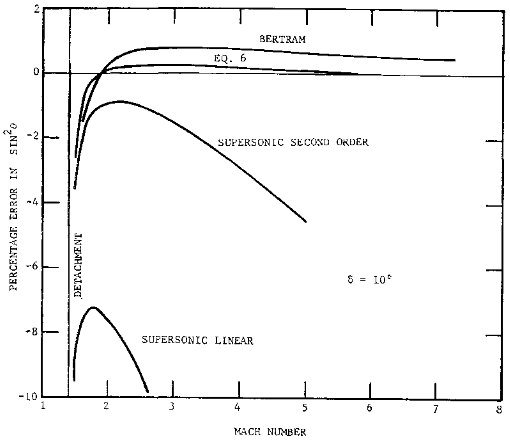
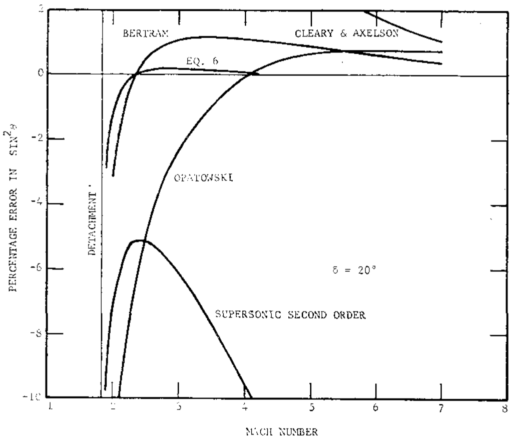


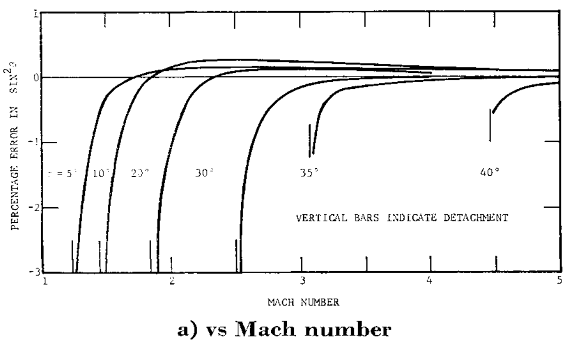
a) Deflection angle of 10°



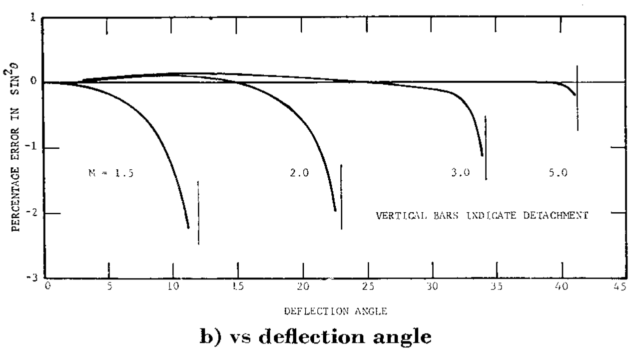
b) Deflection angle of 20°

Fig. 2 Accuracy of various approximations vs Mach number.

In Fig. 1a, at $M = 1.5$, Eq. (6) is seen to be slightly better than the supersonic second-order theory and Bertram's hypersonic theory, which are practically coincident, and much better than the supersonic linear theory. Approximations



a) vs Mach number



b) vs deflection angle

Fig. 3 Accuracy of present approximation.

such as those of Cleary and Axelson or Opatowski are off-scale on this figure. At $M = 3$ (Fig. 1b), Eq. (6) is seen to be greatly superior to any of the other approximations. In Fig. 2, Eq. (6) is seen to be better than the other approximations for 10° and 20° deflection angles. Figure 3 indicates that Eq. (6) is quite accurate, except very close to detachment, even for very large deflection angles. Further improvement at the lower Mach numbers is possible through the use of an additional iteration formula applied to Bertram's equation before substitution into Eq. (2). However, the added complexity of the resulting equations is not justified by the improvement gained.

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VS/TOL All-Weather Guidance

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In spite of some problems still unresolved, there is every reason to believe that an economically viable V/STOL aircraft will be developed and will serve as a competitive medium of intercity short-haul transport in the 1975–1980 time period. The success of V/STOL vehicles to fill a mass transportation role depends heavily on their ability to operate under all weather conditions.

Analyses and studies such as those made by McDonnell Aircraft Company[1] and Stanford Research Institute[2] provide useful guidelines on the nature of typical intercity operations and furnish a tentative set of requirements for an all-weather guidance system. They show that the greatest commercial potential for V/STOL aircraft is on intercity routes of less than 500 miles. Requirements for V/STOL airport design, air traffic control and navigation system, and approach and landing aids are linked with such factors as the economics of urban land values, flow of other traffic modes, location of ports, vehicle characteristics, and the mix of other air traffic.

Requirements

For maximum utility, V/STOL aircraft must operate close to downtown areas, using ports located alongside the waterfront or other open areas surrounded by obstructions. To be economically competitive, a V/STOL transportation system must also achieve schedule reliability equivalent to or better than conventional aircraft. Providing service under instrument conditions, making optimum use of low-altitude airspace, and taking full advantage of the flight characteristics

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of V/STOL aircraft are the goals of the guidance system development program.

A total V/STOL navigation system must consider the enroute, terminal, and approach and landing phases. The approach and landing element presents the major problem since it involves operation in a new physical environment. New techniques are required for overcoming operational limitations imposed by the size of the V/STOL port, its location in downtown metropolitan areas, obstruction clearance problems, and the desire to operate at minimum noise levels in this environment.

It becomes apparent that the approach and landing aid for these ports must have features to accommodate steep low-speed flight profiles with variable glide-path angles as high as 15°. The need to provide high-quality course structures in spite of the presence of numerous interference sources implies microwave frequencies for the guidance source.

Techniques Explored

Enroute and terminal

For enroute navigation, the similarity of flight profiles between V/STOL and conventional aircraft for stage lengths of up to 500 miles suggests the use of present VORTAC facilities. They provide adequate coverage at minimum, enroute altitudes in many high-density traffic areas, and there is every reason to believe that conventional VORTAC accuracies are adequate for enroute V/STOL flight in the present time frame. Looking toward the future, however, when better airspace utilization would be beneficial, VOR accuracy of better than $\pm 1°$ can be achieved through use of Doppler and precision VOR (PVOR) developments, on which much progress has already been made.

For the terminal area, a first approach has been to determine the suitability of the existing enroute navigation system since this has obvious economic advantages. An FAA study to determine the suitability of DME (distance-measuring equipment)/DME (rho/rho) helicopter navigation in the New York metropolitan area concluded that 1) a rho/rho system provides relatively many station pairs suitable for navigation over proposed routes, and 2) system navigation error (2-sigma deviation) will not exceed 0.3 naut miles in cross-course and along-course directions for any given route.

The analysis, which may be applicable to other terminals such as Los Angeles, indicates that, with regard to coverage down to practical, enroute altitudes with operationally usable accuracy, the current short-distance navigation system can be used for both enroute and many terminal area V/STOL operations. This includes application of the VORTAC system for area coverage navigation, with the use of suitable cockpit pictorial displays.

Approach and landing

The totally new components of any V/STOL guidance system are those associated with approach and landing. Military developments now underway may have application for future civil use. These tactical military developments are lightweight, portable microwave equipments combining localizer and glide-path functions in a single unit, some also providing range information (DME). The following brief descriptions cover some types under development and evaluation by the military services:

1) STATE (simplified tactical and terminal equipment): a microwave (C-band) pulse equipment that provides vertical and lateral guidance over a limited azimuth sector and omnidirectional range and range-rate information. The airborne receiver feeds a conventional course deviation indicator with range and range-rate displayed on dial indicators.

2) TALAR (tactical landing approach radar): a microwave (Ku band) equipment providing vertical and lateral guidance no a standard cross-pointer instrument. The beam width coverage is $\pm 3°$ in the vertical plane and $\pm 18°$ in azimuth. No distance information is provided.

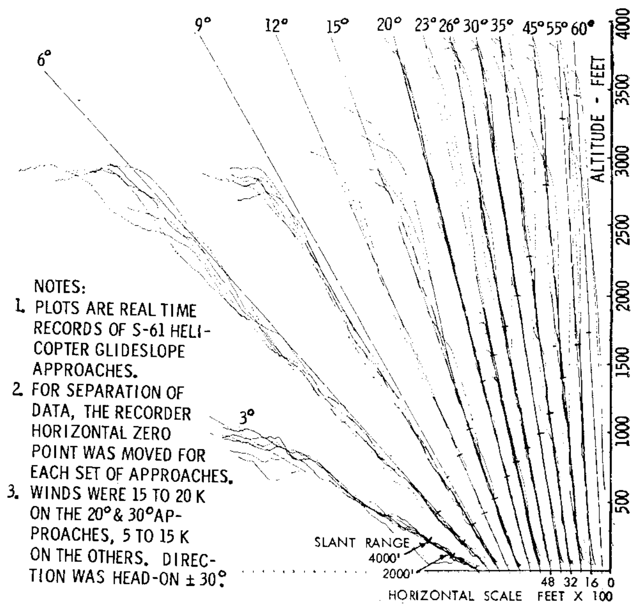

Fig. 1 Family of plots: glide-path tracks.

3) AILS (advanced integrated landing system): a scanning beam guidance system in the Ku band which provides full air-derived landing guidance, including DME. The localizer station contains the DME transponder and can be located on the extended runway centerline at the stop end. Ten degrees of antenna scan are provided for both azimuth and elevation. Simplification of the ground station will be necessary for V/STOL use. Collocation of both guidance elements into one ground station is considered possible by relaxing requirements for guidance signals to touchdown.

4) SAILS (simplified aircraft instrument landing system): a microwave X-band airborne radar and computer which provides the pilot with selectable vertical and lateral guidance and range information. A small omnidirectional ground unit serves as a radar beacon and replies only when interrogated from the aircraft. Selectable glide slopes from 6–12° and azimuth coverage of 360° are displayed on conventional cockpit instruments.

FAA development effort for a V/STOL approach and landing system (VAPS) began in 1963, prior to many of the foregoing developments. Since then, an experimental system has been flight tested at the National Aviation Facilities Experimental Center, Atlantic City, N. J.

The ground station is a single 5-ft-high unit housing the localizer and glide-path antennas and the transmitter. The localizer antenna has a 360° rotation. Azimuth orientation of the glide-slope antenna is fixed to that of the localizer, but its path may be set to any angle from 0–90° in elevation. Handwheel operation rotates the antennas in azimuth and elevation to facilitate desired changes in landing direction for wind changes, or to change glide-slope angles suitable to a heliport environment.

The transmitter generates two channels of CW microwave energy in the Ku band, with power output of 4–8 w. As in conventional ILS, the audio modulation frequencies are 150 and 90 Hz.

Dual receiver installations were made in two helicopters. Using a CH-34C helicopter, glide angles from 3–30° were flown in 3° increments. Angles from 3–60° were flown with an S-16N helicopter. The high-angle approaches were found to be informative in that potential problem areas were encountered, such as loss of visual reference to the heliport and reduced helicopter controllability.

Figure 1 is a composite plot of the helicopter glide-slope tracks recorded and shows that, in general, track dispersions

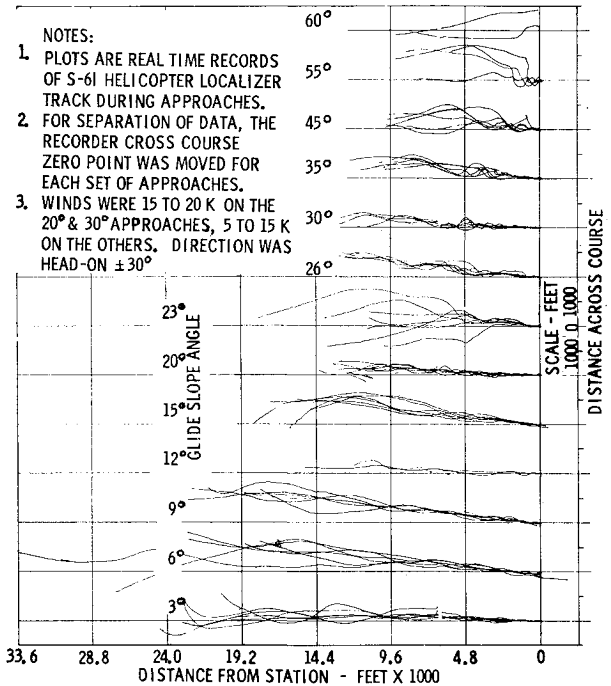

Fig. 2 Family of plots: localizer tracks.

increased with higher approach angle. Pilots' comments on flight ability at the steeper angles emphasize the difficulties encountered in maintaining a good track. Similar results were obtained in tracking the localizer course as shown in the composite plot of Fig. 2.

Pilots' difficulty in maintaining satisfactory tracking at high approach angles was also reflected by an increase in magnitude and variation in rate of descent. For the 3° glide slope, the rate of descent varied from 100 to 700 ft/min, and increased to from 400 to 3000 ft/min at 35° and higher. Such variations in rate of descent are not considered acceptable.

More study is needed before the selection of an optimum glide-slope angle can be made for each type of vehicle. Some conclusions and recommendations resulting from these tests are:

1) 15° maximum glide-slope angle for V/STOL operation.

2) 20–30° minimum localizer course width. ±5° localizer width was found to be too narrow at close proximity to the ground station. A means of providing course softening is required.

3) Greater glide-slope path width than that of present ILS is needed.

4) DME to provide approach progress information is desirable.

Similar tests of steep-gradient glide paths were flown using the Helio Super Courier Aircraft Model H-395 (STOL aircraft) to assess its IFR performance capability. Although approach speeds were nominally 60 mph at 6° approach, 50–55 mph at 9°, and 45–50 mph at $10\frac{1}{2}$°, the pilot workload increased directly with the increase in glide-slope angle. Widening of the course width to a minimum of 3° for a 9° angle glide slope was recommended by the test pilot.

Knowledge derived from these tests will be appropriately incorporated into design requirements for future equipment. A capability for changing glide-slope angles in the ground equipment or selecting glide-slope angles by the pilot, from 3–12°, is highly desirable. Coupling of low-approach guidance signals to the flight-control system has yet to be explored and will be required for all weather landing.

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