AFFDL-TR-71-26-VOL II

AD724186

STOL HIGH-LIFT DESIGN STUDY

Volume II. Bibliography

Fred May
Colin A. Widdison

The Boeing Company

TECHNICAL REPORT AFFDL-TR-71-26-VOL II
April 1971

This document has been approved for public release and sale; its distribution is unlimited.

Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

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)

The Boeing Company, Vertol Division
Boeing Center, P.O. Box 16858
Philadelphia, Pennsylvania 19142

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

STOL HIGH-LIFT DESIGN STUDY
Volume II. Bibliography

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

Final Report January-December 1970

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

Fred May
Colin A. Widdison

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1971	334	0

8a. CONTRACT OR GRANT NO.
F33615-70-C-1277

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
D210-10201-2

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
AFFDL-TR-71-26-Vol II

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES

Volume II of a 2-volume report

12. SPONSORING MILITARY ACTIVITY

Air Force Flight Dynamics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

The state of the art of STOL aerodynamic technology for selected lift/propulsion concepts has been surveyed to identify the available test data and prediction methods in the literature. The report consists of two volumes.

In Volume I important areas of technology and information necessary for the evaluation of STOL aircraft aerodynamics are listed; the aerodynamic test data and prediction methodology relevant to the deflected slipstream and externally blown flap concepts are assessed, with emphasis on the latter; an empirical method for the prediction of the longitudinal aerodynamic characteristics of externally blown flap configurations is presented; and high-lift technology for five lift/propulsion concepts is assessed in application to a medium-sized STOL transport.

Volume II consists of a bibliography that resulted from a literature search for aerodynamic information related to seven lift/propulsion concepts suitable for STOL aircraft. The bibliography contains references to approximately 900 reports classified by concept and by technological area.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Bibliography						
Literature search						
7 lift/propulsion concepts						
STOL aircraft						
900 references						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

STOL HIGH-LIFT DESIGN STUDY

Volume II. Bibliography

Fred May
Colin A. Widdison

The Boeing Company

FOREWORD

This report was prepared for the Air Force Flight Dynamics Laboratory by The Boeing Company. The study was conducted under USAF Contract F33615-70-C-1277, "STOL High-Lift Design Study", with Captain Garland S. Oates as Project Engineer for the Air Force.

The study was performed from January through December, 1970 by Mr. Colin Widdison of the Vertol Division and Mr. Fred May of the Military Airplane Systems Division.

This technical report has been reviewed and is approved.

E. J. Cross, Jr.
Lt. Col. USAF
Chief, V/STOL Technology Division

ABSTRACT

The state of the art of STOL aerodynamic technology for selected lift/propulsion concepts has been surveyed to identify the available test data and prediction methods in the literature. The report consists of two volumes.

In Volume I important areas of technology and information necessary for the evaluation of STOL aircraft aerodynamics are listed; the aerodynamic test data and prediction methodology relevant to the deflected slipstream and externally blown flap concepts are assessed, with emphasis on the latter; an empirical method for the prediction of the longitudinal aerodynamic characteristics of externally blown flap configurations is presented; and high-lift technology for five lift/propulsion concepts is assessed in application to a medium-sized STOL transport.

Volume II consists of a bibliography that resulted from a literature search for aerodynamic information related to seven lift/propulsion concepts suitable for STOL aircraft. The bibliography contains references to approximately 900 reports classified by concept and by technological area.

TABLE OF CONTENTS

Page

INTRODUCTION

This document, consisting of a bibliography of STOL aerodynamic test data and prediction methods, constitutes Volume II of the final report of the "STOL High-Lift Design Study".

The purpose of the study was to assess the aerodynamic state of the art of near-term STOL aircraft concepts and to determine technological programs needed to correct design engineering deficiencies.

The first part of the study consisted of identifying the important aerodynamic technology areas in STOL design and listing the specific information required to permit STOL aircraft design work and the analysis and evaluation of competing designs. This listing was then used as a guideline in a literature search to discover that portion of the required information that is available in the open literature. The scope of the literature search included seven lift/propulsion concepts that are potentially useful for near-term STOL transport aircraft. For the purposes of classification of the literature the listing of required information was divided into six areas of technology. In general terms, two classes of literature were collected: test data and prediction methods.

SCOPE OF THE LITERATURE SEARCH

The literature search was made in order to identify the available test data and prediction methods relevant to the aerodynamics of seven STOL lift/propulsion concepts. The seven concepts were the Externally Blown Flap; Propeller-Driven Deflected Slipstream; Jet Flap; Mechanical High-Lift Devices including Boundary Layer Control; Fan-in-Wing; Tilt-Wing; and Direct-Jet-Lift concepts.

The technological areas in which literature was sought were Forces and Moments, Flow Fields, Ground Effect, Stability and Control, Handling Qualities and Criteria, and Testing.

In addition to the seven STOL concepts and the list of technological areas, a further classification entitled "General" was included to cover literature that was relevant to a number of concepts or areas without being specific to any of them.

SOURCES OF LITERATURE

The main body of references was obtained by means of automated literature searches carried out by the Defense Documentation Center and by NASA and Boeing Company libraries. Other sources of literature included the NASA STAR Index, Royal Aeronautical

Society Library Acquisition List, and a number of relevant AGARD bibliographies. Additional references were obtained by scanning the professional journals.

CLASSIFICATION OF THE BIBLIOGRAPHY

The references in this bibliography are classified at three levels and are identified by a 4-place numbering system. At the first level two major classes are employed that include all others: I, PREDICTION METHODS, and II, TEST DATA.

The second level of classification indicates the STOL concept to which the information is applicable. The order is shown below; the numbers shown against the named concepts appear as the first Arabic numeral. The STOL concepts included in the search were:

1. Externally Blown Flap
2. Deflected Slipstream
3. Jet Flap
4. High-Lift Devices
5. Fan-in-Wing
6. Tilt-Wing
7. Jet-Lift
8. General - related to some or all of the above concepts

At the third level of classification, within the STOL concept grouping, are the areas of technology. These appear in the order shown below; the identifying number appears third in the reference number. The technological areas researched are:

1. Forces and Moments
2. Flow Fields
3. Ground Effect
4. Stability and Control
5. Handling Qualities and Criteria
6. Testing
7. General

The "General" classification is again included to cover areas less specific than items 1 through 6.

The fourth part of the reference number indicates the location of the reference within its particular technological area subgroup.

The following example illustrates the numbering system:

II.3.1.2
second reference
Forces and Moments
Jet Flap
Test Data

SECTION I

PREDICTION METHODS

I.1 EXTERNALLY BLOWN FLAPS

No prediction methods were found during the literature search. The only known available method is that given in Section 4 of Volume I of this report.

I.2 DEFLECTED SLIPSTREAM

I.2.1 Forces and Moments -

I.2.1.1 THEORY OF WINGS IN SLIPSTREAMS, H. S. Ribner U.T.I.A. Report 60, May 1959.
A general potential theory has been developed for the aerodynamics of a wing in one (or more) slipstreams of arbitrary shape or position. The central idea, involving the use of a "reduced" potential within the slipstream jet, is representation of the flow by means of two distributions of vortices (or doublets): one over the wing and its wake, and the other over the jet boundary.

I.2.1.2 INFLUENCE OF THE PROPELLER ON OTHER PARTS OF THE AIRPLANE STRUCTURE, C. Koning in Aerodynamic Theory Ed. W.F. Durand, Pub. Dover 1963, (original Pub. 1935).
A small perturbation potential flow approach is used to calculate propeller slipstream effects. The wing is represented by a lifting line and the combined flow is obtained by superposition. Includes expressions for the change of lift, drag and pitching moment and shows some comparison with experimental data.

I.2.1.3 A PRELIMINARY THEORETICAL INVESTIGATION OF THE EFFECT OF PROPELLER SLIPSTREAM ON WING LIFT, E. W. Graham, et al, Douglas Report No. SM-14991, November 1953.

I.2.1.4 ESTIMATION OF INCREASE IN LIFT DUE TO SLIPSTREAM, R. Smelt and M. Davies, ARC R&M 1788, February 1937.
A theoretical method is used to estimate the inclination and velocity of a propeller slipstream and then to calculate the increase of lift of a wing placed behind the propeller. The result is compared with some test data and shown to be of good accuracy provided the wing bears no high lift devices.

I.2.1.5 A STABILITY ANALYSIS OF TILT-WING AIRCRAFT (ANALYTICAL) by Charles H. Cromwell, III, and Henry E. Payne, III, Princeton University Report No. 477.
A general development of methods for predicting aerodynamic stability derivatives of propeller-driven tilt-wing vertical takeoff and landing (VTOL) aircraft is presented.

The concept of slipstream dynamic pressure (q") is reviewed along with the basic assumptions behind it and their limitations. The use of q" is then extended to give a semi-empirical method of predicting lift and drag on a wing, at any tilt angle, which is fully immersed in slipstream. This analysis is justified by experimental data, and other wind tunnel data which was taken for a general tilt-wing transport model is presented.

The linearized small-perturbation equations of motion are reviewed and then adapted to the tilt-wing aircraft. The aerodynamic terms in the stability derivatives are evaluated in general form using either experimental data or the theoretical method previously mentioned to account for the wing's contributions. The other components of the aircraft considered as contributing to stability are propeller, fuselage and tail.

The methods devised for predicting the stability derivatives are then used to make an illustrative series of calculations for the Hiller X-18 test bed. The stability roots are calculated, and the aircraft's characteristic response is determined by use of an analog computer.

I.2.1.6 THE ANALYSIS OF PROPELLER-WING FLOW INTERACTION, Antony Jameson, NASA SP-228.
Theoretical methods are developed for calculating the interaction of a wing both with a circular slipstream and with a wide slipstream as might be produced if the slipstreams of several propellers merged. To simplify the analysis rectangular and elliptic jets are used as models for wide slipstreams. Standard imaging techniques are used to develop a lifting surface theory for a static wing in a rectangular jet. The effect of forward speed is analyzed for a lifting line in an elliptic jet, and a closed form solution is found in the case when the wing just spans the foci of the ellipse. A continuous wide jet is found to provide a substantially greater augmentation of lift than multiple separate jets because of elimination of edge effects at the gaps. Calculations based on these methods show good correlation with experimental data for wings without flaps, but deflection of flaps seems to result in a greater turning effectiveness than might be expected from the theory. Reference is made to Kuhn's correlation of θ/δ with c_f/c (NASA Memo 1-16-59L). No consideration is made of slipstream rotation effects.

I.2.1.7 EFFECTS OF PROPELLER SLIPSTREAM ON V/STOL AIRCRAFT PERFORMANCE AND STABILITY, L. Goland, N. Miller, and L. Butler, Dynasciences Corp., Fort Washington, Pa., DCR-137 (TRECOM TR 64-47).
Presented is an analytical investigation of the aerodynamic forces acting on wing-prope ler combinations including the effects of propeller slipstreams. The results of the developed theory are then applied to typical two- and four-propeller VTOL and STOL wing configurations. Correlation with existing test data is shown to be poor except when propeller thrust is dominant, and flap deflection is small. Consideration is also given to such associated items as the effects of the slipstream on (1) wing stall (2) aircraft take-off and landing performance and (3) aircraft stability and control.

I.2.1.8 AERODYNAMIC FACTORS TO BE CONSIDERED IN THE DESIGN OF TILT-WING V/STOL airplanes, M.O. McKinney, R. H. Kirby, and W. A. Newsom, New York Academy of Sciences Annals, Vol. 107, Art.1, March 25, 1963, p. 221-248.
Discussion of the aerodynamics of tilt-wing V/STOL aircraft specifically covering the effects of wing span and wing stall. It is found that a large wing span is desirable from the transition, STOL, and cruise performance standpoints. The wing tends to stall in transition, particularly in descent, and has serious effects on performance, flying qualities, and buffet. The wing stalling and its adverse effects can be relieved or eliminated by the use of sufficiently large wing chord, flap, and leading-edge high-lift devices. Ground proximity tends to cause an increase in lift, but also causes adverse dynamic effects on flying qualities and adverse effects on STOL performance. Treated in detail are (1) slipstream flow along the ground; (2) hovering control power in roll,yaw, and pitch; and (3) unstable pitching and rolling oscillations in hovering flight. No prediction method is included but basic physical considerations necessary are covered.

I.2.1.9 DETERMINATION OF BREGUET 941 STOL AIRCRAFT TRANSITION VELOCITIES WITH VARIOUS FLAP DEFLECTIONS, Harlan D. Fowler, Society of Automotive Engineers, International Automotive Engineering Congress, Detroit, Michigan, January 11-15, 1965, Paper 960C, 27p.
Description of a method for calculating the transitional velocities associated with various flap deflections for the Breguet 941 deflected-slipstream STOL. Basic lift and drag curves of the Breguet type of triple-slotted flaps are developed, and accurate

I.2.1.9 (continued)

power and thrust levels for takeoff, climb, and stall are determined. The vital role of induced drag due to flaps is clarified, and the effect of the thrust coefficient on the lift of the wing with zero flap deflection is evaluated. In addition, the drag caused by the slipstream dynamic pressure over the wing is found. Transitional velocities for climb, takeoff and landing are calculated, and formulas are presented for determining the takeoff and landing distances for this type of aircraft. The calculations are found to agree well with flight test data.

I.2.1.10 A LIFTING SURFACE THEORY FOR WINGS EXTENDING THROUGH MULTIPLE JETS IN SEPARATED FLOW CONDITIONS, E. Cumberbatch, October 1963. V.R.C. Report No.10.
A lifting surface theory for wing-propeller slipstream interactions in separated flow conditions was developed. The case where the flow over wing portions immersed in the propeller slipstreams (jets) is attached while the flow over the wing outside the jets is separated has been treated in detail. The case where flow is separated both inside and outside the jets may be analyzed in a similar manner. The theoretical development combines non-separated flow analyses based on the Rethorst lifting surface solution with cavitation (separated flow) theory developed by Wu and Wang. A lifting surface representation based on a generalization of Weissinger's approximation was developed. In the separated flow regions, the location of the lifting line and the station where downwash boundary conditions must be satisfied are determined from cavitation theory and/or experimental results.

I.2.1.11 A LIFTING SURFACE THEORY FOR WINGS AT HIGH ANGLES OF ATTACK EXTENDING THROUGH MULTIPLE JETS, E. Cumberbatch (Vehicle Research Corp, Rep. VRC No.9)
This report consists of the first and second parts of the three part analytical portion of the high angle of attack theory (third phase) of VRC's program of developing methods for assessing the non-uniform flow fields of wing-propeller slipstream aerodynamics. The three parts of the third phase effort are comprised of: (1) wings located at various heights in the jet, (2) highly cambered wings as used in deflected slipstream V/STOL arrangements, and (3) tilt wing configurations where the jet is at an angle to the freestream flow. The present report contains the basic theoretical development of the

I.2.1.11 (continued)
first two parts enumerated above. This portion of the third phase effort has greatly extended the applicability of the analysis by encompassing deflected slipstream V/STOL arrangements currently under development.

I.2.1.12 AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, Volume II, PROPULSION AND INTERFERENCE AERODYNAMICS, Cornell Aeronautical Lab, Inc., Buffalo, N. Y. June 1966.
Contents: Predicted and measured performance of two full-scale ducted propellers; aerothermal dynamic performance of a high bypass tip turbine cruise fan system; thrust deflection nozzles for VTOL aircraft; shrouded propeller research at Mississippi State University leading to application on the United States Army XV-11A; the lift, drag and stability of wings immersed in propeller slipstream; aerodynamic properties of airfoils in non-uniformly sheared flows; experimental investigation of compound helicopter aerodynamic interference effects; maximum lift coefficient for STOL aircraft; a critical review.

I.2.1.13 A COMPUTER STUDY OF A WING IN A SLIPSTREAM, N. D. Ellis, February 1967, Report No. UTIAS-TN-101.
A FORTRAN IV program for the IBM 7094-11 digital computer has been formulated based on a theory of wing-slipstream interference by Ribner which accounts for the slipstream effects by means of a vortex sheath. This sheath together with the wing vorticity lead a pair of simultaneous integral equations for the unknown circulations. A stepwise approximation of the circulations reduces the pair to a system of linear algebraic equations. The format has been modified from that of the earlier work to facilitate inversion of the equations by computer. This first program has been restricted for simplicity to the case of a slipstream centered on a rectangular wing. The printout yields circulation, span loading, integrated lift and other properties. The results show a progression from approximately 'slender body theory' for very narrow slipstreams to 'strip theory' for very broad slipstreams and compare well with experimental data.

I.2.1.14 CHARTS FOR ESTIMATING AERODYNAMIC FORCES ON STOL AIRCRAFT WINGS IMMERSED IN PROPELLER SLIPSTREAMS, K. P. Huang, L. Goland, November 1965, Report No. DCR-161.

I.2.1.14 (continued)
Equations and charts are presented for estimating the lift and longitudinal force coefficients of STOL aircraft wings immersed in propeller slipstreams. Sample calculations are made and the results show fair to good correlation with available experimental data. The effect of many design and operating parameters is analyzed.

I.2.1.15 AN INVESTIGATION OF PROPELLER SLIPSTREAM EFFECTS ON V/STOL AIRCRAFT PERFORMANCE AND STABILITY, L. Butler, K.P. Huang, Report No. DCR-174, February 1966, (USAAVLABS TR 65-81).
Specific areas investigated include wing stall during transition, minimum wing size for stall-free transition, and the effects of slipstream on aircraft pitching moments. In addition, a stability analysis was performed, and analog computer techniques were used to determine the feasibility of utilizing the slipstream for stability augmentation. Finally, the effects of the non-uniformity of slipstream velocity and wing geometry modifications on performance were analyzed.

I.2.1.16 A LIFTING SURFACE THEORY FOR WINGS AT ANGLES OF ATTACK EXTENDING THROUGH INCLINED JETS, T. Yaotsu, October 1963, Report No. 9A. (Vehicle Research Corp.)
The third part of the three part high angle of attack theory is presented. The preceding two parts have been published as VRC Report No.9. The three parts comprise Phase III of VRC's program of developing methods for assessing the non-uniform flow fields of wing-propeller slipstream aerodynamics. This effort consists of the following three parts: (1) wings at various heights in the jet; (2) highly cambered wings as used in deflected slipstream V/STOL arrangements; and (3) tilt wing configurations where the jet is inclined to the freestream flow. Analytical evaluation is presented of the complex flow field encountered by tilt-wing V/STOL aircraft (Vertol 76, Hiller X-18, Tri-Service XC-142, etc.). The analysis provides methods for determining the spanwise lift distribution and induced drag of such aircraft.

I.2.1.17 SEMI-EMPIRICAL PROCEDURE FOR ESTIMATING LIFT AND DRAG CHARACTERISTICS OF PROPELLER-WING-FLAP CONFIGURATIONS FOR VERTICAL- and SHORT- TAKE-OFF-AND-LANDING AIRPLANES, R. E. Kuhn, NASA Memo 1-16-59L, February 1959.
The analysis presented used the momentum theory as a

I.2.1.17 (continued)
starting point in developing semi-empirical expressions for calculating the effect of propeller thrust and slipstream. The method uses measured power-off forward-speed data and measured slipstream deflection data at zero forward speed to provide a basis for estimating the lift and drag at combined forward speed and power-on conditions. A correlation of slipstream deflection data is also included.

I.2.1.18 THE LIFT OF A PROPELLER-WING COMBINATION DUE TO THE SLIPSTREAM, D. H. Chester, Israel Journal of Technology, Vol.3, No.1, 1965, pp. 102-119.
The problem of determining the 'power-on' increment of lift of a practical propeller-wing combination of flight was described. The various parts of the problem were explained and it is claimed that some of the previous attempts to obtain solutions were too limited to be of real practical use. Having analyzed the problem, a solution is found for each part. Some of these solutions have only been obtained after making quite severe assumptions. Synthesis of the various parts produces a general solution to the problem. The program of operations required to supply such an answer is laid out in flow chart format.

I.2.1.19 LIFTING-SURFACE THEORY FOR V/STOL AIRCRAFT IN TRANSITION AND CRUISE II, E. S. Levinsky, H. V. Thommen, P.M. Yager, and C.H. Holland, Journal of Aircraft, Vol. 7 No.1, January-February 1970.
This was the second part of a two-part paper dealing with a large-tilt angle lifting-surface theory for tilt-wing and tilt-propeller (or rotor) type V/STOL aircraft. Part I presented a new inclined actuator disk theory and a model for slipstream swirl. In Part II, the inclined actuator disk analysis was combined with a discrete-vortex Weissinger-type lifting-surface theory for application to wing-propeller combinations at arbitrary wing angle of attack, propeller tilt angle, and thrust coefficient. Configurations with one, two or four slipstreams were considered, and effects of slipstream rotation were included in all but the single-slipstream cases. Agreement between theory and experiment was shown to be satisfactory for small slipstream inclination angles. However, at large tilt angles, the theory, was shown to predict lower downwash angles in the tail region than observed from a single set of test data. Use of only one-

I.2.1.19 (continued)
half the calculated wake displacement was shown to give improved agreement. It is stated that insufficient downwash angle data were available for making a general evaluation of the theory at large slipstream angles.

I.2.1.20 INVESTIGATION OF PROPELLER SLIPSTREAM EFFECTS ON WING PERFORMANCE, M. George and E. Kisielowski, USAAVLABS Technical Report 67-67, November 1967.
A theoretical and experimental study was conducted to determine the effects of propeller slipstream on wing performance. Previously developed theoretical analyses were expanded and modified to account for radial variation of the propeller slipstream velocity. The experimental program consisted of wind tunnel tests conducted with a motor-propeller system mounted on a semi-span wing model. The wing model has eight floating wing segments with and without 45 degree simulated split flap. Located within each floating wing segment is a three-component strain gage balance to provide measurements of lift, drag, and pitching moment. The measurements of total wing lift, drag, and pitching moment were obtained with the six-component main wind tunnel balance. The test data obtained included the effects of the variation of propeller slipstream velocity by utilizing two propellers of different geometries. Propeller rotation for all tests was down at the wing tip. The experimental and theoretical results are compared; in general, good correlation was observed.

I.2.1.21 LIFTING SURFACE THEORY AND TAIL DOWNWASH CALCULATIONS FOR V/STOL AIRCRAFT IN TRANSITION AND CRUISE, E. S. Levinsky, H.V. Thommen, P.M. Yager, and C.H. Holland, USAAVLABS Technical Report 68-67, October 1968.
A large tilt-angle lifting-surface theory was developed for tilt-wing and tilt-rotor aircraft. An inclined actuator disc analysis was used in which closed-form solutions are found for the velocity potential inside and outside a fully contracted circular slipstream at large distances behind the actuator. This was combined with a Weissinger-type lifting surface theory for application to wing-propeller combinations. Agreement between theory and experiment was satisfactory at small slipstream inclination angles. At large tilt angles, downwash angles are under-predicted. This paper was published

I.2.1.21 (continued)
in two parts in J. Aircraft Vol.6, No.6 November-December 1969 and Vol.7 No.1, January-February 1970.

I.2.1.22 AERODYNAMIC CHARACTERISTICS OF PROPELLER-WING-FLAP SYSTEMS, K. Matsuoka, M. Yonezawa, and M. Takahshi, Osake Prefecture, University Bulletin, Series A - Engineering and Natural Science,Vol.17, No.1, 1968, Equations to estimate the aerodynamic characteristics of propeller-wing-flap systems were formulated. The momentum deflection angles of the propeller slipstream were determined, accounting for the mixing effect between the propeller slipstream and the free stream. The theory was in good agreement with some wind tunnel results.

I.2.1.23 LIFT, DRAG AND POWER ESTIMATIONS FOR TILT WING AND DEFLECTED SLIPSTREAM AIRCRAFT, J. Marshall and N. McM. Sinton Short Bros. and Harland, Ltd., AD/TN/89, 1963.
An inclined actuator disc theory is used to calculate velocity in the propeller slipstream and hence the local angle of attack of the wing in the slipstream. A mass flow correction factor is introduced to account for the fact that only part of the wing lies in the slipstream. Comparison of the method with test data shows fairly good agreement for lift and drag at angles of incidence below 'power-off' stall.

I.2.1.24 A SIMPLIFIED THEORETICAL INVESTIGATION OF A WING PROPELLER COMBINATION THROUGH A RANGE OF ANGLES-OF-ATTACK FROM 0° TO 90° AND A COMPARISON WITH EXPERIMENTAL RESULTS, M. Guerrieri and J. Stuart, III, Hiller Report No. 461-3, 14 October 1955.

I.2.1.25 LIFT CHARACTERISTICS OF WINGS EXTENDING THROUGH PROPELLER SLIPSTREAMS, Rethorst, Scott, Royce, Winston an T. Wu, Yao-Tsu. Vehicle Research Corp., Report No.1, September 1958.

I.2.1.26 A THEORY OF WING-PROPULSION COMBINATIONS IN SLOW FLIGHT, R. J. Vidal, Cornell Aero Lab. Report, A1-1190-A-1, September 1959.

I.2.2 Flow Fields -

I.2.2.1 GROUND EFFECT ON DOWNWASH WITH SLIPSTREAM, P. R. Owen and H. Hogg, ARC R&M 2249.
For a given incidence and propelelr thrust coefficient a method for finding the changes of downwash at the tail due to ground effect is presented. Comparison with data is included.

I.2.2.2 EFFECT OF PROPELLER THRUST ON DOWNWASH AND VELOCITY AT TAIL PLANE, Data from low speed tunnel tests. A. Spence, ARC CP 21.

I.2.2.3 AERODYNAMICS OF DEFLECTED SLIPSTREAMS, Part I, Formulation of the Integral Equations, Report No. Al 1190 A6, Cornell Aeronautical Lab. Inc., Buffalo, New York.
The effects of jet curvature are investigated on the premise that at higher angles of flow deflection, this factor should have an important influence on wing lift. The jet boundary is regarded as vortical layer, as is also the wing surface and its wake. The jet vorticity distribution is determined subject to the dynamic equations of rotational flow which are applied in a thin region at the jet boundary. This approach leads to the consideration of jet trailing vorticity or secondary vorticity which occurs in certain curved non-uniform flows. Comparison is made with test data and is shown to be unsatisfactory.

I.2.3 Ground Effect -

See Sections I.2.7 and I.8.3

I.2.4 Stability and Control -

I.2.4.1 STABILITY AND CONTROL OF PROPELLER-DRIVEN TRANSPORT VTOL AIRPLANES, R. H. Kirby, Proc. Thirteenth Annual Forum, Am. Helicopter Society, Inc., May 8-11 1957.

I.2.4.2 THE EFFECT OF SLIPSTREAM ON THE LONGITUDINAL STABILITY OF MULTI-ENGINED AIRCRAFT, D. E. Morris, J.C. Morall, ARC R&M 2701, November 1948.
An empirical approach using only flight test data relates changes of stick fixed static margin to thrust level and wing and tail characteristics. Accuracy of $\pm 2\%$ is achieved for the prediction of Δhn.

I.2.4.3 THE STATIC AND DYNAMIC STABILITY OF A DEFLECTED-SLIPSTREAM VEHICLE, G.A. Cincotta, and H.S. Dunn, Princeton University Report No.407, 1958.
Derived linearized, decoupled, small perturbation equations. Includes comparison with VZ-3 model test data. Forces, static and dynamic stability.

I.2.5 Handling Qualities and Criteria -

I.2.5.1 THE CONTRIBUTION OF INTERCONNECTED PROPELLERS TO STOL TRANSPORT CAPABILITY, M.D. Marks and A.A. Lischer - S.A.E. Paper.

I.2.5.2 SIMULATOR STUDY OF LATERAL-DIRECTIONAL HANDLING QUALITIES OF A LARGE FOUR-PROPELLERED STOL TRANSPORT AIRPLANE, H. C. Quigley and H.F. Lawson, Jr., NASA TND-1773.
The lateral and directional stability and control characteristics of a large four-propellered STOL transport airplane (the boundary-layer-control equipped NC-130) have been studied on the landing approach simulator to determine changes in the characteristics that might be required to achieve satisfactory lateral-directional handling qualities. A satisfactory configuration was achieved by doubling the basic directional stability and including a damping term which gave yawing moments proportional to rate change of sideslip.

I.2.5.3 A FLIGHT AND SIMULATOR STUDY OF THE HANDLING QUALITIES OF A DEFLECTED SLIPSTREAM STOL SEAPLANE HAVING FOUR PROPELLERS AND BOUNDARY-LAYER-CONTROL, C. A. Holzhauser, R.C. Innis and R. T. Vomaske, NASA TND-1966.
Flight and simulator tests were made to study low-speed handling qualities, potential STOL problem areas, and causes of deficiencies and their solutions. Tests of the STOL seaplane were made in the 50- to 60-knot range with Automatic Stabilization Equipment (ASE) engaged and disengaged. During the simulation, several stability and damping derivatives were varied and evaluated.

I.2.6 Testing -

See Section 1.2.7.3

I.2.7 General -

I.2.7.1 EXAMINATION OF SOME OF THE PROBLEMS INVOLVED IN THE DESIGN OF PROPELLER-DRIVEN VERTICAL TAKEOFF TRANSPORT AIRPLANES, M.O. McKinney et al, I.A.S. Preprint.

I.2.7.2 DEVELOPMENT OF METHODS FOR PREDICTING V/STOL AIRCRAFT CHARACTERISTICS, Rethorst, Scott; Fujita, Toshio; AD-285-079.
The analyses of the previous Phase I (AD-244 736) and Phase II (AD-257 571) studies are extended and refined. The relationships among basic V/STOL performance parameters are brought into focus. Results are cast into an engineering form. A 'slide-rule' type computer and a set of nomographs are furnished to simplify prediction of V/STOL aircraft characteristics. Propeller-driven V/STOL aircraft are analyzed in terms of trade-offs among basic performance parameters for a generalized mission profile. The attainment of high performance potential is dependent on the basic aerodynamic parameters governing the forward flight capabilities of conventional aircraft. For V/STOL aircraft, the variable disc area parameter (ratio of hovering disc area to forward flight disc area) has a marked effect on performance potential. The 'slide-rule' and nomographs encompass a wide range of basic parameters including variable disc area and are applicable to prop-driven V/STOL aircraft. The analytical methods are applied to an advanced V/STOL specification (including growth potential as quantitatively determined in the analysis).

I.2.7.3 APPLICATION OF SMALL-SCALE PROPELLER TEST DATA TO V/STOL AIRCRAFT DESIGN, H. E. Payne, III.
A compilation of available experimental and analytical data is presented, dealing with the effects of propellers (and rotors) on V/STOL takeoff and transition flight. Since the majority of the experimental work was conducted with small-scale propellers/rotors, considerable effort was expended to demonstrate the applicability of these data to full-scale propellers. The dependence of take-off performance on blade Reynold's number and tip Mach number is described. Recent results from the Navy flying wind tunnel have conclusively indicated the dependence of model V/STOL transition flight data on the character of the model test facility. Therefore, the correlation of model vs full scale

I.2.7.3 (continued)
propeller/rotor transition data was impossible because of the non-availability of accurate full-scale results. Data are presented describing identical test run on the airship and in three different wind tunnels. A brief analytical treatment is described which might enable more work to proceed to correct for wall interference. In addition, the experimental techniques used to obtain accurate low velocity measurements and to obtain vibration-free strain gage traces are briefly described.

I.2.7.4 AN INVESTIGATION OF THE FUNDAMENTAL PARAMETERS WHICH GOVERN THE AERODYNAMICS OF VARIOUS WING-PROPELLER COMBINATIONS AS RELATED TO VECTORED SLIPSTREAM AIRCRAFT, N. R. Augustine, Princeton University Report No.37, 1958.

I.3 JFT FLAP

I.3.1 Forces and Moments -

I.3.1.1 THE EFFECT OF JET ENTRAINMENT ON LIFT AND MOMENT FOR A THIN AEROFOIL WITH BLOWING, I. Wignanski and B.G. Newman, McGill University, Report 6-31, June 1963. (Also Aero. Qrtly, May, 1964).
Jet-flap theory for thin aerofoils has been extended to include the effect of jet entrainment on the external flow when the jet is blown over the upper surface of the aerofoil. Formulae and charts are presented to facilitate the determination of the increments of lift and pitching moment due to this effect. The new theory is compared with four old sets and one new set of experimental data. The theory is shown to be in 'first order' agreement with the exact solution for the circular-arc airfoil of small camber. (see also I.3.1.23)

I.3.1.2 A THEORETICAL STUDY OF THE GROUND EFFECT ON THE JET FLAP, D.J. Huggett, University of Southampton, Report USAA 112, September 1959.
A theory is developed for a jet flap wing near the ground. Under conditions for which the jet hits the ground, this theory gives, for any jet deflection angle and distance of wing from the ground, the distribution of pressure lift on the wing, the total pressure lift on the wing and the shape of the jet. Results are included for a wide range of jet coefficients with the ground at two different positions. At each ground position two different jet deflection angles are taken. The results of the theory are compared with experiment, and the agreement is discussed.

I.3.1.3 A NOTE ON THE TOTAL DRAG OF JET FLAPPED WINGS, G. K. Korbacher and K. Sridhar, UTIA Report 64, May 1960.
The limitations of the drag hypothesis for jet-flapped wings are discussed from the theoretical and experimental point of view. An empirical relation for calculating the total drag coefficient of quasi two-dimensional jet-flapped wings at zero incidence is derived and presented. This drag coefficient relation, combined with the expression for the total lift coefficient provides an expression for the slope of the C_{DT}/C_{LT}^2 curve. The slopes obtained are in qualitive agreement with those given by Maskell and Spence's theory.

I.3.1.4 A REVIEW OF THE JET FLAP, G. K. Korbacher and K. Sridhar, UTIA Review 14, May 1960.

A review is presented of the theoretical and experimental advances that have beeen made in the study of pure jet flaps, jet control and jet-augmented flaps. Care was taken in defining acting forces and in presenting all equations and graphs in a unified notation. Theories are correlated. Experimental results are quoted, illustrated by relevant graphs and compared with theory. Jet mixing and the jet flap's implication on aircraft design are included. An attempt is made to assess the jet flap on the basis of its possible merits and de-merits. Future research projects are listed. It should be noted that much of this list of needed future research still remains to be done 10 years later.

I.3.1.5 THE JET FLAPPED WING IN TWO- AND THREE-DIMENSIONAL FLOW, IAS Meeting, Prepr. 791, 1958, W. F. Jacobs, and J.H. Paterson.

Calculation of the lift, moment, centre of lift and aerodynamic centre over a large range of jet coefficients and flap angles. A comparison of measurements with the theory shows good agreement in the lift and pitching moment. Investigations of the influence of nose modifications such as droop nose, leading edge flaps, and slats on the moment indicate that the high nose-down pitching moment at high jet coefficients can be partly compensated. A method for calculating three-dimensional effects is developed, and the results of calculations for lift, lift distributions, and induced drag are given for selected values of aspect ratio and taper ratio, as well as for selected spanwise variations of jet momentum.

I.3.1.6 SOME CONTRIBUTIONS TO JET-FLAP THEORY AND TO THE THEORY OF SOURCE-FLOW FROM AEROFOILS, L.C.Woods, C.P.388, 1958.

A theoretical study is presented of the thrust, lift and moment on an aerofoil due to a two dimensional jet of air ejected from the trailing edge at an angle to the main stream.

I.3.1.7 THE EFFECT OF JET ENTRAINMENT ON LOSS OF THRUST FOR A TWO-DIMENSIONAL SYMMETRICAL JET-FLAP AEROFOIL, I. Wygnanski, McGill University, Report 64-13, August 1964 (Also Aero. Qrtly, February 1966).
Jet-drag, defined as the form drag associated with jet entrainment in otherwise inviscid fluid, was analyzed. Exact solutions with the flow incompressible and the jet turbulent, are given for uncambered struts of various shapes, various thickness ratios, and with blowing slots of various widths in quiescent and uniform streaming flow.

I.3.1.8 THEORETISCHE UND EXPERIMENTELLE UNTERSUCHUNGEN AN TRAGFLUGLN ENDLICHER SPANNWEITE MIT STRAHLKLAPPEN, A. Das, DLR FB 64-40, November 1964.
A lifting surface theory for jet-flapped wings was applied to wings of various planforms with different aspect ratios. The pressure distribution was measured and results compared with theory. Aerodynamic forces were obtained by integration.

I.3.1.9 A NOTE ON THE DRAG DUE TO LIFT AS INFLUENCED BY A JET FLAP ON A WING OF FINITE SPAN, S.B. Berndt, FAA Report 85, 1959.
The classical theory for thin and highly loaded wings in subsonic flow is extended by taking into consideration the interaction between the jet and the trailing vortices. It is shown that the minimum induced drag, for given lift, span, and jet thrust, is reduced by a jet flap. It still holds that the minimum drag is obtained when the downwash angle at the trailing sheet for downstream is constant throughout the span.

I.3.1.10 PERFORMANCE AND OPERATION OF QUASI TWO-DIMENSIONAL JET FLAPS, G. K. Korbacher, Institute for Aerospace Studies, University of Toronto, Report 90, November 1952.
True two-dimensional and quasi-two-dimensional jet flap test results are evaluated for experimental evidence in favor of or against the jet-flap thrust hypothesis. It is claimed that the thrust hypotheses is verified experimentally. The development is presented of jet-flap characteristics for two-dimensional jet-flapped wings, for any desired lift; it renders any number of combinations of rate of blowing, jet deflection angle, and angle of attack which can produce this lift.

I.3.1.11 JET FLAP CHARACTERISTICS FOR HIGH-ASPECT-RATIO WINGS, G.K. Korbacher, AIAA Journal, Vol.2, January 1964.
Discussion of the thrust hypothesis, its concept, and its experimental verification. "Characteristics" for jet-flapped wings at zero and non-zero angle of attack are also presented. It is indicated that any combination of jet flap parameters, such as jet deflection angle, rate of blowing, and angle of attack, which produces a desired lift may be read directly from such characteristics.

I.3.1.12 RESEARCH ON A JET FLAP AIR-SEA CRAFT, J.G. Williams, S. G. Hansen Lockheed Co., Rep. LR-21445(1968).
This report describes the pre-test analysis and the results of two wind tunnel investigations of a Canard-configured, swept-wing model with jet flap systems incorporated in both the wing and the Canard. For a jet flap airplane operating at trimmed lift coefficients of about 5, analysis indicates that the total blowing thrust demand for a Canard-configured airplane is significantly less than that for a conventional aft-tail configuration. The Canard-configured model appears to have satisfactory cruise characteristics, and there is little change in the static longitudinal stability on conversion to the STOL, jet flap blowing mode. Out-of-ground effect STOL characteristics are satisfactory at the low incidence proposed for operation; at a certain higher critical inci-ence the wing stalls, and a pitch-up condition ensues. Ground proximity has little effect upon the operational values of lift, static margin, trim, etc., but it does seriously erode the margin between the operating and critical incidence.

I.3.1.13 EMPIRICAL RELATIONSHIPS FOR JET-FLAP LIFT AND DRAG PREDICTION, D. J. Blakeslee, Rand Corp. Rep. P-1889, January 1960.
Presentation of empirical relations for the prediction of the lift and drag of unswept three-dimensional jet-flapped wings. Plotted data show that the equations organize lift and drag data with a consistency sufficient for design use. The principal innovation is that a thrust-recovery coefficient can be subtracted from the drag-coefficient equation to represent the so-called thrust recovery, or induced thrust of jet flaps. This thrust-recovery coefficient is simply related to jet-flap parameters. It is directly proportional to the momentum coefficient and varies approximately as a power of the flap angle.

I.3.1.14 THE FLOW PAST A THIN WING WITH AN OSCILLATING JET FLAP, D.A. Spence, RAE Rep. AERO 2690, August 1964.
An exact solution is obtained for the linearized flow past a thin two-dimensional wing of chord C at zero incidence in an incompressible stream of density Rho and undisturbed velocity U, with a thin jet of momentum, $2_{\rho}U^{2}C_{\mu}$ emerging from its trailing edge at an oscillating deflection-angle. The motion is governed by a singular third-order integro-differential equation, which becomes tractable when μ is small; solutions in this weak-jet limit depend on a single parameter. The possible significance of the critical frequency is discussed. Computations of jet shape and lift force for a range of values of Nu are presented, and the solutions for periodic plunging and pitching motions of the wing are derived from that for deflection.

I.3.1.15 PERFORMANCE, OPERATION AND USE OF LOW ASPECT RATIO JET FLAPPED WINGS, G.K. Korbacher, UTIAS Report 97, May 1964.
The characteristics of a jet flapped wing of aspect ratio 6 are presented, discussed and evaluated for STOL application. Again, as for high aspect ratio (AR=20) jet flapped wings, a range for most economical jet flap operation is well defined. The angle of attack as an efficient means of lift production loses its usefulness with low aspect ratio jet flapped wings, whereas the optimum jet deflection angle seems hardly affected. A most efficient jet flap application for STOL calls for a complet integration of the lifting and propulsive systems. In the range of most economical jet flap operation, semi-empirical relationships predict parameter changes accurately enough for practical purposes.

I.3.1.16 A LINEAR THEORY FOR THE JET FLAP IN GROUND EFFECT, P.B.S. Lissaman, AIAA Journal, July 1968.
The two-dimensional inviscid program is formulated with linearized boundary conditions. Four superposable cases are defined: due to jet angle, thickness, camber, and angle of attack. Using complex variable and mapping into an auxiliary plane gives a boundary-value problem of the Reimann-Hilbert-Poincare type. Part of the solution is expressed in closed analytical form and the balance obtained by computer. The numerical method is claimed to be speedy and convergent. The computer generated solution for a thin flat airfoil is presented.

I.3.1.17 PREDICTING THE PERFORMANCE OF JET FLAP CONFIGURATIONS, S. Pivko, Aircraft Engineering.
A semi-empirical method for estimating the aerodynamic properties of thin flapped aerofoils influenced by high velocity jet sheets is developed. It is assumed that the main flow around the aerofoil does not influence the velocity distribution in the jet. Considering also the effect of the mixing with the surrounding air, a real jet is replaced by an aerodynamic model, having a linear downstream distribution of velocity adopted on the basis of test data. Both thin aerofoil and the jet sheet are replaced by vortex distributions, so that the lift and pitching moment of the aerofoil influenced by the jet may be evaluated in the usual manner. Comparison with some available experimental results shows that the proposed semi-empirical method gives good agreement with experiment.

I.3.1.18 ANALYSIS OF THICK, CAMBERED JET FLAP AIRFOILS IN GROUND EFFECT, P.B.S. Lissaman and C.A. Shollenberger, AIAA Paper, July 1969.
Extending a previous analysis for flat plate airfoils in ground effect a numerical method was developed to solve the title problem. Solutions were given for a number of camber and thickness cases, consisting of a cambered flat plate, and a diamond shaped airfoil, with the kink at various positions. These results can be superimposed to generate an arbitrary thick cambered trapezoidal airfoil. No experimental checks are known, but the results converged to various limiting analytical cases. It was shown that normal values of thickness have very little effect on the lift, but that camber was significant. A general unified curve for the effect of camber was presented, from which performance can be read off for a range of cambers at arbitrary height and blowing coefficient.

I.3.1.19 A NOTE ON THE INDUCED DRAG OF JET-FLAPPED WINGS, G.K. Korbacher, and K. Sridhar, Journal of the Royal Aeronautical Society, Vol.64, May 1960.
Alternate forms to the induced drag expression developed by Maskell and Spence were developed. These were all shown to be compatible.

I.3.1.20 ON THE THRUST HYPOTHESIS FOR THE JET FLAP INCLUDING JET-MIXING EFFECTS, K.T. Yen, Journal of the Aerospace sciences, August 1960.
A "linear" thrust hypothesis was obtained for the

I.3.1.20 (continued)
jet flap assuming linearized potential flow. The linearized jet-flap problem was found to be a linear combination of a lift problem and a thrust problem.

The mixing of the jet with the surrounding fluid was analyzed by the non-integral method. Some approximate formulas relating th ust and jet angle were derived.

I.3.1.21 THE PITCHING-MOMENT COEFFICIENT OF A JET-FLAPPED THIN AIRFOIL, J.C. Erickson, Jr., Journal of the Aerospace Sciences, December 1962.
Extended Spence's theory for jet-flapped thin airfoils to derive expressions for the pitching-moment coefficient.

I.3.1.22 THE LIFT COEFFICIENT OF A THIN, JET-FLAPPED WING, D. A. Spence, Proceedings of the Royal Society, A. Vol. 238, 1956.
A solution was found for the inviscid, incompressible flow past a thin, two-dimensional wing at small incidence with a thin jet emerging from the treiling edge at small deflection. Expressions were obtained for lift, pressure distribution, and pitching moment. Theory correlated one set of data within ±5%.

I.3.1.23 THE LIFT ON A THIN AEROFOIL WITH A JET-AUGMENTED FLAP, D.A. Spence, Aeronautical Qrtly, August 1968.
Spence's theory for a thin jet-flapped airfoil was extended to the case in which the jet is blown tangentially on a deflected flap. The theory indicated that jet-flap effectiveness would be increased by blowing over flaps of 20-30% chord.

I.3.1.24 A THEORY OF THE JET FLAP IN THREE DIMENSIONS, E.C. Maskell and D.A. Spence, Proceedings of the Royal Society A, 251.
Spence's two-dimensional jet-flap theory has been extended to three dimensions. Theory was applicable to arbitrary planform and blowing momentum distribution but only the case where both chord and blowing distributions were elliptical was considered. Expressions for the lift and induced drag were derived. Comparison with the test data for three aspect ratios showed good agreement.

I.3.1.25 A SIMPLIFIED METHOD FOR ESTIMATING THE PROPERTIES OF THIN AEROFOILS INFLUENCED BY JET, S. Pivko, Journal of the Royal Aeronautical Society, Vol.64, May 1960.
A procedure was proposed for estimating the lift and pitching moment of two dimensional thin jet and jet-augmented flaps. The airfoil and jet were represented by vortex distributions; comparison of theory with the experiment shown was good.

I.3.1.26 JET-FLAPPED AIRFOILS IN GROUND PROXIMITY, G.C. Cooke IV, Rensselaer Polytechnic Institute TR AE 6804, January 1968.
This paper considered the lift characteristics of airfoils in ground effect with and without jet flaps for which the jet does not impinge on the ground. The problem is linearized and the airfoil vortex distribution and jet flap shape determined. Results of a sample calculation were shown.

I.3.1.27 DISTRIBUTION OF PRESSURE ON JET-FLAPPED WINGS IN VIEW OF MIXING OF BLOWN OUT AIR CURRENT WITH AMBIENT AIR, M. Klusak, NASA TT-F-12,243, June 1969.
The note examined the effect of mixing on the pressure distribution on a jet-flapped airfoil. The entrainment into the blowing jet was derived from a theory of submerged jets. Examples showed that including entrainment significantly affected the calculated pressure distributions and brought them into good agreement with experiment.

I.3.1.28 LIFTING SURFACE THEORY FOR WINGS WITH JET FLAPS, National Research Council of Canada, NRC TT-1122, 1964.
An approximate method for calculating the lift and pitching moment distribution of wings of arbitrary planform and blowing distribution was given. The chordwise vortex distribution is that of Spence. The method of influence functions was used. Comparison of theory and experiment was good.

I.3.1.29 A LIFTING LINE THEORY OF THE JET FLAPPED WING, Y.A. Yoler, Boeing Scientific Research L boratories, D1-82-0042, January 1960.
Thin wings with jet flaps were represented by a pair of bound substitution vortices located at the one-quarter and three-quarter chord points. The existence of the jet was assumed to nullify the suction force at the trailing edge and the strength

I.3.1.29 (continued)
of the bound vortices were determined using the thrust hypothesis. The theory was in good agreement with experimental results.

I.3.1.30 SOME CONTRIBUTIONS TO JET-FLAP THEORY AND TO THE THEORY OF SOURCE-FLOW FROM AEROFOILS, L.C. Woods, Aeronautical Research Council C.P. No.388, 1958.
Paper presented a theoretical study of the thrust, lift and moment on an airfoil due to a jet of air ejected from the trailing edge at an angle to the freestream. It was proved that the ideal thrust of the jet was independent of the exit angle. This paper has been largely superseded by Spence's work.

I.3.1.31 PRELIMINARY ANALYSIS FOR A JET FLAP SYSTEM IN TWO-DIMENSIONAL INVISCID FLOW, E.C. Maskell and S.B. Gates, Aeronautical Research Council C.P. No.359, 1957.
This paper did not attempt to solve the jet flap problem. It established the properties of a thin curvilinear jet in a uniform flow field.

I.3.1.32 A METHOD FOR CALCULATING THE PRESSURE DISTRIBUTION OVER JET-FLAPPED WINGS, D. Kuchemann, Aeronautical Research Council R&M 3036, May 1956 and RAE Rep. 2573.
A method for calculating the pressure distribution over wings of non-zero thickness and finite aspect ratio with jet flaps was given. The pressure distribution was estimated with reasonable accuracy except in the vicinity of the nozzle given the lift coefficient and jet momentum coefficient.

I.3.1.33 THE LIFT AND DRAG OF A JET-FLAPPED AIRCRAFT, D. H. Aero Dept/2661/DHD/DHW/GEN/Issue 2, May 1962, by Dykins, D.H. Wilkinson.
A method of calculating lift and drag for any incidence, momentum coefficient and deflection angle. Method is based on an extension of the airfoil theory of Maskell and Spence and is restricted by small angle assumptions. Author indicates that the method can be used to give good predictions for externally blown flaps.

I.3.1.34 A JET DEFLECTED FROM THE LOWER SURFACE OF AN AEROFOIL, J. H. Davies, and A.J. Ross, Qrtly Journal of Mechanics and Applied Mathematics, 1957.
The two-dimensional steady motion of an infinite, perfect, compressible fluid past a thin symmetrical

I.3.1.34 (continued)
aerofoil at zero incidence to the main stream is considered, when the jet issues from the lower surface of the aerofoil at an angle to the chord. As an example, lift, pressure distribution moment coefficient and centre of pressure are calculated for a jet exit position near the trailing edge, with a specific angle of ejection and momentum coefficient.

I.3.1.35 ON THE THRUST DUE TO AN AIRJET FLOWING FROM A WING PLACED IN A WIND TUNNEL, J. Fluid Mech. Vol.1 1956. Develops a theory for wind tunnel correction to thrust and demonstrates the thrust recovery principle.

I.3.1.36 THE JET FLAP, J.R.AeS January 1956.
A brief historical review is followed by a description of experimental 2-D and 3-D work at NGTE, together with a comparison with Stratford's theory. Possible applications and considerations are discussed. No theoretical details are presented.

I.3.1.37 THE LIFT OF A BLOWING WING IN A PARALLEL STREAM, H. B. Helmbold, JAS VOL.22, May 1955.
The author derives downwash equations which relate the vorticity distribution on a thin airfoil with a narrow high-velocity jet issuing from its trailing-edge to the slope and curvature of the jet.

I.3.1.38 THEORY OF THE FINITE-SPAN BLOWING WING, H. B. Helmbold, JAS., Vol.24, No.5, 1957.
The essential features of two-dimensional flow around a blowing wing are briefly outlined. The flow around the finite span blowing wing is investigated under the simplifying assumption of undis turbed static pressure at infinity downstream. The effects of finite span are induced drag, and losses of jet thrust and jet-induced lift. The induced drag results from circulation around the wing and jet sheet, the loss of jet thrust from final jet deflection, and the loss of jet-induced lift from loss of jet-sheet curvature. The forces on the finite-span jet wing are functions of the induced angle which is determined either graphically from a sixth-degree equation or by a second-order approximation for moderate induced angles. The jet coefficients are finally represented as functions of jet-power coefficient and jet-sheet thickness ratio.

I.3.1.39 ESTABLISHMENT OF LIFT ON AN AIRFOIL WITH A JET FLAP, R.Hirsch, Aircraft, Eng., December 1957.
Analysis for the circulation lift around an airfoil section which has a trailing edge jet. The circulation is directly dependent on a trailing edge condition similar to the Joukowski condition. The problem is governed by an equation similar to the Wagner equation, into which is introduced the curvature of the downwash at the trailing edge. The movement of the elementary vortices in the downwash is directly dependent on the viscous damping of the vorticity. This effect has been considered, and the drag law of the jet behind the nozzle established. The velocity distribution can be found at any instant, and from this all aerodynamic forces can be calculated. The method is applied to two cases and comparison made with experimental results.

I.3.1.40 CAMBERED JET-FLAP AIRFOIL THEORY, Cornell University Graduate School. Aero. Eng. Rep. 1959.
Extension of Spence's treatment of the jet flap airfoil which used thin airfoil theory to include the effects of camber. The integro-differential equations connecting the vorticity distribution along the airfoil and the slope of the jet sheet are derived. For the particular case of a parabolic arc camber distribution, a solution in Fourier series form is obtained. Expressions are given for lift, chordwise loading, jet vorticity, pitching moment, leading edge suction and jet shape.

I.3.1.41 A DRAG HYPOTHESIS FOR JET-FLAPPED WINGS, G.K. Korbacher, J. Aero. Sci., May 1961.
Using test data and the theory of Maskell and Spence it is shown that the thrust recovery hypothesis is only an approximation to reality.

I.3.1.42 INFLUENCE DE L'EMISSION D'UN JET AU BORD DE FUITE D'UN PROFIL SUR L'ECOULEMENT AUTOUR DE CE PROFIL, R. Legendre, Comptes rendus de l'Academie des Science, May 14, 1956.
The discontinuity of the velocity, which occurs when passing from the exterior potential flow through a thin infinite jet blown out from the trailing-edge of a profile, is proportional to the curvature of the jet. Thus the flow is determined.

I.3.1.43 PRINCIPE D'ETUDE D L'AILE A JET, R. Legendre, Rech. Aeron., No.53, 1956.
This note refers to the report by Maurice Roy with the same title. The lift coefficient induced by a jet-flap is derived under certain simplifications and compared with results by Roy.

I.3.1.44 THE EFFECT OF ENTRAINMENT UPON A JET-FLAPPED AIRFOIL, Cornell University Graduate School, Aero. Eng. Report AFOSR TN 57-761, 1957.
Development of a model for a straight two-dimensional incompressible turbulent jet issuing into a freestream and calculation of the entrained mass flow. The jet is then replaced by a distribution of sinks which gives the same entrainment. With this sink distribution the potential flow is calculated over a thin bi-parabolic airfoil at zero angle-of-attack, with the jet of zero deflection angle, and from this the pressure drag due to entrainment is determined.

I.3.1.45 SUR UN THEORIE LINEARISE DU SOUFFLAGE AU BORD DE FUITE D'UN PROFIL D'AILE, L. Malavard, Comptes rendus de l'Academie des Science, May 14, 1956.
The author uses the classical hypotheses of linearization; the profile of the wing is considered infinitely thin, of weak camber and of small incidence; the line of the jet sheet is supposed to have a small inclination to the direction of the undisturbed flow.

I.3.1.46 THE INFLUENCE OF THE GROUND ON THE AERODYNAMIC PROPERTIES OF AN AIRFOIL WITH JET FLAP, W.J. Prosnak and P. Kucharczyk, Arch. Mech. Stosowanej, No.4 1959.
Analysis considering the problem of whether the jet flap in the proximity to the ground preserves its ability to increase lift over the airfoil. The image profile is used to construct the complex potential corresponding to the flow past the two-jet-flap profiles. The aerodynamic coefficients are then calculated for one profile of the pair. The results show that if the ratio $\delta = l/h$ (l being the chord and h the distance from the ground) is two, the lift of a profile without jet flap increase by about 15% to 30%, and the efficiency of the jet flap by about 8% to 50%, smaller values corresponding to greater angles of incidence ($\alpha = 10°$) and greater ones to smaller angles-of-incidence ($\alpha = 2°$)

I.3.1.47 THE JET FLAP WITH GROUND EFFECT, J. R. Stanton, Lockheed Aircraft Corp., Misc. 749, Negs. 249, 1956.

I.3.1.48 JET DRAG OF WINGS WITH JET FLAPS, P. R. Payne, Aircraft, Eng. March, 1958.

Analysis considering the density of the jet before and after mixing the freestream air in which it is shown that Stratford's equation for jet density after mixing is accurate only for the case where the jet is cold. The flux of momentum behind an airfoil with jet flap is examined, using the basic Stratford's approach, but with the difference that the density correction factor K is included in the analysis and an exact solution to the equation is obtained. It is suggested that contrary to Stratford's hypothesis momentum flux has little relationship to the force acting on the airfoil, because there is no mechanism of jet drag is shown by the construction of a potential flow model.

I.3.1.49 THEORIE DU PROFIL D'AILE A JET, M. Roy, Comptes rendus de l'Academie des Sciences, June 25, 1956. A general expression, also valid in smooth compressible flow, is given for the resulting effect of a wing in which the surrounding medium enters and blows out as a laminar jet. An approximate theory based on the approximations of Prandtl is presented for a simple jet wing in incompressible flow.

I.3.1.50 A TREATMENT OF JET FLAP BY THIN AEROFOIL THEORY, D. A. Spence, RAE Rep. Aero-2568, 1955.

I.3.1.51 THE LIFT OF BLOWING WING IN A PARALLEL STREAM, D. A. Spence, IAS, January 1956. Helmbold (IAS., 1955, p.341) has derived downwash equations which relate the vorticity distribution on a thin airfoil with a narrow high-velocity jet issuing from its trailing edge to the slope and curvature of the jet. In this paper the solutions of these equations are outlined, for the lift induced on a thin uncambered wing at zero incidence when a thin jet, of momentum flux, issues at a small downward angle from its trailing edge.

I.3.1.52 SOME SIMPLE RESULTS FOR TWO-DIMENSIONAL JET-FLAP AEROFOILS, D. A. Spence, Aero Q., Vol.IX, November 1958.

Formulas are derived by elementary consideration for lift coefficient C_L and loading on the chord line of a thin two-dimensional wing at zero incidence with a narrow high-velocity jet of small values of momentum coefficient c_j issuing from trailing edge at a small downward inclination. These formulas agree well with known measurements. Interpolation formulas for derivatives of C_L at larger values of c_j, based on earlier work, are also given.

I.3.1.53 THE LIFT ON A THIN AEROFOIL WITH A BLOWN FLAP, RAE TN Aero. 2420, 1958.

A formula is given for calculating the lift on a thin aerofoil with blown flaps. The classical results for attached flow on flapped aerofoils without supercirculation are also obtained as a special case. It is shown that the effectiveness of the jet flap scheme might be greatly increased by blowing over flaps of the order of 20 or 30 percent of the chord, rather than over the very small shrouds which has hitherto been proposed.

I.3.1.54 A NOTE ON THE THEORY OF JET FLAPS, L.C. Woods, Fluid motion sub-committee, ARC 17563; F.M. 2230, 1955.

I.3.1.55 TWO-DIMENSIONAL THEORETICAL DATA OF THE JET-FLAP, RAE TN Aero 2600, 1959.

I.3.1.56 NEUERE THEORETISCHE UNTERSUCHUNGEN UBER DEN STRAHLFLUGEL IN ZWEIDIMENSIONALER STROMUNG, W. F. Jacobs, ZFW, Nr.5, 1957.

A short survey of theoretical investigations of jet-flapped wings in two-dimensional flow is given. The influence of a jet-stream, exhausted from a slot at the trailing edge of the wing, is replaced by an 'equivalent' flap. Whereas hitherto, most of the authors have employed the analogy of the straight flap, in this work, a curved flap is used to approximate the real path of the jet-stream. The results show that this method is not only capable of accurately predicting the lift but also the pitching moment and herewith the center of pressure.

I.3.1.57 THE CURVED JET FLAP, TWO-DIMENSIONAL THEORY, W. F. Jacobs and J.H. Paterson, Lockheed Report ER-2513, 1956.

I.3.1.58 THE EFFECT OF NOSE MODIFICATION ON THE AERODYNAMIC CHARACTERISTICS OF JET FLAPPED AEROFOILS, W.F. Jacobs, and J.H. Paterson, Lockheed Report ER-2514, 1956.

I.3.1.59 AN INVESTIGATION OF THE EFFECTS OF THICKNESS, CAMBER AND NOSE RADIUS ON THE PERFORMANCE OF JET-FLAPPED AEROFOILS, J.A. Beasley, RAE TN Aero. 2534, 1957.
Pressure distributions are calculated by Kuchemann's method for six aerofoils with jets blowing over deflected trailing edge flaps. Some inaccuracy has been incurred by making approximations in the calculation but it has been possible to study qualitatively the efficacy of thickness, camber and nose radius in preventing flow separation near the nose. The conclusions could thus be used to select aerofoils suitable for use with jet flaps. The effects of jet deflection angle and of incidence are also discussed.

I.3.1.60 THE FINITE ASPECT RATIO JET FLAP, R. A. Hartunian, Cornell Aero. Lab., Report AI-1190-A-3, 1959.
Army-sponsored derivation of lifting surface equations for a finite aspect ratio wing equipped with jet flaps, assuming small perturbations of the undisturbed flow. The limiting case of large aspect ratio is considered in detail, the resulting equations are solved for the special case of a system with elliptic loading. Relations for the lift coefficient, jet shape, and pitching moment are presented. The results of the theory are found to be in good agreement with experiment over a wide range of aspect ratios, angles of attack, jet deflections, and jet momentum coefficients. The induced drag, obtained for the elliptically loaded case, is shown to agree with the results of a momentum theory. Comparison of the induced drag with the experimentally determined drag is also discussed.

I.3.1.61 THEORY OF TWO-DIMENSIONAL AEROFOIL WITH JET-FLAP, W. J. Prosnak, Arch. Mech. Stosowanej, No.1, 1958. With consideration of experimental and theoretical results previously published an investigation is presented of the influence of a jet flap on the aerodynamic coefficients of an aerofoil, assuming perfect fluid and steady plane motion, with no assumption as to jet thickness, type of profile or angle of incidence. The analysis is based on flow past a circular profile with jet flap.

I.3.1.62 LIFTING SURFACE THEORY FOR JET-FLAP WINGS, A. Das, WGL. Jahrbuch, 1960. In this paper a method for calculating the lift distribution of wings of finite span with jet-flaps is given. This method is an extension of the lifting surface theory of Truckenbrodt. The present method of calculation is based upon the two-dimensional jet-flap airfoil theory by D.A. Spence and W. Jacobs. In order to obtain an essential simplification of the problem the two-dimensional vorticity distribution along the chord and the jet as given by Spence was approximated by a combination of the basic distributions of Birnbaum. Some numerical examples were calculated for a straight rectangular wing of aspect ratio A=2.75. The theoretical and experimental results are in very good agreement.

I.3.1.63 INFLUENCE DU SOUFFLAGE AU VOISINAGE DU BORD DE FUITE SUR LES CARACTERISTIQUES AERODYNAMIQUES D'UNE AILE AUX GRANDES VITESSES, Poisson-Quinton, Ph. and P. Jousserandot, Rech. Aeron. No.56, 1957. The application of blowing over wings to get higher lift at takeoff and landing is well-known and in the field of interest today. The next step is the application of blowing at high speeds. With zero flapping the jet permits a remarkable reduction of blowing at high speeds. With zero flapping the jet permits a remarkable reduction of the drag in the subsonic region. An orientation of the jet perpendicular to the wing-surface gives in the subsonic region an effect of increased circulation and in the transonic and supersonic region, a spoiler-effect. The spoiler effect is nearly independent of the speed. A 30° flapping of the jet influences appreciably the shock-formation in the region of the profile-trailing-edge at transonic speeds.
See also I.3.2.4 and I.4.1.11

I.3.2 Flow Fields -

I.3.2.1 LINEARIZED INVISCID-FLOW THEORY OF TWO-DIMENSIONAL THIN JET PENETRATION INTO A STREAM, T. Strand, M.H.Y. Wei, Air Vehicle Corp, La Jolla, California, February 1968.

The potential flow of a stream that interacts with a two-dimensional thin jet of a different total head, being injected into the stream from an infinite plane surface at an arbitrary angle, is analyzed using natural coordinates. The velocity magnitudes along the interface and the non-dimensional shape of the interface between the jet and the stream are obtained as functions of the injection angle and the ratio of the free stream velocity to the velocity in the jet at infinity downstream. Results are presented for several cases when the jet issues at oblique angle from the surface, and also for the limiting case when the jet opposes the free stream. The latter case corresponds to the flow due to one branch of a translating two-dimensional jet after the jet has been split into two branches by impingement on the ground. It might also correspond to the flow of a two-dimensional thrust reverser.

I.3.2.2 AN EXPERIMENTAL INVESTIGATION INTO THE SHAPE OF THRUST AUGMENTING SURFACES IN CONJUNCTION WITH COANDA-DEFLECTED JET SHEETS, Part II, T. Mehus, Toronto University Inst. for Aerospace Studies, Report No. UTIAS TN-79, January 1965.

The present work is a continuation of the experimental investigations described in AD-611 759. The purpose was to increase the thrust augmentation of a configuration consisting of a Coanda surface (quadrant), deflecting the primary jet sheet through 90 degrees, in conjunction with additional (thrust augmenting) surfaces. The effect of a horizontal and vertical gap between the lip of the nozzle and the leading edge of the deflection surface, as well as the effect of a gap between its trailing edge and the downstream diffuser wall (tertiary flow) was studied. These experiments were carried out for a convergent (subsonic) and a convergent-divergent (supersonic) nozzle at various pressure ratios. The subsonic jet sheet produced the highest thrust augmentation. Tilting of the quadrant led to an increase in the augmentation ratio (excluding the

I.3.2.2 (continued)
lift acting on the nozzle), while the total thrust augmentation (including the lift over the nozzle) did not increase. Typical secondary and exit mixed flow velocity profiles were obtained. The highest total thrust augmentation observed was 1.37.

I.3.2.3 THE THEORETICAL EVALUATION OF THE DOWNWASH BEHIND JET FLAPPED WINGS, A. J. Ross, Royal Aircraft Establishment, Report No. Aero 2599, January 1958 and ARC R&M 3119, 1961.
The downwash behind jet-flapped wings of infinite and finite span was evaluated. The wing incidence and jet deflection are assumed to be small, and the displacement of the jet is taken into account by displacing the downwash field so that the relative distance between the jet and tailplane is correct. It is also assumed that the spanwise loading on the finite wing is elliptic, and that the trailing vorticity is generated at one particular chordwise position. The wake is considered to be a flat sheet, and so the effect of the rolling-up of the wake has been neglected.

I.3.2.4 THE AERODYNAMICS OF JET FLAPS, J. Williams, S.F.J. Butler and M.N. Wood, Aeronautical Research Council R&M 3304, 1961.
The paper discussed lift, pitching moments, downwash, thrust, sideslip derivatives, and ground effects of jet flaps. The basic concepts and basis of analysis were discussed. The 2-D theory for a flap lift of Spence and the 3-D theory of Spence and Maskell were reviewed and typical data exhibited. Thrust recovery was discussed. Data were shown on the effects of ground proximity. The statement was made that, while the available theories have provided valuable background, they are essentially inviscid thin airfoil and lifting-line treatments. Semi-empirical approaches must still be used.

I.3.2.5 HYDRAULIC TANK FOR VISUALIZATION OF FLOWS AROUND STATIONARY VEHICLES, H. Werle and M. Gallon, La Recherche Aerospatiale, No.129 March/April 1969.
The new hydraulic tank recently put in operation at ONERA designed for investigating flows around stationary models with sinks, jets or moving parts.

I.3.2.5 (continued)

The tests limited to flow visualization do not suffer in this rather wide tank from wall effects as in the water tunnel used for tests on models with a general relative motion.

This article described the new facility, presented its characteristics and possibilities and gave some test results which concern basic research as well as studies in applied aerodynamics.

I.3.2.6 PRINCIPES ET RESULTATS DE CALCULS D'AILES A JET PAR ANALOGIES RHEOELECTRIQUES, L. Malavard and L. Lepage, Rech. Aeron., No.77 1960.
A simple theoretical scheme, based on the supposition of small deviations, can represent the computation of the effect of the blowing out at the trailing edge of a thin profile or a wing. The method of rheoelectrical calculation permits the establishment of a model analogous to that scheme. This method was applied first in case of two-dimensional profiles; it was used subsequently for the calculation of wings with jets of different forms. The results are given for wings of different aspect ratio, rectangular wings, delta wings and sweptback wings with various values of C_μ.

I.3.2.7 MIXING AND THE JET FLAP, B.S. Stratford, Aero, Q., Vol. III, May 1956.
One of the main problems associated with the 'jet flap' concerns the discrepancy in thrust between idealized theory and the experimental results. This discrepancy is attributable to the mixing with the surrounding flow of the thin two-dimensional jet while still in close proximity to the aerofoil. The effect of the mixing may be calculated to a first approximation from a formula derivable from first principles, while certain second order effects, which can be significant, may be considered qualitatively.

I.3.2.8 INTERFERENCE ON A THREE-DIMENSIONAL JET-FLAP WING IN A CLOSED WIND-TUNNEL, E.C. Maskell, RAE TN Aero,2650, 1959.
Extension of the classical theory of wind-tunnel interference to cover the case of a full-span jet flap at the trailing edge of a high aspect ratio unswept wing. It is shown that, for small

I.3.2.8 (continued)
constraint, corrections, Δc_γ and $\Delta\alpha$ must be added to the observed jet momentum coefficient and wing incidence, respectively. These corrections are derived together with the corresponding corrections to the observed lift and a thrust coefficient. Corrections to the observed downwash field over a limited interval downstream of the trailing edge of the wing are also derived. These lead to a corrected jet path and a downward displacement of the downwash-pattern, in addition to the direct increment to the observed downwash. Corresponding corrections to tail height and setting are also given.

See also, I.3.1.2, .8, .14, .17, .27, .28, .29, .30,.39, .44, .51, .60.

I.3.3 Ground Effect -

I.3.3.1 A NOTE ON GROUND EFFECT ON THE LIFT DUE TO A JET FLAP, A.D. Young, ARC. 19, 971, 1958.
The analysis demonstrates the basic mechanism whereby the lift associated with the circulation round a wing section is limited by the presence of the ground. If it is accepted that the pressure lift on a wing with a jet flap can be identified with the circulation lift, then the analysis goes some way towards explaining the observations of Huggett, who has demonstrated that the lift on a wing with a jet flap can be considerably reduced by ground effect.

I.3.3.2 THE GROUND EFFECT ON A TWO-DIMENSIONAL JET-FLAPPED AEROFOIL, G.J. Hancock, Queen Mary College, London, unpubl. 1958.

I.3.3.3 AN APPROACH TO THE THEORETICAL STUDY OF THE GROUND EFFECT ON A JET FLAP, D.J. Huggett, University of Southampton, Rp. 112, 1959; ARC 20, 279, 1958.
A theory is developed for a jet flap wing near the ground. Under conditions for which the jet hits the ground this theory gives the distribution of pressure lift on the wing and the shape of the jet. Results are included for a wide range of jet coefficients with the ground at two different positions. At each ground position two different jet deflection angles are taken.

See also, I.3.1.2, .12, .16, .18, .26, .47 and I.3.2.4.

I.3.4 Stability and Control

I.3.4.1 A THEORETICAL INVESTIGATION OF THE LONGITUDINAL STABILITY, CONTROL AND RESPONSE CHARACTERISTICS OF JET-FLAP AIRCRAFT, PARTS I and II, A.S. Taylor, A.R.C.R. and M. No. 3272, February 1960.
This report deals with two stages of an exploratory investigation into the longitudinal stability, control and response characteristics of jet-flap aircraft of reasonably high aspect ratio, based on Spence's theoretical two-dimensional lift and moment data. The relative merits of conventional (tail) controls and jet-flap controls (throttle, flap deflection) are considered.

In Part I attention is restricted to considerations of trim, static stability and quasi-steady maneuverability, on the basis of which, jet controls appear to compare somewhat unfavorably with tail controls.

In Part II a study is made of dynamic stability and of comparative response characteristics for step-inputs of the three controls. It is concluded that in the high-lift condition, the quasi-steady maneuverability criterion is not a valid basis of comparison of control effectivenesses, because a divergent phugoid of relatively short period, coupled with a rapid oscillation of relatively long period, prevents the establishment of a quasi-steady condition. Because initial response is much slower for tail control than for jet controls it is possible that jet deflection control may be more effective than tail control for this case. The maneuverability criterion remains substantially valid for the cruising condition,however, a superiority of tail over jet controls for this case is confirmed.

See also, I.3.1.12

I.3.5 Handling Qualities and Criteria

See I.3.4.1 and Sections I.3.7 and I.8.5.

I.3.6 Testing

I.3.6.1 EFFETS DE PAROI SUR UNE AILE AVEC SOUFFLAGE,
R. Duquenne et H. Werle AGARD Report 305,
March 1959.
Blowing at the trailing edge in the presence
of a wall is considered.

See also, I.3.2.7

I.3.7 General -

I.3.7.1 EARLY THOUGHTS ON THE JET FLAP, B.S. Stratford, The Aeronautical Quarterly, February 1956.
A historical sketch of the jet-flap prior to 1956 was given.

I.3.7.2 THE JET AUGMENTED FLAP, J.G. Lowry, J.M. Riebe, and J.P. Campbell IAS Reprint 715, January 1957.
A historical review of the jet flap was given. Guides for predicting jet-augmented flap characteristics were given. Ground effect and downwash were discussed. Longitudinal trim and stability and control problems associated with the jet-augmented flap were discussed.

I.3.7.3 RECHERCHES THEORIQUES ET EXPERIMENTALES SUR LE CONTROLE DE CIRCULATION PAR SOUFFLAGE APPLIQUE AUX AILES D'AVIONS, L. Malavard, P. Jousserandot and others, ONERA TN 37, 1956.
The necessity to reduce the speed and takeoff and landing of modern aircraft has led to new conceptions of lift generation using the turbo-engines which are needed to give the propulsion for the airplanes. Giving the main parameters and a linear theory of blowing the report contains in a number of diagrams two-dimensional and some three-dimensional results of blowing over a flap, blowing symmetrically over and under a flap, results of the jet-flap and results about a configuration with suction at the gap between the profile and the flap and blowing at the rear of the flap. The results were obtained by theory and especially by experiment. The authors give some comments about the applicability of the theory and discuss the different possibilities of blowing together with their problems.

I.3.7.4 SOME COMMENTS OF THE 'JET FLAP' WITH PARTICULAR REFERENCE TO AIRCRAFT CONTROLS AND FLIGHT AT TRANSONIC SPEEDS, H.H. Pearcey, ARC, 16,174, 1953.

I.3.7.5 SUR L'UTILIZATION DES JETS PROPULSIFS A L'HYPERSUSTENTATION D'UN AVION, Poisson-Quinton, PH. and A. Bevert, Techn, et Sc. Aero., September-October 1959.
Survey of various methods of lift generation by means of jets and evaluation of the jet flap principle. Wind tunnel experiments on three

I.3.7.5 (continued)
configurations of hypothetical aircraft capable of high speed with low aspect ratio wings are described. The lift and drag performance, as function of turbine thrust, is compared with that obtained by simple downward deflection of the jets. The longitudinal stabilization achieved by means of auxiliary jets in the nose of the ground effect principle with results of the effect of various (intensity and orientation of the jets) as function of the distance from the ground. The similarity of results obtained on a platform and on jet flaps is pointed out and the possibility of using the favorable ground effect for takeoff and landing application to high-speed aircraft is evaluated.

I.3.7.6 PRINCIPE D'ETUDE DE L'AILE A JET, M. Roy, Rech. Aeron. No.52, 1956.
The report gives some information about the propulsion-wing. The author discusses a special jet-wing configuration with an air-inlet at the wing leading-edge and blowing at the rear of the wing. There are different remarks about definitions, theory and experiment. Some new theoretical results are given.

I.3.7.7 THE JET FLAP AND STOL, G. K. Korbacher, UTIA, Decennial Symposium Proceedings, Part II, October 1959.
The jet flap is briefly reviewed. Its principle is defined and its outstanding virtues - as e.g. summarized in the thrust and lift hypotheses - are discussed and analyzed as to their aerodynamic background. Next the proper jet flap is compared with the jet augmented flap. The most useful and practical theoretical jet flap theories are briefly covered and the total and induced jet flap drag is discussed.

Finally, the jet flap features are evaluated as to their usefulness to all types of jet engine powered aircraft, especially for VTOL.

I.3.7.8 AN INTRODUCTION TO THE JET FLAP, I.M. Davidson and B.S. Stratford, ARC No. 17082, NGTE Report, R. 155, 1954.

I.3.7.9 NOTE ON A 'JET FLAP' THEORY, J. H. Davies, ARC. 17, 113, 1954.

I.3.7.10 THE JET FLAP; A NEW PRINCIPLE FOR THE MORE EFFECTIVE UTILIZATION OF AIRCRAFT JET STREAMS, B.S. Stratford, NGTE, Note NT 56; ARC 15, 996, 1953.

I.3.7.11 BRITISH RESEARCH ON THE JET-FLAP SCHEME, J. Williams, ZFW, June, 1958.
This review outlines British wind-tunnel and theoretical investigations on jet-flaps, and some experiments planned to amplify our knowledge and experience. Relevant engine developments are not discussed, but their importance should not be overlooked.

I.3.7.12 APPLICATION OF THE JET FLAP, J.M. Riebe, NASA Memo 7-3-59L, 1959.

I.3.7.13 THE JET FLAP-REVIEW AND EXTENSION, T. Strand, Convair Aerodynamic Rp. ZA-255, 1956.

See also, I.3.2.4, I.3.1.36,and .54

I.4 HIGH LIFT DEVICES (including BLC)

I.4.1 Forces and Moments

I.4.1.1 HIGH LIFT BOUNDARY LAYER CONTROL, H. Tennekes VTH Report 114, November 1962.

I.4.1.2 AERODYNAMIC ASPECTS OF BOUNDARY LAYER CONTROL FOR HIGH LIFT AT LOW SPEEDS, J. Williams and S.F.J. Butler, AGARD Report 414, January 1963.
Various methods of providing boundary-layer-control are outlined, comprising slot blowing, slot suction, area suction, inclined air-jets, and specially-designed aerofoil shapes. The aerodynamic aspects of slot blowing over trailing-edge flaps and the wing nose are then examined in detail, and slot suction and area suction are considered. The associated practical design features required for good performance are discussed and some flight-handling implications mentioned.

I.4.1.3 A METHOD FOR PREDICTING LIFT INCREMENTS DUE TO FLAP DEFLECTION AT LOW ANGLES OF ATTACK IN INCOMPRESSIBLE FLOW, E. C. Polhamus, NACA TN 3911, January 1957.
A method is presented for estimating the lift due to flap deflection at low angles of attack in incompressible flow. In this method provision is made for the use of incremental section-lift data for estimating the effectiveness of high lift flaps. The method is applicable to swept wings of any aspect ratio or taper ratio. Also included is a simplified method of estimating the lift-curve slope throughout the subsonic speed range.

I.4.1.4 COMPUTATION OF THE INCREMENT OF MAXIMUM LIFT DUE TO FLAPS, A. Roshko, Douglas Report SM-23626, July 1959.

I.4.1.5 APPROXIMATE METHOD FOR DETERMINING THE POTENTIAL FLOW ABOUT AN ARBITRARY AEROFOIL SECTION IN A TWO-DIMENSIONAL FINITE STREAM WITH PARTICULAR REFERENCE TO LARGE STREAM DEFLECTIONS, D. G. Gould, NRC Report LR-260, August 1959.
The flow about and on the surface of an aerofoil section in a finite stream and that about and on the surface of the same aerofoil section in an infinite symmetrical cascade are compared.

I.4.1.6 THE THEORETICAL ESTIMATION OF POWER REQUIREMENTS FOR SLOT-SUCTION AEROFOILS, WITH NUMERICAL RESULTS FOR TWO THICK GRIFFITH TYPE SECTIONS, J. H. Preston, N. Gregory and A.G. Rawcliffe, R&M 2577.
This report describes a method of assessing the performance of slot-suction aerofoils in terms of an effective drag coefficient, which takes into account the power requirements of the suction pump neglecting slot entry and duct losses. When the suction-slot is located at a velocity discontinuity the suction flow required to prevent separation can be calculated, using the elementary theory suggested by Sir Geoffrey Taylor.

I.4.1.7 POWER REQUIREMENTS FOR DISTRIBUTED SUCTION FOR INCREASING MAXIMUM LIFT, R. C. Pankhurst and N. Gregory, ARC CP82.

I.4.1.8 ANALYSIS OF SOME PARAMETERS USED IN CORRELATING BLOWING-TYPE BOUNDARY-LAYER CONTROL DATA, M. W. Kelley, NACA RM A56F12, June 1956.
An examination was made of limitations to the use of the jet momentum coefficient as a correlating factor in comparing tests of blowing-type boundary-layer control. A theoretical analysis indicated that this parameter should be acceptable where the duct pressures are large. At low pressures, when the jet velocity is of the local stream velocity the correlating parameter should include a term involving the flow quantity and ratio of the local velocity at the nozzle to the freestream velocity. Experimental data were shown to substantiate this conclusion.

I.4.1.9 THE AERODYNAMIC CHARACTERISTICS OF FLAPS, A.D. Young, R&M 2622, (February 1947, published 1953.
This report collects and summarizes the results of work that has been done both in this and other countries on the aerodynamic characteristics of flaps both before and during the 1939-45 War.

Includes correlations of much 2- and 3-dimensional test data and gives methods for estimating lift, drag and moment coefficients for wings with flaps. These correlations form the basis for the method described in Royal Aeronautical Society Data Sheets, 01.01.08, 01.01.10, 01.01.10.

I.4.1.10 WIND-TUNNEL INVESTIGATION OF EXTERNAL-FLOW JET-AUGMENTED DOUBLE SLOTTED FLAPS ON A RECTANGULAR WING AT AN ANGLE OF ATTACK OF 0° TO HIGH MOMENTUM COEFFICIENTS, E.E. Davenport, NACA TN 4079, September 1957.

A wind tunnel investigation has been made to determine the characteristics of external-flow jet-augmented double slotted flaps which appear suitable for application to aeroplanes with pod-mounted engines. The investigation included tests of a rectangular wing with an aspect ratio of 6 over a momentum-coefficient range from 0 to 28.

I.4.1.11 DISCUSSION ON AERODYNAMIC ASPECTS OF V/STOL AEROPLANES. H. Schlichting and K. Gersten, DFL Bericht N. 151 Der Deutschen Forschung-sanstalt fur Luftfahrt e.V., Braunschweig, 1961, 23 Seiten, Preis: DM 6,25

This paper gives a contribution to discussions on aerodynamic aspects of V/STOL aeroplanes held in the AGARD Fluid Dynamics Panel in Oslo, July 24, 1961. A survey is given on the following investigations, carried out in the Aerodynamische Versuchsanstalt (AVA) Gottingen and the Deutsche Forschungsanstalt fur Luftfahrt (DFL) Braunschweig:

1. "Boundary Layer Control by Suction; Results of Wind Tunnel Tests and Flight Measurements" (W. Wuest, AVA).

2. "High Lift Investigations on Aerofoils with Boundary Layer Control by Blowing" (F. Tomas, DFL).

3. "Ground Effect on Wings with Jet Augmented Flaps" (K. Gersten, DFL).

4. "Lifting Surface Theory for Wings with Jet Flaps" (A. Das, DFL).

I.4.1.12 THEORETICAL SYMMETRIC SPAN LOADING DUE TO FLAP DEFLECTION FOR WINGS OF ARBITRARY PLAN FORM AT SUBSONIC SPEEDS, J. DeYoung, NACA Report 1071.

A procedure based upon a simplified lifting-surface theory that includes effects of compressibility and spanwise variation of section lift-curve slope is presented in such a manner that the spanwise loading due to flap deflection can be simply found for wings having symmetric plan forms with constant spanwise sweep angle of the quarter-chord line. Aerodynamic characteristics due to flap deflection are considered

I.4.1.12 (continued)
and for straight-tapered wings, values of certain of these characteristics are presented in charts for a range of swept plan forms. Further use of the method gives downwash in the vertical center of the wake of the wing.

I.4.1.13 A SERIES OF AEROFOILS DESIGNED TO DEVELOP EXCEPTIONALLY LARGE LIFT COEFFICIENTS WHEN BOUNDARY LAYER CONTROL BY BLOWING IS EMPLOYED, D. G. Hurley and P.R. Skeat, ARL Report A102, March 1957.
A series of aerofoils has been designed by an extension of classical free streamline theory to develop very large lift coefficients when a blowing slot is used to suppress boundary layer separation. One of the aerofoils which has a thickness/chord ratio of 0.62, a trailing edge angle of 90° and a design lift coefficient of 9.69 has been investigated in detail.

I.4.1.14 METHOD FOR CALCULATING LIFT DISTRIBUTIONS FOR UNSWEPT WINGS WITH FLAPS OR AILERONS BY USE OF NON-LINEAR SECTION LIFT DATA, J.C. Sivells and G. C. Westrick, NACA Report 1090, 1952.
A method is presented for calculating lift distributions for unswept wings with flaps or ailerons using non-linear section lift data. This method is based upon lifitng line theory and is an extension to the method described in NACA Report 865. Simplified computing forms containing detailed examples are given for both symmetrical and asymmetrical lift distributions A few comparisons of experimental and calculated characteristics are also presented.

I.4.1.15 SUMMARY OF WIND TUNNEL DATA FOR HIGH-LIFT DEVICES ON SWEPT WINGS, H. O. Palme, SAAB Technical Note 16, April 1953, published 1954.
Based on a recapitulation of the known aerodynamic characteristics of profiles with high-lift devices a mainly statistical analysis is made of these devices on swept-back wings. It is shown that large aspect ratio variations have very little effect on the effectiveness of the devices. The influence of sweepback, and of the span of the device, is on the other hand large. An approximate method for calculating the lift at a given angle of attack for wings with flaps is given.

I.4.1.16 MAXIMUM LIFT FOR LANDING OF SWEPT WING AEROPLANES, H.O. Palme, SAAB Technical Note 17, April 1953, published 1954.
Based on experiences gained in flight tests of swept wing aeroplanes, a discussion is made of possible methods for determining from wind tunnel tests the maximum obtainable lift coefficient for landing. This is found to be difficult since the dynamic effects experienced in actual flight are not present in the wind tunnel; however, an approximate calculation of obtainable lift for landing is carried through for swept-wing aeroplanes with various wing plan forms. In connection with this, various methods for prevention of tip stall are discussed.

I.4.1.17 SUMMARY OF SECTION DATA ON TRAILING EDGE HIGH-LIFT DEVICES, J.F. Cahill, NACA R 938.

I.4.1.18 STOL PERFORMANCE EMPHASIZED IN AIRCRAFT DESIGN WITH SPECIAL REFERENCES TO JAPANESE CONTRIBUTION, Hiroshi Nakaguchi, Am.Inst. of Aeron.& Astron. RAS & Japan Soc. for Aeron.& Space Sci., A/C Des. & Tech. Mtg., 10/15-18, 1965, Paper 65-771.
Possibilities of improving STOL aircraft performance, with special reference to Japanese experiments on a modified SAAB Safir single-engined monoplane, an experimental flying boat, and lightweight turbojet engines. Increasing demands of STOL performance are discussed, with comment on certain difficulties which have been encountered. Airfoil sections and high lift devices, stability and control at low speed, and thrust tilting are considered. Modifications made to the SAAB Safir are outlined, and some results are described. Stall characteristics were found to be excellent. In the experimental flying boat, a unique feature is a new spray suppressor. High lift is achieved by a deflected slipstream combined with blown flaps and control surfaces. An experimental turbojet engine is briefly described.

I.4.1.19 HIGH LIFT DEVICES FOR SHORT FIELD PERFORMANCE, Interavia, Vol.19, April 1964.
Brief survey of the current state of the art in high lift devices on conventional takeoff aircraft in the supersonic age. It is concluded that there is little or no further scope in the development of aerodynamic lift augmentation devices such as flaps and slats. Boundary layer control has been widely investigated theoretically and experimentally, but applications are in their infancy.

I.4.1.20 EXTRACTS FROM THE FIRST AND SECOND RECOMMENDATIONS OF THE ACOA TO THE TECHNICAL ADVISORY PANEL OF THE NATIONAL AERONAUTICAL RESEARCH COMMITTEE, National Res. Council of Canada, Ottawa, Associate Committee on Aerodynamics, May 1964, 64p. (AD-447541).
The following study proposals are represented: "The effects of Ground Proximity, Ground Roughness, and Low Level Turbulence on the Aerodynamic Characteristics of VTOL-STOL Aircraft and GEMS"; "The Problems of Unsteady Aerodynamics Associated with Separated Flow Including the Determination of Flutter Derivatives"; "Fundamental Aerodynamics of Internal Flow Particularly as Related to Duct Losses and Peripheral Jets"; "The Aerodynamics of Jets and Jet Sheets, the COANDA Effect and the Augmentation of Jet Thrust"; "Theoretical and Experimental Information on the Aerodynamic Characteristics of Propellers at all Angles of Attack"; "The Interaction between the Propulsive Airstream and the Wing"; "Boundary-Layer-Control to Suppress Separation using both Geometric and Aerodynamic Means"; and "High Speed Aerodynamics".

I.4.1.21 EXPERIMENTAL AND THEORETICAL INVESTIGATION ON BLOWN WINGS AND THEIR APPLICATION IN AIRCRAFT DESIGN (EXPERIMENTELLE UND THEORETISCHE UNTERSUCHUNGEN ĀN AUSBLASEFLEGELN UND IHRE ANWENDUNG BEIM FLUGZEUGENTFURF), G. Strut and F. Thomas, In: Wissenschaftliche Gesellschaft fur Luft und Raumfahrt, e.V. (WGLR), Jahrestagung in Braunschweig von 9-12.10.62, Jahrbuch, Edited by Hermann Blenk, Braunschweig, Friedrich Vieweg und Sohn 1963, p.119-132.
Wind-tunnel investigation of the effect of the flap chord and the flap-noise radius on the aerodynamic coefficients of a wing profile with boundary-layer control blowing over the flap length. The value of the momentum coefficient of blowing required to prevent flow separation is determined. The results obtained experimentally are compared with theory and with available experimental data. Calculations showing the effect of the lift increase obtained by blowing on the takeoff and landing distance of an aircraft are presented.

I.4.1.22 DEVELOPMENT OF THREE-DIMENSIONAL PRESSURE-DISTRIBUTION FUNCTIONS FOR LIFTING SURFACES WITH TRAILING-EDGE CONTROLS BASED ON THE INTEGRAL EQUATION FOR SUBSONIC FLOW, A. N. Crespo and H. J. Cunningham, NASA TN-D 5419, October 1969.

I.4.1.23 THE USE OF SLOTS FOR INCREASING THE LIFT OF AIRPLANE WINGS, F. Haus, NACA TM 635, 1931.

I.4.1.24 AERODYNAMIC PROPERTIES OF WINGS WITH LEADING-EDGE FLAPS (NOSE FLAPS), Foreign Technology Div. Wright-Patterson AFB, Ohio, August 69, J. Wisocki.
The work discusses the aerodynamic properties of airfoils with two types of leading edge flaps and with crocodile flaps on the basis of the results of NACA and German wind tunnel investigations published in 1944-1948. Its purpose was to make the information available to designers in the form of an analysis of the pressures on the leading edge of the airfoil.

I.4.1.25 HIGH LIFT RESEARCH, General Dynamics/Convair, San Diego, California, J. Hebert, Jr.
Convair initiated a study of the aerodynamic characteristics of the passive types of high lift systems in 1966. An effort began on a high lift prediction handbook and plans are to complete it in 1968. In conjunction with the handbook, a span load procedure has been programmed for the computer. A number of deficiencies were uncovered as the results of the earlier investigation. As a consequence a two-dimensional wind tunnel test was planned for 1967 to eliminate certain deficiencies. The goal was to investigate multiple slotted trailing edge flaps and leading edge modifications. The primary factor was the selection of the testing technique. After careful consideration, blowing sidewalls and turntables to eliminate wall effects were selected and a calibration and test period was scheduled. The calibration data indicated a number of unknowns in the data. A limited amount of valid data was collected.

I.4.1.26 CAL/USAAVLABS SYMPOSIUM PROCEEDINGS, AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT. VOLUME II, PROPULSION AND INTERFERENCE AERODYNAMICS, Cornell Aeronautical Lab. Inc., Buffalo, N.Y. June 23, 1966.
Contents: predicted and measured performance of two full-scale ducted propellers; aerothermal dynamic performance of a high bypass tip turbine cruise fan system; thrust deflection nozzles for VTOL aircraft; shrouded propeller research at Missisippi State University leading to application on the United States Army XV-11A; the lift, drag and stability of wings immersed in propeller slipstream; aerodynamic properties of airfoils in non-uniformly sheared flow; experimental investigation of compound helicopter aerodynamic interference effects; maximum lift coefficient for STOL aircraft; a critical review.

I.4.1.27 CHARTS FOR LOW-SPEED CHARACTERISTICS OF TWO-DIMENSIONAL TRAILING-EDGE FLAPS, H. C. Garner, Aeronautical Research Council, R&M 3174, August 1957.
Semi-empirical charts are presented for estimating the lift, pitching moment, and hinge moment for airfoils with plain trailing-edge flaps. Information required is: airfoil ordinates, the flap chord, the Reynolds number and fixed positions of boundary-layer transition. The results compare quite well with test data but require knowledge of location of boundary-layer transition.

I.4.1.28 A CORRELATION OF TWO-DIMENSIONAL DATA ON LIFT COEFFICIENT AVAILABLE WITH BLOWING-, SUCTION-, SLOTTED-, AND PLAIN-FLAP HIGH-LIFT DEVICES, J. M. Riebe, NACA RM L55D29a, October 1955.
A correlation was made of data available on various flap-type high-lift devices. Flap chord ratios varied from 20 to 40 percent. The largest lift increments were attained for the blowing flaps. Flap chord ratio had a large effect on the momentum coefficient required.

I.4.1.29 LIFTING CAPABILITIES OF WINGS WITH AND WITHOUT HIGH-LIFT DEVICES. W. A. Schwartzberg and J. L. Burch, G. L. Martin Co., Engineering Report No. 8055, April 1956.
Contains a collection of charts for estimating the maximum lift of wings with and without high-lift devices. Includes boundary-layer-control estimation charts.

I.4.1.30 OPTIMIZATION OF AIRFOILS FOR MAXIMUM LIFT, R. H. Liebeck and A. I. Ormsbee, AIAA Paper 69-739, July 1969.
The pressure distribution which provides the maximum lift without separation for a mono-element airfoil in an incompressible flow is determined using existing boundary-layer theory and the calculus of variations. The airfoil profiles corresponding to these pressure distributions are determined using second-order airfoil theory. The results indicate maximum lift coefficients as high as 2.8 for Reynolds numbers between five and ten million, and the corresponding drag coefficients are on the order of 0.01. Compressibility has not been considered directly, however the form of the optimum pressure distributions suggests that the critical Mach numbers should be on the order of 0.35.

I.4.1.31 THE EFFECTS OF LEADING EDGE AND TRAILING EDGE FLAPS ON THE CL MAX OF THIN WINGS AT LOW SPEED, Royal Aircraft Establishment Farnborough (England), G. G. Brebner, November 1955.

I.4.1.32 LIFT AUGMENTATION AND OPERATION OF AIRPLANES BY CIRCULATION CONTROL, Poisson-Quinton, P. Jousserandot Wichita State Univ., Kansas, August 1955.

I.4.1.33 THE SUPERSONIC BLOWING JET FOR WING-LIFT AUGMENTATION J. S. Attinello, Bureau of Naval Weapons, Washington, D.C., October 1954.

I.4.1.34 CIRCULATION CONTROL BY MEANS OF TRAILING EDGE SUCTION D. C. Hazen, T. E. Sweeney, Princeton University, New Jersey, James Forrestal Research Center, August 1953.

I.4.1.35 AUGMENTING LIFT BY MEANS OF A SUPFRSONIC JET DIRECTED OVER FLAPS, J. S. Attinello, Bureau of Naval Weapons, Washington, D.C., May 1953.

I.4.1.36 FACTORS INFLUENCING THE DESIGN OF FULL-SCALE AND MODEL HIGH LIFT WINGS WHICH UTILIZE BOUNDARY LAYER CONTROL, J. Goldsmith, Northrop Aircraft Inc., Hawthorne, California, October 1954.

I.4.1.37 CIRCULATION CONTROL BY MEANS OF TRAILING EDGE SUCTION D. C. Hazen, T. E. Sweeney, Princeton University, New Jersey, James Forrestal Research Center, September 1953.

I.4.1.38 BLOWING TESTS ON AN AEROFOIL WITH SLOTTED FLAP, F. Ehlers and W. Schwier, German F.B. 1274, 1940. On a rectangular wing of the NACA 23014 profile with slotted flaps of different chord tests were made for boundary-layer influence by blowing out air, at which it has been attempted to increase the effectiveness of the flaps. The results indicated that through the blowing out the flap deflections could be made effective up to 45°.

I.4.1.39 THE LIFT ON A THIN AEROFOIL WITH A BLOWN FLAP, D. A. Spence, RAE TN Aero. 2420, 1958. A formula is given for calculating the lift on a thin aerofoil with blown flaps. The classical results for attached flow on flapped aerofoils without supercirculation are also obtained as a special case. It is shown that the effectiveness of the jet flap scheme might be greatly increased by blowing over flaps of the order of 20 or 30 percent of the chord, rather than over the very small shrouds which has hiterto been proposed.

I.4.1.40 INVESTIGATIONS INTO INCREASING THE LIFT OF WINGS BY BOUNDARY LAYER CONTROL THROUGH BLOWING, F. Thomas, Report No. RAE-Library Trans-1267, November 1967 (Royal Aircraft Establishment).
This report gave a survey of systematic measurements on a rectangular wing with a blown flap at the trailing edge. Along the whole span of the wing air was blown out through a narrow slot over the flap in order to prevent boundary layer separation at high angles of flap detection. Force and pressure plotting measurements were carried out at Reynolds numbers between 400,000 and 800,000. Measurements with an increased momentum coefficient included the region of supercirculation. In order to find a theoretical estimation for the minimum momentum coefficient required for preventing the flow separation, the flow phenomena in the boundary layer downstream of the blowing slot were investigated by special experiment. The velocity ratio of the jet and the free flow had a considerable influence on the characteristic boundary layer values (e.g. momentum thickness). Using the results of these experiments, it was possible to calculate the minimum momentum coefficient necessary to prevent boundary layer separation. Up to flap deflections of 45 degrees these calculated values were in good agreement with the measurements.

I.4.1.41 A REVIEW OF THEORETICAL METHODS RELATED TO BOUNDARY LAYER CONTROL BY BLOWING. B. J. Graham, Boeing Scientific Research Laboratories TM No. 40, April 1965.
Reviewed fundamental equations and assumptions for 2-D incompressible boundary-layer theory. Reviewed available theoretical work on blowing boundary-layer control. Concluded that the present methods are highly empirical and unsatisfactory.

I.4.1.42 TABULATION OF MAXIMUM LIFT COEFFICIENT DATA OBTAINED FROM TESTS ON AIRFOIL SECTIONS WITH HIGH LIFT DEVICES, E. O. Rogers, Naval Ship Research and Development Center, Technical Note AL-106, March 1969.
The results of a literature search to collect maximum lift coefficient data on airfoil sections with high lift devices are presented. The data are tabulated.

I.4.1.43 A CORRELATION FOR THE EFFECT OF CONTROL DEFLECTION UPON PITCHING MOMENT, J. C. Gibbings, Journal of the Royal Aeronautical Society, Vol. 69 November 1965, pp. 793-794.
A design chart is presented for estimating $\Delta C_M/\Delta C_L$ of flap-type controls as a function of control chord. The method would be suitable only for pre-design estimates.

I.4.1.44 A CORRELATION OF BLOWN FLAP TEST DATA WITH DESIGN CHARTS FOR ESTIMATING BLOWN FLAP LIFT AND C REQUIRED, R. B. Owen, Boeing Company D6-8111, March 1962.
A preliminary design method of estimating lift increments due to blown plain flaps and the momentum coefficients required was given. Design charts are given based on NACA and other tests. The method correlated within $\pm$10%.

I.4.1.45 THE AERODYNAMICS OF HIGH-LIFT DEVICES ON CONVENTIONAL AIRCRAFT, PART I., GENERAL DESCRIPTION ON $C_{L_{MAX}}$ AND STALLING BEHAVIOR, D. M. McRae, Aeronautical Journal, Vol. 73, June 1969, pp. 535-541.
Attempted to correlate $C_{L_{MAX}}$ with flap effectiveness. The mechanisms for producing low pressure on various types of flaps was described. The effect of a slot on the pressure distribution is discussed. Typical stall patterns are described and their relation to aircraft handling characteristics at the stall discussed.

I.4.1.46 THE AERODYNAMICS OF HIGH-LIFT DEVICES OF CONVENTIONAL AIRCRAFT, Part II. Some aspects of the RAE High-Lift Research Program, D. N. Foster, Aeronautical Journal, Vol. 73, June 1969.
Surveyed the high-lift research program at the RAE. Current program is concentrated on sweepback angles of less than 40° and aspect ratios of greater than 4.5. Airfoil sections designed for high lift are being considered. A model will be tested with fuselage isolated from wing to isolate fuselage contribution to aerodynamic loads. A theoretical method for calculating loading on a wing with chord-extending flaps is described (RAE TR 69034). Tests on a model to investigate lateral control at high lift are being conducted.

I.4.1.47 THE ESTIMATION OF THE LOADING ON SWEPT WINGS WITH EXTENDING CHORD FLAPS AT SUBSONIC SPEEDS, J. McKie, Royal Aircraft Establishment TR 69034, February 1969.
A method was given for estimating lift and vortex drag increments due to part-span, extending chord flaps on thin, sweptback, tapered wings of large aspect ratio in inviscid, incompressible flow. It was a linear theory and was considered as an extension of the RAE Standard Method for calculating loadings on such wings. Spanwise loadings were obtained by Multhopp's quadrature methods, extended to include discontinuities in wing chord, and examples were given for some typical wing and flap layouts.

I.4.1.48 THEORETICAL AND EXPERIMENTAL CONTRIBUTION TO THE STUDY OF BOUNDARY LAYER CONTROL BY BLOWING, P. Carriere, E. Eichelbrenner, and Ph. Poisson-Quinton, in "Advances in Aeronautical Sciences," Vol. 2, Proceedings of the First International Congress in Aeronautical Sciences, September 8-13, 1958, Pergamon Press, London, 1959.
In order to better understand blowing boundary-layer-control, boundary layer profiles were examined experimentally for a jet emitted along a wall. Using the experimental boundary layer profiles as a guide, a theoretical technique was developed for estimating the critical blowing coefficient. Some empirical results were presented for use in preliminary design work.

I.4.1.49 A METHOD FOR PREDICTING THE LIFT, DRAG AND AIR REQUIREMENTS FOR AN AIRCRAFT WITH BLOWN FLAP, D. H. Aero. Dept/2824/DHD/DHW/Gen. September 1960., by D. H. Dykins, D. H. Wilkinson.
Methods are described for predicting lift increments obtainable by use of a blown flap and the drag increments incurred. Methods are empirical based on mostly NACA experimental data. Geometry of slot and flap are considered and penalties involved in departing from optimum configurations are indicated.

I.4.2 Flow Fields

I.4.2.1 PREDICTION OF DOWNWASH BEHIND SWEPT-WING AIRPLANES AT SUBSONIC SPEED, J. DeYoung and W.H. Barling, NACA TN 3346, January 1955.
The numerical integration method presented enables a rapid prediction of downwash. The principal effects of the rolling-up of the wake are treated as corrections to the flat-sheet wake. A simple approximate correction for the effect of the fuselage is applied. Computing forms and charts of pertinent functions are included. Agreement with available experimental data is good.

I.4.2.2 DESIGN CHARTS FOR PREDICTING DOWNWASH ANGLES AND WAKE CHARACTERISTICS BEHIND PLAIN AND FLAPPED WINGS, Abe Silverstein and S. Katzoff, NACA Report 648, 1939.
Equations and design charts for predicing downwash angles and wake characteristics beynd plain and flapped wings. Unswept wings AR=6,9,12, λ=.2, .33, .5, and 1, and b_f/b=0, .4, .7, and 1.0. Based on span loading from method of NACA TR 585. Wake width and distribution of dynamic pressure across the wake is given in terms of profile-drag coefficient and distance behind wing. Method of estimating wake position is given. No comparison made with test data.

See also I.4.1.5 and I.4.1.12

I.4.3 Ground Effect -

See I.4.1.11 and Section I.8.3.

I.4.4 Stability and Control -

See Section I.4.1 and Section I.8.4.

I.4.5 Handling Qualities and Criteria -

No prediction methods were found in the literature search.

I.4.6 Testing

I.4.6.1 CORRECTIONS FOR SYMMETRICAL SWEPT AND TAPERED WINGS IN RECTANGULAR WIND TUNNELS, W.E.A Acum. R&M 2777, April 1950, published 1953.
It is shown that with wings with straight leading and trailing edges the interference upwash due to the images of the wing in the wind-tunnel walls may be determined in terms of three functions of the parameters defining the size of the wing and tunnel. These functions have been tabulated and used to estimate the effect on C_L and C_M, for wings of a variety of sizes and shapes.

I.4.7 <u>General</u>

I.4.7.1 SUCTION-SLOT DUCTING DESIGN, A. G. Rawcliffe, ARC R&M 2580.

I.4.7.2 SOME AERODYNAMIC AND OPERATIONAL PROBLEMS OF STOL AIRCRAFT WITH BLC, J. J. Cornish Paper 64-193.

I.4.7.3 AIRCRAFT HIGH-LIFT DEVICES, Report Bibliography 1953- January 1959, DDC-TAS-69-25.
This bibliography is a selection of 89 unclassified references to unclassified-unlimited, unclassified-unlimited, and confidential reports on aircraft high-lift devices processed by DDC from January 1953 to January 1969. A list of 14 unclassified titles of 9 confidential reports and 5 secret references to secret reports are included. Corporate author-monitoring agency, subject, personal author, contract and report number indexes are provided.

I.4.7.4 BLOWN FLAPS FOR STOL OPERATION, M. A. Schwartzberg, Aircraft Engineering, October 1959, pp.308-311.
Examined some available information on slipstream deflection by large chord flaps and blown flaps. Information was presented in a form which could be used to estimate probable effects of a blown flap in a propeller slipstream.

I.4.7.5 AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, Volume III, Aerodynamic Research on Boundary Layers, Held june 24, 1966, Statler-Hilton Hotel, Buffalo, New Yorkm June 1966 - Cornell Aeronautical Lab, Inc., Buffalo N.Y.
Contents: spanwise flow effects on rotor performance a preliminary study of the effect of a radial pressure gradient on the boundary layer of a rotor blade; the boundary layer of the hovering rotor; <u>an investigation of the feasibility of a common boundary layer control system for high-lift and low-drag on an airfoil section</u>.

I.4.7.6 BOUNDARY LAYER AND CIRCULATION CONTROL FOR STOL AIRCRAFT, F. Thomas, in "The Aerodynamics of V/STOL Aircraft", AGARDograph-126, May 1968.
A survey was given of the most prominent methods of increasing lift by boundary layer and circulation control. Experimental methods and calculation procedures were described. Emphasis was placed on boundary layer control by blowing.

I.4.7.7 A SIMPLIFIED METHOD FOR ESTIMATING THE PROPERTIES OF THIN AEROFOILS INFLUENCED BY JET, S. Pivko, Journal of the Royal Aeronautical Society, Vol.64, May 1960, pp.292-294.
A procedure was proposed for estimating the lift and pitching moment of two dimensional thin jet and jet-augmented flaps was proposed. The airfoil and jet was represented by vortex distributions; comparison of theory with the experiment shown was good.

I.4.7.8 POWER REQUIREMENTS OF A BLOWING WING WITH SEALED AND SLOTTED TRAILING EDGE FLAPS, H.B. Helmbold, Fairchild Aircraft a. Miss. Div., Eng. Rp. R.246-604 1959.
ONR-supported experimental investigation of a blowing NACA 23015 airfoil with a sealed flap and an effective blowing-slot width of 0.7% chord, over a range of flap deflection angles from 0° to 70°. Only flows fully attached to the flap are considered. A comparison with the results for the slotted flap with wide blowing slot shows that, at high flap deflection angles, the power requirement of the sealed flap is diminished only over a limited range of lift coefficients after reattachment, whereas for higher lift coefficients the slotted flap is definitely superior. Present results are discussed in their context with previous ones.

I.4.7.9 A SURVEY OF LITERATURE PERTINENT TO A MORE BASIC UNDERSTANDING OF BOUNDARY LAYER CONTROL BY EXTERNAL BLOWING, S.G. Rubin, BSRL Flight Sciences Lab., TM no.16.
Reviews experimental and theoretical research on the behaviour of wall jets and indicates areas where there are gaps in the information necessary for a full understanding of them.

I.4.7.10 RECHERCHES THEORIQUES ET EXPERIMENTALES SUR LE CONTROL DE CIRCULATION PAR SOUFFLAGE APPLIQUE AUX AILES D'AVIONS, L. Malavard, P. Jousserandot, and others, ONERA TN 37, 1956.
Defines the main boundary layer blowing parameters and gives theoretical and experimental results for a number of different configurations. The authors give some comments about the applicability of the theory and discuss the possibilities and problems of blowing.

I.4.7.11 HYPERSUSTENTAION ET PILOTAGE DES AVIONS PAR CONTROLE DE CIRCULATION, Poisson-Quinton, Ph. and P. Jousserandot, Bulletin de l'Association Technique Maritime et Aeronautique-Session, 1955.
Study of the circulation control round a wing-profile under theoretical and experimental aspects; in both cases the selected fundamental parameters are satisfying: (1) for suction: slot position and ducted volume; (2) for blowing; momentum coefficient and jet orientation. The blowing on the trailing-edge of a profile leads to the future solution of the jet-wing. The combination of the effect of the flap and the effect of the jet permits two actual solutions applicable to aircraft. Blowing on the trailing-edge or tangential blowing from the gap between wing and flap are discussed. In both cases the controls for boundary-layer and for circulation are close together.

I.4.7.12 QUELQUES ASPECTS PHYSIQUES DU SOUFFLAGE SUR LES AILES D'AVION, Poisson-Quinton, Ph. Paper presented at the Congress of AFITA, Paris, and at the Congress of WGL, Darmstadt, July 1956; Techn. et Sc. Aero., No.4, 1956; WGL-Jahbuch 1956.
There are two ways of application of blowing taken into consideration, the boundary-layer control and the circulation control. The boundary-layer control is applied in those zones of the profile where normally detachments appear. The blowing over a flap grants the flap its theoretically possible effectiveness up to considerable angles of deflection, while by blowing near the leading edge the incidence for maximum lift of the wing will be transferred to greater incidences. By blowing near the trailing edge of the profile circulation control is made possible. Due to this method considerable lift coefficients may be reached, however, the blowing energy, required for this procedure has the size of the total energy, produced by the jet engine. Beside from serving the lift increase for control and stabilization of the aircraft the blowing may be used for reduction of the drag of profiles.

I.4.7.13 BOUNDARY-LAYER CONTROL PRINCIPLES AND APPLICATIONS, G. V. Lachmann, Ed. Pergamon Press
This book presents a comprehensive survey of all aspects of boundary layer control. It contains reviews of boundary layer control work carried out in Europe and the USA, summaries of experimental and analytical research and an extensive bibliography.

I.5 FAN-IN-WING

I.5.1 Forces and Moments

I.5.1.1 ON THE EFFECT OF FAN AND THRUST ENGINE LOADING ON THE TRANSITION POWER REQUIREMENTS OF A FAN WING, N. Gregory, CP 690. 1963.
The ideal power requirements of a fan wing in transition have been calculated and the effects are shown of varying the fan and thrust engine areas relative to that of the wing, and of varying the wing aspect ratio.

I.5.1.2 ON THE REPRESENTATION OF FAN-WING CHARACTERISTICS IN A FORM SUITABLE FOR THE ANALYSIS OF TRANSITION MOTIONS, WITH RESULTS OF TESTS OF AN ASPECT-RATIO-1 WING WITH FAN AT 0.354 CHORD. N. Gregory, CP552, 1961.

I.5.1.3 INDUCED INTERFERENCE EFFECTS ON JET AND BURIED-FAN VTOL CONFIGURATION IN TRANSITION, K. P. Spreemann, NASA TN D-731, March 1961.

I.5.1.4 DESIGN CHARACTERISTICS OF A LIFTING FAN V/STOL LOGISTIC TRANSPORT, E. Kazan and W. Bergen

I.5.1.5 ANALYSIS OF THE PERFORMANCE OF A HIGHLY LOADED 12-INCH VTOL Z-AXIS, FAN-IN-WING MODEL AT ZERO FORWARD SPEED, U. W. Schaub and R. W. Bassett, NRC Report LR-439, September 1965.

I.5.1.6 FAN-IN-WING V/STOL AIRCRAFT, H. A. James and K. L. Sanders, AAE, Volume I, June 1963., pages 66-71.
Brief survey of the technological state-of-the-art of the fan-in-wing concept, with particular reference to the Ryan Vertifan XV-5A program. Discussed is the application of jet-flap theory and empirical relationships to the prediction of the longitudinal forces and moments of finite wing-body combinations that incorporate wing-body-submerged lift fans. Momentum relations are presented which indicate the general relationship of the power and lift parameters. Presented are pertinent relationships of the turbojet engine and lift-fan characteristics, in

I.5.1.6 (Continued)
terms of disk loading. The relative fan size and power effects are illustrated. Noted is the promising application of the lift-fan concept in the design studies of a Mach-3, high-altitude fighter aircraft.

I.5.1.7 LOW SPEED AERODYNAMIC CHARACTERISTICS OF JET VTOL AIRCRAFT AT ANGLES OF ATTACK, Ktyna, D.J., Massachuetts Institute of Technology, Cambridge Department of Aeron. and Astron., May 1965, 90 p.
A VTOL model incorporating a lifting fan mounted vertically in the fuselage was tested in the MIT Wright Brothers Wind Tunnel to examine the variations of the pitching moment and longitudinal forces with changes in the angle of attack and forward velocity. The model was tested at angles of attack between ±90 degrees, but the results were considered reliable only up to ±45 degrees due to stalling of the model fan blades. Moment was found to be unstable between the measured angles of attack from -45 degrees to +10 degrees, increasing moderately as angle of attack increased. An increase in the ratio of forward velocity to fan efflux velocity also produced an increased moment. A theory was employed to predict the results of the experiment. The correlation was found to be reasonably good except at high ratios of free stream to fan efflux velocity.

I.5.1.8 GENERALIZED CHARACTERISTICS OF VERTIFAN AIRCRAFT IN THE FAN MODE, H. A. James, N. Y. Academy of Sciences, Annals, Volume 107, Art. 1, March 25, 1963, pages 196-220.
General review of the basic aerodynamics and characteristics of the fan-in-wing (FIW) type of aircraft. It is noted that no readily usable theory applicable to finite wings with submerged fans is available for general analysis. Pertinent basic fan relationships developed in the technical literature are given. Simple momentum theory is applied to illustrate and compare some of the fundamental characteristics of FIW aircraft and conventional aircraft. Data are used to study lift and

I.5.1.8 (Continued)
and speed capabilities with various disk loadings. Graphs of lift and speed attainable are presented for various combinations of angle-of-attack and exit-louver angle. The data are further generalized to illustrate lifting and transition speed capabilities. It is concluded that incorporation of the FIW concept to conventional turbojet-powered aircraft design offers the possibilities of flight speeds down to hover, as well as high subsonic and perhaps supersonic speeds.

I.5.1.9 THE LIFT PRODUCED BY A WING MOUNTED LIFT FAN AT FLIGHT SPEEDS BELOW TRANSITION, E. E. Martin, American Helicopter Society Journal, Volume 9, April 1964, pages 17-24.
Three-dimensional analysis of the fan-in-wing lift produced during transitional flight. In this analysis, the circulation caused by the flow through the fan creates a strong downwash velocity component. The downwash velocity reduces the effective angle of attack and produces an induced lift coefficient. The three-dimensional solution obtained is shown to provide a better representation of the test data than that obtained with the two-dimensional theory, which does not account for the induced lift coefficient.

I.5.1.10 AERODYNAMICS AND FLYING QUALITIES OF JET V/STOL AIRPLANES, M. O. McKinney, Jr., R. E. Kuhn and P. Reeder, Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N. Y., April 27-30, 1964, Paper 864A, 14 p.
Presentation of a summary of information on aircraft aerodynamics, ground effects, propulsion-system aerodynamics, stability and control, and flying qualities of jet V/STOL aircraft. Both direct jet-lift and lift-fan configurations are considered. The information is applicable to high-speed fighter-type aircraft. Research work is reviewed in the area of wind tunnel experiments on jet-induced effects including ground effects, and in the areas of aerodynamics, stability and control

I.5.1.10 (Continued)
problems in various flight ranges, such as V/STOL, hovering, and transition.
Experimental research on propulsion aerodynamics in the hovering and very low speed ranges of flight is discussed, with a report of flight-test experience on the flying qualities of several jet V/STOL aircraft.

I.5.1.11 AN INVESTIGATION OF THE LIFT PRODUCED BY A FAN IN A TWO-DIMENSIONAL WING, Sven-Anders, American Helicopter Journal, Vol. 7, October 1962, P. 25-32.
Explanation of the decrease in lift occurring at low flight velocity for a fan-in-wing airplane. The treatment is restricted to a two-dimensional, infinite span, problem. A new approach is presented, which may be called ellipse-flat-plate theory and treats a tandem arrangement of an ellipse and a flat plate with potential flow theory. Two-dimensional experiments are then compared to this theory to give a fairly good agreement. The principal conclusion is that a separation exists on the underside of the part of the wing behind the fan at low flight velocities, causing the decrease in lift.

I.5.1.12 A VORTEX LATTICE LIFTING SURFACE THEORY FOR WINGS WITH SUBMERGED FANS, N. V. McEachern and N. M. Currie, National Research Council. National Aeronautical Establishment, NRC LR-311, August 1961.
A vortex lattice lifting surface method of predicting pressure distribution, lift, and pitch moment developed by a wing with a submerged lifting fan is presented. An n^{th} order matrix of downwash influence coefficients is inverted to yield the vortex circulations in terms of a specified downwash distribution. Theoretical results for n=28 and n=84 are compared with experimental measurements of lift, pitching moment, and surface pressure distributions on a wing with a single submerged fan.

I.5.1.13 A GENERAL METHOD FOR DETERMINING THE AERODYNAMIC CHARACTERISTICS OF FAN-IN-WING CONFIGURATIONS, Vol. I, Theory & Application, P. E. Rubbert; G. Saaris;

I.5.1.13 (Continued)
M. B. Scholey; N. M. Standen; R. E. Wallace, The Boeing Company, USAAVLABS TR-67-61A-Volume 1, December 1967.
A general method was presented for the determination of aerodynamic characteristics of fan-in-wing configurations by means of incompressible potential flow theory. The method was applicable to wings, flapped or unflapped, and to a wide variety of other potential-flow boundary-value problems. Arbitrary wing and inlet geometry, fan inflow distribution, thrust vectoring, angle of attack, angle of yaw, and flight speeds from hover through transition can be treated. The theoretical model was completely three dimensional, with no linearization of boundary conditions. The calculated results included pressure distributions, lift, induced drag and side force pitching moment, rolling moment and yawing moment. The numerical potential-flow solution was obtained with source and vortex distributions on the boundary surfaces. The representation was composed of small, constant-strength source sheet panels distributed over the exterior wing surfaces, internal vortex filaments which emanated from the wing trailing edge to provide circulation and to produce the trailing vortex sheet, and a vortex lattice across the fan face and along the periphery of the fan.

I.5.1.14 GENERAL METHOD FOR DETERMINING THE AERODYNAMIC CHARACTERISTICS OF FAN-IN-WING CONFIGURATIONS, Volume II, Computer Program Description, G. R. Hing; R. F. Gilbert; K. A. Sundstrom, The Boeing Company, USAAVLABS TR-67-61A-Volume 2, December 1967.
Described a digital computer program developed to study the aerodynamic characteristics of fan-in-wing configurations. The program was written in the Fortran IV and ascent languages for the control data corporation 6000-series digital computers. Three basic packages were provided by the program: a geometry package produced a detailed description of the configuration, an aerodynamic package provided a theoretical solution for the potential flow

I.5.1.14 (Continued)

about the configuration, and a boundary-layer package furnished the boundary-layer characteristics on the wing surface. The report provided a description of the program, flow charts and segmentation structure diagrams, and input data formats.

I.5.2 Flow Fields

I.5.2.1 LIFT-FAN V/STOL PROPULSION AND AIRFRAME INTEGRATION, H. E. Dickard, Ryan Aeronautical Co., San Diego, California, in AGARD Aerodynamics of power plant Installation, Part 2, October 1965, page 653-688. This paper reviews fundamental preliminary design considerations involved in the integration of turbo-jet powered and past technology. The U. S. Army's XV-5A li t-fan research vehicle is used as a basis of reference for later and improved lift-fan and jet engine technology. A lift-fan mechanical configuration is discussed briefly. Parameters relating lift-fan static lift to the power output of the turbojet engine in terms of gas horsepower and gas flow output are established. The effects of three higher energy turbojet cycles on these parameters are shown. Effects of the higher energy turbojet gas generator on the composite lift-fan propulsion system (engine, fans and gas transmission ducting) are also discussed. A brief demonstration of the influence of a design pressure on propulsion weight and a structural weight trade-off is given and relative increases in useful load due to the more efficient propulsion system are also shown. The paper is concluded by presenting a spectrum of tactical lift-fan aircraft configurations with speed capability up to Mach 2.0.

I.5.2.2 ANALYTIC AND EXPERIMENTAL STUDIES OF NORMAL INLETS, WITH SPECIAL REFERENCE TO FAN-IN-WING VTOL POWER-PLANTS. A - ANALYTIC INVESTIGATION, B - EXPERIMENTAL INVESTIGATION, U. W. Schaub and E. P. Cockshutt, International Council of the Aeronautical Sciences Congress, 4th Paris, France, August 24-28, Paper 64-572, 22 pages.
Examination of the flow of air into a normal inlet by means of a simple mathematical model followed by experimental investigation. The principle is that of potential flow into a quasi-circular two-dimensional bell mouth. Streamline maps and surface velocities are presented for various bell mouth radii and cross flow ratios, using conformal transformation methods. It is demonstrated that

I.5.2.2 (Continued)

the wall contour generated by this method has some deficiencies, but that these are localized and do not affect the flow field as a whole. In Part B, the effects of cross-flow are examined experimentally, using a family of three simple inlets and four different in-flow aids. Two inlets have a circular-arc lip contour and have lip ratios of 9% and 25%. The third inlet is a asymmetrical lip. The aids are: (1) a cambered closure plate, (2) a cascade of inlet shutters, (3) a trip fence, and (4) a perforated wall used for boundary-layer suction. The inlet performance is analyzed on the basis of surface pressure distributions at the symmetry plane and on average total pressure loss. All inlets except the shuttered one performed well under static in-flow conditions. Under cross-flow conditions all three basic inlets showed evidence of strong adverse surface pressure gradients and suffered severely from flow separation.

I.5.2.3 AERODYNAMICS OF POWER PLANT INSTALLATION, PART II. AGARDOGRAPH-102-PART 2.

Contents: An investigation of splitter plates for supersonic twin inlets; boundary-layer interaction effects in intakes with particular reference to those designed for dual subsonic and supersonic performance; possibilities actuelles d'etude theorique d'une tuyere supersonique a double-flux; methods of measuring aerodynamic efficiency and thrust vectors of engine exhaust systems; propulsion system integration in wings; a fully integrated propulsion system for a supersonic transport aircraft; jet VTOL power plant experience during flight test of X-14A VTOL research vehicle; jet lift intakes; techniques for the simulation of jet-lift engines in wind-tunnel models of V/STOL aircraft; aerodynamic interference effects with jet lift schemes on V/STOL aircraft at forward speeds; lift fan V/STOL propulsion and airframe integration; NASA research on the aerodynamics of jet VTOL engine installations, experimental studies of VTOL fan-in-wing inlets.

I.5.2.4 AERODYNAMIC EFFECTS OF LIFT-JET AND LIFT-FAN INLETS IN TRANSITION FLIGHT, W. E. Grahame, Journal of Aircraft, Volume 6 No. 2, March-Arpil 1969, pages 150-155.

An investigation was conducted to determine the force and moment contribution of V/STOL, lift-jet and lift-fan inlets in transition based on momentum theory. A lift-jet or lift-fan inlet with its axis perpendicular to the freestream developes strong forces that contribute to positive pitching moments at low forward speeds. The analysis was based on the addition of freestream flow with the static-induced flow at the inlet, which is represented by a sink flow over a hemispherical control surface. The results of the analysis, which provided total inlet force, inlet lift, and drag force, as well as inlet lip force and inlet pitching moment, agree reasonably well with a limited amount of published inlet test data. It was shown that the lift-fan inlet develops significantly greater lift, drag and moment than the lift-jet inlet at comparable thrust and forward speed. Other comparisons were presented which show the close agreement between inlet drag and total incremental jet-induced drag developed by lift fan-in-fuselage and lift fan-in-wing configurations in transition flight.

I.5.2.5 EFFECTS OF THE AIR INTAKE OF A LIFTING ENGINE ON THE AERODYNAMIC CHARACTERISTICS OF A WING, V. N. Arnol'dov, A. F. Razkin, G. A. Pavlovets and A. A. Savinov, NASA TT F-12, 708, October 1969.

Analysis of the aerodynamic forces and moments developed as a result of engine inlet operation, specifically fan-in-wing, found that the portion of the total thrust on the external surface of the inlet was developed on a small area near the inlet and increased as the airlfow rate increased. An additional moment and drag were developed on the wing which increased with forward speed.

I.5.3 Ground Effect

No prediction methods were found in the literature search.

I.5.4 Stability and Control

I.5.4.1 LIFT FAN PROPULSION SYSTEMS - V/STOL AIRCRAFT CONTROL, E. F. Beeler and L. J. Volk, Society of Automotive Engineers, National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, California, October 4-8, 1965, Paper 650831, 21 pgs. Discussion of aircraft control power requirements provided by lift fan systems. Gas power transfer is described and estimated performance presented. A performance comparison is made between the thrust spoiling system used in the present Army XV-5A flight research vehicle and a gas power transfer system. Fan power can provide adequate aircraft control forces.

See also I.5.1.4 and I.5.1.11.

I.5.5 Handling Qualities and Criteria

No prediction methods were found during the literature search.

I.5.6 <u>Testing</u>

No prediction methods were found during the literature search.

I.5.7 General

I.5.7.1 THE LIFT FAN V/STOL CONCEPT FOR FUTURE APPLICATIONS, AIAA Paper, J. M. Peterson

I.5.7.2 LIFT FAN DESIGN CONSIDERATIONS, E. F. Beeler and Z. J. Przedpelski

I.5.7.3 ON THE EFFECT OF FAN AND THRUST ENGINE LOADING ON THE TRANSITION POWER REQUIREMENTS OF A FAN WING, N. Gregory, Aeronautical Research Council, (ARC-CP 690; supersedes NPL-AERO-1011, ARC-23712), London, HMSO, 1963, 22 pages.
The ideal power requirements of a fan wing in transition have been calculated, and the effects are shown of varying the fan and thrust engine areas relative to that of the wing, and of varying the wing aspect ratio. Comparison with wing-tunnel results confirms the presence of adverse jet-main-stream interaction effects neglected in the calculations.

I.5.7.4 SUGGESTED SPECIFICATION FOR A LIFT FAN PROPULSION SYSTEM, W. B. Davis, May 1969.
The report presents propulsion system component design requirements believed to be necessary for successful development of operational lift fan aircraft. The work was done for the purpose of identifying lift fan airframe and propulsion system performance and installation interfaces. The requirements presented in the report reflect experience gained from the XV-5A lift fan aircraft flight test program.

I.6 TILT WING

I.6.1 Forces and Moments -

I.6.1.1 CALCULATION OF AERODYNAMIC FORCES ON PROPELLER IN PITCH OR YAW, J.L. Crigler and J. Gilman, NACA TN 2585.

I.6.1.2 REVISED CHARTS FOR THE DETERMINATION OF THE STATIC AND TAKEOFF THRUST OF A PROPELLER, A. B. Haines and P.B. Chater, ARC R&M 2358.

I.6.1.3 RECENT DEVELOPMENTS IN SIMPLIFYING AND IMPROVING THE TILT WING DESIGN, C.B. Fay, Am. Helicopter Society, Annual National Forum, 1964.
Discussion of the approach, techniques, and results of analyses and test programs used by the Vertol Division of the Boeing Company to develop and improve the basic tilt-wing design. Efforts to extend the performance, maneuverability, and control characteristics are discussed in addition to the application of the technological developments to specific requirements. Results are said to indicate that tilt-wing technology has arrived at the stage of design and development where, with a simple and efficient design, it is now possible to meet specific military requirements. Includes equations for estimating monocyclic control forces.

I.6.1.4 FORCE AND MOMENT DERIVATIVES DUE TO PROPELLERS OF ARBITRARY CONFIGURATION INCLINED WITH RESPECT TO FREESTREAM, J. DeYoung, Am. Inst. of Aeron. and Astron., General Aviation Aircraft Design and Operations Meeting, Wichita, Kansas, May 25-27, 1964, Paper 64-169.
Generalization of existing small-incidence theory, by use of a propeller solidity based on average blade chord. With this solidity simple expressions, particularly suitable for obtaining rapid, accurate predictions, are developed for propeller normal (or side) force and for the principal derivatives. In addition, an expression is derived which indicates that the ratio of normal force at high incidence to normal force slope at zero inflow equals the tangent of the angle of incidence provided both quantities have equal advance ratios as determined from the velocity normal to the propeller disk. The variations of thrust, torque,

II.6.1.4 (continued)
and power at high incidence are presented as ratios to the zero incidence value. These ratios are approximately proportional to the square of the tangent of the angle of inclination. Except for a small dependence on solidity, these ratios are independent of propeller geometry.

II.6.1.5 PROPELLER AT HIGH INCIDENCE, J. DeYoung, Journal of Aircraft, Vol.2 No.3, May-june 1965.
Existing small-incidence theory was generalized by use of a propeller solidity based on an average blade chord. With this solidity simple expressions were developed for sixteen possible derivatives such as propeller normal (or side) force. In addition, an expression was derived which indicated that the ratio of normal force at high incidence to normal force slope at zero inflow equals the tangent of the angle of incidence, provided that both quantities have equal advance ratios as determined from the velocity normal to the propeller disk. Thrust, torque, and power at high incidence were likewise derived as ratios to the zero incidence value. Except for a small dependence or solidity, these ratios were independent of propeller geometry. Fan correlation is shown with experimental thrust and power ratios to an incidence of 85°.

II.6.1.6 A METHOD OF ANALYSIS FOR PROPELLERS AT EXTREME ANGLES OF ATTACK, G.F.Hall, Journal of Aircraft, Vol.6 No.1, January-February 1969.
The method developed analyzes the propeller at extreme angles of attack by considerations on a simplified model of the wake similar to the classical Prandtl model for axial flight. The analysis conssits of determining a "tip loss"factor for the propeller at an angle of attack. This tip-loss factor is, like Prandtl's, a function of the number of blades, non-dimensional propeller radius, and wake helix geometry; but a dependence on wake skew angle is also observed. The solution is obtained numerically on an IBM 7074 digital computer. A method of solution to the "direct problem" in propeller aerodynamics utilizing this tip-loss factor is suggested. Thrust and power requirements for an existing propeller are determined and compared with experimental values. Thrust and power requirements for an existing propeller are determined and compared with

II.6.1.6 (continued)
experimental values. Reasonable agreement between theory and equipment is obtained within a practical range of angle of attack α, and the parameter μ (i.e., tip-speed ratio) cos α. However, thrust and power are generally under predicted at lot values of μ cos α for all angles of attack. Major sources of error are believed due to the relatively simple mathematical model and inaccurate airfoil data in the regions of blade section stall and reverse flow.

II.6.1.7 INVESTIGATION OF THE DOWNWASH ENVIRONMENTAL GENERATED BY V/STOL AIRCRAFT OPERAING IN GROUND EFFECT, M. George, F. Kisielowski and D.S. Douglas USAAVLABS Technical Report 68-52, July 1968.
Analytical methods were developed for determining the downwash environment generated by multi-propeller V/STOL aircraft operating in ground effect. These methods were used to compute flow fields and dust cloud characteristics for the XC-142, X22A, X-19A, and XV-5A. It was determined that additional full-scale test data are required to verify the theory.

See also Section I.2

I.6.2 Flow Fields -

I.6.2.1 LINEARIZED POTENTIAL THEORY OF PROPELLER INDUCTION IN A COMPRESSIBLE FLOW, R.E. Davidson, NACA TN 2983, September 1953.
The potential-theory representation of the wave-equation flow about a lifting-line propeller of finite number of blades and arbitrary circulation distribution is given. From the velocity potential, the compressible inflow velocities at the blade became known. The induced velocities are known also at any point in the flow because the velocity potential is determined for the whole field.

I.6.2.2 A COMPREHENSIVE REVIEW OF V/STOL DOWNWASH IMPINGEMENT WITH EMPHASIS ON WIND INDUCED RECIRCULATION, P.J. Unit, Air Force Institute of Technology Thesis, GAM/AE/69-9, March 1969.
A summary of the work done in the previous decade on downwash impingement was given. The direct jet lift and rotor downwash fields were described. Recirculation causes, mechanism, and operational problems were discussed. A bibliography was included. The recirculation problem was not solved.

See also Section I.2

I.6.3 Ground Effect -

See I.2.2.1, I.6.1.7 and I.6.2.2

I.6.4 Stability and Control

I.6.4.1 CALCULATION OF THE DYNAMIC LONGITUDINAL STABILITY OF A TILT-WING V/STOL AIRCRAFT AND CORRELATION WITH MODEL FLIGHT TESTS, J.R. Chambers and S.B. Grafton, NASA TN D-4344, February 1968. Calculations were made for the initial condition of steady level flight at wing incidences corresponding to speeds ranging from hovering to conventional forward flight. The results were compared with qualitative measurements of dynamic stability obtained during free-flight tests of a 1/9-scale model. (linear and small perturbation)

I.6.4.2 ESTIMATED FLYING QUALITIES OF THE KAMAN K-16B VTOL/STOL AIRCRAFT, PART II, DYNAMIC STABILITY IN TRANSITIONAL FLIGHT, J. Zon, N. Giansante, J.E. Fitzpatrick, November 1959.

See also, I.2.1.5, .12, .15, I.2.4.1, I.6.1.3 and II.6.4.8

I.6.5 Handling Qualities and Criteria -

I.6.5.1 ESTIMATION OF MINIMUM FIELD REQUIREMENTS OF TWO OVERLOADED, PROPELLER-DRIVEN, TILT-WING VTOL AIRCRAFT (INCLUDING THE EFFECTS OF FLAP SETTING, RUNWAY SURFACE, WIND, WING TILT RATE AND FLAP BOUNDARY LAYER CONTROL), NRC LR-373 National Research Council, Canada, National Aeronautical Establishment, January 1963.
Minimum takeoff and landing distances are calculated for two overloaded, propeller-driven, tilt-wing VTOL aircraft. The boundary layer control are considered at various thrust-to-weight ratios. It appears that takeoff to and landing from a 50-foot obstacle can be achieved in 400 feet at an all-up-weight 60 percent greater than the VTO all-up-weight.

I.6.5.2 THE AERODYNAMIC APPROACH TO IMPROVED FLYING QUALITIES OF TILT-WING AIRCRAFT, J.F. Martin and O.E. Michaelsen, AIAA, Canadian Aero and Space Inst. and Royal Aeron. Society Anglo-American Conference, October 16-18, 1963.
Examination of aerodynamic and control system problems associated with tilt-wing V/STOL aircraft in hovering and transition. Among the areas discussed is longitudinal flight, in terms of the control of flow separation up to high angles of attack, the minimization of out of trim pitching moment, and the provision of an adequate and satisfactory control system.

I.6.5.3 A SIMULATOR STUDY OF TILT-WING HANDLING QUALITIES, Harry T. Breul, Grumman Aircraft Eng. Corp., March 1963.
An experimental investigation was performed to study handling qualities of tilt-wing type VTOL aircraft. A flight simulator consisting of a cockpit free to pitch and roll, and on optical motion in the remaining 4 degrees of freedom was employed in this program. Control sensitivity and rate damping requirements about each axis at hover were investigated relative to the performance of manuevering tasks that require, in general, more positive control applications than trimming and more finely coordinated multiple control utilization than single degree of freedom move and stop maneuvers. That handling qualities requirements depend upon the maneuver

I.6.5.3 (continued)

in later sophistication is clearly suggested by comparing the results of present study and published NASA data representing the extremes in time characteristics, as well as control aerodynamic rate, and gyroscopic coupling effects were also investigated at hover. The results of the control response-time variations are most interesting, for they suggest that the criterion upon which present helicopter specifications are based (i.e., time to reach proper direction of acceleration) is inadequate.

See also, I.6.4.2

I.6.6 Testing -

I.6.6.1 WIND TUNNEL TEST CONSIDERATIONS UNIQUE TO V/STOL AIRCRAFT, E.L. Black, SAE Paper 680303.
Test experience with models of XC-142 airplane in a variety of wind tunnels and the Princeton University track facility led to a number of conclusions relative (but not restricted) to the testing of tilt-wing V/STOL aircraft. The conclusions include:

(i) Model weight should be minimized

(ii) Accurate determination of propulsion system characteristics requires superior instrumentation

(iii) Classical wall effect corrections are inadequate at high lift and there are conditions (at high lift) where the tunnel flow degenerates to a flow that does not correspond to any "free air" condition

(iv) It is very difficult to measure the working section dynamic pressure

I.6.7 General -

I.6.7.1 IAS Preprint
EXAMINATION OF SOME OF THE PROBLEMS INVOLVED IN THE DESIGN OF PROPELLER-DRIVEN VERTICAL TAKEOFF TRANSPORT AIRPLANES, M.O. McKinney et al.

See also I.6.5.2 and I.2.7.3

I.7 JET LIFT

I.7.1 Forces and Moments

I.7.1.1 THE STATIC PRESSURE DISTRIBUTION AROUND A CIRCULAR JET EXHAUSTING NORMALLY FROM A PLANE WALL INTO AN AIRSTREAM, L.J.S.Bradbury and M.N. Wood, CP 822, 1965.

I.7.1.2 TRANSVERSE JET EXPERIMENTS AND THEORIES - A SURVEY OF THE LITERATURE, D.J. Spring, T.A. Street, J.L. Amick, June 1967.
This report is a survey and review of the work that has been done concerning the use of transverse jets as a control device. Comparisons are made within the report of theories available to predict forces and moments. Tables of the experimental data for flat plates, bodies of revolution, and theories have been constructed for further clarification of the material within the report.

I.7.1.3 ANALYSIS OF A JET IN A SUBSONIC GROSSWIND, NASA SP 218, September 1969. Papers presented at a symposium held at Langley Research Center, September 9-10, 1969.

I.7.1.4 PRESSURE DISTRIBUTION ON A RECTANGULAR WING WITH A JET EXHAUSTING NORMALLY INTO AN AIRSTREAM, P.T. Wooler, G.H. Burghart and J.T. Gallagher, Journal of Aircraft, Vol.4 No.6, November-December 1967.
The interaction between a jet exhausting normally from a lifting surface into a uniform airstream was explored theoretically and experimentally. A theoretical model of the flow was discussed in which the entrainment of the mainstream fluid by the jet is accounted for. Making use of the observation that the jet deforms from a circular cross section into an elliptical cross section as it progresses downstream, the continuity and momentum equations are solved to provide the jet path. The velocity field induced by the jet is then determined by raplacing the jet by a sink-doublet distribution. The distribution of sinks represents the entrainment effect of the jet, and the doublet distribution represents the blockage effect of thejet. Lifting surface theory is used to predict the loading on the adjacent lifting surface. There is good agreement between

I.7.1.4 (continued)
theory and the results of an experiment conducted on a 10% thick straight wing at AR=3.

See also I.5.1.3 and .11

I.7.2 Flow Fields -

I.7.2.1 ANALYSIS OF THE FLOW FIELD OF A JET IN A SUBSONIC CROSSWIND, R.J. Margason, SP-228 NASA.
Uses a vortex lattice model to represent jet surface. Describes blockage due to jet, separation of free stream, roll up of jet into two discrete vortices and entrainment of free stream by jet. Describes two methods of calculating pressure distribution on flat plate situated at jet exit and shows comparison with a small amount of test data. Notes lack of systematic experimental data for comparison.

I.7.2.2 PROBLEMS OF AIR INTAKES IN VERTICAL TAKEOFF AIRCRAFT WITH JL-ENGINES (DIE PROELEME DER LUFTEIN LAUFE BEI SENKRECHTSTARTFLUGZEUGEN MIT TL-TRIEBWERKEN), H. Langfelder, Entwicklungering Sud. Munich, September 1963. (EWR-88-63).
For both lifting engines and lift-cruise engines the air intake of vertical takeoff aircraft must satisfy special demands, since extreme operating conditions arise during takeoff and landing. The lifting engine intakes of the VJ101C are described, and their performance is illustrated by means of wind-tunnel measurements. Also, the interference effect of the exhaust jets at the starting of the engine during flight is discussed in connection with the intake pressure recovery. The intake of the pivoting nacelle of the VJ101C in the slow flying range, particularly at large angles-of attack, has an additional auxiliary slit which supplies the engine with sufficient air. A survey is given of the amount of developmental work conducted on the air intake of th VJ101C as an estimate of the even greater work expenditure required for vertical takeoff aircraft.

I.7.2.3 VISCOUS AND FORWARD SPEED EFFECTS ON UNBALANCED JETS IN GROUND PROXIMITY, C.C. Hsu, Hydronautics, Inc., Laurel, Md., Ft. Eustis, Va., Army Transportation Res. Command, October 1963, (TRECOM-TR 63-60; Techn, Report [illegible] 426178).
A previous report presented a theory which included the effects of viscosity on a two-dimensional wall jet. The theory was found to be adequate for the hovering mode. This report extends the theory to include the cases of forward velocity and small angular displacements in hover.

I.7.2.4 ANALYSIS OF A JET IN A SUBSONIC CROSSWIND, A symposium held at Langley Research Center, Hampton, Va., NASA SP-218, September 9-10, 1969.

I.7.2.5 THE PATH OF A JET DIRECTED AT LARGE ANGLES TO A SUBSONIC FREE STREAM, R. J. Margason, NASA TN D-4619, November 1968.

I.7.2.6 RESEARCH ON THE GROUND EFFECT OF JET LIFT V/STOL AIRPLANES, Flugszeugen-Literaturbericht - E. Schwantes, DLR Mitt 68-28, December 1968.

I.7.2.7 A CONTRIBUTION TO THE DESIGN OF INLETS FOR LIFTING ENGINES, (Beitrag zur Gestaltung Von Einlaufen Fuer Hubtriebwerke), J. Barche, April 1968.
A method is proposed for the calculation of inlets of lifting engines. This method is based on the determination of plane constant pressure contours which are determined by means of hodograph mapping and extended to the three-dimensional inlet by a simple interpolation formula. Experiments have shown that such inlets are absolutely practicable.

I.7.2.8 EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS OF JETS EXHAUSTING INTO A DEFLECTING STREAM, D.K. Mosher, J.C. Wu, M.A. Wright, Georgia Institute of Technology, Atlanta, 1969 (Also J. Aircraft Vol.7, NO. 1, January-February 1970)
A circular jet issuing normally from an infinite flat plate into a deflecting stream is treated by the use of a potential flow model which represents the flow field surrounding the jet, exclusive of the wake. The results indicate that the entrainment of deflecting-stream fluid into the jet is important in determining the plate pressure and that, for the case where the jet speed is much higher than the deflecting-stream speed, it is possible to use a two-dimensional representation. The calculated plate pressure distribution is compared with results of experiments. Experimental results (flow visualization, plate pressure, and velocity measurements) are presented for circular as well as non-circular jets exhausting at various jet velocities from a large flat plate. Results indicate that a stream-wise jet exit configuration is desirable.

I.7.2.9 A REVIEW OF JET EFFLUX STUDIES APPLICABLE TO V/STOL AIRCRAFT, J.E. Garner, AEDC TR 67-163, September 1967.
The state-of-the-art of jets exhausting into a subsonic crossflow is presented. These studies complement the current research effort in development of an analytical description of the flow field created by a V/STOL aircraft.

I.7.2.10 SIMULATION OF JET ENTRAINMENT IN A POTENTIAL FIELD, R.J. Schulz, AEDC TR-67-217, November 1967.
The purpose of this report is to establish an analytical method of simulating a three-dimensional, entraining jet which exhausts into a low velocity cross wind from a finite planar surface, so that the surrounding flow field may be calculated. The jet is simulated by a square cylinder constructed from a lattice network of bound horseshoe vortices. The entrainment simulation is accomplished by establishing a set of boundary conditions for the vortices which result in a desired inflow rate normal to the square cylinder defining the jet. Results are presented which show the effect of entrainment on the surrounding potential flow field. The conclusion is drawn that this method could be a powerful tool with which to obtain the potential flow field about V/STOL configurations. The method cannot simulate the viscous effects of the jet on the surrounding flow field other than entrainment.

I.7.2.11 THEORETICAL AND EXPERIMENTAL STUDIES OF IMPINGING UNIFORM JETS, W.G. Brady and G.R. Ludwig, Cornell Aeronautical Laboratory, BB-1657-S1 TRECOM TR63-11 April 1963.
A theoretical and experimental study was conducted to investigate the flow characteristics of circular uniform jets impinging normally on a ground plane in order to further the understanding of the aerodynamic processes associated with ground particle entrainment in the impinging downwash of VTOL aircraft. Particular emphasis was placed on the flow properties in the ground-plane boundary layer where entrainment occurs.

I.7.2.12 AERODYNAMIC INTERFERENCE EFFECTS WITH JET-LIFT SCHEMES ON V/STOL AIRCRAFT AT FORWARD SPEED, J. Williams and M.N. Wood, Aerodynamics of Power Plant Installation, AGARDograph, 1965.
The nature and magnitude of aerodynamic interference effects which can arise with jet and fan lift schemes for V/STOL aircraft were considered, particularly as regards possible adverse flows induced around the airframe by the jet (or fan) efflux during aircraft transition to and from purely wing-borne flight. The discussion was based mainly on aerodynamic research at R.A.E. and concentrates on the understanding and analysis for major features, rather than on optimization of specific aircraft layouts. The paper is primarily VTOL oriented.

I.7.2.13 AERODYNAMIC INTERFERENCE EFFECTS WITH JET-LIFT V/STOL AIRCRAFT UNDER STATIC AND FORWARD SPEED CONDITIONS, J. Williams, M. Wood, Royal Aircraft Establishment, Report No. RAE-TR-66403, December 1966.
The nature and magnitude of aerodynamic interference effects which can arise with jet and fan-lift schemes for V/STOL aircraft were considered. Particular attention was paid to adverse flows which can be induced around the airframe by the jet (or fan) efflux during VTOL operation near ground and during aircraft transition to and from purely wing-borne flight. The discussion concentrated on the understanding and analysis of major aerodynamic features with illustrations mainly from R.A.E. Research Work.

I.7.2.14 THE DEVELOPMENT OF INJECTOR UNITS FOR JET-LIFT ENGINE SIMULATION ON LOW-SPEED-TUNNEL MODELS, M. Wood and J.B. Howard, February 1965.
Discussed ejector units for engine simulation. Concluded that the absolute minimum requirements for engine simulation at model scale were: (1) scaled exit geometry; (2) correct exit momentum coefficient; (3) correct intake location (but not necessarily exact representation of intake geometry); (4) correct intake mass-flow coefficient.

I.7.2.15 SURVEY OF THE GROUND EFFECT ON V/STOL AIRCRAFT WITH JET PROPULSION-REPORT OF LITERATURE, E. Schwantes, NASA TT F-12, 573, October 1969.
A tabular survey was presented of the results of 132 reports on the ground effects with jet lift V/STOL aircraft. The region of the deflected jet investigated was described and the test conditions compared.

I.7.2.16 INVESTIGATION OF THE DOWNWASH ENVIRONMENTAL GENERATED BY V/STOL AIRCRAFT OPERATING IN GROUND EFFECT, M. George, F. Kisielowski, and D.S. Douglas, USAAVLABS Technical Report 68-52, July 1968.
Analytical methods were developed for determining the downwash environment generated by multi-propeller V/STOL aircraft operating in ground effect. These methods were used to compute flow fields and dust cloud characteristics for the XC-142, X-22A, X-19A, and XV-5A. It was determined that additional full-scale test data are required to verify the theory.

See also, I.7.1.1, .2, .3, .4, .5, .6, .7 and I.5.2.3.4.

I.7.3 Ground Effect

See also, I.7.1.3, I.7.2.6, I.7.2.12 and I.7.2.18, I.7.2.19.

I.7.4 <u>Stability and Control</u>

See I.7.1.3 and I.5.1.11.

I.7.5 <u>Handling Qualities and Criteria</u>

I.7.5.1 EFFECT OF SIZE ON VTOL AIRCRAFT HOVER AND LOW SPEED HANDLING QUALITIES, J. F. Johnston and C. F. Friend, New York, American Helicopter Society, Inc., 1965, p. 1-133 to 1-150.

A fundamental investigation of the effect of size on VTOL aircraft hover and low-speed handling qualities is presented. Both helicopter and jet VTOL are treated. Formulas for determination of size effects (with size referred to a characteristic linear dimension) on VTOL vehicle handling qualities capabilities are developed through dimensional analyses. Hypotheses are drawn regarding effect of size on pilot-vehicle compatibility. Some of these pertinent handling quality capability size relationships for similar VTOL vehicles are summarized as follows. Similar VTOL vehicles are defined as those geometrically similar configurations with constant total thrust/weight. The thrust/weight available for control of jet VTOL vehicles is also considered to be invariant with size. Although thrust/weight can be varied with size, this would effect changes in vehicle performance and weight, with aircraft having revised constants of proportionality effecting basic trends only slightly. Capability is defined as the inherent flight handling ability of the vehicle without regard to whether such capabilities are consistent with flight handling requirements.

I.7.6 <u>Testing</u>

I.7.6.1 SOME NOTES ON UNITED KINGDOM EXPERIENCE IN THE TESTING OF VTOL AIRCRAFT, R.T. Shield, AGARD Report 318, April 1961.
Experience to date in the flight testing of VTOL aircraft in the United Kingdom is reviewed. Methods employed in the testing of three aircraft, the Rolls-Royce "Flying Bedstead", Short SC.1, and Hawker P.1127, are considered.

I.7.6.2 JET V/STOL AIRCRAFT AERODYNAMICS, by M. N. Wood.

See also I.7.2.17.

I.7.7 General

I.7.7.1 EFFECTS OF AIRFRAME AND POWERPLANT CONFIGURATION ON V/STOL PERFORMANCE, R.F. Creasey, N.W. Boorer, R. Dickson, AGARD, in AGARDgraph 89 "V/STOL Aircraft", Part I, Sept. 1964, 185-221p.
This paper discusses the large range of layouts that have been studied in relation to both strike and transport V/STOL requirements. The effects on performance of different powerplant arrangements are presented, taking account of the structural and aerodynamic effects on the airframe, which have been brought out by extensive design studies. The effects of changes in wing planform are shown, including the advantages of variable sweep wings, particularly for supersonic STOL designs or where overloading of a supersonic VTOL design is a frequent operational necessity. The complex interactions between the powerplant airflows and the normal lifting effects of the airframe have a considerable effect on performance and are therefore being studied extensively in the British Aircraft Corporation V/STOL test facility. Typical results are presented for a variety of airframe/powerplant combinations. The inevitable performance penalty of VTOL is discussed, leading to the concept of a freighter/platform VTOL aircraft supporting a strike aircraft, which therefore does not suffer the built-in VTOL penalty.

I.7.7.2 LIFT-JET TECHNOLOGY, L.P. Greene and W.E. Cotter Astron. and Aeron. Vol. 3, September 1965, p. 42-45.
Integration of powerplants and airframe to obtain good thrust-to-weight ratio. Comparative safety of operation and system cost effectiveness are considered to be still subject to evaluation. Some lift technology problems encountered in the attempt to develop practical air vehicles are examined, and recent advances in knowledge of aerodynamic phenomena are required. The lift-jet systems discussed are restricted to disk loadings greater than 200 lb/ft^2. Two areas of importance stand out because they directly effect the effective thrust-to-weight ratio: interference effects, specifically as seen in powerplant/airframe integration, and the secondary benefits arising from an effective solution of this integration problem in terms of reduced system weights, landing gear, and structural

I.7.7.2 (continued)
simplicity. It is said that significant gains can be made in these areas without basic propulsion improvements.

I.8 GENERAL

I.8.1 Forces and Moments

I.8.1.1 ON THE LIFT AND INDUCED DRAG ASSOCIATED WITH LARGE DOWNWASH ANGLES, H.S. Ribner, UTIA TN No. 19, January 1958.
The lift and induced drag have been evaluated for an arbitrary wing-wake vortex pattern, with large downwash, via a momentum balance. The entire induction effect of the wake is found to be representable as a "generalized induced drag" vector parallel to the asymptotic trailing vortex direction. The vertical component of this drag constitutes a nonlinear contribution to lift. A possible similar behaviour of the parasite drag is indicated. The Jones low aspect ratio wing theory has been reformulated to apply to large angles of attack.

I.8.1.2 WING LIFT AUGMENTATION METHODS FOR THE IMPROVEMENT OF THE LOW SPEED PERFORMANCE OF HIGH SPEED AIRCRAFT, J.S. Attinello, SAE Preprint.

I.8.1.3 SUMMARY OF WIND TUNNEL DATA FOR HIGH-LIFT DEVICES ON SWEPT WINGS, H.O. Palme, SAAB Technical Note 16 (April 1953, published 1954).
Based on a recapitulation of the known aerodynamic characteristics of profiles with high-lift devices a mainly statistical analysis is made of these devices on swept-back wings. It is shown that large aspect ratio variations have very little effect on the effectiveness of the devices. The influence of sweepback, and of the span of the device, is on the other hand large. An approximate method for calculating the lift at a given angle of attack for wings with flaps is given.

I.8.1.4 METHOD FOR CALCULATING LIFT DISTRIBUTIONS FOR UNSWEPT WINGS WITH FLAPS OR AILERONS BY USE OF NONLINEAR SECTION LIFT DATA, J.C. Sivells and G.C. Westrick, NACA Report 1090, 1952.
A method is presented for calculating lift distributions for unswept wings with flaps or ailerons using nonlinear section lift data. This method is based upon lifting line theory and is an extension to the method described in NACA Report 865. Simplified computing forms containing detailed examples are given for both symmetrical and asymmetrical lift distributions. A few comparisons of experimental and calculated characteristics are also presented.

I.8.1.5 MAXIMUM LIFT FOR LANDING OF SWEPT WING AEROPLANES, H.O. Palme, SAAB Technical Note 17 (April 1953, published 1954).
Based on experiences gained in flight tests of swept-wing aeroplanes, a discussion is made of possible methods for determining from wind tunnel tests the maximum obtainable lift coefficient for landing. This is found to be difficult since the dynamic effects experienced in actual flight are not present in the wind tunnel; however, an approximate calculation of obtainable lift for landing is carried through for swept-wing aeroplanes with various wing plan forms. In connection with this, various methods for prevention of tip stall are discussed.

I.8.1.6 MODULATED THRUST TO IMPROVE STOL AIRCRAFT PERFORMANCE (A FLIGHT TEST EVALUATION), G.W. Johnston, AGARD, in AGARDograph 89 "V/STOL Aircraft", Part I, September 1964, 419-448.
Direct improvements result from the combined section of the deflected slipstream and reverse jet combination including the important interference effects possible with certain aircraft layouts. Achievable improvements based on model and full-scale measurements are given. Indirect operational improvements are associated with the provision of an additional powerful landing control, which complements normal elevator control. The scope of such improvements is indicated clearly from the results of the landing trials performed with the experimental aircraft. These results are also reviewed. The integration of this concept with the lift augmentation obtained by means of flap boundary layer control and the existence of inherent limitations at increased values of auxiliary thrust-to-weight ratios are briefly discussed. The test aircraft, employing slipstream deflection with in-flight reverse thrust, consistently attains total landing distances from 50 ft. or less than 500 ft. in standard atmosphere at a wing loading of 23 lb/ft^2. This compares with a performance level of approximately 1,000 ft. in the unmodified configuration at the same wing loading.

I.8.1.7 METHODS OF PRODUCING HIGH LIFT (METHODEN VOOR DRAGGKRACHTVERGROTING), A.C. deKock, J. Yif and J.A. Zaat, National Lucht-en Rutmtevaartlaboratorium, NLL-IF, 210, 47p.

I.8.1.7 (continued)
A literature survey of high lift aids which can be used for reducing takeoff and landing distances is given. Consecutively the various means for obtaining high lift, such as profile geometry, flaps and slats, suction and blowing, supercirculation, deflected slipstream and tilted wing and propellers, are treated. An extensive bibliography of recent publications is included and arranged to subject.

I.8.1.8 A THEORETICAL INVESTIGATION OF VORTEX-SHEET DEFORMATION BEHIND A HIGHLY LOADED WING AND ITS EFFECT ON LIFT, C.D. Cone, Jr. Report No. NASA-TN-D-657, April 1961.
The induced drag polar is developed for wings capable of attaining extremely high loadings while possessing an elliptical distribution of circulation. This development is accomplished through a theoretical investigation of the vortex wake deformation process and the deduction of the airfoil forces from the impulse and kinetic energy contents of the ultimate wake form. The investigation shows that the induced velocities of the wake limit the maximum lift coefficient to a value of 1.94 times the wing aspect ratio, for aspect ratios equal to or less than 6.5, and that the section properties of the airfoil limit the lift coefficient to 12.6 for aspect ratios greater than 6.5. Relations are developed for the rate of deformation of the vortex wake. It is also shown that linear wing theory is applicable up to lift coefficients equal to 1.1 times the aspect ratio.

I.8.1.9 NEW RESULTS IN INFLUENCING LIFT OF WINGS, Report No. ES083, A. Betz, September 1952.

I.8.1.10 THRUST AUGMENTATION CONSIDERATIONS FOR STOL AND EXTENDED CRUISE PROPULSION, W.S. Campbell, Aerospace Research Labs, WPAFB, ARL-69-0182, November 1969.
The application of thrust augmentation concepts to short takeoff and landing (STOL) aircraft propulsion is described for some typical installations. Aerodynamic and ejector thrust effects are treated separately so that the performance of the ejector-powered wing can be calculated as that of a jet-flapped airfoil and the ejector thrust components then added. Some considerations on the performance

I.8.1.10 (continued)
of the ejector-powered wing in cruise are included. A program for ejector calculations is given.

I.8.1.11 THE THEORY OF THE HIGHLY LOADED FINITE SPAN WING, H.B. Helmbold, Fairchild Aircraft Report RR-35, September 1956.
For wings with high C_L (of the order of 4π) Helmbold indicates that the undeformed wake assumption of Prandtl's lifting line theory is violated. Relationship between C_L and C_{D_i} is developed which degenerates to $C_{D_i} = C_L^2/\pi A$ for the case of vanishingly small downwash.

I.8.1.12 LIMITATIONS OF CIRCULATION LIFT, H.B. Helmbold, JAS, Vol. 24, No. 3, 1957.
The author deals theoretically with the limitations of circulation lift based on the following considerations. With a spanwise elliptic distribution of circulation, the trailing-vortex system far downstream of the wing will move like a rigid flat strip, provided that its cross section is hypothetically endowed with the ability to resist the deforming stress of the pressure field. If now the cross-sectional rigidity is instantaneously destroyed and the sheet is left free to yield to the deforming stresses of the pressure field, the sheet will start rolling itself in from its side edges.

I.8.1.13 A FURTHER DISCUSSION OF THE LIMITING CIRCULATORY LIFT OF A FINITE-SPAN WING, F.J. Davenport, J. Aero/Space Sc., Vol. 27, No. 12, December 1960.
The jet flap's ability to generate extremely large circulation lift coefficients has led to the exploration of limitations to circulation lift inherent in the nature of the finite-span vortex system, which are discussed here.

I.8.1.14 FURTHER COMMENTS ON 'LIMITING CIRCULATORY LIFT OF A WING OF FINITE ASPECT RATIO'. H.S. Ribner, J. Aero/Space Sc., Vol. 27, No. 6, June 1960.
In this brief note is pointed out that for the case where the wake rolls up into a vortex pair, the limiting circulatory lift is higher than for the case of a planar ultimate wake.

I.8.1.15 THE LIMITING CIRCULATORY LIFT OF A WING OF FINITE ASPECT RATIO, B.W. McCormick, J. Aero Sp. Sc., Vol. 26, No. 4, April 1959.
Analytical study which shows that the maximum lift of a finite wing due to circulation, produced by any means whatever (suction boundary-layer control, blowing boundary-layer control jet-flaps, ordinary flaps) increases linearly with increasing aspect ratio.

I.8.2 Flow Fields

I.8.2.1 SOME EFFECTS OF SHED VORTICES ON THE FLOW FIELDS AROUND STABILIZING TAIL SURFACES, R.W. Stone and E.C. Polhamus, AGARD Report 108, April-May 1957. A brief study is made of the effects of vortices shed primarily from bodies on the flow angularities in the regions of stabilizing tail surfaces.

I.8.2.2 A POTENTIAL FLOW MODEL FOR THE FLOW ABOUT A NACELLE WITH JET, A.H. Craven, C. of A. Report No. 101. The inviscid incompressible flow round a thin nacelle from which a jet is issuing is considered. It is shown that the inhomogeneous motion can be trans-formed into an equivalent homogeneous motion which may be represented by two semi-infinite distributions of vortices in the two-dimensional case and by a semi-infinite distribution of circular vortex rings in the axi-symmetric case.

I.8.2.3 CONTRIBUTION A L'ETUDE DE L'EFFET DE PARIO EN ECOULEMENT PLAN INCOMPRESSIBLE, J. Barbieux, Pub. Sc. et Tech. No. 304, 1955.

I.8.2.4 PREDICTION OF DOWNWASH BEHIND SWEPT-WING AIRPLANES AT SUBSONIC SPEED, J. DeYoung and W.H. Barling, NACA TN 3346, January 1955.
The numerical integration method presented enables a rapid prediction of downwash. The principal effects of the rolling-up of the wake are treated as corrections to the flat-sheet wake. A simple approximate correction for the effect of the fuselage is applied. Computing forms and charts of pertinent functions are included. Agreement with available experimental data is good.

I.8.2.5 POTENTIAL FLOW SOLUTIONS FOR INLETS OF VTOL LIFT FANS AND ENGINES, N.O. Stodeman, NASA SP-228. Incompressible potential flow method for calculating surface velocity distribution at engine inlets in static and cross flow conditions.

Based on Douglas' incompressible potential flow computer program for axi-symmetric bodies represented by sources and sinks. Integral equation for source distribution is approximated by a set of algebraic equations at points on the body and solved by matrix method.

I.8.2.5 (continued)
Includes comparison with some test data. Doubtful accuracy for non-axi-symmetric case like fan-in-wing.

I.8.2.6 THRUST DEFLECTION BY MEANS OF SPOILERS FOR DUAL-FLOW ENGINES (STRAHLABLENKUNG AN ZWEIKREISTRIEBWERKEN DURCH SPOILER), W. Seibold, (WGLR) October 12, 1962.
Theoretical and experimental investigation of the effectiveness of solid and pneumatic spoilers in deflecting the thrust of bypass engines, with particular reference to lifting thrust at takeoff analytical results for perpendicular spoilers in plane flow, 45°-spoilers in plane flow, air-cooled vertical spoilers, and thrust deflection by lateral blowing are presented in the form of diagrams.
The effectiveness of thrust deflection is examined as a function of engine design and mode of operation.

I.8.2.7 VISCOUS AND FORWARD SPEED EFFECTS ON UNBALANCED JETS IN GROUND PROXIMITY, C.C. Hsu, Hydronautics Inc., Laurel, Md., Ft. Eustis, Va. Army Transportation Res. Command, October 1963, 42p. (TRECOM-TR-63-60; Techn. Rept. 24-2; AD-426178).
A previous report presented a theory which included the effects of viscosity on a two-dimensional wall jet. The theory was found to be adequate for the hovering mode. This report extends the theory to include the cases of forward velocity and small angular displacements in hover.

I.8.2.8 GROUND EFFECTS ON V/STOL AND STOL AIRCRAFT, R.E. Kuhn, National Aeronautics & Space Admin., Langley Research Center, Langley Station, Va. in NASA, Wash. Conf. on Aircraft Operating Probl, 1965, p. 287-298.
Ground effects on V/STOL and STOL aircraft arise from the fact that these aircraft support themselves by deflecting air downward flow with attendant effects on both the ground and the aircraft. The effects of self-generated turbulence will not be serious if adequate control is provided, and this annoyance to the pilot can be reduced by providing artificial damping. The avoidance of ground-erosion damage involves proper preparation and housekeeping of the landing site for high-disk-loading vehicles and proper operating procedures to avoid running into debris. Research is still in progress to obtain a better understanding of hot-gas ingestion and means of reducing it.

I.8.2.9 EMPIRICALLY DETERMINED WIND AND SCALE EFFECT ON HOT GAS RECIRCULATION CHARACTERISTICS OF JET V/STOL AIRCRAFT, P.E. Ryan and W.J. Cosgrove, NASA CR-1445, October 1969.

I.8.2.10 A PROPOSED AIRCRAFT LIFT/THRUST POWER PLANT ARRANGEMENT, National Research Council of Canada, Ottawa, (Ontario) Div. of Mechanical Engineering, R. A. Tyler, December 1960.
A description is given of an aircraft power plant arrangement of the turbofan type. Research efforts were centered on commercial and civil applications of VTOL. A suitable engine system should satisfy these requirements: (1) an acceptable margin of safety at takeoff and landing, (2) the ability to provide the large thrust or lift required for STOL or VTOL takeoff without undue penalty in weight and fuel economy when cruising, (3) mechanical simplicity and reliability, (4) low overall specific weight, (5) low development and first costs, (6) low noise level, (7) ease of mechanical operation in transition from vertical to normal level flight, (8) absence of adverse aerodynamic effects during transition, and (9) absence of hot high velocity downward directed jets during the lifting phase.

I.8.2.11 A THEORY OF WING-PROPULSION COMBINATIONS IN SLOW FLIGHT, R.J. Vidal, Cornell Aeronautical Laboratory, Inc., CAL Report No. AI-1190-A-1, September 1959.
The development of a theory treating wing-propulsion systems in slow flight is presented. This development is applied to a class of configurations, characterized by wing and propulsion wakes which are equal in span, and is used to predict the performance of this class of aircraft. It is concluded that for aircraft of equal span, those generating thick propulsion wakes require the least power, and that configurations typified by thin jet wakes are inherently inefficient as regards power consumption in the very slow speed range. The theory is compared with the available helicopter data, and good correlation is obtained.

I.8.2.12 STUDY OF THE VORTEX SHEET IMMEDIATELY BEHIND AN AIRCRAFT WING (PENNSYLVANIA STATE UNIVERSITY STUDY), B.W. McCormick and J.L. Tangler, Report 4446-1, Army Research Office-Durham, December 1965.
Investigates sheet thickness, size of vortex core, and rate at which sheet rolls up as function of lift coefficient.

I.8.2.13 REVIEW OF PROPULSION-INDUCED EFFECTS ON AERODYNAMICS OF JET V/STOL AIRCRAFT, R.J. Margason, NASA TN D-5617, February 1970.
This paper reviews several aspects of the effects induced on the aerodynamics of V/STOL aircraft in hover and transition flight by the interference of wakes from relatively high disk-loading propulsion devices. Four problem areas are treated: (1) the performance losses sustained when hovering out of ground effect, (2) induced aerodynamic effects in transition flight out of ground effect, (3) the problems caused by hot-gas ingestion, and (4) the effects induced on performance during hover in ground effect. Some of the conflicts among the design requirements imposed by these different modes of flight are discussed, along with the present state-of-the-art of solutions to some of the problems.

I.8.2.14 STRUCTURE OF TRAILING VORTICES, B.W. McCormick, J.L. Tangler and H.E. Sherrieb, Journal of Aircraft, Vol. 5, No. 3, May-June 1968, pp. 260-267.
A study of aircraft trailing vortex systems, involving flight testing of a U.S. Army O-land a Peper Cherokee, as well as model testing and analytical considerations, resulted in a method for predicting the vortex geometry and velocity field downstream of an aircraft. It was found that the vortex decay could be described by geometric similarity considerations. This conclusion was based on detailed velocity measurements made through the vortex immediately behind a test aircraft up to distances of approximately 1000 chord lengths downstream of the aircraft. A presentation of the data on which the conclusions were based, as well as description of test equipment and procedures are included.

I.8.2.15 JET CIRCULATION EFFECTS ON V/STOL AIRCRAFT, M. Cox and W.A. Abbott, Journal of Sound and Vibration, Vol. 3, No. 3, 1966, pp. 393-406.
Gases from the jets of lifting engines may be recirculated to the engine intakes and cause a loss of thrust. Model tests with heated jets were made to provide data on velocities in the jet around the impingement region and to assist the correlation of model and full-scale measurements. Vertical and inclined jets were studied under steady and transient conditions during the initial establishment of the wall jet flow and the relationship between these two cases is given.

I.8.2.15 (continued)
Tests with jets from nozzles moving over the ground showed that the distance the wall jet travels before being turned back by the relative wind may be obtained from measurements with stationary jets.

Experiments with heated jets showed that a parameter including the initial dynamic pressure and the temperature of the jet may be used to correlate the vertical penetration of a free jet and the lateral extent of an impinging jet to the point where it separates from the ground due to buoyancy effects.

I.8.2.16 VORTEX WAKES BEHIND HIGH-LIFT WINGS, J.E. Hackett and M.R. Evans, AIAA Paper 69-740, July 1969.
A classical unsteady treatment in the cross-flow plane, which calculates the roll-up of an initial span-wise row of point vortices, was modified to allow for the influence of the wing. Additional meaning is thereby given to the streamwise length dimension and hence to aspect ratio and sweep.

The effects of height-above-ground and of various tunnel heights and widths were discussed. Under certain limited conditions, notably with part-span flaps or too narrow a tunnel, part or all of the trailing vortex system may move upwards. Consequent changes in the vertical velocity field were additional to conventional estimates involving only the appropriate image system.

I.8.2.17 AN ANALYTICAL METHOD OF DETERMINING GENERAL DOWNWASH FLOW FIELD PARAMETERS FOR V/STOL AIRCRAFT, D.J. Hohler, Report No. AFAPL-TR-66-90, November 1966. Air Force Aero Propulsion Lab.
Presented a method of analytically determining the general downwash flow field parameters of various types of V/STOL aircraft. V/STOL aircraft produce high downwash air velocities that impinge and spread out over the surface of the ground. Depending on the size, type, and number of engines on the aircraft, this downwash can cause damage to nearby aircraft, equipment, or personnel. Past theoretical methods based on incompressible flow theory have been unsuccessful in establishing a means of computing this downwash flow field. A combined method, of experimental data and certain analytical approaches yielded a means of predicting the general downwash flow field parameters.

I.8.2.18 A REVIEW OF JET EFFLUX APPLICABLE TO V/STOL AIRCRAFT, J.E. Garner, Arnold Engineering Development Center, AEDC-TR-67-163, September 1967.
A state-of-the-art summary of jets exhausting into a subsonic crossflow is presented.

I.8.2.19 SIMPLIFIED APPROXIMATIONS OF INTERFERENCE EFFECTS ON JET V/STOL AIRCRAFT, D.T. Archino, Air Force Institute of Technology Thesis GAM/AE/68-2, March 1968.
A semi-empirical method was developed to predict lift loss and pitching moments caused by interference effects on aircraft in hover and transition. The induced flow in hover was superimposed on the free stream to determine interference effects during transition.

I.8.2.20 RECENT DEVELOPMENTS IN THE METHOD OF THE RHEOELECTRIC ANALOGY APPLIED TO AERODYNAMICS, L. Malavard, JAS, Vol. 24, May 1957.
Rheoelectric analogies can be employed either as a means for the graphical representation of a theoretical flow field or as a procedure for calculating aerodynamic characteristics. The following recent applications, corresponding to these two aspects, are discussed: (1) a simple method for the direct plotting of isogradient and isoargument lines of a plane harmonic field; (2) interpretation by electrical analogy of a linearized theory of a wing jet flap, and results obtained on an airfoil section; a method for studying jet flap action on a lifting surface; (3) calculation by electrical analogy of the aerodynamic characteristics of the annular wing; analog representations of various parameters (camber, thickness, conicity); and the analog model of the annular wing considered as a lifting surface.

I.8.2.21 ENGINE-AIRFRAME INTEGRATION, L.F. Nicholson, JRAS, Vol. 61, November 1957.
Discussion of the engine-airframe integration, in particular of interference between jet and airframe; problems of engine-airframe integration at high speeds; the use of the propulsive jet to augment lift; the general problem of jet lift in cruising flight; the use of the engine thrust to sustain flight at low speeds; and the jet flap.

See also, I.8.1.1, I.8.1.8.

I.8.3 Ground Effect

I.8.3.1 SOME AERODYNAMIC ASPECTS OF GROUND EFFECT, P. Poisson-Quinton and A. Bevert, SAE Preprint 508A, National Aeronautics Meeting, New York, April 1962.

I.8.3.2 INCREASE IN LIFT FOR TWO- AND THREE-DIMENSIONAL WINGS NEAR THE GROUND, R.M. Licher, Douglas Report No. SM-22615, October 1956.
The effect on the lift of a wing near the ground is approximated theoretically by replacing the ground with an image wing and by representing both real and image wings by networks of finite strength bound and trailing vortices.

I.8.3.3 GROUND EFFECTS RELATED TO LANDING OF AIRPLANES WITH LOW-ASPECT-RATIO WINGS, W.B. Kemp et al, NASA TN D3583, October 1966.
The fundamental mechanism of ground induction is reviewed and a simplified landing-flare analysis illustrates the significance of ground effects. Effects of wing planform and aircraft size are shown by use of dynamic calculations of the motion during the landing flare.

I.8.3.4 GROUND EFFECTS ON V/STOL AND STOL AIRCRAFT, R.E. Kuhn, Nat. Aeron. & Sp. Admin., Langley Research Center, Langley Station, Va., in NASA, Washington, Conference on A/C Operating Probl. 1965, p. 287-298.
Ground effects on V/STOL and STOL aircraft arise from the fact that these aircraft support themselves by deflecting air downward with attendant. effects on both the ground and the aircraft. The effects of self-generated turbulence will not be serious if adequate control is provided, and this annoyance to the pilot can be reduced by providing artificial damping. The avoidance of ground-erosion damage involves proper preparation and housekeeping of the landing site for high-disk-loading vehicles and proper operating procedures to avoid running into debris. Research is still in progress to obtain a better understanding of hot-gas ingestion and means of reducing it.

I.8.3.5 THEORETICAL ANALYSIS OF AIR FLOWS AROUND WINGS LOCATED IN THE VICINITY OF THE GROUND, Bureau d' Analyze et de Recherche Appliques, May 1962.
Using rheoelectrical analog, ground effect on lift for a Clark Y airfoil was investigated. For flap

I.8.3.5 (continued)
angles greater than 30° ground effect was unfavorable. Ground effect on an AR=2.0 rectangular wing was also investigated. Ground effect was found to be always favorable.

I.8.3.6 LITERATURE SEARCH AND COMPREHENSIVE BIBLIOGRAPHY OF WINGS IN GROUND EFFECT AND RELATED PHENOMENA, W.F. Foshag, D. Taylor, Model Basin Report 2179, March 1966.
A literature search was made of wings operating in ground effect and related phenomena. Comments are made on some of the papers included. The appendices include a discussion of the theoretical papers. A cross index was provided.

See also, I.8.2.4 and I.8.2.7.

I.8.4 Stability and Control

I.8.4.1 ESTIMATION OF STABILITY DERIVATIVES (STATE-OF-THE-ART), H.H.B.M. Thomas, CP664, 1963.
Methods for the estimation of the usual longitudinal and lateral stability derivatives of an aircraft are discussed for each derivative.

I.8.4.2 PROBLEMS OF LONGITUDINAL STABILITY BELOW MINIMUM DRAG SPEED, AND THEORY OF STABILITY UNDER CONSTRAINT, S. Neumark, R&M 2983, 1957.
Reasoning proposed in 1910 purported that flight below minimum drag speed should be fundamentally unstable, so that any speed error would lead to a divergence. This reasoning is shown to be invalid on the ground of the general theory of dynamic stability in uncontrolled flight, the criterion being a grossly inadequate approximation to the condition of phugoid stability. However, the criterion may be fully vindicated for the case of flight controlled by the elevator in such a way as to maintain constant height. The criterion also applies to the problem of ultimate height response to an elevator deflection. The concept of stability of partially controlled flight is further developed, leading to a general theory of "stability with constraint", i.e. when a control (elevator, throttle, and so on) is used to suppress one component of the disturbance.

I.8.4.3 INVESTIGATION OF LATERAL CONTROL NEAR THE STALL. ANALYSIS FOR REQUIRED LONGITUDINAL TRIM CHARACTERISTICS AND DISCUSSION OF DESIGN VARIABLES, F.E. Weick and H.N. Abramson, NACA TN 3677 (June 1956).
Analytical design procedures for estimating the elevator deflection required to trim in steady longitudinal flight are presented. Pertinent data and formulae for use in evaluating longitudinal trim characteristics are summarized from existing literature and two light aeroplanes are analyzed quantitatively to illustrate the use of the methods and to provide a comparison with flight-test results.

I.8.4.4 REVERSE THRUST, VERTICAL LIFT, AND SIDE FORCE BY MEANS OF CONTROLLED JET-DEFLECTION, L.Meyerhoff and S.A. Meyerhoff

I.8.4.5 A SYSTEM FOR VARYING THE STABILITY AND CONTROL OF A DEFLECTED-JET FIXED-WING VTOL AIRCRAFT, F.A. Pauli et al, NASA TN D-2700, March 1965.
Variable-stability modes provided are rate damping, cross-coupling cancellation, augmented pilot control, and stiffness with maneuverability cut-out.

I.8.4.6 AMERICAN DEVELOPMENT IN STOL AND VTOL AIRCRAFT, C.W. Meshier, AGARD Report 86, August 1956.
To date most research activity on aircraft has been directed towards the development of basic configurations to achieve the required performance. This paper discusses the low speed control problems of short takeoff and vertical takeoff aircraft, to which little effort had been applied until 1956.

I.8.4.7 STABILITY AND CONTROL CONSIDERATIONS FOR STOL AIRCRAFT, S.B. Anderson, H.C. Quigley, R.C. Innis, AGARD Report 504.
Reviews the experience gained in flight tests of several STOL aircraft with special reference to lift performance, limitations to low speed operation, handling qualities and test methods used to investigate stability and control characteristics. Because of generally poor lateral-directional handling qualities inherent in all the aircraft tested, stability augmentation is recommended.

I.8.4.8 SOME DYNAMIC ASPECTS OF STABILITY IN LOW-SPEED FLYING MACHINES, T.A. Dukes, J.M. Carballal and P.M. Lion, Princeton Univ., N.J., November 1963, p.59.
This report is concerned with a linear time varying approximation to the dynamics of low speed flying machines, simplifications and approximations are applied widely in order to emphasize essential aspects. The range of time variation is described in terms of frozen system loci of the roots corresponding to the predominant mode of a system. The rate of the time variation is des-ribed in terms of the deviation from the frozen system approximation. An analog computer study was made to specify quantitatively those rates of time variation which cannot be considered as slow. The longitudinal dynamics of VTOL aircraft is studied as an example in rather-general terms. Approximations and the application of root locus methods in terms of the most significant stability derivatives lead to a construction describing the behavior of the oscillatory roots during transition. The results are

I.8.4.8 (continued)
used in a discussion of the following variable feedback configurations: direct feedback adjustments, adaptive feedback, and programmed feedback adjustments.

I.8.4.9 A PRELIMINARY STUDY OF THE DYNAMIC STABILITY AND CONTROL RESPONSE DESIRED FOR V/STOL AIRCRAFT, D.R. Ellis, G.A. Carter, Princeton, Univ. N.J.
Longitudinal dynamics and control response desired for VTOL/STOL aircraft stabilized automatically.

I.8.4.10 AN ANALYSIS OF THE STICK FIXED DYNAMIC STABILITY OF A TYPICAL VTOL AIRCRAFT DURING TRANSITION FLIGHT OUT OF GROUND EFFECT, R.M. Kraft, R.W.R. Neville, Naval Postgraduate School, Monterey, Calif.,1965, 171 p.
An investigation of the dynamic stability of a typical fixed wing VTOL aircraft operating in the transition region of flight was conducted by means of analog simulation. The Ryan Aeronautical Company XV-5A lift fan research aircraft was used as a basis for the analysis. Wind tunnel tests on a simple 1:24 scale model of the aircraft provided static aerodynamic data throughout the angle-of-attack range - 90 degrees l or = alpha sub w or = +90 degrees. Non-dimensional stability derivative data was extended throughout the angle-of-attack range.

Analog simulation at relative velocities of 100, 60 and 20 knots was conducted using dimensional parameters. Recording of the simulation runs provided period, frequency, damping, and dutch roll parameter information which was analyzed to determine areas of flight instability. The variations of these parameters with both angle-of-attack and velocity is discussed. The need for automatic stabilization is indicated.

I.8.4.11 THE STEADY STATE LATERAL CONTROL EQUATIONS WITH PARTICULAR REFERENCE TO STOL AIRCRAFT, D.H. Henshaw and O.M.S. Colavincenzo, Canadian Aeronautics and Space Journal, Vol. 10, March 1964, p. 67-71.
Evaluation of lateral control equations for application to short takeoff and landing (STOL) aircraft. Problems are analyzed by introduction of two reference frames, one fixed in space and the other, with origin at the aircraft center of gravity and

I.8.4.11 (continued)
fixed with respect to the aircraft, establishing a stability axis system, which is in fact a set of coordinate systems. Study of the equations as applied to various flight conditions indicates that a general solution would be highly complex, and STOL aircraft may be subject to major problems.

I.8.4.12 IMPROVEMENTS IN LONGITUDINAL STABILITY AND CONTROL DURING THE LANDING APPROACH OF STOL AIRCRAFT, M. Brenckmann, Am. Inst. of Aeron. & Astron. and Canadian Aeron. and Sp. Inst., Joint Meeting, Ottawa, Canada, October 26,27, 1964, Paper 64-804, 16p. Analytical definition of the short-field landing characteristics of a STOL experimental aircraft as determined by performance studies, maneuver dynamics analysis, and flight simulation.

I.8.4.13 RESULTS OF RECENT INVESTIGATIONS OF V/STOL CONTROL AND RESPONSE REQUIREMENTS USING VARIABLE STABILITY HELICOPTERS, D.G. Gould, AGARD-519, October 1965. Theoretical predictions, based on a pilot-aircraft system, of root-mean-square control response, root-mean-square heading response and minimum pilot gain were found to correlate well with pilot opinion assessments of the directional control and response requirements for flight of simulated V/STOL aircraft in turbulence. The comparisons were made for two visual flight tasks, a circuit including approach and landing, and precision hovering in a simulated wind, for four values of the weathercock stability parameter. Pilot assessments of the pitch, roll and yaw control sensitivity and control power requirements for maneuver in calm air for visual circuit and hover tasks were compared for two aircraft weighing 2,900 lb. and 15,000 lb. The results did not agree with the predictions of the existing requirements for scaling control power with weight, indicating a trend opposite to that of the present recommendations. Preliminary results from this investigation suggest that scale effects are over-shadowed by the requirements to ensure satisfactory flight in turbulent conditions. The report is one of the series 515-522 of papers presented at the 27th meeting of the AGARD flight mechanics panel, held 11-12 October, 1965, in Rome, Italy.

I.8.4.14 SIMULATION OF HELICOPTER AND V/STOL AIRCRAFT, Volume V. Summary of Final Results, R.L. Faith, December 1964.
Summary of the results, conclusions, and recommendations which were derived from a study program designed to develop the equations of motion of helicopter and V/STOL aircraft in a form suitable for simulation using either an analog or a digital computer.

I.8.4.15 SIMULATION OF HELICOPTER AND V/STOL AIRCRAFT, Volume III, Part I. Computational Methods Analog. Study, Equations of Motion of Vertical/Short Takeoff and Landing Operational Flight/Weapon System Trainers, R.A. Castle, A.L. Gray, W. McIntyre, May 1964.
This report demonstrates methods of mechanizing the equations of motion of helicopters and V/STOL aircraft by the use of analog computing equipment. The equations of motion of these aircraft are presented in NAVTRADEVCEN Technical Reports 1205-1, (AD-601 022, AD-602 427), and this report assumes a knowledge of such equations by the reader. The report reviews and discusses criteria for the selection of analog computer type as 60 cycle and 400 cycle, and choice of carrier, as well as specific computer components. A helicopter and a tilt wing V/STOL are selected for computer mechanization and the presentation of computer flow diagrams which may be typical computer diagrams used in the analog simulation of such aircraft are discussed.

I.8.4.16 IMPORTANT V/STOL AIRCRAFT STABILITY DERIVATIVES IN HOVER AND TRANSITION, Master's Thesis, J.M. Rampy, December 1965.
The purpose of this study is to determine the most important stability derivatives for hover and transition, affix a relative magnitude to their importance, and to determine the dynamic behavior of V/STOL aircraft in low speed flight. The study was limited to a stability analysis using linearized equations of motion. Although there are limitations to this method, the aerodynamic data available or the time required to accomplish a more complex study were not available.

I.8.4.17 CONTROL CHARACTERISTICS OF V/STOL AIRCRAFT IN TRANSITION, C. Henderson, J. Kroll, A. Hesby, July 1962.
Simulator study was made of the longitudinal control and flight handling characteristics of three types

I.8.4.17 (continued)
of V/STOL aircraft during the transitional phase of flight between hover and conventional level flight. The aircraft configurations studied were in the 35,000 pound weight class and of the following types: (1) dual tandem ducted propeller, (2) tilt rotor, and (3) tilt wing with deflected slipstream. Flight evaluation of control power and damping were conducted to determine pilot rating boundaries for each configuration. Other aerodynamic and control parameters investigated were: (1) speed stability parameter, (2) static ability parameter, (3) change in pitching moment due to change in thrust, (4) conversion rate, (5) throttle gradient and (6) slope of the power required curve.

I.8.4.18 DISPLAY AND CONTROL REQUIREMENTS STUDY FOR A V/STOL TACTICAL AIRCRAFT, Volume I, Analyses, B.A. Olson, December 1966.
A study of the display/control requirements for a tactical V/STOL aircraft was conducted using analytical and simulation techniques. Workload levels were calculated by the discontinuous control analysis technique for the V/STOL crew's discrete tasks. Pilot workload levels were empirically established for level aerodynamic flight, transition to hover, hover, and landing from hover. A scientific data systems 9300 hybrid computer was used to simulate the unique mission phases of a V/STOL aircraft. The STOL landing and takeoff mission phases were also simulated. Three landing display formats, two manual control modes, three thrust-to-weight ratios and three wind conditions were evaluated. A landing display format was developed that was demonstrated on the hybrid simulation to be feasible for operating a V/STOL IFR with minimum electronic aids on the ground and less than 100 percent pilot workload.

I.8.4.19 SIMULATION OF HELICOPTER AND V/STOL AIRCRAFT, Volume III, Part II. COMPUTATIONAL METHODS DIGITAL. STUDY, EQUATIONS OF MOTION OF VERTICAL/SHORT TAKEOFF AND LANDING OPERATIONAL FLIGHT/WEAPON SYSTEM TRAINERS, B.G. Tregub, M.P. Coffee, C.E. Russell, August 1963.
This report was written with the purpose of demonstrating the methods of mechanizing the equations of motion of helicopters and V/STOL aircraft by digital computing equipment. The report is based on the mechanization of the final equations developed

I.8.4.19 (continued)
in Volumes I and II of this report and assumes a knowledge of them. A general treatment of mathematical methods of analysis and of digital computer techniques is presented. The mathematical models developed in Volumes I and II for helicopters, both single and tandem rotor, and for V/STOL aircraft are presented in a digitally applicable form. Recommendations are given for computer memory size and for computer sophistication based on the findings of the study reported.

I.8.4.20 COLLECTION OF TEST DATA FOR LATERAL CONTROL WITH FULL-SPAN FLAPS, J. Fischel and M.F. Iney, NACA TN 1404, 1947.
A collection of test data on lateral control with full-span flaps was presented. Lateral-control effectiveness and hinge-moment data obtained from two-dimensional, three-dimensional and flight tests were presented. A discussion was given of the characteristics of the lateral-control devices considered and of the application of the data to specific airplane design.

I.8.4.21 AN INVESTIGATION OF THE EFFECTS OF ROLL-SPIRAL COUPLING ON THE LATERAL-DIRECTIONAL HANDLING QUALITIES OF A STOL SUBSONIC TRANSPORT, F.L. Moore, NASA TM-X-61898.
Presented the results of an investigation of the effects of the roll-spiral coupled mode of motion on the lateral-directional handling characteristics of a hypothetical subsonic STOL transport. The investigation consisted of analytical calculations of the lateral dynamics of the transport having various types of roll-spiral oscillations. Also, a fixed base simulator study was conducted. The results indicated that qualities could be acceptable with a roll-spiral oscillation present provided small lateral inputs are used.

I.8.5 Handling Qualities and Criteria

I.8.5.1 FACTORS LIMITING THE LANDING APPROACH SPEED OF AIRPLANES FROM THE VIEWPOINT OF A PILOT, R.C. Innis, AGARD Report 358, April 1961.
Two aircraft have been considered; one a swept-wing jet fighter employing blowing-type boundary-layer control (BLC) on highly deflected leading- and trailing-edge flaps, and the other a straight-wing, twin-engine cargo aircraft using propeller slipstream in conjunction with an area suction BLC system on the flaps and drooped ailerons to develop high life. An attempt is made to provide a better understanding of the effect of various stability and control characteristics on the pilot's selection of approach speeds.

I.8.5.2 THE INFLUENCE OF DRAG CHARACTERISTICS OF THE CHOICE OF LANDING APPROACH SPEEDS, D. Lean and R. Eaton, AGARD Report 122, May 1957.
A study has been made of the lift-drag characteristics of 19 jet aircraft which have minimum comfortable approach air speeds that are fairly well established.

I.8.5.3 APPROACH AND LANDING PROBLEMS IN JET VTOL AIRCRAFT, F.P. Youens, AGARD Report 489, October 1964.
The influence of operational environment and the characteristics of the aircraft on the approach technique is considered with a detailed survey of the transition phase including crosswind transition limits and control techniques.

I.8.5.4 AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT, S. B. Anderson, NASA, TN D-331, July 1960.
A study has been made of handling qualities of V/STOL aircraft. With the current military requirements for aeroplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of V/STOL aircraft, BLC equipped aircraft, and flight simulators. The reasoning behind suggested V/STOL requirements and the areas where existing information is inadequate and further research is required are discussed.

I.8.5.5 AMERICAN DEVELOPMENT IN STOL AND VTOL AIRCRAFT, C.W. Meshier, AGARD Report 86, August 1956.
To date most research activity on aircraft has been directed towards the development of basic configurations to achieve the required performance. This paper discusses the low speed control problems of short takeoff and vertical takeoff aircraft, to which little effort has been applied until recently.

I.8.5.6 THE VARIATIONS OF THE LANDING DISTANCE OF FIXED WING AIRCRAFT IN STOL OPERATIONS, P.A. Puvrez, 1st AIAA Annual Mtg., July 1964, Paper 64-345, also in J. Aircraft, July-August 1965.

I.8.5.7 A COMPARISON OF V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES CRITERIA FOR VISUAL AND INSTRUMENT FLIGHT USING AN AIRBORNE SIMULATOR, R.E. Smith, NRC Report LR-465, September 1966.
The directional handling qualities criteria for an instrument approach task in controlled turbulence were determined using an airborne V/STOL simulator, and compared with the results for a visual approach task. Theoretical criteria from a pilot-aircraft synthesis were correlated with pilot ratings.

I.8.5.8 FIELD REQUIREMENTS OF OVERLOADED PROPELLER-DRIVEN VTOL AIRCRAFT, B. Neal and H.N.C. Lyster, Canadian Aeronautics and Space Journal, Vol. 9, December 1963, p. 319-326.
Calculation of minimum takeoff and landing distances for two overloaded, propeller-driven, tilt-wing VTOL aircraft. The effects of flap setting, propeller thrust variation with forward speed, runway surface, wing tilt rate and flap boundary layer control are considered at various thrust-to-weight ratios. It appears that takeoff to and landing from a 50 ft. obstacle can be achieved in 500 ft. at an all up-weight (AUW) between 40% and 50% greater than the VTO AUS, depending on the assumed thrust variation with forward speed.

I.8.5.9 SOME PERFORMANCE AND HANDLING-QUALITIES CONSIDERATIONS FOR OPERATION OF STOL AIRCRAFT, S.B. Anderson, H.C. Quigley, and R.C. Innis, NASA Ames Research Center, Moffett Field, Calif., in NASA, Washington, Conference on Aircraft Operating Probl. 1965, p. 309-317.

I.8.5.9 (continued)
Studies of a number of STOL aircraft show that relatively high maximum lift coefficients and large increases in lift due to power are within the present state-of-the-art. With these lift characteristics, approach speeds of the order of 60 knots for aircraft of moderate wing loading can be realized. Full advantage of the STOL performance of aircraft such as those discussed herein may not be realized on a routine operational basis, however, without some form of damping augmentation system because of lateral-directional handling considerations, particularly for large aircraft operating under instrument flight conditions. Satisfactory characteristics can be obtained by use of only a servodriven rudder.

I.8.5.10 HANDLING QUALITIES RESEARCH IN THE DEVELOPMENT OF A STOL UTILITY TRANSPORT AIRCRAFT, T.R. Nettleton, CASI, and AIAA, Low-Speed Flight Meeting, Montreal, Canada, October 18-19, 1965, Paper 65-713, 20p.
Discussion of the stability and control research conducted by deHavilland Aircraft of Canada during the design of the twin-engine, propeller-driven DHC-5 Buffalo STOL utility transport, with review of flight test results. The Buffalo evolved from a series of design studies of the weight and power growth potential of the DHC-4 Caribou. A slot-lip aileron control system was studied which contributed significantly to good lateral behavior in stalls. It was found that a considerable increase in rudder effectiveness could be achieved if a power control system was used. Problems of directional stability were encountered and solved. Extensive research was carried out in the areas of longitudinal stability and control, selective integration of analytical studies, and wind tunnel and flight research led to a relatively unsophisticated design which complied with all stability and control objectives.

I.8.5.11 SUGGESTED REQUIREMENTS FOR V/STOL FLYING QUALITIES P.R. Curry, J.T. Matthews, Jr., AAML, Fort Eustis, Va., June 65, 55p. USAAML-TR-65-45, RTM-37.
Presents suggestions for a specification on flying and handling qualities requirements for subsonic V/STOL aircraft. In addition to including the ideas of many others, the authors have incorporated two basic suggestions: (1) the use of a pilot rating system (since the ultimate measures of handling

I.8.5.11 (continued)
qualities are determined by the pilot) and (2) the use of servo-analysis techniques and terms to define quantitative requirements.

I.8.5.12 AN ANALYTICAL STUDY OF V/STOL HANDLING QUALITIES IN HOVER AND TRANSITION, R.I. Stapleford, J. Wolkovitch, R.E. Magdaleno, C.P. Shortwell and W.A. Johnson, Systems Technology Inc., Hawthorne, Calif., October 1965, 172p. TR-140-1.
The hover analysis considered pilot attitude and position control tasks in the presence of horizontal gusts. The effects of each of the stability derivatives on the difficulty of the control tasks and on the closed-loop gust responses are determined.

It is clearly shown that the handling qualities studies of control sensitivity and angular damping must consider the influences of M sub U (or L sub V) and should include gust inputs.

I.8.5.13 CONTROL REQUIREMENTS AFFECTING STOL's, R.E. Kuhn, and A.D. Hammond, Astron. & Aeron. Vol. 3, May 1965, p. 48-52.
Discussion of requirements for the adequate control of short takeoff/landing (STOL) aircraft. Available high-lift systems for achieving the low speeds needed to operate into and out of small fields are discussed. The handling quality requirements and lateral and longitudinal control requirements for STOL aircraft are examined, and the low-speed operational envelope for the landing and takeoff of the STOL is described.

I.8.5.14 PROGRESS IN FLYING QUALITIES RESEARCH RELATING TO STOL AND VTOL AIRCRAFT, A.D. Wood, Aeron. Soc. of India, Journal, Vol. 17, Feb. 1965, p. 12-25.
Review of some aspects of research as STOL and VTOL flying qualities. Comments are offered on the progress that has been made in approaching and exploring some of the significant areas of uncertainty in this field. The subjects considered are technique of flight simulation, longitudinal characteristics of STOL aircraft, directional control cross-coupling, general stability and control considerations, and scaling factors. It is concluded that progress has been made in identifying many of the parameters having a major influence on the flying qualities of aircraft of these types, and relationships among

I.8.5.14 (continued)
some of these parameters leading to acceptable or to minimum tolerable flying qualities have been established. The broad nature of the STOL and VTOL flight regimes necessarily introduces a very large number of variables and, consequently, there are wide gaps in understanding. More research is required to clarify the effects of scale on flying qualities, to further examine the limiting factors involved in carrying out steep approaches leading to a short landing roll, and to consolidate the parameters influencing lateral-directional behavior into fewer generally applicable expressions.

I.8.5.15 RECOMMENDATIONS FOR V/STOLHANDLING QUALITIES, A. Botrel, D.G. Gould, D. Lean, J. Reeder and J.M.H. VanVlaenderen, Advisory Group for Aeron. Research and Develop. Paris, October 1962, 41p. (AGARD-408). Recommendations are presented on desirable handling qualities for military V/STOL aircraft. These recommendations, which are tentative, particularly as to their application to large aircraft, are based in some respects on requirements for U.S. Military helicopters, but considerable use has been made of the results of flight assessments of handling qualities of a number of V/STOL research aircraft.

I.8.5.16 COMMENTS ON AGARD REPORT 408 BY THE V/STOL HANDLING QUALITIES TECHNICAL ASSISTANCE PANEL, J.P. Reeder, AGARD, Paris, January 1964, 28p.
Concurrent with the 23rd AGARD Flight Mechanics Panel meeting, a Technical Assistance Group, comprised of specialists on V/STOL aircraft and aircraft-handling qualities, met in Athens on July 8 and 9, 1963 to discuss AGARD report 408 "Recommendations on V/STOL Handling Qualities". Generally, report 408, was regarded as an excellent attempt to provide comprehensive handling criteria for the class of aircraft considered. However, several criticisms were offered; these fall into two categories - the first, of a general nature, concerned with the scope of the report, and the other directly connected with specific recommendations. The present draft is an attempt to present, in an organized manner, all the comments made. Added to the draft, as appendices, are the "Report of the Chairman to the Flight Mechanics Panel" as

I.8.5.16 (continued)
well as a summary by the Chairman and the Secretary of the V/STOL Handling Qualities Working Group.

I.8.5.17 AN INVESTIGATION OF THE EFFECTS OF LATERAL-DIRECTIONAL CONTROL CROSS-COUPLING ON FLYING QUALITIES USING A V/STOL AIRBORNE SIMULATOR, D.M. McGregor, NRC, Canada, NAE, NRC, LR-390, December 1963, 23pp. + 6 figures.
Since many V/STOL aircraft being proposed, or under development, have potentially serious lateral-directional control cross-coupling effects, a handling qualities investigation was undertaken. A visual flight task which included hovering, accelerating and decelerating transitions, and steep angle approaches was used to give the pilots a realistic function to perform while assessing the various configurations.

I.8.5.18 A FLIGHT INVESTIGATION OF THE INFLUENCE OF VARIOUS LEVELS OF DIHEDRAL EFFECT ON V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES, D.M. McGregor, NRC, Canada, NAE, November 1964, 28pp + 12 figures (NRC-LR-412).
An investigation into the influence of dihedral effect on the directional angular rate dampings and control sensitivities required for both normal and emergency operation was undertaken, using an airborne V/STOL simulator. The visual flight task performed by the pilots during the evaluation included hovering turns and a complete circuit terminated by a low speed, steep angle approach to touchdown.

I.8.5-19 RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES (WITH AN ADDENDUM CONTAINING COMMENTS ON THE RECOMMENDATIONS), AGARD Paris, October 1964, 71p (AGARD-408-A).
This report presents the recommendations of a Working Group sponsored by the AGARD Flight Mechanics Panel, on desirable handling qualities for military V/STOL aircraft. The recommendations, which are necessarily tentative, particularly as regard their application to large aircraft, are based in some respects on requirements for U. S. Military helicopters, but considerable use has been made of the results of flight assessments of handling qualities of a number of V/STOL research aircraft. To improve their validity, they should be kept under continual review by critical, systematic comparison

I.8.5.19 (continued)
with the accepted handling qualities of as many new V/STOL aircraft as possible. An addendum now included with the report contains comments from various sources on the Recommendations.

I.8.5.20 STATISTICAL APPROACH TO LOW SPEED CONTROL CRITERIA FOR V/STOL AIRCRAFT, D.O. Carpenter and R.B. Jenny, AIAA, Annual Meeting, 1st, Washington,D.C., June 29-July 2, 1964, Paper 64-286, 4p.
Statistical analysis of V/STOL control criteria using characteristics satisfactory for STOL, SFA, and VTOL aircraft. Data from industry and NASA are correlated and compared with criteria from helicopter specification MIL-H-8501A, NATA AGARD Report 408, and conventional fixed-wing specification MIL-F-8785. The variation of control criteria with gross weight is found to fluctuate approximately according to the relationship (GW + 10000)-1/3. V/STOL aircraft control criteria are somewhat greater than those found acceptable for helicopters. The analysis shows the roll control power to be twice the IFR helicopter requirement, and pitch and yaw criteria to be about 1.5 and 1.0 times the IFR helicopter requirements, respectively.

I.8.5.21 EFFECTS OF REDUCED AIRSPEED FOR LANDING APPROACH ON FLYING QUALITIES OF A LARGE JET TRANSPORT EQUIPPED WITH POWERED LIFT, H.L. Crane, et al NASA TN D4804, October 1968.

I.8.5.22 A NOTE ON TURBULENCE PROBLEMS ASSOCIATED WITH TAKE-OFF AND LANDING, J. Burnham, September 1967.
The effects of turbulence on the takeoff and landing of conventional and V/STOL aircraft are briefly described. The adequacy and relevance of existing knowledge of the atmosphere is discussed, together with plans for further research.

I.8.5.23 ON THE RELATIVE IMPORTANCE OF THE LOW SPEED CONTROL REQUIREMENT FOR V/STOL AIRCRAFT, S. Goldberger, December 1966.
The closed loop dynamic response of a V/STOL airplane, pilot, and autostabilization system was studied with the purpose of demonstrating which airplane parameters are most important in determining the airplane's low speed flight characteristics. The influence of the stability augmentation system was found to be so great that the other parameters

I.8.5.23 (continued)
are small by comparison. The most important stability and control parameter in low speed, V/STOL aircraft flight, therefore, is control power.

I.8.5.24 STUDY, SURVEY OF HELICOPTER AND V/STOL AIRCRAFT SIMULATOR TRAINER DYNAMIC RESPONSE, Volume II, DYNAMIC RESPONSE CRITERIA FOR V/STOL AIRCRAFT FLIGHT TRAINERS, H.G. Streiff, May 1967.
The results of a study to determine the dynamic response criteria for V/STOL aircraft simulator trainers are presented. The fundamentals of V/STOL dynamics, control, and simulation within the various V/STOL flight regimes are described. Difficulties likely to be encountered in developing an adequate V/STOL aircraft simulation are also presented. Methods and procedures for determining the accuracy to which specific dynamic response parameters must be simulated are presented, and based upon these, simulation tolerances are developed for each significant handling qualities parameter in each flight regime. The dynamic attributes of the pilot-aircraft combination with regard to each specific parameter are discussed. A detailed description of various V/STOL aircraft equations of motion, is included and the practical limitations of various methods and procedures for programming the equations of motion for piloted flight simulation purposes are discussed.

I.8.5.25 ACHIEVING CONSISTENCY IN MAXIMUM PERFORMANCE STOL LANDINGS, A.J. Craig, January 1961.
Factors influencing the achievement of minimum distance landings over a barrier were investigated to determine what might be done to provide consistency in landing in a computed minimum distance. It was found that the pilot regularly extracted the maximum aerodynamic performance of the airplane, but that limitations accompanying maximum aerodynamic performance prevented consistently short landings. The primary limitation was the inability to flatten or steepen the descent path during the approach to the barrier.

I.8.5.26 OPERATIONAL TECHNIQUE FOR TRANSITION OF SEVERAL TYPES OF V/STOL AIRCRAFT, F.J.Drinkwater, III, TND 774 Ad-252-988, National Aeronautics and Space Admin., Washington.

I.8.5.26 (continued)
Flight test experience was obtained with five test bed aircraft which employed widely differing principles of V/STOL operation. At high speeds these aircraft were supported by wing lift and in the hovering condition they were supported by engine-produced thrust. The techniques used to transfer the lift from the wing to the engine are examined. The primary items considered in the transition region are longitudinal trim changes, stability, stalled flow during descending transitions, and the flexibility of the transition procedure of each type of aircraft.

I.8.5.27 A COMPARISON OF V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES CRITERIA FOR VISUAL AND INSTRUMENT FLIGHT USING AN AIRBORNE SIMULATOR, R.E. Smith, National Research Council of Canada, National Aeron. Establishment LR-465, September 1966.
The directional handling qualities criteria for an instrument approach task in controlled turbulence were determined using an airborne V/STOL simulator, and compared with the results for a visual approach task, to show that instrument flight demanded more stringent criteria. Increasing the weathercock stability, in the presence of turbulence, required significantly larger values of damping. These levels, which were dependent on the task, were apparently determined by the aircraft's response to turbulence as shown by the good correlation obtained between pilot ratings and theoretical criteria based on the aircraft's turbulence response. Existing recommendations for minimum damping levels did not correlate with the results, but the recommendations for minimum directional response were found to be adequate for normal operation.

Theoretical criteria from a pilot-aircraft synthesis were correlated with pilot ratings and provided an insight into the possible behavior of the pilot while flying an approach task in turbulence.

I.8.5.28 STATE-OF-THE-ART SURVEY FOR MINIMUM APPROACH, LANDING, AND TAKEOFF INTERVALS AS DICTATED BY WAKES, VORTICES, AND WEATHER PHENOMENA, W.J. Bennett, Report No. RD64-4, The Boeing Company, January 1964.
A study is made of the generation and decay of the wake behind an aircraft, both in free air and ground effect, and its effect on following aircraft. An

I.8.5.28 (continued)
analysis is presented for both fixed- and rotary-wing aircraft which defines the wake movement with time and the wake-induced velocities. The wake due to the propulsion system is analyzed both for normal operation and reversed thrust, as well as for pure propulsion lift. The influence of atmospheric parameters such as wind, temperature, and turbulence is discussed as it applies to the generation and decay of the wake.

I.8.5.29 FLYING QUALITIES CONFERENCE, Wright-Patterson Air Force Base, Ohio, 5 and 6 April 1966, AFFDL-TR-148, December 1966.
Presented papers given at conference intended to provide assistance in revising MIL-F-8785.

I.8.5.30 <u>Stability and Control</u>

Rolling pullout study, Part I, Development of Large Disturbance Theory for Calculating Airplane Motions and Tail Loads in a Rolling Pullout Maneuver, WADC Tech. Report 6701.
Develops large disturbance theory and surveys the effects on the accuracy of predicted responses of applying simplifying assumptions.

I.8.6 Testing

I.8.6.1 LINEARIZED THEORY OF WIND-TUNNEL JET-BOUNDARY CORRECTIONS AND GROUND EFFECT FOR VTOL-STOL AIRCRAFT, H.H. Heyson, NASA TRR-124, 1962.
Interference factors are developed as a function of the degree to which the wake is deflected downward. Methods are given for extending the present numberical results to tests involving multi-element and finite-span models. Tables of calculated interference factors are presented in NASA Technical Notes D-933, D-934, D-935 and D-936.

I.8.6.2 TABLES OF INTERFERENCE FACTORS FOR USE IN WIND-TUNNEL AND GROUND-EFFECT CALCULATIONS FOR VTOL-STOL AIRCRAFT, PART I -- WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 2.0, H.H. Heyson, NASA TN D-933, January 1962.

I.8.6.3 TABLES OF INTERFERENCE FACTORS FOR USE IN WIND-TUNNELS AND GROUND-EFFECT CALCULATIONS FOR VTOL-STOL AIRCRAFT, PART II -- WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 1.5, H.H.Heyson, NASA TN D-934, January 1962.

I.8.6.4 TABLES OF INTERFERENCE FACTORS FOR USE IN WIND-TUNNEL AND GROUND-EFFECT CALCULATIONS FOR VTOL-STOL AIRCRAFT, PART III -- WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 1.0, H.H. Heyson, NASA TN D-935, January 1962.

I.8.6.5 TABLES OF INTERFERENCE FACTORS FOR USE IN WIND-TUNNEL AND GROUND-EFFECT CALCULATIONS FOR VTOL-STOL AIRCRAFT, PART IV -- WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 0.5, H.H. Heyson, NASA TN D-936, January 1962.

I.8.6.6 SOME COMMENTS ON HIGH-LIFT TESTING IN WIND TUNNELS WITH PARTICULAR REFERENCE TO JET-BLOWING MODELS, A. Anscombe and J. Williams, AGARD Report 63, August 1956, and JRAeS, August 1957.
Some of the special problems of wind tunnel testing which arise in high-lift work are considered. Discussion is confined to current experience in the RAE and NPL low-speed wind tunnels, and refers mainly to tests on blowing over flaps or jet flaps. Comments are made on suitable size of model, methods of feeding compressed air into models without affecting balance readings and general test technique. Methods of model construction are not specifically discussed.

I.8.6.7 VTOL WIND TUNNEL TESTING TECHNIQUES AND FACILITIES, R.C. McWherter, SAE Preprints - SAE Summer Meeting 1961

I.8.6.8 INTERFERENCE CORRECTIONS FOR ASYMMETRICALLY LOADED WINGS IN CLOSED RECTANGULAR WIND TUNNELS, H.C. Garner and WEA Acum. R&M 2948, 1957.
The basic theory of wall interference in closed rectangular tunnels is outlined. The tunnel-induced upwash is expressed in terms of the loading on the wing and four quantities dependent on the shape of tunnel. These quantities are evaluated for a duplex tunnel and may be computed for a general rectangular shape. The correction to incidence, pitching moment, rolling moment, drag and yawing moment are discussed in detail and all the corrections are summarized and expressed as products of experimental aerodynamic coefficients and theoretically determined quantities. These are evaluated for an arrowhead wing with various ailerons in a duplex tunnel.

I.8.6.9 UPWASH INTERFERENCE ON WINGS OF FINITE SPAN IN A RECTANGULAR WIND TUNNEL WITH CLOSED SIDE WALLS AND POROUS-SLOTTED FLOOR AND ROOF, D.R. Holder, R&M 3395, 1965.

I.8.6.10 WIND TUNNEL WALL EFFECTS AT EXTREME FORCE COEFFICIENTS, H.H. Heyson.

I.8.6.11 TABLES OF INTERFERENCE FACTORS FOR USE IN CORRECTING DATA FROM VTOL MODELS IN WIND TUNNELS WITH 7 by 10 PROPORTIONS, H.H. Heyson, NASA, SP-3039, 1967.
Tables of the interference factors are given for models whose span is parallel to either the long or short side of the wind tunnel. Instructions for their use with semi-span models are included.

I.8.6.12 THE STUDY OF OPERATIONAL PROBLEMS AND TECHNIQUES IN WIND TUNNEL TESTING OF VTOL AND STOL VEHICLES, W.H. Rae, Jr., Wash. Univ., Seattle, Progress Report No. 3, 1 October 64-31, March 65, 3p.
The primary purpose of this investigation is to develop an economical method of experimentally checking the effect of wind tunnel wall constraints on rotors, ducted fans, tilt props, and other methods of obtaining aircraft with V/STOL performance, by the use of inserts within a wind tunnel to simulate different size test sections.

I.8.6.13 WALL EFFECTS AND SCALE EFFECTS IN V/STOL MODEL TESTING, NASA, Langley Research Center, Powered-Lift Aerodynamics, Section, Langley Station, Hampton, Va. New York, AIAA 1964, p. 8-166.
Study of the limits of applicability of wind-tunnel data on V/STOLs configurations, primarily with regard to wall effects and scale effects. Tunnel wall effects on the transition aerodynamics of a tilt-wing, fan-in-wing, and a fan-in-fuselage configuration, as determined from tests of a model of each configuration in three different size tunnels, are discussed. Data from the VZ-2 configuration, the XV5-A fan-in-wing configuration and the Ames fan-in-fuselage configuration are used. The wall-induced lift and drag errors experienced by all three types of configurations could, in general, be adequately corrected by Heyson's method.

I.8.6.14 FURTHER DEVELOPMENTS IN LOW-SPEED WIND-TUNNEL TECHNIQUES FOR VSTOL AND HIGH-LIFT MODEL TESTING, J. Williams and S.F.J. Butler, New York, AIAA, 1964, p. 17-32.
Discussion of recent advances in wind-tunnel testing of low-speed high-lift models with boundary-layer and circulation control. Topics of study are: (1) special mechanical and strain-gage balance rigs for jet-blowing models; (2) engine exit and intake flow simulation at model scale, and (3) ground simulation by a moving-belt rig. Recent developments, particularly those to expedite investigations on jet and fan lift models at the Royal Aircraft Establishment, are reviewed.

I.8.6.15 EXPERIMENTAL AND THEORETICAL INVESTIGATION OF WIND TUNNEL GEOMETRY, EMPHASIZING FACTORS PERTINENT TO V/STOL VEHICLES TESTING, R.J. Joppa, Wash. Univ., Seattle, Dept. of Aero. Engrg. Progress Report No. 2, March 16, Sept. 15, 1965, 15 January 1966, 26p. (GRANT NGR-48-002-010) (NASA-CR-70331).
Discussions are presented of an experiment concerning the installation of a powered rotor model in a wind tunnel; and analysis of tunnel internal flow using the vortex ring method; and the basic problem of calculating flow fields of highly loaded systems in free air. The wind tunnel analysis was extended and improved by distributing the vorticity from discrete rings to continuous sheets along the walls. Relative to calculating flow fields, it was found that a simple representation of the vortex system

I.8.6.15 (continued)
was adequate to calculate the trajectory of a streamline. In determining interference it was demonstrated that the vortex filaments trail downward at about one-fourth the angle of the mass of air as calculated by simple momentum theory.

I.8.6.16 CONCEPTUAL AND REQUIREMENT STUDY FOR V/STOL FLIGHT TEST SUPPORT FACILITIES, D.V. Harding, T.A. Brady, M.A. Sousa, July, September, and October 1966. The increased activity in V/STOL hardware programs has been accompanied by increased flight test workloads and requirements for increased flight test center capabilities. These present hardware programs are recognized as only the beginning of development of a new type of aircraft which will increase and become more demanding as the technology is advanced. In order to test, study, and evaluate development of this type aircraft through the year 1980, the capabilities of the flight test support facilities must be increased concurrently the predicted vehicle development. A study was conducted to determine what facility capabilities the Air Force Flight Test Center (AFFTC) would require through 1980. This study through a nationwide survey of government agencies and companies in the aircraft industry identified the spectrum of V/STOL aircraft expected to be in flight test status during 1967-1980. The parameters of weight (assault transport), exhaust (lift-jet fighter), and size (large diameter rotorplane) were established as the most critical and represented the maximum values predicted. The flight test objective, flight regimes, and type of testing were identified for these aircraft.

I.8.6.17 TUNNEL-WALL EFFECTS ASSOCIATED WITH VTOL-STOL MODEL TESTING, R.E. Kuhn, R. Naeseth, AGARD-303, March 1959. Wind tunnel investigations of VTOL and STOL airplane models involve configurations in which a large amount of power is being used to generate part of the lift through the medium of propeller slipstreams or jet exhausts directed downward at large angles to the freestream direction. For many configurations the propellers or jet exhausts are arranged, for example, as in the jet flap, to cover the entire span of the wing and thus to assist the wind in its natural process of producing so called 'circulation' lift. This arrangement results in the streamlines in the vicinity of the wing also being turned through large

I.8.6.17 (continued)
angles to the freestream direction of flow. The presence of the tunnel walls, however, imposes the conditions that the streamlines at the tunnel walls must be parallel to the freestream. Thus, the problem of tunnel-wall effects on VTOL-STOL model testing is similar to that associated with conventional model testing but differs greatly in degree. Experience has shown that, in addition to these usual tunnel-wall effects, flow separation on the model can also be induced by the tunnel walls. The experiences of the Langley Research Center of NASA, related to these problems in closed-throat wind tunnels are reviewed.

I.8.6.18 TEST SECTIONS FOR SMALL THEORETICAL WIND-TUNNEL-BOUNDARY INTERFERENCE ON V/STOL MODELS, R.H. Wright, NASA TR-286, 1968.
A wind-tunnel test section with closed upper wall, slotted side walls, and open lower boundary was found theoretically to produce zero tunnel-boundary lift interference on a small wing with horizontal wake mounted at the center of the test section. For this test section the variation of the interference with angle of the vortex wake behind a high-lift-coefficient model was not large. Because of the small slot widths required for zero interference and of the effects of boundary layer, the theory is regarded as unreliable for predicting the slot widths required. The interference in the region likely to be occupied by the tail of a model was investigated in some detail and was found to change with slot width and with wake angle more strongly than did the interference at the lifting element.

I.8.6.19 USE OF SUPERPOSITION IN DIGITAL COMPUTERS TO OBTAIN WIND-TUNNEL INTERFERENCE FACTORS FOR ARBITRARY CONFIGURATIONS, WITH PARTICULAR REFERENCE TO V/STOL MODELS, H.H. Heyson, TR R-302.
A superposition method utilizing a digital computer is developed to obtain wall interference for arbitrary configurations. A variety of specific configurations are treated. Sample numerical results indicate that a large number of variables, such as wind-tunnel configuration, model configuration, wake deflection, model location, span of wing and tail, load distribution, sweep, angle of attack, pivot location, tail length, and tail height, may individually or collectively produce substantial effects on wall interference.

I.8.6.20 EQUATIONS FOR THE APPLICATION OF WIND-TUNNEL WALL CORRECTIONS TO PITCHING MOMENTS CAUSED BY THE TAIL OF AN AIRCRAFT MODEL, H.H. Heyson, TN D-3738. Equations are derived for the application of wall corrections to pitching moments due to the tail in two different manners. The first system requires only an alteration in the observed pitching moment; however, its application requires a knowledge of a number of quantities not measured in the usual wind tunnel tests, as well as assumptions of incompressible flow, linear lift curves, and no stall. The second method requires a change in the tailplane incidence and, in general, a smaller change in the observed pitching moment. The use of a separate tail balance is recommended whenever the corrections are expected to be large.

I.8.6.21 FORTRAN PROGRAMS FOR CALCULATING WIND-TUNNEL BOUNDARY INTERFERENCE, H.H. Heyson, NASA TM X-1740, February 1969. Boundary-interference programs, developed in NASA TR R-302, are presented.

I.8.6.22 A THEORY OF THE BLOCKAGE EFFECTS ON BLUFF BODIES AND STALLED WINGS IN A CLOSED WIND TUNNEL, E.C. Maskell, Royal Aircraft Establishment Report No. AERO 2685, November 1963.
A theory of blockage constraint on the flow past a bluff body in a closed wind tunnel is developed, using an approximate relation describing the momentum balance in the flow outside the wake and two empirical auxiliary relations. The theory leads to the correction formula.

$$q_c | q = \varepsilon C_D / (S/C)$$

where Δq is the effective increase in dynamic pressure due to constraint, and ε is a blockage factor dependent on the magnitude of the base pressure coefficient.

The theory is extended to stalled wings, and a technique for the correction of wind-tunnel data is given.

I.8.6.23 WALL INTERFERENCE EFFECTS IN WIND-TUNNEL TESTING OF STOL AIRCRAFT, R.G. Joppa, Journal of Aircraft, Vol. 6, No. 3, May-June 1969, pp. 209-214.
A problem associated with the wind-tunnel testing of very slow flying aircraft is the correction of

I.8.6.23 (continued)
observed pitching moments to free air conditions. The most significant effects of such corrections are to be found in the domain of flight between high speed and the STOL approach. The wind-tunnel walls induced interference velocities at the tail location different from those induced at the wing, and these induced velocities also alter the trajectory of the trailing vortex system. The relocated vortex system induces different velocities at the tail from those experienced in free air. A method of calculating the interference velocities was presented in which the effects of the altered wake location are included, as well as the wall-induced velocities. Results were presented comparing the computed tail interference angles, with and without including the effect of the vortex wake relocation, which show the importance of the wake shift. In some cases, the tail angle corrections were reduced to zero and may even change sign. It was concluded that, to calculate correctly the interference velocities affecting pitching moments, the effects of vortex wake relocation must be included.

I.8.6.24 A V/STOL WIND-TUNNEL WALL INTERFERENCE STUDY, C.L. AND T.W. Binion, Jr., Journal of Aircraft, Vol. 7, No. 1, Jan.-Feb. 1970.
A theoretical and experimental study of slotted wall tunnels was described. Theoretical calculations based on a modification of the point-matching method with equivalent homogeneous boundary conditions was used to show the relationship between the lift and blockage-interference factors and wall porosity. Experimental interference factors were obtained by comparing lift coefficient vs angle of attack data obtained in a 30 x 45 inch tunnel with those from a 7 x 10 foot tunnel. Theoretical results indicated that the lift interference for conventional models was insensitive to the porosity of the vertical walls for a height to width ratio less than 0.8. It was shown that certain combinations of vertical and horizontal wall slots gave simultaneous zero lift and blockage interference. It was claimed that the discrepancy between theoretical and experimental results may be caused by non-homogeneous slots and viscous effects.

I.8.6.25 AERODYNAMIC INTERFERENCE EFFECTS WITH JET-LIFT V/STOL AIRCRAFT, J. Williams and M.N. Wood, DGRR/WGLR -

I.8.6.25 (continued)
Jahrestagung Bad Godesberg, October 1966.
An outline was given of the nature, magnitude and correlation of aerodynamic interference effects which can arise from the flows induced around the aircraft by the jet-lift efflux.

I.8.6.26 WALL CORRECTIONS TO LONGITUDINAL COMPONENTS MEASURED ON WIND TUNNEL MODELS WITH TAILS, D.A. Lovell, RAE TR 68212, August 1968.
Calculations were made of the magnitude of the wall corrections to pitching moment for two models with tails using two methods. The correction to lift calculated for the two models was shown not to be negligible and it was recommended that the corrections be made.

I.8.6.27 SOME CONSIDERATIONS IN WIND-TUNNEL TESTS OF V/STOL MODELS, H.H. Heyson, NASA TM-X-60772, September 29, 1967.
Minimum features which must be considered in applying wind tunnel wall interference corrections are: type of tunnel and proportions, effective wake skew angle, span of both lifting system and tail, configuration, model location, tail length and height, angle of attack, and pivot location. Auxiliary balances may be required to obtain the forces on each component of a complex lifting system. The boundary layer on the tunnel floor must be considered especially in ground effect testing. Recirculation will limit minimum test speed.

I.8.6.28 WIND-TUNNEL CORRECTIONS FOR V/STOL MODEL TESTING, D.L. Kirkpatrick, Thesis, University of Virginia, August 1962.
Extended Heyson's wall correction theory by considering curved wake. A theory for the jet path was formulated. Wall-corrections shown for this theory were significantly different from Heyson's. Suggestions for further improvement were given.

I.8.6.29 A SURVEY OF V/STOL WIND TUNNEL WALL CORRECTIONS AND TEST TECHNIQUES, J.W. Olcott, Princeton University Report No. 725, December 1965.
A discussion of wind tunnel boundary corrections as they apply to V/STOL model testing was presented. Conventional wall correction theory was judged to be inadequate since it does not account for the presence of the wake and the total lift acting on the model.

I.8.6.29 (continued)
Correction theories that do consider the lift and wake of V/STOL models were judged to give satisfactory results, provided there is no wake distortion due to the tunnel walls. Kirkpatrick's theory was judged to be better than Heyson's because it included a more realistic jet wake shape.

I.8.6.30 WIND TUNNEL WALL EFFECTS IN V/STOL MODEL TESTING, G.B. Matthews; University of Virginia Report No. AEEP-4036-102-68V (NASA CR-66721), July 1968.
This report contained a refinement of Kirkpatrick's method for representing the entrainment of free-stream air and the patch of the wake.

I.8.6.31 ON THE ERRORS INDUCED AT TUNNEL REFERENCE PRESSURE TAPPINGS BY HIGH LIFT MODELS, D.S. Woodward, RAE TR 66049, February 1966.
Expressions were derived for the velocities induced at typical positions of reference pressure taps by a lifting model. It was shown that these induced velocities can be sufficiently large to produce significant errors in determining the tunnel dynamic pressure.

I.8.6.32 THE CHOICE OF WORKING SECTION SIZE AND SHAPE FOR V/STOL WIND TUNNELS, R.J. Templin, Quarterly Bulletin of the DME/NAE, 1956, (4), pp. 63-93.
Model span should be 10 feet or more to achieve adequate wing Reynolds numbers. Test speed range required is about 0.562.0 times the aircraft reference velocity. It was concluded that the 30 x 30 foot NRC tunnel size is about the minimum required and that even these wall effects are probably not negligible for V/STOL testing.

I.8.6.33 THEORETICAL STUDY OF THE USE OF VARIABLE GEOMETRY IN THE DESIGN OF MINIMAL-CORRECTIONS, R.A. Kroeger and W.A. Martin, AIAA Paper 67-183, January 1967.
Presented an approach to the problem of wind tunnel data correction by providing matched stream surfaces in the near flow field. The flow conditions at the walls would be first analytically calculated and then wall modifications made where necessary. The analytical method, the important parameters, and a proposed experimental evaluation were discussed.

I.8.7 <u>General</u>

I.8.7.1 NACA RESEARCH IN THE FIELD OF VTOL AND STOL AIRCRAFT, C.H. Zimmerman, IAS Preprint 814.

I.8.7.2 RECENT ADVANCES IN STOL AIRCRAFT DESIGN AND OPERATION, G.W. Johnston, Paper 64-183.

I.8.7.3 STATUS OF V/STOL RESEARCH AND DEVELOPMENT IN THE UNITED STATES, J.P. Campbell, AIAA/CASI/RAeS ith Anglo American Conference, October 1963.

I.8.7.4 CONFERENCE ON V/STOL AND STOL AIRCRAFT AMES RESEARCH CENTER, NASA SP-116, 1966.

I.8.7.5 DESIGN CONSIDERATIONS CRITICAL TO OPERATIONAL ACCEPTABILITY OF A STOL TRANSPORT, M.D. Marks, and A.A. Lischer, IN: AIAA and USAF, Vehicle design & Propulsion Meeting, Dayton, Ohio, Nov. 4-6, 1963, Proceedings, New York American Institute of Aeron. & Astron. 1963, p. 18-23.
Consideration of supplementary ground rules for the design of a military STOL transport. The rules are related to mission reliability, off-design versatility, aircraft control, flying qualities, and safety. It is proposed that the design field length for the Assault STOL Transport be approximately 1,000 feet, that operation be possible under light loads for 750 foot fields, and that more conventional operation at overload be allowable by designing the structure, cargo hold, fuel tanks, and aerodynamic surface to take full advantage of the inherently greater payload-radius capability.

I.8.7.6 THE AERODYNAMICS OF V/STOL AIRCRAFT, AGARDOGRAPH-126, May 1968.
The publication contains the lecture notes prepared for the AGARD-VKI lecture series on "the aerodynamics of V/STOL aircraft" which took place at the VonKarman Institute, Rhode-Sainte Genese, Belgium, from May 13 to 17, 1968. The lecture series was designed to provide an up-to-date account of special aerodynamic problems and aerodynamic requirements for V/STOL aircraft, including a discussion of the present state of knowledge, novel aerodynamic advances, important areas for research and development, experimental and theoretical treatments as well as immediate and long-term V/STOL aircraft prospects.

I.8.7.7 AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, Volume IV, Panels on RECOMMENDED V/STOL AERODYNAMIC RESEARCH, Panel Summaries, Featured Speakers, and Technical Paper discussions, June 22-24, 1966.
The following technical papers were presented: Aeronautical Research Requirements as Determined from the X-19 and X-100 VTOL programs; Thoughts on Progress in Rotating-Wing Aerodynamics; Some Possibilities for Research on Stability and Control at STOL Flight Speeds; Aerodynamic Research - Improvements of the Tilt Wing Concept; Aerodynamic Problem Areas of V/STOL Aircraft and Recommended Research; A Discussion of Low Speed VTOL Aerodynamic Problems and Suggestions for Related Research; Areas of Fruitful Research and Development for Rotary Wing Aircraft; A comeback of Low-Speed Aerodynamics Research; Required Aerodynamic Research for V/STOL Aircraft; Low Speed Aerodynamic Problems Associated with Helicopters and V/STOL Aircraft; Selected Research Results and Recommendations for Aerodynamic Research; Recommendations for Aerodynamic Research on Helicopters and V/STOL Aircraft.

I.8.7.8 UNIFIED PERFORMANCE THEORY FOR V/STOL AIRCRAFT IN EQUILIBRIUM LEVEL FLIGHT, T. Strand, Air Vehicle Corp., La Jolla, California, May 1966.
A unified V/STOL performance theory of equilibrium level flight is developed. The theory is applicable for wings in the presence of slipstreams, and is based upon an analysis of minimum induced drag for a given airplane weight. The theory has been correlated with existing test results on a number of different V/STOL aircraft by presenting lift/drag and non-dimensional power required curves versus non-dimensional velocity. In general, close agreement between theory and experiment is found over the entire velocity range from cruise to hover.

I.8.7.9 VTOL/STOL AIRCRAFT -- FIRST SUPPLEMENT 1961/62, H. Klug, H. Spintzyk, AGARD.
The bibliography covers the literature published during the years 1961/1962. It comprises all available publications related to problems in the field of V/STOL. Reports on helicopters and on ground-effect vehicles, however, are generally not included. The list of literature contains approximately 550 references. In part 2, 'classification', the different fields of V/STOL are

I.8.7.9 (continued)
divided into eight main sections, the titles of which are: (1) General Studies, (2) Aerodynamic Problems, (3) Stability and Control in Hovering- and Transition-Flight, (4) Powerplants, (5) Test Techniques, (6) Atmosphere, (7) Operational Problems, and (8) Loads and Construction.

I.8.7.10 VTOL-STOL AIRCRAFT (Bibliography) Advisory Group for Aeronautical Research and Development, Paris (France), March 1961.

I.8.7.11 SYMPOSIUM ON VERTICAL/SHORT TAKEOFF AND LANDING AIRCRAFT, Part I, AGARDograph-46, June 1960. One of the aims of the AGARD V/STOL symposium was to obtain an extensive survey of the state-of-the-art of V/STOL aircraft, Volume I includes the following papers: Capabilities and Costs of Various Types of VTOL aircraft; Evaluation of V/STOL aircraft: Generalized Weight and Performance Studies on V/STOL Low-Level Strike Fighter Aircraft; Operating Economics of VTOL and STOL transport Aircraft; Parametric Investigation of STOL Aircraft; The STOL Experimental Aircraft DO29; Aerodynamic Aspects of Some Basic VTOL/STOL Systems; Engine and Lifting Unit Configurations; and Supersonic Engines with References to Short and Vertical Takeoff of Single Seat Combat Aircraft. Prepared comments and other contributions are also included.

I.8.7.12 REVIEW OF BASIC PRINCIPLES OF V/STOL AERODYNAMICS, R.E. Kuhn, TND 733.
The principal factors that determine the performance of V/STOL aircraft are reviewed. The power requirements, fuel consumption, and the downwash dynamic pressure in hovering are all determined by, and increase with, the increase of the slipstream area loading. In transition, the wing span, the distribution of load on the span, and the power required in hovering determine the shape of the power-required curve. Through this the engine-out safety and STOL performances are determined. In general the same rules for designing good cruise performance into conventional airplanes apply to V/STOL configurations. Aerodynamic cleanliness is necessary to reduce the parasite power and a wing of appreciable span is needed to reduce the induced power.

I.8.7.13 A STUDY OF AERODYNAMIC PERFORMANCE EVALUATION AND COMPARISON TECHNIQUES FOR V/STOL AIRCRAFT, D.W. Boatwright, July 1969.

The report presents the results of an investigation of performance evaluation and comparison methods as applied to V/STOL aircraft. Attention is given to a number of aircraft having different sizes, gross weights, geometric configurations, and propulsion systems. Particular regard is given to the use of thermal fuel energy as a common basis for evaluation and comparison of V/STOL performance. The performance capabilities of typical V/STOL aircraft are presented and compared using both dimensional and non-dimensional parameters containing fuel flow rate as a variable. In addition, three aircraft of different configurations are analyzed with regard to the effects of altitude, gross weight, and payload-to-fuel load ratio on the performance capability of each aircraft as indicated by both new and conventionally used methods. The total energy concept is discussed with regard to the optimization of climb schedules, and consideration is given to the limitations which apply to the use of non-dimensional parameters which are used to describe the flow regimes of V/STOL aircraft.

I.8.7.14 A SIMPLE GRAPHICAL METHOD FOR EVALUATING THE EFFECT OF THRUST VECTOR TILT ON THE AIRCRAFT PERFORMANCE, P. Bielkowicz, July 1968.

The semi-graphical method presented in the report may be useful for the preliminary performance computation for an aircraft with the variable thrust axis tilt. Application to different flight problems is shown. Optimization of some flight parameters can be achieved by simple graphical construction.

I.8.7.15 PARAMETRIC INVESTIGATION OF STOL AIRCRAFT, B. Gabrielli, Agardograph-46, June 1960.

The parametric investigation consists of the evaluation of the minimum takeoff and landing lengths, as affected by some parameters (wing loading, maximum lift coefficient, engine thrust to aircraft AUW, ratio, thrust deflection angle), for a jet propelled STOL aircraft capable of complying with any other requirement of GOR 2 (including mission profile, military loads, etc.). The takeoff performances are evaluated under the basic assumptions that the takeoff from the ground is

I.8.7.15 (continued)
obtained mainly through the aerodynamic lift of a wing provided with high lift devices and that the aircraft is mainly controlled during takeoff by conventional aerodynamic means. Aircraft with geometrically similar wings are considered (that is, having identical wing sections, planform, sweep-back angle, etc.). The wing shape was selected. Aircraft powered by two different propulsion systems are considered and compared. The first propulsion system consists of a single high bypass and medium compression ratio turbofan engine provided with swivelling propelling nozzles. The alternate is a composite system, consisting of a single medium by-pass and high compression ratio turbojet engine giving horizontal thrust and of two, or more, booster turbojets, to be used during takeoff only, having a low compression ratio and provided with propelling nozzles which may be deflected downwards at different angles.

I.8.7.16 PROCEEDINGS OF NATIONAL V/STOL AIRCRAFT SYMPOSIUM, WPAFB, Ohio, November 3-4, 1965.
The technical papers presented are grouped into the following three categories: (1) V/STOL Aircraft Design, (2) V/STOL Subsystem Design, and (3) V/STOL Aircraft Testing and Operation.

I.8.7.17 DEVELOPMENT OF METHODS FOR PREDICTING V/STOL AIRCRAFT CHARACTERISTICS, S. Rethorst, T. Fujita, December 1961.
The analyses of the previous Phase I (AD-244 736) and Phase II (AD-257 571) studies are extended and refined. The relationships among basic V/STOL performance parameters are brought into focus. Results are cast into an engineering form. A 'slide-rule' type computer and a set of nomographs are furnished to simplify prediction of V/STOL aircraft characteristics. Propeller-driven V/STOL aircraft are analyzed in terms of tradeoffs among basic performance parameters for a generalized mission profile. The attainment of high performance potential is dependent on the basic aerodynamic parameters governing the forward flight capabilities of conventional aircraft. For V/STOL aircraft the variable disc area parameter (ratio of hovering disc area to forward flight disc area) has a marked effect on performance potential. The 'slide-rule' and nomographs encompass a wide range of

I.8.7.17 (continued)
basic parameters including variable disc area and are applicable to prop-driven V/STOL aircraft. The analytical methods are applied to an advanced V/STOL specification (including growth potential as quantitatively determined in the analysis).

I.8.7.18 STATUS OF V/STOL TECHNOLOGY, R.H. Miller, April 1962.
The mission and capabilities of a tilt-wing VTOL logistic transport, as required by the Navy, are discussed. The design parameters needed to fulfill these requirements as well as the current state-of-the-art are presented.

I.8.7.19 DEVELOPMENT OF METHODS FOR PREDICTING V/STOL AIRCRAFT CHARACTERISTICS, S. Rethorst, W.W. Royce, December 1960.
Analyses are developed which enable prediction of the performance characteristics of a generalized spectrum of V/STOL aircraft. The analyses also define optimum configurational features within this broad spectrum. A resolution to the conflict between the hovering and forward flight regimes is provided by the analysis. Both aerodynamic and structural weight aspects are investigated. These two basic factors are analyzed separately, and then combined to provide an integrated analysis as a basis for quantitative performance prediction. The analysis defines quantitatively the performance potential of any VTOL vehicle as a function of its geometry, operating conditions, and weight. This unique potential is charted to illustrate the various tradeoffs in performance characteristics available to the operator.

I.8.7.20 DDC REPORT BIBLIOGRAPHY, SEARCH CONTROL NO. 034285, VTOL-STOL, June 1960.
Descriptors: Airplanes, Short takeoff planes, Vertical takeoff planes, Aerodynamic characteristics, Airplane engines, Airplane landings, Army aircraft, Bibliographies, Control, Economics, Ground effect, Human engineering, Stability, Structures.

I.8.7.21 MOMENTUM RULE FOR OPTIMUM AIRCRAFT PERFORMANCE IN THE V/STOL TRANSITION REGIME, R.J. Templin, Aeronautical Report LR 470, National Aeronautical Establishment, January 1967.
Applies momentum theory to lifting wings and propulsion systems with deflected thrust so minimum thrust is required in flight condition with momentum deflection angles of wing wake and propulsive jet are approximately equal.

I.8.7.22 NOTE ON THE MINIMUM POWER REQUIRED FOR FLIGHT AT LOW AIRSPEEDS, R.J. Templin, National Research Laboratories, Canada National Aeron. Establishment, LR-245, May 1959.
An idealized form of aircraft, having a lifting wing and a jet or slipstream issuing at an angle to the flight direction so as to produce lift and thrust, is considered. The power required to produce the kinetic energy of the jet is calculated for all flight speeds down to zero. For sustained level flight at any speed there is an optimum wing lift coefficient for minimum power. In some cases, the achievement of optimum lift may require circulation control.

I.8.7.23 FACTORS AFFECTING THE FIELD LENGTH OF STOL AIRCRAFT, G.W. Johnston, AGARD Report 81, August 1956.
The note considers a STOL aircraft to be one requiring a 500 foot field. At a given T/W and AR there is shown to be an optimum $C_{L_{MAX}}$ for minimum fie field length. Concludes that $C_{L_{MAX}}$ is most important leverage on field length.

I.8.7.24 THE AERODYNAMIC APPRAISAL OF STOL/VTOL CONFIGURATIONS, R.J. Vidal, A. Sowyirda, and R.A. Hartunian, Cornell Aeronautical Laboratory, Report No. Al-1190-A-4, June 1960 and IAS Paper 60-37.
Methods for estimating the characteristics of different STOL/VTOL configurations are discussed.

The results of a small perturbation theory for the finite high aspect-ratio jet flap are presented. The results of the theory are found to be in good agreement with experiment over a wide range of aspect ratios, angles of attack, jet deflections, and jet momentum coefficients.

I.8.7.24 (continued)
Certain aspects of the deflected slipstream configuration have been treated, and it is concluded that the classical model of a tabular propulsive jet cannot be physically realized. The velocity gradients due to the wing alter the solenoidal vortices defining the jet to form secondary or trailing vortices on the jet boundary. The implications of this final wake configuration and the rolling-up process are discussed. The effect of vertical gradients of velocity present in a propeller slipstream are discussed, and the theoretical and experimental results for the two-dimensional case show that there is an interaction effect associated with the slipstream velocity gradients and the wing thickness and camber which results in increased lift.

I.8.7.25 TAKEOFF TRAJECTORY OPTIMIZATION OF A THEORETICAL MODEL OF A STOL AIRCRAFT, F.H. Schmitz, AIAA Paper 69-935, February 1969.
Optimal control theory was applied to the STOL takeoff of a flapped short takeoff and landing aircraft. The object of the analysis was to determine the optimal trajectory which maximizes the terminal vertical distance at a given fixed horizontal takeoff distance. The basic character of the solution was explored by using theoretical aircraft models of gradually increasing degrees of complexity. The optimal control policy can be characterized by an initial level acceleration followed by an accelerating and then decelerating climbout and finally, by a negatively curving flight path near the terminal point. The preliminary sensitivity studies indicate that for the STOL aircraft considered in this paper, the optimal trajectory resulting in the clearance of a fifty-foot obstacle is rather insensitive to sophisticated refinements of the final dynamic model.

I.8.7.26 PREDICTION OF OFF-RUNWAY TAKEOFF AND LANDING PERFORMANCE, A.J. Kuchinka, Journal of Aircraft, pp213-218, May-June 1966.
Theoretical equations are presented for the determination of static and dynamic soil forces against a pneumatic tire. The equations require that the soil properties k, k_{ϕ}, and n must be known. Particular application is made to the prediction of

I.8.7.26 (continued)
aircraft takeoff and landing ground roll distances. Correlation of calculated vs measured distance is shown for both landing and takeoff.

I.8.7.27 TAKEOFF PERFORMANCE OF JET-PROPELLED CONVENTIONAL AND VECTORED-THRUST STOL AIRCRAFT, A.R. Krenkel and A. Salzman, Journal of Aircraft, pp 429-449, September-October 1968.
An analytical method for the determination of the air distance of jet-propelled conventional (CTOL) and vectored-thrust short takeoff and landing (STOL) aircraft was developed. The method assumes constant lift and drag coefficients during the climb and a constant value of the horizontal acceleration based on the aircraft's average velocity from touchoff to the 35- or 50-foot obstacle. It was indicated by this method that some "classical" or specification methods for computing CTOL, air distances are not generally applicable. Design charts were developed for determining the ground, air, and total takeoff distance in terms of: a STOL thrust-to-weight ratio, $(T_x/W)/(1-T_y/W)$; and effective wing loading (W/S)1/C); and the L/D ratio. A parametric study of approximately 100 hypothetical CTOL and STOL aircraft was made, and graphs of the takeoff performance presented. It was shown that thrust-to-weight ratios greater than approximately 0.6 are required in order to show performance gains by thrust vectoring, that the major improvement in takeoff distance derives from the reduction in ground roll while air distance is relatively unaffected, and that reduced wing loadings or improved high-lift capabilities are equally as beneficial.

I.8.7.28 SHORTENING THE TAKEOFF AND LANDING DISTANCES OF HIGH SPEED AIRCRAFT, J.K. Wimpress, Boeing, D6-16168 (also presented at the Twenty-Sixth Meeting of the AGARD Flight Mechanics Panel, 9-10 June 1965) (AGARD Report 501).
Examined some of the fundamental relationships involved in shortening the takeoff and landing distances of high speed aircraft. Reviewed the fundamental parameters that determine takeoff and landing distance with particular emphasis on the influence of lift coefficient (C_L), lift-to-drag ratio (L/D), and thrust-to-weight ratio (T/W). Since lift coefficients are so vital to field length per-

I.8.7.28 (continued)
formance, recent (1965) developments in high lift systems were presented. The results of fitting various high-lift systems into the field length requirements of transport and STOL aircraft were discussed. Demonstrated some of the compromises that must be made to achieve short field length.

I.8.7.29 PROGRAMMES FOR ANALYZING THE SHORT TAKEOFF PERFORMANCE OF DEFLECTED-JET AIRCRAFT, B.A.M. Piggott, D.M. Pullen, Royal Aircraft Establishment, Report No. RAE-TR-67304, November 1967.
Programmes were written to calculate and display the minimum horizontal distance within which a deflected-jet aircraft can reach a specified height. Simplified equations of motion were used and thus the results obtained provide only a rough guide to the performance of the aircraft.

I.8.7.30 RECENT BASIC RESEARCH ON V/STOL AERODYNAMICS AT RAE, J. Williams, Zeitschrift fur Flugweissenchaften, Vol. 14, No. 6, June 1966 pp 257-276.
This paper described briefly V/STOL aerodynamic research carried out at the Royal Aircraft Establishment. Areas covered are jet-lift and fan-lift schemes, BLC, jet-flaps, ground effects, and tunnel-testing techniques.

I.8.7.31 A PARAMETRIC STUDY OF TAKEOFF AND LANDING DISTANCES FOR HIGH-LIFT AIRCRAFT, W.A. Mair and B.J. Edwards, ARC CP 823, 1965.
For propeller aircraft, calculations were made to study the effects of takeoff and landing distances of maximum lift coefficient, wing loading, aspect ratio, and thrust/weight ratio. The maximum lift coefficient that can be usefully employed was shown to be a function of aspect ratio and thrust/weight ratio.

I.8.7.32 NOMOGRAPHIC SOLUTION OF THE MOMENTUM EQUATION FOR VTOL-STOL AIRCRAFT, H.H. Heyson, NASA TN D-814, 1961.
A general nomographic solution for the induced velocities and wake angle is presented for use with VTOL-STOL systems.

I.8.7.33 STOL-SOME POSSIBILITIES AND LIMITATIONS, W.A. Mair, JRAeS, September 1966.
Stresses the importance of keeping $(-C_p)_{max}$ of high lift wings as low as possible and includes some expressions for $(-C_p)_{max}$. Discusses power requirement for BLC both suction and blowing, finite aspect ratio effects, ground effect and operational considerations. Indicates that values of $C_{L_{max}} = 6.0$ can be obtained by future STOL aircraft.

I.8.7.34 CONSIDERATION OF SOME AERODYNAMIC CHARACTERISTICS DURING TAKEOFF AND LANDING OF JET AIRPLANES, J.M. Riebe, NASA TN D-19, 1959.
These considerations are limited to lift-drag relations and do not include such possible related factors as noise, heating, foreign-matter ingestion, or ability to obtain thrust reversal.

I.8.7.35 AERODYNAMIC ASPECTS OF SOME BASIC VTOL/STOL SYSTEMS, Paper presented at the AGARD/V/STOL Symposium, Paris, June 1960.
The paper considers the present state of knowledge on the aerodynamics of the following types of VTOL/STOL systems: direct jet lift (turbo-jet and turbo-fan), propeller lift (tilt wing and deflected slip-stream), jet flaps, boundary layer control (blowing and suction). The first two of these methods for providing adequate lift are relevant to both VTOL and STOL applications. The last two are mainly restricted to STOL applications, or to improving the forward flight performance (transition, control, maximum speed) of VTOL aircraft. Some of the major aerodynamic problems which have been investigated recently or which need further study are discussed.

SECTION II

TEST DATA

II.1 EXTERNALLY BLOWN FLAP

II.1.1 FORCES/MOMENTS

II.1.1.1 AERODYNAMIC CHARACTERISTICS, TEMPERATURE, AND NOISE MEASUREMENTS OF A LARGE-SCALE EXTERNAL-FLOW JET-AUGMENTED-FLAP MODEL WITH TURBO-JET ENGINES OPERATING, M.P. Fink, NASA TN D-943, September 1961. The tests included the measurement of the longitudinal aerodynamic chracteristics over a range of angles-of-attack for a range of momentum coefficients at several trailing-edge flap deflections with half- and full-span flaps. Wing surface temperatures and acoustic loadings were measured on an area of the wing immersed in the jet exhaust.

II.1.1.2 WIND-TUNNEL INVESTIGATION OF EXTERNAL-FLOW JET-AUGMENTED DOUBLE SLOTTED FLAPS ON A RECTANGULAR WING AT AN ANGLE OF ATTACK OF 0° TO HIGH MOMENTUM COEFFICIENTS, E.E. Davenport, NACA TN 4079, September 1957.
A wind tunnel investigation has been made to determine the characteristics of external-flow jet-augmented double slotted flaps which appear suitable for application to aeroplanes with pod-mounted engines. The investigation included tests of a rectangular wing with an aspect ratio of 6 over a momentum coefficient range from 0 to 28.

II.1.1.3 A COMPARISON OF THE AGILITY PERFORMANCE OF A NUMBER OF V/STOL AND STOL AIRCRAFT, R. G. Stuts & G. Price, AIAA, GAADO, Meeting, Wichita, Kansas, May 25-27, 1964, Paper 64-181.
Presentation of a comparison of five V/STOL and STOL aircraft designs for the purpose of determining the effect of their configuration characteristics on agility performance. Agility is defined as the combination of performance and maneuverability that determines how rapidly any aircraft can accelerate, decelerate, and turn at specified rates of climb and airspeed. The five configurations considered are: (1) pure helicopter; (2) winged helicopter; (3) tilt-wing propeller V/STOL aircraft; (4) fixed-wing tilt-propeller V/STOL aircraft; and (5) fixed-wing, direct-control STOL aircraft. To facilitate comparison, the aircraft are all designed to meet the requirements of a single tactical support mission. Due to its high deceleration capability, the winged helicopter has the best agility performance up to its maximum

II.1.1.3 (continued)
speed of 180 knots. Of the propeller-driven designs, the tilt-wing propeller configuration has the best acceleration and normal load factor capability, due primarily to the favorable effect of the propeller slipstream on wing airflow at low speeds. It is felt that agility performance may be as important a design consideration as range, payload, and cruise performance for many V/STOL aircraft missions.

II.1.1.4 EFFECTS OF REDUCED AIRSPEED FOR LANDING APPROACH ON FLYING QUALITIES OF A LARGE JET TRANSPORT EQUIPPED WITH POWERED LIFT, H.L. Crane et al NASA TN D-4804, October 1968.

II.1.1.5 FLIGHT TESTS OF A DIRECT LIFT CONTROL SYSTEM DURING APPROACH AND LANDING, J. W. Stickle, et al, NASA TN D4854, November 1968.

II.1.1.6 INVESTIGATION OF A 0.3-SCALE JET-TRANSPORT MODEL HAVING A JET-AUGMENTED BOUNDARY-LAYER-CONTROL FLAP WITH DIRECT-LIFT CONTROL CAPABILITY, K. Aoyagi et al NASA TN D 5129, July 1969.

II.1.1.7 WIND TUNNEL INVESTIGATION OF THE STATIC LONGITUDINAL STABILITY AND TRIM CHARACTERISTICS OF A SWEPT-BACK-WING JET-TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED FLAP, J. L. Johnson, Jr., NACA TN 4177, January 1958.
The investigation included tests of the model to determine the effects of wing position, vertical position of the horizontal tail, and size of the horizontal tail for a range of momentum coefficients up to about 4. The model had a 30° swept-back wing with an aspect ratio of 6.60. Calculations were made to compare the relative merits of various trim devices for use on airplanes equipped with jet-augmented flaps.

II.1.1.8 WIND TUNNEL INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A MODEL REPRESENTATIVE OF A SUPERSONIC FIGHTER-CLASS AIRPLANE WITH AN EXTERNAL FLOW JET-AUGMENTED FLAP IN LOW SPEED FLIGHT, W.A. Newsom Jr., NASA TN D-50, September 1959.
The model used in the investigation had an unswept

II.1.1.8 (continued)
wing of aspect ratio 3.0 equipped with a full-span double slotted flap. An engine nacelle was strut mounted beneath each wing with the jet diverted upward and outward toward the slot of the double slotted flap. Compressed air was used to represent the exhaust of these pod-mounted engines. The investigation was made for three different wing positions and two different horizontal-tail positions for each wing position and included measurements of both longitudinal and lateral stability characteristics.

II.1.1.9 LOW SPEED INVESTIGATION OF BLOWING FROM NACELLES MOUNTED INBOARD AND ON THE UPPER SURFACE OF AN ASPECT RATIO 7.0 35° SWEPT WING WITH FUSELAGE AND VARIOUS TAIL ARRANGEMENTS, T. R. Turner, E. E. Davenport, and J.M. Riebe, NASA Memo 5-1-59L, June 1959.
An investigation of inboard jet flaps on a semi-span model, representative of current jet transport airplanes, has been made in the Langley 300-MPH 7- by 10-foot tunnel. The jet momentum coefficient range was from 0 to 7.0 and the model angle-of-attack range was from about -14° to about 30°.

II.1.1.10 STATIC AND DYNAMIC-STABILITY DERIVATIVES OF A MODEL OF A JET TRANSPORT EQUIPPED WITH EXTERNAL-FLOW JET-AUGMENTED FLAPS, D.C. Freeman, S.B. Grafton, and R. D'Amato, NASA TN D 5408, September 1969.
A wind tunnel investigation has been made to determine the static and dynamic stability derivatives of a model of a large jet transport equipped with external-flow jet-augmented flaps. The tests were conducted in the Langley full-scale tunnel, and a model powered by scale-model, compressed-air-driven turbofan engines was used.

The results of the investigation showed that blowing on the flap system increased the lift-curve slope, delayed the stall, and increased the maximum lift coefficient. The data also showed that all model configurations generally had static longitudinal stability over the test angle-of-attack range except those at the higher flap-deflection angles where the effects of power were destabilizing. The results also showed that the model had positive damping in pitch, roll, and yaw throughout the test angle-of-attack range up to and slightly beyond the stall for all test

II.1.1.10 (continued)
conditions. The application of power in the flap system resulted in appreciable increases in roll damping but produced essentially no effects in pitch and yaw damping. There were essentially no effects due to oscillation frequency on the damping derivatives.

II.1.1.11 FLIGHT-DETERMINED AERODYNAMIC PROPERTIES OF A JET-AUGMENTED, AUXILIARY-FLAP, DIRECT LIFT CONTROL SYSTEM INCLUDING CORRELATION WITH WIND TUNNEL RESULTS, L.S. Rolls, A.M. Cook and R.C. Innis, NASA TN D-5128, May 1969.
Flight tests were conducted on the modified Boeing 367-80 prototype, jet-transport aircraft to determine the aerodynamic characteristics of an externally blown auxiliary-flap system. These flight data were compared with data from a similarly modified one-third scale model in the Amex 40- by 80-foot wind tunnel. Flight data for dynamic steps of the auxiliary flaps indicate a lower peak normal acceleration capability than that indicated by the flight data for static steps; the lower peak is attributed to a rate limit of the flap actuator. The pilots reported an improvement in the landing flare and touchdown tasks resulting from the increased vertical response of the direct-lift-control system.

II.1.1.12 WIND TUNNEL INVESTIGATION OF AN STOL AIRCRAFT CONFIGURATION EQUPPED WITH AN EXTERNAL-FLOW JET FLAP, L.P. Parlett and J.P. Shivers, NASA TN D 5364, August 1969.
Longitudinal tests were conducted at engine gross-thrust coefficients of from 0 to 3.4 through a range of angle of attack which included the stall; and lateral tests were made, both power-off and power-on, through a sideslip range of +30° at angles of attack of 0° and 10°. Untrimmed lift coefficients of 2.83 in the tail-off condition. With the tail on, nearly all high-lift conditions were characterized by a marked longitudinal instability (or pitch-up tendency) which began at an angle of attack of 7°. The instability was apparently caused by the tip vortices which, under the influence of the highly loaded center section of the wing, were drawn into the region of the horizontal tail. The tail-on configuration was directionally stable and had positive dihedral effect al all flap and power settings tested; and in the takeoff and

II.1.1.12 (continued)
landing conditions increasing power increased directional stability and decreased dihedral effect. With one outboard engine not operating, the model could be trimmed laterally and directionally up to lift coefficients of 4.2 in the takeoff condition and 5.7 in the landing condition. Above these lift coefficients, the model could not be trimmed in roll, but trim in yaw could still be attained.

II.1.1.13 UNPUBLISHED NASA DATA ON A HIGH THRUST WEIGHT RATIO JET TRANSPORT AIRCRAFT CONFIGURATION WITH AN EXTERNAL FLOW JET FLAP.
A wind tunnel investigation was conducted to determine the aerodynamic and stability and control characteristics of a high thrust-weight ratio jet transport configuration equipped with an external-flow jet flap. The tests were made in the Langley full-scale tunnel using a model powered by four high-bypass-ratio turbofan engines.

The results of the investigation showed that maximum lift coefficients of about 8 were measured for test conditions which simulated a jet transport configuration having a thrust-weight ratio of about 0.5. Longitudinal instability was encountered at high-thrust coefficients because of adverse downwash variations in the vicinity of the tail. This problem could be solved by raising the tail and moving it forward to a more favorable downwash field. The model was laterally and directionally stable under all power conditions. The engine-out moments associated with an engine failure were too large to be trimmed out by conventional aileron and rudder control; spoilers provided enough control to offset the engine-out rolling moments but the lift loss associated with the use of spoilers was severe.

II.1.1.14 WIND TUNNEL INVESTIGATION OF A SMALL-SCALE SWEPTBACK JET TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL FLOW JET AUGMENTED DOUBLE SLOTTED FLAP, J. L. Johnson, Jr., NASA Memo 3-8-59L, April 1959.
A wind tunnel investigation at low speeds was made to study the aerodynamic characteristics of a small-scale sweptback-wing jet-transport model equipped with an external-flow jet-augmented double slotted flap. Tests of the wing alone with varying spanwise extent of blowing on the full-span flap

II.1.1.14 (continued)

were made. The results indicated that the double-slotted-flap of the present investigation was more efficient than were the external-flow single-slotted flap previously tested.

II.1.1.15 LARGE SCALE WIND TUNNEL INVESTIGATION OF A MODEL WITH AN EXTERNAL JET AUGMENTED FLAP, J. V. Kirk, D. H. Hickey and K. Aoyagi, NASA TN D-4278, December 1967.

An investigation conducted in the Ames 40- by 80-foot wind tunnel of a large scale model powered by turbojet engines. The wing had 38.5° sweep of the leading edge, an aspect ratio of 5.38, a taper ratio of 0.23, and a dihedral of 3°. The wing airfoil section was an NACA 65-412. The trailing-edge flaps extended from 8 to 63 percent semispan. A small auxiliary flap spanned the main flap. The exhaust from the engines was directed against the flaps to augment lift.

II.1.1.16 UNPUBLISHED NASA DATA ON AN EXTERNAL FLOW JET FLAP TRANSPORT CONFIGURATION HAVING INBOARD POD-MOUNTED ENGINES.

A wind tunnel investigation was conducted to determine the aerodynamic and stability and control characteristics of an external-flow jet-flap transport configuration having inboard pod-mounted engines. The effectiveness of close-inboard-mounting of the engines as a means of reducing the large engine-out moments inherent in an external-flow jet-flap system was investigated. Asymmetric blowing on drooped ailerons and the use of differential flap deflection were evaluated as a means of providing trim to offset the engine-out moments.

The investigation indicated that by locating pod-mounted engines fairly close inboard, it was possible to reduce engine-out moments. The use of either asymmetric blowing over drooped ailerons or differential flap deflection offered a means of achieving roll trim for engine-out conditions over the normal operational angle-of-attack range, but neither method was able to trim the rolling asymmetries that occurred when the wing with an engine inoperative stalled first. The combination of aileron blowing and spoilers provided roll trim capability up to the stall angle of attack but the roll asymmetries exceeded this capability beyond the stall.

II.1.1.17 WIND TUNNEL INVESTIGATION AT LOW SPEEDS OF FLIGHT CHARACTERISTICS OF A SWEPTBACK-WING JET-TRANSPORT AIRPLANE MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED SLOTTED FLAP, J.L. Johnson, Jr., NACA TN 4255, July 1958.
A wind tunnel investigation at low speeds was made to determine the flight characteristics of a model of a sweptback-wing jet-transport airplane equipped with an external-flow jet-augmented slotted flap. The model was blown in the flap-retracted configuration over a lift-coefficient range from 0.6 to 0.9 and in the flap-extended configuration over a lift-coefficient range up to about 12.5 for a range of angles of attack from -12° to about 13°. For tests at the very high lift coefficients, a downwardly directed nose jet was used to supplement the trimming power of the horizontal tail.

II.1.1.18 WIND TUNNEL INVESTIGATION OF A LARGE JET TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET FLAP, J.P.Parlett, M.P. Fink, and D.C. Freeman, NASA TND 4928, December 1968.
A wind tunnel investigation was conducted to determine the aerodynamic characteristics of a model of a large jet transport aircraft equipped with an external-flow jet-augmented flap. The investigation simulated an airplane having a thrust-weight ratio of 0.30 for both takeoff and landing. Static longitudinal stability and trim could be achieved over the entire lift range by the use of a horizontal tail with an area of 22 percent of the wing area. The out-of-trim moments caused by operation with the critical engine out could be trimmed throughout the entire lift range by the use of conventional rudder, aileron and spoiler controls.

II.1.1.19 INVESTIGATION OF A 0.3-SCALE JET TRANSPORT MODEL HAVING A JET-AUGMENTED BOUNDARY-LAYER-CONTROL FLAP WITH DIRECT LIFT CONTROL CAPABILITY, K. Aoyagi and S.O. Dickson, NASA TN D-5129, July 1969.
An investigation was conducted to define a trailing-edge flap system for a large-scale subsonic jet transport model that would provide high lift at low-thrust-to-weight ratios (0.05 to 0.10) and direct-lift control. The model had a 35° swept wing of aspect ratio 6.43 and four pod-mounted engines under the wing. The flap system was externally jet-augmented from the exhaust of the inboard jet engines. The flap system consisted of a main flap with blowing boundary-layer-control and a small auxiliary flap for

II.1.1.19 (continued)
providing direct-lift control.

The results of descent performance computations indicated that the resultant flap system was capable of providing $\pm 0.2g$ incremental acceleration normal to the flight path at an approach speed of 117 knots (1g flight wing loading = 53 psf) or a 4° change in flight-path angle with a thrust-to-weight ratio of 0.05.

II.1.1.20 WIND TUNNEL INVESTIGATION OF AN EXTERNAL FLOW JET-AUGMENTED FLAP SUITABLE FOR APPLICATION TO AIRPLANES WITH POD-MOUNTED JET ENGINES, J. P. Campbell and J. L. Johnson, Jr., NACA TN 3898, 1956.
This was the first externally-blown flap wind tunnel test.

A wind tunnel investigation was conducted out to determine the characteristics of an external-flow jet-augmented slotted flap. The investigation included tests of an unswept wing and of a model of a swept-wing jet transport or bomber. Compressed air jets exhausting from nozzles attached to the lower surface of the wings were used to simulate the jets from pod-mounted jet engines.

The results indicated that static longitudinal stability and trim up to a lift coefficient of 6 could be achieved with an airplane equipped with a jet-augmented flap and having a horizontal tail area equal to 25 percent of the wing area. In order to achieve this result, it was necessary to locate the horizontal tail in a position well above the chord plane of the wing and to incorporate both variable tail incidence and an elevator. The results indicated that an external-flow jet-augmented flap would produce lift coefficients of about 3 for thrust-weight ratio of 0.25 and lift coefficients of about 5 for thrust-weight ratio of 0.40.

II.1.1.21 STATIC TESTS OF AN EXTERNAL-FLOW JET-AUGMENTED FLAP TEST BED WITH A TURBOJET ENGINE, M.P. Fink, NASA TND-124, 1959.
An investigation was conducted on a static test setup representing an external-flow jet-augmented flap arrangement with a slotted flap and a turbojet engine. The investigation consisted of tests in the static condition to determine the turning efficiency of the flap with several slot entrance configurations

II.1.1.21 (continued)
for a range of slot-gap heights with various flattened tailpipes on the turbojet engine. The investigation consisted of tests in the static condition to determine the turning efficiency of the flap with several slot entrance configurations for a range of slot-gap heights with various flattened tailpipes on the turbojet engine.

II.1.1.22 EXPLORATORY WIND TUNNEL INVESTIGATION TO DETERMINE THE LIFT EFFECTS OF BLOWING OVER FLAPS FROM NACELLES MOUNTED ABOUVE THE WING, J.M. Riebe and E. E. Davenport, NACA TN 4298, June 1958.
An exploratory wind tunnel investigation was made of a configuration having blowing from nacelles over the upper surface of flaps. Jet-circulation lift coefficients larger than the jet reactions were produced. Large nose-down pitching moments were encountered.

II.1.2 Flow Fields -

No test data was found during the literature search.

II.1.3 Ground Effect -

No test data was found during the literature search.

II.1.4 Stability and Control -

See Section II.1.1

II.1.5 Handling Qualities and Criteria

See Section II.2.5.2

II.1.6 Testing -

See Section II.8.6

II.1.7 General -

No test data was found during the literature search.

II.2 Deflected Slipstream

II.2.1 Forces and Moments -

II.2.1.1 A SMALL WIND TUNNEL FOR INVESTIGATING THE CHARACTERISTICS OF A WING IN A FINITE JET INCLUDING RESULTS OF A MODEL WITH A SUCTION FLAP, D. J. Marsden, NRC Report LR-255, May 1959.
An open return blower tunnel producing a 0.667 ft. diameter free jet is described. This jet is considered to be a simplified model of a fully contracted propeller slipstream which can be used to investigate the interactions of propeller slipstreams and wings with flaps. Measurements were made using a wing flap model having a 30 percent chord flap with suction boundary layer control. Results obtained with this facility were comparable with results of other similar investigations made with wing flap models operating in a propeller slipstream.

II.2.1.2 SOME FLIGHT CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT, H.L. Turner and F.J. Drinkwater, NASA TN D-1891, July 1963.
The Ryan VZ-3RY was flight tested at speeds from 80 knots to below 6 knots. Results include response to control inputs, takeoff and landing data, rate of climb and sink, α for level flight, and static longitudinal stability.

II.2.1.3 WING AND FLAP LOADS OBTAINED FROM A WIND TUNNEL INVESTIGATION OF A LARGE-SCALE V/STOL MODEL, R. J. Huston, et al., NASA TND-1634, April 1963.
Wing and flap loads on tilt-wing, tilt-wing-with-slat and deflected-slipstream configurations, obtained during tests of the model in the Langley full scale tunnel, are presented for an angle of attack corresponding to transition flight of a vertical or short takeoff and landing aircraft. Included are wing root moments and shears, flap forces and moments and partial-span-wing pressure distributions for a range of flap deflections and lift-drag conditions corresponding to longitudinal acceleration and deceleration.

II.2.1.4 WING PRESSURE MEASUREMENTS WITHIN THE PROPELLER SLIPSTREAM FOR A LARGE-SCALE V/STOL WIND TUNNEL MODEL SIMULATING TRANSITION, M.M. Winston, and R. J. Huston NASA TND 2014, October 1963.

II.2.1.4 (continued)
Pressure data on tilt-wing, tilt-wing-with-slat, and deflected-slipstream configurations are presented. Included are pressure data for a range of flap deflections and lift-drag conditions corresponding to longitudinal acceleration and deceleration.

II.2.1.5 INVESTIGATION OF EFFECTIVENESS OF A WING EQUIPPED WITH A 50-PERCENT-CHORD SLIDING FLAP, A 30-PERCENT CHORD SLOTTED FLAP, AND A 30-PERCENT-CHORD SLAT IN DEFLECTING PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF, R.E. Kuhn, NACA TN 3919, January 1957.
Results are presented of an investigation of the effectiveness of a wing equipped with a 50 percent chord sliding flap and a 30 percent chord slotted flap in deflecting a propeller slipstream downward for vertical takeoff.

II.2.1.6 LARGE-SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT, ASPECT-RATIO-10 WING, TWO PROPELLERS, AND BLOWING FLAPS, R.N. Griffin et al, NASA memo 12-3-58A, TIL 6103, December 1958.
An investigation was made to determine the lifting effectiveness and flow requirements of blowing boundary layer control applied to a propeller-driven aeroplane.

II.2.1.7 LARGE-SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT, ASPECT-RATIO-10 WING, FOUR PROPELLERS, AND BLOWING FLAPS, J.A. Weiberg and V.R. Page, NASA TN D-25, September 1959.
The longitudinal aerodynamic characteristics were determined and compared with data previously presented for the model with two propellers. Spanwise loading, and downwash at the tail are also shown.

II.2.1.8 INVESTIGATION OF THE EFFECTIVENESS OF BOUNDARY-LAYER CONTROL BY BLOWING OVER A COMBINATION OF SLIDING AND PLAIN FLAPS IN DEFLECTING A PROPELLER SLIPSTREAM DOWNWARD FOR VERTICAL TAKEOFF,. K. P. Spreemann and R.E. Kuhn, NACA TN 3904, December 1956.
An investigation was conducted in order to determine the effectiveness of blowing a jet of air over the flaps of a wing equipped with a 50 percent chord sliding flap and a 25 percent chord plain flap in deflecting a propeller slipstream downward for vertical takeoff and the results are presented herein. The effects of a leading edge slat, ground proximity end plate, and propeller position were also

II.2.1.8 (continued)
investigated. The tests were conducted in a static-trhust facility at the Langley Aeronautical Laboratory.

II.2.1.9 WIND TUNNEL INVESTIGATION OF EFFECT OF PROPELLER SLIPSTREAMS ON AERODYNAMIC CHARACTERISTICS OF A WING EQUIPPED WITH A 50-PERCENT-CHORD SLIDING FLAP AND A 30-PERCENT-CHORD SLOTTED FLAP, R. E.Kuhn, and W.C. Hayes, NACA TN 3918, February 1957.
Results are presented of an investigation at low speed of the effect of propeller slipstreams on the aerodynamic characteristics of a wing equipped with a 50 percent chord sliding flap in combination with a 30 percent chord slotted flap.

II.2.1.10 EXPERIMENTAL INVESTIGATION OF THE AERODYNAMICS OF A WING IN A SLIPSTREAM, M. Brenckmann, UTIA TN No.11, April 1957.
An experimental study of a wing in a propeller slipstream is made to determine the distribution of the lift increase due to slipstream at different angles of attack of the wing and at different free-stream-slipstream velocity ratios, the results being intended as an evaluation basis for different theoretical treatments of this problem.

II.2.1.11 THE STATIC AND FORWARD SPEED TESTING OF A FLAPPED WING WITH BOUNDARY LAYER CONTROL FOR USE IN DEFLECTING SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF, Part I, B. Neal, NRC Report LR-288, July 1960.
Force and moment data are presented for a four-propeller model of a slipstream deflection type VTOL aircraft wing using a slotted forward flap together with a plain rear flap over which boundary layer control air was blown. Tests were performed out of ground effect both statically and at forward speed for a wide range of flap settings on a mobile test rig that can be towed at speeds up to 50 ft/sec.

II.2.1.12 AN EXPERIMENTAL INVESTIGATION OF THE DEFLECTION OF A FREE-AIR JET BY A FLAPPED WING: THE SUPER-ADDITIVE EFFECTS OF SHIELDED FLOW CONTROL DEVICES, D. J. Marsden and P.J. Pocock, NRC Report LR-285, July 1960.
Methods for improving the slipstream deflection effectiveness of a 40 percent chord single-slotted double flap were studied experimentally using a half-wing model in a free-air jet. The tests were conducted out of ground effect.

II.2.1.13 LARGE SCALE WIND TUNNEL TESTS OF A DEFLECTED SLIPSTREAM STOL MODEL WITH WINGS OF VARIOUS ASPECT RATIOS, V.R. Page et al, NASA TN D 4418, March 1968. Test configurations included: three wing spans, full-span leading-edge slats, full span triple-slotted trailing-edge flaps deflected from 0° to 100°, two directions of propeller rotation, and spanwise variation of propeller thrust. Shows lift, drag and pitching moment coefficients for various configurations and the effect of propellers on spanwise lift distribution.

II.2.1.14 RESULTS OF A BRIEF FLIGHT INVESTIGATION OF A COIN-TYPE STOL AIRCRAFT, T.W. Feistel and R.. Innis, NASA TN D-4141,August 1967.
Includes takeoff, landing, descent performance and compares wind tunnel and flight test polars.

II.2.1.15 INVESTIGATION OF THE EFFECTS OF PROPELLER DIAMETER ON THE ABILITY OF A FLAPPED WING, WITH AND WITHOUT BOUNDARY LAYER CONTROL, TO DEFLECT A PROPELLER SLIPSTREAM DOWNWARD FOR VERTICAL TAKEOFF, K. P. Spreeman, NACA TN 4181, December 1957.

II.2.1.16 PRELIMINARY INVESTIGATION OF THE EFFECTIVENESS OF A SLIDING FLAP IN DEFLECTING A PROPELLER SLIPSTREAM DOWNWARD FOR VERTICAL TAKEOFF, R. E. Kuhn and K.P. Spreeman, NACA TN 3693, May 1956.
Results are presented of an investigation of the effectiveness of a sliding flap in deflecting propeller slipstreams downward for vertical take-off. The model consisted of a semi-span wing equipped with a 50 percent chord sliding flap and a 25 percent chord plain flap and was tested in hover.

II.2.1.17 INVESTIGATION AT ZERO FORWARD SPEED OF A LEADING-EDGE SLAT AS A LONGITUDINAL CONTROL DEVICE FOR VERTICALLY RISING AIRPLANES THAT UTILIZE THE RE-DIRECTED-SLIPSTREAM PRINCIPLE, R.E. Kuhn, NACA TN 3692, May 1956.
Results are presented of an investigation of a leading-edge slat as a longitudinal control device for vertically rising aeroplanes, in hovering flight. The model consisted of a semi-span wing equipped with a 60 percent chord and a 30 percent chord slotted flap operating in the slipstreams of two large diameter propellers.

II.2.1.18 A REVIEW AND SUMMARY OF THE AVAILABLE AERODYNAMIC DATA ON DEFLECTED SLIPSTREAM ARRANGEMENTS SUITABLE FOR VTOL APPLICATIONS, J.A. Dunsby, NAE Report LR-205, September 1957.
A review is made of the existing experimental and theoretical aerodynamic data on wing-propeller combinations intended for vertical takeoff utilizing the deflected slipstream principle. While a considerable volume of data is available indicating the trends of many important characteristics, it is clear that much theoretical and experimental work remained to be done in 1957.

II.2.1.19 WIND TUNNEL AND PILOTED FLIGHT SIMULATOR INVESTIGATION OF A DEFLECTED-SLIPSTREAM VTOL AIRPLANE, THE RYAN VZ-3RY, H.A. James, et al, NASA TN D-89, November 1959.
The characteristics of the deflected-slipstream VTOL aeroplane during a transition from hovering to normal flight were studied. The longitudinal, lateral, and directional stability and control characteristics of the vehicle were measured in the tunnel. The data were used for the simulation to document the handling qualities of the vehicle; the simulator cockpit was free to pitch and roll.

II.2.1.20 PRESSURE DISTRIBUTION AND FORCE MEASUREMENTS ON A VTOL TILTING WING-PROPELLER MODEL, PART I: DESCRIPTION AND TABULATED RESULTS, J.A. Dunsby, M.M. Currie, and R.L. Wardlaw, NRC-Aeronautical Report LR-252.
This report presents tabulated results of pressure and force measurements on a half wing model of a twin-engined tilt-wing VTOL configuration over a range of thrust coefficient for a range of incidence -10° to +10°.

II.2.1.21 PRESSURE DISTRIBUTION AND FORCE MEASUREMENTS ON A VTOL TILTING WING-PROPELLER MODEL, PART II: ANALYSIS OF RESULTS, M.M. Currie and J. A. Dunsby, NRC-Aeronautical Report LR 284., 1959.
This report presents in graphical form the results presented in Reference 2 from pressure distribution and force measurements on a half-wing model of a twin-engined tilt-wing VTOL configuration. The profound influence of the slipstream on these results is discussed in some detail.

II.2.1.22 INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A COMBINATION JET-FLAP AND DEFLECTED-SLIPSTREAM CONFIGURATION AT ZERO AND LOW FORWARD SPEEDS, K.P. Spreemann, and E.E. Davenport, NASA TN D363, May 1960.

An investigation of the aerodynamic characteristics of a semi-span wing equipped with a 38.5 percent chord sliding flap partially immersed in the slipstream of two propellers has been conducted. A jet of air was ejected over the knee of the flap through a momentum range from zero to about 1.0. This investigation was made to provide data on the combined effects of a jet flap and a flap-deflected slipstream at zero and low forward speeds. Pressure distributions near the wing leading edge behind the inboard propeller for conditions out of ground proximity and within ground proximity were obtained.

II.2.1.23 INVESTIGATION OF EFFECTIVENESS OF LARGE-CHORD SLOTTED FLAPS IN DEFLECTING PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF AND LOW-SPEED FLIGHT, R. E. Kuhn and J.W. Draper, NACA, TN 3364, January 1955.

An investigation of the effectiveness of a wing equipped with large-chord slotted flaps and an auxiliary vane in rotating the effective thrust vector of propellers to a near-vertical direction for vertical takeoff and low-speed flight has been conducted. The model consisted of a semispan wing equipped with 60 percent, chord and 30 percent, chord slotted flaps. Two large-diameter overlapping propellers, driven by electric motors, were used. The effect of wing incidence, propeller blade angle, and an auxiliary vane on the ability of the wing equipped with slotted flaps to deflect the propeller slipstreams downward were also investigated.

II.2.1.24 SOME EFFECTS OF PROPELLER OPERATION AND LOCATION ON ABILITY OF A WING WITH PLAIN FLAPS TO DEFLECT PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF, J. W. Draper and R.E. Kuhn, NACA TN 3360, January 1955.

An investigation has been conducted of the effects of propeller blade angle, mode of propeller rotation, propeller location, and ratio of wing chord to propeller diameter on the ability of a wing with plain flaps to deflect the propeller slipstream downward in order to achieve vertical takeoff. The basic model consisted of a semispan wing with 30 percent, chord and 60 percent, chord plain flaps.

II.2.1.24 (continued)
Two large diameter overlapping propellers driven by electric motors were used.

II.2.1.25 MODULATED THRUST TO IMPROVE STOL AIRCRAFT PERFORMANCE (A FLIGHT TEST EVALUATION) G. W. Johnston, AGARD in AGARDograph, 89 "V/STOL Aircraft", Part I, September 1964.

Direct improvements result from the combined section of the deflected slipstream and reverse jet combination including the important interference effects possible with certain aircraft layouts. Achievable improvements based on model and full-scale measurements are given. Indirect operational improvements are associated with the provision of an additional powerful landing control, which complements normal elevator control. The scope of such improvements is indicated clearly from the results of the landing trials performed with the experimental aircraft. These results are also reviewed. The integration of this concept with the lift augmentation obtained by means of flap boundary layer control and the existence of inherent limitations at increased values of auxiliary thrust-to-weight ratios are briefly discussed. The test aircraft, employing slipstream deflection with in-flight reverse thrust, consistently attains total landing distances from 50ft. of less than 500 ft. in standard atmosphere at a wing loading of 23 lb/ft^2. This compares with a performance level of approximately 1,000 ft. in the unmodified configuration at the same wing loading.

II.2.1.26 INVESTIGATION OF MAXIMUM LIFT DUE TO THE PROPELLER SLIPSTREAM DEFLECTION, F. Wenk, Luftfahrttechnik Raumfahrttechnik, Vol.10, January 1964.
Presentation of the results of measurements conducted to increase the maximum lift of an aircraft by means of the propeller slipstream. In particular, the possibility of lift increase through propeller tilting, as in the case of the Do29 aircraft, or through the slipstream deflection by means of suitable flaps is considered. The effect of a boundary layer on the lift and drag caused by the exhaust over the landing flaps is also investigated. It is shown that with a relatively simple flap configuration the propeller slipstream deflections can be achieved, thus making possible a glide-angle landing without pulling out, which is in effect a short landing.

II.2.1.27 THE STATIC AND FORWARD SPEED TESTING OF A FLAPPED WING WITH BOUNDARY LAYEP CONTROL FOR USE IN DE-FLECTING PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF, PART II: TESTS AT INCIDENCE AND GROUND PROXIMITY EFFECTS, B. Neal, NAE Report LR-383.
Results from test at incidence and in the region of ground effect are presented for a large scale, four-propeller, flapped, VTOL aircraft wing model using the mobile test rig developed at this laboratory. Data are presented for two flap configurations with various amounts of blowing boundary layer control for values of blowing boundary layer control for values of the thrust coefficient T_c'' from 0.6 to 1.0. A comparison of ground proximity effects over a fixed and moving ground was made and a theory was used to predict successfully the effect of ground proximity on the thrust recovery factor and the slipstream turning angle.

II.2.1.28 RECENT FRENCH EXPERIENCE IN THE FIELD OF V/STOL AIRCRAFT, P.E. Lecomte, SAE, ASE, NAN, meeting Washington, D.C., April 8-11, 1963. paper 670B., Review of some of the problems raised by the flying qualities of French V/STOL aircraft. A comparison is made with the AGARD provisional requirement. From the experience gained during flight tests the adequacy of the requirements is analyzed. Refers to Breguet 941 and Dassault Balzac. Includes lift-drag polar and takeoff and landing performance of Breguet 941.

II.2.1.29 EFFECTS OF PROPELLER POSITION AND OVERLAP ON THE SLIPSTREAM DEFLECTION CHARACTERISTICS OF A WING-PROPELLER CONFIGURATION EQUIPPED WITH A SLIDING AND FOWLER FLAP, NACA TN 4404, 1958, W.C.Hayes, Jr., P.E. Kuhn, and I.R. Sherman.
Static tests out of ground effect; separate winged propeller.

II.2.1.30 LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A FOUR-PROPELLER DEFLECTED SLIPSTREAM VTOL MODEL INCLUDING THE EFFECTS OF GROUND PROXIMITY, R.E. Kuhn, and K.J. Grunald, NASA TN D 248, 1960.
Model tests of the VZ5FA. Lift, drag, moment, trim.

II.2.1.31 AN INVESTIGATION OF A WING-PROPELLER CONFIGURATION EMPLOYING LARGE-CHORD PLAIN FLAPS AND LARGE-DIAMETER PROPELLERS FOR LOW SPEED FLIGHT AND VERTICAL TAKE-OFF, R. E. Kuhn and J.W. Draper, NACA TN 3307, December 1954.

II.2.1.31 (continued)
An investigation of the effectiveness of a wing equipped with large chord plain flaps and auxiliary vanes in rotating the effective thrust vector from two large diameter propellers to a near vertical attitude for vertical takeoff and low-speed flight has been conducted in the Langley 300 mph 7- by 10-foot tunnel. The model consisted of a semispan wing equipped with a 60-percent-chord and a 30-percent-chord plain flap. Two large diameter overlapping propellers, driven by electric motors, were used. The tests covered a range of angle of attack from 0° to 90° and a thrust-coefficient range representative of free-flight velocities from zero to the normal range of cruising velocities.

II.2.1.32 AERODYNAMIC CHARACTERISTICS OF TWIN-PROPELLER DEFLECTED SLIPSTREAM STOL AIRPLANE MODEL WITH BOUNDARY-LAYER CONTROL ON INVERTED V-TAIL, R.J. Margason and G. L. Gentry, NASA TN D4856, November 1968.
The model was tested both with and without tail at a number of different thrust coefficients over a range of angles of attack. Measurements were made with flap deflections of 0 and 45°. Lateral directional stability parameters C_{Y_β} and C_{ℓ_β} were measured for a range of angle of attack. Non-linearities were apparent in lateral characteristics at large sidewash angles (>10°). Engine out tests are made at β=10° for a range of α and at α=1° for a range of β with the engine out. Some configurations chosen to trim the'engine out' moments are also tested.

II.2.1.33 FLIGHT TEST EVALUATION OF THE UF-XS JAPANESE STOL SEAPLANE, Naval Air Test Center, TR FT 212-03lR-64, N. J. Vagianos, E.C. Rooney, August 1964.
The UF-XC Japanese STOL seaplane was evaluated to determine the flying qualities at approach speeds in the vicinity of 55 KT and the hydrodynamic characteristics while on the water. The NASA Ames simulator showed good correlation with the airplane's aerodynamic characteristics. The airplane has neutral to unstable static longitudinal stability, weak directional stability, large adverse yaw, a long period moderatly damped dutch roll mode, a divergent spiral mode, and trims for flight in a 13 degree left sideslip. An automatic stabilization equipment (ASE) makes the static longitudinal

II.2.1.33 (continued)
stability and spiral modes positive but does not improve the remaining items. Takeoff and landing touchdown speed is 50 KT. The airplane has a hydrodynamic stable elevator range of 20 to 35 degrees up elevator. A 'digging in' and slight 'porpoising' tendency is exhibited at elevator positions less than 20 degrees. The airplane posseses good spray characteristics. The mission capability of a STOL seaplane should greatly improve with reduction in takeoff and landing speed; however, evaluation of the airplane at lower speeds was not possible due to several airplane limitations.

II.2.1.34 BREGUET 941.01 (BR 941) LIMITED FLIGHT EVALUATION, C. J. Henshaw, J.S. Schiele.
This report presents the results of a limited flight test evaluation of the Breguet 941 prototype aircraft. The objectives of the evaluation were to collect limited performance data, qualitative stability and control data, and to evaluate the BR 941 during STOL operation on- and off-runway. The cross-shaft driven propellers used on the BR 941 airplane provided safe operation and created pilot confidence at the low flight speeds required for STOL operation. The control power available, even at minimum flying speed, was more than adequate about all three axes. The propeller cross-shaft design concept of the BR 941 should be a primary consideration for all future similar V/STOL vehicles. Aircraft longitudinal static stability was essentially neutral in all configurations tested. Center of gravity location had very little effect on longitudinal static stability. The maximum speed of the test aircraft, using normal rated power, was only 215 KTAS at 10,000 feet.

II.2.1.35 A REVIEW OF THE WING SLIPSTREAM PROBLEM WITH EXPERIMENTS ON A WING SPANNING A CIRCULAR JET, F. W. Gobetz, Princeton Univ., N. J. AD-233 722.

II.2.1.36 PERFORMANCE RECORD OF BREGUET 941-942 AIRPLANE, F. Beaume, Army Foreign Science and Technology Center Washington,D.C., March 1965.

II.2.1.37 AN EXPERIMENTAL INVESTIGATION OF THE AERODYNAMIC FORCES AND MOMENTS ON A JET FLAPPED WING IN THE PRESENCE OF A PROPELLER SLIPSTREAM AND A FREESTREAM, W.R. Fimple, AD-270 966 Princeton University.

II.2.1.38 EXPERIMENTAL DETERMINATION OF SPANWISE LIFT EFFECTS ON A WING OF INFINITE ASPECT RATIO SPANNING A CIRCULAR JET, R.S. Snedeker AD 259 534, Princeton Univ.
The propeller slipstream-wing interaction and it effects on spanwise lift distribution are discussed. Recent theoretical and experimental work is briefly reviewed. A more detailed discussion is given of experiments which make use of circular non-rotating jets for slipstream simulation. Features of the present experimental program are presented with lift distributions showing marked correlation with the theory of Rethorst for a plane wing of infinite span. Additional results are presented for this wing with a .20c split flap at deflection angles of 20 and 40 deg. It is concluded that Rethorst's theory represents the most satisfactory approach to date for analyzing the spanwise effects of the interaction.

II.2.1.39 INVESTIGATION OF THE EFFECTS OF GROUND PROXIMITY AND PROPELLER POSITION ON THE EFFECTIVENESS OF A WING WITH LARGE CHORD SLOTTED FLAPS IN REDIRECTING PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKEOFF, R.E. Kuhn, NACA TN 3629, March 1956.
An investigation of the effects of ground proximity and propeller position on the effectiveness of a wing equipped with large-chord slotted flaps in redirecting the slipstreams from large-diameter propellers downward for vertical takeoff was conducted in a static-thrust facility.

The results indicate that, with the propeller thrust axis on the wing chord plane, both the angle through which the slipstream is deflected and the ratio of resultant force to thrust are reduced as the ground is approached. At positions nearest the ground some of the loss in resultant force is regained. Lowering the thrust axis below the wing chord plane reduces the adverse effects of the ground and also reduces the large diving moments associated with the slotted-flap arrangement. The static-thrust efficiency of the propellers is slightly reduced by the ground effect.

II.2.1.40 WIND TUNNEL INVESTIGATION OF A DEFLECTED-SLIPSTREAM CRUISE-FAN V/STOL AIRCRAFT WING, W.A. Newsom Jr., NASA TN D 4262, December 1967.
An investigation of a wing ducted fans mounted so that the slipstream would spread over most of the span of the wing was made. The wing was equipped

II.2.1.40 (continued)
with a double slotted flap and the ducts were mounted at various positions on the leading edge. Tests were made for three different duct-exit configurations over a range of angles of attack and fan thrust for various flap angles. The greatest amount of circulation lift was induced on the wing when the two ducts were mounted at the 1/4- and 3/4 semispan stations and when the slipstream from the ducts was divided with one-third of it going over the wing and two-thirds of it beneath the wing. The investigation also showed that chordwise fences on the upper surface of the flaps were effective in improving the turning effectiveness of the flaps and increasing the lift induced on the wing by the duct-exit flow. The efficiency of the subject powered-lift system was such that the model had a desirably low thrust-required curve throughout the transition speed range. In this speed range, the thrust required closely approximated that required as calculated from momentum relations based on the idealized assumption of an elliptical distribution of lift across the entire span of the wing. A slipstream-deflection angle for hovering flight of 88° with a thrust loss of only 8 percent was obtained.

II.2.1.41 AN EXPERIMENTAL INVESTIGATION BY FORCE AND SURFACE PRESSURE MEASUREMENTS OF A WING IMMERSED IN A PROPELLER SLIPSTREAM, PART I: FORCE AND MOMENT MEASUREMENTS, Y.Nishimura, National Aeronautical Establishment, LR-501.
A wind tunnel investigation was made of wings immersed in a propeller slipstream. Three wing configurations were tested with various flap deflections and propeller thrust coefficients through a range of wing incidences from 0° to 120°. Wing forces have been isolated from the total forces. There was a slight increase in propeller thrust due to the presence of the wing. A method for estimating lift and drag of a wing-in-slipstream was given in an appendix. No comparison between theory and experiment was made.

II.2.1.42 PROPELLER SLIPSTREAM EFFECTS AS DETERMINED FROM WING PRESSURE DISTRIBUTIONS ON LARGE-SCALE SIX-PROPELLER VTOL MODEL AT STATIC THRUST, M. M. Winston, R. J. Huston, NASA TND 1509.
Pressure distribution on flapped wings have been measured at a number of different spanwise locations

II.2.1.42 (continued)
in the propeller slipstream of a large model at zero forward speed. Pressure distributions are illustrated and some have been integrated to show spanwise variations of normal and chordwise force on the wing.

II.2.1.43 DATA FROM A STATIC-THRUST INVESTIGATION OF A LARGE-SCALE GENERAL RESEARCH VTOL/STOL MODEL IN GROUND EFFECT, R. J. Huston, and M.M. Winston, NASA TND-397, 1960.

II.2.1.44 EFFECTIVENESS OF BOUNDARY LAYER CONTROL OBTAINED BY BLOWING OVER A PLAIN REAR FLAP IN COMBINATION WITH A FORWARD SLOTTED FLAP, IN DEFLECTING A SLIP-STREAM DOWNWARD FOR VERTICAL TAKEOFF, K.P. Spreeman, NACA TN 4200, 1958.

II.2.1.45 EXPERIMENTAL INVESTIGATION OF THE LATERAL TRIM OF A WING-PROPELLER COMBINATION AT ANGLES OF ATTACK UP TO 90° WITH ALL PROPELLERS TURNING IN THE SAME DIRECTION, Q. A. Newsom, Jr., NACA TN 4190, 1958. Measured longitudinal and lateral forces and moments in sideslip and bank.

II.2.1.46 PROPELLER SLIPSTREAM EFFECTS AS DETERMINED FROM WING PRESSURE DISTRIBUTION ON A LARGE SCALE SIX-PROPELLER VTOL MODEL AT STATIC THRUST, M.M. Winston and R.J. Huston, NASA TN D 1509, 1962.

II.2.1.47 V/STOL DEVELOPMENT OF THE C-130 HERCULES, T. Dansby, W.C.J. Garrand, D. M. Pyle and L.J. Sullivan, J. Aircraft Vol.1 No.5, September-October 1965. Reviewed STOL performance of STOL C-130 and the BLC-130. Noted negative longitudinal and lateral stability at low speed.

II.2.1.48 A FLIGHT INVESTIGATION OF OPERATING PROBLEMS OF V/STOL AIRCRAFT IN STOL-TYPE LANDING AND APPROACH, R.C. Innis, and H.C. Quigley, NASA TND 862. Flight test data is presented from tests on YC-134A, a 2-propeller deflected slipstream STOL airplane. Indicated poor directional control at approach speed.

II.2.1.49 HANDLING QUALITIES AND OPERATIONAL PROBLEMS OF A LARGE FOUR-PROPELLER STOL TRANSPORT AIRPLANE, H. C. Quigley, R.C. Innis, NASA TND 1647. Flight tests were carried out to evaluate the NC-130B. The airplane takeoff and landing

II.2.1.49 (continued)
performance was evaluated. Other information includes longitudinal and lateral trim sideslip and bank performance, lift-drag curves and operational envelopes. Unsatisfactory lateral-directional handling qualities were exhibited in approach configuration.

II.2.1.50 FLIGHT TESTS UNDER IFR WITH AN STOL TRANSPORT AIRCRAFT, R. C. Innis, C.A. Holzhauser, R. P. Gallant, NASA TND-4939.
Flight tests of BR-941 in instrument flight are reported. Directional stability was not satisfactory during landing approach. The control system of the airplane has been considerably modified since the tests reported in Ref. II.2.4.1.

II.2.1.51 LONGITUDINAL TRIM CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT DURING LEVEL FLIGHT AT TRANSITION FLIGHT SPEEDS, H.L. Turner, F.J. Drinkwater, III., NASA TND 1430.
Trim characteristics of VZ3-RY.

II.2.1.52 THE EFFECT OF PROPELLER SLIPSTREAM ON WING AND TAIL, J. Stuper, NACA TM 874, 1938.
This report contains a large amount of test data for propeller slipstreams flowing over wings at low incidence. They are not really representative of STOL conditions since most of the propellers are relatively small. Downwash measurements in the wake have also been measured.

See also II.6.1.4, 8, 12, 13, 15, 16.

II.2.2 Flow Fields -

II.2.2.1 EFFECT OF PROPELLER THRUST ON DOWNWASH AND VELOCITY AT TAIL PLANE, A. Spence, ARC CP 21, Data from low speed tunnel tests.

II.2.3 Ground Effect -

II.2.3.1 LATERAL STABILITY AND CONTROL CHARACTERSITICS OF A FOUR-PROPELLER DEFLECTED-SLIPSTREAM VTOL MODEL INCLUDING THE EFFECTS OF GROUND PROXIMITY, R. E. Kuhn and K.J. Grunwald, NASA TN D-444, January 1961.
The investigation covered the transition speed range from hovering to normal flaps-retracted flight. The tests covered the effects of flap deflection, thrust coefficient, aileron deflection, rudder deflection, and ground proximity.

II.2.3.2 INVESTIGATION OF LONGITUDINAL AND LATERAL STABILITY CHARACTERISTICS OF A SIX-PROPELLER DEFLECTED-SLIPSTREAM VTOL MODEL WITH BOUNDARY LAYER CONTROL INCLUDING EFFECTS OF GROUND PROXIMITY, K. J. Grunwald, NASA TND-445, January 1961.
The high-wing configuration had a 50 percent chord sliding flap and a 30 percent chord Fowler flap to deflect the propeller slipstream for vertical take-off and landing. The tests covered the transition speed range from hovering to normal flight with flaps retracted. Variables were flap deflection, thrust coefficient, stabilizer incidence, ground proximity, and blowing boundary layer control effectiveness.

See also, II.2.1.8, 18, 22, 27, 30, 39, 43.

II.2.4 Stability and Control -

II.2.4.1 A FLIGHT INVESTIGATION OF THE PERFORMANCE,HANDLING QUALITIES,,AND OPERATIONAL CHARACTERISTICS OF A DEFLECTED SLIPSTREAM STOL TRANSPORT AIRPLANE HAVING FOUR INTERCONNECTED PROPELLERS, H. C. Quigley et al, NASA TN D2231, March 1964.
Results include: takeoff, landing, and cruise performance; correlation of control characteristics with pilot opinion; stability.

II.2.4.2 LATERAL CONTROL CHARACTERISTICS OF A POWERED MODEL OF A TWIN-PROPELLER DEFLECTED SLIPSTREAM STOL AIRPLANE CONFIGURATION, R. J. Margason and A. D. Hammond, NASA TND 1585, November 1964.
The investigation covered the takeoff and landing speed range. Tunnel-tests were made at several flap deflections to show effects of thrust coefficient, aileron deflection, differential propeller thrust, and spoiler projection on the lateral control characteristics.

II.2.4.3 LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A POWERED MODEL OF A TWIN PROPELLER DEFLECTED SLIPSTREAM STOL AIRPLANE CONFIGURATION, R. J. Margason, A. D. Hammond, and G. L. Gentry, NASA TND-3438.
Longitudinal characteristics of the same model as that reported in II.2.4.2.

II.2.4.4 LONGITUDINAL TRIM CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT DURING LEVEL FLIGHT AT TRANSITION FLIGHT SPEEDS, H. L. Turner and F. J. Drinkwater, III, NASA TND 1430, 1962.

II.2.5 Handling Qualities and Criteria -

II.2.5.1 A FLIGHT AND SIMULATOR STUDY OF THE HANDLING QUALITIES OF A DEFLECTED SLIPSTREAM STOL SEAPLANE HAVING FOUR PROPELLERS AND BOUNDARY LAYER CONTROL, C. A. Holzhauser, R. C. Innis, and R. T. Vomaske, NASA Ames Research Center, MOffet Field, Calif., Wash. NASA, September 1965, (NASA TND 2966). Flight and simulator tests were made to study low-speed handling qualities, potential STOL problem areas and causes of deficiencies and their solutions. Tests of the STOL seaplane were made in the 50- to 60-knotspeed range with Automatic Stabilization Equipment (ASE) engaged and disengaged. During the simulation, several stability and damping derivatives were varied and evaluated.

II.2.5.2 AIRWORTHINESS CONSIDERATIONS FOR STOL AIRCRAFT, R. C. Innis, C. A. Holzhauser and H.C. Quigley. Presents discussions on the lowspeed envelope; field length factors and handling qualities. Propose criteria for satisfactory handling per- and performance of powered-lift STOL airplanes. Includes results of flight tests of seven deflected slipstream STOL airplanes. (NASA TND-5504)

II.2.5.3 A FLIGHT AND SIMULATOR STUDY OF DIRECTIONAL AUGMENTATION CRITERIA FOR A FOUR-PROPELLERED STOL AIRPLANE, H. C. Quigley, R.C. Innis, R. F. Vomaske and J.W. Ratcliff, NASA TND-3909. The NC-130B deflected slipstream STOL airplane was equipped with an augmentation system to drive the rudder in response to a selection of inputs. Lateral characteristics were improved but still unsatisfactory.

See also, II.2.1.2, 14, 28, 33, 47, 48, 49 50.
II.2.4.1, II.2.5.1, II.2.6.1.

II.2.6 Testing -

II.2.6.1 A TEST PILOT REPORT ON THE X-13 VERTIJET AND VZ-3RY VERTIPLANE, P.F. Girard and W.L. Everett, New York Academy of Sciences, Annals, Vol.107, Art.1, March 25, 1963

Discussion of the technical and operational problems which came to light during the development of the Ryan X-13 turbojet VTOL aircraft, the effects of these problems, and the solutions employed in overcoming them. A brief design analysis of the original X-13 configuration is presented, outlining the reasons for selection of the various approaches. Problems, which manifested themselves during flight testing of the Ryan VZ-3RY experimental deflected-slipstream V/STOL aircraft, are reviewed. The specific problems discussed are ground effect, lateral control deterioration with steep forward approach paths, and pitching moment at very low airspeeds.

See also, II.2.1.1

II.3 JET FLAP

II.3.1 Forces and Moments -

II.3.1.1 WIND TUNNEL INVESTIGATION OF JET-AUGMENTED FLAPS ON A RECTANGULAR WING TO HIGH MOMENT COEFFICIENTS, V. E. Lockwood, et al. NACA TN 3865, December 1956.
Results and a discussion are presented of a preliminary investigation of jet flaps made in 300 m.p.h. 7 by 10-foot tunnel on an unswept,untapered wing with an aspect ratio of 8.4 and a thickness of 16.7 percent.

II.3.1.2 AN EXPERIMENTAL INTRODUCTION TO THE JET FLAP, N. A. Dimmock, C.P. 344, 1957.
The experimental results obtained from two two-dimensional aerofoils, each having a 12.5 percent thick elliptical cross section with a narrow full span jet slot at the trailing edge, the jet deflections being respectively 90° and 31.4° are recorded. The losses in the system have been considered and some of them investigated, those due to Reynolds number and jet entrainment effects being included. Also, the influence of ground proximity on the lift and centre of lift of the 31.4° model was measured at zero incidence. A tentative empirical expression is suggested for the pitching moment coefficient.

II.3.1.3 THREE-DIMENSIONAL WIND TUNNEL TESTS OF A 30° JET FLAP MODEL, J. Williams and A.J. Alexander, British ARC C.P. 304, 1957.
As a first investigation of finite aspect ratio effects in relation to the jet flap scheme, pressure plotting experiments were made on a small-scale model, with a 12 1/2 percent thick wing section already tested under two-dimensional conditions at the NGTE.

II.3.1.4 WIND TUNNEL INVESTIGATION OF EXTERNAL-FLOW JET-AUGMENTED DOUBLE SLOTTED FLAPS ON A RECTANGULAR WING AT AN ANGLE OF ATTACK OF 0° TO HIGH MOMENTUM COEFFICIENTS, E. E. Davenport, NACA TN 4079, September 1957.
A wind tunnel investigation has been made to determine the characteristics of external-flow jet-augmented double slotted flaps which appear suitable for application to aeroplanes with pod-

II.3.1.4 (continued)
mounted engines. The investigation included tests of a rectangular wing with an aspect ratio of 6 over a momentum-coefficient range from 0 to 28.

II.3.1.5 UNTERSUCHUNGEN UBER DIE ERHOHUNG DES AUFTRIEBES VON TRAGFLUGELN MITTELS GRENZSCHICHTBEEINFLUSSUNG DURCH AUSBLASEN, F. Thomas, DFL Bericht 174, 1962. In German.
A survey on systematic measurements on a rectangular wing with a blown flap at the trailing edge is given. Along the whole span of the wing air was blown out through a narrow slot over the flap in order to prevent boundary layer separation at high angles of flap deflection. Numerous force and pressure plotting measurements were made at Reynolds numbers between 4×10^5 and 8×10^5. Measurements with an increased momentum coefficient (c up to 1) included the region of supercirculation. To find a theoretical estimate for the minimum momentum coefficient required for preventing the flow separation, the flow phenomena in the boundary layer downstream of the blowing slot were investigated by special experiments.

II.3.1.6 LOW SPEED INVESTIGATION OF A FULL-SPAN INTERNAL-FLOW JET-AUGMENTED FLAP ON A HIGH-WING MODEL WITH A 35° SWEPT WING OF ASPECT RATIO 7.0, T. R. Turner, NASA TN D 434, August 1960.
An investigation of full-span internal-flow jet-augmented flap on a semispan jet transport model has been made in the Langley 300 mph 7x10ft. tunnel. The large diving moments were trimmed by blowing over the deflected elevator or by downward blowing from a fuselage nose jet. The jet momentum coefficient range was 0 to 6.33, the flap deflection range was 0° to 7° and the angle-of-attack range extended from -25° to the stall angle.

II.3.1.7 SOME FURTHER JET FLAP EXPERIMENTS, N. A. Dimmock, CP 345, 1957.
The jet deflection is 58.1°from the chord line. In addition to the measurement of the forces and moments acting on the model the flow pattern in the vicinity of the aerofoil was revealed with smoke filaments and was recorded photographically.

II.3.1.8 THE JET AUGMENTED FLAP, IAS Preprint 715, J.G. Lowry, J.M. Riebe, C.P. Campbell.
Considers separately the three components of lift, $C_{L_\mu}=0$, C_{L_Γ} and $C_\mu \sin(\alpha+\delta)$. These are respectively lift with no blowing, circulation lift and direct thrust component. Test data are compared with some theoretical estimates but no details are given of the theories. Topics discussed include lift, ground effect, drag and thrust, pitching moment, trim and stability and control. A test data comparison is made between internally and externally blown flaps.

II.3.1.9 LOW-SPEED TUNNEL TESTS OF AN ASPECT-RATIO 9 JET-FLAP MODEL, WITH GROUND SIMULATION BY MOVING-BELT RIG, S.F.J. Butler et al, CP 849, 1966.

II.3.1.10 AERODYNAMIC ASPECTS OF BOUNDARY LAYER CONTROL FOR HIGH LIFT AT LOW SPEEDS, J. Williams and S.F.J. Butler, AGARD Report 414, January 1963.
Various methods of providing boundary-layer control are outlined, comprising slot blowing, slot suction, area suction, inclined air-jets, and especially-designed aerofoil shapes. The aerodynamic aspects of slot blowing over trailing-edge flaps and the wing nose are then examined in detail, and slot suction and area suction are considered. The associated practical design features required for good performance are discussed and some flight-handling implications mentioned.

II.3.1.11 JET FLAP CHARACTERISTICS FOR HIGH ASPECT RATIO WINGS, J.K. Korbacher, AIAA Journal, Vol.2 January 1964
Discussion of the thrust hypothesis, its concept and its experimental verification, "Characteristics" for jet-flapped wings at zero and nonzero angle of attack are also presented. It is indicated that any combination of jet flap parameters, such as jet deflection angle, rate of blowing, and angle of attack, which produces a desired lift may be read directly from such characteristics.

II.3.1.12 JET-FLAP THRUST RECOVERY - ITS HISTORY AND EXPERIMENTAL REALIZATION, D.B. Garland, AIAA and CASI, Joint meeting, Ottawa, Canada, October 26, 27, 1964, Paper 64-797.
Review of some aspects of the thrust-recovery hypothesis and illustration of the experimental

II.3.1.12 (continued)
results recently obtained with a detailed analysis of data from a jet-augmented flap wing, a configuration tested to provide a comparison with the augmentor wing. Some possible reasons for less than complete thrust recovery are presented. These include: (1) measurement of recovered thrust at zero forward speed which is sometimes less than the ideal or isotropic value; (2) increase in profile drag, due to separation of the flow around the airfoil; (3) "jet-mixing drag"; and (4) the presence of a large diffuse wake of low energy, nonturbulent air immediately above the jet. The implications of thrust recovery to STOL performance are considered with respect to takeoff, landing, and approach.

II.3.1.13 VERIFICATION AND EXPLANATION OF THE CONTROLLABILITY OF JET FLAP THRUST, Final Report, G. Alexander Tsongas, Stanford University, California, October 1962.
Since the practical use of "air" jet flaps for reducing the approach and landing speeds of airplanes depends largely upon whether the resulting forward jet-flap thrust can be suppressed, experiments were conducted to see if this type of thrust control was possible and if the mechanism of such control could be identified. Devices which were thought to have potential merit as jet thrust suppressors were investigated by determining the forces experienced by appropriately modified forms of a jet-flapped model wing under the conditions of two-dimensional flow. Results indicated that the extent of thrust control provided by large deflections of a simple jet flap was not augmented by any of large flap deflectins (95°). Flow visualization studies showed that the aerodynamic phenomenon which enables such control is the development, with large flap deflections, of a rapidly diverging, low energy wake which lies immediately behind and above the deflected jet and is almost free of a large-scale turbulence.

II.3.1.14 WIND TUNNEL EXPERIMENTS ON A RECTANGULAR-WING JET-FLAP MODEL OF ASPECT-RATIO 6, A. J. Alexander and J. Williams, ARC, R&M 3329, June 1961.
Balance measurements of lift, pitching moment and thrust on an aspect-ratio 6 half-model wing and body in the NPL 13ft x 9ft wind tunnel are

II.3.1.14 (continued)
discussed and compared with theoretical estimates. The experimental investigation concentrated on full-span flap deflections and blowing, with and without a horizontal tail at verying incidence and height. The effects of slot blockage and of part-span flaps on lift and thrust were also examined briefly. Downwash was extracted and compared with theory.

II.3.1.15 WIND TUNNEL TESTS OF BLOWING BOUNDARY-LAYER CONTROL WITH JET PRESSURE RATIOS UP TO 9.5 ON THE TRAILING-EDGE FLAPS OF A 35° SWEPTBACK WING AIRPLANE, M.W. Kelly and J.H. Tucker, NACA RMA 56G19.
A full scale wind tunnel investigation was made to determine whether the effects of blowing high-velocity air over trailing-edge flaps could be adequately correlated by the jet momentum over a wide range of jet velocities (i.e., jet pressure ratios from subcritical to 9.5). The model selected for these tests was a 35° sweptback wing airplane which had been equipped with plain flaps having blowing boundary-layer control. Three-component force data and flow and pressure ratio requirements of the blowing boundary-layer control system were obtained at Reynolds numbers of $7.6x10^6$ and $10x10^6$.

II.3.1.16 GROUND INFLUENCE ON A MODEL AIRFOIL WITH A JET-AUGMENTED FLAP AS DETERMINED BY TWO TECHNIQUES, T.R. Turner, NASA TND-658, February 1961.
An investigation was made in the Langley 300 MPH 7- by 10-foot tunnel with a conventional ground-board setup and in the Langley tank No.1 by using the tow carriage to move the model over a ground board to evaluate the simulation of flight conditions in ground influence with a conventional ground-board setup. The 12-percent-thick airfoil was unswept and untapered with an aspect ratio of 6.0 and had a 10-percent-chord jet-augmented flap.

II.3.1.17 LOW SPEED WIND TUNNEL MEASUREMENTS OF DAMPING IN YAW ON AN ASPECT RATIO 9 JET FLAP COMPLETE MODEL, ARC Report No-ARC-CP-869, 1967, A.P. Cox, S.F. Butler.
Measurements were made of the yaw-damping derivative on an A.R.9 jet-flap complete model, using the free-oscillation technique. The experimental apparatus and procedure were described. Results were given of damping measurements at wing

II.3.1.17 (continued)
incidences of 0, 10, and 20 degrees with jet-flap angles of 0 and 30 deg. and a C_μ range of 0 to 4.2. The effects of the wing, fin, tail plane and fuselage were measured, and it was found that the latter gave a large and unpredicted de-establishing contribution, while damping due to the fin was smaller than the estimated value.

II.3.1.18 SIX-COMPONENT LOW SPEED TUNNEL TESTS OF JET-FLAP COMPLETE MODELS WITH VARIATION OF ASPECT RATIO, DIHEDRAL, AND SWEEPBACK, INCLUDING THE INFLUENCE OF GROUND PROXIMITY, S.F. Butler, M.B. Guyett, B.A. Moy, ARC-R&M-3441, 1967.
The basic aerodynamic characteristics of jet-flap aircraft, six-component force and moment measurements were investigated on jet-flap complete models. The tests covered the effects produced by variations of wing aspect ratio,dihedral, and sweepback, and by ground proximity, on longitudinal and lateral static stability, Some of the more significant results outside ground influence included the high stalling incidence and the coefficient of lift values possible with a thick, heavily cambered jet-flap wing and the effects of the jet flap on lateral static stability. Proximith to the ground produced appreciable changes in downwash at the tailplane as soon as the jet sheet neared the ground, and caused large reductions in lift and stalling incidence once jet impingement occurred.

II.3.1.19 SOME EXPLORATORY THREE-DIMENSIONAL JET FLAP EXPERIMENTS, J. Williams and A.J. Alexander, The Aeronautical Quarterly, February 1957.
The paper described an early attempt to establish the order of magnitude of finite aspect ratio effects for jet-flap wings. Lift, pitching moment, and drag were presented from integrated pressure measurements on a jet flap model of aspect ratio 2.75.

II.3.1.20 SOME EARLY JET FLAP EXPERIMENTS, N.A. Dimmock, The Aeronautical Quarterly, November 1957.
Some early, simple two-dimensional jet flap experiments are briefly described.

II.3.1.21 MEASUREMENTS OF FLOW BREAKDOWN IN RECTANGULAR WING TUNNEL WORKING SECTIONS, P. South, NAE NRC-10616, November 1968.
This report described an experimental investigation into flow breakdown in low speed wind tunnels having width-to-height ratios of 0.5, 1.0, and 2.0. A family of jet flap models was used. Flow breakdown was shown to be a function of the drag-tol-lift ratio and a lift coefficient based on the measured dynamic pressure, measured lift, and the tunnel cross-sectional area beneath the model span.

II.3.1.22 WIND TUNNEL INVESTIGATION AT LOW SPEEDS TO DETERMINE FLOW-FIELD CHARACTERISTICS AND GROUND INFLUENCE ON A MODEL WITH JET-AUGMENTED FLAPS, R.D. Vogler and T.R. Turner, NASA TN 4116, 1957.
A wind tunnel investigation was made to determine the flow-field characteristics and ground influence on an airplane model having an untapered, unswept wing with an aspect ratio of 8.3 equipped with jet-augmented flaps. Jet-augmented-flap deflections of 55° and 85° were investigated. The high lift coefficients associated with jet-augmented flaps were greatly reduced in ground effect. The adverse effects of the ground incrased rapidly as the wing approached the ground, as the jet-deflection angle increased, or as the momentum coefficient increased. Associated with these reductions in lift coefficient were reductions in both drag coefficient and nose-down pitching-moment coefficient.

High angles of downwash were measured. The jet-augmented full-span flap produced wing-tip vortices that increased in strength as the jet momentum coefficient increased and resulted in angles of upflow as large as 20° at a location 3 chords behind the wing-tip region.

II.3.1.23 WIND TUNNEL INVESTIGATION OF JET-AUGMENTED FLAPS ON A RECTANGULAR WING TO HIGH MOMENTUM COEFFICIENTS, V. E. Lockwood, T.R. Turner and J.M. Riebe, NASA TN 3865, 1956.
Jet flaps were tested unswept, untapered wing with an aspect ratio of 8.4 and a thickness of 16.7 percent. The investigation showed that the ratioof total lift to jet-reaction lift increased as the jet deflection angle increased and reached a maximum value for jet deflections of 86° and

II.3.1.23 (continued)
110°. Although the jet-circulation lift coefficient increased as the momentum coefficient increased in the low momentum-coefficient range, the ratio of jet-circulation lift to jet momentum decreased. The jet flap gave large pitching-moment coefficients. A limited amount of data showed that it was possible to reduce the pitching moments of the jet flap by the addition of a split-flap arrangement for directing the line of action of the jet through the center of moments, but at the expense of additional drag.

II.3.1.24 COMPARATIVE THRUST MEASUREMENTS ON A SERIES OF JET-FLAP CONFIGURATIONS AND CIRCULAR NOZZLES, M.N. Wood, ARC-CP-616, January 1962.
Thrust measurements were made with a range of jet-flap blowing configurations to clarify the causes of momentum losses. Thrust measurements were also made of a series of circular nozzles. The main sources of momentum loss were boundary-layer growth in the blowing slot and skin friction losses over the flap surface.

II.3.1.25 LOW SPEED TUNNEL TESTS OF AN ASPECT RATIO 6 JET FLAP MODEL, WITH GROUND SIMULATION BY MOVING-BELT RIG, S.F.J. Butler, B.A. Moy and G.D. Hutchins, ARC CP 849, 1966.
The ground boundary-layer condition had an important influence only once jet sheet impingement occurred. The wing incidence at which a large portion of the jet efflux flowed upstream along the ground was 10° higher with the moving ground plane than with the fixed ground plane. The use of a moving ground plane was found to be preferable.

II.3.1.26 AN EXPERIMENTAL STUDY OF JET FLAP THRUST RECOVERY, W.M. Foley, Stanford University, SUDAER No. 136, September 1962.
The investigation was intended to verify or disprove the jet-flap thrust hypothesis. Approximately 94% of the ideal jet reaction was recovered as thrust. The conclusion was that the thrust hypothesis was verified. It was deduced that for this experiment the thrust recovery was not due to leading edge suction forces as has been proposed but due to internal (plenum chamber) pressure forces.

II.3.1.27 LOW SPEED WIND-TUNNEL INVESTIGATION TO DETERMINE THE AERODYNAMIC CHARACTERISTICS OF A RECTANGULAR WING EQUIPPED WITH A FULL-SPAN AND AN INBOARD HALF-SPAN JET-AUGMENTED FLAP DEFLECTED 55°, T.G. Gainer, NASA Memo 1-27-59L, February 1959. The ratio of total lift to jet-reaction lift for the wing was 35 percent less for the half-span jet-augmented flap than for the full-span. The thrust recovery of the half-span flap was poorer than that of the full-span flap. The half-span flap had larger pitching moments at a given lift because of the larger jet reaction required to produce the lift.

II.3.1.28 INVESTIGATION OF CIRCULATION CONTROL AIRFOILS BY MEANS OF JETS, S.W. Yuan, WestKaemper, J.C., L.D. Kemp, and W. L. Richter, USAAVLABS TR-66-72. Presents wind tunnel test results of jet flapped elliptical airfoils of 12% and 18% thickness. Includes comparison of test data with Spence's expression for C_L.

II.3.1.29 JET FLAP THRUST RECOVERY, J. Aero. Sci., June 1959, W.M. Foley and F.G. Ried. Results of 2-D tests to investigate the "thrust recovery paradox." About 94% of full recovery was demonstrated.

II.3.1.30 THE GROUND EFFECT ON THE JET FLAP IN TWO DIMENSIONS, II. PITCHING MOMENT AND DOWNWASH CHANGES ON A 58° FLAP AND FURTHER EXPERIMENTS, INCLUDING PITCHING MOMENT CHANGES ON A 31° FLAP, ARC 19, 906, 1958. D.J. Huggett and A.J. Wilson. The effect of the ground on a jet-flap aerofoil in two-dimensional flow is investigated, with particular reference to the conditions under which the jet flow hits the ground. Experimental results are included for the change of lift and pitching moment for 58.1° and 31.4° jet-deflection angles, with a limited investigation into the downwash changes behind the model with a 58.1° jet-deflection angle. It is concluded that there is a definite limit to the jet coefficient, which may be used at any ground position, if the problems of a sudden change to lift and pitching moment are to be avoided. There remains the unresolved difficulty of the downwash variation at the tail arising from the presence of the ground. A provisional assessment of the performance of a jet-flap aircraft near the ground is made, and

II.3.1.30 (continued)
shows that for a 58.1° jet-deflection angle there is a definite limit to the minimum flying speed for any given distance of the wing from the ground.

II.3.1.31 SOME TESTS ON A 90° JET FLAP MODEL, N.A. Dimmock, NGTE Note NT.88; ARC 16, 138, 1953.

II.3.1.32 BRIEF EXPERIMENTS ON A FLAPPED AEROFOIL HAVING A CUSPED CAVITY AND A FLOWING JET AT THE CUSP, A.D. Wood, NRC LR-269, 1959.
Experiments on a simple flapped aerofoil incorporating a cusped cavity and having a blowing jet at the cusp show that it is possible to produce a flow regime in which the cavity is occupied by a stable trapped vortex. With the aerofoil immersed in a quasi-two-dimensional finite stream, grater rotation of the resultant force vector was obtained with a flap of this type than with a flap having no cavity. The results indiate that the combination of a blowing jet and a trapped vortex may be used to advantage in enabling an external flow to overcome an adverse pressure gradient.

II.3.1.33 INTERIM NOTE ON WIND TUNNEL EXPERIMENTS ON A RECTANGULAR WING JET-FLAP MODEL OF ASPECT RATIO 6, A. J. Alexander and J. Williams, ARC 19, 888 Perf. 1638, 1957.

II.3.1.34 CONTROLE DE CIRCULATION SUR AVION DE FAIBLE ALLONGEMENT, RECH AERON No. 52, 1956, Poisson-Quinton, Ph, Jousserandot, P. and A. Bevert.

See also I.3.1.4

II.3.2 Flow Fields -

II.3.2.1 THE LIFT, STALLING, AND WAKE CHARACTERISTICS OF A JET-FLAPPED AIRFOIL IN A TWO-DIMENSIONAL CHANNEL, C.S. Hynes, Stanford University, SUDAAR No. 363, November 1968.

The effect of angle of attack upon lift, drag, thrust recovery, and pitching moment has been determined by testing a jet-flapped airfoil under two-dimensional conditions for jet deflection angles up to 65°. Stalling occurred within a relatively narrow band in the C plane. The large drag forces responsible for the negation of thrust recovery found by Tsongas (Stanford University Thesis, 1962) at large jet deflection angles were due to the three-dimensionality of the flow, and were thus characteristic of the test installation rather than the model.

See also, II.3.1.5, .7, .12, .13, .14, .15, .16, .18, .21, .22 and .30

II.3.3 Ground Effect -

II.3.3.1 A MOVING-BELT GROUND PLANE FOR WIND TUNNEL SIMULATION AND RESULTS FOR TWO JET-FLAP CONFIGURATIONS, T.R. Turner, NASA TN D 4228, November 1967.
The effects of ground proximity on the characteristics of a swept and an unswept full-span blowing-flap configuration were investigated using a moving-belt ground plane. The results indicate that the moving belt satisfactorily remove the boundary layer on the ground plane. The lift loss of models at small distances from the ground and high lifts were considerably less with the belt moving at stream velocity (boundary layer removed) than with the belt at zero velocity. For configurations with full span lift devices, the data indicated that the moving-belt ground plane was not needed for ratios of wing height (in spans) to lift coefficient greater than about 0.050,but is desirable for smaller ratios.

See also II.3.1.2, .16, .18, .23, .25, .26 and .30

II.3.4 Stability and Control -

See II.3.1.17

II.3.5 Handling Qualities and Criteria -

No data related to this category were found during the literature search.

II.3.6 Testing -

II.3.6.1 SOME LOW SPEED WIND TUNNEL TECHNIQUES FOR THE MEASUREMENT OF OSCILLATORY AERODYNAMIC DERIVATIVES ON JET-BLOWING MODELS, T. B. Owen and A.P. Cox Journal of Sound and Vibration, Vol.4 No.3, 1966. A description was given of a rig developed to measure directly the damping in yaw on a jet flap blowing model, using a decaying oscillation technique with the model supported on an internal air bearing. Solutions to some of the problems encountered in the rig design and in the model testing were discussed, and the importance of the flow-field associated with the proximity of the efflux to the fuselage was illustrated. Finally, a new inexorable-forcing external-support rig was describe.

See also II.3.1.21 and .25

II.3.7 General -

II.3.7.1 See Section I.3.7

II.4 HIGH LIFT DEVICES (including BLC)

II.4.1 Forces and Moments -

II.4.1.1 LOW SPEED WIND TUNNEL TESTS ON A TWO-DIMENSIONAL AEROFOIL WITH SPLIT FLAP NEAR THE GROUND, J.A. Bagley, CP 568, 1961.
Pressure distributions are measured on a 10 percent thick two-dimensional aerofoil of RAE 101 section fitted with split flaps deflected at 15°and 55°. Measurements are made at two distances above a ground plate and without a ground plate. Results are integrated to give the sectional lift, drag and pitching moment coefficient.

II.4.1.2 LOW-SPEED WIND TUNNEL TESTS OF FOWLER FLAPS, SLATS AND NOSE FLAPS ON A MODEL OF A JET AIRCRAFT WITH A 40° SWEPT BACK WING, A. Spence ARC R&M 2752.

II.4.1.3 FLIGHT TESTS AND WIND TUNNEL MEASUREMENTS ON AEROFOILS WITH BOUNDARY LAYER SUCTION FOR INCREASING MAXIMUM LIFT, F. Schwartz and W. Wuest.

II.4.1.4 AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE UNSWEPT WING-BODY-TAIL CONFIGURATION WITH BLOWING APPLIED OVER THE FLAP AND WING LEADING EDGE, H.C. McLemore and J.P. Peterson, NASA TN D 407, September 1960.
Tests were conducted in the Langley full-scale tunnel to determine the effects of blowing boundary layer control on the aerodynamic characteristics of a large scale, wing-body-tail configuration having an unswept wing with an aspect ratio of 2.86 and a and a thickness ratio of 0.04. The tests were conducted for a range of angles of attack from approximately 5.2×10^6 corresponding to a Mach number of 0.08. Longitudinal stability and control characteristics were obtained for three tail heights, and lateral-control characteristics for two aileron and several spoiler configurations.

II.4.1.5 LOW-SPEED WIND TUNNEL INVESTIGATION OF A REFLECTION PLANE WING MODEL EQUIPPED WITH PARTIAL-SPAN JET-AUGMENTED FLAPS, J.H. Otis, NASA TN D 815-, May 1961.
Three 50 percent partial-span jet-augmented flap configurations located inboard, outboard, and at the mid-semispan position were tested through a

II.4.1.5 (continued)
momentum coefficient range from 0 to about 10 and an angle-of-attack range from -10° to approximately 28°. The corresponding flow-field characteristics are presented for a longitudinal-tail position of 4 wing chord behind the trailing edge of the wing through a range of tail-height locations of ± 2 chord.

II.4.1.6 INVESTIGATIONS OF THE BOUNDARY LAYER CONTROL ON A FULL SCALE SWEPT WING WITH AIR BLED OFF FROM THE TURBOJET, P.Rebuffet and Ph. Poisson-Quinton, NACA TM 1331.
The report shows the different stages of the research done in the field of increasing the maximum lift coefficient of swept wings by combined suction and blowing by means of ejectors which are fed with air by bleeding the turbo-engine.

II.4.1.7 PRESSURE-PLOTTING MEASUREMENTS ON AN 8 PERCENT THICK AEROFOIL WITH TRAILING-EDGE FLAP BLOWING, J. Williams and A.J. Alexander, R&M 3087, 1958.
Wind tunnel experiments were made on an 8 percent thick aerofoil between end plates, with blowing from a slot in the knee of a 25 percent chord trailing-edge flap, to improve the lifting efficiency of the flap. Both the blowing-slot width and position were varied. The sectional lift and pitching moment were derived by chordwise integration of the surface static pressures measured at the mid-span station. Tuft observation as well as surface-pressure measurements were made to determine the extent of the turbulent separation region on the trailing-edge flap and of the laminar separation bubble on the aerofoil nose.

II.4.1.8 FULL SCALE WIND TUNNEL TESTS OF A 35° SWEPTBACK WING AIRPLANE WITH BLOWING FROM THE SHROUD AHEAD OF THE TRAILING-EDGE FLAPS, W.H. Tolhurst, NACA TN4283, July 1958.
Data are presented showing the effect of flap position relative to the blowing nozzle on the air flow requirements for boundary layer control on flaps deflected from 45° to 75° at a Reynolds number of 7.5×10^6. A direct comparison of shroud blowing and flap blowing is shown for a plain flap configuration. Also presented are data showing the effect on the air flow requirements of spacers in the nozzle, discontinuities on the flap upper surface,

II.4.1.8 (continued)
and of sealing the slot when the flap was in the single-slotted flap configuration.

II.4.1.9 SOME EXPERIMENTS IN THE APPLICATION OF BOUNDARY LAYER CONTROL, J. Flatt.

II.4.1.10 ANALYSIS OF AERODYNAMIC DATA ON BLOWING OVER TRAILING-EDGE FLAPS FOR INCREASING LIFT, J. Williams, ARC CP No. 209, September 1954, published 1955.
Available results on blowing over trailing edge flaps are discussed and the force measurements from wind-tunnel tests are correlated in terms of the blowing moment coefficient. Simple methods are tentatively suggested for the practical prediction of the lift increment (at constant incidence) attainable on finite wings, and the associated increase in pitching moment. Theoretical curves, relating to compressible isentropic flow through the blowing slot, are presented for the determination of the various blowing coefficients in terms of the blowing pressure ratio.

II.4.1.11 LOW SPEED WIND TUNNEL EXPERIMENTS ON THICK HIGH LIFT AEROFOILS EMPLOYING BOUNDARY LAYER CONTROL BY BLOWING, N. J. Munro, ARL Note A.229, September 1965.

II.4.1.12 FLIGHT INVESTIGATIONS OF THE LOW SPEED CHARACTERISTICS OF A 45° SWEPT-WING FIGHTER-TYPE AIRPLANE WITH BLOWING BOUNDARY-LAYER CONTROL APPLIED TO THE LEADING- AND TRAILING-EDGE FLAPS, H. Wuigley et al, NASA TN D-321, September 1960.
Includes documentation of the low-speed handling qualities as well as the pilots' evaluation of the landing-approach characteristics. The results are compared with those for the aeroplane with a slatted leading edge and the same trailing-edge flap. Several of the factors limiting the use of the high lift possible with leading-edge boundary layer control flaps were associated with the high angles of attack required for low-speed flight in the test aeroplane.

II.4.1.13 INSTALLATION DE LA PORTANCE SUR UN PROFIL MUNI D' UNE FENTE DE SOUFFLAGE AU BORD DE FUITE ET CORRECTION DUE A L'ENVERGURE FINIE, (PRODUCTION OF LIFT ON AN AIRFOIL WITH A BLOWING SLOT AT THE TRAILING EDGE INCLUDING CORRECTION FOR FINITE ASPECT RATIO.)

II.4.1.13 (continued)
R. Hirsch, Pubs, Sc. et Tech. NT 69, 1957.
Includes integral equations for circulation; considers dissipative effects on the jet. Provides expressions for lift and drag in the limiting stationary case.

II.4.1.14 LOW SPEED WIND TUNNEL TESTS ON THE deHAVILLAND SEA VENOM WITH BLOWING OVER THE FLAPS, S.F.J. Butler and M. B. Guyett, R&M 3129, 1959.
The results of low-speed tunnel tests of longitudinal stability on a modified Sea Venom Mk.21 fitted with blowing over the flaps are given. At each flap angle, a range of values of the sectional momentum coefficient was tested. A comparison is made between estimated and measured effects of blowing.

II.4.1.15 BOUNDARY-LAYER CONTROL FOR HIGH LIFT BY SUCTION AT THE LEADING EDGE OF A 40° SWEPT-BACK WING, E. D. Poppleton, R&M 2897 October 1951, published 1955.
Wind tunnel tests have been made on a 40° swept-back wing, 10 percent thick with constant chord and an aspect ratio of 4.6. Boundary layer control was applied along the whole leading edge, and a comparison was made between the effects of distributed suction and suction through a slot. A 45 percent Fowler flap was used in some tests.

II.4.1.16 BLOWING TYPE BOUNDARY LAYER CONTROL AS APPLIED TO THE TRAILING EDGE FLAPS OF A 35° SWEPT WING AIRPLANE, M. W. Kelly et al, NACA Report 1369, 1958.

II.4.1.17 THE AERODYNAMIC CHARACTERISTICS OF AN ASPECT RATIO-20 WING HAVING THICK AIRFOIL SECTIONS AND EMPLOYING BOUNDARY-LAYER CONTROL BY SUCTION, B. W. Cocke, Jr., M. P. Fink and S. M. Gottlieb, NACA TN 2980, August 1953.
An investigation has been conducted to study the aerodynamic characteristics of an aspect ratio-20 wing employing thick aerofoil sections and boundary-layer control by suction. Data from models tested in the Langley full-scale tunnel and the Langley low-turbulence pressure tunnel are included.

II.4.1.18 FLIGHT DEVELOPMENT OF A HIGH LIFT RESEARCH AIRCRAFT USING DISTRIBUTED SUCTION, D.G. Clark, AGARD Report 502, June 1965.
A modified, single-engined light aircraft was fitted with means for applying distributed suction to the wing upper surface and was flown at $C_L > 5.0$.

II.4.1.19 LOW SPEED FLIGHT INVESTIGATION OF A JET TRANSPORT WITH A POWERED LIFT BOUNDARY-LAYER CONTROL SYSTEM, R.O. Schade and H.L. Crane, AGARD Report 503, June 1965.
The low speed flight characteristics of a large jet transport equipped with a powered lift blown flap are studied.

II.4.1.20 SOME AERODYNAMIC AND OPERATIONAL PROBLEMS OF STOL AIRCRAFT WITH BLC, J.J. Cornish, III, AIAA, GAAD and Operations Meeting, Wichita, Kansas, May 25-27, 1964, Paper 64-193.
Summary of some of the findings of tests made on conventional aircraft modified to employ the technique of boundary-layer control by suction to attain STOL flight. It is stated that, from the flight tests conducted on these vehicles, several characteristic problems typical of this method of increasing lift have become apparent. The methods or approaches used to alleviate or to avoid the particular problem are described. Flight test results from a number of aircraft using suction boundary-layer control for lift augmentation are examined and compared. It is concluded that the attainment and utilization of high lift coefficients have emphasized several shortcomings of currently used aerodynamic theories and have brought into prominence the interference effects of some aircraft components not ordinarily considered at relatively low lift coefficients.

II.4.1.21 EFFECTS OF SEVERAL HIGH-LIFT AND STALL-CONTROL DEVICES ON THE AERODYNAMIC CHARACTERISTICS OF A SEMI-SPAN 49° SWEPTBACK WING, NACA RM L52D17a, 1952. U. Barnett Jr., and S. Lipson.

II.4.1.22 EFFECT ON THE LOW-SPEED AERODYNAMIC CHARACTERISTICS OF A 49° SWEPTBACK WING HAVING AN ASPECT RATIO OF 3.78 OF BLOWING AIR OVER THE TRAILING-EDGE FLAP AND AILERON, NACA RM L54C05, 1954, E.F. Whittle, Jr., and S. Lipson.

II.4.1.23 FULL SCALE WIND TUNNEL TESTS OF A 35° SWEPTBACK WING AIRPLANE WITH HIGH VELOCITY BLOWING OVER THE TRAILING-EDGE FLAPS, M.W. Kelly and W.H. Tolhurst, Jr., NACA RM A55I09, 1955.

II.4.1.24 AERODYNAMIC CHARACTERISTICS AND PRESSURE DISTRIBUTIONS OF A 6-PERCENT THICK 49° SWEPTBACK WING WITH BLOWING OVER HALF-SPAN AND FULL-SPAN FLAPS, E. F. Whittle, Jr., H.C. McLemore, NACA RM L55F02, 1955.

II.4.1.25 THE EFFECTS OF BLOWING OVER VARIOUS TRAILING EDGE FLAPS ON AN NACA 0006 AIRFOIL SECTION, COMPARISONS WITH VARIOUS TYPES OF FLAPS ON OTHER AIRFOIL SECTIONS, AND AN ANALYSIS OF FLOW AND POWER RELATIONSHIPS FOR BLOWING SYSTEMS, NACA RM A56C01, 1956, J. B. Dods, Jr., E. C. Watson.

II.4.1.26 APPLICATION OF AREA SUCTION TO LEADING AND TRAILING EDGE FLAPS ON A 44° SWEPT WING MODEL, C.A. Holzhauser, R.K. Martin and V.R. Page, NACA RM A56F01, 1956.

II.4.1.27 INVESTIGATION OF THE USE OF AREA SUCTION TO INCREASE THE EFFECTIVENESS OF TRAILING EDGE FLAPS OF VARIOUS SPANS ON A WING OF 45° SWEEPBACK AND ASPECT RATIO 6, R.N. Griffin, and D.H. Hickey, NACA RM A56B27, 1956.

II.4.1.28 BLOWING OVER THE FLAPS AND WING LEADING EDGE OF A THIN 49° SWEPT WING-BODY-TAIL CONFIGURATION IN COMBINATION WITH LEADING-EDGE DEVICES, NACA RM L56E16, 1956.

II.4.1.29 A FLIGHT EVALUATION OF A WING-SHROUD-BLOWING BOUNDARY-LAYER CONTROL SYSTEM APPLIED TO THE FLAPS OF AN F9F-4 AIRPLANE, L.S. Rolls, R.C. Innis, NACA RM A55K01, 1956.

II.4.1.30 FULL SCALE WIND TUNNEL TESTS OF A 35° SWEPTBACK WING AIRPLANE WITH HIGH VELOCITY BLOWING OVER THE TRAILING EDGE FLAPS LONGITUDINAL AND LATERAL STABILITY AND CONTROL, W.H. Tolhurst, Jr., M.W. Kelly, NACA RM A56E24, 1956.

II.4.1.31 HIGH PRESSURE BLOWING OVER FLAP AND WING LEADING EDGE OF A THIN LARGE SCALE 49° SWEPT WING-BODY-TAIL CONFIGURATION IN COMBINATION WITH A DROOPED NOSE AND A NOSE WITH A RADIUS INCREASE, M.P. Fink, and H.C. McLemore, NACA RM L57D23, 1957.

II.4.1.32 SURFACE PRESSURE DISTRIBUTION ON A LARGE-SCALE 49° SWEPTBACK WING-BODY-TAIL CONFIGURATION WITH BLOWING APPLIED OVER THE FLAPS AND WING LEADING EDGE, M.P. Fink and H. C. McLemore, NACA RM L57K25, 1958.

II.4.1.33 AERODYNAMIC CHARACTERISTICS IN SIDESLIP OF A LARGE-SCALE 49° SWEPTBACK WING-BODY-TAIL CONFIGURATION WITH BLOWING APPLIED OVER THE FLAPS AND WING LEADING EDGE, NASA Memo 10-11-58L, 1958.

II.4.1.34 LARGE-SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT, ASPECT-RATIO-10 WING, TWO PROPELLERS, AND AREA SUCTION FLAPS, G.L. Florman and J. A. Weiberg, R.N. Griffin, Jr., NACA TN 4365, 1958.

II.4.1.35 LOW SPEED WIND TUNNEL INVESTIGATION OF BLOWING BOUNDARY-LAYER CONTROL ON LEADING- AND TRAILING-EDGE FLAPS OF A LARGE-SCALE, LOW-ASPECT-RATIO, 45° SWEPT-WING AIRPLANE CONFIGURATION, NASA Memo 1-23-59A,1959, R. L. Maki.

II.4.1.36 LOW SPEED INVESTIGATION OF A FULL SPAN INTERNAL-FLOW JET-AUGMENTED FLAP ON A HIGH-WING MODEL WITH A 35° SWEPT WING OF ASPECT RATIO 7.0, T. R. Turner, NASA TN-D434, 1960.

II.4.1.37 SOME INVESTIGATIONS INTO WINGS WITH LEADING EDGE FLAPS WITH AND WITHOUT FUSELAGE, RAE, Farnborough, England,F. Thomas,December 1967.
Three-component measurements have been carried out in the low-speed wind tunnel of the DFL with swept back wings with leading edge flaps and trailing edge flaps. For the three wings investigated, the angle of sweep varied from 0 to 57.3° and the taper ratio from 1 to 1/8, while the aspect ratio A=2 and the aerofoil section NACA 005 were constant. The flap extended over the outer 75% of the span, the trailing edge flaps being continuous and the leading edge flaps in three sections. The three wings were tested not only alone but also in combination with a fuselage. The largest increment in lift due to deflection of the leading edge

II.4.1.37 (continued)
flaps is in the region 0.3. Additional deflection of the trailing edge flaps increased the increment in lift to 0.5. In order to enable a comparison to be made with theory the Truckenbrodt lifting surface theory was applied to the aerofoil with leading edge flaps. Comparing test results with theory the agreement was satisfactory with regard to pitching moments, but unsatisfactory for the lift.

II.4.1.38 A REVIEW OF LEADING EDGE HIGH LIFT DEVICES, ARL, Melbourne (Australia), K.D. Thomson, June 1951.

In the first part of the paper some notes are given on the maximum lift of thin wings. The rest of the paper then deals with the effect of leading edge high lift devices on wings with and without sweepback. Of all the devices examined the leading edge flap appears to most promising and gives substantial increases in maximum lift for both swept and unswept wings. All the devices examined seemed to be fairly effective in preventing leading edge separation.

A stable stall can be obtained for a sweptback wing of moderate taper ratio if leading edge devices are used on the outer half of the span, with or without the presence of trailing edge flaps on the inner half of the span. With both part span leading and trailing edge devices on a sweptback wing, a $C_{L_{MAX}}$ of 1.3 to 1.6 is obtainable, the actual value depending on the angle of sweepback.

II.4.1.39 INVESTIGATIONS INTO THE INCREASE IN LIFT OF A FLAPPED WING BY SLOT SUCTION, RAE, Farnborough, England, K.O. Arnold, December 1967.
Systematic measurements are reported for a rectangular flapped wing on which, for the purpose of boundary layer control, air was sucked into the wing by means of a slot in the upper surface of the flap. In order to approximate two-dimensional flow conditions the wing with the slot extending over the entire span was equipped with lateral-end plates of large size. By controlling the boundary layer separation of flow was prevented over the range of the investigated flap angles (0 to 75°). The pressure distribution came close to that of the potential flow theory so that a considerable gain in lift was achieved. Extensive

II.4.1.39 (continued)

three-component and pressure distribution measurements were carried out at the Reynolds number Re= 330,000. The development of the two-dimensional turbulent boundary layer donwstream of the suction slot was investigated by means of a special test device. These measurements included the attached condition of flow as well as that of separated flow in the absence of control.

II.4.1.40 EMERGENCY CONTROL OF BOUNDARY LAYER ON AIRCRAFT WINGS BY PROPELLANT ENERGY, A. E. Larsen, C.J. Litz, D.C. Hazen, April 1962.

Operating with the demonstrated and proven state-of-the art of boundary layer phenomenon as related to airfoils, this project studies two objectives: the uses of safely stored propellant energy instantly released and directed through ducting, ejectors, and/or other means, to appropriately located apertures on the on the airfoil surfaces; and the reattachment of the circulation flow through ballistic-combustion-powered boundary layer control of the airflow over and around stalled airfoil test models. The preliminary research efforts were directed toward the study of acquisition of time interval data and was accomplished by recording and measuring the time interval required for decay of circulation flow with the breakdown of lift in stall, and the measurement of time for the reattachment of circulation flow in the restoration of lift. The expenditures of energy involved for restoration of circulation flow were also recorded and measured. These values of transient energy were subsequently utilized in computations to determine the propellant energy requirements for full scale application of these emergency boundary layer control concepts on the U.S. Army Caribou airplane.

II.4.1.41 FLIGHT INVESTIGATION OF LEADING EDGE SUCTION BOUNDARY LAYER CONTROL ON A LIAISON-TYPE STOL AIRCRAFT, D. Gyorgyfalvy, February 1961. Mississippi State University State College.

Leading edge boundary layer control has been studied on a modified YL-24, helio courier liaison airplane. The original leading edge slats were removed from one wing panel of the test airplane and instead, a fiberglass nose was installed accommodating leading edge slat and leading edge BLC. Results of this investigation have shown

II.4.1.41 (continued)
that the leading edge BLC produced the same increment in maximum lift as the slat. The BLC wing, however,demonstrated 35 percent lower profile drag in cruising flight. Effects of the leading edge suction were manifested in delayed transition and reduced growth of the boundary layer in the low speed flight regime. The practical application of leading edge boundary layer control seems to be most feasible as a supplementary device together with distributed suction BLC system for very high lift STOL airplanes. It may find application, however, as an alternative to leading edge slats or as a high lift device to prevent tip stall. Some fundamental design aspects are outlined.

II.4.1.42 AERODYNAMIC CHARACTERISTICS IN SIDESLIP OF A LARGE-SCALE 49 SWEPTBACK WING-BODY-TAIL CONFIGURATION WITH BLOWING APPLIED OVER THE FLAPS AND WING LEADING EDGE, NASA, Washington, D.C., H.C. McLemore.

II.4.1.43 LIFT AUGMENTATION AND OPERATION OF AIRPLANES BY CIRCULATION CONTROL, Wichita State University Kansas, Ph. Poisson-Quinton, P. Jousserandot, August 1955.

II.4.1.44 THE SUPERSONIC BLOWING JET FOR WING-LIFT AUGMENTATION, Bureau of Naval Weapons, Washington, D.C., J.S. Attinelo, October 1954.

II.4.1.45 A PRELIMINARY INVESTIGATION OF THE USE OF CIRCULATION CONTROL TO INCREASE THE LIFT OF A 45 SWEPTBACK WING BY SUCTION THROUGH TRAILING-EDGE SLOTS, W. L. Cook, R. Griffin, Jr., D.H. Hickey.

II.4.1.46 WIND TUNNEL TESTS OF AN AEROJET ELLIPTICAL WING WITH BOUNDARY LAYER CONTROL, H.W. Davidson, May 1951.

II.4.1.47 PREVENTION OF TURBULENT SEPARATION BY SUCTION THROUGH A PERFORATED SURFACE, J.J. Cornish, October 1953.

II.4.1.48 WIND TUNNEL INVESTIGATIONS OF A WING WITH JUNKERS SLOTTED FLAP AND THE EFFECT OF BLOWING THROUGH THE TRAILING EDGE OF THE MAIN SURFACE OVER THE FLAP, RAE, Farnborough (England), H.H. Hagerdorn, P. Ruden.

II.4.1.49 CIRCULATION CONTROL BY MEANS OF TRAILING EDGE SUCTION, D.C. Hazen, T.E.Sweeney, August 1953, Princeton University, N.J., James Forrestal Research Center.

II.4.1.50 AUGMENTING LIFT BY MEANS OF A SUPERSONIC JET DIRECTED OVER FLAPS, J.S. Attinello, May 1953.

II.4.1.51 LOW SPEED WIND TUNNEL TESTS ON A WING FUSELAGE MODEL WITH AREA SUCTION THROUGH PERFORATIONS AT THE LEADING EDGE FLAP KNEE, S.F.J. Butler, July 1967, RAE, Farnborough, England.

II.4.1.52 SUMMARY OF HIGH LIFT WIND TUNNEL TESTING FOR THE TAC AIRPLANE, Boeing Company, Seattle, Washington, W. J. Runciman, April 1961.
These wind tunnel tests were part of a series in the development of the variable sweep TAC fighter. The original purpose was to investigate various high lift flap configurations. During the first test period the emphasis was shifted to consider configurations having a more direct application to airplanes then under consideration. All of the tests were conducted on a wing with a NACA 23012 airfoil section at a LE sweep of 15°. The configurations tested include Fowler flaps, triple slotted flaps, slats, leading edge flaps and drooped leading edges. Various combinations of flaps were tested that developed lift coefficients in excess of three.

II.4.1.53 FLIGHT MEASUREMENTS OF THE LIFT AND DRAG OF A 40-DEGREE SWEPT WING AIRCRAFT (MODIFIED HUNTER MK.1) WITH BLOWING OVER PLAIN TRAILING EDGE FLAPS, J.K. Staples, P. Atkins, J.K. Blackmore, RAE, Farnborough, England, January 1963.
Tests have been made on a modified Hunter aircraft to find the effects of flap deflection and flap blowing on lift and drag. The lift increments for flap deflection, blowing off, were higher than estimated; those with blowing were less than expected. Surface tufts showed that fully attached flow could be established over the entire flap deflected up to 37 degrees and in this condition the estimated lift increments were obtained, although excessive blowing momentum was required. Failure to achieve fully attached flow at larger flap angles was attributed to nozzle and flap imperfections unavoidable in applying blowing to an existing aircraft. The measured drag was

II.4.1.53 (continued)
always somewhat higher than estimated but at least some of the discrepancy was attributed to areas of detached flow giving a higher profile drag than estimated.

II.4.1.54 WATER TUNNEL EXPERIMENTS ON A ZAP-FLAPPED SUCTION AEROFOIL, R.H. Wickenn, U. Okapuu,R.R. Clifford, December 1960.
Suction was used to control the circulation about a two-dimensional aerofoil with a zap flap; the suction served to eliminate the turbulent wake behind the flap and provided a substantial increase in lift. Flow photographs were taken from which force data were inferred. The test facility was the NAE flow visualization water tunnel.

II.4.1.55 SOME PHYSICAL ASPECTS OF BLOWING ON AIRCRAFT WINGS, Douglas Aircraft Co., Inc., El Segundo, Calif. Ph, Poisson-Quinton, G. Montalvo, September 1957.

II.4.1.56 LOW SPEED BOUNDARY LAYER CONTROL INVESTIGATION ON A THIN RECTANGULAR SEMISPAN WING WITH LEADING EDGE AND TRAILING EDGE FLAPS, NASA, Washington, D.C., D.R. Croom, T.R.Turner, AD-151-429, RML57J15.

II.4.1.57 FLIGHT INVESTIGATION OF THE LOW SPEED CHARACTERISTICS OF A 35° SWEPT WING AIRPLANE EQUIPPED WITH AN AREA SUCTION EJECTOR FLAP AND VARIOUS WING LEADING EDGE DEVICES, S.B. Anderson, A.E. Faye,Jr., R.C. Innis, September 1957.

II.4.1.58 NEW RESULTS IN INFLUENCING LIFT OF WINGS, A. Betz, September 1952.

II.4.1.59 WIND TUNNEL TESTS OF A SWEPT-WING SEMISPAN MODEL WITH CIRCULATION CONTROL, R. Wallace, R.J. Bondie, Jr., J.L. Stalter, August 1953, Wichita State University, Kansas.

II.4.1.60 EFFECT ON THE LOW SPEED AERODYNAMIC CHARACTERISTICS OF A 49° SWEPTBACK WING HAVING AN ASPECT RATIO OF 3.78 OF BLOWING AIR OVER THE TRAILING EDGE FLAP AND AILERON, S. Lipson, E.F. Whittle, Jr., NASA Washington, D.C., April 1954.

II.4.1.61 CIRCULATION CONTROL BY MEANS OF TRAILING EDGE SUCTION, D.C. Hazen, T.E. Sweeney, R.F. Lehnert, Princeton University, N.J., James Forrestal Research Center, September 1953.

II.4.1.62 EXPERIMENTAL DEVELOPMENT AND TESTS OF A HIGH-LIFT, CIRCULATION-CONTROL WING, K. Razak, V. Razak, Wichita State University, Kansas School of Engineering.

II.4.1.63 WIND TUNNEL STUDY TO EXPLORE THE USE OF SLOT SPOILERS TO MODULATE THE FLAP INDUCED LIFT OF A WING, J.W. Stickel and R.C. Henry NASA TN D4664, July 1968.

II.4.1.64 XV-11A DESCRIPTION AND PRELIMINARY FLIGHT TEST, S.C. Roberts, A.W. Steward, V.L. Boaz, G.D. Bryant, L.J. Mertaugh, Jr., May 1967. Mississippi State University, State College Department of Aerophysics. The XV-11A is a polyester reinforced fiberglass STOL aircraft. This four-place aircraft powered by a 250-horsepower T-63 turbine engine was designed to achieve high-lift coefficients by means of a variable camber wing with distributed suction boundary layer control. A shrouded propeller was used for thrust augmentation at low forward velocities, and Beta control on the propeller was successfully used as a drag increment for glide path control. To date, the XV-11A aircraft has flown 49 flights with a total flight time of 35 hours. The majority of the flight time was involved in aerodynamic research of the shrouded propeller, the distributed suction boundary layer control system and in an evaluation of the general handling characteristics of the aircraft. A minimum of performance data was collected since the primary objective was aerodynamic research. The fiberglass material demonstrated the excellent possibilities of this type of construction when complex, aerodynamically smooth curvatures are desired.

II.4.1.65 AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, VOLUME III, Aerodynamic Research on Boundary Layers, Cornell Aeron. Lab. Inc., Buffalo,N.Y. June 1966.
Contents: Spanwise flow effects on rotor performance; a preliminary study of the effect of a radial pressure gradient on the boundary layer of a rotor blade; the boundary layer of the hovering rotor; an investigation of the feasibility of a common boundary layer control system for high-lift and low-drag on an airfoil section.

II.4.1.66 POWERED MODEL INVESTIGATION OF THE EFFECTS OF GATED SPOILERS ON THE AERODYNAMIC CHARACTERSITICS OF

II.4.1.66 (continued)
WINGS AT ANGLES OF ATTACK FROM 0 TO 90 DEGREES, K. R. Reader, R. D. Murphy, Naval Ship Research and Development Center, Washington, D.C., April 1967.
An investigation was conducted to evaluate the effects of a gated spoiler near the upper surface leading edge of a propeller powered wing model. The device was considered appropriate for solution of a particular handling qualities problem in tilt-wing stall phenomena. The data gathered indicate that a descending-decelerating approach of perhaps 20° may be possible with the spoiler system. The most significant aspect of the benefits of the subject spoiler lies in the probable high insensitivity to wing planform (aspect ratio) which will allow freedom in the optimization of wing design.

II.4.1.67 INVESTIGATION OVER MOVING GROUND PLANE OF A TRANSPORT AIRPLANE MODEL USING BLOWING OVER FLAPS FOR BOUNDARY-LAYER CONTROL, R.D. Vogler, NASA TND 4083, August 1967.
An investigation at low speeds over a still and a moving ground plane was made to determine the effects of ground proximity on the longitudinal aerodynamic characteristics of a model of a transport airplane. The four-engine model was equipped for blowing over the flaps for boundary-layer control. Compressed air was used to furnish flap blowing as well as to furnish the thrust for the two inboard engines.

Results show that flap blowing substantially increases the lift coefficient at constant angle of attack in or out of ground effect. The presence of the ground reduces the lift and drag coefficients and reduces the download on the tail; thereby, more negative tail incidence is required for trim. The lift reduction increases with increase in flap blowing and height reduction to a maximum of about 20 percent of the out-of-ground-effect lift. The still and the moving ground plane show negligible difference in effect on model forces and moments except for the model very close to the ground with a large amount of blowing momentum. The more realistic moving ground plane shows small increments of increased lift, decreased drag, and positive pitch when compared with the still ground plane.

II.4.1.68 WIND TUNNEL TESTS OF BLOWING BOUNDARY-LAYER CONTROL WITH JET PRESSURE RATIOS UP TO 9.5 ON THE TRAILING-EDGE FLAPS OF A 35° SWEPTBACK WING AIRPLANE, M.W. Kelly and J.H. Tucker, NACA RMA 56G19.

A full scale wind tunnel investigation was made to determine whether the effects of blowing high-velocity air overtrailing-edge flaps could be adequately correlated by the jet momentum over a wide range of jet velocities (i.e., jet pressure ratios from subcritical to 9.5). The model selected for these tests was a 35° sweptback wing airplane which had been equipped with plain flaps having blowing boundary-layer control. Three-component force data and flow and pressure ratio requirements of the blowing boundary-layer control system were obtained at Reynolds numbers of 7.6×10^6 and $10. \times 10^6$.

Good correlation of lift with jet momentum was obtained over the above range of jet pressure ratios.

II.4.1.69 LIFT AUGMENTATION BY LATERAL BLOWING OVER A LIFTING SURFACE, C.J. Dixon, AIAA Paper 69-193, February 1969.

The potential and analysis of a lift augmentation concept based on simply blowing high-momentum jet air from the side of a fuselage over the low-pressure side of a lifting surface are presented. Wind tunnel pressure tests have been conducted with lateral blowing over a rectangular wing of aspect ratio 4.4, with a sharp-edged flat-plate airfoil. A 25%-chord flap was added at 70° flap deflection with lateral blowing over the flap. Lift augmentation ratios for the wing and flap blowing are between 2 and 5. The concept is shown to be one which controls leading-edge separation from either the wing or flap by free-air entrainment into the jet. The effect of nozzle size and position is shown to be quite significant. One of several promising applications is lateral blowing over the vertical and horizontal stabilizers to control and trim a high-lift wing-flap system or to augment VTOL control during transition.

II.4.1.70 ANALYSIS OF SOME PARAMETERS USED IN CORRELATING BLOWING-TYPE BOUNDARY-LAYER CONTROL DATA, M. W. Kelley, NACA RM A56F12, June 1956.

An examination was made of limitations to the use of the jet momentum coefficient as a correlating factor in comparing tests of blowing-type boundary-layer control. A theoretical analysis indicated

II.4.1.70 (continued)
that this parameter should be acceptable where the duct pressures are large. At low pressures, when the jet velocity is of local stream velocity, the correlating parameter should include a term involving the flow quantity and ratio of the local velocity at the nozzle to the freestream velocity. Experimental data were shown to substantiate this conclusion.

II.4.1.71 SHORTENING THE TAKEOFF AND LANDING DISTANCES OF HIGH SPEED AIRCRAFT, J.K. Wimpress, Boeing, D6-16168 (also presented at the Twenty-sixth Meeting of the AGARD Flight Mechanics Panel, June 9-10, 1965, (AGARD Report 501).
Examined some of the fundamental relationships involved in shortening the takeoff and landing distances of high speed aircraft. Reviewed the fundamental parameters that determine takeoff and landing distance with particular emphasis on the influence of lift coefficient (C_L), lift-to-drag ratio (L/D), and thrust-to-weight ratio (T/W). Since lift coefficients are so vital to field length performance, recent (1965) developments in high lift systems were presented. The results of fitting various high-lift systems into the field length requirements of transport and STOL aircraft were discussed. Demonstrated some of the compromises that must be made to achieve short field length.

II.4.1.72 COLLECTION OF TEST DATA FOR LATERAL CONTROL WITH FULL-SPAN FLAPS, J. Fischel and M.F. Iney, NACA TN 1404, 1947.
A collection of test data on lateral control with full-span flaps was presented. Lateral-control effectiveness and hinge-moment data obtained from two-dimensional, three-dimensional and flight tests were presented. A discussion was given of the characteristics of the lateral-control devices considered and of the application of the data to specific airplane design.

II.4.1.73 GROUND INFLUENCE ON A MODEL AIRFOIL WITH A JET-AUGMENTED FLAP AS DETERMINED BY TWO TECHNIQUES, T. R. Turner, NASA TN D658, February 1961.
An investigation was made in the Langley 300-MPH 7- by 10-foot tunnel with a conventional ground-board set-up and in the Langley tank No.1 by using the tow carriage to move the model over a ground board to evaluate the simulation of flight

II.4.1.73 (continued)
conditions in ground influence with a conventional ground-board setup. The 12-percent-thick airfoil was unswept and untapered with an aspect ratio of 6.0 and had a 10-percent-chord jet-augmented flap.

From this investigation it appears that the loss in lift of an airfoil with a jet-augmented flap in ground influence as determined in a wind tunnel with a conventional ground-board setup is considerably larger than would be obtained in free flight.

II.4.1.74 EFFECTS OF GROUND PROXIMITY ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN UNSWEPT ASPECT-RATIO-10 WING, A.W. Carter, NASA TN D 5662, February 1970.
A wind tunnel investigation was made of the effects of ground proximity on the longitudinal aerodynamic characteristics of an unswept wing with an aspect ratio of 10 and a taper ratio of 0.3 Data were obtained over a stationary and moving-belt ground plane with flaps retracted and with full-span double-slotted flaps deflected 30° and 50°. Ground-effect data were also obtained for the model with leading-edge slats on the wing with trailing-edge flaps deflected 50°. The results indicated the need for a moving-belt ground plane in order to remove the boundary-layer buildup and to predict the correct aerodynamic characteristics for a plain wing as well as for wings with trailing-edge flaps and leading-edge slats.

II.4.1.75 LOW SPEED WIND TUNNEL TESTS OF AN A.R.8 SWEPT WING SUBSONIC TRANSPORT RESEARCH MODEL WITH BLC BLOWING OVER NOSE AND REAR FLAPS FOR HIGH-LIFT, R.C. Eyre, S. Butler, RAE-TR-67112, March 1967.
Systematic low speed longitudinal stability measurements were made on a model with a 13% thick wing of 28° leading-edge sweepback, with knee blowing BLC over full-span nose and rear flaps. Minimum flowing requirements and lift increments at attachment were generally consistent with estimates; but further increases in the supercirculation regime were larger than predicted. Experimental values were in reasonable agreement with estimates. The drag results showed that current methods gave close estimates of the zero-lift drag for flaps deflected 40° and 60°, the discrepancy

II.4.1.75 (continued)
between experimental and estimated values was large for flaps deflected 80°. With both nose and rear flaps deflected, low induced drag factors were obtained.

II.4.1.76 DESIGN FEATURES AND LOW SPEED TUNNEL RESEARCH PROGRAMME FOR A BLC HIGH LIFT SUBSONIC TRANSPORT MODEL WITH JET-LIFT NACELLES FOR STOL AND VTOL, S.F.J. Butler, R. Eyre, RAE-TM-AERO-1029, December 1967.
The model had a 28° leading edge sweepback wing of AR8 with high-lift blowing BLC flaps, powered lift-thrust underslung engine nacelles and powered multiple lift-engine nacelles straddling the outer wing. The model was designed to facilitate an intensive, yet flexible, programme of aimed research. This introductory paper considered the possible scope of a tunnel test programme as well as the design, development and calibration of the complex model and associated rigs. The latter as the development of a 6-component strain-gauge balance arrangement, suitable for other jet-blowing models with transmission of the large air quantities (10 lb/sec at 9 atmospheres gauge) needed for VTOL jet efflux simulation.

II.4.1.77 WIND TUNNEL INVESTIGATION AT LOW SPEEDS TO DETERMINE FLOW-FIELD CHARACTERISTICS AND GROUND INFLUENCE ON A MODEL WITH JET-AUGMENTED FLAPS, R.D. Vogler and T.R. Turner, NASA TN 4116, 1957.
A wind tunnel investigation was made to determine the flow-field characteristics and ground influence on an airplane model having an untapered, unswept wing with an aspect ratio of 8.3 equipped with jet-augmented flaps. Jet-augmented-flap deflections of 55° and 85° were investigated. The high lift coefficients associated with the jet-augmented flaps were greatly reduced in ground effect. The adverse effects of the ground increased rapidly as the wing approached the ground, as the jet-deflection angle increased, or as the momentum coefficient increased. Associated with these reductions in lift coefficient were reductions in both drag coefficient and nose-down pitching-moment coefficient.

II.4.1.78 DEVELOPMENT OF BLC HIGH-LIFT SYSTEM FOR HIGH-SPEED AIRPLANES, L.B. Gratzer and T.J. O'Donnell, Journal of Aircraft, Vol.2 No.9, November, December 1965. The significant steps in the development of a boundary-layer control (BLC) high-lift system for the 367-80 (707 prototype) airplane are presented. The design was based on a boundary-layer control concept using an ejector for momentum augmentation of BLC air and primary air bleed from the propulsion system. A modulated thrust reverser for flight-path control was used. Considerations leading to the selection of the design concept were discussed. Results of research involving two-dimensional and complete configuration tests in the laboratory were given. Landing speeds less than 85 knots at 140,000 lbs. airplane gross weight were achieved.

II.4.1.79 INCREASE IN MAXIMUM LIFT OF A RECTANGULAR WING IN GROUND EFFECT BY COMBINED BLOWING AT THE WING NOSE AND AT THE TRAILING EDGE FLAP, R. Loehr, RAE-LIB-TRANS-1270, December 1967. Wind tunnel tests were conducted on a rectangular wing with plain trailing-edge flap in ground effect. The effectiveness of combined leading-edge and trailing-edge blowing was evaluated. Combined blowing was better for increasing maximum lift than trailing edge blowing alone.

II.4.1.80 EXPLORATORY LOW-SPEED TUNNEL TESTS OF PART-SPAN FLAP AND FUSELAGE EFFECTS ON A HIGH-LIFT WING, D.N. Foster, RAE TR 65288, December 1965. Full-span and part-span blowing BLC flaps were tested on a high aspect ratio, unswept wing. The effect of adding a fuselage was investigated. Although inferior to the wing alone with full span flaps, the wing-fuselage had more lift and less drag than the wing alone with part-span flaps. Simple spanwise loading calculations could predict part-span flap and fuselage effects for moderate trailing-edge flap loadings.

II.4.1.81 SOME NOTES ON UNITED KINGDOM EXPERIENCE IN THE TESTING OF VTOL AIRCRAFT, R.T. Shields, AGARD Report 318, April 1961. Experience to date in the flight testing of VTOL aircraft in the United Kingdom is reviewed. Methods employed in the testing of three aircraft, the Rolls-Royce "Flying Bedstead", Short SC.1, and Hawker, P.1127, are considered.

II.4.1.82 TABULATION OF MAXIMUM LIFT COEFFICIENT DATA OBTAINED FROM TESTS ON AIRFOIL SECTIONS WITH HIGH LIFT DEVICES, E.O. Rogers, Naval Ship Research and Development Center, Technical Note, AL-106, March 1969.

The results of a literature search to collect maximum lift coefficient data on airfoil section with high lift devices are presented. The data are tabulated.

II.4.1.83 LOW-SPEED FLIGHT INVESTIGATION OF A JET TRANSPORT WITH A POWERED-LIFT BLC SYSTEM, R.O. Schade and H.L. Crane, AGARD 503, June 1965.

Briefly summarises results of flight tests of the Boeing 707 prototype (367-80), by NASA-Langley with a powered lift boundary-layer-control system. The following results were noted:

The performance speed margins required seemed to be related to the power on stall speeds.

There were no large detrimental effects on handling qualities with powered lift.

Noise levels were high.

II.4.1.84 THEORETICAL AND EXPERIMENTAL CONTRIBUTION TO THE STUDY OF BOUNDARY LAYER CONTROL BY BLOWING, P. Carriere, E. Eichelbrenner and Ph. Poisson-Quinton, in "Advances in Aeronautical Sciences", Vol.2,Proceedings of the First International Congress in Aeronautical Sciences, September 8-13, 1958, Pergamon Press, London, 1959.

In order to better understand blowing boundary-layer-control, boundary layer profiles were examined experimentally for a jet emitted along a wall. Using the experimental boundary layer profiles as a guide, a theoretical technique was developed for estimating the critical blowing coefficient. Some empirical results were presented for use in preliminary design work.

II.4.1.85 BLOWING TESTS ON AN AEROFOIL WITH SLOTTED FLAP, German F.B. L274, F. Ehlers, and W. Schwier, 1940.

On a rectangular wing of the NACA 23014,profile with slotted flaps of different chord tests were made for boundary-layer influence by blowing out air, at which it has been attempted to increase the effectiveness of the flaps. The results indicated that through the blowing out the flap deflections could be made effective up to 45°.

II.4.1.86 POWER REQUIREMENTS OF A BLOWING WING WITH SEALED AND SLOTTED TRAILING EDGE FLAPS, Fairchild Aircraft Miss. Div. Eng. Report R-246-604, H.B. Helmbold, 1959.
ONR-supported experimental investigation of a blowing NACA 23015 airfoil with a sealed flap and an effective blowing-slot width of 0.7% chord, over a range of flap deflection angles from 0° to 70°. Only flows fully attached to the flap are considered. A comparison with the results for the slotted flap with wide blowing slot shows that, at high flap deflection angles, the power requirement of the sealed flap is diminished only over a limited range of lift coefficients after re-attachment, whereas for higher lift coefficients the slotted flap is definitely superior. Present results are discussed in their context with previous ones.

II.4.1.87 LARGE SCALE WIND TUNNEL TESTS AND EVALUATION OF THE LOW SPEED PERFORMANCE OF A 35° SWEPTBACK WING JET TRANSPORT MODEL EQUIPPED WITH A BLOWING BOUNDARY-LAYER CONTROL FLAP AND LEADING EDGE SLAT, NASA TN D333, D. H. Hickey and K. Aoyagi, 1960.
The typical four-engine jet transport model had a wing of aspect ratio 7. Three-component longitudinal force and moment data and boundary-layer-flow requirements are presented. The test results are analyzed in terms of estimated takeoff and landing performance. The effect on performance of the source of boundary-layer control airflow is considered.

II.4.1.88 APPLICATION A UNE MAQUETTE D'AVION COMPLETE DU CONTROLE DE LA COUCHE LIMITE PAR SOUFFLAGE SUR LES VOLETS ET LES AILERONS, Rech. Aeron., No.23, P. Jousserandot, 1951.
Report on the tests made with a complete model of the ME 109 aircraft, equipped with an installation for blowing out over the flaps and the ailerons. The blowing is a means of boundary-layer control which permits the increase of efficiency of the flaps (maximum lift for landing) and of the ailerons (lateral control) preventing the stalling caused by large flap deflections and large angles-of-attack. The increase of the pitching moment caused by the blowing leads to a problem of equilibrium of the model. The problem was studied having regard to the resulting loss of lift.

II.4.1.89 BLOWING-TYPE BOUNDARY-LAYER CONTROL AS APPLIED TO THE TRAILING-EDGE FLAPS OF A 35° SWEPT-WING AIRPLANE, NACA Report 1369, M.W. Kelly, S.B. Anderson and other, 1958.
A wind tunnel investigation was made to determine the effects on the aerodynamic characteristics of a 35° swept-wing airplane of applying blowing-type boundary-layer control to the trailing-edge flaps. Flight tests of a similar airplane were then conducted to determine the effects of boundary-layer control on the handling qualities and operation of the airplane, particularly during landing and takeoff. The wind tunnel and flight tests indicated that blowing over the flaps produced large increases in flap lift increment, and significant increases in maximum lift. The use of blowing permitted reductions in the landing approach speeds of as much as 12 knots.

II.4.1.90 RECHERCHES THEORIQUES ET EXPERIMENTALES SUR LE CONTROLE DE CIRCULATION PAR SOUFFLAGE APPLIQUE AUX AILES D'AVIONS, ONERA TN37, L. Malavard, P. Jousserandot, and others 1956.
The necessity to reduce the speed and the takeoff and landing of modern aircraft has led to new conceptions of lift generation using the turbo-engines which are needed to give the propulsion for the airplanes. Giving the main parameters and a linear theory of blowing the report contains in a number of diagrams two-dimensional and some three-dimensional results of blowing over a flap, blowing symmetrically over and under a flap, results of the jet-flap and results about a configuration with suction at the gap between the profile and the flap and blowing at the rear of the flap. The results were obtained by theory and especially by experiment. The authors give some comments about the applicability of the theory and discuss the different possibilities of blowing together with their problems.

II.4.1.91 TESTS CONCERNING THE INCREASE OF LIFT BY BLOWING ON A SYMMETRICAL AEROFOIL WITH CAMBER FLAP OF LARGE CHORD, W. Schwier, German F.B. 1462, 1941.
On rectangular wing with the symmetrical profile Gott. 409 with trailing-edge flap of 40% chord tests made for the increase of lift by blowing out air. The results indicate an essential increase of the lift.

II.4.1.92 BLOWING TESTS FOR THE INCREASE OF LIFT OF A 9% THICK AEROFOIL WITH A SLAT AND FLAP, W. Schwier, German F.B. 1622, 1942.
On a rectangular wing with a symmetrical profile of 9% thickness blowing tests were made for the increase of lift. The profile was equipped with a movable slotted flap of 25% chord and an also changeable slat of 13% chord. It was measured the lift in dependency on the blown out quantity of air.

II.4.1.93 BLOWING TESTS FOR THE INCREASE OF LIFT OF 12% THICK AEROFOIL WITH DIFFERENT FLAP SHAPES, W. Schwier, German F.B. 1658; Translation NACA TM 1148, 1942.
Blowing tests were made to increase the lift of the NACA 23012-64 profile. The wing was investigated with trailing-edge flaps of various forms and a slotted flap of 25 percent chord. There was also a slat which could be used for increasing the lift. The results indicate the lift of the aerofoil dependent on the blown out quantity of air, and show a considerable increase of lift with increasing quantity. The report gives also the flap moments, the normal and tangential forces.

II.4.1.94 TWO-DIMENSIONAL WIND TUNNEL TESTS OF AN F9F-5 AIRPLANE WING SECTION USING A HIGH-SPEED JET BLOWING OVER THE FLAP; Part I, TESTS OF A 6-FOOT CHORD MODEL, E. L. Harkleroad, and R.D. Murphy, DTMB Aero Report 845, 1953.

See also, II.3.1.5, II.3.1.6, I.4.1.2, 9, 15, 16, 17, 19, 23, 24, 28, 45, 46, I.2.1.44, I.4.7.4, 6, 9, 11.

II.4.2 Flow Fields -

II.4.2.1 IN-FLIGHT INVESTIGATION OF SOME EFFECTS OF BOUNDARY-LAYER CONTROL ON WAKE PROPERTIES, Mississippi State University State College, W. E. Crouch, Jr., June 1959.

II.4.3 Ground Effect -

See II.4.1.1, .79, .86, .87, .91, .97 and .99

II.4.4 Stability and Control -

II.4.4.1 LOW-SPEED WIND TUNNEL MEASUREMENTS OF DAMPING IN YAW (n_{μ}) ON AN AR9 JET-FLAP COMPETE MODEL, A.P. Cox and S.F.J. Butler, CP 869, 1967.
The experimental apparatus and procedure are described. Results are given at wind incidences of 0°, 10° and 20° with jet flap control angles of 0° and 30° and a C_{μ} range of 0 to 4.2. The effects of the wing, fin, tailplane and fuselage were measured.

II.4.4.2 FLIGHT MEASUREMENTS OF THE LOW-SPEED CHARACTERISTICS OF A 35°SWEPT-WING AIRPLANE WITH AREA-SUCTION BOUNDARY LAYER CONTROL ON THE FLAPS, NASA, Washington, D.C., S.B. Anderson, H.C. Quigley, Report No. RM A55K29.

II.4.4.3 LOW SPEED WIND TUNNEL TESTS ON AN AR8 SWEPT WING SUBSONIC TRANSPORT RESEARCH MODEL WITH BLC BLOWING OVER NOSE AND REAR FLAPS FOR HIGH LIFT, R.C. W. Eyre, S.F.J. Butler, Royal Aircraft Establishment Tech. Report 67112, May 1967.
Systematic low speed longitudinal stability measurements have been made on a model with a 13% thick wing of 28° leading-edge sweepback, with knee blowing BLC over fullspan nose and rear flaps.

Minimum blowing requirements and lift increments at attachment were generally consistent with estimates, but further increases with C_{μ_R} in the supercirculation regime were larger than predicted. Experimental values of $C_{m_{c/4}}/C_L$ were in reasonable agreement with estimates. The drag results showed showed that while current methods gave close estimates of the 'zero-lift drag' for flaps deflected 40° and 60°, the discrepancy between experimental and estimated values was large for flaps deflected 80°. With both nose and rear flaps deflected, low induced drag factors were obtained.

Typically, the lift increment with full-span rear flaps at 60° increased from 1.1(C_{μ_R}=0) to 2.6 (C_{μ_R}=0.06) with moderate trimming losses. The increased loading due to BLC resulted in significant and progressive reductions in stalling incidence, with tip stall and pitch-up. Compensating increases in stalling incidence were obtained by

II.4.4.3 (continued)

deflection of full-span nose flaps and further increases occurred as a result of nose blowing BLC without materially improving the nature and severity of the stall. By simply restricting the nose blowing to the outer 75% of the exposed wing, it was possible to achieve a confined root stall (stall 18°, $C_{L_{max}}$=3.6) and preclude pitch-up, with only moderate penalties on $C_{L_{max}}$ and stall.

Some preliminary lateral stability measurements at high-lift are also included.

II.4.5 Handling Qualities and Criteria -

II.4.5.1 FLIGHT MEASUREMENTS OF THE LOW SPEED CHARACTERISTICS OF A 35°SWEPT WING AIRPLANE WITH AREA SUCTION BLC ON THE FLAPS, S.B. Anderson, H.C. Quigley, Report No. RM A55K29, NASA, Wash. D.C.

II.4.6 Testing -

See Section II.

II.4.7 General -

II.4.7.1 METHODS OF PRODUCING HIGH LIFT (METHODEN VOOR DRAAG-KRACHTVERGROTING), A.C. DeKock, J. Yif and J.A. Azzf, National Luchten Rutmtevaartlaboratorium, NLL-IF,210.
A literature survey of high lift aids which can be used for reducing takeoff and landing distances is given. Consecutively the various means for obtaining high lift, such as profile geometry, flaps and slats, suction and blowing, supercirculation, deflected slipstream and tilted wing and propellers, are treated. An extensive bibliography of recent publications is included and arranged to subject.

II.4.7.2 AIRCRAFT HIGH-LIFT DEVICES, Report Bibliography, Defense Documentation Center, Alexandria, Va. April 1969.
This bibliography is a selection of 89 unclassified references to unclassified-unlimited, unclassified-limited, and confidential reports on aircraft high-lift devices processed by DDC from January 1953 to January 1969. A list of 14 unclassified titles of 9 confidential reports and 5 secret references to secret reports are included. Corporate author-monitoring agency, subject, personal author, contract and report number indexes are provided.

II.4.7.3 TRANSVERSE JET EXPERIMENTS AND THEORIES - A SURVEY OF THE LITERATURE, D.J. Spring, T.A. Street, J.L. Amick, June 1967.
This report is a survey and review of the work that has been done concerning the use of transverse jets as a control device. Comparisons are made within the report of theories available to predict forces and moments. Tables of the experimental data for flat plates, bodies of revolution, and theories have been constructed for further clarification of the material within the report.

II.5 FAN-IN-WING

II.5.1 Forces and Moments

II.5.1.1 AERODYNAMIC CHARACTERISTICS OF A FULL-SCALE FAN-IN-WING MODEL INCLUDING RESULTS IN GROUND EFFECT WITH NOSE-FAN PITCH CONTROL, J.V. Kirk et al, NASA TN-D 2368, July 1964.
The model had a mid-mounted wing of aspect ratio 3.1. Results cover the fan-powered flight speed range from 0 to 120 kt. Longitudinal and lateral directional characteristics with and without fan exhaust vectoring, downwash at the horizontal tail, and the effects on performance of exhaust gas reingestion are included.

II.5.1.2 WIND TUNNEL TESTS OF A SEMISPAN WING WITH A FAN ROTATING IN THE PLANE OF THE WING, D.H. Hickey and D.R. Ellis, NASA TN D-88, October 1959.
An investigation was conducted to determine the aerodynamic characteristics of an aspect ratio 4 wing model with a fan rotating in the plane of the wing. Force, pressure, and power measurements were obtained with fan-duct inlet and exit vanes. These data were obtained for tip speed ratios from 0.1 to 0.5.

II.5.1.3 AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE MODEL WITH TWO HIGH DISK-LOADING FANS MOUNTED IN THE WING, D.H. Hickey and L.P. Hall, NASA TN D-1650, February, 1963.
The model had a shoulder-mounted wing of aspect ratio 3.5. Results cover the fan-powered flight-speed range from 0 to 125 knots. Longitudinal forces and moments, downwash at the horizontal tail, wing-surface static-pressure distributions, and lateral forces and moments when the fans were throttled to give control are presented.

II.5.1.4 AERODYNAMICS OF A FAN-IN-FUSELAGE MODEL, R.L. Maki and D.H. Hickey, NASA TN D-789, May 1961.
A large-scale model with an unswept wing and a high disk-loading fan mounted in a fuselage duct was tested in the wind tunnel. The test results were used to study transition flight characteristics associated with the submerged fan concept.

II.5.1.5 PRELIMINARY WIND TUNNEL TESTS OF A LIFTING FAN IN A TWO-DIMENSIONAL AEROFOIL, R.L. Wardlaw and R.J.

II.5.1.5 (continued)
Templin, NAE Report LR-207, September 1957.
Preliminary wind tunnel tests done with a two-dimensional aerofoil with a single fan mounted in the wing are outlined. A simple momentum theory is developed which provides reasonable agreement with the test results at low speeds. The use of fan outlet guide vanes to reduce drag is discussed, and the results of one test are presented.

II.5.1.6 WIND TUNNEL TESTS OF A WING FITTED WITH A SINGLE LIFTING FAN, N. Gregory et al, R&M 3457, 1967.
A square wing with a lifting fan of 1/44th the wing area located at 0.354 chord was tested. Forces and pressure distributions were measured both on the bare wing and with plain and split flaps.

II.5.1.7 TESTS ON A SIMULATED LIFTING FAN SYSTEM WITH INLET CROSS FLOW, R.C. Turner and D.W. Sparkes, R&M 3461, 1967.
A single-stage fan was fitted with three simple annular intakes in turn, and tested with inlet cross flow to simulate the conditions during aircraft transition.

II.5.1.8 RESULTS OF WIND TUNNEL TESTS OF A FULL-SCALE, WING-MOUNTED, TIP-TURBINE-DRIVEN LIFT FAN, General Electric Co., Cincinnati, Ohio, September 1963, 379 p.
The full-scale wing-tip turbine-driven lift fan was model tested in the NASA Ames Research Center 40-foot by 80-foot wind tunnel. This series of tests has provided the first large scale test data with fans installed in wings. Detailed discussions and tabular data are presented on the following: wind tunnel; test instrumentation; test procedures and results. Analysis of results considers the basic aircraft performance (power off), fan aerodynamic performance, fan thermodynamic performance, fan powered aircraft performance, fan mechanical performance and hardware inspection.

II.5.1.9 CHARACTERISTICS OF LIFTING-FAN V/STOL AIRCRAFT, R.H. Goldsmith and D.H. Hickey, AAE Vol. 1, October 1963, p. 70-77.
Description of full-scale wind tunnel tests of lifting-fan-aircraft. Discussed are the aerodyna-

II.5.1.9 (continued)
mic features peculiar to lifting-fan configurations and analog studies of transition and conversion together with the propulsion-system design, hovering controls, and application of the lifting-fan concept to both a small Mach 0.85 strike aircraft and a large assault transport. Full-scale wind-tunnel tests of practical configurations for lifting-fan aircraft have shown that lift increases as a forward flight speed increases, and that pitching moments during transition can be kept at levels comparable to those for conventional aircraft.

II.5.1.10 LIFT FAN FLIGHT EXPERIENCE, D. Clark and E. Smith, AIAA, Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 14-18, 1965, paper 65-603, 14p.
Description of wind tunnel testing which can be used as the basis for design of a VTOL aircraft. Fan component tests can be used as a basis for the design and proportioning the controls of a VTOL aircraft, as shown by the correlation of predicted vs measured values. The comparison of flight test data with wind tunnel results is made and good agreements are shown. The wind tunnel data formed a basis for the safe and successful conduct of the flight research program. A number of problem phases encountered during the program point to recommendations and improvements for future systems.

II.5.1.11 AERODYNAMIC CHARACTERISTICS OF A FULL-SCALE FAN-IN-WING MODEL INCLUDING RESULTS IN GROUND EFFECT WITH NOSE-FAN PITCH CONTROL, J. V. Kirk, D.H. Hickey, and L.P. Hall, NASA, Ames Research Center, Moffett Field, California, Washington, NASA, July 1964, 147p., (NASA-TN-D-2368).
An investigation was conducted to determine the low-speed aerodynamic characteristics (in and out of ground effect) of a full-scale fan-in-wing VTOL model incorporating a fan in the nose of the fuselage for trim and pitching-moment control. The model had a mid-mounted wing of aspect ratio 3:1. Results were obtained with the wing at 3.85, 2.2, 1.7 and 1.0 fan diameters above the tunnel floor. The high position was considered out of ground effect. The effects on longitudinal characteristics of lift-fan performance were obtained at all positions tested while longitudinal characteristics

II.5.1.11 (continued)
with the pitch fan operating were obtained for only the three positions considered in ground effect. Longitudinal and lateral-directional characteristics were studied in the high position with the lift fans operating and with various settings of the fan exit vanes to control fan thrust and produce yaw and roll. Various trailing-edge flap deflections were tested with the model in the high position and the optimum setting of 45° was then used throughout the remainder of the program.

II.5.1.12 AN ANALYSIS OF THE STICK FIXED DYNAMIC STABILITY OF A TYPICAL VTOL AIRCRAFT DURING TRANSITION FLIGHT OUT OF GROUND EFFECT, R.M. Kraft, R.W.R. Neville, Naval Postgraduate School, Monterey, California, 65, 171 p.
An investigation of the dynamic stability of a typical fixed wing VTOL aircraft operating in the transition region of flight was conducted by means of analog simulation. The Ryan Aeronautical Company XV-5A lift fan research aircraft was used as a basis for analysis. Wind tunnel tests on a simple 1:24 scale model of the aircraft provided static aerodynamic data throughout the angle-of-attack range - 90 degrees or = alpha sub w or = +90 degrees. Non-dimensional stability derivative data was extended throughout the angle-of-attack range.

Analog simulation at relative velocities of 100, 60 and 20 knots was conducted using dimensional parameters. Recording of the simulation runs provided period, frequency, damping, and dutch roll parameter information which was analyzed to determine areas of flight instability. The variations of these parameters with both angle-of-attack and velocity is discussed. The need for automatic stabilization is indicated.

II.5.1.13 CHARACTERISTICS OF AIRCRAFT WITH LIFTING-FAN PROPULSION SYSTEMS FOR V/STOL, R.H. Goldsmith and D.H. Hickey, IAS, Annual Meeting, 31st, New York, N.Y., January 21-23, 1963, paper 63-27, 31 p.
Analysis of wind tunnel tests of several large-scale fan-in-fuselage and fan-in-wing configurations. In contrast to small-scale studies which indicate a lift reduction with forward speed, the

II.5.1.13 (continued)
large-scale configurations tested have a sizable positive induced lift.

II.5.1.14 XV-5A AERODYNAMIC-PROPULSION DATA CORRELATION AND CHARACTERISTICS DEVELOPMENT BASED ON WIND TUNNEL CHARACTERISTICS, Ryan Aeronautical Company, San Diego, California, July 1968, W.C. Parks, R.L. Swingle, W.A. Swope.
The report presents the results of efforts to correlate data for the XV-5A V/STOL aircraft configuration, including small-scale and full-scale wind tunnel investigations and wind tunnel and thrust stand tests of the actual aircraft. The majority of the data correlation work was performed utilizing results from 1/6-scale and full-scale model tests which were conducted during the period of aircraft development. Correlation was limited primarily to wing-body characteristics. Corrections for configuration differences were developed, and the effects of dynamic dissimilarity of the fan systems were evaluated in the data comparison effort. Wind tunnel wall corrections were applied to the full-scale data.

II.5.1.15 RESULTS OF WIND TUNNEL TESTS OF A FULL SCALE FUSELAGE MOUNTED, TIP TURBINE DRIVEN LIFT FAN, Volume 2.
Additional 30 hours of wind tunnel tests, September-December 1960.

Analyses of the results are presented in considerable depth defining fan hover performance and variation with flight speed, comparing fan powered with basic aircraft performance and calculating various transition performance characteristics and configuration requirements for cases of maximum acceleration, maximum climb, controlled descent, unaccelerated level flight and short takeoff (with and without overloads).

II.5.1.16 WING-SUBMERGED LIFTING FAN EXPERIMENTS: AN EXTENSION OF PREVIOUS N.A.E. WIND TUNNEL INVESTIGATIONS, N.V. McEachern and R.L. Wardlaw, NRD, Canada, NAE, NRC LR-371, February 1963.
Extensive measurements of lift, drag and moment on a two-dimensional wing with a submerged lifting fan are presented. The data obtained at high advance ratios show that abrupt changes in incre-

II.5.1.16 (continued)

mental forces can be expected (lift and pitching moment decreasing, and drag increasing). The use of chordwise lower surface fences to improve the aerodynamic characteristics at low speeds was explored; three pairs of fences were investigated and found ineffective. The measurements show that Reynolds number effects are smaller than suggested by previous NAL experiments.

II.5.2 Flow Fields

II.5.2.1 THE EFFECT OF FORWARD SPEED ON THE INLET FLOW DISTRIBUTION AND PERFORMANCE OF A LIFTING FAN INSTALLED IN A WING, N. Gregory, W. G. Raymer, E. M. Love, ARCR and Mem. (R&M 3388/ARC 23839) 41pp, 1965, U.K.

Yaw meter traverses show that flow maldistributions due to forward speed can be removed by a deep duct or an inlet cascade. Non-uniformity of exit static pressure does not affect the flow distribution. Since forward speed reduces the pressure rise required, stalling of the fan blades appears not to be a great danger except at very high speeds, or when a deflected exit cascade is fitted.

II.5.2.2 EXPERIMENTAL STUDIES OF VTOL FAN-IN-WING INLETS, U.W. Schaub, NRC, Canada, Div. of Mech. Engrg., 1965, AGARDograph 103, Part 2, October 1965, pp. 715-747.

The inflow problems associated with inlets, whose axes are perpendicular to the plane of the wing, have been studied in detail statically and at forward speed. The inlet annulus distributions feature, in general, a quasi-two-dimensional appearance with the inflow velocities being highest in the leading annulus sector. Flow distortion is observed to be a function of inflow ratio, inlet geometry, leading lip boundary layer separation and wind incidence angle. In the family of inlets dealt with, the leading lip boundary layer separates only at forward speed. Separated inlet flows cause substantially greater flow distortion than fully attached flows at the same inflow ratio.

II.5.2.3 EXPERIMENTAL INVESTIGATION OF FLOW DISTORTION IN FAN-IN-WING INLETS, V. W. Schaub, Journal of Aircraft, Vol. 5, No. 5, Sept.-October 1968, pp. 473-478.

The aerodynamic performance of an inlet with circular arc lips was evaluated. The lip radius-to-diameter ratio was 0.09, and tests were conducted both with and without a set of radial and annular vanes. Other inlets assessed with an elliptic leading lip (major axis perpendicular to the wing chord line). The "mixed vane"configuration in the datum inlet reduced the extent of

II.5.2.3 (continued)

separated flow in the inflow ratio range 0.0 to 0.7. It was also effective in attenuating the residual momentum over the entire range. The sharp-edged inlet data were helpful primarily in comparing the present results with data in hydraulic engineering. Good agreement was exhibited between the velocity distortion index at zero forward speed and the classical flow coefficient for Borda tube entrances. The total pressure loss was qualitatively in concord with Borda tube entrance losses. The elliptic lip inlet extended the unseparated flow regime to inflow ratios 0.45, from 0.25 for the datum inlet.

See also, II.5.1.16.

II.5.3 <u>Ground Effect</u>

See II.5.1.1, and 11.

II.5.4 Stability and Control

II.5.4.1 STATIC AND DYNAMIC LONGITUDINAL STABILITY DERIVATIVES OF A POWERED 0-18-SCALE MODEL OF A FAN-IN-WING VTOL AIRCRAFT, J. R. Chambers and S. B. Grafton, NASA TN D-4322, February 1968.
The study was made for flight at $\alpha = 0^{o}$. A lift fan was in each wing panel and a smaller fan in the nose for pitch control. A range of thrust condition and oscillatory frequencies for the model with the horizontal tail both on and off was considered.

II.5.4.2 FLIGHT INVESTIGATION OF DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A 0.18-SCALE MODEL OF A FAN-IN-WING VTOL AIRPLANE, R.H. Kirby and J.R. Chambers, NASA TND-3412, August 1966.
The study included hovering flight, in and out of ground effect, and fan-powered low-speed forward flight.

II.5.4.3 DYNAMIC TESTS OF V/STOL TRANSPORT MODELS, M.O. McKinney and R.H. Kirby, AIAA, Transport Aircraft Design and Operations Meeting, Seattle, Wash., Aug. 10-12, 1964, Paper 64-619, 16p.
Presentation of a summary of results obtained in dynamic tests of free-flight models of various configurations suitable for V/STOL transport aircraft at the NASA Langley Research Center. Three configurations are discussed: the tilt-wing propeller-driven XC-142A tri-service transport, the fan-in-wing XV-5A, and the jet-lift Dornier DO-31. The first two configurations were found to have certain dynamic stability problems (mainly unstable stick-fixed oscillations) in hovering and low-speed flight; these instabilities can be controlled by the pilot without artificial stabilization, although artificial stabilization is helpful. As the airspeed approaches that required for normal wing-borne flight, these instabilities are markedly reduced and usually disappear. In descending flight in the transition speed range, the poor behavior that can result from a stalling tendency (if the aircraft is not designed to avoid it) limits the descent angles the pilot is willing to use. The jet V/STOL types have no real dynamic stability problems other than those associated with static stability.

II.5.4.4 LIFT FAN PROPULSION SYSTEMS - V/STOL AIRCRAFT CONTROL, E.F. Beeler and L.J. Volk, SAE, NAS Engrg. & Mfg., meeting, Los Angeles, Calif., Oct. 4-8, 1965, Paper 650831, 21p.
Discussion of aircraft control power requirements provided by lift fan systems. Gas power transfer is desribed and estimated performance presented. A performance comparison is made between the thrust spoiling system used in the present Army XV-5A flight research vehicle and a gas power transfer system. Fan power can provide adequate aircraft control forces.

II.5.4.5 ENGINEERING FLIGHT RESEARCH EVALUATION OF THE XV-5A LIFT-FAN AIRCRAFT, Part I - STABILITY AND CONTROL, W. L. Welter, R. L. Finnestead, R. Ferrell, Army Aviation Test Activity, Edwards AFB, Calif., August 1966.

See also, II.5.1.12.

II.5.5 Handling Qualities and Criteria

See II.5.4.2 and 5, and II.5.6.2.

II.5.6 <u>Testing</u>

II.5.6.1 WALL EFFECTS AND SCALE EFFECTS ON V/STOL MODEL TESTING, NASA, Langley Research Center, Powered-Lift Aerodynamics Section, Langley Station, Hampton, Va.
Study of the limits of applicability of wind-tunnel data on V/STOL configurations, primarily with regard to wall effects and scale effects. Tunnel wall effects on the transition aerodynamics of a tilt-wing, fan-in-wing, and a fan-in-fuselage configuration, as determined from tests of a model of each configuration in three different size tunnels, are discussed.

II.5.6.2 INITIAL FLIGHT EXPERIENCE WITH LIFT FAN PROPULSION, E.F. Beeley and H.O. Russell, SAE, NAS Engrg., & Mfg., meeting, Los Angeles, Calif., Oct. 5-9, 1964, paper 923D, 30p.
Brief review of the development program and first ten flight hours of the Army XV-5A lift-fan aircraft. In the tests, approximately equal flight time has been accumulated in low speed conventional turbojet-powered flight and VTOL fan-powered flight. It is seen that conventional flight between wing stall speed and 160 knots has met design objectives in terms of installed turbojet performance, compatibility of the convertible lift-fan propulsion system, power requirements, stability, and general handling qualities. Over thirty vertical lift-offs have demonstrated a thrust augmentation of nearly three, with fan-derived control performance achieving desirable levels. Qualitative pilot evaluations indicate XV-5A simpler to fly than most rotorcraft.

II.5.6.3 TECHNIQUES FOR THE AERODYNAMIC TESTING OF V/STOL MODELS, W.J.G. Trebble, RAE-TMAero-1080, July 1968.
Concentrated on techniques for testing lift-jet or lift-fan models including engine simulation. Need for adequate ground simulation was discussed. The need for special V/STOL wind tunnels and other facilities was commented on.

II.5.7 General

II.5.7.1 NOISE STUDIES FROM THE FAN-IN-WING MODEL, NRC, of Canada, Ottawa, (Ontario) Div. of Mechanical Engineering, June 1968.
Some preliminary measurements of noise from a highly loaded fan-in-wing configuration are reported. Measurements of the spectra are presented for fan speeds of 7500, 9750, and 13,125 RPM (corresponding to tip Mach number 0.35, 0.45, and 0.62) at an angle of 20^{o} from the axis of the fan and at 5 ft. from the inlet and efflux faces of the fan. The experimental results show a discrete peak at blade-passing frequency, superimposed on a broad band noise that extends from 1000 c/s to 15,000 c/s. An analysis of the duct transmission of higher order modes at the above rotational speeds reveals high decay rates. This explains the absence of discrete tones at the harmonics of the blade-passing frequencies. The presence of high intensity broad band noise may be attributed to the turbulence in the wake and freestream turbulence ahead of the rotor blades.

II.6 TILT WING

II.6.1 Forces and Moments -

II.6.1.1 PRESSURE DISTRIBUTION AND FORCE MEASUREMENTS ON A VTOL TILTING WING-PROPELLER MODEL, J. A. Dunsby et al, NRC Report LR-252, June 1959.
Tabulated results of pressure and force measurements on a half wing model of a twin-engined tilt-wing VTOL configuration over a range of thrust coefficient for a limited range of incidence are presented.

II.6.1.2 RAPID-TRANSITION TESTS OF A 1/4-SCALE MODEL OF THE VZ-2 TILT WING AIRCRAFT, L.P. Tosti, NASA TND-946, October 1961.

II.6.1.3 FLIGHT- AND FORCE-TEST INVESTIGATION OF A MODEL OF AN AERIAL VEHICLE SUPPORTED BY TWO UNSHROUDED PROPELLERS, R.H. Kirby, NASA TND-1965, September 1963.

II.6.1.4 INVESTIGATION OF A SEMISPAN TILTING-PROPELLER CONFIGURATION AND EFFECTS OF RATIO OF WING CHORD TO PROPELLER DIAMETER ON SEVERAL SMALL-CHORD TILTING-WING CONFIGURATIONS AT TRNSITION SPEEDS, K.P. Spreeman, NASA TND 1815, July 1963.
Presents lift, drag and pitching moment data for wing and propeller tilitng separately and together for 3 different wing chords.

II.6.1.5 AERODYNAMIC CHARACTERISTIS OF A FULL SCALE PROPELLER TESTED WITH BOTH RIGID AND FLAPPING BLADES AND WITH CYCLIC PITCH CONTROL, K.W. Mort and P.F. Yaggy, NASA TND-1774, May 1963.
The characteristics are presented for freestream velocities ranging from 0 to 140 knots for angles of attack ranging from 0° to 70°.

II.6.1.6 FULL SCALE WIND TUNNEL TEST OF THE VZ-2 AIRPLANE WITH PARTICULAR REFERENCE TO THE WING STALL PHENOMENA, R.G. Mitchell, NASA TND 2013, December 1963.
A correlation was made at the trim level-flight condition which showed good agreement between the wind tunnel force data corresponding flight data on lift and drag. The wind tunnel force-test results showed no apparent correlating factor with

II.6.1.6 (continued)
the flying-qualities problems associated with wing stall.

II.6.1.7 LARGE SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT TILT WING OF ASPECT RATIO 5.5, AND WITH VARIOUS STALL CONTROL DEVICES, J. A. Weiberg, and D.J. Giulianetti, NASA TND-2133, February 1964.
Results are given of the effects of slats, flaps, wing-fuselage ramp fairing, and propeller rotation on the flow separation, buffet, and descent characteristics of a tilt-wing deflected-slipstream VTOL model. Shows buffet delay by means of slat, BLC nose flap, trailing edge flap.

II.6.1.8 AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH 0.6-DIAMETER CHORD, FOWLER FLAP, AND SINGLE PROPELLER ROTATING UP AT TIP, M.P. Fink et al, NASA TN D2180, February 1964.
The tests included the measurement of the longitudinal aerodynamic characteristics and photographic records of wing flow over a range of angles of attack from -20° to 90° for a range of thrust coefficients from 0 to 1.00 for a range of Fowler flap deflections from 0° to 60° and with three different leading-edge flow-control devices.

II.6.1.9 FORCE TEST INVESTIGATION OF A 1/4-SCALE MODEL OF THE MODIFIED VZ-2 AIRCRAFT, R. H. Kirby et al, NASA TND 2382, August 1964.
Longitudinal aerodynamic characteristics and the aileron control effectiveness were measured. Thrust measurements are not included. All tests were set up such that the thrust used was just sufficient to overcome drag at $\alpha_{FUSELAGE} = 0$.

II.6.1.10 FORCE TEST INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A 1/8-SCALE MODEL OF A TILT WING VERTICAL-TAKEOFF-AND-LANDING AIRPLANE, L. P. Tosti, NASA TND-44, March 1960.
The model had two 6-blade dual-rotating propellers that were not interconnected mounted on a wing that could be tilted up to an incidence angle of about 90° for vertical takeoff and landing.

II.6.1.11 FLIGHT INVESTIGATION OF STABILITY AND CONTROL CHARACTERISTICS OF A 1/8-SCALE MODEL OF A TILT-WING VERTICAL TAKEOFF AND LANDING AIRPLANE, L.P. Tosti, NASA TND 45, March 1960.

Tests were made of hovering flights in still air, vertical takeoffs and landings, and slow constant-altitude transitions from hovering to forward flight. The model had two 6-blade dual-rotating propellers mounted on a wing tiltable up to an incidence angle of approximately 90°. Two wing spans were used. The model had conventional aileron, rudder, and elevator controls for forward flight. For hovering flight the ailerons provided yaw control, on air jet at the tail provided pitch control and differential total pitch of the propellers provided roll control.

II.6.1.12 WIND TUNNEL INVESTIGATION OF LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF THREE PROPELLER-DRIVEN VTOL CONFIGURATION IN THE TRANSITION SPEED RANGE, INCLUDING EFFECTS OF GROUND PROXIMITY, R. E. Kuhn, and W. C. Hayes, NASA TND-55, February 1960.

The investigation used a semispan wing model with two propellers arranged so that their slipstreams covered most of the wing semispan. A sliding flap and a Fowler flap were fitted so that the model could be tested as a tilt-wing configuration, a deflected-slipstream configuration, or a combination tilt-wing-deflected-slipstream configuration. Some measurements of the flow field (angularity and dynamic pressure) in the general location of a horizontal tail were made.

II.6.1.13 AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.6-DIAMETER CHORD, SINGLE-SLOTTED FLAP, AND SINGLE PROPELLER ROTATING DOWN AT TIP, M. P. Fink et al, NASA TN D 2412, August 1964.

Longitudinal aerodynamic characteristics are presented with photographic records of wing flow for $-20° < \alpha < 90°$ for a range of thrust coefficients from 0 to 1.0, a range of flap deflections from 0° to 50° and with three leading edge flow-control devices. Tuft photos show stall patterns.

II.6.1.14 FLIGHT TESTS OF A MODEL OF A HIGH-WING TRANSPORT VERTICAL TAKEOFF AIRPLANE WITH TILTING WING AND PROPELLERS AND WITH JET CONTROLS AT THE REAR OF THE FUSELAGE FOR PITCH AND YAW CONTROL, P.M. Lovell and L.P. Parlett, NACA TN 3912, March 1957.

II.6.1.14 (continued)
An investigation of the stability and control of a high-wing transport vertical takeoff aeroplane with four engines during constant altitude transitions from hovering to normal forward flight was conducted with a remotely controlled free-flight model.

II.6.1.15 INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A MODEL WING-PROPELLER COMBINATION AND OF THE WING AND PROPELLER SEPARATELY AT ANGLES OF ATTACK UP TO 90°, R.E. Kuhn and J.W. Draper, NACA Report 1263, 1956.
Results are presented of a wind tunnel investigation of the effects of slipstream for two large-diameter propellers on the aerodynamic characteristics of a wing model. The investigation covered angles of attack from -10° to 90° and thrust coefficients representing freestream velocities from zero to the normal range of cruising flight.

II.6.1.16 EFFECT OF PROPELLER LOCATION AND FLAP DEFLECTION ON THE AERODYNAMIC CHARACTERISTICS OF A WING-PROPELLER COMBINATION FOR ANGLES OF ATTACK FROM 0° TO 89°, W. A. Newsom, NACA TN 3917, January 1957.
The investigation was conducted with a model having four propellers, the slipstream from which covered practically the entire span of the wing. The wing had a 30% chord slotted flap and an 8.5% chord slat. The tests covered two longitudinal and two vertical positions of the propeller relative to the wing, and a range of flap deflections, with slat off and slat on.

II.6.1.17 WAKE SURVEY AND STRAIN GAUGE MEASUREMENTS ON AN INCLINED PROPELLER IN THE RAE 24-FT TUNNEL, Part I, WAKE SURVEY, J. G. Russell, ARC Current Paper No.117, February 1952, published 1953.
This report describes tests made in the RAE 24 ft wind tunnel with 16ft. diameter, 4 bladed propeller. Wake survey and blade strain gauge measurements were made at tunnel speeds of 100 and 170 fps with the propeller axis inclined at angles of 0, 5, 10 and 15° to the air flow. The blade angles and propeller rotational speeds were also varied within the limits imposed by the 1500 hp electric motor. The lift grading curves at the points of maximum and minimum loading, derived from total head measurements made in the slipstream by means of a pitot comb, have been compared with estimated

II.6.1.17 (continued)
values, and estimated power absorption figures with measured values.

II.6.1.18 TRANSITION FLIGHT TESTS OF A MODEL OF A LOW WING TRANSPORT VERTICAL TAKEOFF AIRPLANE WITH TILTING WING AND PROPELLERS, P.M. Lovell and L.P. Parlett, NACA TN 3745, September 1956.
An investigation of the stability and control of a low-wing four-engined transport vertical-take-off aeroplane during the transition from hovering to normal forward flight has been conducted with a remotely controlled free-flight model. The model had four propellers distributed along the wing with the thrust axes in the wing-chord plane. The wing could be rotated to 90° incidence so that the propeller thrust axes were vertical for hovering flight.

II.6.1.19 LARGE SCALE WIND TUNNEL INVESTIGATION OF AN AIRPLANE MODEL WITH A TILT WING OF ASPECT RATIO 8.4, AND FOUR PROPELLERS IN THE PRESENCE OF A GROUND PLANE, S.O. Dickinson et al, NASA TND 4493, April 1968.
Aerodynamic characteristics were measured at various heights above a fixed ground plane. Model configurations included wing tilt angles from 0° to 90° trailing edge flap deflections from 0° to 60°, and partial span wing leading edge slats.

II.6.1.20 SLIPSTREAM FLOW AROUND SEVERAL TILT WING VTOL AIRCRAFT MODELS OPERATING NEAR THE GROUND, W. A. Newsom and L.P. Tosti, NASA TND 1382, September 1962.
Slipstream dynamic-pressure measurements and tuft surveys as well as a short series of erosion and buffet tests were made.

II.6.1.21 FORCE TEST INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A FOUR-PROPELLER TILT WING VTOL MODEL WITH A PROGRAMMED FLAP, W. A. Newsom, NASA TND 1389, September 1962.
The model was equipped with a 35% chord slotted flap which was programmed to deflect at the wing rotated. Three flap-aileron configurations were tested and the control effectiveness of the all-movable horizontal tail and the ailerons determined.

II.6.1.22 FLIGHT INVESTIGATION OF THE LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF A FOUR-PROPELLER TILT WING VTOL MODEL WITH A PROGRAMMED FLAP, W. A. Newsom, NASA TN D1390, September 1962.
Transition flight tests have been made with a flying model equipped with a 35% chord slotted flap. The flight tests showed that the transition could be performed and that, by proper programming of the deflection of a full-span flap and the incidence of the horizontal tail, the variation of longitudinal trim throughout the transition range could be practically eliminated.

II.6.1.23 AERODYNAMIC CHARACTERISTICS OF A FOUR-PROPELLER TILT WING VTOL MODEL WITH TWIN VERTICAL TAILS, INCLUDING EFFECTS OF GROUND PROXIMITY, K. J. Grunwald, NASA TND 901, June 1961.
The tests covered three general configurations: a pure tilt wing; a tilt wing flap, slats, and wing-span extension; and a tilt wing with flap, slats, and wing-span extension; and a tilt wing with speed brakes and slats. These tests were conducted in and out of ground effect and included investigation of stabilizer and tail-fan effectiveness.

II.6.1.24 LARGE SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT, TILT WING OF ASPECT RATIO 5.5, AND WITH FOUR PROPELLERS AND BLOWING FLAPS, J.A. Weiberg and C.A. Holzhauser, NASA TND 1034, June 1961.
The model was tested with flap deflections of 0° without BLC, 50° with and without BLC and 80° with BLC for wing-tilt angles of 0°, 30°, and 50°. Included are results of tests of the model equipped with a leading-edge flap and the results of tests of the model in the presence of a ground plane.

II.6.1.25 AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.6 DIAMETER CHORD, SINGLE SLOTTED FLAP, AND SINGLE PROPELLER ROTATING UP AT TIP, M.P. Fink et al, NASA TND-1586, October 1964.
The longitudinal aerodynamic characteristics are given and photographic records of wing flow for $-20° < \alpha < 90°$, a range of thrust coefficients from 0 to 1.0, a range of flap deflections from 0° to 50° and with two leading-edge flow-control devices are included.

II.6.1.26 LARGE SCALE WIND TUNNEL TESTS OF DESCENT PERFORMANCE OF AN AIRPLANE MODEL WITH A TILT WING AND DIFFERENTIAL PROPELLER THRUST, W. H. Deckert et al, NASA TN D 1857, October 1964.
Three-component longitudinal characteristics are given for wing tilt angles from 0° to 40°, trailing-edge flap deflections from 0° to 60°, and various wing leading-edge Kruger flap and slat devices.

II.6.1.27 FLIGHT INVESTIGATION OF STABILITY AND CONTROL CHARACTERISTICS OF A 1/9-SCALE MODEL OF A FOUR-PROPELLER TILT WING V/STOL TRANSPORT, W. A. Newsom and R.H. Kirby, NASA TND 2443, September 1964.
The tests included hovering flights in and out of ground effect and level flight and descent tests in the transition speed range.

II.6.1.28 WIND TUNNEL INVESTIGATION OF A TILT WING VTOL AIRPLANE WITH ARTICULATED ROTORS, J. A. Weiberg and D. J. Giulianetti, NASA TND 2538, March 1965.

II.6.1.29 FLIGHT INVESTIGATION OF THE VZ-2 TILT WING AIRCRAFT WITH FULL SPAN FLAP, R.J. Pegg et al, NASA TND-2680, March 1965.
The results include rate of descent, measurements of control sensitivity and angular velocity damping about the roll and yaw axes in hover and low-speed flight, and operational and aerodynamic aspects of STOL problems.

II.6.1.30 AERODYNAMIC INVESTIGATION OF A FOUR-BLADE PROPELLER OPERATING THROUGH AN ANGLE OF ATTACK RANGE FROM 0° TO 180°, H. Clyde McLemore and MD. Cannon NACA Technical Note 3228, June 1954.
The results of an investigation in the Langley full scale tunnel of the aerodynamic characteristics of a four-blade, 5.33-foot diameter propeller are presented for angles of attack from 0°to 67.5°, and a range of advance ratio from 0 to 6.2. The results include a preliminary exploration of vertical descent and a comparison with theory of the rate of change of the normal force coefficient with angle of attack and the aerodynamic characteristics of the propeller at zero angle of attack.

II.6.1.31 AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH A 0.5 DIAMETER CHORD, A DOUBLE-SLOTTED FLAP, AND LEF- and RIGH-HAND ROTATION OF A SINGLE PROPELLER, IN PRESENCE OF FUSELAGE, M.P. Fink, NASA TND 3674, November 1966.

The model was tested in the presence of a fuselage and the loads on the fuselage were measured separately. The rectangular wing had a double-slotted flap, and aspect ratio of 4.88 and an NACA 4415 aerofoil section. The wing chord/propeller diameter ratio was 0.5. Tests were made with and without leading-edge slat and fences. The data were not analyzed but examined to observe the predominant trends.

II 6.1.32 AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH 0.5-DIAMETER CHORD, DOUBLE-SLOTTED FLAP, AND BOTH LEFT- AND RIGHT-HAND ROTATION OF A SINGLE PROPELLER, M.P. Fink et al, NASA TND 3375, April 1966.

The longitudinal aerodynamic characteristics were obtained. The wing had a chord-to-propeller-diameter ratio of 0.5, and aspect ratio of 4.88 (2.44 for the semispan), a taper ratio of 1.0, and a NACA 4415 section. The data were examined only to observe the predominant trends.

II.6.1.33 AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.5 DIAMETER CHORD, SINGLE-SLOTTED FLAP, AND SINGLE PROPELLER 0.08 CHORD BELOW WING, M.P. Fink, NASA TND 4030, July 1967.

The model had a half-fuselage on which loads were measured separately. The rectangular wing had a ratio of chord to propeller diameter of 0.5, a 40%-chord single-slotted flap, an aspect ratio of 4.88 and a NACA 4415 section. Tests were made with right and left hand propeller rotations.

II.6.1.34 LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A FLAPPED TILT WING FOUR-PROPELLER V/STOL TRANSPORT MODEL, K.W. Goodson, NASA TND 3217, February 1966.

Tests were made of a model through the transition-speed range for various combinations of wing tilt angle and thrust coefficient using propellers with a blade pitch of 12°. Some tests were made in ground effect downwash estimates were made by testing with and without horizontal tail.

II.6.1.35 AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.5-DIAMETER CHORD, SINGLE SLOTTED FLAP, AND SINGLE PROPELLER 0.19 CHORD BELOW WING, M.P. Fink, NASA TND 3884, April 1967.
The longitudinal characteristics were measured. The model had a half-fuselage on which loads were measured separately. The rectangular wing had a chord-to-propeller-diameter ratio of 0.5, a 40% chord single-slotted flap, an aspect ratio of 4.88 and an NACA 4415 section. The data were not analyzed in detail.

II.6.1.36 GROUND EFFECTS ON A FOUR-PROPELLER TILT-WING CONFIGURATION OVER A FIXED AND A MOVING GROUND PLANE, K. W. Goodson, NASA TND 3938, May 1967.

II.6.1.37 STATIC AND DYNAMIC LONGITUDINAL STABILITY DERIVATIVES OF A POWERED 1/9-SCALE MODEL OF A TILT WING V/STOL TRANSPORT, J.R. Chambers and S.B. Grafton, NASA TND 3591, September 1966.

II.6.1.38 AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES, R. H. Wickens, NRC Report LR-454, May 1966.
The results of six-component measurements on a propeller yawed through 120 degrees, for various values of blade pitch setting and advance ratio are given.

II.6.1.39 AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH A 0.5-DIAMETER CHORD, A SINGLE-SLOTTED FLAP, AND BOTH LEFT- and RIGHT-HAND ROTATON OF A SINGLE PROPELLER, M.P. Fink and R.G. Mitchell NASA TND 3754, January 1967.
The longitudinal aerodynamic characteristics were studied. The model was tested in the presence of a half-fuselage, and the loads on the fuselage were measured separately. The configuration with and without leading-edge slat and fences was tested. No detailed analysis is given.

II.6.1.40 ANALYSIS AND COMPARISON OF AERODYNAMIC DATA OBTAINED IN A LARGE WIND TUNNEL AND A MOVING-MODEL TRACK FACILITY FOR A GENERAL RESEARCH TILT WING/PROPELLER VTOL CONFIGURATION, USAAVLABS TR 69-74, J. J. Traybar.
A comparison and analysis was conducted of the aerodynamic characteristic data obtained in a large wind tunnel and a moving-model/track facility

II.6.1.40 (continued)
for a general research tilt-wing/propeller VTOL configuration. The two facilities were the Langley 30-by-60 full scale wind tunnel and the Princeton Dynamic Model Track. The experiments included test conditions corresponding to free-stream velocities from transition flight to hovering and wing angles of attack up to 90 degrees. The experimental data obtained from both facilities are compared in several ways in a series of graphs plotted in coefficient form for the range of slipstream thrust coefficients of 0.80 to 0.95. The comparisons and analyses first are made on the basis of wind-axes force and moment coefficients and drag polars. An additional comparison is made of the wing forces by using body-axes force coefficients and polars.

II.6.1.41 AERODYNAMIC CHARACTERISTICS OF A GENERAL TILT WING/PROPELLER MODEL TESTED AT LOW SPEEDS AND HIGH ANGLES OF ATTACK, USAAVLABS TR 67-79, J.J. Traybar.
The aerodynamic characteristics of a general tilt-wing/propeller model were investigated at the Princeton dynamic model track facility. The experiments included test conditions corresponding to freestream velocities from slow backward flight through hovering and transition. Wing incidence angles ranging from 30 degrees (forward flight) to 90 degrees (hovering flight) were investigated. The experimental data are presented in graphs of lift, horizontal force, and pitching moment versus thrust in coefficient form based on freestream velocity.

II.6.1.42 A COMPARISON OF THE AGILITY PERFORMANCE OF A NUMBER OF V/STOL AND STOL AIRCRAFT, R.G. Stutz and G. Price, AIAA, Gen.Aviation Aircraft Design & Operations meeting, Wichita, Kansas, May 25-27, 1964. Paper 64-181.
Presentation of a comparison of five V/STOL and STOL aircraft designs for the purpose of determining the effect of their configuration characteristics on agility performance. Agility is defined as the combination of performance and maneuverability that determines how rapidly any aircraft can accelerate, decelerate, and turn at specified rates of climb and airspeed. The five configurations considered are: (1) pure helicopter; (2) winged helicopter; (3) tilt-wing propeller V/STOL

II.6.1.42 (continued)
aircraft; (4) fixed-wing tilt-propeller V/STOL aircraft; and (5) fixed-wing, direct control STOL aircraft. To facilitate comparison, the aircraft are all designed to meet the requirements of a single tactical support mission. Due to its high deceleration capability, the winged helicopter has the best agility performance up to its maximum speed of 180 knots. Of the propeller-driven designs, the tilt-wing propeller configuration has the best acceleration and normal load factor capability, due primarily to the favorable effect of the propeller slipstream on wing airflow at low speeds. It is felt that agility performance may be as important a design consideration as range, payload, and cruise performance for many V/STOL aircraft missions.

II.6.1.43 WIND TUNNEL TESTS OF AN AERODYNAMICALLY CONTROLLED TILTING WING VTOL CONFIGURATION. H. E. White, D. Taylor Model Basin, Washington, D.C. August 1963, Aero Report No.1057.
Wind tunnel tests were conducted on a model of a VTOL aircraft using a free-pivoted tilting wing with aerodynamically controlled tilt angle. The results of the test show that it is not possible to trim the pitching moment and the axial force on the wing simultaneously at all angles of wing tilt. The effect of pivot location on ability to trim is shown, and modifications to improve ability to trim are suggested.

II.6.1.44 LOW SPEED AERODYNAMIC FLIGHT BOUNDARIES AND CONTROL ASPECTS OF TILT WING AIRCRAFT, B.L. Fry, New York AHS, 1965.
Discussion of the tilt wing aircraft approach to achieving satisfactory levels of deceleration and rate of descent without encountering wing stall, and obtaining sufficient control power without adding complexity and weight. The results of the aerodynamic test programs associated with solution of these problems are also given. The effects of leading edge devices, flaps, fences, propeller position and direction of rotation, and center-section configuration on the wing stall characteristics and related transition performance are discussed. Tuft studies used to develop criteria for limiting flight conditions are substantiated by comparison of model and flight test results. The

II.6.1.44 (continued)
results of a hover yaw control investigation and of a wind tunnel tests of a tilt wing model with monocyclic propellers are also presented. Pitch control with cyclic propellers does not adversely affect transition performance, and spoilers are shown to be effective for hover yaw control.

II.6.1.45 WING PRESSURE MEASUREMENTS WITHIN THE PROPELLER SLIPSTREAM FOR A LARGE SCALE V/STOL WIND TUNNEL MODEL SIMULATING TRANSITION, N.M. Winston and R.J. Huston, NASA Langley Research Center, Langley Station, Va., October 1963 (NASA TND 2014).
Wing pressure data on tilt wing, tilt-wing-with-slat, and deflected-slipstream configuration, obtained during tests of the model in the Langley full-scale tunnel, are presented for an angle-of-attack range corresponding to transition flight of a vertical or short takeoff and landing (V/STOL) aircraft, included are pressure data for a range of flap deflections and lift-drag conditions corresponding to longitudinal acceleration and deceleration. A limited analysis of the pressure measurements for the tile-wing configuration is also included.

II.6.1.46 EFFECT OF WING STALLING IN TRANSITION ON A 1/4-SCALE MODEL OF THE VZ-2 AIRCRAFT, R.O. Schade and R.H. Kirby, NASA TND 2381, August 1964.
Flight tests, including level and descent flights, were made over the transition range where wing stalling occurred. Variation of M_α with V and descent boundaries are included.

II.6.1.47 LARGE SCALE WIND TUNNEL TESTS OF DESCENT PERFORMANCE OF AN AIRPLANE MODEL WITH A TILT WING AND DIFFERENTIAL PROPELLER THRUST, W.H. Decker, V.R. Page and S.D. Dickinson NASA, Ames Research Center, MOffett Field, Calif., Washington NASA October 1964, NASA TN D1857.
Tests were conducted to determine the wing stall, performance and longitudinal stability and control characteristics of a large model of a V/STOL tilt-wing transport aircraft. The scope of the tests was limited primarily to the low speed transitional regime. Test configurations included wing-tilt-angles from 0° to 40°, double slotted trailing-edge flaps deflected from 0° to 60°, various wing leading edge devices, such as partial span and full span Kruger flaps and slats, and several ramps that

II.6.1.47 (continued)
extended from the top of the fuselage to the tilted-wing center section.

II.6.1.48 DYNAMIC TESTS OF V/STOL TRANSPORT MODELS, M.O. McKinney and R.H. Kirby, AIAA, Transport Aircraft Design and Operations Meeting, Seattle, Wash., August 10-12, 1964. Paper 64-619.
Presentation of a summary of results obtained in dynamic tests of free-flight models of various configurations suitable for V/STOL transport aircraft at the NASA Langley Research Center. Three configuration are discussed: the tilt-wing propeller-driven XC-142A tri-service transport, the fan-in-wing XV-5A, and the jet lift Dornier DO-31. The first two configurations were found to have certain dynamic stability problems (mainly unstable stick-fixed oscillations) in hovering and low-speed flight; these instabilities can be controlled by the pilot without artificial stabilization, although artificial stabilization is helpful. As the airspeed approaches that required for normal wing-borne flight, these instabilities are markedly reduced and usually disappear. In descending flight in the transition speed range, the poor behavior that can result from a stalling tendency (if the aircraft is not designed to avoid it) limits the descent angles the pilot is willing to use. The jet V/STOL types have no real dynamic stability problems other than those associated with static stability.

II.6.1.49 EXPERIMENTAL STUDY OF WIND TUNNEL WALL EFFECTS AND WALL CORRECTIONS FOR A GENERAL-RESEARCH V/STOL TILT WING MODEL WITH FLAP, K. J. Grunwald, NASA Langley Research Center, Langley Station, Va., Wash., NASA July 1965, (NASA TN D 2887).
The wall effects investigation conducted in the Langley 300-mph 7-by 10-foot tunnel, the 17-foot test section in this 7-by 10-foot tunnel, and the Langley full scale tunnel (30-by 60-foot tunnel) on a tilt wing configuration (with neither fuselage nor tail) showed small wall effects on the force data. The application of a wall correction theory (which accounts for wake deflection) to the force data from the 7- by 10-foot tunnel resulted in large corrections to angle of attack and dynamic pressure. This compensating effect appears to be unique for the configuration used in this investigation. Wall effects on pitching moment (flaps on)

II.6.1.49 (continued)
were large, particularly for data taken in the 7- by 10-foot tunnel.

II.6.1.50 PRELIMINARY FULL SCALE INVESTIGATION OF A 1/3-SCALE MODEL OF A CONVERTIBLE-TYPE AIRPLANE, R. H. Lange, B. W. Cocke, and A.J.Proterra, NACA RM L9C 29, 1949.

II.6.1.51 FORCE TEST INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT WING VERTICAL TAKEOFF AND LANDING AIRCRAFT, NASA Memo 11-3-58L, 1958, W. A. Newsom, Jr., and L.P. Tosti.

II.6.1.52 FLIGHT INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT WING VERTICAL TAKEOFF AND LANDING AIRCRAFT, L. P. Tosti, NASA Memo 11-4-58L, 1959.

II.6.1.53 WIND TUNNEL INVESTIGATION OF EFFECT OF RATIO OF WING CHORD TO PROPELLER DIAMETER WITH ADDITION OF SLATS ON THE AERODYNAMIC CHARACTERISTICS OF TILT WING VTOL CONFIGURATIONS IN THE TRANSITION SPEED RANGE, NASA, TND 17, R.T.Taylor.
An investigation has been made in the Langley 300 MPH 7- by 10-foot tunnel to determine the effect of changes in wing chord and the effect of addition of 0.15c leading-edge slats on the longitudinal aerodynamic characteristics of a small wing-propeller combination simulating a twin-engine, tilt-wing, vertical takeoff and landing aircraft.

Increases in wing chord serve to reduce the severity of the stall in the transition speed range. Extending a 0.15c leading-edge slat also decreases the severity of the stall but in some cases gives sizeable nose-up pitching moments.

II.6.1.54 LARGE SCALE WIND TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT, TILT WING OF ASPECT RATIO 5.5, AND WITH FOUR PROPELLERS AND BLOWING FLAP, NASA, Wash., D.C. June 1961.
Tests were made of a large-scale tilt wing deflected slipstream VTOL airplane with blowing-type BLC trailing edge flaps. The model was tested with flap deflections of 0° without BLC, 50° with and without BLC, and 80° with BLC for wing tilt angles of 0, 30 and 50 degrees. Included are

II.6.1.54 (continued)
results of tests of the model equipped with a leading-edge flap and the results of tests of the model in the presence of a ground plane.

II.6.1.55 PRESSURE DISTRIBUTION OF A LARGE SEMISPAN TILTING WING WITH 0.4 DIAMETER-CHORD, SINGLE SLOTTED FLAP, AND A SINGLE PROPELLER 0.22 CHORD BELOW WING, M.P. Fink and C.C. Smith, NASA TND 5481, October 1969.

II.6.1.56 THE MODEL K-16B V/STOL AIRPLANE RESEARCH PROGRAM, Kaman Aircraft Corp., Bloomfield Conn., September 1961.
This report has been prepared to briefly describe the Kaman Model K-16B V/STOL research aircraft, and to summarize the research probram that is being carried out under Bureau of Naval Weapons contract NOA(S) 56-549C. The major accomplishments of the program to date are set forth, along with the general plan for completion of the program. The vehicle is described in some detail; the unique flight control and operation is explained; and the performance, stability and control are summarized.

II.6.1.57 TRI-SERVICE EVALUATION OF THE CANADAIR CL-84 TILT WING V/STOL AIRCRAFT, J.S. Honaker, R.A. Chubboy, T.C. West, W.Davies, and R. J. Reschak, USAAVLABS TR 67 84, November 1967.
The Canadair CL-84 V/STOL aircraft was evaluated at Montreal, Canada, during the period from 28 April to 29 August 1967. Thirty-three flights were flown, encompassing the hover, powered-lift, and aerodynamic flight regimes and speeds from 20 knots rearward to 230 KTAS at 5,000 feet. The primary objectives of the evaluation were to determine the characteristics, capabilities, and limitations of the CL-84 aircraft and to assess the feasibility of using a CL-84-type aircraft for military missions, with emphasis on the search and rescue mission.

II.6.1.58 WIND TUNNEL CORRELATION STUDY OF NORTH AMERICAN TILT WING MODEL TESTED IN THE NAVAL 14'x16' TUNNEL AND THE AIRSHIP MODEL TEST FACILITY, J. W. Olcott, September 1962.

II.6.1.59 LOW SPEED FREE AIR TESTS OF A POWERED .165 SCALE FOUR ENGINE TILT WING V/STOL MODEL, NAA Inc., Los Angeles, California, March 1962.

II.6.1.60 WIND TUNNEL TESTS OF A 1/8-SCALE POWERED MODEL K-16B KAMAN VTOL/STOL AIRPLANE, D.T.M.B. Report Aero No. 998, Washington, D.C., F.T. Burgan, J.T. Matthews, February 1961.
Wind tunnel tests were made on a powered model of the Kaman K-16B tilt wing VTOL/STOL airplane in the transitional and forward flight configurations. Directional instability in the clean configuration was corrected by vertical tail extensions. The model was otherwise stable in pitch and sideslip in the forward flight configuration, flaps up and down. The transitional flight configuration results show a nose-up trim change with increase in wing tilt and power. The model is directionally stable at all wing tilt angles tested. The model had weathercock stability when tested 90 degrees to the wind. Brief static thrust turning effectiveness tests with flaps full down show a ninety percent thrust recovery at a turning angle of 20 degrees.

II.6.1.61 A STABILITY ANALYSIS OF TILT WING AIRCRAFT, (Experimental) Princeton University, N.J., H.E. Payne, C.H. Cromwell, III.

II.6.1.62 WIND TUNNEL TESTS OF A 1/16-SCALE MODEL OF A ROTATABLE WING SEAPLANE, PART III, ANALYSIS OF THE TEST DATA, R.D. Murphy, February 1960.

II.6.1.63 WIND TUNNEL INVESTIGATION OF A 1/20-SCALE POWERED MODEL TILT WING V/STOL SEAPLANE IN THE CRUISE CONFIGURATION, R.O. Thomas, August 1965.
Low speed wind tunnel tests were conducted on a 1/20-scale powered model of a proposed open-ocean V/STOL seaplane. Some cruise flight performance parameters and the effects of power on longitudinal and lateral stability and control, in the cruise flight regime, were determined.

II.6.1.64 XC-142A V/STOL TRANSPORT TRI-SERVICE LIMITED CATEGORY I, EVALUATION, G. E. Jones, R. K. Ransone, January 1966.
The objective was to evaluate the tilt wing V/STOL's capabilities, characteristics, and problems, and to determine its readiness for Category II testing. Performance, stability and

II.6.1.64 (continued)
control, and systems operation data were obtained. The XC-142A design objective was to provide a full scale tilt wing V/STOL transport aircraft with which the operational capabilities could be determined for V/STOL aircraft in general and tilt-wing V/STOL aircraft in particular. It was not intended to be a production model. As a concept evaluation vehicle it was generally satisfactory. The aircraft was safe and simple to fly.

II.6.1.65 INVESTIGATION OF AN ISOLATED MONOCYCLIC V/STOL PROPELLER PERFORMANCE AND OSCILLATORY STRESS, R. W. DeDecker, February 1966.
Test results confirmed: (1) that there is an apparent phase shift of the monocyclic axis at high collective angle, caused by hysteresis in the airfoil's stall characteristics, and (2) that there is an increase in side force as collective angle is increased, caused by a nonlinear variation in airfoil drag with cyclic pitch. The monocyclic propeller test program also included investigation of the effects of control system stiffness on the dynamic response of the propeller and control system. The results indicate that the use of cyclic-blade-pitch control reduces the harmonic content of control system oscillatory loads to bascially a first-harmonic response. Higher harmonic loads are present, but their amplitudes are less than 10 percent of the resultant peak-to-peak load, and are therefore considered negligible. The results of the program also indicate that the increase of control system stiffness resulted in an increase in blade-pitch-ling oscillatory loads.

II.6.1.66 THE EFFECTS OF A MODEL PROPELLER ON THE VELOCITY AND PRESSURE DISTRIBUTIONS AHEAD OF THE MODEL IN A CLOSED CIRCUIT WIND TUNNEL, R.C.W. Eyre, February 1968.
Measurements made at speeds between 20 and 60 ft/sec in an 11 1/2 x 8 1/2 foot-tunnel showed that the effects of an unyawed propeller running at constant rotational speed and high thrust on the static pressure differential in the tunnel contraction were generally small. The effects on the distribution of dynamic head in the working section were also slight with evidence of a high velocity core persisting round the tunnel. Changes in model incidence of up to 40 degrees produced

II.6.1.66 (continued)
only detail alternatives. However, with the propeller yawed 20 degrees in either direction, marked asymmetry in the pressure distribution in the contraction was introduced, which seriously affected the normal tunnel calibration and also resulted in asymmetric distributions in the working section. The relative significance of these effects was reduced, with an increase in tunnel speed.

II.6.1.67 INVESTIGATION OF PROPELLER SLIPSTREAM EFFECTS ON WING PERFORMANCE, M. George and E. Kisielowski, USAAVLABS Technical Report 67-67, November 1967.
A theoretical and experimental study was conducted to determine the effects of propeller slipstream on wing performance. Previously developed theoretical analyses were expanded and modified to account for radial variation of the propeller slipstream velocity. The experimental program consisted of wind tunnel tests conducted with a motor-propeller system mounted on a semi-span wing model. The wing model has eight floating wing segments with and without 45-degree simulated split flap. Located within each floating wing segment is a three-component strain gage balance to provide measurements of lift, drag, and pitching moment. The measurements of total wing lift, drag, and pitching moment were obtained with the six-component main wind tunnel balance. The test data obtained included the effects of the variation of propeller slipstream velocity by utilizing two propellers of different geometries. Propeller rotation for all tests was down at the wing tip. The experimental and theoretical results are compared; in general, good correlation was observed.

II.6.1.68 AN EXPERIMENTAL INVESTIGATION BY FORCE AND SURFACE PRESSURE MEASUREMENTS OF A WING IMMERSED IN A PROPELLER SLIPSTREAM, Part I: FORCE AND MOMENT MEASUREMENTS, Y. Nishimura, NAE, LR-501.
A wind tunnel investigation was made of wings immersed in a propeller slipstream. Three wing configurations were tested with various flap deflections and propeller thrust coefficients through a range of wing incidences from 0° to 120°. Wing forces have been isolated from the total forces. There was a slight increase in propeller thrust due to the presence of the wing. A method for estimating lift and drag of a wing-in-slipstream was given in an appendix. No comparison between

II.6.1.68 (continued)
theory and experiment was made.

See also, I.2.1.3, 4, II.2.1.21

II.6.2 Flow Fields -

See II.6.1.12, 17, 20, 34

II.6.3 Ground Effect

See II.6.1.12, 19, 20, 23, 24, 27, 34, 36.

II.6.4 Stability and Control -

II.6.4.1 EFFECT OF WING STALLING IN TRANSITION ON A 1/4-SCALE MODEL OF THE VZ-2 AIRCRAFT, R.O. Schade and R.H. Kirby, NASA TND 2381, August 1964.
Flight tests, including level and descent flights, were made over the transition range where wing stalling occurred. Variation of M_α with V and descent boundaries are included.

II.6.4.2 CALCULATION OF THE DYNAMIC LONGITUDINAL STABILITY OF A TILT WING V/STOL AIRCRAFT AND CORRELATION WITH MODEL FLIGHT TESTS, J.R. Chambers and S.B. Grafton, NASA TND 4344, February 1968.
Calculations were made for the initial condition of steady level flight at wing incidences corresponding to speeds ranging from hovering to conventional forward flight. The results were compared with qualitative measurements of dynamic stability obtained during free-flight tests of a 1/9-scale model, (linear and small perturbation).

II.6.4.3 LONGITUDINAL STABILITY AND CONTROL OF A TILT WING VTOL AIRCRAFT MODEL WITH RIGID AND FLAPPING PROPELLER BLADES, L.P. Tosti, NASA TN D 1365, July 1962.

II.6.4.4 FLIGHT TEST INVESTIGATION OF AILERONS AS A SOURCE OF YAW CONTROL ON THE VZ-2 TILT WING AIRCRAFT, R. J. Pegg, NASA TND 1375, July 1962.

II.6.4.5 AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE, L.P. Tosti, NASA TND 390, September 1960.
The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight on 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidenced from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

II.6.4.6 AN INVESTIGATION OF THE LATERAL/DIRECTIONAL DYNAMIC STABILITY CHARACTERISTICS OF A TILT WING V/STOL TRANSPORT MODEL IN SIMULATED LOW-SPEED DESCENDING FLIGHT, W. F. Putman, TR 69-46 USAAVLABS.
This report represents the results of an experimental program to measure the lateral/directional dynamic stability characteristics of a tilt-wing V/STOL transport model in simulated descending flight. A 0.1-scale dynamically similar model of the XC-142A V/STOL aircraft was tested on the Princeton Dynamic Model Track in the three degrees of lateral/directional freedom: roll, yaw, and sideslip. The test conditions simulated a full-scale aircraft with wing loading of 70 pounds per square foot (gross weight = 37,400 pounds), flying at approximately 40 knots at a wing incidence of 40 degrees and flap deflection of 60 degrees. The simulated descent conditions encompassed level flight and four sink rates up to approximately 1,000 feet per minute equivalent full-scale sink rate.

II.6.4.7 SUMMARY OF A FLIGHT-TEST EVALUATION OF THE CL-84 TILT WING V/STOL AIRCRAFT, H.L. Kelley, J.P. Reeder, and R. A. Champine, NASA TM X-1914, March 1970.
A flight-test evaluation of a second-generation tilt-wing V/STOL aircraft was conducted. The flying qualities were considered generally good except for a slow arrest of rate of descent at constant power and airspeed that could be of particular significance during instrument flight. This characteristic was document in flight at an airspeed of about 40 knots.

Included is a bibliography that contains reports concerning much of the work of the NASA in tilt-wing V/STOL research.

II.6.4.8 DYNAMIC STABILITY ANALYSIS OF A VTOL VECTORED SLIPSTREAM VEHICLE DURING TRANSITION, G. A. Williamson, Princeton Univ. , Report No.535.
Development of 6 degree-of-freedom equations applicable to tilt wing airplane.

II.6.4.9 DYNAMIC STABILITY OF V/STOL AIRCRAFT AT LOW SPEEDS, M. C. Curtiss, Jr. J. Aircraft Vol.7 No.1 January-February 1970.
Discusses longitudinal stability characteristics of propeller driven V/STOL aircraft and reviews test data obtained from three tilt-wing dynamic models. Demonstrated that linearized equations of motion adequately predicted the measured transient motions in most cases. Also indicated nonlinearity in M_u and M_w that caused responses to differ depending on whether the initial disturbance was nose-up or nose-down.

See also, II.6.1.2, .7, .10, .11, .14, .18, .21, .22, .27,.37, .50, .51, .52 and .64

II.6.5 Handling Qualities and Criteria -

II.6.5.1 A FLIGHT STUDY OF THE CONVERSION OF A TILT WING VTOL AIRCRAFT, L.P. Thomas, NASA TND 153, December 1959.
A study of longitudinal data is presented which reveals the nature of the task of flying a tilt-wing vertical takeoff and landing aircraft through the conversion maneuver in level flight and favorable weather and visibility conditions.

See also, II.6.1.29, 42, 46 and 48.

II.6.6 Testing -

II.6.6.1 WALL EFFECTS AND SCALE EFFECTS IN V/STOL MODEL TESTING, Langley Research Center, Powered-Lift Aerodynamics Section, Langley Station, Hampton, Va., New York, AIAA, 1964.
Study of the limits of applicability of wind-tunnel data on V/STOL configurations, primarily with regard to wall effects and scale effects. Tunnel wall effects on the transition aerodynamics of a tilt wing, fan-in-wing, and a fan-in-fuselage configuration, as determined from tests of a model of each configuration in three different size tunnels, are discussed. Data from the VZ-2 configuration, the XV5-A fan-in-wing configuration, and the Ames fan-in-fuselage configuration are used. The wall-induced lift and drag errors experienced by all three types of configurations could, in general, be adequately corrected by Heyson's method.

II.6.6.2 FIRST TWELVE MONTHS OF FLIGHT OF THE XC-142 PROGRAM, SETP, Technical Review, Vol.7 No.4, 1965.
Description of a year of flight test activities with the four-engine XC-142A V/STOL aircraft, considered to be the largest of its type flown to date. The four propellers are interconnected, and a tilt wing is used which operates through a total angle of 100°. Design hover gross weight is 37,500 lb. with a 8000-lb payload. Under STOL conditions, payload is nearly doubled. The aircraft is controlled conventionally by a stick and rudder pedals throughout the flight envelope.
The process of demonstrating satisfactory characteristics during hover and during the conversion. Reconversion maneuver is discussed extensively, and problems encountered are examined. A primary area of investigation was the effect of stabilization failure in the hover, conversion, and STOL areas of operation. It was found that the relative importance of the three axes - from least important to most important - was yaw, pitch, and roll. Results of stall investigations are presented.

See also, II.6.1.49, 66, II.2.1.1.

II.6.7 General -

II.6.7.1 FLIGHT TESTING EXPERIMENTS WITH THE TILT-WING AIRCRAFT, W.Z. Stepniewski, and P. J. Dancik, Aerospace Eng., Institute of Aerospace Sciences Report 59-8, February 1959.

II.7 JET LIFT

II.7.1 **Forces and Moments** -

II.7.1.1 INVESTIGATION OF INTERFERENCE OF A DEFLECTED JET WITH FREESTREAM AND GROUND ON AERODYNAMI CHARACTERISTICS OF A SEMISPAN DELTA-WING VTOL MODEL, K. P. Spreemann, NASA TN D-915, August 1961.

II.7.1.2 AN INVESTIGATION INTO THE EFFECTS OF GROUND PROXIMITY OF TWIN CO-AXIAL ANNULAR JETS, USING HOT AND COLD AIR, R.V. Barrett and J.C. Tipping, CP578, 1962.
The conditions in a jet, issuing from a twin co-axial annular nozzle, due to proximity of a ground board perpendicular to the flow have been studied. The inner annular jet could be heated. Measurements have been made of thrust and temperature distribution in the jet and extensive flow visualization was made. An attempt has been made to correlate the thrust and temperature measurements with the observed flow.

II.7.1.3 SURFACE PRESSURE DISTRIBUTIONS INDUCED ON A FLAT PLATE BY A COLD AIR JET ISSUING PERPENDICULARLY FROM THE PLATE AND NORMAL TO A LOW-SPEED FREE-STREAM FLOW, R.D. Vogler, NASA TN D 1629, March 1963.
The effect of surface pressures of a round cold air jet and a cylindrical rod simulating a jet were determined with the axis of the jet or rod normal to both the plate surface and the free-stream air.

II.7.1.4 INTERFERENCE EFFECTS OF SINGLE AND MULTIPLE ROUND OR SLOTTED JETS ON A VTOL MODEL IN TRANSITION, R.D. Vogler, NASA TN D2380, August 1964.
Data were obtained through an angle of attack range, with 10 different geometric arrangements of nozzles in the bottom of the model fuselage, with and without jet deflection. The ground effects at zero forward speed without jet deflection were obtained.

II.7.1.5 THE STATIC PRESSURE DISTRIBUTION AROUND A CIRCULAR JET EXHAUSTING NORMALLY FROM A PLANE WALL INTO AN AIRSTREAM, L.J.S. Bradbury and M.N.Wood, CP 822, 1965.

II.7.1.6 THRUST CHARACTERISTICS OF MULTIPLE LIFTING JETS IN GROUND PROXIMITY, F.E. Davenport and K.P. Spreemann, NASA TN-D513, September 1960.
An investigation of a series of nozzle lifting-surface combinations which might represent a VTOL configuration which used direct thrust from wing- or fuselage-mounted engines for takeoff has been made. Configurations tested include a simple jet, 4,6 and 8 exit multiple jets and a double jet with fuselage.

II.7.1.7 INDUCED INTERFERENCE EFFECTS ON A FOUR-JET VTOL CONFIGURATION WITH VARIOUS WING PLANFORMS IN THE TRANSITION SPEED RANGE, J.H. Otis, NASA TN D1400, September 1962.
A limited investigation has been conducted, with a simplified model at zero angle-of-attack, to study the jet interference effects in transition from hovering to forward flight out of the region of ground effect.

II.7.1.8 EFFECT OF GROUND PROXIMITY ON AERODYNAMIC CHARACTERISTICS OF TWO HORIZONTAL-ATTITUDE JET VERTICAL-TAKEOFF-AND-LANDING AIRPLANE MODELS, W.A. Newsom, NASA TN D 419, August 1960.
The first model had a tilting wing-engine assembly which was set at 90° incidence for takeoff and landing. The second had a cascade of retractable turning vanes to deflect the exhaust of the horizontally mounted jet engines downward for vertical takeoff and landing while the entire model remained in a horizontal attitude. Tests were made for a range of heights above the ground and included force tests and tuft studies of the flow field caused by the jet exhaust.

II.7.1.9 AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE V/STOL TRANSPORT MODEL WITH LIFT AND LIFT-CRUISE FANS, L.P. Hall et al, NASA TN D 4092, August 1967.
The aerodynamic characteristics of two configurations powered by tip-turbine-driven fans were studied. The VTOL propulsion system for the first was a combination of lift fans and rotating cruise fans, and for the second was tandem mounted

II.7.1.9 (continued)
lift fans. Both used a high mounted wing of aspect ratio of 5.8, swept back 35° at the quarter chord line, and taper ratio of 0.3.

II.7.1.10 GROUND EFFECTS ON SINGLE- AND MULTIPLE-JET VTOL MODELS AT TRANSITION SPEEDS OVER STATIONARY AND MOVING GROUND PLANES, R. D. Vogler, NASA TN D3213, January 1965.
Ground effects and jet-freestream interference effects on the longitudinal characteristics of a VTOL wing-fuselage model with various arrangements of single and multiple vertical jets including slots were studied.

II.7.1.11 WIND TUNNEL EXPERIMENTS ON A LIFTING JET IN A BLUFF BODY WITH AND WITHOUT WINGS, W.J.G. Trebble, CP 859, 1966.

II.7.1.12 RESULTS OF FLIGHT TESTS ON THE SHORT SC1 VTOL RESEARCH AIRCRAFT WITH PARTICULAR REFERENCE TO HANDLING QUALITIES IN THE HOVER AND TRANSITION, H. W. Chinn, NATO AGARD Report 527, 1966.
Results are given of flight tests made on the Short SC1 jet VTOL research aircraft, covering control and stability characteristics, and performance throughout the flight envelope, but with particular reference to the hover and transition. Pilots' assessments of the aircraft in different conditions are considered in relation to its measured characteristics and such features as cockpit layout, view and control arrangement which can have an important influence on the overall flying qualities.

II.7.1.13 FULL SCALE WIND TUNNEL INVESTIGATION OF A VTOL AIRCRAFT WITH A JET-EJECTOR SYSTEM FOR LIFT AUGMENTATION, J.V. Kirk and D.H. Hickey, NASA TN D 3725, November 1966.
Longitudinal and lateral aerodynamic characteristics were examined from hover up to and including wing-supported flight. Ejector performance was measured statically and with forward speed.

II.7.1.14 LOW SPEED AERODYNAMIC CHARACTERISTICS OF JET VTOL AIRCRAFT AT ANGLES OF ATTACK, D.J. Ktyna, MIT, Cambridge Dept. of Aeronautics and Astronautics, May 1965.

A VTOL model incorporating a lifting fan mounted vertically in the fuselage was tested in the MIT Wright Brothers Wind Tunnel to examine the variations of the pitching moment and longitudinal forces with changes in the angle of attack and forward velocity. The model was tested at angles of attack between +90 degrees, but the results were considered reliable only up to +45 degrees due to stalling of the model fan blades. Moment was found to be unstable between the measured angles of attack from -45 degrees to +10 degrees, increasing moderatly as angle of attack increased. An increase in the ratio of forward velocity to fan efflux velocity also produced an increased moment. A theory developed by A.R. Kriebel based upon a Fourier Analysis of the vortex distribution on a thin cylindrical ducted fan was employed to predict the results of the experiment. Considering the simplifying assumptions used in the theory, the correlation was found to be reasonably good except at high ratios of free stream to fan efflux velocity. At these ratios, an uncompensation for low pressure area aft of the exhaust duct resulted in considerably erroneous predictions. Thrust generally increased with angle of attack and varied with the velocity ratio, the variation being related to the sign of the angle of attack.

II.7.1.15 AERODYNAMIC CHARACTERISTICS IN GROUND EFFECT OF A LARGE SCALE MODEL WITH A HIGH DISK-LOADING LIFTING FAN MOUNTED IN THE FUSELAGE, R.A. DeSavigny and D.H. Hickey, NASA, Ames Research Center, Moffett Field, California, January 1963(NASA TN D 1557).

The large scale VTOL airplane model tested had a shoulder-mounted unswept-wing-of-aspect ratio 5. Characteristics of the model with and without the horizontal tail were obtained with the wing at 1.83 and 2.39 fan diameters from the simulated ground plane installed above the wind tunnel floor. Test airspeeds ranged from 20 to 80 knots. Longitudinal forces and moments, some installed fan performance, static-pressure distributions on the fuselage, and downwash at the horizontal tail are presented.

II.7.1.16 WIND TUNNEL WALL EFFECTS AND SCALE EFFECTS ON A VTOL CONFIGURATION WITH A FAN MOUNTED IN THE FUSELAGE, E.E. Davenport and R.F. Kuhn, NASA, Langley Research Center, Langley Station, Va., Washington, NASA, January 1965, (NASA TN D 2560).

An investigation of the aerodynamic characteristics of a model of a VTOL configuration with a lifting-fan mounted in the fuselage was conducted to determine the effects of scale and the effects of tunnel walls on the characteristics of this configuration, which had previously been investigated at full scale. The results of the investigation indicate that significant wall effects were encountered with the model in the small test section and with the full scale configuration. After correcting both model and full-scale data for wall effects and after considering differences in vane characteristics, the data with exit vanes deflected were in good agreement. However, with the vanes undeflected, significant differences between the model and full-scale data remain. These differences were found to be largely due to differences in the suction pressures induced on the bottom of the fuselage behind and beside the jet; and, to a smaller extent, to differences in the model and full scale power-off characteristics; and to differences in the inlet mass flow for the model and full-scale configuration. A large part of the wing lift induced on the model and the full-scale configuration at zero angle-of-attack was found to be due to the wall-induced upwash field in which the wing was operating.

II.7.1.17 DYNAMIC TESTS OF V/STOL TRANSPORT MODELS, M.O. McKinney and R.H. Kirby, AIAA, Transport Aircraft Design and Operations Meeting, Seattle, Wash., August 10-12, 1964 paper 64-619.

Presentation of a summary of results obtained in dynamic tests of free flight models of various configurations suitable for V/STOL transport aircraft at the NASA Langley Research Center. Three configurations are discussed: the tilt wing propeller-driven XC-142A tri-service transport, the fan-in-wing XV-5A, and the jet-lift Dornier DO-31. The first two configurations were found to have certain dynamic stability problems (mainly unstable stick-fixed oscillations) in hovering and low-speed flight; these instabilities can be controlled by the pilot without artificial stabilization, although artificial stabilization is

II.7.1.17 (continued)
helpful. As the airspeed approaches that required for normal wing-borne flight, these instabilities are markedly reduced and usually disappear. In descending flight in the transition speed range, the poor behavior that can result from a stalling tendency (if the aircraft is not designed to avoid it) limits the descent angles the pilot is willing to use. The jet V/STOL types have no real dynamic problems other than those associated with static stability.

II.7.1.18 EFFECTS OF JET-EXHAUST LOCATION ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A JET V/STOL MODEL, A. W. Carter NASA TN D 5333, July 1969.
A wind tunnel investigation of the jet-location interference effects on the longitudinal aerodynamic characteristics of a jet V/STOL model has been made for an unswept, untapered wing with an aspect ratio of 6 and 30-percent-chord slotted flaps. The effects of jet location were explored systematically from several wing-chord lengths ahead to several chord lengths behind the wing. Various vertical locations were also investigated. Aerodynamic and pressure data are presented.

The results indicated that all locations of the jet exhaust ahead of the wing resulted in a detrimental effect on the wing lift; aft of the wing midchord, favorable lift interference was obtained.

II.7.1.19 AERODYNAMIC CHARACTERISTICS OF A FIVE-JET VTOL CONFIGURATION IN THE TRANSITION SPEED RANGE, R. J. Margason and G. L. Gentry, NASA TN D 4812, October 1968.

II.7.1.20 USAF EVALUATION OF THE HARRIER GR MK1, K. J. Mason, June 1969.

II.7.1.21 WIND TUNNEL EXPERIMENTS ON A SIMPLE LIFTING-JET BODY WITH AND WITHOUT WINGS, W. J. G. Trebble, RAE TN Aero 2882.
Low speed wind tunnel tests have been made on a body with a vertical jet efflux to investigate the interference loads arising from the interaction between the mainstream and the efflux. As the ratio of freestream velocity to jet efflux velocity is increased from zero, the lift

II.7.1.21 (continued)
increment due to the jet is reduced by the interference and a nose-up pitching moment increment is produced. Forward movement of the jet exit increases the lift loss. If a wing is fitted, an appreciable alleviation of the lift loss arises from the circulation lift carried on the wing, but the nose-up pitching moments are larger.

II.7.1.22 EXPLORATORY WIND TUNNEL INVESTIGATION ON A BLUFF BODY CONTAINING A LIFTING FAN, W.J.G. Trebble and J. Williams, CP 597, 1962.
The body width slightly exceeded the duct diameter and body length was two or three times the fan duct diameter.

II.7.1.23 JET SIMULATION IN GROUND TEST FACILITIES, M. Pindzola, North Atlantic Treaty Organization, Advisory Group for ARD, AGARDograph 79, November 1963.
This paper presents a review of various techniques employed in the simulation of a jet exhaust in ground test facilities. A brief summary of the characteristics of a jet exhausting into both quiescent and moving media is presented. The importance of duplicating the initial inclination angle of the jet when conducting simulation studies is pointed out. Various scaling parameters are enumerated. Experimental data are also presented which verify the importance of these parameters in simulation studies.

II.7.1.24 POWERED LIFT MODEL TESTING FOR GROUNDPROXIMITY EFFECTS, P.E. Colin, AGARD TN 14, October 1963.
The effect of ground proximity on the performance of powered lift vehicles was investigated on simple models using two different testing methods. Single and doubl-jet models representing VTOL configurations and an air-cusihon model with peripheral jet were tested both in the wind tunnel with a stationary ground plane and on a special pendulum rig allowing the models to be moved over a fixed ground board. The lift and center of pressure location have been determined with both techniques for various model heights over a range of momentum coefficients.

II.7.1.25 DESIGN FEATURES AND LOW-SPEED-TUNNEL RESEARCH PROGRAMME FOR A B.L.C. HIGH-LIFT SUBSONIC TRANSPORT MODEL WITH JET-LIFT NACELLES FOR STOL AND VTOL, S.F.J. Butler, R. Eyre, Report No. RAE-TM-AERO-1029, December 1967.

The model had a 28-degree leading-edge sweepback wing of A.R.8, with high lift blowing BLC flaps, powered lift-thrust underslung engine nacelles and powered multiple lift-engine nacelles straddling the outer wing. The model was designed to facilitate an intensive, yet flexible, programme of aimed research. This introductory paper considered the possible scope of a tunnel test programme as well as the design, development and calibration of the complex model and associated rigs. The latter as the defelopment of a 6-component strain-gauge balance arrangement, suitable for other jet-blowing models, with transmission of the large air quantities (10 lb/sec at 9 atmospheres gauge) needed for VTOL jet efflux simulation.

II.7.1.26 AERODYNAMIC INTERFERENCE EFFECTS WITH JET-LIFT V/STOL AIRCRAFT, J. Williams and M.N. Wood, DGRR/WGLR-Jahrestagung Bad Godesberg, October 1966.

An outline was given of the nature, magnitude and correlation of aerodynamic interference effects which can arise from the flows induced around the aircraft by the jet-lift efflux.

II.7.1.27 WIND TUNNEL INVESTIGATION OF AVTOL JET-TRANSPORT MODEL WITH POWERED LIFT ENGINES IN PODS AT WING MID SPAN ON INBOARD, R. D. Vogler, NASA TN D 5770, April 1970.

Eight lift engines were simulated by ejectors powered with compressed air. The investigation included the determination of the effects of engine-pod location, ground-plane movement, flaps, tail size and location, and sideslip on the aerodynamic characteristics, and the effects of configuration changes on the jet and freestream interference increments.

Comparison of engine-pod showed that the inboard location gives higher lift coefficients with flaps and power before inboard wing stall occurs. The midspan location gives more stability, less downwash at the tail, and smaller undesirable interference increments. For the model with power on

II.7.1.27 (continued)
and pods at midspan, the ground produced increments of negative pitch, negative drag, positive lift, and large upwash angles. The model over the moving ground plane had more lift and more negative pitching moments than the model over the still ground plane. Lateral forces and moments produced by sideslip were generally the desired direction, and the vertical tail was more effective when the engine pods are inboard than when they are at the wing midspan.

II.7.1.28 WIND TUNNEL TESTS OF A STREAMLINED FAN-LIFT NACELLE, J. E. Haskett, ARC R&M 3470, October 1965.
Described tests on a streamlined body with a lifting fan in a 5' x 4' wind tunnel and a 11-1/2' x 8-1/2' wind tunnel. Large differences existed between data from the two tunnels at high incidences and high forward speeds. The theoretical effect of forward speed on fan operation was investigated.

See also I.5.1.11, I.7.2.9 and I.7.1.4

II.7.2 Flow Fields -

II.7.2.1 FLOW IN A JET DIRECTED NORMAL TO THE WIND, R. Jordinson, R&M 3074, 1958.
Experiments to study the flow in an air jet, which is ejected normal to an air stream from an orifice in a plane floor, have been made for several values of the ratio of wind velocity to jet exit velocity. The path of the jet and the shape of the jet cross-section were determined.

II.7.2.2 STUDIES OF FLOW FIELDS CREATED BY VERTICAL AND INCLINED JETS WHEN STATIONARY OR MOVING OVER A HORIZONTAL SURFACE, W. A. Abbott, CP 911, 1967.
Model tests were made with single and twin nozzle arrangements, at varying inclinations. The decay of maximum velocity and temperature of the jet after impingement on the ground was measured.

II.7.2.3 NASA RESEARCH ON THE AERODYNAMICS OF JET VETOL ENGINE INSTALLATIONS, R. E. Kuhn and M.O. McKinney, Jr., Was. D.C., NASA, Langley Research Center, Langley Station, Va., NASA 1965, presented at the AGARD Specialist Mtg. on Aero. of Power Plant Installation, Tullahoma, Tenn. 25-27 October 1965, (NASA TM-X-56820).
This paper summarizes some of the more pertinent results of NASA investigations related to the aerodynamics of jet VTOL engine installations. It shows that there is a base loss in hovering due to suction forces created on the underside of the fuselage by the magnitude of this effect is related to the turbulence in the jet stream and its consequent rate of mixing with ambient air. It also shows that there are losses and pitching moments due to jet-freestream interference and that these characteristics can be significantly altered by proximity to the ground. And, finally, it shows that simple bellmouth inlets give good pressure recovery and low distortion for vertically mounted lift engines if the inlet lip radius is sufficiently large, but that such inlets are not suitable for windmill starting of the engines.

II.7.2.4 JET LIFT INTAKES, W. F. Wiles, Rolls Royce Ltd., Derby (England), in AGARD Aerodyn. of Power Plant Installation, Pt.2, October 1965.
The air intakes for lift and cruise engines present particular problems because they have to work over a wide range of conditions. The paper gives a summary of these and a brief history of the problems which have arisen. From the early days of work on the Short SC.1, it became apparent that considerable effort was required on lift intakes and an extensive model research programme has been done at Rolls-Royce. Initial work covered a very wide range of intakes to find the most suitable type. Scoop type intakes were selected early on and have been used on several aircraft. Simpler intakes were then developed, for example, those with a cascade of vanes in front of the first engine. Work is still going on in this field on various engine configurations, the main objective being to reduce the installed volume of the engine, in particular that requried for the intake.

II.7.2.5 INVESTIGATION OF AIR INTAKES OF VERTICAL LIFT ENGINES FOR A VTOL TRANSPORT AIRCRAFT USING WIND TUNNEL MODELS, J. Mollerus and E. Uhrig, DLR Mitt. 65-14 November 1965..
Following points are discussed: air inlet requirements for vertical lift jet engines, especially these located in wing pods; air flow and distortion, pressure distribution and loss and thrust loss, using different types at devices for flow deflection in intakes with respect to DO31 aircraft using Rolls-Royce RB 162-4 lift engines; test methods and equipment.

II.7.2.6 HOT-GAS INGESTION INVESTIGATION OF LARGE SCALE JET VTOL FIGHTER-TYPE MODELS, H.C. McLemore and C.C. Smith, NASA TN D 4609, June 1968.

II.7.2.7 RECIRCULATION EFFECTS PRODUCED BY A PAIR OF HEATED JETS IMPINGING A GROUND PLANE, G.R. Hall and K.H. Rogers, NASA CR-1307, May 1969.

II.7.2.8 A GENERALIZED EXPERIMENTAL INVESTIGATION OF HOT GAS RECIRCULATION AND INGESTION FOR JET VTOL AIRCRAFT, P.E. Ryan et al, NASA CR-1147, September 1968.

II.7.2.9 A GENERALIZED EXPERIMENTAL STUDY OF INLET TEMPERATURE RISE OF JET V/STOL AIRCRAFT IN GROUND EFFECT, Book I, P.E. Ryan, R.F. Speth, October 1965.
This report has been prepared to document the data which served as the basis for the technical analysis. The data were automatically reduced and tabulated on the IBM 7090 computer employing a program especially prepared for this purpose. An available program was utilized which automatically plotted the increments in temperature etween that sensed by the thermo-couples and the 'selected' ambient temperature. This volume (Book I) consists of the explanatory text and automatic data plots.

II.7.2.10 JET RECIRCULATION EFFECTS ON V/STOL AIRCRAFT, M. Cox, and W.A. Abbott, Journal of Sound and Vibration, Vol.3, No.3, 1966.
Gases from the jets of lifting engines may be recirculated to the engine intakes and cause a loss of thrust. Model tests with heated jets were made to provide data on velocities in the jet around the impingement region and to assist the correlation of model and full-scale measurements. Vertical and inclined jets were studied under steady and transient conditions during the initial establishment of the wall jet flow and the relationship between these two cases is given.

Tests with jets from nozzles moving over the ground showed that the distance the wall jet travels before being turned back by the relative wind may be obtained from measurements with stationary jets.

Experiments with heated jets showed that a parameter including the initial dynamic pressure and the temperature of the jet may be used to correlate the vertical penetration of a free jet and the lateral extent of an impinging jet to the point where it separates from the ground due to buoyancy effects.

II.7.2.11 TESTS TO ESTABLISH FLOW DISTORTION CRITERIA FOR LIFT ENGINES, B.L. Tyson, Journal of Aircraft, Vol.2 No.5, September-October o965, (Also AIAA Paper 64-608).

A test program was conducted to investigate performance of lift-engine inlets and to develop a static test device that would simulate flow distortions at the face of a lift engine. Wind tunnel tests indicate that the combinations of high forward speed and low engine power would cause flow separation and excessive distortion. A scoop inlet was developed that enabled the flow to turn without separation. For improved pressure recovery in static and near-static operation, longitudinal vanes in the scoop were used to augment the inlet area. By opening the vanes at low speed and closing them for engine restart, acceptable inlet performance was obtained. The wind tunnel data showed that for a given engine-face velocity, the pressure losses, both with and without scoops, were in good agreement when compared at the same approach velocity. This led to the development of a static-test distortion generator that simulated the pressure gradients measured in the wind tunnel. The distortion-generator data agree well with the wind tunnel data.

II.7.2.12 AN EXPERIMENTAL INVESTIGATION OF VTOL LIFT-ENGINE INLETS, R. Lavi, Journal of Aircraft, Vol.4 No.2, 1967.

Tests of VTOL lift-engine plain inlets and inlets with scoop-type doors were conducted in the NASA Ames 40- by 80-foot wind tunnel using the Ames Lift Engine Pod containing five YJ85 engines. The objectives were to determine inlet/door performance characteristics during lift-engine operation and to establish engine start and acceleration characteristics during transition. Overall inlet pressure distortion levels were, in general, lower than 10%. Acceptable inlet total pressure recoveries were achieved, and considerable improvement in engine windmilling characteristics was observed with the inlet doors. Results also showed the feasibility of windmill starting of lift engines equipped with scoop-type inlet doors at speeds between 200 and 240 knots.

See also, II.7.1.1, .2, .3, .7, .18, .23, .24,
I.7.1.4, I.7.2.8, .9, .11, and .13

II.7.3 Ground Effect -

II.7.3.1 RESEARCH ON THE GROUND EFFECT OF JET LIFT V/STOL AIRPLANES, E. Schwantes, DLR Mitt 68-28, December 1968.

II.7.3.2 SURVEY OF THE GROUND EFFECT OF V/STOL AIRCRAFT WITH JET PROPULSION-REPORT OF LITERATURE, E. Schwantes, NASA TT F-12, 573, October 1969. A tabular survey was presented of the results of 132 reports on the ground effects with jet lift V/STOL aircraft. The region of the deflected jet investigated was described and the test conditions compared.

See also, II.7.1.1, .2, .4, .6, .8, .10, .15, .18, .24, .27, II.7.2.2, .3, .7, .8, .9 and .10

II.7.4 Stability and Control

II.7.4.1 FLIGHT TESTS OF A 0.13-SCALE MODEL OF A VECTORED-THRUST JET VTOL TRANSPORT AIRPLANE, C.C. Smith, and L.P. Parlett, NASA TN D 2285, August 1964. Dynamic stability and control characteristics were studied in hovering and transition flight.

II.7.4.2 LONGITUDINAL AND LATERAL STABILITY CHARACTERISTICS OF TWO FOUR-JET VTOL MODELS IN THE TRANSITION SPEED RANGE, R.D.Vogler and R. E. Kuhn, NASA, Langley Research Center, Langley Station, Va., Wash., NASA May 1965, (NASA TM X1092).
The investigation of the longitudinal and lateral stability characteristics of two four-jet vectored-thrust-type VTOL models in the transition speed range indicated significant effects of both the inlet and exit flow. The basic model experienced the expected induced nose-up pitching moments and loss in lift in the transition speed range. Removing the area of the delta wing rearward of the jets reduced the direct jet-induced interference effects for the tail-off configuration. Adding a conventional horizontal tail to this modified model, however, revealed high jet-induced downwash angles in the region of the horizontal tail that produced a severe tail-on pitch-up for this model. The inlet effects for the basic model, which had the inlet far ahead of the center of gravity, were reasonably well predicted by simple calculations based on the inlet mass flow. The effective dihedral of the basic model at transition speeds with the jets deflected downward was greatly increased by the induced effects of the existing jets. These jet-induced rolling moments arise from the same jet-induced pressure reduction on the lower surface that produced the jet-induced nose-up pitching moments.

II.7.4.3 LOW-SPEED WIND TUNNEL INVESTIGATION OF THE ROLL STABILITY OF A 1/5 SCALE MODEL OF THE SHORT SC1 AT LARGE SIDESLIP, W.J.G. Trebble, May 1967.
In order to facilitate the study of the roll stability of V/STOL aircraft at large angles of sideslip, low speed wind-tunnel tests have been made on a 1/5 scale model of the short SC1. The results show that very large rolling moments can be produced if roll and sideslip are present together because of the lateral movement of the wing center of pressure. This rolling problem is

II.7.4.3 (continued)
aggravated by a loss in aileron power as sideslip angle is increased. Recovery is feasible by turning into wind (reducing sideslip) and thus reducing the rolling moments to an acceptable level.

See also II.7.1.18

II.7.5 Handling Qualities and Criteria -

II.7.5.1 V/STOL HANDLING QUALITIES AS DETERMINED BY FLIGHT TEST AND SIMULATION TECHNIQUES, F. J. Drinkwater, III, L.S. Rolls, H.L. Turner, and H.C. Quigley, ICAS, Congress 3rd, Stockholm, Sweden, August 27-31,1962.

Investigation of the control-power and damping requirements for V/STOL aircraft, using a variable stability and control Bell X-14A test vehicle. The X-14A is a low-winged, jet-propelled aircraft which derives its vertical lift ability from the jet exhaust of two turbojet engines. Satisfactory and unacceptable boundaries for control along the pitch, roll, and yaw axes, as evaluated by test pilots, are presented. In addition, a chart based on flight-test performance measurements is presented showing takeoff speed plotted against ground-run time for various values of thrust/weight ratio, thrust vector angle, and takeoff distance. The results of tests with boundary-layer control Lockheed C-130B are also reviewed.

See also II.7.1.12 and II.7.4.1, .2, .3

II.7.6 Testing -

II.7.6.1 TECHNIQUES FOR THE SIMULATION OF JET-LIFT ENGINES IN WIND TUNNEL MODELS OF V/STOL AIRCRAFT, Ugo Sacerdote, Fiat S.P.A. Turin (Italy), Aviation Div., in AGARD Aerodyn. of Power Plant Installation, Pt.2, October 1965.
A special technique has been developed at FIAT Aviation Division, based on the application of compressed air ejectors. The basic assumptions on which this particular technique is based, the calibration tests performed, and the data-reduction methods are illustrated, together with a summary of wind tunnel results.

II.7.6.2 THE DEVELOPMENT OF INJECTOR UNITS FOR JET-LIFT ENGINE SIMULATION ON LOW-SPEED TUNNEL MODELS, M.N. Wood and J.B.W. Howard, Aeron. Res. Council, ARC-R&M-3464,February 1965.
Discussed ejector units for engine simulation. Concluded that the absolute minimum requirements for engine simulation at model scale were:

(1) scaled exit geometry
(2) correct exit momentum coefficient
(3) correct intake location (but not necessarily exact representation of intake geometry)
(4) correct intake mass-flow coefficient

II.7.6.3 TECHNIQUES FOR THE AERODYNAMIC TESTING OF V/STOL MEDELS, W.J.G. Trebble, RAE-TM-Aero-1080, July 1968.
Concentrated on techniques for testing lift-jet or lift-fan models including engine simulation. Need for adequate ground simulation was discussed. The need for special V/STOL wind tunnels and other facilities was commented on.

See also II.7.1.16, .23, .24 and II.7.2.11

II.7.7 General -

See Section I.7.7

II.8 GENERAL

II.8.1 **Forces and Moments**

II.8.1.1 CORRELATION OF WIND TUNNEL AND FLIGHT TEST AERODYNAMIC DATA FOR FIVE V/STOL AIRCRAFT, D. H. Hickey, W. L. Cook, AGARD-520, October 1965.
The five aircraft tested represent a wide variety of V/STOL concepts. Correlation between the wind-tunnel and flight-test aerodynamic results is generally good when wind tunnel wall corrections are omitted; in some cases wall corrections are shown to degrade the correlation. The aircraft and wind tunnel geometry are related to model-tunnel sizing parameters and a VTOL lift parameter, in order to establish tentative sizing criteria for V/STOL wind tunnel testing with small wall effects.

II.8.1.2 A FLIGHT AND WIND TUNNEL INVESTIGATION OF THE EFFECT OF ANGLE-OF-ATTACK RATE ON MAXIMUM LIFT COEFFICIENT, F. Conner, C. Willey, and W. Twomey, NASA CR-321, July 1965.
The effect of angle-of-attack rate on maximum lift at stall was investigated for a related series of six half-wing models in wind tunnel as well as for a single-engine, jet-propelled airplane. Mach numbers from 0.25 to 0.75, Reynolds numbers from 1,4 to 21 x 10^6, thickness ratios of 9, 13 and 16%, sweep angles of 0 and 35 degrees, aspect ratios of 3 and 6 and cambers corresponding of ideal lift coefficient of 0 and 0.2 were tested. All wings were composed of 65_1 maximum lift with angle-of-attack rate was small and, in general, linear. There were no clear indications of a limit for the maximum lift obtainable. Of the parameters tested, thickness, camber and sweep had the greatest effect. The effect of angle-of-attack rate on maximum lift was increased as camber of thickness decreased, or sweep increased. The flight test results correlated with the trends derived from the wind tunnel tests.

II.8.1.3 SUR L'UTILIZATION DES JETS PROPULSIFS A L'HYPER-SUSTENTATION D'UN AVION, Poisson-Quinton, Ph and Bevert, A. Techn. at Sc. Aero, September-October 1959.

Survey of various methods of lift generation by means of jets and evaluation of the jet flap principle. Wind tunnel experiments on three configurations of hypothetical aircraft capable of high speed with low aspect ratio wings are described. The lift and drag performance, as function thrust, is compared with that obtained by simple downward deflection of the jets. The longitudinal stabilization achieved by means of auxiliary jets in the nose of the ground effect principle with results of the effect of various (intensity and orientation of the jets) as function of the distance from the ground. The similarity of results obtained on a platform and on jet flaps is pointed out and the possibility of using the favorable ground effect for takeoff and landing application to high-speed aircraft is evaluated.

II.8.2 Flow Fields

II.8.2.1 MEASURED CIRCULAR INTAKE PERFORMANCE IN INCLINED FLOW FOR A SERIES OF SEMI-CIRCULAR LIP PROFILES, R. A. Tyler and R. G. Williamson, NRC LR-424, NRC, Canada, Division of Mechanical Engineering, January 1965, 16 pages, 35 figures.
Data, relating mainly to mean total pressure loss, in inclined flow, are presented for a series of five circular intakes with common center-body (0.5 diameter ratio) and employing semi-circular lip profiles. Lip radius to intake radius ratios were 0, 10, 0.15, 0.20, 0.25 and 0.30. Measurements were made at velocity ratios up to 2.0 and crossflow angles up to 165 degrees. Test intake Reynolds numbers ranged from 0.5 x 10^6 to 2.8 x 10^6 depending on velocity ratio. The available range of comparatively loss-free operation in inclined flow is presented for each intake and discussed in relation to previous data on elliptical lip profiles (Reference 1) and in terms of the effects of Reynolds number, lip radius and lip profile. The regime characterized by strong flow separation effects is described by contours of mean total pressure loss (in terms of both intake and freestream dynamic pressure) and by estimates of maximum/mean velocity ratios associated with intake volocity distribution.

II.8.2.2 A GENERALIZED EXPERIMENTAL STUDY OF INLET TEMPERATURE RISE OF JET VTOL AIRCRAFT IN GROUND EFFECT, BOOK I, R. F. Speth, P. E. Ryan, October 1966.
This report has been prepared to document the data which served as the basis for the technical analysis. The data were automatically reduced and tabulated by computer. An available program was utilized which automatically plotted the increments in temperature between that sensed by the thermocouples and the 'selected' ambient temperature. This volume (Book I) consists of the exploratory test and automatic data plots.

II.8.2.3 STATE-OF-THE-ART SURVEY FOR MINIMUM APPROACH, LANDING, AND TAKEOFF INTERVALS AS DICTATED BY

II.8.2.3 (Continued)

WAKES, VORTICES, AND WEATHER PHENOMENA, W. J. Bennett, Report No. RD644, The Boeing Company, January 1964.

A study is made of the generation and decay of the wake behind an aircraft, both in free air and ground effect, and its effect on following aircraft. An analysis is presented for both fixed- and rotary-wing aircraft which defines the wake movement with time and the wake-induced velocities. The wake due to the propulsion system is analyzed both for normal operation and reversed thrust, as well as for pure propulsion lift. The influence of atmospheric parameters such as wind, temperature, and turbulence is discussed as it applies to the generation and decay of the wake.

II.8.2.4 STUDY OF THE VORTEX SHEET IMMEDIATELY BEHIND AN AIRCRAFT WING (PENNSYLVANIA STATE UNIVERSITY STUDY), B. W. McCormick and J. L. Tangler, Report 4446-1, Army Research Office-Durham, December 1965.

Investigates sheet thickness, size of vortex core, and rate at which sheet rolls up as function of lift coefficient.

II.8.2.5 REVIEW OF PROPULSION-INDUCED EFFECTS ON AERODYNAMICS OF JET V/STOL AIRCRAFT, R. J. Margason, NASA TND 5617, February 1970.

This paper reviews several aspects of the effects induced on the aerodynamics of V/STOL aircraft in hover and transition flight by the interference of wakes from relatively high disk-loading propulsion devices. Four problem areas are treated: (1) the performance losses sustained when hovering out of ground effect, (2) induced aerodynamic effects in transition flight out of ground effect, (3) the problems caused by hot-gas ingestion, and (4) the effects induced on performance during hover in ground effect. Some of the conflicts among the design requirements imposed by these different modes of flight are discussed, along with the present state of the art of solutions to some of the problems.

II.8.2.6 STRUCTURE OF TRAILING VORTICES, B. W. McCormick, J. L. Tangler and H. E. Sherrieb, Journal of Aircraft, Volume 5, No. 3, May-June 1968, pages 260-267.

A study of aircraft trailing vortex systems, involving flight testing of a U. S. Army O-1 and a Piper Cherokee, as well as model testing and analytical considerations, resulted in a method for predicting the vortex geometry and velocity field downstream of an aircraft. It was found that the vortex decay could be described by geometric similarity considerations. This conclusion was based on detailed velocity measurements made through the vortex immediately behind a test aircraft up to distances of approximately 1000-chord lengths downstream of the aircraft. A presentation of the data on which the conclusions were based, as well as a description of test equipment and procedures are included.

II.8.2.7 AN EXPERIMENTAL INVESTIGATION OF INCLINED COMPRESSOR INFLOW, R. A. Tyler, R. G. Williamson, Canadian Aeronautics and Space Journal, February 1966, pages 45-62.

Results of experiments in the NRC 10 ft. x 20 ft. VTOL propulsion tunnel on unassisted cowled intakes in inclined flow are reported. A series of ten simple intake configurations, of 15.0 in. internal diameter, incorporating a common centrebody (0.5 diameter ratio), and with various lip profiles, was investigated over a range of freestream to intake velocity ratio up to 2.0 and cross-flow angle from 0° to 165°. The available range of cross-flow conditions for comparatively loss free operation, together with approximate pressure loss data in the separated flow regime, are discussed in terms of lip profile. Measurements were repeated for one of the intake geometries with the inclusion of a two-stage fan of relatively high thrust loading (up to 800 lb/sq. ft.). Preliminary data on the effect of the presence of the fan on intake flow, and on fan performance under highly distorted intake flow conditions arising

II.8.2.7 from cross-flow, are presented.

II.8.2.8 A COMPREHENSIVE REVIEW OF V/STOL DOWNWASH IMPINGEMENT WITH EMPHASIS ON WIND INDUCED RECIRCULATION, P.J. Unit, Air Force Institute of Technology Thesis GAM/AE/69-9, March 1969.
A summary of the work done in the previous decade on downwash impingement was given. The direct jet lift and rotor downwash fields were described. Recirculation causes, mechanism, and operational problems were discussed. A bibliography was included. The recirculation problem was not solved.

II.8.3 Ground Effect -

II.8.3.1 A MOVING-BELT RIG FOR GROUND SIMULATION IN LOW-SPEED WIND TUNNELS, S.F.J. Butler, B.A. Moy, T.N. Pound, ARC R&M 3451, December 1963.
The need for reliable wind-tunnel model measurements of the effect of ground proximity at low forward speed has become more important with the trend towards V/STOL aircraft exhibiting large ground effects, often adverse. To ensure the correct boundary-layer development on the simulated tunnel ground, relative movement between the ground and the mainstream air strictly should be precluded, so that the conventional stationary 'groundboard' is not truly representative.

Better ground representation can be achieved by substituting the surface of a motor-driven endless belt for the conventional stationary 'groundboard'. This paper describes the design and development of a Moving-Belt Rig affording an eight-foot wide belt capable of speeds up to 90 ft/sec.

In order to assess the importance of the incorrect boundary-layer development with the stationary 'groundboard', the Rig has been used for comparative tests, which will be reported separately, on a series of representative models. On the basis of current test experience with these models, some further rig improvements are being incorporated to facilitate the testing of round-jet V/STOL models.

II.8.3.2 A METHOD FOR IN-FLIGHT MEASUREMENT OF GROUND EFFECT ON FIXED-WING AIRCRAFT, W. Schiveikhard, AIAA Paper 66-468, June 1966.
A flight-test method is discussed for evaluating ground effect on fixed-wing aircraft. The method requires the pilot to fly at constant angle of attack and power setting during an approach to the runway at various initial sink rates. With

II.8.3.2 (continued)
this flight condition, lift, drag and pitching moment are constant prior to approaching the ground. When ground effect is encountered, changes in flight path, velocity, and control-surface positions are interpreted as changes in lift, drag and pitching moment, respectively. The fundamental principals and operational problems involved in applying this method were discussed in detail. The advantage claimed for this technique is that the entire ground-effect characteristics of a configuration can be evaluated during a few approaches rather than by means of the multitude of fly-by required by the classical constant-altitude fly-by method. The method was applied to two low-aspect-ratio aircraft - a straight-wing and a delta-wing configuration. Some of the results of these tests are presented and compared with wind-tunnel predictions.

II.8.3.3 A MOVING-BELT GROUND PLANE FOR WIND TUNNEL GROUND SIMULATION AND RESULTS FOR TWO JET-FLAP CONFIGURATIONS, T. R. Turner, NASA TN D 4228, November 1967.
The effects of ground proximity on the characteristics of a swept and an unswept full-span blowing-flap configuration were investigated using a moving-belt ground plane. The results indicate that the moving belt satisfactorily remove the boundary layer on the ground plane. The lift loss of models at small distances from the ground and high lifts were considerably less with the belt moving at stream velocity (boundary layer removed) than with the belt at zero velocity. For configurations with full-span lift devices, the data indicated that the moving-belt ground plane was not needed for ratios of wing height (in spans) to lift coefficient greater than about 0.050, but is desirable for smaller ratios.
See also II.8.2.8

II.8.4 Stability and Control -

II.8.4.1 A FLIGHT INVESTIGATION OF THE EFFECTS OF WEATHER-COCK STABILITY ON V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES, D.F. Daw et al, NRC Report LR-400, May 1964.
The visual flight task performed by the pilots included hovering turns, in the presence of a simulated wind, and a complete circuit terminated by a steep angle, low speed approach to landing. Synthetic turbulence disturbed the simulator to produce realistic flight conditions.

II.8.4.2 EFFECTS OF GROSS CHANGES IN STATIC DIRECTIONAL STABILITY ON V/STOL HANDLING CHARACTERISTICS BASED ON A FLIGHT INVESTIGATION, J.F. Garren et al, NASA TN D 2477, October 1964.
The study used a variable-stability helicopter. Tasks under simulated instrument and visual conditions were used for evaluation of the handling characteristics provided by various combinations of static directional stability,directional sensitivity and damping and dihedral effect.

II.8.4.3 INVESTIGATION OF LATERAL CONTROL NEAR THE STALL. ANALYSIS FOR REQUIRED LONGITUDINAL TRIM CHARACTERISTICS AND DISCUSSION OF DESIGN VARIABLES, F.E. Weick and H.N. Abramson, NACA TN 3677 (June 1956).
Analytical design procedures for estimating the elevator deflection required to trim in steady longitudinal flight are presented. Pertinent data and formulae for use in evaluating longitudinal trim characteristics are summarized from existing literature and two light aeroplanes are analyzed quantitatively to illustrate the use of the methods and to provide a comparison with flight-test results.

II.8.4.4 INVESTIGATION OF LATERAL CONTROL NEAR THE STALL: FLIGHT TESTS WITH HIGH-WING AND LOW-WING MONOPLANES OF VARIOUS CONFIGURATIONS, F.E. Weick and H.N. Abramson, NACA TN 3676, June 1956.
Flight tests were made with typical light aeroplanes to investigate possibilities for obtaining [illegible] lateral control at low flight speeds. The maximum angle of attack below the stall at which control is still available was determined for each aeroplane, as well as the elevator deflection required to trim at this condition, with power off and on, and to make a three-point landing.

II.8.4.4 (continued)
One aeroplane was tested with different horizontal tail configurations in an attempt to provide an arrangement that would give near-optimum conditions with regard to the effect of power change on longitudinal trim near the stall.

II.8.4.5 PROGRESS IN FLYING QUALITIES RESEARCH RELATING TO STOL AND VTOL AIRCRAFT, A. D. Wood, ASI, Journal, Vol.17, February 1965.
Review of some aspects of research as STOL and VTOL flying qualities. Comments are offered on the progress that has been made in approaching and exploring some of the significant areas of uncertainty in this field. The subjects considered are technique of flight simulation, longitudinal characteristics of STOL aircraft, directional flying qualities in hovering and low-speed flight, lateral-directional control cross-coupling, general stability and control considerations, and scaling factors. It is concluded that progress has been made in identifying many of the parameters having a major influence on the flying qualities of aircraft of these types, and relationships among some of these parameters leading to acceptable or to minimum tolerable flying qualities have been established. The broad nature of the STOL and VTOL flight regimes necessarily introduces a very large number of variables and, consequently, there are wide gaps in understanding. More research is required to clarify the effects of scale on flying qualities, to further examine the limiting factors involved in carrying out steep approaches leading to a short landing roll, and to consolidate the parameters influencing lateral-directional behavior into fewer generally applicable expressions.

II.8.4.6 STABILITY AND CONTROL OF PROPELLER-DRIVEN TRANSPORT VTOL AIRPLANES, R. H. Kirby, Proc. Thirteenth Annual Forum, AHS, May 8-11, 1957.

II.8.4.7 INVESTIGATION OF THE LONGITUDINAL CHARACTERISTICS OF A LARGE-SCALE JET TRANSPORT MODEL EQUIPPED WITH CONTROLLABLE THRUST REVERSERS, D.H. Hickey, W. H. Tolhurst, K. Aoyagi, Jr., Report No. TN D786.
An investigation was conducted to determine the effect of thrust control by means of controllable thrust reversers on the longitudinal characteristics of a large-scale airplane model with a 35°

II.8.4.7 (continued)
sweptback wing of aspect ratio 7 and four pylon-mounted jet engines. The model was equipped with target-type thrust reversers designed to provide thrust control ranging from full forward thrust to full reverse thrust. The use of thrust control in landing-approach configurations formed the major portion of the study. Results were obtained with both leading- and trailing-edge high-lift devices. Lift, drag, and pitching-moment coefficients and reverser effectiveness data are presented. Test Reynolds numbers ranged from 4.2 to 8 million. Examination of the data indicates that thrust control by means of thrust reversers can bring about a deterioration of longitudinal characteristics when reversers closure is more than 40%. However, analysis indicates that with closure up to 40% the reversers can provide a significant improvement in landing approach performance.

II.8.4.8 AN INVESTIGATION OF THE PERFORMANCE OF VARIOUS REACTION CONTROL DEVICES, P.A. Hunter, NASA Memo 2-11-59L, March 1959.
Tests were made in still air utilizing both subsonic and supersonic internal flows. The range of nozzle total-exit-pressure ratio covered was from approximately 1.3 to 6.5. The specific parameters investigated were the ratio of lateral force to resultant force of the undeflected jet, the ratio of resultant force to resultant force of the undeflected jet, and the ratio of weight flow referred to the weight flow of the undeflected jet.

II.8.4.9 THE DETERMINATION OF LATERAL STABILITY AND CONTROL DERIVATIVES FROM FLIGHT DATA, J. Howard, Canadian Aeronautics and Space Journal, March 1967.
A refined version of the equations of motion technique has been applied to the determination of the lateral stability and control derivatives of a STOL aircraft. This technique incorporates an allowance for unknown constant errors in the measured quantities. The author claims that this allowance makes a significant contribution to the overall accuracy of the method. The results showed a good level of precision and demonstrated the existence of important derivatives.

II.8.4.10 SOME RECENT AERODYNAMIC ADVANCES IN STOL AIRCRAFT, Journal of Aircraft, Vol.2, No.5, September-October 1965, G.W. Johnston.
A brief review was presented of the results of some of the developments carried out by the deHavilland Aircraft of Canada Ltd., in two broad areas: (1) basic STOL performance, and (2) low-speed control and handling. In connection with basic STOL performance, the case for the classical STOL deflected slipstream configuration and some of its limitations were reviewed. Some evolutionary improvements to this basic design appr ach were outlined. In addition, the possibility of re-lacing the classical propeller installation with a true jet STOL aircraft was briefly discussed. Some improvements in longitudinal low-speed control were discussed. Other criteria were reviewed and some observed inherent limitations noted. Finally, the flight-test results obtained with an experimental aircraft incorporating a modified longitudinal control system were discussed.

II.8.4.11 COLLECTION OF TEST DATA FOR LATERAL CONTROL WITH FULL-SPAN FLAPS, J.Fischel and M.F. Iney, NACA TN 1404, 1947.
A collection of test data on lateral control with full-span flaps was presented. Lateral-control effectiveness and hinge-moment data obtained from two-dimensional, three-dimensional and flight tests were presented. A discussion was given of the characteristics of the lateral-control devices considered and of the application of the data to specific airplane design.

II.4.1.12 STABILITY AND CONTROL CONSIDERATIONS FOR STOL AIRCRAFT, S.B. Anderson, H.C. Quigley and R.C. Innis, AGARD Report 504, June 1965.
Some form of damping augmentation system may be required because of lateral-directional handling considerations. In addition to the STOL aircraft flown, more experience was required before firm requirements for augmentation systems could be established.

II.8.5 Handling Qualities and Criteria -

II.8.5.1 A FLIGHT EXAMINATION OF OPERATING PROBLEMS OF V/STOL AIRCRAFT IN STOL-TYPE LANDING AND APPROACH, R.C. Innis and H.C. Quigley, NASA TN D 862, June 1961.
The operating envelope of a large twin-engined STOL aircraft has been examined and general limitations have been pointed out which the pilot must consider when choosinga minimum landing approach speed for STOL aircraft. The significance of satisfactory stability and control characteristics in this regard is discussed. The problems reviewed in the report would also be representative of those of a large, overloaded STOL aircraft operating in an STOL manner.

II.8.5.2 THE INFLUENCE OF DRAG CHARACTERISTICS ON THE CHOICE OF LANDING APPROACH SPEEDS, D. Lean and R. Eaton, AGARD Report 122, May 1957.
A study has been made of the lift-drag characteristics of 19 jet aircraft which have minimum comfortable approach air speeds that are fairly well established.

II.8.5.3 INVESTIGATION OF LATERAL CONTROL NEAR THE STALL, ANALYSIS FOR REQUIRED LONGITUDINAL TRIM CHARACTERISTICS AND DISCUSSION OF DESIGN VARIABLES, F.E. Weick and H.N. Abramson, NACA TN 3677, June 1956.
Analytical design procedures for estimating the elevator deflection required to trim in steady longitudinal flight are presented. Pertinent data and formulae for use in evaluating longitudinal trim characteristics are summarized from existing literature and two light aeroplanes are analyzed quantitatively to illustrate the use of the methods and to provide a comparison with flight-test results.

II.8.5.4 A FLIGHT INVESTIGATION OF THE INFLUENCE OF VARIOUS LEVELS OF DIHEDRAL EFFECT ON V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES, D. M. McGregor, NRC LR-412 November 1964.
Dihedral effect on directional angular rate dampings and control sensitivities required for normal and emergency operation was studied using an airborne V/STOL simulator. The visual flight task included hovering turns and a complete circuit with a low speed, steep angle approach to touchdown.

II.8.5.5 A COMPARISON OF V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES CRITERIA FOR VISUAL AND INSTRUMENT FLIGHT USING AN AIRBORNE SIMULATOR, R. E.Smith, NRC Report LR-465, September 1966.
The directional handling qualities criteria for an instrument approach task in controlled turbulence were determined using an airborne V/STOL simulator, and compared with the results for a visual approach task. Theoretical criteria from a pilot-aircraft synthesis were correlated with pilot ratings.

II.8.5.6 INVESTIGATIONS OF THE STEEP-GRADIENT LANDING MANEUVER EMPLOYING MODULATED REVERSE JET THRUST, R. Fowler, CAS Journal, Vol.11, February 1965.
Description of an experimental flight program, underway at deHavilland of Canada, in which modulated reverse jet thrust has been utilized as a means of steepening fixed-wing approach angles, and shortening post-touchdown ground roll. This program and a parallel analog simulator study have improved landing performance in the test aircraft by over 50% and developed a new and powerful means of controlling approach speed and angle. A valuable insight into problems of the pilot in performing steep gradient approaches has also been gained.

II.8.5.7 SOME PERFORMANCE AND HANDLING QUALITIES CONSIDERATIONS FOR OPERATION OF STOL AIRCRAFT, S.B. Anderson, H.C. Quigley and R.C. Innis, NASA Ames Research Center, Moffett Field, Calif., in NASA Washington, Conf. on Aircraft Operating Probl. 1965.
Studies of a number of STOL aircraft show that relatively high maximum lift coefficients and large increases in lift due to power are within the present state of the art. With these lift characteristics, approach speeds of the order of 60 knots for aircraft of moderate wing loading can be realized. Full advantage of the STOL performance of aircraft on a routine operation basis, however, without some form of damping augmentation system, because of lateral-directional handling considerations, particularly for large aircraft operating under instrument flight conditions. Satisfactory characteristics can be obtained by use of only a servodriven rudder. Additional experience is needed to determine how the STOL aircraft is to be operated before more firm requirements for augmentation systems can be established.

II.8.5.8 EFFECT OF SIZE ON VTOL AIRCRAFT HOVER AND LOW SPEED HANDLING QUALITIES, J. Ford Johnston and Carl F. Friend, New York, AHS, Inc. 1965.
A fundamental investigation of the effect of size on VTOL aircraft hover and low-speed handling qualities is presented. Both helicopter and jet VTOL are treated. Formulas for determination of size effects (with size referred to a characteristic linear dimension) on VTOL vehicle handling qualities capabilities are developed through dimensional analyses. Hypotheses are drawn regarding effect of size on pilot-vehicle compatibility. Some of these pertinent handling quality-capability-size relationships for similar VTOL vehicles are summarized as follows. Similar VTOL vehicles are defined as those geometrically similar configurations with constant total thrust/weight. The thrust/weight available for control of jet VTOL vehicles is also considered to be invariant with size. Although thrust/weight can be varied with size, this would effect changes in vehicle performance and weight. Aircraft having revised constants of proportionality effecting basic trends only slightly. Capability is defined as the inherent flight handling ability of the vehicle without regard to whether such capabilities are consistent with flight handling requirements.

II.8.5.9 STATISTICAL APPROACH TO LOW SPEED CONTROL CRITERIA FOR V/STOL AIRCRAFT, D. O. Carpenter, and R. B. Jenny,AIAA, Annual meeting 1st, Washington, D.C., June 29, July 2, 1964, Paper 64-286.
Statistical analysis of V/STOL control criteria using characteristics satisfactory for STOL, SFA, and VTOL aircraft. Data from industry and NASA are correlated and compared with criteria from helicopter specification MIL-H-8501A, NATO AGARD Report 408, and conventional fixed-wing specification, MIL-F-8785. The variation of control criteria with gross weight is found to fluctuate approximately according to the relationship (GW + 1000)-1/3. V/STOL aircraft control criteria are somewhat greater than those found acceptable for helicopters. The analysis shows the roll control power to be twice the IFR helicopter requirement, and pitch and yaw criteria to be about 1.5 and 1.0 times the IFR helicopter requirements, respectively.

II.8.5.10 HANDLING QUALITIES EXPERIENCE WITH SEVERAL VTOL RESEARCH AIRCRAFT, J.P. Reeder, March 1961.
All of the VTOL research aircraft discussed successfully demonstrated conversion from hovering to airplane flight and vice versa. However, control about one or more axes of these aircraft was inadequate in hovering flight. Furthermore, ground interference effects were severe in some cases and accentuated the inadequacy of control in hovering and very low speed flight. Stalling of wing surfaces resulted in limitations in level-flight deceleration and in descent, particularly for the tilt-wing aircraft. Minor modifications to the wing leading edge produce suprisingly large and encouraging reductions in adverse stall effects. Height control in hovering and in low-speed flight proved to be a problem for the aircraft not having direct control of the pitch of the rotors. The other systems showed undesirable time lags in development of a thrust change.

II.8.5.11 A PILOTED FLIGHT SIMULATOR STUDY OF SPEED INSTABILITY DURING THE LANDING APPROACH, D. H. Perry, CP 980, April 1966.

II.8.5.12 FLIGHT ASSESSMENT OF A VARIABLE-STABILITY HELICOPTER FOR STOL SIMULATIONS AND EVALUATION OF THE INFLUENCE OF SEVERAL LATERAL-DIRECTIONAL STABILITY DERIVATIVES, D.M. McGregor, NRC Report LR-524, June 1969.

II.8.5.13 EFFECTS OF REDUCED AIRSPEED FOR LANDING APPROACH OF FLYING QUALITIES OF A LARGE JET TRANSPORT EQUIPPED WITH POWERED LIFT, H.L. Crane et al NASA TN D 4804, October 1968.

II.8.5.14 FLIGHT TESTS UNDER IFR WITH AN STOL TRANSPORT AIRCRAFT, R.C. Innis et al, NASA TND 4939, December 1968.

II.8.5.15 OPERATIONAL TECHNIQUE FOR TRANSITION OF SEVERAL TYPES OF V/STOL AIRCRAFT, F.J. Drinkwater, III, Report No. TN D 774- NASA AD 252 988.
Flight test experience was obtained with five test bed aircraft which employed widely differing principles of V/STOL operation. At high speeds these aircraft were supported by wing lift and in the hovering condition they were supported by engine-produced thrust. The techniques used to transfer the lift from the wing to the engine are examined.

II.8.5.15 (continued)
The primary items considered in the transition region are longitudinal trim changes, stability, stalled flow during descending transitions, and the flexibility of the transition procedure of each type of aircraft.

II.8.5.16 A COMPARISON OF V/STOL AIRCRAFT DIRECTIONAL HANDLING QUALITIES CRITERIA FOR VISUAL AND INSTRUMEN FLIGHT USING AN AIRBORNE SIMUALTOR, R.E. Smith, NAC of Canada, NAF, LR-465, September 1966.
The directional handling qualities criteria for an instrument approach task in controlled turbulence were determined using an airborne V/STOL simulator, and compared with the results for a visual approach task, to show that instrument flight demanded more stringent criteria. Increasing the weathercock stability, in the presence of turbulence, required significantly larger values of damping. These levels, which were dependent on the task, were apparently determined by the aircraft's response to turbulence as shown by the good correlation obtained between pilot ratings and theoretical criteria based on the aircraft's turbulence response. Existing recommendations for minimum damping levels did not correlate with the results, but the recommendations for minimum directional response were found to be adequate for normal operation.

Theoretical criteria from a pilot-aircraft synthesis were correlated with pilot ratings and provided an insight into the possible behavior of the pilot while flying an approach task in turbulence.

II.8.5.17 LOW-SPEED STALLING CHARACTERISTICS, J.C. Wimpenny, AGARD Report 356, April 1961.
Low speed stalling requirements are reviewed. It is concluded that design for good stalling properties is based on AdHoc foundations.

II.8.5.18 A FLIGHT EXAMINATION OF OPERATING PROBLEMS OF V/STOL AIRCRAFT IN STOL-TYPE LANDING AND APPROACH, R.C. Innis and H.C. Quigley, NASA TN D 862.
A flight investigation was conducted using a large twin engine cargo aircraft to determine the problems associated with operating propeller-driven aircraft in the STOL speed range where appreciable engine power is used to augment aerodynamic lift.

II.8.5.18 (continued)
The study showed that operation at low approach speeds was compromised by the necessity of maintaining high thrust to generate high lift and yet achieving the low lift-drag ratios needed to steep descents. The usable range of airspeed and flight path angle was limited by the pilot's demand for a positive climb margin at the approach speed, a suitable stall margin, and a control and/or performance margin for one engine inoperative. The optimum approach angle over an obstacle was found to be a compromise between obtaining the shortest air distance and the lowest touchdown velocity. In order to realize the greatest low-speed potential from STOL designs, the stability and control characteristics must be satisfactory.

II.8.5.19 FLYING QUALITIES CONFERENCE, Wright-Patterson Air Force Base, Ohio, 5 and 6 April 1966, AFFDL-TR-66-148, December 1966.
Presented papers given at converence intended to provide assistance in revising MIL-F-8785.

II.8.5.20 AN INVESTIGATION OF THE EFFECTS OF ROLL-SPIRAL COUPLING ON THE LATERAL-DIRECTIONAL HANDLING QUALITIES OF A STOL SUBSONIC TRANSPORT, F.L. Moore, NASA TM-X-61898.
Presented the results of an investigation of the effects of the roll-spiral coupled mode of motion on the lateral-directional handling characteristics of a hypothetical subsonic STOL transport. The investigation consisted of analytical calculations of the lateral dynamics of the transport having various types of roll-spiral oscillations. Also, a fixed base simulator study was conducted. The results indicated thatqualities could be acceptable with a roll-spiral oscillation present provided small lateral inputs are used.

See also II.7.1.27, II.8.2.11, II.8.4.1,.2,.3,.4

II.8.6 Testing

II.8.6.1 A FACILITY FOR DYNAMIC TESTING OF MODELS OF AIRBORNE VEHICLES WITH GROUND EFFECT, J. Liiva UTIA TN 53 October 1961.
A feasibility study has been made of the testing of self-powered models of vehicles with ground effect. Preliminary testing of a GETOL model with a wing of aspect ratio 3.5 and 17 in. wingspan was performed by flying over ramps in the groundboard of the track. The motion of the vehicle was recorded by film. A theoretical study of the cable derivatives introduced by the harnessing and of their magnitudes relative to the aerodynamic derivatives was made. Problems associated with the model construction and performance are outlined and experimental test results are presented.

II.8.6.2 FURTHER DEVELOPMENTS IN LOW SPEED WIND TUNNEL TECHNIQUES FOR VSTOL AND HIGH-LIFT MODEL TESTING, J. Williams and S.F.J. Butler, R.A.E. TN Aero 2944 (1964).
Discussion of recent advances in wind tunnel testing of low-speed high-lift models with boundary-layer and circulation control. Topics of study are: (1) special mechanical and strain-gage balance rigs for jet-blowing models; (2) engine exit and intake flow simulation at model scale, and (3) ground simulation by a moving-belt rig. Recent development, particularly those to expedite investigations on jet and fan lift models at the Royal Aircraft Establishment, are reviewed.

II.8.6.3 EXPERIMENTAL AND THEORETICAL INVESTIGATION OF WIND TUNNEL GEOMETRY, EMPHASIZING FACTORS PERTINENT TO V/STOL VEHICLES TESTING, R.G. Joppa, Wash. Univ., Seattle, Dept. of Aeron. Engrg., Progress Report No. 2, March 16 - Sept. 15, 1965, 15 Jan., 1966, 26p. (GRANT NGR-48-002-010-)(NASA-CR-70331).
Discussions are presented on an experiment concerning the installation of a powered rotor model in a wind tunnel; an analysis of tunnel internal flow using the vortex ring method; and the basic problem of calculating flow fields of highly loaded systems in free air. The wind tunnel analysis was extended and improved by distributing the vorticity from discrete rings to continuous sheets along the walls. Relative to calculating flow fields, it was found

II.8.6.3 (continued)
that a simple representation of the vortex system was adequate to calculate the trajectory of a streamline. In determining interference it was demonstrated that the vortex filaments trail downward at about one-fourth the angle of the mass of air as calculated by simple momentum theory.

II.8.6.4 TEST TECHNIQUES USED BY NASA FOR INVESTIGATING DYNAMIC STABILITY CHARACTERISTICS OF V/STOL MODELS, L.P. Parlett and R.H. Kirby, New York, American Institute of Aeronautics and Astronautics, 1964 p. 42-49.
Discussion of three model test techniques used by NASA to investigate the dynamic stability characteristics of V/STOL aircraft, with emphasis on the use of the techniques and the type of results that can be obtained. In the free-flight technique, the model is flown without restraint, in the 30- by 60-ft open-throat test section of the Langley full-scale tunnel, remotely controlled about all three axes by human pilots. The control-line technique employs a model that is connected to a cable and flown in a circle of 130 ft. diameter. It is used in the study of acceleration effects on longitudinal stability and control. The forced-oscillation technique involves a model mounted on a sting which, by means of an electrical drive system, can be made to rotate about its own longitudinal axis in an angular oscillation of adjustable frequency and amplitude. A strain-gage balance connects the model to the sting. It is employed in quantitative computer or simulator studies, where numerical values for dynamic stability derivatives are required. The results of several V/STOL tests using these methods are reviewed.

II.8.6.5 LIMITS ON MINIMUM-SPEED V/STOL WIND TUNNEL TESTS, W.H. Rae, Jr., January 1967. (AD656810).
The paper presents the results of a systematic series of wind-tunnel tests, which have determined the maximum size rotor that can be tested in closed-throat wind tunnels both as a function of the downwash angle and as a function of tunnel geometry. For a given size rotor and tunnel there appears to be a maximum value of downwash that can be tolerated. If this value of downwash is exceeded, the flow through the wind tunnel is no longer similar to the flow that would be encountered in free flight.

II.8.6.5 Similar results have also been obtained using jet flaps and jet-lift models. It is also shown that this flow breakdown is a function of tunnel geometry and that the allowable downwash angles are different for rectangular tunnels with different width-to-height ratios. The addition of fillets to the test section is also shown to have an adverse effect on the allowable downwash angle. At the present time, the optimum tunnel configuration for rotors and other types of V/STOL vehicles is not known.

II.8.6.6 TEST SECTIONS FOR SMALL THEORETICAL WIND TUNNEL BOUNDARY INTERFERENCE ON V/STOL MODELS, R.H. Wright, NASA TR R-286, August 1968.

II.8.6.7 THE DEVELOPMENT OF A VERTICAL STRAIN GAUGE BALANCE STRUT FOR JET BLOWING V/STOL MODELS, D.N. Foster, R.C. Eyre, July 1966.
A hollow tubular strain gauge balance and an air connector arrangement, forming part of a vertical support strut, have been developed for tests of V/STOL models using large quantities of compressed air. It was found that pressurization of the air feed system produced only small changes of the zeros for the unloaded balance, and had no effect on the response to loading. The layout of the balance and air feed system enabled heat insulation to be added to minimize the adverse effects of the passage of warm air through the connector and air feed system.

II.8.6.8 FLIGHT TEST INSTRUMENTATION FOR V/STOL AIRCRAFT, AGARD 317, April 1961.
The flight testing of V/STOL aircraft involves the measurement of certain quantities, some of which are the same as for conventional aircraft, where the quantities are different, those concerned in the V/STOL field have tackled the new problems in their own way. General aspects are considered, some illustrative examples are given, the physical quantities of interest in V/STOL testing are discussed, and recording methods are described. Finally, an attempt is made to suggest an optimum instrumentation. It is concluded that most of the quantities of interest can be measured by conventional methods, whereas others, such as low horizontal speeds, altitude, and rate of climb and descent, present difficulties. There is an obvious

II.8.6.8 (continued)
demand for lighter airborne equipment than is available at present.

II.8.6.9 THE STUDY OF OPERATIONAL PROBLEMS AND TECHNIQUES IN WIND TUNNEL TESTING OF VTOL AND STOL VEHICLES, W. H. Rae, Jr., October 1965. (AD 482115).
The primary purpose of this investigation is to develop an economical method of experimentally checking the effect of wind tunnel wall constraints on rotors, ducted fans, tilt props, and other methods of obtaining aircraft with V/STOL performance, by the use of inserts within a wind tunnel to simulate different size test sections.

II.8.6.10 WIND TUNNEL BOUNDARY EFFECTS STUDIES FOR VTOL/STOL DATA USING A FOUR-PROPELLER, DUCTED-FAN, GENERALIZED TRANSPORT DESIGN, R.D. Murphy, January 1966, DTMB Report AL-4.
Studies were made to provide data in order to increase the general understanding of the effects of tunnel jet boundaries on the results from models producing high downwash wakes. Considered are data from a four-propeller, ducted-fan model with the ducts arranged in tandem pairs. Powered tests were made with the model carried beneath an airship, for free-air conditions, and with the model mounted in an 8 x 10 foot closed wind tunnel test section. The results obtained during tests are compared in their uncorrected form. Attention is drawn to one existing correction theory which may be used at a subsequent time at this laboratory or at Forrestal Research Center of Princeton University.

II.8.6.11 THE DESIGN AND DEVELOPMENT OF AN AIR-BEARING FOR THE MEASUREMENT OF DAMPING IN YAW ON A JET-BLOWING MODEL, A.P. Cox, RAE TN Aero 2958 (1964).
An air-bearing support assembly is described for damped oscillation measurements of yaw damping derivatives on V/STOL blowing models, commencing with a jet flap model. The bearing, fitted within the fuselage, allowed freedom in yaw, but supported all the other forces and moments.

II.8.6.12 CONCEPTUAL AND REQUIREMENT STUDY FOR V/STOL FLIGHT TEST SUPPORT FACILITIFS, D.V. Harding, M. A. Sousa, T.A. Brady, October 1966.

The increased activity in V/STOL hardware programs has been accompanied by increased flight test workloads and requirements for increased flight test center capabilities. These present hardware programs are recognized as only the beginning of development of a new type of aircraft which will increase and become more demanding as the technology is advanced. In order to test, study, and evaluate development of this type aircraft through the year 1980, the capabilities of the flight test support facilities must be increased concurrently with the predicted vehicle development. A study was conducted to determine what facility capabilities the Air Force Test Center (AFFTC) would require through 1980. This study through a nationwide survey of government agencies and companies in the aircraft industry identified the spectrum of V/STOL aircraft expected to be in flight test status during 1967 - 1980. The parameters of weight (assault transport), exhaust (lift-jet fighter), and size (large diameter rotorplane) were established as the most critical and represented the maximum values predicted. The flight test objective, flight regimes, and type of testing were identified for these aircraft.

II.8.6.13 TUNNEL WALL EFFECTS ASSOCIATED WITH VTOL-STOL MODEL TESTING, R. Kuhn, R. Naeseth, March 1959.

Wind tunnel investigations of VTOL and STOL airplane models involve configurations in which a large amount of power is being used to generate part of the lift through the medium of propeller slipstreams or jet exhausts directed downward at large angles to the freestream direction. For many configurations the propellers or jet exhausts are arranged, for example, as in the jet flap, to cover tne entire span of the wing and thus to assist the wind in its natural process of producing so-called 'circulation' lift. This arrangement results in the streamlines in the vicinity of the wing also being turned through large angles to the freestream direction of flow. The presence of the tunnel walls must be parallel to the freestream. Thus, the problem of tunnel wall effects in VTOL-STOL model testing si similar to that associated with conventional mcdel testing but differs greatly in degree. Experience has shown

II.8.6.13 (continued)
that, in addition to these usual tunnel wall effects, flow separation on the model can also be induced by the tunnel walls. The experiences of the Langley Research Center of NASA related to these problems in closed-throat wind tunnels are reviewed.

II.8.6.14 RECENT TRENDS IN LOW SPEED WIND TUNNEL DESIGN AND TECHNIQUES, R.J. Templin, Annals of the New York Academy of Science, Vol.154, Art2; pp.1055-1073, 1968.
A review is given showing the need for large low speed wind tunnels for V/STOL testing. The V/STOL tunnels in planning or construction in April 1967 are described.

II.8.6.15 AN EXPERIMENTAL STUDY OF ALLEVIATING THE LIMITS ON MINIMUM-SPEED V/STOL WIND TUNNEL TESTS, Univ. of Wash.; Shindo, Shojiro; W.H. Rae, Jr., Report No.68-1, January 1968.
An experimental study was made to investigate some means to alleviate flow breakdown by using a number of different strake or fence configurations. A total of 23 different configurations were studied in the 4'x6' insert with a 2' diameter rig rotor at about 7 PSF disk loading. None of the strake configurations studied in the experiment completely eliminate the effect of flow breakdown.

II.8.6.16 A V/STOL WIND TUNNEL WALL INTERFERENCE STUDY, C.L. and T.W. Binion, Jr., Journal of Aircraft, Vol.7 No.1, Jan-Feb 1970, pp51-57.
A theoretical and experimental study of slotted wall tunnels was described. Theoretical calculations based on a modification of the point-matching method with equivalent homogeneous boundary conditions was used to show the relationship between the lift and blockage-interference factors and wall porosity. Experimental interference factors were obtained by comparing lift coefficient vs angle of attack data obtained in a 30"x45" tunnel with those from a 7'x10' tunnel. Theoretical results indicated that the lift interference for conventional models was insensitive to the porosity of the vertical walls for a height to width ratio less than

II.8.6.16 (continued)
0.8. It was shown that certain combinations of vertical and horizontal wall slots gave simultaneous zero lift and blockage interference. It was claimed that the discrepancy between theoretical and experimental results may be caused by non-homogeneous slots and viscous effects.

II.8.6.17 BALANCE BRIDGING TECHNIQUES ASSOCIATED WITH POWERED LOW SPEED WIND TUNNEL MODELS, J.A.Dougherty, AIAA paper 66-751, September 1966.
Techniques used to bridge a balance with air supply lines required for powered model testing were described. Looped hoses, coiled tubing and labyrinth seals, and a rubberized fabric diaphragm seal were used on various models. Each technique had limitations and no one technique was considered applicable to all tests.

II.8.6.18 SOME COMMENTS ON HIGH-LIFT TESTING IN WIND TUNNELS WITH PARTICULAR REFERENCE TO JET BLOWING MODELS, A. Anscombe and J. Williams, JRAE, S.Vol.61, 8/57.
This paper considered some of the problems of high lift wind tunnel testing. This was based on experience in RAE and NPL. Comments were made on model size, methods of getting air onboard models, and general test technique. The appendices discussed suitable locations of surface pressure points, suggestions for end-plate size for two-dimensional testing, formulas for calculating momentum coefficient and comments on accuracy of its measurement, and some design details of NAE blowing arrangements.

II.8.6.19 SOME CONSIDERATIONS IN WIND-TUNNEL TESTS OF V/STOL MODELS, H.H. Heyson, NASA TM-X-60772, September 29, 1967.
Minimum features which must be considered in applying wind tunnel wall interference corrections are: type of tunnel and proportions, effective wake skew angle, span of both lifting system and tail, configurations, model location, tail length and height, angle of attack, and pivot location. Auxiliary balances may be required to obtain the

II.8.6.19 (continued)
forces on each component of a complex lifting system. The boundary layer on the tunnel floor must be considered especially in ground effect testing. Recirculation will limit minimum test speed.

II.8.6.20 HYDRAULIC TANK FOR VISUALIZATION OF FLOWS AROUND STATIONARY VEHICLES, H. Werle and M. Gallon, La Recherche Aerospatiale, No.129 March/April 1969.
The new hydraulic tank recently put in operation at ONERA designed for investigating flows around stationary models with sinks, jets or moving parts.

The tests limited to flow visualization do not suffer in this rather wide tank from wall effects as in the water tunnel used for tests on models with a general relative motion.

This article described the new facility, presented its characteristics and possibilities and gave some test results which concern basic research as well as studies in applied aerodynamics.

II.8.6.21 A SURVEY OF V/STOL WIND TUNNEL WALL CORRECTIONS AND TEST TECHNIQUES, J.W. Olcott, Princeton University Report No. 725, December 1965.
A discussion of wind tunnel boundary corrections as they apply to V/STOL model testing was presented. Conventional wall correction theory was judged to be inadequate since it does not account for the presence of the wake and the total lift acting on the model. Correction theories that do consider the lift and wake of V/STOL models were judged to give satisfactory results, provided there is no wake distortion due to the tunnel walls. Kirkpatrick's theory was judged to be better than Heyson's because it included a more realistic jet wake shape.

II.8.6.22 COMMENTS ON V/STOL WIND TUNNEL DATA AT LOW FORWARD SPEEDS, W.H. Rae, Jr., and S. Shindo. In: Aerodynamics of Rotary wing and V/STOL aircraft. Cornell Aeronautical Laboratory and U.S. Army Aviation Materiel Laboratories, June 18-20, 1969. A systematic series of wind tunnel tests were made to study the problems of testing rotors in the transition speed range. Tests showed that there was a minimum speed test limit that was a function of the model size, downwash angle, and tunnel geometry.

II.8.6.23 TECHNIQUES FOR THE AERODYNAMIC TESTING OF V/STOL MODELS, W.J.G. Trebble Royal Aircraft Establishment RAE-TM-Aero-1080, July 1968.
Concentrated on techniques for testing lift-jet or lift-fan models including engine simulation. Need for adequate ground simulation was discussed. The need for special V/STOL wind tunnels and other facilities was commented on.

II.8.6.24 SHORT NOTE ON TUNNEL TECHNIQUES FOR TESTING STOL AIRCRAFT, A.J. Anscombe, J. Williams, NPL Paper presented to AGARD Wind Tunnel Panel meeting, Brussels, August 1956.

II.8.6.25 STATIC CALIBRATION OF AN EJECTOR UNIT FOR SIMULATION OF JET ENGINES IN SMALL-SCALE WIND TUNNEL MODELS, R.J. Margason and G.L. Gentry, NASA TN D 3867, March 1967.
Described static calibration of an ejector that was developed to simulate performance characteristics of a jet engine in small-scale wind tunnel models. The thrust could be repeated within 1 percent. Exhaust deflections up to 30° changed only the angle of the resultant thrust. Each ejector must be calibrated separately. Thrust from integrated pressures differed from balance measured thrust due to non-uniformity of exit velocity profile. Jet dynamic-pressure decay was nearly identical with the J-85 engine. Calibrations were, unfortunately, not done at forward speeds.

See also, II.8.3.1 and II.7.1.23.

II.8.7 General

II.8.7.1 THE VARIATIONS OF THE LANDING DISTANCE OF FIXED WING AIRCRAFT IN STOL OPERATIONS, P.A. Puvrez, 1st AIAA Annual Mtg, July 1964, Paper 64-345, Also in J. Aircraft July-August 1965.

II.8.7.2 SHORT TAKEOFF PLANES, VOLUME I, DDC-TAS-68-62 December 1968.
This bibliography is a compilation of unclassified and limited references on short takeoff planes. The references were selected from the DDC collection and cover a period from 1956 to February 1968. The references evaluate and analyze development, design, configurations, structure, handling qualities, performance and stability.

II.8.7.3 CAL/USAAVLABS SYMPOSIUM PROCEEDINGS. AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, Vol. IV, RECOMMENDED V/STOL AERODYNAMIC RESEARCH, June 22-24, 1966, Statler-Hilton Hotel, Buffalo, New York.
The following technical papers were presented: Aeronautical Research Requirements as determined from the X-19 and X-100 VTOL programs; Thoughts on Progress in Rotating-Wing Aerodynamics; Some Possibilities for Research on Stability and Control at STOL Flight Speeds; Aerodynamic Research - Improvements of the Tilt Wing Concept; Aerodynamic Problem Areas of V/STOL Aircraft and Recommended Research; A Discussion of Low Speed VTOL Aerodynamic Problems and Suggestions for Related Research; Areas of Fruitful Research and Development for Rotary Wing Aircraft; A Comeback of Low-Speed Aerodynamics Research; Required Aerodynamic Research for V/STOL Aircraft; Low Speed Aerodynamic Problems Associated with Helicopters and V/STOL Aircraft; Selected Research Results and Recommendations for Aerodynamic Research; Recommendations for Aerodynamic Research on Helicopters and V/STOL Aircraft.

II.8.7.4 CAL/USAAVLABS SYMPOSIUM PROCEEDINGS, AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, VOL. II, PROPULSION AND INTERFERENCE AERODYNAMICS, Held June 23, 1966, Statler-Hilton Hotel, Buffalo, New York.
Contents: Predicted and measured performance of two full-scale ducted propellers; aerothermal dynamic performance of a high bypass tip turbine cruise fan system; thrust deflection nozzles for VTOL aircraft; shrouded propeller research at Mississippi State University leading to application on the United States Army XV-11A; the lift, drag and stability of wings immersed in propeller slipstream; aerodynamic properties of airfoils in non-uniformly sheared flows; experimental interference effects; maximum lift coefficient for STOL aircraft: a critical review.

II.8.7.5 VTOL/STOL AIRCRAFT -- FIRST SUPPLEMENT 1961/62, H. Spintzyk, H. Klug (AGARD Bibliography).
The bibliography covers the literature published during the years 1961/62. It comprises all available publications related to problems in the field of V/STOL. The list of literature contains approximately 550 references. In Part 2, 'Classification,' the different fields of V/STOL are divided into eight main sections, the titles of which are: (1) General Studies, (2) Aerodynamic Problems, (3) Stability and Control in Hovering- and Transition-Flight, (4) Powerplants, (5) Test Techniques, (6) Atmosphere, (7) Operational Problems, and (8) Loads and Construction.

II.8.7.6 SYMPOSIUM ON VERTICAL/SHORT TAKEOFF AND LANDING AIRCRAFT, Part I, June 1960 AGARDograph.
One of the aims of the AGARD V/STOL symposium was to obtain an extensive survey of the state-of-the art of V/STOL aircraft. Volume I includes the following papers: capabilities and costs of various types of VTOL aircraft; evaluation of V/STOL aircraft; generalized weight and performance studies on V/STOL low-level strike fighter aircraft; operating economics of VTOL and STOL transport aircraft; parametric investigation of STOL

II.8.7.6 (continued)
aircraft; the STOL experimental aircraft DO29; aerodynamic aspects of some basic VTOL/STOL systems; engine and lifting unit configurations; and supersonic engines with references to short and vertical takeoff of single seat combat aircraft. Prepared comments and other contributions are also included.

II.8.7.7 REVIEW OF BASIC PRINCIPLES OF V/STOL AERODYNAMICS, R.E. Kuhn, TND733.
The principal factors that determine the performance of V/STOL aircraft are reviewed. The power requirements, fuel consumption, and the downwash dynamic pressure in hovering are all determined by, and increase with, the increase of the slipstream area loading. In transition, the wing span, the distribution of load on the span, and the power required in hovering determine the shape of the power-required curve, through this the engine-out safety and STOL performance are determined. In general, the same rules for designing good cruise performance into conventional airplanes apply to V/STOL configurations. Aerodynamic cleanliness is necessary to reduce the parasite power and a wing of appreciable span is needed to reduce the induced power.

II.8.7.8 PROCEEDINGS OF NATIONAL V/STOL AIRCRAFT SYMPOSIUM, Wright-Patterson AFB, Ohio, November 1965.
The technical papers presented are grouped into the following three categories: (1) V/STOL aircraft design, (2) V/STOL subsystem design, and (3) V/STOL aircraft testing and operation.

II.8.7.9 RECENT BASIC RESEARCH ON V/STOL AERODYNAMICS AT R.A.E., J. Williams, Zeitschrift fur Flugweissenchaften, Vol.14 No.6, June 1966, pp 257-276.
This paper described briefly V/STOL aerodynamic research carried out at the Royal Aircraft Establishment. Areas covered are jet-lift and fan-lift schemes, BLC, jet-flaps, ground effects, and tunnel-testing techniques.

II.8.7.10 FURTHER COMMENTS ON HIGH-LIFT TESTING IN WIND TUNNELS WITH PARTICULAR REFERENCE TO JET-BLOWING MODELS, S.F.J. Butler and J. Williams, The Aeronautical Quarterly, August 1960, pp 285-308.
This paper discussed some of the problems of wind-tunnel testing with high-lift jet blowing models. Comments were made on tunnel-wall interference, test rigs and methods of minimizing effects from airfeed to models, and on test and model design techniques.

II.8.7.11 SOME BRITISH RESEARCH ON THE BASIC AERODYNAMICS OF POWERED LIFT SYSTEMS, J. Williams, Journal of the Royal Aeronautical Society, Vol.64, July 1960, pp 413-437.
Paper discussed RAE and NPL research on the aerodynamics of direct jet lift, propeller lift jet flaps, and boundary layer control. Most of the work had been published elsewhere.

II.8.7.12 COMMENTS ON SOME RECENT BASIC RESEARCH ON V/STOL AERODYNAMICS, J. Williams RAE Tech Note No. Aero 2795, November 1961.
Research conducted at RAE into basic aerodynamics of V/STOL systems during the period 1959-1961 was reviewed. Comments were made on work in the areas of direct jet lift, propeller lift, jet flap, and boundary layer control.

II.8.7.13 AERODYNAMIC ASPECTS OF SOME BASIC VTOL/STOL SYSTEMS, Paper presented at the AGARD/V/STOL Symposium, Paris, June, 1960.
The paper considers the present state of knowledge on the aerodynamics of the following types of VTOL/STOL systems: direct jet lift (turbo-jet and turbo-fan), propeller lift (tilt wing and deflected slip-stream), jet flaps, boundary layer control (blowing and suction). The first two of these methods for providing adequate lift are relevant to both VTOL and STOL applications. The last two are mainly restricted to both VTOL and STOL applications. The last two are mainly restricted to STOL applications, or to improving the forward flight performance (transition, control, maximum speed) of VTOL

II.8.7.13 (continued)
aircraft. Some of the major aerodynamic problems which have been investigated recently or which need further study are discussed.