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STUDY TO DETERMINE OPERATIONAL AND PERFORMANCE CRITERIA FOR STOL AIRCRAFT OPERATING IN LOW VISIBILITY CONDITIONS

by John A. Gorham

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Gorham Associates
P. O. Box 1347
Thousand Oaks, CA 91360

for

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Moffett Field, California 94035

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FOREWARD

A study was conducted for Ames Research Center in 1976 to determine the data requirements of the civil aircraft industry which could assist in the design of STOL aircraft GN & C systems. One of the areas identified which required further clarification was the low weather minima operation of STOL airplanes, since the significantly different characteristics of these aircraft indicated possible revisions to the criteria already well established for CTOL operation.

This study is intended to provide an information base on the applicability of current CTOL low weather minima operational criteria. It is not intended to make or suggest specific revisions to existing advisory circulars or other regulatory documents since this function is the prerogative of the industry and government groups concerned, and many factors which could not be covered in this document must be taken into account. The intent of this study is to identify potential areas for further debate or upon which useful and productive flight experiments can be based.

Reference must be made to the fact that enthusiastic cooperation and interest was shown by the various companies, individuals, and government agencies visited during the course of this study. However, significant impediment to a free exchange of information was caused by protraction of the Air Force selection program for a STOL airplane. In addition, fundamental changes in the most pertinent advisory circular relating to low weather minima operation, AC 120-28A, were also debated and decided during the course of the study program. Both these factors had an adverse impact upon the intended quality and timing of this report.

SUMMARY

The operational and performance criteria for civil CTOL passenger-carrying airplanes landing in low visibilities depend upon the characteristics of the airplane, the nature and use of the ground and airborne guidance and control systems, and the geometry and lighting of landing field. Based upon these criteria, FAA advisory circulars, airplane and equipment design characteristics, and airline operational and maintenance procedures have been formulated.

The appropriate documents have been selected, described, and discussed in relationship to the potential low weather minima operation of STOL aircraft. An attempt has been made to identify fundamental differences between CTOL and STOL aircraft characteristics which could impact upon existing CTOL documentation. Further study and/or flight experiments are recommended.

GLOSSARY OF ABBREVIATIONS

ACs	Advisory Circulars
ADI	Attitude Director Indicator
AEEC	Airlines Electronic Engineering Committee
AIA	Aerospace Industries Association
AL	Alert Height
ALPA	Air Line Pilots Association
ALS	Approach Light System
ARINC	Aeronautical Radio, Inc.
ARP	Aerospace Recommended Practices
AS	Aerospace Standards
ATA	Air Transport Association
ATC	Air Traffic Control
AWOP	All-Weather Operations Panel
AZ	MLS Aziumth Guidance
BCAR	British Civil Airworthiness Requirements
BITE	Built-In Test Equipment
CAA	Civil Airworthiness Authority (British)
CL	Center Line Lights
CRT	Cathode Ray Tube
CTOL	Conventional Take-Off and Landing
DH	Decision Height
DME	Distance Measuring Equipment
DOT	Department of Transportation
EADI	Electronic Attitude Director Indicator
EHSI	Electronic Horizontal Situation Indicator
EL	MLS Elevation Guidance
FAC	Final Approach Course
FAF	Final Approach Fix
FARs	Federal Aviation Regulations
FAS	Final Approach Surface

GN&C	Guidance, Navigation, and Control
GPI	Glide Slope Intersection
GS	Glide Slope
HSI	Horizontal Situation Indicator
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
INS	Inertial Navigation System
LOC	Localizer
LWM	Low Weather Minima
MALS	Medium Intensity Approach Light System
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
MLS	Microwave Landing System
MOC	Minimum Operational Characteristics
MODILS	Modular Instrument Landing System (developed experimental system for STOL by the FAA)
OC	Obstruction Clearance
OFZ	Runway Obstacle Free Zone
RL	Runway Edge Lights
ROC	Required Obstacle Clearance
RVR	Runway Visual Range
SAE	Society of Automotive Engineers
SALS	Short Approach Light System
SAS	Stability Augmentation System
STOL	Short Take-Off and Landing
SVR	Slant Visual Range
TARC	Transport Aircraft Recommended Criteria
TCH	Threshold Crossing Height
TDZ	Touch Down Zone Lights
TERPS	United States Terminal Procedures Standards
TRSB	Time Reference Scanning Beam
VASI	Visual Approach Slope Indicator
V/STOL	Vertical/Short Take-Off and Landing

1.0. INTRODUCTION

The operational and performance criteria for civil CTOL passenger-carrying airplanes operating in weather limits lower than Category I (1/2 mile and 200' decision height) have now been established through Category II (1200' and 100' decision height), to include Category IIIA (700' and no decision height). These criteria depend heavily upon the characteristics of the airplane, the nature and use of the ground and airborne guidance and control systems and the geometry and lighting of landing field. Based upon these criteria, a number of FAA Advisory Circulars, airplane and equipment design characteristics and airline operational and maintenance procedures have been formulated.

Recently, approval has been granted to operate a specific airline aircraft type fitted with a fail-passive automatic landing system to as low as 50 feet decision height, indicating that airplane handling qualities have a significant influence upon decision heights in low visibility operations.

It is apparent that many of the factors upon which the CTOL low-weather operational categories were based are not the same for a STOL airplane. Glide slope angle, approach speed, maneuverability, even runway size and runway lighting may be considerably different. Examination of the applicability of the CTOL criteria is particularly important so far as the cost-effectiveness of the STOL airplane is concerned. Equipment to operate CTOL airplanes to Category II limits is costly and the costs of operating airplanes to Category III limits will be many times greater. If the STOL airplane can achieve better arrival certainty in low visibility conditions for the same or less total cost than the CTOL, this could be one of the factors upon which the effectiveness of the STOL airplane may be judged.

This study will examine these potential differences and relate them to the design and operational criteria for civil STOL passenger-carrying operations. Where these criteria are not obvious, studies and/or flight experiments will be recommended which could clarify any uncertain areas.

2.0. LOW VISIBILITY DOCUMENTATION AND CRITERIA

2.1. General

The safe operation of civil aircraft under all flight regimes in the USA is regulated by the Federal Aviation Administration. For convenience, and so that the regulations are appropriate to the size and operational use of the aircraft concerned, the regulations are divided into basic parts or sections. For instance, regulations relating to airworthiness standards of airline transport category aircraft are contained in Part 25 - "Airworthiness Standards: Transport Category Aircraft", and those relating to certification and operational use of airline transport category aircraft are contained in Part 121 - "Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft". Other classes of aircraft are covered by their own appropriate sections or parts, but in all cases the basic purpose is to specify an engineering or design criteria requirement and an operational (or use) requirement for specific aircraft types. Most of these criteria will be directly applicable also to a STOL aircraft since the same basic safety standards for design and operation must apply. Additional criteria related to any unique design or flying qualities of the STOL aircraft, however, might cause additions or amendments to the existing criteria. FAA/NASA Report - "Progress Toward Development of Civil Airworthiness Criteria for Powered-Lift Aircraft" provides results of one study of possible new requirements in this regard. As will be discussed later, the flying qualities of a STOL airplane will also influence its low weather minima operation capability especially in terms of decision height when related to forward visibility. Apart from the basic criteria discussed here, the landing operation of civil passenger-carrying aircraft under IFR and very low visibility conditions are also covered quite thoroughly in various other documents - some guidance and others regulatory in nature. These documents range from ICAO criteria concerning physical airport and radio beam characteristics, to specific sections of FAA regulations - Parts 25, 121, 135, etc.

'TERPS' - Terminal Area Instrument Procedures, and FAA advisory circulars also provide information relating to operation in low visibilities. The following sections will describe only those criteria which are applicable to low weather minima operation of civil passenger-carrying transport aircraft. All of the relevant criteria will be described, but only those sections which may need special consideration with respect to STOL aircraft will be discussed in the appropriate degree of detail.

A more overall description of the applicability of these criteria to the design and operation of a STOL civil transport aircraft is contained in a recent NASA report by the author, "Study of Information Requirements for Flight Control and Navigation Systems of STOL Aircraft". This report discusses the inter-relationship of industry and government criteria to the design and operation of STOL aircraft.

2.2. ICAO Criteria and Documentation

The general operation of ICAO is also described in the above referenced report. The two primary areas of ICAO influence upon the low weather minima operation of U.S. civil air transport aircraft are: (a) the recommendations contained in Annex 10 to the Air Navigation Commission, and (b) the discussions and agreements of the All Weather Operations Panel (AWOP), which was established by the Commission in 1963. The principles of operation of civil air transport aircraft in visibilities below 1/2 mile were initially discussed in great detail for ten days during an IATA sponsored technical conference held in Lucerne, Switzerland, in 1963. Certain basic concepts and tenets for safe operation were established during this conference, and these have formed the basis of nearly all the practices and documentation, including the ICAO criteria, which exist today.

2.3. Principles of Low Weather Minima Operation

The 15th Technical Conference of IATA was based upon the establishment of three phases for "All-weather" operation of civil aircraft. Appendix B provides the objectives set by IATA prior to the conference. One important outcome of the conference was the agreement of the currently well known categories set out below:

Category I - Operation down to a decision height (DH) of not less than 200 feet, and a Runway Visual Range (RVR) limit not less that 1/2 mile (1800 feet with appropriate lighting).

Category II - Operation down to an RVR as low as 1200 feet and a DH as low as 100 feet.

Category IIIA- Operation with no decision height and an RVR not less than 700 feet. External visual reference during the final phase of landing is assumed.

Categories IIIB and IIIC relate to operation in visibilities of as low as 150 feet and zero repectively. Criteria for these operations have not yet been formally established.

It should be noted that the Category II phase was originated to be an interim step to the final goal of "All-weather" operation. This interim stage was premised upon 100 feet being the lowest decision height at which a pilot could be reasonably expected to take over manually and execute a safe landing by visual reference or to go around safely in the event of inadequate visual contact or an unsatisfactory airplane situation (attitude, position, speed, etc.) with respect to the runway surface.

The lowest RVR' appropriate to 100 feet height for 3° approach angles has been established at 1200 feet, and this value must permit the pilot's view of a segment of ground equivalent to at least 750 feet (see figure 1). This in turn allows continuous view of at least three centerline lights from 100 feet down, thereby providing adequate azimuth visual guidance.

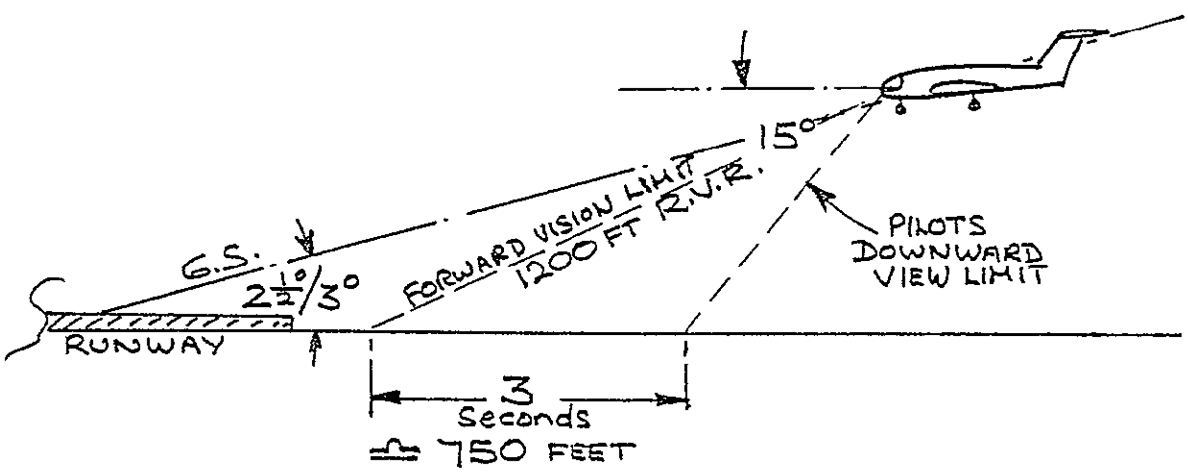

Figure 1 - Required Visual Segment during a Category II Approach

The ILS beam and aircraft coupler tolerances were examined and a 'window' of ±75 feet laterally and ±12 feet vertically was established as a 2 sigma error value at the Category II decision height. The handling and flight dynamic characteristics of the Boeing 707 aircraft were used as a basis for confirming that lateral and vertical corrections could be reasonably accomplished from as low as 100 feet prior to a safe landing on the runway surface being accomplished. One very important element, also relating to the 100 feet decision height criteria was contained in a study conducted by A. B. Winnick of the FAA - "Height of the ILS Glide Path Over the Threshold". This study was used as a basis for the ICAO criteria for the threshold crossing height values of the ILS beam, and hence the airplane's landing gear height over the runway threshold. The now much quoted "19 feet from the glideslope antenna to the lowest part of the landing gear wheels" resulted from this study. It should be realized that the study was based upon the characteristics of the beams, couplers, and aircraft of the early 1960's, and reassessment of the conclusions can reasonably be made from time to time as aircraft and systems performances improve. Figure 2 shows graphically the original ICAO definition for the permissible lateral and vertical errors (the decision height "window") at the decision height of 100 feet. Figure 3 shows the FAA interpretation of the intended criteria for the minimum wheel height over threshold.

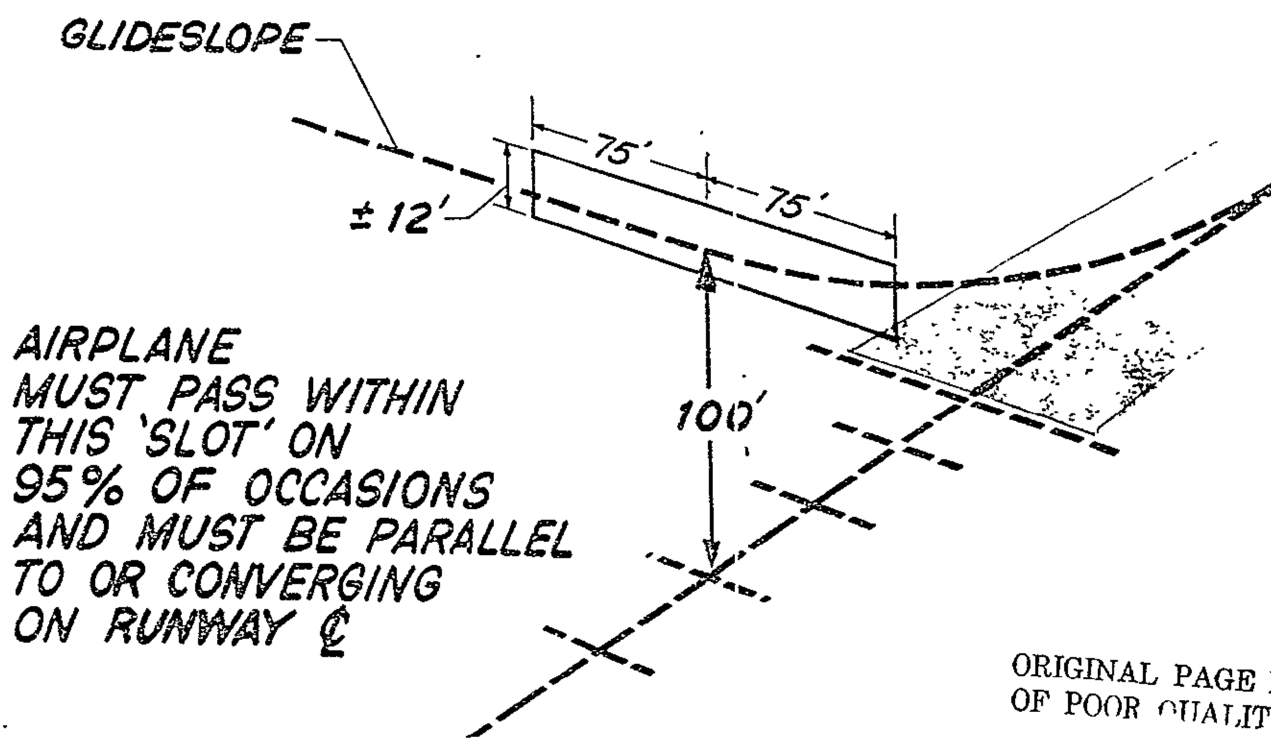

Figure 2 - The Category II Decision Window

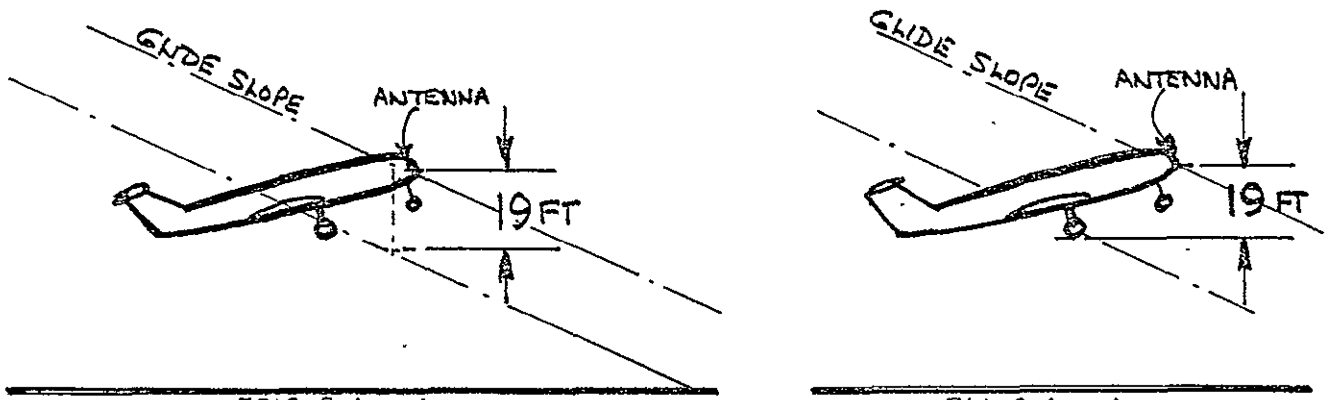

Figure 3 - Wheel Height over Threshold Criteria for Automatic Landing of a CTOL Airplane

Category II operation, then, as we now know it, was originally intended as the lowest realistic extension of the IFR low visibility guided approach to an instrument runway using currently available equipment. Phase 3, now known as Category IIIA, IIIB, and IIIC, required new equipment development, including fully automatic landing, and new standards of safety analysis for equipment hitherto not used in a flight critical mode. This development of equipment and standards was promoted by the ICAO discussions in 1963, and is now at a stage when Category IIIA operation is commencing in the USA at a small number of major hub airports.

Considerable experience has now been amassed by the CTOL civil aircraft fleets during Category II operation, and considerable study and equipment development has been conducted for Category IIIA. Low weather minima operation of STOL aircraft can obviously draw heavily upon the development concepts and programs for the CTOL aircraft since the general principles, operational practices, and safety standards would, of necessity, be identical for the two aircraft types when in a civil passenger-carrying role.

2.4. Basic Regulatory Requirements

Any system installed in a civil transport aircraft must be demonstrated to meet FAA requirements to show that it will not cause a hazard to safe flight conditions. Until the advent of Category II and below operation, most of the guidance and control systems were in the non flight-critical category. That is, a failure could be readily tolerated provided that the pilot was made aware of the occurrence. Enough redundancy existed to permit the immediate and safe use of alternative systems so that there would be no hazard to the continued safe flight of the airplane.

The use of airborne and ground systems, such as the autopilot, its approach coupler, and the ground based ILS beam during the low altitude phases of approach and landing called for a more stringent appraisal of the failure characteristics, and the hazards which might arise as a result of the failure. Time for pilot response was shorter, and the effect of attitude or positional errors more profound at the very low altitudes for Category II and IIIA operation. Several Advisory Circulars exist to cover the basic safety requirements for the approach autopilot, and FAR 25 has been amended to cover the failure detection and prevention requirements for the more complex systems needed for Category IIIA approach and landing operation. The requirements for the approach beam, runway, and other ground facilities are covered in the Category IIIA documents, such as AC 120.28B, and for Category II, in AC 120.29 and the various FAA Orders which are issued from time to time to provide basic guidelines to be used by the FAA field offices in confirming and maintaining beam performance.

The following is a representative sample of basic regulations, Advisory Circulars, and Orders.

2.5. Engineering Design Regulations

Various sections of the FAR Part 25 cover the basic safety requirements for automatic pilot approval.

FAR 25.1309 provides a basic requirement for equipment, systems, and installations to perform their intended function under all foreseeable operating conditions. Compliance with this FAR is specified in terms of warnings, analysis, and the need to consider multiple and undetected failures.

FAR 25.1329 covers the basic disengagement and interlock devices of an autopilot installation.

FAR 25.1353 covers the safety requirements for wiring and batteries.

FAR 25.1431 covers the need to obviate adverse interaction between electronic or radio systems.

Advisory Circular 25.1329 - 1A provides criteria for assessing the effect of autopilot malfunctions upon the airplane's flight path. The circular is quite comprehensive and specifies the minimum pilot response times to a malfunction in various regimes of flight as well as the acceptable 'g' loads and recovery wheel forces when overpowering the autopilot servos. Additionally, this AC covers the recovery profiles following a malfunction, and relates them to decision heights and approach gradients. This circular, although much less well known than some of the others, contains information which is very pertinent to STOL operation, since it defines some very basic criteria illustrating FAA thinking in terms of safety margins following faults and subsequent recovery profiles.

2.6. Operational Use Approval Criteria

The criteria for approval of a Category II or Category IIIA airplane will obviously be very comprehensive and detailed since all facets of aircraft operation are involved in a low visibility landing operation:

- o System design - ground and air
- o Pilot proficiency
- o Aircraft response
- o Malfunction protection
- o Ground based guidance
- o Runways - lighting, marking, etc.
- o ATC

Three basic advisory circulars cover these criteria very completely, at least for CTOL airplanes using ILS beams on standard CTOL runways. Most of these criteria would apply, however, and should be considered in the assessment of the design of the total STOL system.

2.6.1. AC 120-29 provides the criteria for approval of Category I and II landing minima for FAR 121 operators. This circular incorporates the requirements of AC 120-20 which provided the early requirements for Category II operation. This circular is lengthy and involved, and a brief summary only of its contents is given here, but since the circular can provide such excellent background in understanding the requirements for STOL operation, it should be read in detail with this in mind. The circular covers:

- o Definitions
- o Airfield, runway, and ground system requirements
- o Pilot training and proficiency program
- o Airborne equipment requirements
- o Ground equipment requirements
- o Operational demonstration criteria
- o Maintenance requirements
- o Obstruction clearance profiles and areas

Nearly all of the requirements of this circular would apply to STOL aircraft with the exception of the runway and airfield characteristics including, of course, the siting of the guidance beams and the definition of the approach and missed approach profiles and surfaces. These latter criteria will depend heavily upon the airfield siting and the requirement of FAA concerning the required obstacle clearance zones, etc. It was found during the course of this study that an appendix to Order 8260.28 - "IFR Approval of the Interim Standard Microwave Landing System (ISMLS)" has been drafted by FAA Flight Standard personnel. This document defines some of the equivalent material for a STOL airport and procedures to that contained in Appendix 2 - "Ground System and Obstruction Clearance Criteria for Category II Operations" of AC 120-29. However, although this material relates to IFR operation, it does not specifically define any decision heights below 200 feet or visibilities below 1/2 mile. This document also refers to certain criteria contained in the TERPs (Terminal Instrument Procedures).

AC 120-29, then, provides a complete and comprehensive coverage of the rules and requirements of the total system, ground and air, which applicants must meet in order to obtain approval to operate civil passenger-carrying transport aircraft in Category I and II landing minima. Aircraft which do not fall into the Part 121 category because of weight or operational use would not be required to meet all of the criteria of 120-29, especially under Category I conditions. However, as minima decrease to Category II and below, the applicability of AC 120-29 and other pertinent Category II and III documents increases. As is normal, the applicant can always submit data to justify deviations from an Advisory Circular. Equally, FAA may ask for additional data or tests if the aircraft characteristics (such as a powered-lift STOL aircraft) vary significantly from the type of aircraft for which the circular was intended to apply.

2.6.2. AC 120-28B - Criteria for Approval of Category IIIA Landing Weather Minima

This circular provides the basic ground rules for aircraft operating under Parts 121, 123, and 135 (large aircraft only). Criteria are described to identify airport and ground facilities, airborne systems, training requirements, and maintenance standards which must be met before Category IIIA minimums can be approved. It is important to realize that a rethinking of the original ICAO tenets has taken place over the past year or so, and this is reflected in a new and revised version of 120-28A now known as 120-28B. This reissue took place in January 1978, and it was felt that the revised philosophy was important enough for it to be incorporated in this study report. This philosophy is well described in the discussion section of 120-28B as follows:

"The criteria initially established by the FAA for Category IIIA operations were based on a conservative approach to reduction of landing minimums below Category II. As a result of considerable experience and further review, it has been determined that in some respects the previous criteria were too stringent. Accordingly, the following amended criteria are issued to identify the airport and ground facilities, airborne systems, training requirements, and maintenance standards which must be met for approval of Category IIIA landing minima. The first principal change included in this revision permits certain aircraft with fail-operational automatic landing systems to operate to Category IIIA minima on ILS facilities which previously were limited to use for Category II approaches in the U.S. The second change permits Category IIIA approaches with a 50-foot decision height for aircraft up to and including the B-727, DC-9, or B-737 size when equipped with a fail-passive automatic landing system. The effect of these changes will be to permit Category IIIA operations at an increased number of facilities.

Definitions and Operational Concepts

The definitions and operational concepts contained in 120-28B provide very comprehensive guidelines and ground rules for Category IIIA operation and are also included here in the text of this report because they would relate in nearly all respects (except perhaps for actual DH or RVR values) directly to STOL operation.

a. Category IIIA Operations (ICAO definition). Operations with no decision height limitation, to and along the surface of the runway with external visual reference during the final phase of the landing and with runway visual range not less than a value on the order of 700 feet.

> NOTE: In the U.S., any operations which are conducted with runway visual range between 1200 feet and 700 feet, and with a decision height below 100 feet HAT or no decision height are considered to be Category IIIA operations.

b. Alert Height. A height (100 feet or less above the highest elevation in the touchdown zone), established, based on the characteristics of an aircraft and its particular fail-operational airborne Category IIIA system, above which a Category IIIA approach would be discontinued and a missed approach executed if a failure occurred in one of the required redundant operational systems in the aircraft or in the ground equipment.

c. Fail-Passive Automatic Flight Control System. An automatic flight control system, which upon occurrence of any single failure, should not:

(1) Cause significant displacement of the aircraft from its approach path or altitude loss below the nominal glide path.

(2) Upon system disconnection, involve any out of trim condition not easily controlled by the pilot.

(3) Cause any action of the flight control system that is not readily apparent to the pilot, either by control movement or advisory display.

d. Fail-Operational Category IIIA System. An airborne system which provides redundant operational capability down to touchdown. The redundant operational systems must have no common failure modes, and need not be the same (e.g., one system may be automatic-to-touchdown, and the other manually flown, using computed displays). If one of the two required operational systems fails below the alert height, the flare and touchdown may be accomplished using the remaining operational system.

e. Automatic Fail-Operational Category IIIA System. A system which provides redundant operational capability using automatic systems. If one of the automatic systems fails below the alert height, the flare and touchdown may be accomplished using the remaining automatic system.

f. Decision Height.

(1) U. S. Definition. With respect to the operation of aircraft, means the height at which a decision must be made during an ILS or PAR instrument approach to either continue the approach or to execute a missed approach.

(2) ICAO Definition. A specified height at which a missed approach must be initiated if the required visual reference to continue the approach to land has not been established.

Operational Concepts. The total airborne system must be designed and must provide sufficient information to the pilot so that the landing may be safely continued and completed or a go-around safely executed from any altitude following any single failure or combination of failures not shown to be extremely improbable. The primary mode of Category IIIA operations will be automatic-to-touchdown. The automatic landing system should provide a high degree of reliability in assuring safe landings on the runway. Pilot intervention other than decrab and power adjustment shall not normally be required.

a. Operations Without a Decision Height. For operations without a decision height, a redundant operational flight control capability will be required at least down to the touchdown. The redundancy may be provided by multiple automatic landing systems or by a manual backup capability for landing by reference to instruments. The reliability and performance of each of the required redundant operational systems must be such that below the alert height continued safe operation to a successful landing can be effected with a high level of confidence after a failure occurs in one of the redundant operational systems. The following are typical arrangements by which this requirement may be met:

(1) Two (or possibly more) monitored autopilots (making up an automatic, fail-operational system), one remaining operative after a failure.

(2) Two monitored systems, each consisting of an integrated autopilot and flight director system with common flare computation, with one monitored system remaining operational after a failure.

(3) Three autopilots, two remaining operative (to permit comparison and provide necessary hardover protection) after a failure.

(4) A single, monitored fail-passive automatic flight control system with flare computation and automatic

flare and landing, plus an adequately failure-protected flight director system with dual displays (or dual flight director system) with flare computation (independent of that used for the autopilot), supplied to the command bars.

> NOTE: The flight director displays (head-down and/or head-up) required in paragraph 3a(4) above must provide sufficient guidance so that a pilot of average skill can demonstrate the same degree of repeatable performance as required by AC 20-57A. This demonstration is required over the portion of the approach and landing during which the manual takeover is a part of the operational Category IIIA system, i.e., from the alert height to touchdown.

b. Operations with a 50-Foot Decision Height.

(1) For operations with a 50-foot decision height, a fail-passive automatic landing system may be used if the system is shown to provide the capability to safely touchdown in the touchdown zone or go around from any point on the approach. When a fail-passive automatic landing system is used, a decision height is specified to ensure that adequate external visual reference is available to verify that the aircraft is in a position which will permit a successful landing in the touchdown zone. If after decision height visual cues are lost or a reduction of visual cues occurs which prevents the pilot from verifying the performance of the automatic landing system, a missed approach will be executed. In the event of a failure of the system on approach either before or after decision height, a missed approach will be executed, unless the pilot determines that adequate visual cues are available to manually complete the landing and that continuation of the landing would be a safe course of action.

NOTE #1 Due to considerations of approach geometry related to "wheel to glide slope antenna height," "wheel to pilots eye height", and such factors as landing gear width, the authorization for the Category IIIA 50-foot decision height based on use of a fail-passive autoland is currently limited to aircraft of the B-727, DC-9, B-737 size or smaller.

NOTE #2 Performance criteria for aircraft with fail-passive systems are outlined in AC 20-57A or AC 20-57 as appropriate to the original approval of the automatic landing system.

NOTE #3 The requirement for a missed approach in the event of an automatic flight control system failure does not preclude continuation of an approach to Category I or Category II minima if the failure relates only to the system elements needed for the Category IIIA minima.

(2) Typical arrangements which could be used to meet the requirements for operating to a 50-foot Category IIIA decision height include the following:

(a) A single monitored fail-passive flight control system with automatic landing.

(b) A fail-operational automatic landing system which has reverted to fail-passive due to the occurrence of a failure during flight, or has been dispatched in a fail-passive configuration.

The above extracts from AC 120-28B are self explanatory and should need no further elaboration in this report. The number of aircraft types certificated to operate to Category IIIA are very few and the exposure, thus far, to Category IIIA operation in the actual weather limits is also small. However, the definitions and requirements of this circular are based upon much experience of all parties involved with Category II operation and a considerable background of simulation and analysis research and development by the various aircraft companies and government agencies concerned. AC 120-28B does reflect a basic philosophy and a set of ground rules which would apply almost 'in toto' to STOL aircraft.

2.6.3. AC 20-57A - Automatic Landing Systems

This circular was originally written at a stage when aircraft were being designed for future Category IIIA operation, and although the equipment redundancy requirements were reasonably established, the actual accuracy which the airplane must achieve at touchdown were undefined. These criteria were needed to establish design tolerances and performance characteristics of the various airborne equipments involved in the approach and landing process.

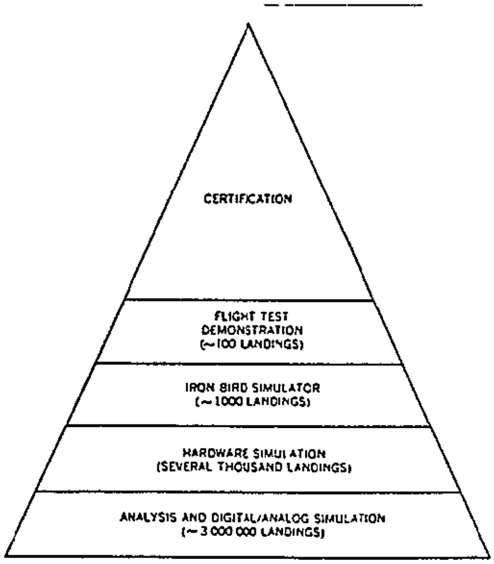

Fig. 4 Landing Performance Statistical "Pyramid"

AC 20-57A establishes the environmental conditions which must be considered in confirming the performance limits in a format which can be confirmed by a suitable program of statistical analysis and testing. Figure 4 shows a typical composition of the analysis and testing which might be involved in the certification process and Figure 5 illustrates the landing dispersion criteria which must be met.

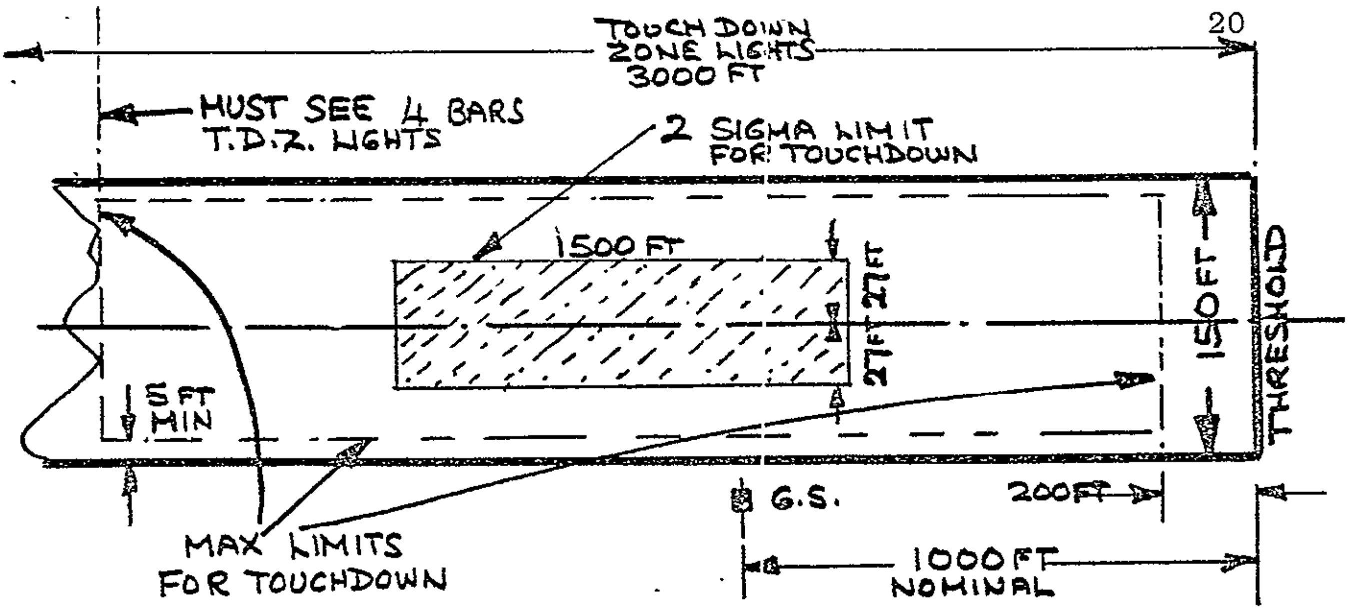

Figure 5 - Two Sigma Touchdown Accuracies Required by AC 20-57A

AC 20-57A defines four characteristics concerning the malfunction protection required by the FAA. These criteria are tabulated below because of their importance and direct application to STOL low weather minima operational requirements. The circular states:

Automatic landing system malfunction should not -

1) Cause significant displacement of the aircraft from its approach path, including altitude loss.

2) Upon system disconnection, involve any out of trim condition not easily controlled by the pilot.

3) Cause any action of the flight control system that is not readily apparent to the pilot, either by control movement or advisory display.

4) Means should be provided to inform the pilot continuously of the mode of operation of the automatic landing system. Indication of system malfunction should be conspicuous and unmistakable. Positive indication should be provided that the flare mode has or has not engaged at the minimum normal flare engage heights.

In addition to the performance, general environmental and malfunction requirements of AC 20-57A, the circular also defines a wind model which must be used in the performance analysis required by the FAA before approval of the airplane and its system can be issued.

As with the other low weather minima circulars, AC 20-57A would apply directly to STOL operation in Category IIIA weather, except that the touch-down performance values would obviously differ.

2.6.4. TERPS

This acronym stands for Terminal Instrument Procedures. This document is issued by the FAA as document number 8260-3A - "United States Standard for Terminal Instrument Procedures".

For civil aircraft the criteria contained in the document are developed by the relevant specialists and organizations of the FAA, and flight checked and reviewed as necessary.

The TERPS are not a basic FAA regulation, but they are used by the military services, the Coast Guard, and civil transport aircraft, and hence they serve the same purpose in defining and regulating IFR traffic flow into and from civil and military airports.

The TERPS manual establishes criteria which are used to formulate, review, and/or approve IFR procedures. These criteria include:

a) Obstacle clearance for IFR approaches and departures.
b) Missed approach requirements.
c) Definition of minimum descent altitudes (MDA) and decision heights (DH).
d) Procedures for IFR approaches and departures.
e) Determination of take off and landing minimums.

f) Establishment of visibility minimums especially in terms of approach and runway lighting.
g) Holding pattern.
h) Use of precision approach aids.
i) Use of non-precision approach aids.
j) Transition to and from IFR approach and departure procedures.

By themselves, the TERPS do not define Category II or Category IIIA operational criteria. However, many of the criteria of TERPS must be considered in establishing changes in current procedures or operational techniques. In terms of STOL aircraft, the TERPS are a vital document to consider since STOL operation will require a change or additional utilization of airspace and, essentially, because of the wide use of TERPS in ensuring safe and orderly use of that airspace, the document must be up-graded to cover these potential changes.

There is an increasing activity to date concerning up-grading the TERPS to suit VTOL (Helicopter) operation and a similar activity to cover STOL aircraft will obviously be needed if their use becomes widespread.

The three most important elements of STOL operation applicable to the TERPS document would be:

a) Obstruction clearance limits for approach and go-around.
b) Airfield lighting.
c) Decision heights.

2.6.5. AC 150/5300-8 - Planning and Design Criteria for Metropolitan STOL ports

This circular was issued in 1970 and was intended as a general guide in the planning and design of metropolitan STOL (Short Take Off and Landing) ports. The document stresses that the criteria are advisory in nature and intended to describe the average or usual location and environment. The technical aspects of a typical STOL port which may impact on Category II or lower minima operation are described basically in sections:

a) Design Criteria
b) Visual Aids

a) The Design Criteria call for a runway having a length of 1500 to 1800 feet and a width of 100 feet. Figure 6 illustrates this runway and the suggested safety areas, clearances, MLS siting, etc. Figure 7 shows the recommended criteria for the protection surface slopes, widths, and lengths. A 15:1 approach/departure surface angle is specified. The crossing height of the MLS beam is not specified, but with a 6° beam angle and a location 250 feet from threshold, the crossing height would be around 25 feet. Later draft FAA criteria suggest 30 feet plus or minus 5 feet.

b) Visual Aids. The recommendations of the Advisory Circular are based upon flight tests conducted at NAFEC and on operational experience at Washington National and Dulles Airports. Runway marking is described and the touchdown aim point is indicated by a 200 feet long solid paint block commencing 300 feet from threshold.

The lighting system for IFR or night operation includes:

- o threshold lights with wing bars of four lights each
- o Runway edge lights spaced not less than 100 and not more than 200 feet apart
- o Runway distance remaining lights spaced 50 feet apart installed on the centerline of the runway.

A VASI (Visual Approach Slope Indicators) is also specified differing only from the standard CTOL version in terms of location and angle (6° to 8°).

There is no attempt to define a Category I, II, or III approach and landing lighting system nor have other important parameters of low weather minima operation such as tolerances of beam location and crossing height beam considered. As mentioned before, AC 150/5300-8 is a document reflecting the early stages of FAA thinking on STOL operation to be used as a general guide in planning metropolitan STOL ports.

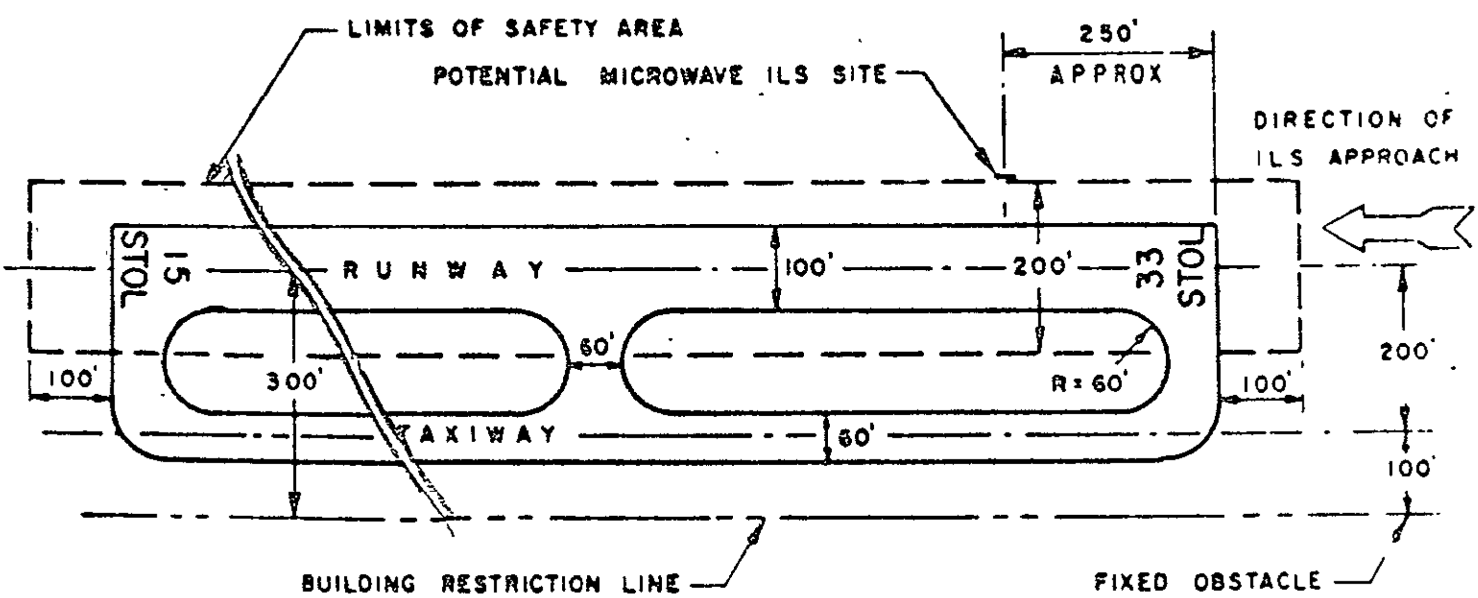

Figure 6 - Suggested STOL Port Dimensional Criteria - Per AC 150/5300-8

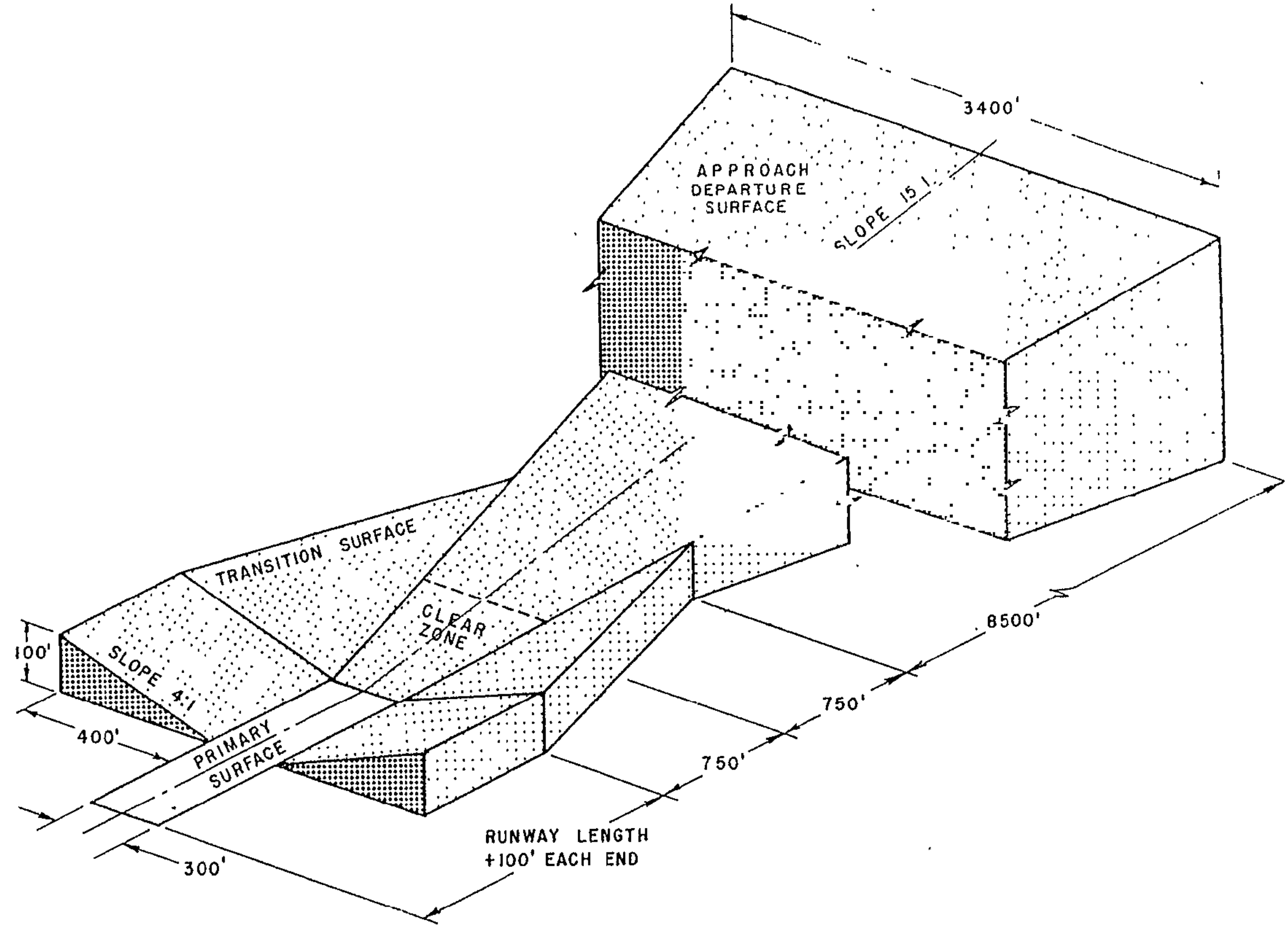

Figure 7 - Recommended Criteria for Departure Protection Surfaces - Per AC 150/5300-8

3.0. VISITS AND DISCUSSIONS

3.1. General

A number of visits and meetings in support of this study were scheduled and carried out to major airframe companies, FAA, NASA, and Air Force groups. A summary of the organisations visited is provided in Appendix C. Excellent cooperation was afforded in all cases, but the results of the discussions were less informative than expected for three reasons: the first was the low priority of research and engineering effort aimed specifically towards a civil STOL airplane design mainly because of an uncertain market demand; the second was a natural restraint of some of the groups visited in providing information because of the impending Air Force decision regarding the future of the AMST program; the third was a dearth of experience in operating and certifying STOL or near STOL aircraft for low weather minima operation.

Notwithstanding these restraints, a natural enthusiasm for a 'bull' session concerning new horizons in airplane design and operation resulted in at least spirited, and in most cases very informative, discussions.

The composition of the personnel at the various meetings varied, but included many pilots with STOL experience, a wide spectrum of FAA R & D and Flight Standards personnel, and an excellent representation at the three airframe companies which were visited. There is no doubt that low weather minima operation of STOL would be regarded as a challenging subject.

A formal questionaire was prepared and used in all the discussions in order that the information obtained could be correlated. This questionaire is provided in Appendix D. The practical results of the meetings, however, fell more naturally under slightly different headings, and so the results will be reported as a general trend of opinions under appropriate headings rather than specific answers by each group to each formal question. While this method is believed to be the most appropriate for this final study report, it should be noted that detailed visit reports were compiled to cover each meeting. It should also be noted that the following represents the author's summary of a number of discussions and a subsequent survey of appropriate literature. It does not necessarily reflect the specific views of any of the organizations visited.

3.2. STOL Implementation

Several interesting factors emerged concerning the practicality of implementing civil passenger-carrying STOL operation as follows:

a) STOL airplanes should not necessitate special traffic control arrangements (like VTOL), because of the inherent need to operate at CTOL airports as well as STOL airports.

b) STOL operations would probably be instigated one hub at a time rather than a sporadic widespread operation.

c) The energy shortage would increasingly favor LWL STOL rather than powered lift STOL.

d) Powered lift STOL (as a primary mode) may not be economic because of large weight ranges in a practical design.

e) Power plant design for STOL is uncertain because of the rapid advance in and requirements for exotic fuels.

f) Collocated MLS installations posed inherent difficulties in providing the accurate control required for fully automatic landing (offset azimuth guidance, etc.). However, a collocated MLS installation may be the only practical method for many existing CTOL runways if also used for STOL operation.

3.3. STOL Runways

a) It was generally agreed that at least a 2000' length was required, and even this was dependent upon minimum flare profiles and maximum sink rates which could be tolerated in civil operation.

b) A 100' width for civil use appeared to be generally acceptable, although this would depend upon the handling qualities (and hence the lateral landing accuracy) of the particular design of STOL aircraft involved.

c) Suggested lighting for a STOL airfield has been generally defined in various documents (e.g., AC 150/5300-8). However, lighting for Category II, and below, operation does not appear to have been explored to any degree. Although the spacing and location of center line and edge individual lights needs exploration, the alternative (or augmentation) of flood lighting of the touchdown area also merits consideration. Here again the potential problem of the lighting of runways intended for joint CTOL/STOL operation arises.

d) A general view was supported that STOL operation tailored to 3000' runways would be more practical because of the many more common facilities which would become available.

e) It was envisaged that the percentage of STOL/CTOL landings for a STOL aircraft might be 50/50 for shuttle operations, and 75/25 if operating into large CTOL hub airports.

3.4. Landing Approach Characteristics

The landing approach characteristics are based upon the need to arrive at some decision altitude in a condition which would result in a successful Category II landing most of the time, or a safe go-around in a small percentage of cases. The relevant factors which were discussed included:

- Glide slope angle
- Stability
- Sidestep ability
- Pilot visibility
- Wind
- Go-around capability
- Decision height

3.4.1. Glide Slope Angle

It was generally agreed that glide slope angles between 4° and 8° may be acceptable for operation in the STOL mode, but around 6° would be a good nominal. The higher angles would be limited by an $\dot{h}$ restraint. Rate of descent should not exceed 1000'/minute at breakout/decision height, and the 800/900 feet/minute appeared to be a preferred nominal value. Another factor discussed was that it appeared necessary that the STOL aircraft should be operable on CTOL glide slopes (3°), and at CTOL approach speeds. This would be required if the CTOL runway was an alternate landing facility or if a STOL runway and facilities were not available at specific hubs or airports.

The foregoing indicates that a STOL airplane should also be able to operate normally at glideslope angles as low as $2\frac{1}{2}^{\circ}$. The point then arises whether Category II or even IIIA operation should then be available over this wide range of glide slope angles ($2\frac{1}{2}^{\circ}$ - 8°) and, of course, in view of the resulting speed and configuration variations. No conclusion was reached, except that it could be impractical to do this for Category IIIA and probably uneconomical for Category II.

3.4.2. Stability

The stability of powered-lift STOL was discussed in relationship to its handling qualities during a low visibility approach. It was agreed that, as with a CTOL airplane, the handling qualities would have to be acceptable to the FAA and the line pilots who would fly the airplane. However, this type of aircraft is operating near or at the back side of the power curve, and any maneuvers which might cause a speed reduction or descent rate increase would be more cautiously conducted. Also, the roll, pitch, and yaw stability tends to be less at the lower STOL approach speeds. If augmented, the handling qualities would improve but the safety implications of a failure during the last stages of a low visibility landing could become a flight critical item.

In general, it was felt that pilots would tend to be more than usually cautious in IFR flight near the ground and therefore less likely to correct large flight path errors. Equally, however, a go-around would present at least a higher workload if not a greater hazard with a powered-lift STOL than with a conventional CTOL airplane.

3.4.3. 'Sidestep' Capability

This item was included in the questions for debate since it became a major factor in establishing decision heights for CTOL Category II operation. During initial consideration of this item, it appeared that a STOL airplane could maneuver laterally in a more effective manner than its CTOL counterpart because the lower forward speeds result in a smaller turn radius for a given bank angle. However, with a forward speed nearly half, but a descent angle more than twice, the <u>time</u> to touchdown from a given decision altitude, would be about the same as for a CTOL airplane. Other factors, such as a nominally foreshortened flare could result in even less time for the decision altitude to touchdown phase of the approach/landing maneuver. The other major factor which influences the 'sidestep' is the maximum bank angle (ignoring the roll rate in this case) which can be safely employed. Here the general concensus was that similar maximum angles to those of the CTOL airplane would be used, e.g., not greater than 10° below 150 feet. Figure 8 illustrates the similar times to touchdown from the same decision height.

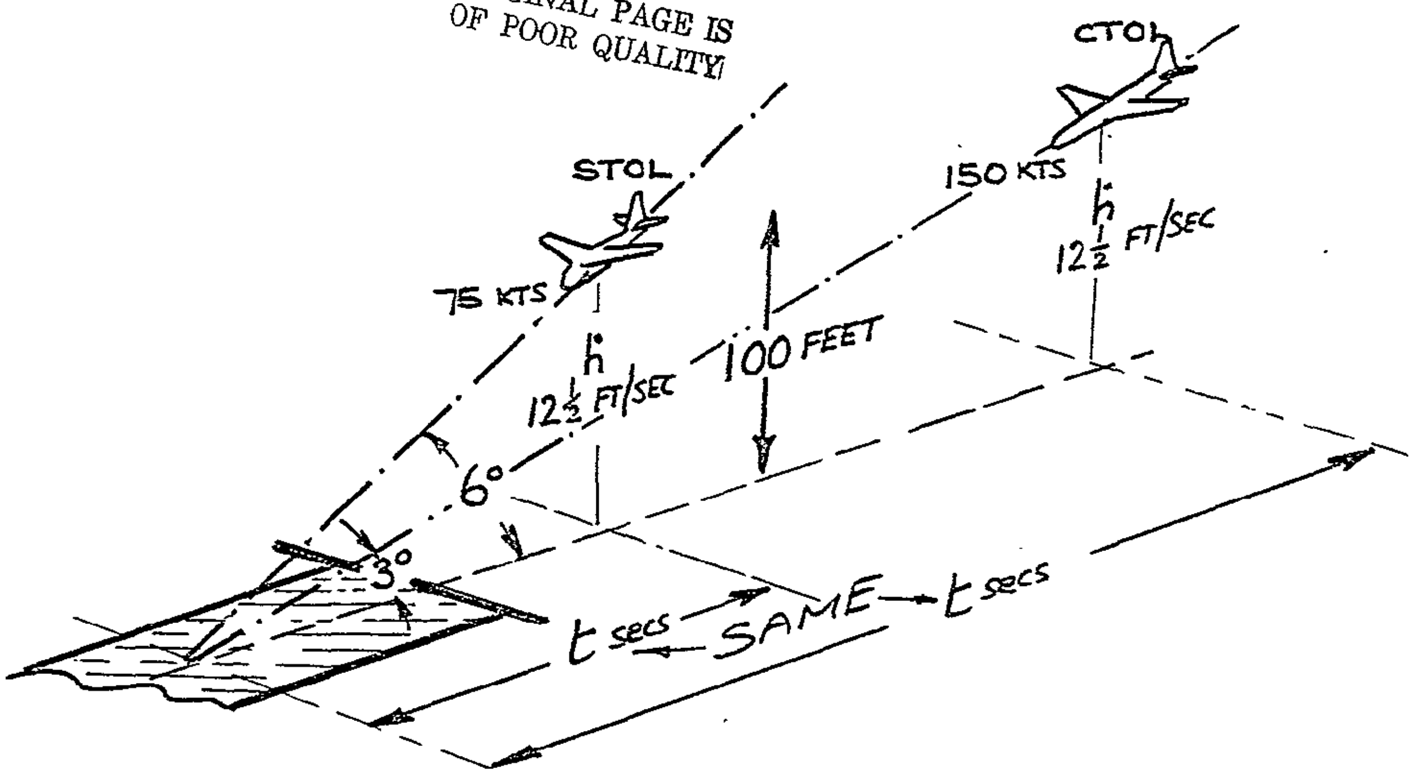

Figure 8 - Time to Touchdown for CTOL and STOL Airplanes

If any conclusion could be drawn from the various discussions, it would be that a medium-sized powered-lift STOL airplane might sidestep about as well as the smaller CTOL jet transport aircraft, and that a light wing loading STOL airplane might possess an improved sidestep ability. These conclusions, however, did not fully consider the effect of high cross winds and gusts, and the fact that the lower flare time of the STOL airplane could result in less air time from the same decision height than for the CTOL airplane. These factors should be examined for their influence upon 'sidestep' capability.

3.4.4. Pilot Visibility

The pilot visibility criteria for a CTOL low visibility approach is shown in figure 1. These criteria are needed to ensure that the pilot can see enough of the approach lighting to maintain (or monitor) adequately good tracking to the runway centerline. Also, the degree and nature of cockpit visibility influences the ability to maintain (or monitor) the vertical descent profile. SAE document AS 580 - "Pilot Visibility for the Flight Deck, Requirements for Commercial Transport Aircraft" provides an industry accepted standard for CTOL aircraft. This may need revising for STOL aircraft if required to operate under Category II and III conditions.

It was noted that the pitch attitudes of STOL airplanes, powered-lift and LWL, may vary over a wide range, although the tendency to fly more nose down when approaching at STOL airspeeds might further favor a STOL aircraft over a CTOL in terms of ground visibility for the pilot.

3.4.5. Wind

As mentioned earlier, the influence of wind on the STOL airplane approach and landing performance was a major item in the discussions. The following aspects emerged:

a) Simply because of the much reduced airspeeds of the STOL airplane, wind and wind variations would exert a greater influence on approach and landing accuracy.

b) Cross winds would significantly influence the low visibility landing. The use of higher crab angles would limit pilot visibility of the approach and landing area. The alternative of forward slip may be limited because of the safety implications of high bank angles near to the ground.

c) The influence of large wind velocity and/or directional changes (wind shear) would be greater than for a CTOL airplane. There appears to be a tendency with STOL airplanes to land with a minimum flare in order to offset 'long' landings, which can be caused by wind shear. This, in turn, may result in an emphasis on 'hard' landings, especially when a reversal of the shear profile occurs.

d) The influence of wind gusts and shears caused by buildings was mentioned as an additional factor to be included in any statistical performance analysis of landing accuracy.

3.4.6. Go-Around Capability

The go-around maneuver of the STOL airplane was one of the two most discussed topics in all the meetings. The effect of wind was the other. Various factors which would influence the go-around maneuver were debated. It was agreed that an engine failure could present a critical consideration for the height loss during a go-around. The number of engines would obviously influence this effect. Transition time from a full STOL configuration to one which provided sufficient excess thrust/lift would be another important consideration which could increase the height needed for a safe go-around following the decision to carry one out. No specific data for height loss during a go-around maneuver was produced, but the concensus of pilot opinion (for a powered-lift STOL airplane) was that between 75 feet and 200 feet could be the range of values.

It was noted that one major factor in the CTOL go-around was the reducing rates of descent (and increasing attitude) during the flare which might commence as high as 70 feet. This factor is also in favor of the CTOL airplane's ability to go-around safely from low altitudes.

3.4.7. Decision Height

Some of the major factors discussed which would influence the establishment of the lowest decision height for Category II operation of a civil transport category STOL airplane are:

a) Sidestep capability

b) Visibility of the runway

c) Go-around capability

It appears that (a) may be similar to that of a CTOL airplane, (b) has not yet been studied sufficiently for its influence to be duly appreciated, and (c) appears to be a major influence in establishing low decision heights. However, since the approach angles are much steeper for a STOL airplane, the RVR for a given decision height may be lower. If this is the case, the STOL airplane may be able to be utilized in similar RVRs, but with a higher decision height for Category II operation.

3.5. Landing

For the purpose of discussion, landing was established as the segment from decision height through flare to touchdown. Various facets emerged as follows:

a) There was no firm conclusion on the minimum wheel height over threshold, except that it must be safe (analysis required). The same opinion was offered that a 10 feet over threshold would certainly be a minimum value.

b) There would be a tendency for a minimum flare maneuver to be conducted in a manual landing, because it appears to decrease the uncertainty in the location of the touchdown point. This is especially true in conditions of wind gusts and potential shears.

c) Opposing point (b) above was an expressed general concern with some STOL airplanes of landing with nose wheel touching first. However, the variation in air distance with a longer flare maneuver appeared to be the greatest concern.

d) Ground effect, at least on some STOL airplanes, was strong, and a figure of it reducing the rate of descent from 14 feet/second to 9 feet/second was opined.

In general, the operational people present at the discussions concluded that a 75 feet wide 2000 feet long runway was adequate for manual landings with the reservations expressed above.

3.6. Certification

The certification of a STOL airplane was debated, and the various groups concurred that existing certification techniques and ground rules would be applicable. Equipment design and operational safety standards, ground and air, should be identical since the same safety standards would be required. The influence of failures in airline (and ground) equipment on airplane response may require a wider scope, because the influence of airplane controls and/or thrust malfunction on flight path excursions and hence safety, is probably greater with a powered-lift STOL airplane. However, again the techniques for conducting the appropriate failure analysis are well known, and the same choice would apply if either showing the result of a failure can be handled by the pilot, or that it is highly improbable that it would occur.

One common and major theme of discussion was the potentially much greater variation in the configuration and performance characteristics of a STOL airplane. As mentioned earlier, it may be required to operate over a range varying from CTOL approach speeds and angles to a fully configured STOL approach and low speed and steep angle. There was also debate concerning a possible pilot tendency to conduct an approach and landing in the minimum necessary degree of STOL configuration to improve handling, possibly to increase safety margins or minimize noise levels.

All of the foregoing indicated that several degrees of STOL may need to be considered in the certification process, and this could constitute both a costly initial certification program, plus higher costs of maintaining operational proficiency of equipment and flight crew.

4.0. CONCLUSIONS AND RECOMMENDATIONS

4.1. Documentation Review

The documents reviewed in this study are listed in Appendix E. As can be seen, a wide spectrum of design and operational facets are related to operation of a civil airplane in low visibilities, and all of these must be considered when formulating the "requirements" relating to the approval of an airplane to operate in visibilities less than 1/2 mile.

The results of the initial review led to the segregation of the documents into two classes:

- o Those which specifically defined contemporary industry and government criteria and/or requirements for CTOL airplane operation in Category II and Category IIIA weather conditions.
- o Those which provided general information applicable to the subject of this report.

The review also led to the formulation of a number of pertinent questions which were used as a basis for the visits and discussions conducted for this study. These questions are summarized in Appendix D, and the results of the survey are reported upon in Section 3.

Conclusions reached regarding the industry and government criteria are provided in each relevant section of this report, but in summary, the documents selected are all generally applicable to STOL as well as CTOL airplanes.

Actual numerical values for:

a) Airfield, runway and system requirements
b) Obstruction clearance profiles and areas
c) Decision heights and, possibly, RVR values

would need to be reconsidered and possibly revised for STOL aircraft. These revisions would be established by the FAA and the airplane manufacturer in the normal course of their approval activities and especially when a specific application for STOL operation in low visibilities is being planned.

However, the NASA STOL program could assist in establishing early identification and clarification of some of the more major differences identified as potentially significant in STOL low weather minima operation, and recommendations in this regard are provided in sections 4.2. and 4.3.

Conclusions reached during the various visits and discussions conducted during this study are described generally under the appropriate headings in section 3 of this report. These conclusions, together with those derived from reviewing the applicable documentation listed in Appendix D, are also formalized and summarized below.

4.2. Elements of Low Visibility Operation Sensitive to STOL Aircraft

4.2.1. Decision Height - Category II Operation

There are many factors to be considered in determining the decision height (DH) of an airplane when operating in low visibilities, (Category II - decision heights of 100 feet and visibilities as low as 1200' RVR).

The main concern, of course, is safety, and the three major elements to be considered as potentially different for STOL airplanes are:

- o Accurate arrival at the decision height "window"
- o Adequate and timely pilot visual contact of landing area
- o Sufficient height allowance for a safe go-around

The CTOL Category II 'window' (at 100 feet decision height) is ± 75 feet wide and ± 12 feet deep. As described earlier in this report, these criteria permit a reasonable assurance that the approach will not be discontinued because of unsatisfactory positioning at the decision height on more than 1 in 20 approaches.

A study conducted by Lear Siegler for NASA (referenced in Appendix E) indicates that a 'window' for the Buffalo powered-lift STOL of ± 10 feet wide and ± 7.5 feet deep could be attained with the same performance probabilities. Considering the relative runway widths of 150 feet for CTOL and 100 feet for STOL, it would appear that these figures are considerably tighter than required. It should be mentioned that the study was based upon recommending a system to perform to the landing accuracies required for Category III operation and this would result in small performance variations at the 100 feet point. However, if the STOL criteria is to relate to the CTOL for a reasonable accuracy at the decision height, then ± 50 feet would appear to be adequate laterally. The comparative vertical size of the 'window' would require further consideration mainly because of the fundamental different performance qualities of the STOL airplane in the pitch plane.

<u>A brief study accompanied by suitable flight experiments could provide useful data in this regard</u>.

Adequate visual recognition by the pilot at the decision height, that he can proceed to land safely or that he should execute a go-around, will be influenced most by the approach and runway markings and lighting. This aspect of CTOL operations has been subjected to considerable study and, of course, much practical experience in line operation.

The well known requirement for '3 seconds' of lighted segment to be visible to the pilot at the decision height may also apply to STOL airplanes. A report by Richard F. Haines, of NASA, (see Appendix E) on the subject of airfield lighting required in low visibilities indicates that while a 700 feet segment (equivalent to 3 seconds at 230 feet/sec) is adequate at 140 KTS, a 450 feet segment would be adequate at 90 KTS.

This report could be useful in assisting in the determination of STOL lighting requirements for Category II operation. It should be noted, however, that floodlighting of the touchdown area was recommended by several pilots during the study visits and discussions, and the same recommendation is found in several of the referenced reports.

Work needs to be conducted to establish the optimum blend of flood and individual incandescent lighting arrangement best suited for this phase of STOL operation.

The actual value of the decision height for STOL airplanes could considerably influence this work, however, and as discussed in the following section, the decision heights for STOL aircraft could well be limited to higher values than for CTOL aircraft.

The go-around maneuver influences the determination of decision height more than any other parameter. The FAA requires a safety factor of altitude allowance over and above the demonstrated go-around height loss (usually around two to one). The height loss of a CTOL airplane during the go-around maneuver is generally small and around zero to 30 feet. This value is normally achieved without reconfiguring the aircraft's high lift devices. Consequently, a decision height of 100 feet provides a very adequate "pad" and only a severe siting problem of obstacle clearance would cause an increase in the decision altitude for that particular airport or runway. In the case of the STOL airplane, its qualtiies of a steep approach angle and high degree of reconfiguration for the approach would appear to lead to a greater height loss during the go-around maneuver. Height losses of around 80 feet are reported upon in Roman Spangler's FAA report (see Appendix E) for light wing loading STOL airplanes and pilots during the study discussions report "at least seventy-five feet" for the powered-lift STOL airplane. Figure 9 illustrates the likely trend comparison between CTOL and STOL aircraft for the height loss during a go-around. If substantiated, this characteristic would result in higher decision heights for the Category II operation of the STOL airplane.

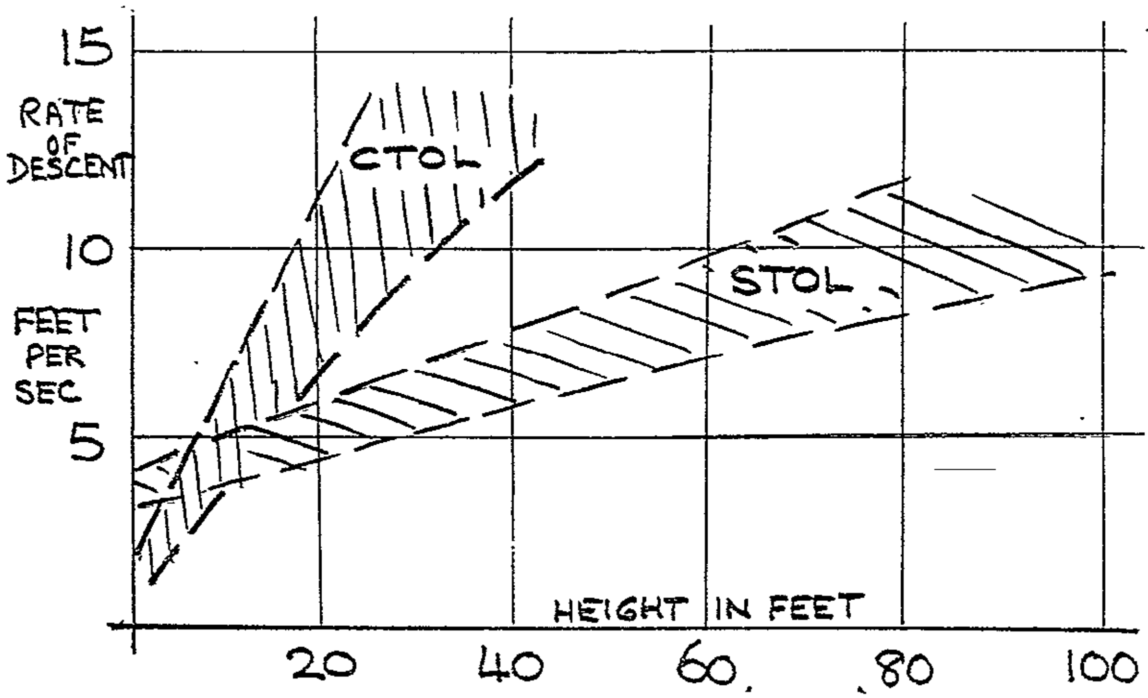

Figure 9 - Comparative Height Loss During a Go-Around

Study and/or flight experiments should be conducted for both the LWL and PL STOL airplanes to establish the height loss characteristics for various approach configuration and reconfiguration arrangements.

However, even if the decision height for the STOL Category II approach is higher, it does not necessarily mean that the accompanying visibility is also proportionately higher. As discussed in earlier sections, the slower speed and steeper approach angle of the STOL airplane may well permit operation in visibilities as low as 1200 feet RVR, even though the decision heights may be around 150 feet or more.

This topic needs resolving, and further study or fog chamber simulator work is indicated.

4.2.2. Landing - Category IIIA Operation

Category IIIA operation is, for the purpose of this discussion, assumed to be "operation with no decision height limitation to and along the surface of the runway with external visual reference during the final phase of the landing, and with a runway visual range not less than a value of the order of 700 feet". The other definition assumed for the same purpose is that the "alert height" is the height above which a Category IIIA approach would be discontinued and a missed approach executed if a failure occurred in one of the required redundant operational systems in the aircraft or in the ground equipment.

The elements of this Category IIIA operation which are to be considered in this section as meriting special attention in the case of a STOL airplane are:

- Go-around
- Runway alignment
- Touchdown accuracy

The go-around maneuver assumes a different importance during Category IIIA operation. The prime concern during Category II operation is to be able to conduct a go-around with virtually no risk to the total safety level of the approach. This is achieved by the extra height allowance above the expected height loss due to the go-around. In the case of Category IIIA operation, it is assumed that a go-around may be executed as a result of an equipment malfunction or some unusual cause such as runway obstruction or visibility reasons.

For the purpose of the safety analysis required by the FAA or CAA, a go-around is considered to be a maneuver attended by a significant hazard factor during a CTOL Category IIIA approach down to between 50 feet and around 10 feet, dependent upon aircraft type. The probability of a go-around is normally assessed to be around 10^{-4}, and the hazard factor around 1:200 to 1:300 during this higher risk altitude segment. In the case of a STOL airplane with a height loss during a go-around of up to 100 feet, the landing appears to be committed (without relief from a go-around) from around 150 to 200 feet. This means that the alert height must also be around this same value instead of 100 feet, which is specified for the CTOL airplane. However, the normal safety analysis for CTOL allows for an alert height of 300 feet so far as <u>exposure</u> time is concerned, even though 100 feet is stipulated by the FAA. For this reason, the exposure time for STOL could actually be at least as short as a CTOL airplane, and the automatic landing avionic equipment complexity (redundancy level) no greater.

However, if a safe go-around cannot be contemplated below, say, 100 feet, then the question arises "Can STOL really conduct operations in RVR's which allow for visual roll out after touchdown since the airplane appears to be committed <u>before</u> the pilot can assess the visibility on the runway surface".

<u>Useful study and/or flight experiments can be done to assist in providing the answer to this question</u>.

The <u>runway alignment</u> procedure on early automatic landing airplanes was to "decrab" or remove the influence of cross wind on the aircraft's heading at around 10 feet from the runway surface. This technique had three potential disadvantages:

a) Touchdown accuracy was very sensitive to the timing of the decrab maneuver.

b) The pilot's view of the runway was degraded because of the crab angle down to a very low height.

c) Pilots were often unnerved by an automatic maneuver taking place so late in the landing.

The original Buffalo STOLAND system removed cross wind effect by a flat 'decrab' technique. Forward slip is now the method used in modern automatic landing systems mainly because this method alleviates all three disadvantages listed above. 'Forward slip' consists of applying a limited bank angle and enough rudder so as to track the beam with a minimum heading error. This maneuver is usually timed to be fully in effect by the decision height which then improves the quality of the pilot's decision to land or not because of his improved forward vision and knowledge that one more automatic system has safely completed its task.

The Lear Siegler study by Feinreich and Gevaert also demonstrates an improved touchdown performance when employing the forward slip technique, but initiated the maneuver at 100 feet, thus not taking advantage of the improved forward vision of the runway offered by a maneuver <u>completed</u> at the decision height. However, since the decision height may be as high as 200 feet, a question to be answered is: "<u>What is the influence on touchdown accuracy and the quality of pilot recognition of his potential landing success of different heights of completion of the runway alignment maneuver</u>?"

Naturally, the second part of this question is only relevant when using the automatic landing system under Category II conditions, but as with the CTOL airplane, this could be a common mode of operation, especially in the early days of 'confidence building' during line service.

The Lear Siegler study results show a <u>touchdown accuracy</u> illustrated for the two sigma case of improved landing control laws in Figure 10 below.

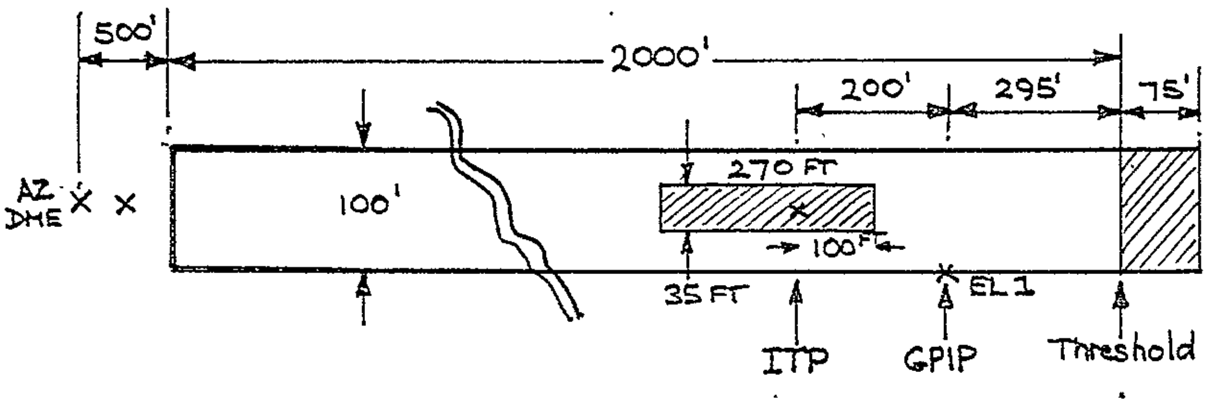

Figure 10 - Two Sigma Lateral and Longitudinal Dispersion for an Improved Landing System

The predicted lateral dispersion of ± 17.5 feet is nearly 30% better than required (and normally met by a small margin) than the lateral performance of ± 27 feet indicated in AC 20-57A. The longitudinal performance on the same basis is nearly four times better than the CTOL figure of 270 feet versus 1500 feet.

Since these touchdown accuracies are critical to the size of runway required by a CTOL airplane, it is most important that the study figures are shown to be demonstrable in 'real life'.

<u>Reasonable correlation between flight experiments and study results should be demonstrated</u>.

APPENDIX A

IATA OBJECTIVES - INSTRUMENT APPROACH AND LANDING

15th Technical Conference - April 1963

IATA Member Airlines require early implementation of the landing system and related operational techniques essential to the attainment of an all-weather capability in scheduled operations. To reach this goal, three basic operational phases in the evolution of Instrument Approach and Automatic Landing procedures have been established as follows:

Phase I - Operation of Jet Aircraft to Minima now applicable Piston-engined Operations

i) Minimum values in current use for propeller-driven aircraft are generally 200 feet ceiling and half-a-mile visibility. Their universal application to large jet aircraft is an immediate airline objective. Ground installations which now provide reliable and stable guidance are considered satisfactory for Phase I operation with large jets.

ii) Any ILS guidance difficulties which prevent use of these limits by jet aircraft at certain airports are considered a local problem and not necessarily a basic system limitation. To eliminate such local problems, improved azimuth guidance of high stability is urgently needed, such as that provided by Performance Category II ILS localizers.

Phase 2 - Reduction of Present Operating Minima for all-Aircraft Types

i) This phase, which airlines would enter as soon as practicable, involves certain ILS system improvements to enable safe and routine non-visual penetration below 200 feet. This degree of precision guidance will generally require a fully automatic or semi-automatic approach, transition to visual reference and manual landing.

ii) Introduction of lower minima should occur progressively in operationally proven stages. The minimum ceiling and visibility values marking the lower limits of Phase 2 must be ultimately determined by actual test and operating experience.

iii) Although precise operational values cannot, and need not, be determined at this time, it is desirable that suitable Phase 2 target values, associated with recognized ceiling and visibility increments, be adopted as system design criteria. Consequently, values of 100 feet ceiling and ¼-mile visibility have been selected in defining the approximate lower limit of this phase.

iv) ILS system improvements for this phase (Performance Category II ILS facility) should provide reliable, stable radio guidance down to an on-glide path height of about 50 feet. Continuation of the automatic approach to this height should be a system capability although visual reference may have been established at a height of 100 feet and the pilot has determined that the approach is proceeding satisfactorily. A primary requirement is <u>improved azimuth guidance of high stability and integrity</u> to -

a) ensure smooth, accurate tracking of the aircraft along the extended runway center line, and

b) eliminate the need for subsequent visual correction of lateral displacement.

v) In addition, the accuracy and stability of the vertical guidance provided by the glide path system should be improved to the extent required by the mode of operation and the techniques applied. Finally, positive height/distance checks should be available. It is preferable that marker beacons be located at specific, operationally significant points which favor the pilot's decision-making process during successive transition phases.

<u>Phase 3</u> - <u>Safe and Regular Operation in All-Weather Conditions</u>

i) This phase, representing the ultimate airline objective, probably involves fully automatic or assisted landing techniques. Appropriate system characteristics and flight techniques for ground and airborne components are under active study by administrations, research establishments, and airlines. Further research and extensive operational testing are required to determine that azimuth guidance, suitable for automatic landing, is within the capability of the ILS technique.

APPENDIX B

Extracts from ICAO ANNEX 10, Volume 1

Recommendation. The operationally referred ILS glide path angle is 2.5 degrees. ILS glide path angles in excess of 3 degrees should be used only where alternative means of satisfying obstruction clearance requirements are impracticable.

Recommendation. The height of the ILS reference datum should be as close as possible to the optimum of 15 metres (50 feet) and should be:

i) for Facility Performance Category I - ILS:

   15 metres (50 feet) with a tolerance of plus or minus 3 metres (10 feet);

ii) for Facility Performance Categories II and III - ILS:

   15 metres (50 feet) with a tolerance of plus 3 metres (10 feet); exceptionally the component authority may consider the use of heights down to, but not below, 14 metres (47 feet).

Note: In arriving at the above height values for the ILS reference datum for Categories II and III - ILS, a maximum vertical distance of 5.8 metres (19 feet) between the path of the aircraft glide path antenna and the path of the lowest part of the wheels at the threshold was assumed. For aircraft exceeding this criterion, appropriate steps may have to be taken either to maintain adequate clearance at threshold or to adjust the permitted operating minima.

The total period of radiation, including period(s) of zero radiation, outside the performance limits specified* shall be as short as practicable, consistent with the need for avoiding interruptions of the navigation service provided by the localizer.

The total period referred to above, shall not exceed under any circumstances:

10 seconds for Category I localizers;
5 seconds for Category II localizers;
2 seconds for Category III localizers.

<u>Note 1</u>: The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of localizer guidance outside the monitor limits. For this reason, they include not only the initial period of outside tolerance operation, but also the total of any or all periods of outside tolerance radiation including period(s) of zero radiation, which might occur during action to restore service, for example, in the course of consecutive monitor functioning and consequent change-over(s) to localizer equipment(s) or elements thereof.

<u>Note 2</u>: From an operational point of view, the intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempts be made to restore service until a period in the order of 20 seconds has elapsed.

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* in other sections 3.1.3.11.2. of Annex 10

<u>Recommendation</u>. Where practicable, the total period mentioned above should be reduced so as not to exceed 2 seconds for Category II localizers.

<u>Note</u>: It is intended that a period not exceeding 1 second should be the objective for Category III localizers.

Design and operation of the monitor system shall be consistent with the requirement that navigation guidance and identification will be removed and a warning provided at the designated remote control points in the event of failure of the monitor system itself.

APPENDIX C

SUMMARY OF MEETINGS AND VISITS IN SUPPORT OF STUDY PROGRAM

January 1977 - September 1977

AIAA/NASA Ames V/STOL Conference - Palo Alto

Presented Paper No. 77-577 - "Operational and Performance Criteria for STOL Aircraft Landings in Low Visibility Conditions."

Air Force STOL Project Office, Edwards Air Force Base

Boeing Airplane Company, Seattle

FAA Headquarters, Washington, DC

Systems Research and Development Service
Flight Standards Service

FAA Western Region, Los Angeles

Lear Siegler, Santa Monica

Lockheed California Company, Burbank

Lockheed Georgia Company, Atlanta

NASA Ames

Various coordination meetings and technical discussions

NASA Langley - TCV Program staff

APPENDIX D

STOL LOW WEATHER MINIMA OPERATION STUDY

Typical Questions Used During the Visits & Discussions Survey

1. What landing aids are anticipated for STOL ports? ILS - MLS - DME/DME - LORAN - VORTAC.
2. What percentage of landings will be at STOL ports? What percentage on CTOL runways?
3. What runway/airport geometry is considered 'nominal' for STOL ports?
4. What glide path angle is optimum? What range of angles? What is maximum descent path?
5. What is nominal approach speed? Touch-down speed?
6. What are the effects of wind gusts, turbulence, shear, on a STOL aircraft, compared with a CTOL?
7. What is the 'side-step' capability of a STOL airplane at 100 feet?
8. Should STOL aircraft have same stability criteria as CTOL aircraft? If not, how would they differ?
9. For go-around, how much time to transition from high drag to minimum drag configuration? With one engine out?
10. How do go-around profiles differ from CTOL airplanes?
11. Should runway light spacing be closer on STOL ports than CTOL airports, (because of lower touch-down speeds)?
12. What minimum cockpit visual cut-off angle is envisaged for final approach? (Influences lighting).
13. Should STOL aircraft have same airborne system design standards as CTOL aircraft for the same weather minima?
14. Should there be any piloting and/or operational differences between powered-lift STOL and light wing-loading STOL? For what reasons?

APPENDIX E

REFERENCES AND APPLICABLE DOCUMENTS

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