Proposed STOL Definition and Field Length Criteria

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The effective use of STOL in the efficient door to door transportation of people is dependent upon special capabilities which allow the aircraft to operate safely in restricted areas. A definition of STOL must therefore be in terms meaningful to the problem, but permitting full realization of STOL operational benefits. This paper describes STOL field length, terminal area performance and minimum handling qualities requirements which are considered essential for safe, efficient STOL operations. They are expected to provide an improved level of safety over present CTOL operations and allow full utilization of STOL aircraft capabilities. Field length assurance criteria includes no arbitrary factors whatever, but provides for a rational/statistical approach for certification, a reliable means for the pilot to continually compare his situation to the certification conditions, and a predetermined course of action for any problem during takeoff or landing. These specifications are meant only to distinguish between STOL and CTOL aircraft, and are not intended to replace other specifications or regulations needed to ensure airworthiness or handling qualities. An aircraft should be called "STOL" only if it meets these requirements.

Introduction

THE purpose of this definition is to quantitatively define the minimum requirements and parameters of a STOL system essential to safe operations at congested metropolitan STOLports, without unnecessarily restricting the aircraft design or operation. Aircraft, landing facilities, and other elements of the system can be labeled STOL only if they meet these requirements.

The purpose of STOL is to help solve the problem of the efficient door to door short-haul transportation of people. Conventional aircraft have proven inadequate for this purpose due to congestion and lack of convenient locations for large new airports. The effective use of STOL is dependent upon special performance capabilities which allow the aircraft to operate safely in a restricted area. STOL must therefore be defined in terms of safety and restricted space operations, since these are the terms meaningful to the problem.

One of the problems to be solved is rapid access of the passengers to the aircraft. Because of ground traffic congestion, the solution requires locating the STOLport near the people. This means flight operations relatively close to buildings, populated areas and obstructions. More becomes involved than just the aircraft, for example; approach and departure routes and procedures, facility restrictions, obstacle clearance, and navigation aids. The problem is complex, and its solution requires the control of all elements affecting the operation. A systems approach is clearly needed.

City-center and suburban STOLport sites will impose certain constraints upon the system which will have significant influence on the aircraft design and operations. A reasonable statement of these system constraints must be made; not to arbitrarily limit the system, but to acknowledge the presence of the constraints and identify them. This is necessary to provide adequate guidance to those working with the various elements in order to develop the best coordinated system practically attainable.

The requirements specified herein are intended only to define STOL and terminal area safety. It is not intended to define an aircraft which is airworthy or acceptable from pilot handling qualities or passenger riding qualities standpoints, for which other documents apply.

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STOL Definition

Field Length

This is to be defined as 1800 ft + 100 ft maneuvering space at each end for a total surface length of 2000 ft. (1900 ft clearway may be used for takeoff). City planners indicate they can probably provide up to 2000 ft for a STOLport, but they object to anything longer. They complain of being "hundred-footed to death." One hundred feet of aircraft maneuvering space at each end would be sufficient and permit the maximum runway length possible (1800 ft). It is reasonable to expect city-center STOLport access to be partly by Intrametropolitan third-level (air-taxi) feeder service from dispersed suburban STOLports with small, Twin Otter type aircraft. Simple and complex STOL aircraft can both operate safely from an 1800 ft runway, each with its own advantages and disadvantages. The carrier can choose the type of service he wants to provide and can afford.

Takeoff Flight-Path Gradient

The suggested gradient is as follows: (+) 6.0° minimum (normal); (+) 4.4° minimum (second segment with one engine failed). The 6.0° normal climbout will provide good clearance above obstacles and minimize noise exposure on the ground. The 4.4° second segment for the engine failed case will provide a 1% gradient above the approach surface. Steeper gradient requirements, especially for the engine-failed case, could dictate a thrust-to-weight ratio too high for an 1800 ft field length. A shorter resultant takeoff field length would seriously increase direct operating costs.

Landing Flight-Path Gradient

The suggested flight-path gradient is (−) 7.5 degrees. This optimum final approach and landing flight-path gradient for STOL aircraft has been determined from several FAA and NASA flight test programs on different type STOL aircraft. Use of steeper angles are not operationally practical due to pilot visibility limits and performance requirements needed to capture, follow, and recapture the glide-slope.

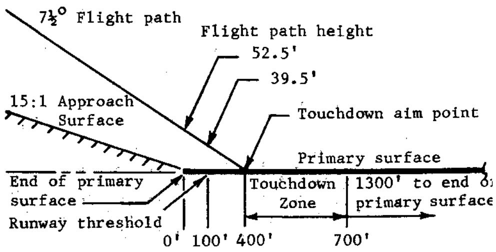

Fig. 1 STOLport approach profile.

Approach Surface Slope

The desired approach surface slope is 15:1 (3.8°). This slope is compatible with the takeoff and landing flight-path gradients defined above and provides the best practical obstacle clearance heights. The relationship of this approach surface slope to the flight-path gradient is shown in Fig. 1.

STOLport Criteria

These are identical to criteria in the FAA Advisory Circular except as noted herein.[1] Exceptions to the FAA Advisory Circular criteria are the runway threshold marking, the touchdown zone and take-off decision point. Other provisions of the Advisory Circular are acceptable. It should be noted that since this Advisory Circular is under revision, these comments necessarily apply to only the specifically referenced issue.

Turning Radius

The turning radius in the terminal area should be 1500 ft. The 1500 ft turning radius is based on an assumed approach over the end of a runway on which the landing is required in the opposite direction. A 90°/270° turn aligns the aircraft with the runway 1000 ft from the threshold as shown in Fig. 2. The maximum expected bank angle and load factor expected for zero wind conditions are 28° and 1.14 g (i.e. $+0.14\ g$ incremental), respectively.

Normal Load Factor

This criterion is (+) 1.30 g (i.e., + 0.3 g incremental) in landing configuration. Power application may be used if thrust response time constants are acceptable. $+0.3\ g$ incremental normal acceleration will permit breakout at 100 ft height above runway surface (Category II), a 2 sec pilot/aircraft reaction time allowance, and a fully arrested sink rate 35 ft above the primary surface. This can be performed with power application, but thrust response time constants will probably have to be better than 0.5 sec.

Bank Requirements

10° change in bank angle should be accomplished in not more than 1.0 sec, in takeoff, landing and wave-off configurations. Important for gust upset control, it is based on NASA Ames' requirement of no more than 2.9 sec to bank 30° (Ref. 2). The immediate response is felt to be critical, however, so it is stated here for 1.0 sec.

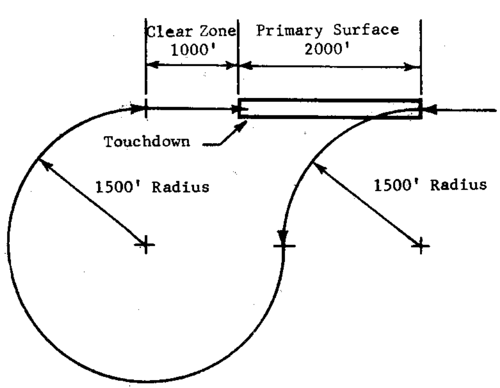

Fig. 2 STOL aircraft turning radius.

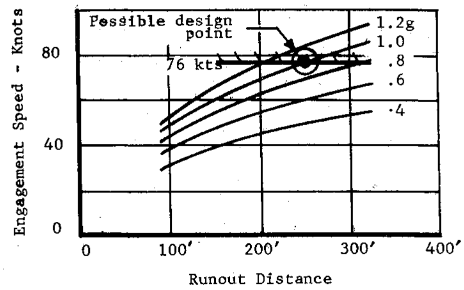

Fig. 3 End arrestment decelerations.

Control in Crosswind

The aircraft will be controllable during maximum defined crosswind with regard to trim, upset and maneuvering capability during all terminal area operations.

Windspeed

The windspeed during which STOL flight operations will be permitted will be determined for each different type of aircraft by the user. The permissible wind levels will affect the aircraft design and cost. It should be left up to individual choice, since it affects the service reliability instead of safety. For airline operations where schedule reliability is of primary importance this level is expected to be at least 25 knots, perhaps as high as 35 knots.

Crosswind Component

The crosswind component for STOL flight operations will be determined for each different type of aircraft by the user. The same reasons apply as for the windspeed discussed above. Since STOLports in congested areas will likely be limited to one runway heading, crosswinds could be as large as 25 to 35 knots.

Tailwinds

Tailwinds equal to the windspeed will be encountered in the terminal area, but no downwind operations will be permitted during final approach and landing or during the takeoff roll. Tailwinds have a large effect on STOL runway length requirements, and cannot be permitted.

Stall Margins

There will be no altitude loss greater than 35 ft, no load factor increment greater than $\pm 0.30\ g$, no loss in control, nor a change in bank angle greater than 15° nor a change in pitch angle of 5°, as a result of a horizontal gust from the worst direction equal in magnitude to 50% of the wind speed, or a vertical gust equal in magnitude to 25% of the wind speed. This requirement is applicable whether the aircraft is subject to stall or not. A stall is not hazardous, but rather the consequences of a stall, such as undesirable losses in altitude or control, or changes in aircraft attitude. Some types of STOL aircraft are not subject to normal aerodynamic stall, but can still get into some of the undesirable or dangerous flight conditions which are normally the consequences of aerodynamic stall of a conventional aircraft. Power variations may be used if the thrust response time constants are adequate.

Waveoff

A waveoff will be possible without touching down at any time during landing before the decision is made to land.

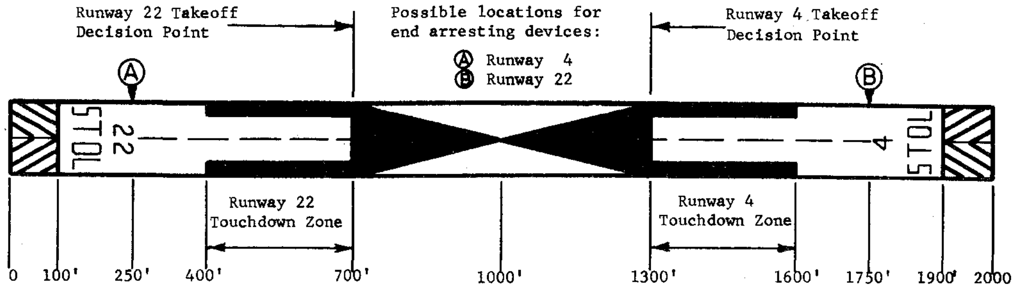

Fig. 4 STOL runway markings.

After the decision to land is made a touch-and-go will be permitted. Pilot confidence and safe day-in and day-out operations in all weather require "outs," such that the pilot can use his judgment and start over at any time during final approach and landing. Configuration changes such as partial flap retraction may be required, and would be permitted if fast, reliable operation is provided.

Arresting Barrier

Aircraft arresting devices along the sides and ends of the STOLport runway will probably be required and are acceptable for emergency use only. Side arrestment will be important due to the crosswind landing requirements. Engagement of the end devices would be under conditions similar to those presently resulting in aircraft running off the ends of conventional runways, but the probability would be less because of the improved landing guidance to be described. Much work remains to be done in this area. A runout distance of 250 ft (i.e., distance from device to end of primary surface) would require an average deceleration of 1.0 g for an engagement speed of 76 knots.† Since most engagement speeds would be much lower, this may be a good design point. Variation of runout distance with engagement speed is shown in Fig. 3.

Propulsion System Failure

The probability of any failure occurring in the propulsion system such that the aircraft cannot meet the performance, maneuvering and safety requirements described herein will be less than 1.0×10^{-8}. The objective here is to ensure safe STOL operations, which may involve flight below the power-off stall/control speeds. Several different means are possible for providing the required level of safety including multiple engines, thrust-interconnects, cross-ducting, etc. The 1.0 in 10^{-8} is essentially a crash probability.

Combined Requirements

Appropriate combinations of the above requirements will be determined by the user or STOL operations will be restricted in order to accomplish the intent of the requirements.

Certain combined conditions must be considered, but where they affect schedule reliability rather than safety the requirements will be left up to the user. For example, the 1500 ft turning radius is no big problem, but to meet that requirement with one engine failed at a 4.4° climbout in a 35-knot crosswind could be difficult.

STOL Runway Markings

The STOL runway markings are similar to those specified in the FAA Advisory Circular and are shown in Fig. 4. The differences proposed are markings for 1) runway threshold, 2) touchdown zone and 3) takeoff decision point. A STOL aircraft would normally be at about 67 KTAS (Knots True Airspeed) at the takeoff decision point. Takeoff speed is expected to be in the order of 76 KCAS (Knots Calibrated Airspeed).

The relationship of the 700 ft touchdown zone end/takeoff decision point to the barrier location is better understood from studying Fig. 4 and Table 1.

This results in the aircraft nose presumably extending beyond the end of the primary surface, which is not desirable. It should be recognized, however, that this is a possibility for any arresting device location, and the only difference is in the probability of occurrence which would be quite small in this case due to the conservatism of the design point conditions. This conservatism consists of the following assumptions: a) no headwind (T. O. and landing); b) takeoff refusal at 76 knots takeoff speed (T.O.); c) touchdown at end of touchdown zone (landing); d) 2-sec delay at 76 knots (T.O. and landing); e) arrestment at full 76 knots (T.O. and landing)

STOL Field Length Determination

These STOL field length certification requirements do not include arbitrary safety factors, such as those provided for CTOL aircraft. This is due to the inadequacy of such factors to provide the required level of safety for STOL aircraft. It should be emphasized that the field length is already known: it is defined as 1800 ft. The requirement is to assure that STOL aircraft can operate from the 1800 ft field with the desired probability of safety.

A rational, statistical probability method is used to define limits and procedures which will provide this assurance. Special reference aids are provided to assist the pilot in continuously comparing the situation to the certification conditions. Predetermined emergency procedures would be followed in the event the certification conditions are exceeded. Special landing aids are provided to direct the pilot to a precise touchdown, and specific runway markings provide missed approach (landing) and abort (takeoff) guidance to the pilot. In addition, side and end arresting barriers are provided to safely stop the aircraft in the unlikely event this becomes necessary. This would probably happen only in the event of a multiple failure of some type.

The statistical probability of significant flight conditions will be design parameters and will be confirmed by flight test by airline pilots as part of the STOL field length certification. These conditions are outlined in this paper in the Appendix. A probability distribution is required for each variable. This method will ensure a greater and more consistently controlled

Table 1 Emergency end barrier location

Event	Runway station, ft
T.O. refusal/T.D.	700
2 sec delay @ 76 knots (256 ft)	956
0.333 g decel to stop (769 ft)	1725
End arresting device location	1750
End arresting device runout (250 ft)	2000

† FAA, NASA and airline pilots who have flown STOL aircraft do not want to exceed a sink rate of 1000 fpm below a height of 1000 ft. On a 7.5° descent gradient, this equates to 76 knots.

Table 2 Landing field length assurance criteria

Landing phase	Pilot action required	Decision point	Adverse situation	Specific problem	Basis for definition	Pilot's reference
Before touchdown	Waveoff	End of touchdown zone	Excess speed at touchdown	Excess speed at threshold	See note 1	Airspeed or angle-of-attack indicator
				Excess speed at touchdown	" " 2	Airspeed or angle-of-attack indicator
			Touchdown too far down runway	Too high over threshold	" " 3	VASI type landing aid
				Floating	" " 4	Touchdown zone marked on runway
				Sink rate at touchdown	" " 5	Visual reference
			Lateral alignment	Touchdown off center	" " 6	Runway markings
				Lateral speed at touchdown	" " 6	Visual reference
After touchdown	Prepare to engage the end arresting barrier	None	Excess speed at start of deceleration	Excess speed at start of deceleration	" " 2	Airspeed or angle-of-attack indicator
			Low deceleration force	Wet runway	" " 7	Decelerometer
				Icy runway	" " 8	Decelerometer
				Worn tires	" " 9	Decelerometer
				Low braking torque	" " 10	Decelerometer
				Reverse thrust failure	" " 8	Decelerometer

level of safety for STOL than that presently provided for CTOL.

Landing Field Length Criteria

Table 2 lists the various types of adverse situations which affect the landing field length and the way it is determined, monitored and controlled. Note that it is considered in two separate phases and controlled accordingly. An adverse situation occurring during the first (before touchdown) phase requires a waveoff, because the probability of engaging the end arresting barrier is high in the event the deceleration factors (i.e., runway surface conditions, braking torque, reverse thrust, etc.) are either collectively adverse or would be insufficient to compensate. An adverse situation occurring after touchdown could result in end arresting barrier engagement (but not necessarily), and the pilot should react accordingly. Note that full credit for reverse thrust, anti-skid braking, grooved runways, etc., can be taken to the limit it can be substantiated to the required probability.

Takeoff Field Length Criteria

Table 3 lists the various types of adverse situations which affect the takeoff field length and the way it is determined, monitored and controlled. Note that it is considered in two separate phases and controlled accordingly: an adverse situation occurring before reaching V_1 (accelerate-stop situa-

Table 3 Takeoff field length assurance criteria

Takeoff phase	Pilot action required	Decision point	Adverse situation	Specific problem	Basis for definition	Pilot's reference
Before reaching V_1	Abort takeoff See Appendix, note 11	Takeoff decision point	Low total thrust	Engine performance below certification limits	See note 12	Airspeed indicator and takeoff decision point
				Sudden thrust loss	See Appendix, note 13	Airspeed indicator and takeoff decision point
After reaching V_1	Continue takeoff	Takeoff decision point	Low total thrust	Sudden thrust loss	See Appendix note 14	Airspeed indicator and takeoff decision point

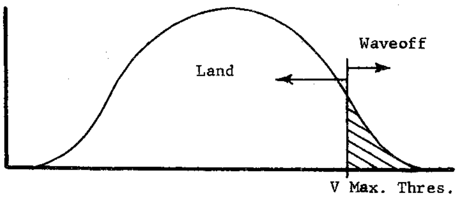

Fig. 5 Airspeed at threshold.

tion), and an adverse situation occurring after reaching V_1 (continued takeoff situation). V_1 is the takeoff decision speed, and may or may not be the refusal point for a balanced field length. A 2 sec allowance will be made for delays in operating deceleration devices. This means 2 sec. from problem recognition to full effectiveness of all deceleration devices. Flight test must confirm this capability to within the desired probability.

Landing Waveoff and Refused Takeoff Propability

The methods proposed for controlling STOL field length essentially define landing waveoff and refused takeoff probabilities. If the acceptable limits of the takeoff and landing conditions are too severe there will be too many landing waveoffs and refused takeoffs or the aircraft will be too difficult to fly. Obviously, the required safety cannot be attained if the limits are too broad. The preferred STOL aircraft will inherently have small variations in the takeoff and landing variables and require a minimum of pilotage to maintain those variations. The probabilities of each variable must be combined to determine the total probability of certificable conditions or design considerations resulting in a landing waveoff or takeoff refusal. The total probability should be less than 1 in 1000 for a waveoff and less than 1 in 10,000 for a takeoff refusal. This method will ensure a greater and more consistently controlled safety level for STOL than presently provided for CTOL.

Appendix: Notes

1) The maximum certification airspeed reasonably expected over the threshold ($V_{\text{Max. Thres.}}$) will be determined from flight test to within the required probability as shown in Fig. 5.

2) The maximum certification touchdown airspeed ($V_{\text{Max. T.D.}}$) reasonably expected will be determined from flight test to within the required probability as shown in Fig. 6. This is the same speed for the start of the deceleration.

3) The maximum height over the threshold ($H_{\text{Thres.}}$) is 70.0 ft based on STOL field and 7.5° flight-path geometry. Confirmation from flight test must show that this is attainable within the required probability as shown in Fig. 7.

4) Floating is one of several factors which affect the touchdown point. Confirmation that touchdowns will occur within the allotted 600 ft must be substantiated by flight test to within the required probability as shown in Fig. 8.

5) NASA flight tests have indicated pilots prefer not to exceed $R/S = 1000$ fpm (i.e., 16.7 fps) below 1000 ft altitude. This maximum sink rate must be confirmed by flight test to the required probability as shown in Fig. 9.

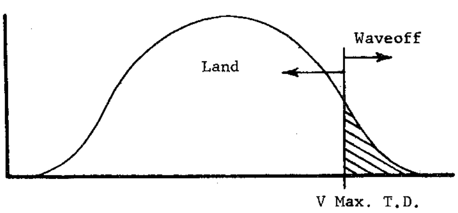

Fig. 6 Airspeed at touchdown.

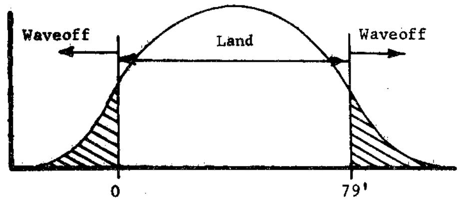

Fig. 7 Height over threshold.

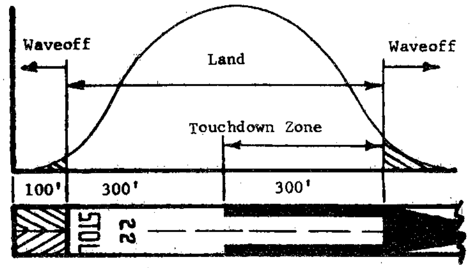

Fig. 8 Touchdown zone.

6) Off runway centerline touchdowns are expected to be a problem during crosswind landings, and are greatly affected by the width of the runway. Limits are shown in Figs. 10 and 11.

7) STOL runways will be grooved. The deceleration on the wet, grooved runway will be confirmed by flight test to the required probability as shown in Fig. 12. This will allow credit for reliable benefits of grooving.

8) Statistical weather data and reverse thrust failure analysis will be combined to show that the chance of an icy runway and a reverse thrust failure occurring simultaneously is within the required probability.

9) Deceleration performance will be determined to the required probability from flight tests with all tires at their tread wear limit.

10) Deceleration performance will be determined to the required probability from flight tests with all brakes at their replacement limit condition. This will also allow credit for reliable use of such devices as nosewheel brakes and antiskid.

11) In the event of an aborted takeoff (accelerate-stop situation) the "after touchdown" phase of the landing field length assurance criteria will apply. End arresting barrier engagement is possible, but unlikely. The airspeed occurring

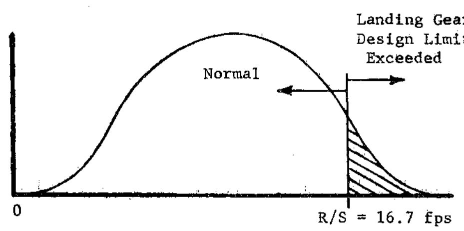

Fig. 9 Sink rate at touchdown.

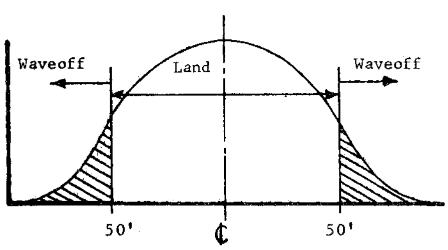

Fig. 10 Off centerline touchdown.

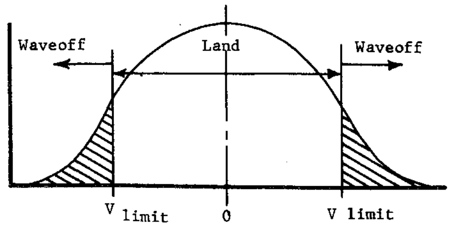

Fig. 11 Crossrunway speed.

at the takeoff decision point (see the preceeding Sec. STOL Runway Markings) must be compatible with the V_1 speed definition and requirements.

12) The aircraft operator will define the engine power/thrust deterioration limits he will accept. Acceleration performance will be based upon that minimum value, and propulsion system maintenance quality controls will be established to ensure the limit is not exceeded.

13) The takeoff will be aborted in the event of a sudden thrust loss, normally resulting from a sudden engine failure, occurring before passing the takeoff decision point. Automatic warning devices may be required.

14) The takeoff will be continued in the event of a sudden thrust failure after passing the takeoff decision point. In this event the aircraft must not descend below the flight-path gradient defined in the Sec. STOL System Requirements. Flight test must confirm this capability to within the required probability.

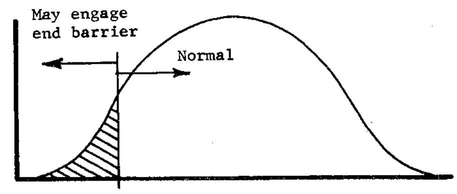

Fig. 12 Braking force on grooved, wet runway.

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[1] "Planning and Design Criteria for Metropolitan STOLports," FAA AC 150/5325, July 1970.

[2] Innis, R. C., Holzhauser, C. A., and Quigley, H. C., "Airworthiness Considerations for STOL Aircraft," TN D-5594, Jan. 1970, NASA.

[3] "Basis for Determination of the Operational Landing Field Lengths of Turbine Powered Airplanes," Engineering R and D Rept. 16A, Sept. 1961, American Airlines, Inc.

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Intercity V/STOL Service and the Businessman Traveler

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Nondemographic data, including attitudinal and preference structures, are generated for a demand analysis of two feasible V/STOL systems assumed to be suitable for operation in a business travel market composed of New York, Philadelphia, and Washington, D.C. A sample of frequent or potential businessman travelers was surveyed by a comprehensive questionnaire, the results serving as input to a linear, nondemographic factor, mode choice-market share model designed to predict modal splits in a future environment. The model is applied to the selected V/STOL designs and the resulting predictions are assessed with respect to technological planning.

I. Introduction

FORECASTS of the demand for V/STOL aircraft service in the Northeast Corridor and elsewhere generally rely on gravity, interactance, abstract, or utility models of modal split based on historical travel and demographic data. The techniques developed by Howrey and by McLynn and Woronka are typical demographical approaches.[1-2] Most V/STOL demand analyses with demographic foundations present an optimistic forecast; that is, they conclude that fast, short haul, intercity service at reasonable rates and with minimum ground connection delay will lure large volumes of travelers away from other modes of transportation. Critics challenge this optimism by arguing that travelers will not choose an unfamiliar aircraft with a potentially high accident rate, given the unlikely assumption, in their judgment, that V/STOL's will be permitted to land in downtown areas where noise and pollution levels are already unacceptable. The dilemma to the aircraft industry is enigmatic. Should aircraft be developed at great expense on the premise that travelers prefer the service that V/STOL's potentially offer? Suppose travelers are not willing to exchange the relative comfort, low cost, and low risk of conventional systems for the reduced travel time and greater convenience of a V/STOL system? On the other hand, even though travelers may prefer V/STOL's over other modes, local governments may banish them to conventional airports or to other suboptimal landing areas where their advantages are nullified. This latter prob-

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