a useful adjunct to other navigational aids. This combination would be especially useful for continuous present position information when direct off-airway routing is desired. The accuracy of these systems is sufficient to enable navigation of the aircraft to well within the range of a very low-powered terminal aid. However, they are not in themselves accurate enough to allow the pilot to make a low pass to the field.

The remaining systems can now be classified into four broad categories, Table 2. The GAIL and VASI systems employ color-coded lights to aid the pilot during the last portion of a visual final approach. The angle of the desired glide slope to clear local obstructions is preset upon installation. However, these systems must use additional terminal aid equipment in order to enable the pilot to position the aircraft at the proper intercept point when he breaks out into the clear weather. In addition, these systems are in themselves unsuitable for category III 0-0 landings.

The VORTAL and MODILS systems (Fig. 9) are similar to the TACAN or VORDME with one exception. The difference in this case is that the beacon emits an omnidirectional pattern that is electronically coded relative to elevation angle. These systems provide accurate azimuth and glide slope information, both of which can be selected by the pilot and hence allow considerable flexibility regarding the desired approach path without reducing accuracy. In addition, the DME portions of these beacons, which have been designed for this application, can provide either slant or over-the-ground approach speed to be monitored with excellent accuracy.

Microvision consists of radar beacons located on each side of the runway, Figs. 10 and 11. The energy detected by the aircraft antennas is displayed on a heads-up type display. The dots of light give the illusion of seeing the runway lights on a dark night.[15]

If a STATE, TALAR, VAPS, or AILS system is used as a terminal aid, the other aids are still required to vector or guide the aircraft to a satisfactory intercept point. Only after successful interception, which may require the execution of a procedure turn or equivalent maneuver, can the approach be started. These requirements increase the length of time the aircraft is in the airport control zone and create the need for a premium block of airspace for this period. In addition, the operation of this equipment is such that it reduces the number of approach paths, thus limiting the flexibility of ATC.

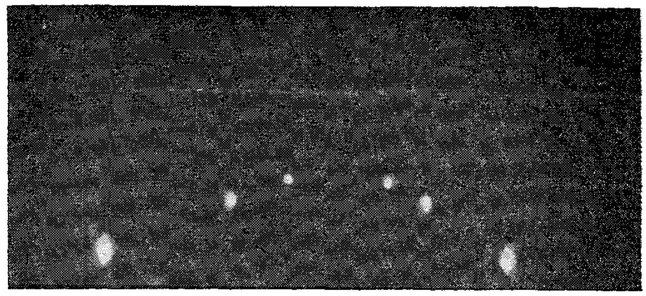

Fig. 10 Microvision: blind.

The problems are alleviated to a great extent by using either the MODILS or VORTAL systems. In either case, these systems can provide terminal area navigation guidance and can be used to allow the pilot to place the aircraft at the final approach fix with a minimum of time expenditure or distance traveled.

It is therefore apparent that, in order to meet the conditions specified, a combination of several systems is required. The most obvious and promising combination at this time being the Microvision System, and either the MODILS or VORTAL. With this combination the approaching aircraft can be navigated to the approach point in the best manner. For the actual final approach, the pilot would use the combined output of the integrated instruments and/or heads-up display. The latter would give him a real-world-type orientation down to touchdown and will eliminate the time lag that is required to transition from instruments to visual runway acquisition. In addition, this type of display enhances pilot confidence because of its relative simplicity and familiarity.

STOL Instruments and Displays

STOL performance doesn't alter the basic types of instrumentation considered germane to the complement of commercial transport aircraft. However, the larger climb and descent angles necessary to exploit fully the capabilities of STOL aircraft in metropolitan or heavily populated urban centers places increasing importance on basic aircraft flight instrumentation and visual pilot aids, and emphasizes the need for specialized reliable design in these areas. Even under visual conditions, STOL rotation and climb-out at high incidence angles can substantially reduce pilot forward visibility, requiring instrument reference. Similarly, short runway operation, independent of visibility consideration, does not permit any significant overrun of the ideal touchdown point,

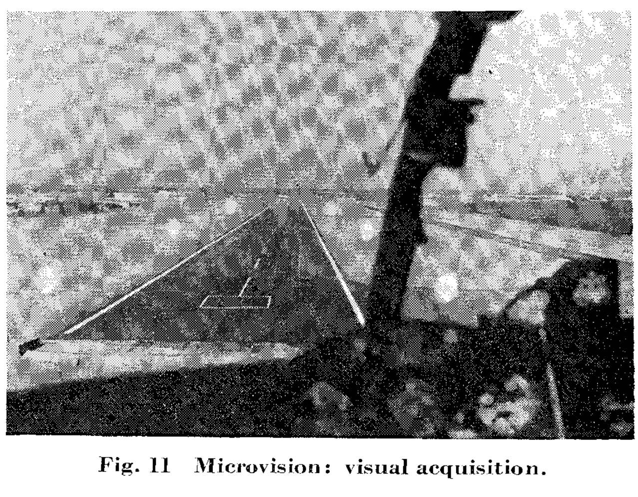

Fig. 11 Microvision: visual acquisition.

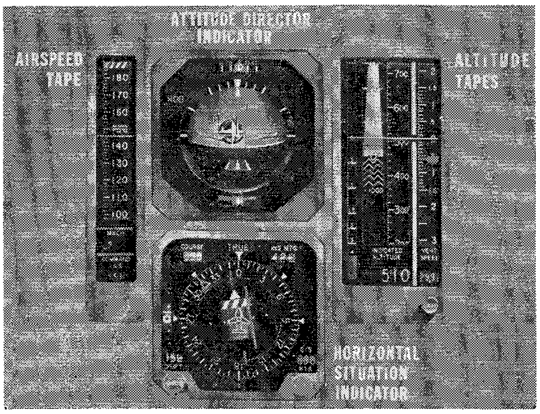

Fig. 12 Typical integrated instrument panel display.

and may require instrument assists, particularly of the "heads-up" and peripheral vision types to assure consistently repeatable landings under varying wind conditions.

Preliminary studies conducted on V/STOL operation at Langley concerning the IFR landing phase indicate that instrument scan rates approach excessively high values. These same studies have also shown a direct correlation between pilot work load and aircraft approach angles. Several potential solutions involving improved instrumentation and automatic control are available to minimize this problem. Under these conditions, considering the latter possibility, the utilization of automatic flight control landing, or approach control equipment for precision flight-path guidance, appears attractive but does not eliminate the scan rate problem (although it does reduce its severity). Regardless of the reliability level attainable through the use of microelectronics and redundant design techniques, it can not be assumed that a pilot would delegate complete responsibility to an automatic system without retaining both a monitoring function and manual override capability.[16] To augment this monitor-decision-command function, the pilot must be aided by instrumentation and displays that not only provide an accurate, reliable presentation of all key information but that have also been optimized from the standpoint of human factors.

In the area of basic flight instruments, advanced flight director displays of the integrated instrument type (Fig. 12) carefully designed for compatibility with their associated sensory equipment provide a monitoring function for automatic flight control operation as well as necessary data for manual operation. Developed primarily for military application, the term "integrated instruments" refers to the airspeed group: Airspeed and Mach Indicator (AMI), Attitude Director Indicator (ADI), Horizontal Situation Indicator (HSI), and altitude group: Altitude and Vertical Velocity Indicator (AVVI). Each of these instruments displays all parameters associated with its function in a single centralized location formerly requiring many individual instruments. In addition, command data can also be displayed on both the AMI and AVVI and aircraft guidance or steering information on the ADI and HSI. Considering the necessity for presenting flight information in a form which the pilot can rapidly identify and interpret, these instruments in the grouping illustrated provide an excellent starting point for developing efficient STOL instrumentation.

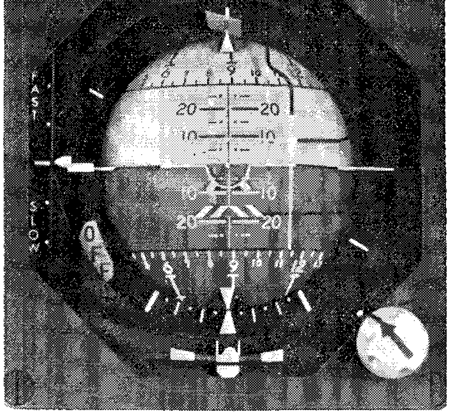

Fig. 13 Three-axis attitude director indicator with speed error scale.

Airspeed Display Group

As a basic minimum the airspeed group provides vertical scale indicated airspeed and angle-of-attack readout capabilities within a single instrument unit. Mach number normally associated with this group must be carefully assessed in terms of specific performance and utility before this parameter should be included, because instrument readability and reliability is compromised as a function of presentation data density and circuit complexity. Flight-path angle (the algebraic difference between pitch attitude and angle-of-attack) is another questionable parameter associated with this group. Although dependent on airspeed, it is also related to altitude and as such has been successfully evaluated within the altitude group as part of an Air Force funded V/STOL display study.[17]

Airspeed during landing approach is a critical parameter, and to simplify pilot interpretation, both command function and digital readout options associated with this unit should be considered. The command function permits the pilot to position manually a set of command markers to the airspeed desired while the readout window provides a numerical indication of the value selected or can be mechanized to display actual airspeed.

Attitude Director Indicator (ADI)

STOL aircraft require more precise attitude data for rotation, climb-out, and landing approach than conventional aircraft and as a result require a more sensitive scale for monitoring this parameter than the 5° increments provided on most commercial and military units currently available. Advanced units configured for newer transport aircraft employ 1° increments over the attitude range of prime interest with larger 5° increments beyond this point. Other changes advantageous to STOL operation, depending on the degree of automatic flight control operation considered, involve the three-axis indicator (Fig. 13). In the absence of heading hold, which reduces the monitoring frequency of this parameter, a three-axis indicator can provide heading information and hence reduce pilot scan rate by centralizing more relevant data on a single instrument assembly.

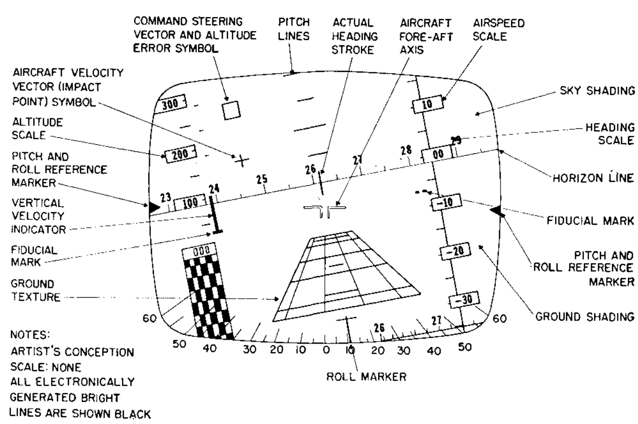

Fig. 14 Vertical situation display: contact analog mode.

Vertical Situation Display (VSD)

Advancing beyond the electromechanical limitations of the ADI, a relatively new unit known as the VSD has been introduced by the military. Using a high-brightness cathode ray tube and electronically generated symbols on a TV format, a much more flexible information presentation is available for discrete, representative displays, and flight cues unencumbered by mechanical limitations. Of particular advantage to STOL aircraft operation is the IFR landing display, which provides a perspective, variable-size, contact analog runway presentation, ILS command steering and deviation symbols, heading, altitude, and airspeed scales in digital form, and an aircraft symbol (Fig. 14). Although this type of display has received enthusiastic pilot comment during simulator studies, operational data are limited at this time. Inherent reliability of this unit can readily exceed 5000 hr; however, it is anticipated that periodic display tube replacement (preventive maintenance) within this interval will be required to attain this figure operationally.

Summary

Low-speed, high-lift characteristics make the STOL type of aircraft uniquely suited for short-haul transport operation within relatively confined areas and on short runways. However, this will introduce a need for increased pilot skill and proficiency in all phases of operation. A high degree of reliability in the man-machine systems must therefore be available to insure confidence and maximum safety of the STOL mode. The necessity for a very rapid and precise response of the STOL aircraft in the low-speed regimes requires control system augmentation. To utilize the peculiar capabilities of these airplanes to their fullest extent, certain changes in air traffic control must be made. Finally, different methods of using the presently installed navigational aids as well as associated cockpit instrumentation will be required.

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