THE GENERATION OF A MILITARY SPECIFICATION FOR FLYING QUALITIES OF PILOTED V/STOL AIRCRAFT - MIL-F-83300

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FOREWORD

This document was prepared for the United States Air Force by the Cornell Aeronautical Laboratory, Inc. (CAL), Buffalo, N.Y. in partial fulfillment of Contracts AF33(615)-3736 and F33615-70-C-1322 under Project 698DC.

Also prepared under these contracts was a new specification for V/STOL Flying Qualities, MIL-F-83300 Military Specification - Flying Qualities of Piloted V/STOL Aircraft, and a Background Information and User Guide for MIL-F-83300, published as AFFDL-TR-70-88.

The work was performed by CAL's Flight Research Department, under the sponsorship of the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Project Engineers for the Air Force during the five year program were Messrs. W.J. Klotzback, R. K. Wilson, and T. L. Neighbor. Principal Investigator at CAL was Mr. C. R. Chalk, and Project Engineers were Messrs. G. H. Saunders and D. L. Key. The report covers work performed during the period April 1966 through March 1971.

The contractor's report number is BB-2925-F-1.

This report was submitted by the author 15 February 1971 and concludes the work on the contract.

This technical report has been reviewed and is approved.

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ABSTRACT

This document describes a four year effort which led to the adoption of a new military specification MIL-F-83300, "Flying Qualities of Piloted V/STOL Aircraft," and the publication of a supporting document, "Background Information and User Guide for MIL-F-83300, Military Specification - Flying Qualities of Piloted V/STOL Aircraft" (AFFDL-TR-70-88).

Included in the report is an assessment of the status of V/STOL flying qualities research and recommendations for future work.

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Section I

INTRODUCTION

In April 1966 Cornell Aeronautical Laboratory, Inc. (CAL) was awarded a contract by the Air Force Flight Dynamics Laboratory to develop VTOL handling qualities criteria. This effort has subsequently led to the adoption of a new military specification, MIL-F-83300 "Flying Qualities of Piloted V/STOL Aircraft," and the publication of a supporting document, "Background Information and User Guide for MIL-F-83300, Military Specification-Flying Qualities of Piloted V/STOL Aircraft"(AFFDL-TR-70-88). The purpose of this report is to summarize the results of those efforts and to give an impression of the current state of V/STOL flying qualities research.

Section II traces the historical development of the project. Section III gives an outline of the V/STOL Specification, MIL-F-83300, and Section IV outlines the Background Information and User Guide. An impression of the current state of V/STOL flying qualities research and some recommendations for future efforts are given in Section V.

Section II

HISTORICAL DEVELOPMENT

The development of MIL-F-83300, Flying Qualities of Piloted V/STOL Aircraft (Reference 1) was one of the prime efforts of an Air Force advanced development program called the VTOL Integrated Flight Control System (VIFCS) program. As originally conceived, this program had four basic parts which can be briefly described as:

1. Flight control system design, integration, and test including definition of the total flight control system criteria to meet VTOL requirements, and integration and fabrication of a total flight control system for control technology demonstration and validation in a modified XV-4.

2. Analysis, design, development, and flight investigation of specific flight path display techniques suitable for all-weather operation and their integration with the pilot-control system combination.

3. Development of VTOL handling qualities design criteria.

4. Modification of a jet VTOL airplane (the XV-4) for use as a variable stability test vehicle (the XV-4B).

The Cornell Aeronautical Laboratory, Inc. (CAL) was awarded a contract for part three above in April 1966. Under the contract, CAL's over-all responsibilities included:

1. experimental simulator investigations into the handling qualities of VTOL airplanes,

2. developing techniques for analyzing and evaluating VTOL handling qualities, and

3. utilizing experimental data and analysis to generate VTOL handling qualities requirements and design criteria.

The initial effort during the first year of the program involved a survey of the VTOL flying qualities literature. This involved reading many reports and papers and attempting to digest the relevant information, data, opinions, ideas, and methods presented by various authors representing different agencies and companies.

In order to supplement the literature surveys, a series of meetings was held with representatives of airframe companies engaged in design, development, and manufacture of VTOL aircraft. At these meetings, held during the weeks of 10 October 1966 and 24 October 1966, the attendees discussed:

(1) views, feelings and opinions on the applicability of existing handling qualities documents to VTOL aircraft, and

(2) the format and content of a future VTOL handling qualities specification.

The following manufacturers were represented:

Bell Aerosystems
Bell Helicopter
Boeing
Canadair
General Dynamics - Ft. Worth
Grumman
Kaman
Ling-Temco-Vought
Lockheed-California
Lockheed-Georgia
McDonnell
Norair
North American Aviation - Columbus
North American Aviation - Los Angeles
Republic
Ryan
Sikorsky

In addition, the following government agencies and contractors were present:

Air Force Flight Dynamics Laboratory
Air Force Aeronautical Systems Division
Air Force Flight Test Center
Army Aviation Materiel Laboratories
Cornell Aeronautical Laboratory, Inc.
Federal Aviation Agency
National Aeronautics and Space Administration
Systems Technology, Inc.

By providing a broad view of the overall V/STOL flying qualities picture, the literature surveys and meetings established a basis for more intelligent planning and coordination of the subsequent program activities. Reference 2 summarizes some of the results of the first year efforts.

To promote the attainment of the flying qualities program objectives, CAL was authorized to issue subcontracts. These subcontracts were planned and coordinated so that the work devoted to preparing a V/STOL flying qualities specification would benefit from the experimental and analytical capability of other organizations known to have a direct interest in V/STOL. It should be mentioned that although the specification work originated as part of a broad Air Force program that included the development of the variable stability XV-4B, the unfortunate loss of this aircraft eliminated the possibility of fulfilling all of the VIFCS program objectives within the original timetables. Thus the subcontract efforts took on additional importance as a means of acquiring relevant data and information to use in formulating a flying qualities specification.

During the course of the program, four organizations participated as subcontractors: United Aircraft Research Laboratories (UARL), Systems Technology Inc. (STI), Northrop-Norair, and National Research Council of Canada (NRC). Each subcontractor was selected so that, as shown in the following listing, V/STOL flying qualities could be systematically investigated by using different techniques and approaches to acquire and analyze data.

UARL	- fixed-base simulation
STI	- pilot model analyses
Norair	- moving-base simulation
NRC	- flight simulation with VSS helicopter

Both UARL and STI were awarded two subcontracts. The first subcontracts were initiated in late 1966 with work performed throughout most of 1967. The second subcontracts, basically extensions of the first, were pursued throughout most of 1968. Both the Norair and NRC work was started early in 1968 and continued for one year.

CAL efforts during 1967 and 1968 were, in addition to administering the subcontracts and participating in the simulations, concentrated on formulating flying qualities requirements using the pertinent data in the literature and the data generated during the subcontracts as it became available. This work culminated in the publication in October 1968 of the first version of a proposed V/STOL flying qualities specification (Reference 3) along with an accompanying report containing related backup information and data (Reference 4). Both of these documents were submitted to industry for review. Review comments were returned by the following industry organizations:

Bell Aerosystems Company
Boeing-Seattle
Boeing-Vertol
Grumman
Ling-Temco-Vought
Lockheed - California
Lockheed - Georgia
McDonnell
North American Rockwell - Los Angeles
Ryan
Sikorsky

The two documents were also reviewed by, and comments received from, the following Government agencies:

Air Force Flight Dynamics Laboratory
Air Force Aeronautical Systems Division
Air Force Flight Test Center
Army Aviation Materiel Laboratories
National Aeronautics and Space Administration
Naval Air Systems Command

CAL then proceeded with a thorough study of the review comments along with continued data analysis during much of 1969. A revised specification was prepared in September 1969 (Reference 5). In October 1969, Reference 5 was jointly reviewed by representatives of the Air Force, Army, Navy and CAL. This latter review took place in order to screen Reference 5 prior to submitting it to a second cycle of industry review. Some changes were recommended and these changes were incorporated into the pertinent requirement paragraphs and resulted in the publication of Reference 6.

A new document entitled "Background Information and User Guide" (BIUG) (Reference 7) was then prepared by CAL and in January 1970 these two documents (References 6 and 7) were distributed to industry and Government agencies for a second review cycle.

Detailed review comments were received from the following organizations:

Bell Aerospace
Boeing - Military Airplane Systems Division
Boeing - Vertol Division
Flight Systems
General Dynamics, Convair Division
General Electric, Aircraft Equipment Division
Grumman Aerospace
Lockheed - Georgia
LTV Aerospace -Vought Aeronautics Division
McDonnell Aircraft
North American Rockwell - Autonetics Division
North American Rockwell - Columbus Division
North American Rockwell - Los Angeles Division
Northrop - Aircraft Division
Princeton University
Teledyne Ryan Aeronautical
United Aircraft Research Laboratories
United Aircraft - Sikorsky Aircraft Division

In addition, letters giving an overall appraisal were received from:

Bell Helicopter Co.
Douglas Aircraft Co.
Kaman Aerospace Co.

The documents were also reviewed by, and written comments received from, the following U.S. Government and foreign agencies:

Air Force Flight Dynamics Laboratory
Aerospace Research Pilots School
British Ministry of Technology (A and AEEE Boscombe Down)
Dornier Company
Messerschmitt - Boelkow - Blohm GMBH

On the basis of these comments, CAL prepared some suggested changes and in April 1970 distributed copies to potential attendees of an Air Force - Navy - Army review meeting. This review took place at the end of April 1970 and substantial agreement on a final version was obtained by the Air Force, Navy and Army representatives.

Resolution of final details continued until about 4 July 1970 when CAL published a new version (Reference 8). The Air Force made some minor additional changes and printed a version which was distributed for the third and final review coordination (Reference 9). Detailed review comments were received from the following organizations:

Boeing Military Airplane Systems Division
Boeing Vertol
General Dynamics - Convair Division
Grumman Aerospace
Kaman
Lear Siegler, Astronics Division
Lockheed - California
Lockheed - Georgia
LTV Aerospace - Vought Aeronautics Division
McDonnell Douglas - Douglas Aircraft
McDonnell Douglas - McDonnell Aircraft
North American Rockwell - Autonetics Division
North American Rockwell - Columbus Division
North American Rockwell - Los Angeles Division
Northrop - Aircraft Division
Sperry - Flight Systems Division
Systems Technology
Teledyne Ryan Aeronautical
United Aircraft Research Laboratories
United Aircraft - Sikorsky Aircraft Division

These comments were reviewed and several changes made to the specification requirements. The final version was agreed to by the Air Force and Navy representatives on 11 December 1970, and submitted for adoption as MIL-F-83300. During development of the specification it was intended to cover all V/STOL aircraft, including helicopters, for the Air Force, Navy and Army. At the time of publication of this report, the specification has been adopted by the Air Force for all V/STOL's, by the Navy and Army for all except helicopters.

While Reference 9 was being reviewed, CAL prepared the draft of a new Background Information and User Guide (BIUG) for the specification. The purpose of the BIUG is to document the substantiating data used in the specification and also provide notes and explanations which should help the user of the specification. The draft was submitted to the Air Force on 15 September 1970. The review comments were given to CAL on 11 December 1970. These comments and the most recent changes made to the specification were incorporated, and the final version was submitted for publication as AFFDL-TR-70-88 on 1 February 1971 (Reference 10).

This final report for the project is to summarize the efforts and accomplishments which have been made, and also to suggest areas for future efforts.

Section III

OUTLINE OF THE V/STOL SPECIFICATION MIL-F-83300

The contents of the new Military Specification for the Flying Qualities of Piloted V/STOL aircraft are as follows:

- 1 SCOPE AND CLASSIFICATIONS
  - 1.1 Scope
  - 1.2 Application
    - 1.2.1 Ground effect
    - 1.2.2 Operation under instrument flight conditions
  - 1.3 Classification of aircraft
  - 1.4 Flight Phase Categories
  - 1.5 Levels of flying qualities
- 2 APPLICABLE DOCUMENTS
- 3 REQUIREMENTS
  - 3.1 General requirements
    - 3.1.1 Operational missions
    - 3.1.2 Loadings
    - 3.1.3 Moments of inertia
    - 3.1.4 External stores
    - 3.1.5 Configurations
    - 3.1.6 State of the aircraft
      - 3.1.6.1 Aircraft Normal States
      - 3.1.6.2 Aircraft Failure States
        - 3.1.6.2.1 Aircraft Special Failure States
    - 3.1.7 General Discussion
    - 3.1.8 General Discussion
    - 3.1.9 General Discussion
    - 3.1.7 Operational Flight Envelopes
    - 3.1.8 Service Flight Envelopes
      - 3.1.8.1 Maximum service speed
      - 3.1.8.2 Minimum service speed
      - 3.1.8.3 Service side velocity
      - 3.1.8.4 Maximum service altitude
      - 3.1.8.5 Service load factors
    - 3.1.9 Permissible Flight Envelopes
      - 3.1.9.1 Maximum permissible speed
      - 3.1.9.2 Minimum permissible speed
    - 3.1.10 Applications of Levels
      - 3.1.10.1 Requirements for Aircraft Normal States
      - 3.1.10.2 Requirements for Aircraft Failure States
        - 3.1.10.2.1 Specific failures

- 3.1.10.3 Exceptions
  - 3.1.10.3.1 Ground operation
  - 3.1.10.3.2 When Levels are not specified
  - 3.1.10.3.3 Flight outside the Service Flight Envelope
  - 3.1.10.3.4 Operation in critical height-velocity conditions
- 3.1.11 Cockpit controls

3.2 Hover and low speed
- 3.2.1 Equilibrium characteristics
  - 3.2.1.1 Changing trim
  - 3.2.1.2 Fixed trim
  - 3.2.1.3 Cockpit control gradients
- 3.2.2 Dynamic response requirements
  - 3.2.2.1 Pitch (roll)
  - 3.2.2.2 Directional damping
- 3.2.3 Control characteristics
  - 3.2.3.1 Control power
  - 3.2.3.2 Response to control input
  - 3.2.3.3 Maneuvering control margins
- 3.2.4 Control lags
- 3.2.5 Vertical flight characteristics
  - 3.2.5.1 Height control power
  - 3.2.5.2 Thrust magnitude control lags
  - 3.2.5.3 Response to thrust magnitude control input
  - 3.2.5.4 Vertical damping

3.3 Forward flight
- 3.3.1 Longitudinal equilibrium
- 3.3.2 Longitudinal dynamic response
- 3.3.3 Residual oscillations
- 3.3.4 Pitch control feel and stability in maneuvering flight
  - 3.3.4.1 Pitch control forces in maneuvering flight
- 3.3.5 Pitch control effectiveness in maneuvering flight
  - 3.3.5.1 Maneuvering control margins
  - 3.3.5.2 Speed and flight path control

3.3.6 Pitch control in sideslips
3.3.7 Lateral-directional characteristics
3.3.7.1 Lateral-directional oscillations (Dutch roll)
3.3.7.2 Roll mode time constant
3.3.7.3 Spiral stability
3.3.8 Roll-sideslip coupling
3.3.8.1 Bank-angle oscillations
3.3.8.2 Sideslip excursions
3.3.8.3 Control of sideslip in rolls
3.3.8.4 Turn coordination
3.3.9 Roll control effectiveness
3.3.9.1 Roll control forces
3.3.9.2 Linearity of roll response
3.3.9.3 Wheel control throw
3.3.9.4 Yaw control induced rolls
3.3.10 Directional control effectiveness
3.3.10.1 Directional response to yaw control input
3.3.10.2 Linearity of directional response
3.3.10.3 Directional control with speed change
3.3.10.3.1 Directional control with asymmetric loading
3.3.11 Lateral-directional characteristics in steady sideslips
3.3.11.1 Yawing moments in steady sideslips
3.3.11.2 Bank angle in steady sideslips
3.3.11.3 Rolling moments in steady sideslips
3.3.11.3.1 Positive effective dihedral limit
3.4 Transition
3.4.1 Acceleration-deceleration characteristics
3.4.2 Flexibility of operation
3.4.3 Tolerance in transition program.
3.4.4 Control margin
3.4.5 Trim changes
3.4.6 Rate of pitch control movement
3.5 Characteristics of the flight control system
3.5.1 Mechanical characteristics
3.5.1.1 Control centering and breakout forces
3.5.1.2 Cockpit control force gradients
3.5.1.3 Cockpit control free play

3.5.1.4 Rate of control displacement
3.5.1.5 Adjustable controls
3.5.1.6 Control harmony
3.5.1.7 Mechanical cross-coupling
3.5.2 Dynamic characteristics
3.5.2.1 Damping
3.5.3 Limit cockpit control forces
3.5.4 Augmentation systems
3.5.4.1 Performance of augmentation systems
3.5.5 Failures
3.5.5.1 Control force to suppress transients
3.5.6 Transients and trim changes
3.5.6.1. Transfer to alternate control modes
3.5.7 Trim system
3.5.7.1 Rate of trim operation
3.5.7.2 Trim system irreversibility
3.6 Takeoff, landing and ground handling
3.6.1 Pitch control effectiveness in takeoff
3.6.2 Pitch control forces in takeoff
3.6.3 Pitch control effectiveness in landing
3.6.4 Pitch control forces in landing
3.6.5 Crosswind operation
3.6.5.1 Landing and takeoff
3.6.5.2 Final approach
3.6.5.3 Cold- and wet-weather operation
3.6.6 Power run-up
3.6.7 Ground handling
3.7 Atmospheric disturbances
3.8 Miscellaneous requirements
3.8.1 Approach to dangerous flight conditions
3.8.1.1 Warning and indication
3.8.1.2 Prevention
3.8.2 Loss of aerodynamic lift
3.8.2.1 Warning
3.8.2.2 Prevention of loss of aerodynamic lift
3.8.2.3 Control and recovery following loss of aerodynamic lift
3.8.3 Pilot-induced oscillations

3.8.4 Buffet
3.8.5 Release of stores
3.8.6 Effects of armament delivery and special equipment
3.8.7 Cross-coupled effects
3.8.7.1 Gyroscopic effects
3.8.7.2 Inertial and aerodynamic cross-coupling
3.8.8 Failures
3.8.8.1 Transients following failures
3.8.9 Control following loss of thrust/powered lift
3.8.9.1 Thrust/powered lift loss on the ground
3.8.9.2 Thrust/powered lift loss in flight
3.8.9.2.1 Continued mission
3.8.9.2.2 Safe landing
3.8.9.2.3 Crew escape
3.8.10 Autorotation
3.8.10.1 Autorotation entry
3.8.10.2 Autorotative landing
3.8.11 Vibration characteristics

4 QUALITY ASSURANCE PROVISIONS
4.1 Determination
4.2 Interpretation of qualitative requirements

5 PREPARATION FOR DELIVERY

6 NOTES.
6.1 Intended use
6.2 Definitions
6.2.1 General
6.2.2 Speeds
6.2.3 Thrust and power
6.2.4 Control parameters
6.2.5 Longitudinal parameters
6.2.6 Lateral-directional parameters
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6.4 Effects of aeroelasticity, control equipment, and structural dynamics
6.5 Application of Levels
6.5.1 Theoretical compliance
6.5.2 Level definitions
6.5.3 Computational assumptions
6.6 Superseding data
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Section IV

OUTLINE OF THE BACKGROUND INFORMATION AND USER GUIDE (BIUG)

The Background Information and User Guide (BIUG) (Reference 10) was published to explain the concept and philosophy underlying the V/STOL Specification and to present some of the data and arguments upon which the requirements were based.

The philosophy and structure of the specification is outlined in an attempt to give the user of the specification an appreciation for the manner in which the requirements have been grouped; especially in distinguishing between the fixed operating point requirements and the requirements for the actual transition maneuver. Also presented is a review of the entire V/STOL Specification, in order, paragraph by paragraph. The format used is to present the pertinent paragraph, or group of paragraphs from the Specification, and then to follow this with a discussion of the requirement. Attention is directed at explaining the intent of the requirement, a discussion of the theoretical background and experimental data on which the requirement is based, and a discussion of the possible limitations or inadequacies of the requirement. Where a similar requirement or design criteria existed before, the earlier version is mentioned to provide a basis for comparison.

Section V

ASSESSMENT OF V/STOL FLYING QUALITIES RESEARCH

As outlined in Section I there is now an adopted military specification on V/STOL Flying Qualities, MIL-F-83300 (Reference 1). It is now appropriate to stand back and assess this document.

A considerable amount of V/STOL research work has been done in the past 15 years; the MIL-F-83300 has been developed based on the results of these efforts. It is nonetheless safe to say that there are no topics which would not benefit from more and better data.

As anyone who has been involved in flying quality data gathering fully realizes, it takes a long time to proceed from experimental plans through the test program to results, and it can take just as much subsequent effort to fully analyze the results. In view of this, it is essential to choose priorities carefully so that the most needed information is obtained first. It may also be mentioned that full and complete documentation is well worth striving for. All too often in preparing the V/STOL specification the authors have encountered reports of experiments which investigated an area of interest, but which were documented in a skimpy fashion. Too frequently the investigator gave a description of the experiment and results which satisfied his immediate interests, but were almost useless for someone trying to analyze the data from a different point of view; this is a waste.

Perhaps one of the most valuable indirect benefits of adopting the V/STOL Specification as a military specification is that during design and flight testing for compliance, the standard will now be MIL-F-83300; this will inevitably result in a gradual accumulation of data on the topics in the specification. This is obviously good since it will facilitate future improvements in the requirements. However, future investigators will have to be wary of the chicken and egg effect - do V/STOL's satisy the specification because they are acceptable or because they were designed to satisfy the specification?

It is convenient to consider V/STOL flying qualities as made up of two basic flight regimes: transition flight and fixed operating point flight.

- Transition Flight.

  In the BIUG for the V/STOL Specification, Reference 10, transition has been defined as "the act of going from one fixed operating point to another." It may or may not involve a conversion in the sense of a geometry change, e.g., a helicopter does not have a geometry change, the X-22A does.

- Fixed Operating Point Flight.

  Fixed operating point (FOP) flight is the name used for maneuvering about a constant trim condition. The characteristic which distinguishes FOP flight for V/STOL aircraft from FOP flight of conventional aircraft is the lower speed range and the ramifications of this such as the diminishing effect of the basic aerodynamic forces and moments and the increased dependence on power (thrust) for lift and control.

Most of the quantitative research on V/STOL's to date has been done on the FOP condition. The techniques developed for conventional aircraft seem to apply at such conditions and so have been used as the basis for flying qualities studies. Within this context a considerable amount of research has been performed, specifications have been developed, and can be reasonably substantiated, though there are of course still many areas where precise quantitative data need to be obtained. Some topics which need attention will be discussed later, but first the transition maneuver will be discussed.

5.1 Transition Flight

When considering the flying qualities of conventional aircraft it has been possible to virtually ignore the effects of acceleration (acceleration referring here to changing flight condition, particularly speed, rather than accelerations due to maneuvering) except for a few special conditions, such as passing through the transonic speed range. This happy circumstance is probably because the changes occur relatively slowly when compared to the frequencies of the rigid body modes. The acceleration capabilities of a V/STOL and the significant changes in dynamics and response which occur between zero speed and, say, 100 knots make it unlikely that we will be so lucky with V/STOL aircraft. It is desirable that a good understanding of the importance and extent of the transition problem be obtained as soon as possible.

Unfortunately the dynamics involved in a rapid transition are not yet well understood. Obviously transitions can be flown, investigated or simulated and the pilot will know whether or not that particular maneuver or aircraft is satisfactory, acceptable or unacceptable. Unfortunately, without better understanding of the dynamics of transition, neither the pilot that flew the aircraft, nor the engineer who analyzed the results will be able to define mathematically what the characteristics were. Without such a definition the information cannot be applied to future aircraft, nor can flying qualities criteria be established.

For understanding, it is tempting to consider the dynamics of transition as though represented by a sequence of equilibrium or fixed operating points. On this basis, the changes in dynamics can be considerable, so bearing in mind that the changes can occur in as little as 18 seconds, the question is how to interpret these changes. There is, as yet, no general answer to this question; however, some comments can be made.

First, if one does wish to treat the accelerated flight condition as a series of "frozen points" it is necessary to evaluate the aerodynamic characteristics for the appropriate aircraft state. An aircraft such as the X-22A can encounter a wide range of speeds and power settings, at a given conversion angle, depending on the rate of conversion and whether accelerating or decelerating (Reference 11). Such changes can have a very marked influence on the nature of the aerodynamic force and moment characteristics and hence on the "frozen dynamics".

Second, it is simple to show (Reference 11) that representing a time-varying system as a sequence of time-invariant systems can give misleading information about the nature of the dynamics. However, it is not a simple matter to put a quantitative measure on such effects of devise alternative techniques which can be used to understand the dynamics of a rapid transition. A notable attempt has been made in Reference 12 to develop such a technique, and some interesting trends are shown for simple variations of the derivatives (e.g., linearly proportional to speed). However the problem is by no means solved.

Now consider how this complicated dynamic situation has been accommodated in the specification.

Transition can be thought of as two basic parts:

1. Control of the speed and altitude as though the aircraft was a point mass.

2. Control of perturbations in speed, altitude and attitude from the desired values.

A knowledge of the first part can be obtained by controlling the aircraft with a very tight feedback loop. From this can be obtained a pseudo-trim for that particular transition. When flying, the pilot has to provide this pseudo-trim and also control the perturbations from the desired transition.

The difficulty of this task will be strongly dependent on how quickly the aircraft diverges from the desired nominal value. This will be a function of the rate at which the out-of-trim moments increase, and the basic dynamics of the aircraft. The difficulty of the task will also be influenced by how much effort the pilot has to exert to keep the aircraft within the transition corridor, i.e., within the permissible space of speed, conversion angle, power settings, and angle of attack. These are the factors to which attention has been directed in the requirements. Because of the current lack of knowledge concerning the dynamics in transition, these dynamics have not been prescribed. If an aircraft is designed to comply with the FOP requirements, it seems reasonable to assume that the resulting transition dynamics will also be acceptable or at least can be made to meet the qualitative requirements without excessive redesign. Some V/STOL aircraft (e.g., X-22A, XC-142A) have flight phases which require FOP operation at most speeds below V_{con} and as a result will have to comply with the FOP requirements. Other aircraft, such as the P.1127, may have no flight phase which requires FOP flight at speeds between about 35 knots and V_{con}. Applying the FOP requirements between 35 knots and V_{con} might be unduly conservative for these aircraft and so the flight-phase flight-envelope structure has been arranged so that the FOP requirements are not imposed unless the mission requires such operation. This statement has to be slightly qualified because any aborted transition is in fact required to be safe. Of course, the manufacturer may still use the FOP requirements as a design guide, but research needs to be performed to determine whether or not the resulting transition characteristics are adequate, ultraconservative or deficient. If they are deficient, of course, even the vehicle which has to perform FOP flight will have unsatisfactory transition characteristics. This is a subject which needs systematic research.

One way around all these worries about changing dynamics is to augment the aircraft so that the resultant dynamics do not change. This may result in overly complex augmentation systems and be inefficient. However, until the analytical problems are better understood it would give a basis on which to build investigations into other aspects of transition. For example, it is no use investigating the requirements for guidance control and displays during rapid transitions at various descent angles if the dynamics of the aircraft being flown change dramatically and yet cannot be defined or understood. The emphasis here is not on the fact that the dynamics change, but that the resulting effective dynamics cannot be defined for comparison with "better" or "worse" dynamics (like the dynamics of linear time-invariant systems can be defined in terms of parameters in the transfer functions).

With the foregoing discussion in mind as a constraint on the vehicle dynamics, a number of interesting problems present themselves for study during transitions. First narrow the problem to consideration of landing transitions. Landing transitions are more critical than takeoff transitions since a landing imposes tighter and tighter constraints on the allowable deviations in velocity and position: i.e., it is like flying into the open end of an inverted cone and aiming for the point. Clearly the converse is true for a takeoff.

The most desirable form of landing transition will vary widely with the mission or role of the aircraft. A number of criteria can be envisioned, e.g.,

1. Transition and land using the minimum amount of fuel.

2. Transition and land in the minimum time or so as to present the least exposure to possible hostile actions.

3. Transition and land so as to pose the least interference with other aircraft using the same landing facility.

4. Transition and land so as to minimize the noise exposure to the precincts of the landing site.

5. Transition and land in the manner that is least dependent on good visibility minimums or low wind and gust environment.

The optimum ways of satisying some of the above criteria will be very dependent on the configuration, others will be less dependent on the configuration and generally applicable (analogous to the energy management techniques applied to minimizing the time to altitude for a fighter).

A start to studying transitions could be made by hypothesizing criteria such as 1-5 above and determining the optimum trajectories for a representative range of VTOL configurations, e.g.,

Jet lift - (a) with separate lifting engines
(b) with tilting engines.

Tilt wing or tilt ducted propellers.

Tilting prop-rotor.

Helicopter.

Armed with this knowledge, it should be possible to typify the maneuvers involved in desirable transitions and base flying qualities studies on these maneuvers. As mentioned earlier, the dynamic characteristics could be kept constant or varied in a way typical of the type of VTOL under investigation. Thus with the basic aircraft dynamics defined and with the maneuver of interest defined, research can be conducted into the guidance, control and displays required as a function of the augmentation provided. NASA already have done some research along these lines (Reference 13) using a CH-46C with essentially a model following variable stability system. The model was kept constant and descents were studied using a fairly complex guidance system. Constant speed and decelerating approaches were studied. It is interesting to note that the descent angle was six degrees and it was found that decelerations were limited to 0.06g because greater levels required nose up attitudes greater than twelve degrees which was the maximum the pilot would permit.

The X-22A has the capability of being able to choose a range of fuselage attitudes at each speed by trading fuselage angle of attack with duct angle relative to the fuselage. This means that such studies as the one mentioned above could be performed in the X-22A without encountering limits on attitudes.

At the present time the X-22A does not have the complex guidance equipment installed that would be necessary to accomplish decelerated approaches similar to those in the NASA study. For this reason and for reasons of safety and simplicity, it is recommended that transition simulations be delayed until the aircraft has been operated in a less demanding situation, that is at fixed operating points. In the meantime, analytical and perhaps ground simulator studies should be conducted to develop some understanding of the basic factors of changing dynamics and desirable trajectories.

5.2 Fixed Operating Point (FOP) Flight

This is the name that has been used for flight consisting of maneuvering about a constant trim condition. For this condition, the techniques of linearized constant coefficient analysis, which have been used for years on conventional aircraft, seem to apply. As a result, the conventional techniques of understanding and specifying flying qualities have been extrapolated into the lower speed range.

In the specification, MIL-F-83300, quantitative requirements have been placed on familiar concepts such as static stability, control power, response to control inputs (sensitivity), and control lags.

The requirements have to cover all speeds from hover to V_{con}, where V_{con} is the speed at which the requirements of the conventional airplane specification, MIL-F-8785B, Reference 14, begin to apply. Within this speed range significant changes take place which make it necessary to change the flying qualities requirements. Examples of this are apparent in the detailed discussion of requirements in the BIUG (Reference 10). The reasons can be summarized as follows:

- The characteristic modes of motion undergo substantial changes in form, as forward speed increases.
- The change from direct lift to aerodynamic lift, as forward speed increases, results in changes in important stability derivatives, and necessitates changes in pilot control technique.
- The parameters, and the specific values of those parameters, which adequately describe a level of handling qualities in hover, are inadequate or inappropriate to assure a similar level at high forward speeds.

It would be ideal if the requirements could be made a continuous function of some parameter such as speed. Unfortunately the detail of existing knowledge of V/STOL flying qualities has not allowed this, and so a two part arrangement has been chosen with the division at 35 knots. There is nothing profound about 35 knots - it is a compromise chosen on the basis of our present understanding and includes the following considerations:

- There is a substantial amount of published data resulting from experiments done in and around the hover condition. These experiments typically involved tasks in which the vehicle achieved translational velocities as high as 35 knots.
- Many aircraft begin to develop "significant" amounts of aerodynamic lift above 35 knots, at which time there often exists a basic change in the dynamics. For example, one usually finds that hover approximations, such as an effectively decoupled height (or w) mode, begin to break down at about 35 knots.

- Along with the changing nature of the dynamics there is usually a change in the piloting technique.

- Hovering over a spot at any angle to a 35 knot wind is a requirement of the proposed specification (and others). Consideration was given, by the Air Force, to increasing the wind speed in which hovering capability is required. However, it was found that the probability of encountering winds greater than 30-40 knots did not justify a change. Certainly winds higher than 35 knots can be encountered, but it was assumed that the margin of the Service Flight Envelope over the Operational Flight Envelope will provide Level 2 hovering capability at speeds greater than 35 knots. Further margins may have to be demanded in special cases.

- Since 35 knots is a satisfactory dividing speed from a point of view of both aircraft dynamics and operational considerations, it was convenient to group the requirements by speeds. If it has been decided that hovering capability was necessary up to some significantly higher speed such as 60 knots, then a more complex division of the dynamics and operational aspects would have been necessary and thereby created the need for a much more complicated specification structure.

With the step change at 35 knots, considerable care has been exercised to allow the requirements for speeds less than 35 knots to blend with the requirements for speeds greater than 35 knots, and to blend with the requirements of MIL-F-8785B at V_{con}.

The discussion presented above, outlining the rationale for dividing the FOP requirements into two parts divided at 35 knots, immediately suggests an area needing research: how can the requirements be made to change smoothly with some parameter such as speed, n_z/α , etc? The answer to this question relies on having a supply of good data, adequately covering the speed range, and will doubtless not be solved in the near future.

There are a number of areas which can be suggested for study. It is convenient to discuss them in the context of the specification breakdown, i.e., for the speed region less than 35 knots (Section 3.2) and for between 35 knots and V_{con} (Section 3.3). No attempt will be made to assign priorities between these two flight regimes; that decision rests with the sponsor of future work. If STOL aircraft are to be developed first then the topics deserving priority are for the speed range greater than 35 knots (Section 3.3). If aircraft with "Vertical" rather that "Short" capability are to be emphasized, then sections of interest expand to include Hover ($V < 35$ knots, Section 3.2) and Transition (Section 3.4) as well as Forward Flight (35 knots $< V <$ V_{con}, Section 3.3). If the mission will be that of a jet fighter, then the Hover and Transition topics (Sections 3.2 and 3.4) would take precedence over Forward Flight (Section 3.3). Conversely if the aircraft was to be an LIT type of aircraft with vertical takeoff and landing capabilities but with flight phases such as STOL, low speed air drop, etc., then the Forward Flight requirements (Section 3.3) would still be important and may indeed deserve primary emphasis.

The following paragraphs discuss some of the areas deserving future work in the groupings Hover and Low Speed ($V < 35$ knots, Section 3.2) and Forward Flight (35 knots $< V < V_{con}$, Section 3.3).

5.3 Topics for Investigation - Hover and Low Speed Flight ($V < 35$ knots)

Dynamic Stability

The flying qualities literature gradually expanded from Control Power versus Rate Damping studies to more realistic models including the effects of derivatives such as M_θ , M_u , and X_u (and their equivalent in the lateral-directional plane). Such models have been investigated on fixed base simulators and moving base simulators (e.g. References 15 and 16 respectively) and have also included the effects of wind, turbulence, and control system lags.

Attempts at correlating the results of these studies with parameters that can be used as flying qualities criteria have used techniques based on:

(1) Location, in the s-plane, of the roots of the system's characteristic equation, (see Reference 10)

(2) On matching the time history of the response to a specified input (Reference 7).

(3) By minimizing a performance index made up of parameters in an assumed form of loop closure around the model (Reference 17).

Because they were still novel, methods (2) and (3) were set aside for further development and method (1) was adopted in the current version of MIL-F-83300.

It is realized that methods (2) and (3) offer advantages which should be exploited as soon as possible. These advantages include the ability to include the effects of control system dynamics along with the characteristic responses, and also the ability to be generalized to cover higher order systems.

In addition to the problem of obtaining correlation of the experimental data with a suitable flying qualities criteria, there is a need to verify that the experimental models contain all the important effects. Clearly a linearized constant coefficient model of a hovering VTOL is not exact, but it has been used on the assumption that it contains all the important features; a truly representative model is too complex to study in a generalized sense so has to be simplified to its essential features (though as complete a model as possible can always be used during design and evaluation of a specific design, it is difficult to apply the results of such a study to other configurations).

An important area for research then, is to determine if the simple models on which criteria are being based really do direct attention to all the characteristics which need to be specified.

Equilibrium Characteristics

Longitudinal equilibrium requirements are presently specified in terms of the pitch control force and displacement gradients with speed. Both stick force and position are required to be stable for Level 1 and for Level 2, IFR. For Level 2, VFR and for Level 3 a small unstable position gradient is allowed. These requirements are a constant source of contention between the military and the aircraft manufacturers. Demanding stick force and position stability throughout the speed range 0 to V_{con} will frequently necessitate a complicated control system with a series actuator. There is presently scant data to substantiate the requirements,though qualitatively, most authorities will agree that they are desirable.

MIL-F-8785B forbids an unstable aperiodic root and points to the sign of the steady state control position-airspeed gradient as an indicator of an unstable aperiodic root. For a conventional aircraft, a negative or stable gradient implies that the aircraft has no unstable aperiodic root. Although a pair of aperiodic roots could result in a stable control gradient this situation is unlikely to occur with a conventional aircraft. Thus a stable control position-airspeed gradient assures no single unstable aperiodic root, and, with a simple force feel system, stable control force-airspeed gradients will be provided as well. Consider, for example, the situation where the speed-pitch control position transfer function is of the form:

$$\frac{u}{\delta_{ES}} = \frac{As^2 + Bs + C}{(s^2 + 2\zeta_{SP}\omega_{SP}s + \omega_{SP}^2)(s^2 + 2\zeta_p\omega_p s + \omega_p^2)}$$

Depending on the sign of C , the sign of u/δ_{ES} in the steady state is determined by the number of poles of the transfer function in the right half plane as summarized in the table below.

	Poles in Right Half-Plane	Sign of Numerator Coefficient of C	Stick Position Gradient	Aircraft Stability
1	Odd	Positive	Stable	Unstable
2	Odd	Negative	Unstable	Unstable*
3	Even	Positive	Unstable	Unstable*
4	Even	Negative	Stable	Unstable
5	None	Positive	Unstable	Stable
6	None	Negative	Stable	Stable*

For all these possibilities to exist assumes that all the coefficients of s^n may assume values independent of each other. Note that only in 3 of the cases (indicated by *) does the sign of the stick position gradient correlate with the stability of the aircraft. In the development of MIL-F-8785B it was found to be extremely unlikely that the coefficient C would be positive. Therefore, only cases 2, 4, and 6 needed to be considered for conventional aircraft. For case 4, the stick position gradient does not correlate with the stability of the aircraft because of the existence of an even number of unstable roots in the right half plane. These could be any of the following combinations:

(a) 2 or 4 aperiodic, all unstable

(b) 2 aperiodic, 1 complex pair, all unstable

(c) 1 or 2 complex pairs, all unstable

Since it is unlikely that multiple, aperiodic unstable roots will occur, cases (a) and (b) will probably not be observed. One complex pair, case (c), may be observed but the intent of the requirement in MIL-F-8785 is to legislate against unstable aperiodic roots. Thus, for conventional aircraft, the stability of the equilibrium control position-airspeed gradient is an indicator of the existence of an unstable aperiodic root of the longitudinal characteristic equation.

With a V/STOL aircraft, the situation may not be this straightforward. That is, it may be possible for the numerator coefficient of s^0 (i.e., C) to become positive. In this situation, the implications of the specification requirements on control force, and position stability and the existence of unstable aperiodic roots are not clear. There is a need to determine the possibilities, and investigate the realistic combinations.

Control Power, Control Usage

Much has been said and written about the need to obtain control usage data (Reference 18). Control power can be a very important design parameter. This is true in general, but can be particularly critical in and around hover where all the lift is obtained from power (or thrust) and, very often, providing control subtracts significantly from the lift available. It is, therefore, highly desirable to provide the minimum necessary control power.

A great deal of work has been done in investigating control power along with control sensitivity. Control gain (sensitivity or gearing) is relatively straightforward in the sense that one can be sure that whatever is provided, was really used. Control power is a very different matter. If a level of control power is provided and quoted in a report, one is seldom able to determine if the full available was ever used, and if so, how often. A further question arises in experiments utilizing a trade-off between control power and control sensitivity. The test vehicle will always have only a certain amount of control power available, hence, if the gearing is such that more than the maximum available can be commanded by the pilot, should the stick hit mechanical stops, or should it continue to deflect without actually obtaining any more control moment? It is intuitively reasonable that the pilot's reaction would be different when evaluating a control system which hit stops from one which saturated without any apparent limit especially if the pilot's request for more than the maximum available was only slight and for a brief period. This idea is verified by the results of a simple ground simulator study performed by United Aircraft Research Laboratories. The results are as yet unpublished but are quoted in Reference 10, Section 3.2.3.1.

There is a need to increase the useful data base on control power usage. This means that data should be presented in the form of probability density function plots or cumulative probability plots, and power spectral density function plots (see Reference 18). Sufficient information should also be given so that it is possible to distinguish the control used for trim from the control used to maneuver and to overcome upsets. Data presentation in the form of power spectral density plots and, to a lesser extent, probability density function plots, involve handling large quantities of data and expensive calculations. However, cumulative probability plots are extremely simple to obtain, especially on ground simulation studies. (The control power exceedance data presented in Section 3.2.3.1 of Reference 10 are basically cumulative probability plots.) In the past, the expense of data handling has no doubt inhibited the presentation of power spectral density plots of control usage. However, developments in equipment make it a more realizable objective for the future; there is no excuse whatever, for not presenting cumulative probability (or exceedance) plots of control usage.

Height Control in Hover

There is a need to improve the precision with which VTOL aircraft can be hovered. Anyone who has taken one step too many, or one too few, when descending a stairway, knows the jolt that results from the misinterpreted height. How severe the shock must be for a fully laden infantryman descending a rope ladder from a helicopter, if, just as he steps off, the helicopter climbs or descends a couple of feet.

Ideally a height control requirement would include the combined effects of T/W , engine thrust response, height damping (Z_w) and perhaps even the pitch and roll dynamics. This is certainly not possible at present, in fact, there are detailed questions about the current data base for even interpreting $T/W \sim Z_w$ boundaries. The problem hinges around the difference between natural or aerodynamic height damping, and height damping achieved by feedback to the thrust controls. The present specification accounts for the tendency of minimum T/W required to increase at low damping levels by requiring the capability to develop certain levels of incremental vertical acceleration from a 4 ft/sec rate of descent. As is pointed out in the BIUG (Reference 10) this phrasing of the requirement has brought out the fact that there is a difference between artificial and inherent damping, since higher minimum T/W is required for compliance when damping is provided by augmentation. One would expect that from a piloting standpoint, it would be immaterial whether damping is inherent or artificial. Previous simulation testing and analysis provides little guidance since no distinction was made.

Another problem which has been virtually ignored in the literature to date is the time duration that vertical thrust increments are required for representative maneuvering situations. For example, some VTOL's may be capable of achieving the required acceleration levels instantaneously by trading off stored kinetic energy in the propulsion system for vertical thrust. However, sustained thrust increments may be impossible because of the attendant deceleration of the propulsion system. This aspect of the problem should be addressed in future simulation efforts by including representative dynamic characteristics of VTOL vertical thrust systems.

General

There are a number of requirements in MIL-F-83300 which may not be applicable to certain types of configurations. Examples of this are:

(1) the control force and sensitivity limits which are written for conventional stick (or wheel) and rudder pedals. They would be inappropriate for a side arm controller,

(2) the investigations into dynamic stability and control have been made for types of configurations which have to tilt to translate. It is not possible to say how applicable these would be for a type of configuration which had direct control of forces and used thrust vectoring (independently of attitude) for translation, and

(3) augmentation systems of the complexity up to attitude systems have been considered, but there are no provisions to cover such systems as the velocity command system developed by MIT (Reference 19).

Each of these three areas deserve study to see if some guidance can be incorporated into the specification. However, in assessing priorities, it is worthwhile bearing in mind that topic (3) is a highly augmented situation, probably providing flying qualities well in excess of minimum acceptable. Hence, in developing a general specification of minimum requirements, it may be assigned a lower priority.

5.4 Topics for Investigation - Forward Flight (35 knots $< V < V_{con}$)

Requirements for the speed range 35 knots to V_{con} include STOL, but also have to cover other possible flight phases such as ground attack, nap-of-the-earth flight, slung load transportation, etc.

In MIL-F-83300 the speed range 35 knots $< V < V_{con}$ has been treated in a similar way to conventional aircraft, primarily by making extrapolations into the lower speed situation. All the topics in the specification need more data, though many of the lateral-directional requirements are based on a better data base than are the longitudinal requirements.

There is a need to obtain an understanding of the basic changes in control technique which occur as speed reduces:

- Longitudinally, as n_z/α reduces below some value, maneuverability capability has to be augmented by some means of thrust vector control.

- In the lateral-directional plane, as n_y/β becomes small, the need to maintain sideslip nearly zero can reduce, so that slipping or skidding can be desirable ways of making lateral displacements in the flight path.

It is emphasized that all possible flight phases have to be covered in MIL-F-83300, however it seems safe to assume that (except for helicopters which are undoubtedly the most efficient hovering machines) the low speeds which make an aircraft into a VTOL or STOL will be primarily encountered during the terminal flight phases, i.e., takeoff and landing. The primary objective of most V/STOL's will be to keep the flying time at low speeds as short as possible. Thus takeoff and landing are the flight phases of primary interest. Of the two, landing is almost certainly the more demanding task, since as pointed out in the discussion for the speed range 0 to 35 knots, it is a task with ever tighter constraints, whereas takeoff allows ever looser constraints. However, the differences in power setting, configuration, weight, etc., may result in the takeoff being the critical design condition in terms of obtaining a certain set of dynamics or a given control power. Because of this, the takeoff task could be studied to determine the extent to which the requirements established for the landing task can be relaxed. Such an objective is desirable rather than essential as it is related to optimization of a specific design rather than the understanding of essential characteristics; for the present time landing deserves the primary emphasis.

Longitudinal and lateral-directional studies have been performed in the landing approach. However, the longitudinal degrees of freedom contain the real essence of the problem. It is impossible to study longitudinal flying qualities without taking account of the fact that the task is landing approach so that in addition to the aircraft dynamics and control characteristics there are the additional parameters of speed, descent angle, fuselage attitude, visibility and/or displays. The pilot has to control pitch attitude with the pitch control, and speed and flight path angle with the pitch control and the thrust magnitude and angle controls; this is a complex multiloop problem. The lateral-directional problem is somewhat subservient since lateral attitude changes are used primarily to change heading. Though this is a complex multiloop problem it can be studied relatively independent of the descent angle. These comments are not meant to discount the lateral-directional problems, rather they are meant as a rationale for choosing longitudinal - if a choice must be made.

Before outlining some specific topics needing data it will be re-emphasized that there is a dire need for data on all topics in the Forward Flight section (3.3) of MIL-F-83300. As mentioned earlier, it is hoped, and expected, that having a specification to test against, the various test activities will utilize the specification and publish data - thus broadening the data base. It is particularly hoped that the Army will do this, for they do operate and test most of the present V/STOL's (helicopters). It may also be worthwhile pointing out, that for test data to be of value in providing background for future development of a specification, it must contain the following information:

(1) The aircraft stability and control parameters must be accurately identified and quoted - preferably with the records from which they were extracted.

(2) Sufficient pilot comment data must be included to be able to determine the answer to the question. If it met (or failed) a given requirement, was that particular characteristic satisfactory, unsatisfactory or unimportant?

Remember, if an aircraft has an overall pilot rating of Level 1, then all the different characteristics should meet the Level 1 requirements. If the aircraft is rated Level 2, then one or more characteristics will be Level 2 and others could be Level 1. Pilot comment data is the only known way of differentiating between the good and bad aspects in these circumstances.

Most of the aspects outlined in the Hover and Low Speed discussion are equally valid for 35 knots $< V < V_{con}$. In particular there is need for work on:

- better methods of generating and correlating dynamic requirements.
- investigation of the need for stable stick force and position gradients.
- control power - control usage data.

Longitudinal Dynamics

The method of specifying longitudinal dynamics in MIL-F-83300 is a carryover from MIL-F-8785B (Reference 14). It is fully realized that at the speeds of interest, the short period and phugoid modes of response become less distinct; the short period takes longer and the phugoid becomes quicker. This has been recognized, and the terminology "short-period mode" and "phugoid mode" has not been used. Instead, MIL-F-83300 addresses the "short-term response of angle of attack following an abrupt pitch control input". In the limit this will be the short period mode. The phugoid is covered by a blanket requirement on "all roots of the characteristic equation". It is expected that such statements are sufficiently general. However, there is a need to study all the aspects of longitudinal dynamics, and equilibrium, for the special conditions of STOL's.

Considerable effort should be spent on developing mathematical models which contain all the essential features of STOL aircraft currently being considered in preliminary design studies. Experimental investigations should then be performed to determine how the short term response dynamics and equilibrium characteristics (in terms of stick force and position gradients) interact with other aspects such as:

closing speed, V

fuselage attitude, θ

flight path angle, γ

flight path stability, $d\gamma/dV$

normal load factor capability, n_z/α

direct lift control requirements in terms of thrust inclination, $\left.\frac{\Delta z}{\Delta X}\right|_{\delta_t}$ and moment due to thrust control, M_{δ_t}

displays, breakout altitude.

It is unlikely that a simple way will be found to correlate such a multiplicity of factors, and techniques such as closed loop analysis using pilot models may be useful in deriving better understanding. It may also be useful to try techniques such as response matching and minimizing the performance index, mentioned in the Hover and Low Speed discussion.

Lateral-Directional Problems

Several of the forward flight lateral-directional requirements in MIL-F-83300 are STOL and conventional flight oriented. For example, requirements 3.3.8, Roll-sideslip coupling, were derived empirically from test data generated from aircraft having conventional modal characteristics. These requirements, which are stated in terms of parameters such as ϕ_{osc}/ϕ_{AV} and $\Delta\beta/\phi_1$, are all based on an underlying theme, which, briefly stated, is that in lateral-directional maneuvering roll control inputs are "primary" and that associated sideslip excursions are for the most part unwanted effects that can require complicated and objectionable rudder coordination in order to be suppressed. At higher speeds there is substance to this theme in the way of experimental flight test data. At lower speeds, the development of large sideslip angles during maneuvering does not appear to be as objectionable. Large sideslip motions are common at hover. Thus, somewhere between V_{con} and hover, the role played by sideslip excursions as a flying qualities consideration changes and perhaps the requirements should be phased accordingly.

The lateral-directional stability requirements in MIL-F-83300 were formulated using a data base that reflected low values of Dutch roll frequency but there is a need to obtain data for very low frequencies. In addition, the data base for the MIL-F-83300 stability requirements reflected neutral spiral stability and a well damped roll mode. Data on more stable spirals along with less damped roll modes is needed. Finally, there is a general need for data on configurations having stability augmentation systems with roll attitude feedback, heading hold and rate command control loops. Control mechanizations such as these are not represented in the data used to formulate MIL-F-83300 requirements.

Control Power, Control Usage, Maneuvering Control Margins

As with hover and low speed, there is a distinct need for control power, control sensitivity and control usage data about all three axes.

Longitudinal control is intimately coupled with the maneuvering control margins. In fact, in the forward flight section (3.3) of MIL-F-83300, the maneuvering control margins are the only way in which pitch control power is specified. Unfortunately the desirable levels of maneuvering control margins themselves are not clearly defined so it is presently impossible to be more specific about control power. Hopefully this is another area which will benefit from a broader data base of the form recommended in the discussion on control power and control usage for the hover and low speed requirements.

Roll control power has been specified in MIL-F-83300 based on extrapolation of MIL-F-8785 (Reference 14) data. The levels specified appear reasonable for STOL aircraft, but it is questionable how they should fare into the Low Speed Requirements (3.2) at speeds around 36 knots. Control usage data would be valuable here too.

Yaw control has been specified in two distinct ways; as a minimum sideslip requirement and as a minimum capability to change heading. The rationale here was to ensure a minimum level of yaw control at low speeds ($\approx$ 36 knots) when the stiffness (N_β) was small and the sideslip requirement was relatively meaningless. A background of data is certainly desirable to increase confidence in these requirements.

General

The topics discussed under General for speeds less than 35 knots are also valid here.

(1) control force and sensitivity requirements are for conventional stick (or wheel) and pedals and would be inappropriate for side arm controllers,

(2) the dynamic and response requirements are for aircraft which tilt to translate, and may, or may not, be applicable for aircraft which can translate by thrust vectoring independently of the aircraft attitude, and

(3) the requirements are basically for rate systems. Aircraft having a significant degree of attitude augmentation may not be covered by the requirements as they are written. This is particularly true in the case of lateral-directional augmentation, where heading hold or turn rate systems may or may not meet the requirements. In the longitudinal plane, velocity command systems are not covered.

Future work should give consideration to each of the above areas. The side arm controller could find its way into many types of aircraft. The Huey Cobra (AH-1G) already utilizes such a system for the front (gunner's) seat.

There is an obvious advantage to designing an aircraft which does not have to tilt to translate; the attitude can remain about constant and hence large attitudes can be avoided. This could be particularly advantageous in the terminal flight phases where large attitudes interfere with the field of view. The dynamics which would be desirable for such an aircraft will no doubt be different from the type studied to date. Hence, if preliminary design studies show such an arrangement to be feasible or desirable, then efforts should be made to cover them in the requirements.

5.5 Wind and Turbulence

Unlike MIL-F-8785 (Reference 14) the V/STOL Specification MIL-F-83300 (Reference 1) does not define the turbulence model which should be used in investigating the requirements. Many investigations have demonstrated that wind and turbulence is an essential ingredient of valid flying qualities simulator studies. During the last few years much work has been devoted to developing new and better turbulence models and incorporating these into simulator studies. For these reasons it is considered that an effort should now be made to incorporate a suitable model into the specification.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Cornell Aeronautical Laboratory, Inc. Box 235 Buffalo, New York 14221	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

THE GENERATION OF A MILITARY SPECIFICATION FOR FLYING QUALITIES OF PILOTED V/STOL AIRCRAFT - MIL-F-83300

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

final report April 1966 to March 1971

5. AUTHOR(S) (Last name, first name, initial)

Key, David L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1971	33	19

8a. CONTRACT OR GRANT NO. AF33(615)-3736 F33615-70-C-1322 b. PROJECT NO. 698DC c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) BB-2925-F-1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-71-23

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13. ABSTRACT

This document describes a four year effort which led to the adoption of a new military specification MIL-F-83300, "Flying Qualities of Piloted V/STOL Aircraft", and the publication of a supporting document, "Background Information and User Guide for MIL-F-83300, Military Specification - Flying Qualities of Piloted V/STOL Aircraft" (AFFDL-TR-70-88).

Included in the report is an assessment of the status of V/STOL flying qualities research and recommendations for future work.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
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Flying Qualities						
V/STOL Flying Qualities Requirements						
V/STOL Aircraft						
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