NASA Technical Memorandum 89066

Wind Tunnel Wall Interference in V/STOL and High Lift Testing

A Selected, Annotated Bibliography

Marie H. Tuttle, Raymond E. Mineck,
and Karen L. Cole

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Scientific and Technical
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INTRODUCTION

This bibliography lists 260 publications that may be of interest to persons involved in correcting aerodynamic data, from high lift or V/STOL (Vertical/Short Take-off and Landing) type configurations, for the interference arising from the wind tunnel test section walls. The term "walls" is used for the wind tunnel test section boundaries which may be open or closed on one or more sides. For the purpose of this bibliography, the term "high lift" is used in connection with testing at high angles of attack or at lift coefficients higher than could be obtained from a single element airfoil. These high lift coefficients may be generated mechanically by devices such as flaps, or aerodynamically by interaction of the free stream with the flow from a propulsive device. Aerodynamically generated high lift coefficients are usually associated with V/STOL concepts.

This bibliography attempts to provide references which may be useful in correcting high lift data from wind tunnel to free air conditions. High lift or V/STOL testing often involves the simulation of the effect of ground proximity. References have been included which deal with the simulation of ground effect, since this could be viewed as having interference from three tunnel walls. It should be noted that the references could also prove useful in designing tests from the standpoint of model size and ground effect simulation, or to determine the available testing envelope with consideration of the problem of flow breakdown.

This publication is one of a series of bibliographies dealing with wall interference. The reduction or elimination of wall interference through the use of adaptive walls is covered in NASA TM-87639 (August 1986). The general subject of wind tunnel wall interference is to be covered in a two part bibliography.

The arrangement of the citations is chronological by date of publication in the case of reports or books, and by date of presentation in the case of papers. Included are some documents of historical interest in the development of high lift testing techniques and wall interference correction methods.

Subject, corporate source, and author indices, by citation numbers, have been provided to assist the users. The subject index, especially, should be used only for quick reference since it is not intended to be complete. The appendix includes citations of some books and documents which may not deal directly with high lift or V/STOL wall interference, but include additional information which may be helpful. Documents cited in the appendix are identified by numbers having an "A" prefix, and are included in the indices.

In most cases, abstracts used are from the NASA announcement bulletins "Scientific and Technical Aerospace Reports" (STAR) and "International Aerospace Abstracts" (IAA). In some cases, authors' abstracts were used. License was taken to modify or shorten abstracts, using parts pertinent to the subject of the bibliography. If it is known that a paper has appeared in several forms, mention is made of this fact. Accession numbers, report numbers, and other identifying information is included in the citations in order to facilitate the filling of requests for specific items.

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ISSN - is an acronym for International Standard Serial Number, an internationally accepted code for the identification of serial publications; it is precise, concise, unique, and unambiguous.

ISBM - is an acronym for International Standard Book Number, a number which is given to every book or edition of a book before publication to identify the publisher, the title, the edition, and volume number.

BIBLIOGRAPHY

1 *Wood, R. McK.; and *Harris, R. G.: **Some Notes on the Theory of an Airscrew Working in a Wind Channel.** British, Advisory Committee for Aeronautics R&M No. 662 (Revised), Feb. 1920, 14 pp.

Langley Research Center library number 4101
91 (rev.)

The momentum theory of R. E. Froude leads to equations which require some modification when the airscrew is working in a tunnel of dimensions comparable with the diameter of the screws. Some correction to the speed of the air in a wind channel must be made to obtain the equivalent speed of advance of the airscrew in free air. Formula for the thrust-momentum relation, inflow-outflow ratio and contraction ratio of the slipstream are deduced. A method of correcting the speed of advance for the effect of channel constraint of flow is obtained based upon the momentum theory, which may probably be relied upon so long as the correction required is reasonably small.

*Royal Aircraft Establishment, Farnborough, Hampshire, U.K.

2 *Glauert, H.: **Wind Tunnel Interference on Wings, Bodies and Airscrews.** British ARC R&M 1566, 1933, 96 pp., 45 refs.

Langley Research Center library number 1105.5
89

Note: This report is a separate monograph and is not included in the bound volumes of early British reports.

A comprehensive survey of the subject of wind tunnel interference on wings, bodies and airscrews is given. The basis of the theoretical treatment of the subject is examined critically and the method of analyzing particular problems is explained in detail, but the reader is referred to the original papers for the more complex parts of the mathematical analysis. Experimental results are quoted to justify the theoretical formula or to derive empirical values to complete the theoretical analysis. The results required for the practical application of the correction formulae are given in suitable tables and figures, and a full list of references is appended to the report grouped according to the four main parts of the report and arranged chronologically in each group. (Pages 54-58 are of special interest.)

*Royal Aircraft Establishment, Farnborough, Hampshire, U.K.

3 *Recant, I. G.: **Wind-Tunnel Investigation of Ground Effect on Wings With Flaps.** NACA TN-705, May 1939, 17 pp., 14 figures.

Langley Research Center library number 1115.5
NACA 23012/21

An investigation was conducted in the N.A.C.A. 7- by 10-foot wind tunnel to determine the effect of ground proximity on the aerodynamic characteristics of wings equipped with high-lift devices. A rectangular and a tapered wing were tested without flaps, with a split flap, and with a slotted flap. The ground was represented by a flat plate, completely spanning the tunnel and extending a considerable distance ahead and back of the model. The position of the plate was varied from one-half to three chord lengths below the wing. The results are presented in the form of curves of absolute coefficients, showing the effects of the ground on each wing arrangement. The effect of the ground on lift, drag, and pitching moment is discussed. An appendix (pp. 14-15) gives equations for calculating tunnel-wall corrections to be applied to ground-effect tests conducted in rectangular tunnels when a plate is used to represent the ground. The tests indicated that the ground effect on wings with flaps is a marked decrease in drag, a decrease in diving moment, and a substantial reduction in maximum lift.

*National Advisory Committee for Aeronautics (NACA) Langley Field, Virginia, U.S.A.

4 *Mendelson, R. A.; and *Polhamus, J. F.: **Effect of the Tunnel-Wall Boundary Layer on Test Results of a Wing Protruding from a Tunnel Wall.** NACA TN-1244, 1947, 8 pp.

Two-dimensional span-loading tests were made of a two-foot-chord NACA 65_1-012 airfoil model in the 2.5-foot by 6-foot test section of the Langley stability tunnel to determine tunnel- wall boundary-layer effects. The tests indicated that a small loss (less than one percent of the load at the center) in average load may be expected. At the tunnel wall the load may be as much as 10 percent lower than that at the center of the tunnel, and large changes in the tunnel-wall boundary-layer thickness produce small changes in load. At low angles of attack the tunnel-wall boundary layer had little effect on the pitching moment. At high angles of attack, the average pitching moment for the wing may differ from the pitching moment at the center of the tunnel because of nonuniform stall.

*NACA, Langley Aeronautical Laboratory, Langley Field, Virginia, U.S.A.

5 *Pankhurst, R. C.; and *Pearcey, H. H.: **Camber Derivatives and Two-Dimensional Tunnel Interference at Maximum Lift.** British ARC CP 28, 1950, 5 pp.

Langley Research Center library number N-4974

This paper concerns the corrections due to lift effect in tunnel tests of an aerofoil in two-dimensional flow. The circulation around the aerofoil is usually represented by the bound vortex at the centre of pressure, the influence of the boundaries of the working section being deduced from the induced field of the appropriate system of images. The chordwise variation of the upwash (i.e., the transverse component of the induced velocity) gives rise to an effective curvature of flow, which produced an effective change of aerofoil camber (aerodynamic camber) combined with an effective change of incidence corresponding to the upwash at mid-chord. These are discussed separately and tables of several alternative forms for the corrections in a closed-throat tunnel are given.

*National Physical Laboratory, Teddington, Middlesex, U.K.

6 *Prouty, R. W.: **Wind Tunnel Wall Corrections for a Lifting Rotor in a Closed, Rectangular Test Section.** Univ. of Washington, ScM thesis, 1954, 55 pp.

Langley Research Center library number N-30809

A method has been developed for evaluating the wind tunnel wall corrections for a lifting rotor in a closed, rectangular test section. Use has been made of the concept of a doubly infinite series of image wakes surrounding the test section and consisting of vortex rings which induce a vertical velocity at the rotor. The magnitude of this induced velocity is derived as a function of the tunnel velocity, the rotor's induced velocity, and the test section and rotor dimensions. The induced velocity thus obtained may be used to correct the rotor angle of attack. An example has been worked out for a rotor in a test section which has a height twice the rotor radius and a width three times the radius. It is shown that for this case, the wind tunnel wall corrections for the rotor are very much smaller than for a corresponding wing. Model tests were made in a wind tunnel, but because of the inadequacy of both the equipment and the testing technique, the results neither prove nor disprove the theory.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

7 *Owen, J. B.; *Fail, R. A.; and *Eyre, R. C. W.: **Wind Tunnel Tests on a 6 Ft Diameter Helicopter Rotor.** British ARC CP 216, Tech. Note Aero 2378, May 1955, 33 pp.

Langley Research Center library number N-40507

Thrust, torque and flapping angle have been measured on a 6 ft diameter rotor over a range of blade angle, shaft inclination and tip speed ratio for comparison with the 12 ft diameter rotor previously tested in the 24 ft tunnel. In addition to tests in the 24 ft tunnel, the 6 ft diameter rotor was also tested in the No. 2 11.5 ft tunnel to investigate tunnel constraint. It was intended to test both the 6 ft diameter rotor and a 12 ft diameter rotor in the 24 ft tunnel in order to assess the reliability of model test in a wind tunnel. The intention was to obtain a method of tunnel corrections from the 6 ft rotor tests in the two tunnels, and then to compare the corrected results on the 6 ft. and 12 ft. rotors. The tests on the 6 ft. rotor in the 24 ft and 11.5 ft tunnels indicate that the usual tunnel constraint correction to incidence is satisfactory so far as thrust is concerned. Higher torques were measured in the smaller (closed) tunnel. This discrepancy is not removed by the usual constraint correction; this implies a redistribution of the induced velocity.

*Royal Aircraft Establishment, Farnborough, Hampshire, U.K.

8 *Anscombe, A.; and **Williams, J.: **Some Comments on High-Lift Testing in Wind Tunnels With Particular Reference to Jet-Blowing Models.** Journal of the Royal Aeronautical Society, vol. 61, pp. 529-540, Aug. 1957. Also: Rep. 63, AGARD, North Atlantic Treaty Organization (Brussels), Aug. 1956.

Langley Research Center library number N-46250

This paper considers some of the special problems of wind tunnel testing which arise in high-lift work. Discussion is confined to current experience in the R.A.E. and N.P.L. 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. The problem of wall interference is discussed.

*Royal Aircraft Establishment, Bedford, U.K.
**National Physical Laboratory, Teddington, U.K.

9 *Kuhn, R. E.; and *Draper, J. W.: **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°.** NACA Rep. 1263, 1956, 40 pp. (Supersedes NACA TN 3304.)

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 free-stream velocities from zero to the normal range of cruising flight. An appreciable increase in the angle of attack for maximum lift with increasing power is indicated. A modification of the method of Smelt and Davies for estimating the effects of slipstreams on the lift-curve slope is presented. Performance calculations for an assumed vertical take-off airplane are also included. Forces and moments on the wing-propeller combination and on the wing and propellers separately are included. A large nose-up pitching moment on the propeller itself was found at high angles of attack. The data presented have been corrected for the effect of the tunnel walls on the velocity in the tunnel and in the slipstream. The jet-boundary corrections were applied to the angle of attack and longitudinal force. Appendix A gives equations and method of determining the wall corrections.

*Langley Aeronautical Laboratory, Langley Field, Virginia, U.S.A.

10 *Curtis, J. T.: **A Study of the Interference of a Perforated-Wall Wind Tunnel Upon Propeller Performance.** Cornell Aeronautical Lab., Inc., AB-1040-W-4, July 1958, 55 pp.

Langley Research Center library number N-65545

Theoretical and experimental studies of the interference of a perforated-wall wind tunnel on a propeller tested therein are reported. It is shown that this interference is greater than that associated with a conventional wind tunnel and depends explicitly on the tunnel speed, the propeller size and thrust, and on the porosity of the boundary. The required correction factors approach smoothly the solid-wall values in the limit of vanishing porosity. It is also demonstrated that the velocity in the plane of the propeller close to the wall is a better approximation to the free-stream velocity than the tunnel speed but not so good as in the solid-wall case.

*Cornell Aeronautical Laboratories, Buffalo, NY, U.S.A.
Contract AF-33 (616)-3207

11 *Huggett, D. J.: **The Ground Effect on the Jet Flap in Two Dimensions.** The Aeronautical Quarterly, vol. 10, Feb. 1959, pp. 28-46.

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 of 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 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. The fact that there appears to be a maximum pressure lift coefficient, independent of the jet-deflection angle, which may be obtained at any ground position, is investigated. An attempt is made to provide a theoretical explanation of this on the basis of the critical condition of blockage underneath the aerofoil.

*The University, Southampton S09 5NH, Hampshire, U.K.

12 *Kuhn, R. E.; and *Naeseth, R. L.: **Tunnel-Wall Effects Associated With VTOL/STOL Model Testing.** Presented at the Interference Effects Meeting of the AGARD Fluid Dynamics Panel, Mar. 2-5, 1959, Rhode St. Genese, Belgium, AGARD Rep. 303, 31 pp., 6 refs.

N62-15912

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 by directing propeller slipstreams or jet exhausts downward at large angles to the free-stream direction. For many configurations the propellers or jet exhausts are arranged, as, for example, in the jet flap, to cover the entire span of the wing and thus to assist the wing 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 free-stream 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 free stream. Thus, the problem of tunnel-wall effects in 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.

NASA, Langley Research Center, Hampton, VA 23665-5225, U.S.A.

13 *Butler, S. F. J.; and *Williams, J.: **Further Comments on High-Lift Testing in Wind Tunnels with Particular Reference to Jet Blowing Models.** Presented at the Interference Effects Meeting of AGARD Fluid

Dynamics Panel, Rhode St. Genese, Belgium, Mar. 2-5, 1959. AGARD Rep. 304, 37 pp.

Langley Research Center library number N-79256X

For another form and abstract of this report see no. 18 in this bibliography.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

14 *Duquenne, R.; and *Werle, H.: **Effects of a Wall on a Wing With Blowing at the Trailing Edge.** (Effects de paroi sur une aile avec soufflage.) Presented at the Interference Effects Meeting of the AGARD Fluid Dynamics Panel, Rhode St. Genese, Belgium, Mar. 2-5, 1959, AGARD Rep. 305, 35 pp. In French.

N62-15889#

This report, relating to blowing at the trailing edge of a wing in the presence of a wall, consists of two parts. In the first part, the possibilities of calculating the potential flow are examined, and two examples are dealt with in which the profile and the jet are replaced by a line of velocity discontinuity and the inclination of the jet is not necessarily small. The calculation is performed by rheoelectrical analogy. The second part concerns tests making visible the flow of water at low velocities over a wing with a jet normal to the plane of the chord. Subject to the laws of similarity, these tests permit the mechanism of the flow and the effect of the principal parameters to be determined. The development of the stagnation point observed during these tests agrees well with the results of a simple calculation made in the first part.

*ONERA, BP 72, 92322 Chatillon Cedex, France

15 *de Jager, E. M.; and *van Speigel, E.: **Calculated Tunnel-Wall Corrections for Two-Dimensional High-Lift Wings.** Rept. MP. 181 of the National Aeronautical Research Institute (National Luchtvarrtlaboratorium, NLL), at Amsterdam, the Netherlands. Presented at the Joint STA-AGARD-Meeting at Marseilles, France, Sept. 1959. Also presented at the Boundary-Layer Research Meeting, AGARD Wind Tunnel and Model Testing Panel, London, Apr. 25-29, 1960, 23 pp.

N69-72714 or N69-76867

The aerodynamic research of wings with high-lift devices in wind tunnels requires the knowledge of the tunnel wall corrections. The investigation, described in this paper is divided in two parts: (i) The determination of the tunnel wall corrections due to large flap deflections, which has been performed by non-linearized theory. (ii) The evaluation of the corrections due to a jet which is blown over the flap. This problem is treated in linear approximation. Some preliminary results for the corrections of pressure, lift- and moment-coefficients are presented.

*National Aero- and Astronautical Research Institute, Amsterdam, The Netherlands

16 *Koenig, D. G.; *Greif, R. K.; and *Kelly, M. W.: **Full-Scale Wind-Tunnel Investigation of the Longitudinal Characteristics of a Tilting-Rotor Convertiplane.** NASA TN D-35, Dec. 1959, 39 pp.

Tests of a tilting-rotor convertiplane, designated the XV-3, were made to investigate both mechanical and aerodynamic aspects of this type of aircraft. Only the longitudinal aerodynamic characteristics are the subject of this report. Aircraft configuration variables were angle of attack, rotor-pylon angle, power, and longitudinal control. No wind-tunnel wall corrections were applied to the data used. For an estimation of these effects, the reader is referred to a reference where a method is outlined for computing the effects for the XV-3 type aircraft.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

17 *Ganzer, V. M.; and *Rae, W. H., Jr.: **An Experimental Investigation of the Effect of Wind Tunnel Walls on the Aerodynamic Performance of a Helicopter Rotor.** NASA TN D-415, May 1960, 35 pp.

The purpose of this test was to determine, experimentally, the range of advance ratio and balance angle in which wind tunnel wall corrections as developed for wings might be used for helicopter rotors. A three foot diameter, two bladed rotor was tested in the University of Washington 8 ft. by 12 ft. tunnel and in 3 by 4.5 ft. and 2.4 by 3.6 ft. cross section inserts within the main tunnel. Lift and drag coefficient data were corrected by standard wing type wall corrections using the full span of the wing area. Data from the three test section sizes were compared to determine at which blade angles and advance ratios the wind tunnel wall corrections gave satisfactory agreement. It was found that standard wind tunnel wall corrections gave satisfactory agreement in advance ratios above 0.10. At the advance of ratio of 0.10, reasonable agreement occurred at a blade angle of -3.9 deg., corresponding to lift coefficients of less than 0.5, but agreement at high blade angles was unsatisfactory.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

18 *Butler, S. F. J.; and Williams, J.: **Further Comments on High-Lift Testing in Wind-Tunnels With Particular Reference to Jet-Blowing Models.** Aeronautical Quarterly, vol. XI, pp. 285-308, Aug. 1960.

Note: For another form of this report see no. 13 in this bibliography.

This paper discusses some of the special problems of wind-tunnel testing which arise with high-lift jet-blowing models, supplementing earlier comments. Further detailed remarks are made about recent developments on tunnel-wall interference, test rigs and models, and on general test and model design techniques.

*Royal Aircraft Establishment, Farnborough, Hampshire, GU14 6TD, U.K.

19 *Heyson, H. H.: **Ground Effect for Lifting Rotors in Forward Flight.** NASA TN D-234, 14 pp., 1960.

A theoretical analysis indicates that, for rotors, ground effect decreases rapidly with increases in either height above the ground or forward speed. The decrease with height above the ground in forward flight is greater than that in hovering. The major part of the decrease in ground effect with forward speed occurs at speeds less than 1.5 times the hovering mean induced velocity. Consequently, the total induced velocity at the rotor center increases rather than decreases when a helicopter gathers speed at low height above the ground.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

20 *Heyson, H. H.: **Jet-Boundary Corrections for Lifting Rotors Centered in Rectangular Wind Tunnels.** NASA TR R-71, 1960, 62 pp.

A theoretical analysis provides numerical values of the correction factor. The results indicate that at high speeds the corrections are the same as those for a wing but that at low speeds, for the cases considered, there is a large tunnel-induced upwash at the rotor. Increasing the rotor size decreases the correction factors for wide wind tunnels but has little effect upon the correction factors in deep narrow wind tunnels. The corrections are equivalent to a wind-tunnel-induced rate of climb (or sink), and considerable care will be required in the application to very low speed flight conditions.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

21 *Heyson, H. H.: **Wind-Tunnel Wall Interference and Ground Effect for VTOL-STOL Aircraft.** Journal of the American Helicopter Society, vol. 6, no. 1, Jan. 1961, pp. 1-9.

A theoretical treatment of wind-tunnel wall interference and ground effect for VTOL-STOL aircraft is described. Improved correlation between experimental results from different wind tunnels is shown. The corrections are largely dependent upon the degree to which the wake is deflected downward. The horizontal interference velocities as well as the vertical interference is such that models, in general, must be smaller than those used in more conventional tests. Ground effect is equivalent, in general, to a free-air condition with an increased rate of sink and a decreased forward speed.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

22 *Heyson, H. H.: **Nomographic Solution of the Momentum Equation for VTOL-STOL Aircraft.** NASA TN D-814, Apr. 1961, 16 pp.

A general nomographic solution for the induced velocities and wake skew angle is presented for use with VTOL-STOL systems. VTOL-STOL aircraft are characterized in general by the fact that in some portion of their flight envelope the wake is sharply inclined to the free stream. Under such conditions, the usual small-angle assumptions used in determining the induced velocities, and consequently the power required, are no longer valid. The problem of estimating the induced velocities becomes of additional importance since the induced velocities combine with the forward velocity to determine the wake skew angle upon which wind-tunnel corrections and ground effect have been shown to depend. The wake skew angle can be read directly from the nomograph presented.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

23 *Payne, H. E., III: **Study of V/STOL Aerodynamic Static Test Facilities.** Princeton Univ. Rep. 545, May 1961, 28 pp.

Langley Research Center library number N-105.079

A study of the need for a new V/STOL aerodynamic test facility has been conducted. The results indicate that accurate, reliable low-speed VTOL transition data is urgently required. It is shown that existing wind tunnels are unable to provide this data. A large low-turbulence wind tunnel designed specifically to obtain VTOL transition test data is the best solution for future needs.

*Princeton Univ.; Princeton, NJ 08540, U.S.A.
Contract DA-44-177-TC-524

24 *Payne, H. E., III: **Application of Small-Scale Propeller Test Data to V/STOL Aircraft Design.** Princeton Univ. Rep. 503, Oct. 1961, 24 pp. and illus.

Langley Research Center library number N-106,398

Available experimental and analytical data concerning effects of propellers (and rotors) on V/STOL take-off and transition flight are compiled. The application of small scale propellers/rotors to full-scale propellers is demonstrated along with a description of the dependence of take off performance on blade Reynold's number and tip Mach number. Identical tests run on the Navy's Flying Wind Tunnel and in three different facilities as well as several experimental techniques incorporated are described. A brief analytical treatment indicating a direction for future work concerning corrections for wall interference on V/STOL tunnel testing is included.

*Princeton Univ., Princeton, NJ 08540, U.S.A.
Contract N-onr-185814

25 *Williams, J.; and *Butler, S. F. J.: **Experimental Methods for Testing High-Lift and Circulation Control Models.** In: Boundary Layer and Flow Control; *G. V. Lachmann, Editor, Pergamon Press, London, 1961, pages 390-423, 22 refs.

TL 574.B6L3, pp. 390-423

Section 2 (pages 392-398) is titled **Tunnel-Wall Interference**, and is subdivided into:

1. General Comments
2. Wake Blockage Corrections
3. Lift-Constraint Corrections for Jet-Flap Models
4. Jet Constraint Effects
5. Size Limitations for Jet-Flap Models

The problem of tunnel-wall interference discussed in Section 2 is a very involved and difficult one. Such interference is the primary factor limiting the model size relative to that of the tunnel working-section, particularly with circulation-control models, where the lift coefficients may be as high as 10. The corrections for high-lift models are inevitably larger than those arising in conventional tests on models of the same size, and the simple mathematical models formulated for the derivation of standard tunnel correction factors are much less representative of the physical model conditions, while novel types of interference arise, particularly with jet-blowing models. Experimental arrangements for force measurements on blowing and suction models are naturally more complex than those for conventional models.

*Royal Aircraft Establishment, Farnborough, Hampshire,
GU14 6TD, U.K.

26 *Maskell, E. C.: **The Interference on a Three-Dimensional Jet-Flap Wing in a Closed Wind Tunnel.** British ARC R&M 3219, 1961, 12 pp. (Supersedes RAE-Aero-2650 and ARC-21598.) Also: ARC Aerodynamic Research Including Heating, Airfoils, and Boundary Layer Studies, Vol. 1, 1971, N 73-24999, pp. 143-154.

N73-25005

The classical theory of wind-tunnel interference is extended to cover interference on the effectiveness of a full-span jet flap issuing from the trailing edge of a high aspect ratio unswept wing. It is shown that, for small constraint corrections ΔC_J and Δ_∞ 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 thrust coefficients. 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.

*Royal Aircraft Establishment, Farnborough, Hampshire,
GU14 6TD, U.K.

27 *Heyson, H. H.: **Tables of Interference Factors for Use in Wind-Tunnel and Ground Effect Calculations for VTOL-STOL Aircraft. Part 1: Wind Tunnels Having Width-Height Ratio of 2.0.** NASA TN-D-933, Jan. 1962, 209 pp. (Intended for use with NASA TR R-124, which is no. 29 in this bibliography.)

N62-10016

Part II: Wind Tunnels Having Width-Height Ratio of 1.5. NASA TN-D-934, 201 pp.

N62-10017

Part III: Wind Tunnels Having Width-Height Ratio of 1.0. NASA TN-D-935, 202 pp.

N62-10018

Part IV: Wind Tunnels Having Width-Height Ratio of 0.5. NASA TN D-936, 201 pp.

N62-10019

These tables were machine-calculated and are intended for use with the procedures of NASA Technical Report R-124. These tables are presented without comment.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

28 *Kirkpatrick, D. L. I.: **Wind-Tunnel Corrections for V/STOL Model Testing.** Univ. of Virginia, M.S. Thesis, Aug. 1962, 88 pp.

N70-72248

Classical wind-tunnel wall-interference theory assumes that the wake of a model generating lift may be represented by point doublets uniformly distributed along a line extending rearward from the model parallel to the free stream. For high lift models this representation is not realistic, because the wake of such a model is appreciably deflected from the direction of the free stream. The analysis presented in this thesis attempts to improve Heyson's assumed model of the flow field by assuming that the wake is curved due to its interaction with the free stream and that the doublet distribution along it is nonuniform. The greatest disadvantage of the present theory is its numerical complexity, and several suggestions are made for improvement.

*Univ. of Virginia, Charlottesville, VA 22901, U.S.A.

29 *Heyson, H. H.: **Linearized Theory of Wind-Tunnel Jet-Boundary Corrections and Ground Effect for VTOL-STOL Aircraft.** NASA TR R-124, 1962, 273 pp. 20 refs.

N63-10219

Interference factors are developed as a function of the degree to which the wake is deflected downward. At large wake deflections the interference may be much greater than indicated by classical theory. Methods are given for extending the present numerical results to tests involving multielement and finite-span models. The theory can be at least partially verified by means of available data. Tables of calculated interference factors are presented in NASA Technical Notes D-933, D-934, D-935, and D-936. These tables were machine calculated and are intended for use with the procedures of NASA Technical Report R-124. The tables are presented without comment.

*NASA Langley Research Center, Hampton, Virginia 23665-5225, U.S.A.

30 *Joppa, R. G.; and *Ganzer, V. M.: **An Aerodynamic Feasibility Study of Two-Test-Section Wind Tunnels for V/STOL Testing.** In: AIAA-Navy Aerodynamic Testing Conference (N64-17014), Washington, D.C., Mar. 9, 10, 1964, Proceedings, pp. 1-7.

A64-14522 or N64-17015

Outline of an analysis on the use of two-test-section wind tunnels for V/STOL testing. Aerodynamic testing of V/STOL vehicles from very low speeds through transition to cruising speeds requires a large test section for the low end of the speed range in order to minimize wind tunnel wall effects. One possible solution is the two-test-section tunnel in which a small high speed test section and a large low speed test section utilize the same drive equipment and return ducting. Such a facility has advantages in speed control and stability at low speeds, and in reasonable model size for adequate Reynolds number and ease of construction. To find the best geometry of the test section and contractions which will provide the proper flow field, a study based on thin airfoil theory is presented, in which the tunnel walls are represented by vortex rings and the test section flow fields are calculated. The velocity gradient and profile can be controlled by appropriate adjustments of the geometry of the wind tunnel walls.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

31 *Grunwald, K. J.; and the *Staff of the Powered-Lift Aerodynamics Section of NASA, Langley Research Center. **Wall Effects and Scale Effects in V/STOL Model Testing.** In: AIAA-Navy Aerodynamic Testing Conference, (N64-17014), Washington, D.C., Mar. 9, 10, 1964, Proceedings, pp. 8-16.

A64-14523

Note: For another form of this paper see NASA TM-X-51400, (N65-89052) 1964, 28 pp.

This paper reviews the present status of knowledge with regard to the limits of applicability of wind-tunnel data on V/STOL configurations, primarily with regard to wall effects and scale effects. The effects of the tunnel walls on the transition aerodynamics of a tilt-wing, a 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 presented and discussed. The effects of the walls on pitching moment as well as lift and drag are included. The applicability of Heyson's wall-effect theory is reviewed. Comparison of small model results with large model or full-scale flight-test results is made, where possible, to show where small-scale model data can or cannot be used to determine full-scale characteristics. Data from the VZ-2 configuration, XV5-A fan-in-wing configuration, and the Ames fan-in-fuselage configuration are used. The overlap of wall effects with scale effects in making such comparisons is discussed. A brief discussion of the problems of ground simulation is included.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

32 *Williams, J.; and Butler, S. F. J.: **Further Developments in Low-Speed Wind-Tunnel Techniques for V/STOL and High-Lift Model Testing.** In: AIAA-Navy Aerodynamic Testing Conference, (N64-17014) Washington, D.C., Mar. 9, 10, 1964, Proceedings, pp. 17-32.

N64-17017 or A64-14524

Note: For a later form of this paper see no. 35 in this bibliography.

This paper discusses 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.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14, 6TD, U.K.

33 *Lee, J. L.: **An Experimental Investigation of the Use of Test Section Inserts as a Device to Verify Theoretical Wall Corrections for a Lifting Rotor Centered in a Closed Rectangular Test Section.** University of Washington, M.S. Thesis, Aug. 20, 1964, 84 pp.

N67-86583

The results of an experimental investigation confirm that the use of test section inserts is satisfactory as a device to verify theoretical wall corrections for a lifting rotor centered in a rectangular test section. The standard wing corrections and Heyson's corrections are essentially equivalent for models centered in a rectangular test section for downwash angles up to approximately 12° (which corresponded to tip speed ratios from 0.30 through 0.15 for the two-bladed, three-foot-diameter rotor tested). Heyson's corrections more accurately correct the data than do the standard corrections for downwash angles of 15° through 51° (which corresponded to tip speed ratios from 0.10 through 0.05 for the model tested).

*Univ. of Washington, Seattle, WA 98195, U.S.A.

34 *Davenport, E. E.; and *Kuhn, R. E.: **Wind Tunnel-Wall Effects and Scale Effects on a VTOL Configuration with a Fan Mounted in the Fuselage.** NASA TN D-2560, Jan. 1965, 99 pp.

N65-13574#

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.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

35 *Williams, J.; and *Butler, S. F. J.: **Recent Developments in Low-Speed Wind-Tunnel Techniques for V/STOL and High Lift Model Testing.** Zeitschrift fur Flugwissenschaften, vol. 13, March 1965, pp. 73-89. In English.

A65-21162

Note: For an earlier form of this report and an abstract see no. 32 in this bibliography.

*Royal Aircraft Establishment, Farnborough, Hampshire
GU14 6TD, U.K.

36 *de Jager, E. M.; and *van de Vooren, A. I.: **Tunnel Wall Corrections for a Wing-Flap System Between Two Parallel Walls.** NLR-TR-W-7, June 1965, 26 pp.

N66-20653# or N67-86307

A method is presented for the calculation of the corrections due to the tunnel walls to be applied to the measured lift and moment of a two-dimensional wing flap between two parallel walls. The theory developed here is non-linearized since the angle of flap deflection may be large. Calculations have been performed for three values of the ratio of wing to flap chord, for three values of the ratio of wing chord to tunnel height, and for angles of flap deflection up to 75°.

*National Aerospace Laboratory, Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands

37 *Grunwald, K. J.: **Experimental Study of Wind-Tunnel Wall Effects and Wall Corrections for a General-Research V/STOL Tilt-Wing Model With Flap.** NASA TN D-2887, July 1965, 115 pp.

N65-28634#

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) were large, particularly for data taken in the 7- by 10-foot tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

38 *Hickey, D. H.; and *Cook, W. L.: **Correlation of Wind-Tunnel and Flight-Test Aerodynamic Data for Five V/STOL Aircraft.** AGARD-R-520, presented at the 27th Meeting of the AGARD Flight Mechanics' Panel held in Rome, Italy, Oct. 11-12, 1965, 30 pp.

N67-29536#

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 correction 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.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

39 *de Jager, E. M.: **Two-Dimensional Tunnel-Wall Corrections for a Wing With a Blown Flap Between Two Parallel Walls.** NLR (Netherlands) Rep. NLR-TR-W.8, Nov. 1965, 28 pp.

N67-86308

The aerodynamic research of wings with high lift devices in wind tunnels requires the knowledge of the tunnel wall corrections. The investigation described in this paper, is divided in two parts: (i) The determination of the tunnel wall corrections due to large flap deflections, which has been performed by nonlinearized theory. (ii) The evaluation of the corrections due to a jet which is blown over the flap. This problem is treated in linear approximation.

*National Aerospace Laboratory (NLR), Anthony Fokkerweg 2,
1059 CM Amsterdam, The Netherlands

40 *Olcott, J. W.: **A Survey of V/STOL Wind Tunnel Wall Corrections and Test Techniques,** Princeton Univ. Rep. 725, Dec. 1965, 169 pp., 29 refs.

AD-629004 N66-30290#

A discussion of wind tunnel boundary corrections as they apply to VTOL model testing is presented. Conventional wall correction theory is inadequate since it fails to account for both the presence of a highly developed wake and the total lift acting on the model. Correction theories that do consider the lift and wake characteristics of VTOL designs give satisfactory results provided there is no wake distortion due to the interference of tunnel walls. Both the Heyson and Kirkpatrick VTOL boundary correction theories are examined and their limitations discussed. A comparison of free air and tunnel results for a .165 scale North American Aviation Tilt Wing design and a free air study of an early Hamilton Standard XC 142 propeller model are discussed. The propeller data agreed with theoretically predicted values, but discrepancies, particularly in drag force, appeared when the North American Aviation airship data were compared with similar tunnel results. The exact cause of the differences was not determined. The importance of the VTOL model wake is substantiated. Minimum tunnel sizes necessary to avoid wake impingement and disturbance are presented.

*Princeton Univ., Princeton, NJ 08540, U.S.A.
Contract N-onr-1858(14)

41 *Templin, R. J.: **The Choice of Working Section Size and Shape for V/STOL Wind Tunnels.** National Research Council, Division of Mechanical Engineering and National Aeronautical Establishment, Ottawa, Canada. Quarterly Bulletin, no. 4, 1965, pp. 63-93.

A66-23657# or N66-21597#

This paper discusses the question of the required test section size and shape for V/STOL wind tunnels mainly from the standpoint of limiting the magnitude of the wall effects to an acceptable value, while permitting the use of powered models of practical size. It is concluded that the proposed 30 x 30-ft tunnel size is about the minimum required for adequate testing of complete V/STOL models throughout the significant transition speed range. At this size, elaborate corrections of the Heyson type must be applied up to the probable limit of accuracy of the theory. It is pointed out that the 30-ft tunnel will not reduce wall effects to negligible proportions for typical V/STOL models, except at speeds that are in the upper part of the transition speed range or beyond.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

42 *Rae, W. H., Jr.: **The Study of Operational Problems and Techniques in Wind Tunnel Testing of VTOL and STOL Vehicles. Progress Rep., 1 Oct. 1964 - 31 Mar. 1965.** PR-3, 3 pp. 1965.

AD-619538 N65-34538#

Work continued in the development of 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. A hub hinge assembly was built for the four bladed rotor, and a series of tests were made using this rotor and inserts. Although preliminary data analyses indicate that the basic insert may be too short, and that the rotor with this disk loading is too large for the insert size at tip speed ratios below 0.10, modifications are being made for another test program. Test results were encouraging because some of the limits of the rotor size for a given disk loading tunnel cross section area and tunnel length were beginning to be defined.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Contract DA-ARO(D)-31-124-G481

43 *Maskell, E. C.: **A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel.** (Supersedes RAE-AERO-2685; ARC-25730) British ARC-R&M-3400, 1965, 25 pp.

N66-12950#

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 is well supported by experiment and leads to the correction formula $\Delta q/q = \epsilon C_D S/C$ 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 factor ϵ is shown to range between a value a little greater than 5/2 for axisymmetric flow to a little less than unity for two-dimensional flow. But the variation from 5/2 is found to be small for aspect ratios in the range of 1 to 10. The theory is extended to stalled wings, and an appropriate technique for the correction of wind-tunnel data is evolved.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

44 *Joppa, R. G.: **Experimental and Theoretical Investigation of Wind Tunnel Geometry, Emphasizing Factors Pertinent to V/STOL Vehicles Testing.** Progress Rep. No. 2, Mar. 15 - Sept. 15, 1965. NASA CR-70331, Jan. 15, 1966, 26 pp.

N66-17086#

Discussions are presented of 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 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.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant NGR-48-002-010

45 *Heyson, H. H.; and *Grunwald, K. J.: **Wind-Tunnel Boundary Interference for V/STOL Testing.** In: NASA, Ames Research Center Conference on V/STOL and STOL Aircraft, NASA SP-116, (N66-24606), Apr. 4-5, 1966, pp. 409-434.

N66-24631#

The adequacy of current aerodynamic theory to predict the effects of the wind tunnel boundary interference on the data from specific models was experimentally investigated. In addition, some information is presented on the degree of relief from corrections which can be obtained by appropriate slotting and opening of the wind tunnel walls. The following conclusions were reached: Because of the large scale recirculation effects, there is a finite lower limit to the test speed at which reliable and correctable data can be obtained in closed wind tunnels. Although a zero-correction wind tunnel for V/STOL testing has not yet been achieved, it is shown that the use of suitably mixed wind tunnel boundaries can alleviate boundary effects on V/STOL data.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

46 *Turner, T. R.: **Endless-Belt Technique for Ground Simulation.** In: NASA, Ames Research Center Conference on V/STOL and STOL Aircraft, NASA-SP-116, (N66-24606), Apr. 4-5, 1966, pp. 435-446.

N66-24632#

The use of an endless-belt ground plane for ground simulation in wind-tunnel tests has been investigated. Results of the investigation presented herein indicate that the endless-belt ground plane correctly simulates the ground but that not all models require this technique of simulation. In general, those configurations in which the lift is carried primarily in discrete jets (tilting ducted and jet V/STOL) do not require the endless belt for ground simulation and those in which the lift is distributed over the span of the wing do require the endless-belt ground plane. However, the need is dependent upon the lift coefficient and height above the ground.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

47 *Cook, W. L.; and *Hickey, D. H.: **Comparison of Wind-Tunnel and Flight Test Aerodynamic Data in the Transition-Flight Speed Range for Five V/STOL Aircraft.** In NASA, Ames Research Center Conference on V/STOL and STOL Aircraft, NASA SP-116, (N66-24606), Apr. 4-5, 1966, pp. 435-446.

N66-24633#

Four aircraft and one large-scale model which represent the V/STOL spectrum from low-disk-loading rotocraft to high disk-loading lift-fan systems have been studied in a 40- by 80-foot wind tunnel. In general, the aircraft were tested in the tunnel near trimmed, level-flight conditions. The power required, angle of attack, and control positions for the appropriate flight conditions as measured in the wind tunnel, are compared with flight-test results. Agreement between wind-tunnel and flight test measurements was generally good when wind-tunnel wall corrections were omitted. The aircraft and wind-tunnel geometry is related to wind-tunnel model sizing parameters and a VTOL lift parameter in order to establish tentative sizing criteria for V/STOL wind-tunnel testing with small wall effects.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

48 *Rae, W. H., Jr.: **An Experimental Investigation of the Effect of Test Section Geometry on the Maximum Size Rotor That Can be Tested in a Closed Throat Wind Tunnel.** AIAA Aerodynamic Testing Conference, Los Angeles, Calif., Sept. 21-23, 1966, 12 pp., 7 refs.

AIAA Paper 66-736 A66-40626#

Note: For a later form of this paper see no. 54 in this bibliography.

This paper presents the results of a systematic series of wind tunnel tests that have determined the maximum size rotor that can be tested in closed throat wind tunnels, both as a function of the rotor downwash angle and as a function of tunnel geometry. If a particular value of downwash is exceeded, the flow through the wind tunnel is no longer similar to the flow that the rotor would encounter in free flight, but rather represents a flow similar to recirculation. 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 height to width ratios of W/H = 1.50, 1.00, 0.67, and 0.50. 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, although the problem is being actively studied.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

49 *Maskell, E.: **Bluff Bodies and High-Lift Systems, Chapter VII in AGARDograph 109, Subsonic Wind Tunnel Wall Corrections,** Oct. 1966, 29 refs.

N67-34612, pp. 437-463

The chapter consists of: (1) Introduction, (2) Blockage Effects on Bluff Bodies, (3) Lifting Wings With Separated Flow, and (4) V/STOL Configurations.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

50 *Heyson, H. M.: **Equations for the Application of Wind-Tunnel Wall Corrections to Pitching Moments Caused by the Tail of an Aircraft Model.** NASA TN D-3738, Nov. 1966, 20 pp.

N67-11814#

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 latter system appears preferable even though it may require tests with several tailplane settings. In any event, the use of a separate tail balance is recommended whenever the corrections are expected to be large.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

51 *Kroeger, R. A.; and **Martin, W. A.: **The Streamline Matching Technique for V/STOL Wind Tunnel Wall Corrections.** AIAA 5th Aerospace Sciences Meeting, Jan. 23-26, 1967, New York, N. Y., 9 pp.

AIAA Paper 67-183 A67-19439#

Description of 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 are first analytically calculated, and then wall modifications are made where necessary to provide adequate aerodynamic relief, such that relatively interference-free test data may be obtained. The analytical method and its important parameters are described, and the status of an experimental evaluation is discussed.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
**Northrop Corp., Northrop Norair, Hawthorne, CA 90250, U.S.A.
Contract AF40(600)-1200
Contracts 66-42-TS/OMD and 67-39-TS/OMD

52 *Halliday, A. S.; *Cox, D. K.; and *Gregory, N.: **An Experimental Investigation of Wind-Tunnel Constraint Effects on the Performance of Helicopter Rotors.** NPL-AERO-Note-1054; British ARC-28936, Mar. 22, 1967, 31 pp.

N68-29465#

Measurements were made on 3 ft., 4.5 ft. and 6 ft. (0.91 m, 1.37 m and 1.83 m) diameter rotors in a 9 ft. x 7 ft. (2.7 m x 2.1 m) tunnel. Corrections based on effective skew angle correlated the results satisfactorily at $\mu = 0.1$, and $\theta_o = 12°$. At lower blade settings, corrections did not reduce the spread of the data: at higher advance ratios, constraint was negligible. Confirmation on a rig with much less interference from the drive system is desirable.

*National Physical Lab., Teddington, Middlesex TW11 0LW, U.K.

53 *Heyson, H. H.: **Wind-Tunnel Wall Effects at Extreme Force Coefficients.** Presented at the New York Academy of Sciences International Congress on Subsonic Aeronautics, New York, N. Y., Apr. 3-6, 1967. In: New York Academy of Sciences, Annals, vol. 154, pp. 1074-1093, Nov. 1968, NASA TM X-59742, 38 pp., 37 refs.

N68-25433 or A69-15574

Study of wall constraints at extreme force coefficients, the magnitude of which in V/STOL testing has been shown experimentally to be large and to differ from the effects noted in conventional testing. A progress report on theoretical work conducted by NASA, the University of Washington, and the Boeing Company is presented. Some of the real effects encountered in wind-tunnel testing are also discussed. These include the requirements for moving belts in ground-effect testing, and the recirculation limits on minimum speed which have been discovered in tests at the University of Washington.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

54 *Rae, W. H., Jr.: **Limits on Minimum-Speed V/STOL Wind-Tunnel Tests.** Journal of Aircraft, vol. 4, no. 3, May - June 1967, pp. 249-254.

AIAA Paper 66-736

Note: For an earlier form of this paper and an abstract see no. 48 in this bibliography.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant DA-ARO(D)-31-124-G481

55 *Joppa, R. G.: **A Method of Calculating Wind Tunnel Interference Factors for Tunnels of Arbitrary Cross-Section.** NASA CR-845, July 1967, 32 pp.

N67-30923

A new method of calculating the wind tunnel wall induced interference factors has been developed. The tunnel walls are represented by a vortex lattice of strength sufficient to satisfy the boundary conditions at the wall. The vortex lattice is then used to calculate the interference velocities at any point in the wind tunnel. The resulting interference factors agree with the classical results that are available for square and circular tunnels. Calculations are also presented for a rectangular tunnel, with a V/STOL model, and they can be made to closely approximate a tunnel of any cross-section.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant NGR 48-002-010

56 *South, P.: **Measurements of the Influence of Mixed Boundaries on the Aerodynamic Characteristics of a V/STOL Wind Tunnel Model.** 1967, AGARD-CP-22, pp. 25-1 through 25-15, Sept. 1967.

N68-13151

The relatively large wall effects that occur in wind tunnel tests of V/STOL models require that either the correction must be accurately known, or that some method of reducing the wall effects is used. Measurements of the wall effects in an open and in a closed wind tunnel are compared with existing theory and a series of tests of working sections with mixed boundaries are described in an effort to reduce the wall effects. Lift, drag, pitching moment, propeller thrust, and flow angle in the region of the tailplane were measured for a twin propeller tilt wing aircraft model. For the completely open and completely closed working sections, the results are compared with the correction predicted by Heyson's method. The tests in the mixed boundary working sections show that it is possible to greatly reduce the effect upon angle of attack by using suitable working sections and that it is also possible to modify the dynamic pressure effects but that mixed boundaries are not as effective in reducing the latter effects.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

57 *Heyson, H. H.: **Some Considerations in Wind-Tunnel Tests of V/STOL Models.** Paper presented at Univ. of Tenn. Space Institute, Tullahoma, Tenn., Sept. 29, 1967. NASA TM X-60772, 60 pp.

N68-13016#

Considerable care is required in applying wall interference corrections to V/STOL data. The following items comprise a minimum list of features which should be considered: 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, pivot location, and center-of-gravity location. Auxiliary balances may be required to obtain the forces of each component in complex lifting systems. Some discrepancies may remain, largely because of the imperfect knowledge of the aerodynamics of many V/STOL configurations. The boundary layer on the tunnel floor requires careful consideration, particularly in ground-effect testing. Recirculation will limit the minimum speeds at which successful data can be obtained. Many questions, such as the effect of angular and velocity rates, remain to be answered for evaluating V/STOL testing techniques.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

58 *Turner, T. R.: **A Moving-Belt Ground Plane for Wind-Tunnel Ground Simulation and Results for Two Jet-Flap Configurations.** NASA TN D-4228, Nov. 1967, 39 pp.

N68-10060

A moving-belt ground plane designed to eliminate the ground boundary layer for tests in ground proximity has been installed in a 17-foot (5.18-meter) wind-tunnel test section at the Langley Research Center. The test section was calibrated with this moving belt installed, and the effects of ground proximity on the characteristics of a swept and an unswept full-span blowing-flap configuration have been investigated. The results indicate that the moving belt satisfactorily removes the boundary layer on the ground plane. The lift loss of models at small distances from the ground and high lifts is 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 indicate that the moving-belt ground plane is not needed for ratios of wing height (in spans) to lift coefficient greater than about 0.050, but is desirable for smaller ratios.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

59 Heyson, H. H.: **Tables of Interference Factors for Use in Correcting Data From VTOL Models in Wind Tunnels With 7 by 10 Proportions.** NASA SP-3039, 1967, 653 pp.

N67-22897#

Because of the widespread use of wind tunnels having 7 by 10 proportions, tables of interference factors are presented for VTOL models whose span is parallel to either the long or the short side of the wind tunnel. Instructions for the use of these values for semispan models are included. Factors for use in obtaining tail corrections of finite-span models are discussed along with longitudinal, lateral, and vertical distributions. The tables are presented directly from the computer outputs.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

60 *Shindo, S.; and *Rae, W. H., Jr.: **An Experimental Study of Alleviating the Limits on Minimum-Speed V/STOL Wind-Tunnel Tests.** Univ. of Washington, Rep. 68-1, AROD-4506-3-E, Jan. 1968, 27 pp.

AD-671041 N68-31127#

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 x 6 ft. insert with a 2 ft. diameter rigid rotor at about 7 psf disk loading. None of the strake configurations studied in the experiment completely eliminate the effect of flow breakdown. A further experimental investigation is desirable because of the increasing interest in testing V/STOL vehicles in the transition speed range.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant DA-ARO(D)-31-124-G481

61 *South, P.: **Research on Reduction of Wall Effects in Low Speed Wind Tunnels.** National Research Council of Canada, Division of Mechanical Engineering, National Aeronautical Establishment, Quarterly Bulletin, no. 1, 1968, pp. 57-77.

A68-40091#

Describes recent measurements of reduction of wall effects in a low-speed vertical wind tunnel. The object of the research program was to determine how reliable existing theoretical wall corrections were when applied to a twin-prop tilt-wing aircraft at a relatively large ratio of model span to tunnel width. A further object was to investigate possible mixed-boundary working-section configurations that might reduce the wall effects. The experimental results show that the very large wind tunnel appears to remain unchallenged as the tool for testing models of V/STOL aircraft. The results also show that tunnel walls may be designed to alleviate wall effects on high-lift models, but that the different types of mixed boundaries that were tried have definite limitations.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

62 *Joppa, R. G.: **Wall Interference Effects in Wind-Tunnel Testing of STOL Aircraft.** AIAA 3rd Aerodynamic Testing Conference, San Francisco, Calif., Apr. 8-10, 1968, 10 pp.

AIAA-68-399 A68-25372#

Note: For a later form of this paper see no. 72 in this bibliography.

A problem associated with the wind-tunnel testing of very slow flying aircraft is the correction of 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 induce 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 is presented in which the effects of the altered wake location are included, as well as the wall-induced velocities. Results are 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 are reduced to zero and many even change sign. It is concluded that, to calculate correctly the interference velocities affecting pitching moments, the effects of vortex wake relocation must be included.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant NGR-48-002-010

63 Hunter, G. S.: **V/STOL Push Requiring Tunnel Advances.** Aviation Week & Space Technology. July 8, 1968, pp. 39-43, 46, 51.

A critical need to understand aerodynamic transitions between vertical and horizontal flight forced major revisions in wind tunnel testing of short takeoff and landing aircraft. Specific needs for V/STOL testing has resulted in changes to some of the existing slow-speed tunnels, as well as generating construction of new facilities. These changes and new construction are discussed and described. A table of representative V/STOL wind tunnels is included which gives dimensions and operational information.

64 *Heyson, H. H.: **Some Considerations in Wind Tunnel Tests of V/STOL Models.** Presented at the Pennsylvania State University 'Aerodynamics of V/STOL Aircraft Seminar,' University Park, Pa., Aug. 25-30, 1968.

N68-33878#

Note: For an earlier presentation and an abstract see no. 57 in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

65 *Wright, R. H.: **Test Sections for Small Theoretical Wind-Tunnel-Boundary Interference on V/STOL Models.** NASA TR R-286, Aug. 1968, 85 pp.

N68-31592#

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 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; however, the variation of the interference with the slot width for widths somewhat greater than those needed for zero interference was found to be small. 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. A limited investigation of the lift interference in a test section with closed upper wall and slotted side and lower boundaries was made to obtain the theoretically indicated slot width required for zero lift interference at a center-mounted wing with the wake horizontal.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

66 *Lovell, D. A.: **Wall Corrections to Longitudinal Components Measured on Wind-Tunnel Models With Tails.** British ARC CP-1075, Aug. 1968, 33 pp. (Supersedes RAE-TR-68212 and ARC-30826).

N70-23493#

Calculations have been made of the magnitude of the wall corrections to pitching moment for two models (an airbus and a jet flap aircraft) with tails using two methods of correction and two stages of approximation for each method. It is found that the first stage of approximation is accurate enough for values of lift coefficient up to four. For higher values of lift coefficient, it is not worth using the second approximation as the theory of wind tunnel wall-interference is not sufficiently accurate in its predictions for flows with the large values of downwash inherent in high-lift systems such as lifting jets or rotors. The correction to lift calculated for the two models is shown to be non-negligible, and it is recommended that it is applied in tests where differences are to be taken between tail-on and tail-off tests.

*Royal Aircraft Establishment, Farnborough, Hampshire
GU14 6TD, U.K.

67 *Michel, P.: **Wall Effect on a Helicopter Rotor in a Closed Circular Tunnel: Incompressible Flow Around a Doublet Placed in a Closed Circular Tunnel.** Effet de paroi sur un rotor d'helicoptere en veine fermee de section circulaire: ecoulement incompressible autour d'un doublet place dans une veine fermee circulair, ONERA document no. 12/2751 GN, Nov. 1968, pp. 1-78, IXXVII. In French.

Note: For an English translation and an abstract see no. 86 in this bibliography.

*ONERA, BP 72, 92322 Chatillon Cedex, France

68 *South, P.: **Measurements of Flow Breakdown in Rectangular Wind Tunnel Working Sections.** NAE-LR-513; NRC-10616; Nov. 1968, 16 pp.

AD-684711 N69-29198#

The report describes an experimental investigation of the model lift coefficients required to cause flow breakdown in low speed wind tunnels having test section breadth-to-height ratios of 0.5, 1.0, and 2.0. A family of jet flap wing models was used in the investigation. The model height-to-span, the momentum area-to-tunnel area, and the model drag-to-lift ratios were varied. Flow breakdown is shown to be primarily a function of the drag-to-lift ratio and a lift coefficient based upon the measured dynamic pressure, measured lift, and the tunnel cross-sectional area beneath the model span.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

69 *Binion, T. W., Jr.; and *Lo, C. F.: **A V/STOL Wind Tunnel Wall Interference Study.** AIAA 7th Aerospace Sciences Meeting, New York, N. Y., Jan. 20-22, 1969, 10 pp.

AIAA Paper 69-171 A69-18203#

Note: For another form of this paper see no. 78 in this bibliography.

An integrated theoretical and experimental study of slotted wall tunnels is described. Theoretical calculations based on a modification of the point-matching method with equivalent homogeneous boundary conditions have been used to show the relationship between the lift- and blockage-interference factors and wall porosity. Experimental interference factors are obtained by comparing lift coefficient vs. angle of attack data obtained in a 30 x 45 in. tunnel with those from a 7 x 10 ft. tunnel. Theoretical results indicate that the lift interference for conventional models is insensitive to the porosity of the vertical walls for a height to width ratio less than 0.8. It is shown that certain combinations of vertical and horizontal wall slots give simultaneous zero lift and blockage interference. The discrepancy between theoretical and experimental results may be caused by nonhomogeneous slots and viscous effects.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract AF 40/600/-69-C-0001

70 *Heyson, H. H.: **Use of Superposition in Digital Computers to Obtain Wind-Tunnel Interference Factors for Arbitrary Configurations, With Particular Reference to V/STOL Models.** NASA TR R-302, Feb. 1969, 114 pp.

N69-19028#

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 distributions, sweep angle, tail height, may individually or collectively produce substantial effects on wall interference. Interference is particularly severe at the rear rotor of tandem systems; the maximum size of such systems for reasonable wall effects is discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

71 *Heyson, H. H.: **FORTRAN Programs for Calculating Wind-Tunnel Boundary Interference.** NASA TM X-1740, Feb. 1969, 74 pp.

N69-17818#

Boundary-interference programs, developed in NASA TR R-302, are presented without comment. These programs should be utilized only after careful consideration of the assumptions and procedures given in that report. A systematic computer procedure is developed for calculating the wind tunnel interference factors for arbitrary configurations from the interference calculations for a vanishingly small model. The method is not limited to any one tunnel configuration since it is necessary only to substitute a subroutine appropriate to the tunnel for that given herein. The underlying theory (subroutine DLTAS) in the present computer programs is directly applicable to models which produce large wake deflections, such as V/STOL models. These programs may also be used directly for more conventional testing at moderate lift coefficients by means of the few simple modifications. No sample calculations or check cases are provided.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

72 *Joppa, R. G.: **Wall Interference Effects in Wind-Tunnel Testing of STOL Aircraft.** Journal of Aircraft, vol. 6, no. 3, May - June, 1969, pp. 209-214.

A69-34022#

Note: For an earlier form and abstract of this paper see no. 62 in this bibliography.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant NGR-48-002-010

73 *Heyson, H. H.: **The Flow Throughout a Wind Tunnel Containing a Rotor With a Sharply Deflected Wake.** Presented at the Cornell Aeronautical Lab. and U.S. Army Aviation Material Labs. Symposium, 3rd, Aerodynamics of Rotary Wing and V/STOL Aircraft, held at Buffalo, N. Y., June 18-20, 1969. In: Proceedings, Vol. 2 - Wind Tunnel Testing, New Concepts in Rotor Control, (A69-35226), 1969, 45 pp.

A69-35228#

This paper presents an examination of the flowfield throughout a wind tunnel of a rotor with sharply deflected blades, using modified NASA TR R-124 and TR R-302 computer programs. The general nature of the computed flowfield is verified by flow studies. The predominant effect at low speed is a region of reversed flow in front of the wake near the floor. This region initiates large-scale vortices in the flow which are the apparent cause of the minimum-speed V/STOL testing limits.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

74 *Rae, W. R., Jr.; and *Shindo, S.: **Comments on V/STOL Wind Tunnel Data at Low Forward Speeds.** Presented at Cornell Aeronautical Lab. and U.S. Army Aviation Material Labs. Symposium, 3rd, Aerodynamics of Rotary Wing and V/STOL Aircraft, held at Buffalo, N.Y., June 18-20, 1969. In: Proceedings, Vol. 2 - Wind Tunnel Testing, New Concepts in Rotor Control, (A69-35226), 1969, 31 pp.

A69-35229#

Results are given of a systematic series of wind-tunnel tests that have been made to study the problems that are encountered in testing rotors in the transition speed range. The tests have shown that there is a minimum speed test limit that is a function of the model size, downwash angle, and tunnel geometry. The application of wind-tunnel wall corrections to data above the test limit is valid. However, below the test limit the flow in the tunnel resembles recirculation-type flow, and wall corrections will not correct for this type of flow.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

75 *Lazzeroni, F. A.; and *Carr, L. W.: **Problems Associated With Wind Tunnel Tests of High Disk Loading Systems at Low Forward Speeds.** Presented at Cornell Aeronautical Lab. and U.S. Army Aviation Material Labs. Symposium, 3rd, Aerodynamics of Rotary Wing and V/STOL Aircraft held at Buffalo, N. Y., June 18-20, 1969. In Proceedings, Vol. 2 - Wind Tunnel Testing, New Concepts in Rotor Control, (A69-35226), 1969, 28 pp.

A69-35230#

This is a study of mechanisms responsible for the flow breakdown phenomenon in wind tunnel tests of high disk loading systems. Various configurations of disk loading models and of models incorporating jet-flap airfoils were tested to investigate the effects of downwash distribution on the flow mechanisms associated with the phenomenon of flow breakdown. The ability to correct data by currently available methods was explored.

*U.S. Army Aeronautical Research Lab., Moffett Field, CA 94035, U.S.A.

76 *Heyson, H. H.: **Theoretical Study of the Use of Variable Geometry in the Design of Minimal-Correction V/STOL Wind Tunnels.** NASA TR R-318, Aug. 1969, 137 pp., 32 refs.

N70-14133#

Theory indicates that, if either the width-height ratio or the model height is properly scheduled, the vertical interference velocities at the lifting system can be reduced to zero in closed on bottom only tunnels. Reductions in interference at the tail, nonuniformity of interferences, and minimum speed for recirculation free testing can be obtained simultaneously; however, these reductions are much greater in the case of variable width ratio. Variable width-height ratio operation of a closed tunnel can reduce the interference at the lifting system by a factor of 2 or 3. This configuration, at low speeds, can reduce interference at the tail, nonuniformity of interference, and minimum speed for recirculation free testing to almost negligible values.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

77 *Heyson, H. H.: **Variable Geometry Wind Tunnels, Patent.** Issued Nov. 16, 1971, Files Oct. 20, 1969, 7 pp.

N72-22246

A variable geometry wind tunnel is described for testing aircraft models in subsonic tests representing the low speed phases of flight. The system provides for variation of the test section of the tunnel during a test and reduces the corrections needed in data obtained in subsonic wind tunnel tests. The system is computerized to attain optimum test conditions.

Official Gazette of the U.S. Patent Office

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

78 *Lo, C.-F.; and *Binion, T. W., Jr.: **A V/STOL Wind-Tunnel Wall Interference Study.** Journal of Aircraft, vol. 7, no. 1, Jan. - Feb., 1970, pp. 51-57.

AIAA Paper 69-171 A70-20407#

Note: For another form and an abstract of this paper see no. 69 in this bibliography.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 38389, U.S.A.
Contract F406000-69-C-0001-SA10

79 *van den Berg, B.: **Some Notes on Two-Dimensional High-Lift Tests in Wind Tunnels.** In: AGARD-LS-43-71, Assessment of Lift Augmentation Devices, (N71-20051), Feb. 1971. A Lecture Series held at von Karman Institute, Rhode-Saint-Genese, Belgium, Apr. 20-24, 1970, paper no. 5, 17 pp.

N71-20056#

Problems associated with two dimensional high lift tests are discussed in terms of the test setup in the wind tunnel, the design of the models, and the methods to determine the forces on the model. Tunnel wall interference effects are also discussed. These include the effect of the constraint which the tunnel walls impose on the flow as well as the danger of boundary layer separations on the tunnel walls. The necessity of boundary layer control at the model tunnel wall junctions is demonstrated.

*National Aerospace Laboratory, Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands

80 *Russell, C.: **Model Testing Requirements and Techniques for High-Lift Schemes: Three-Dimensional Aspects.** In: AGARD-LS-43-71, Assessment of Lift Augmentation Devices, (N71-20051), Feb. 1971. A Lecture Series held at von Karman Institute, Rhode-Saint-Genèse, Belgium, Apr. 20-24, 1970, paper no. 6, 22 pp.

N71-20057#

The subject of three-dimensional high lift model testing is dealt with from the point of view of the development of a specific full-size project. Various topics and problems are dealt with in approximately the order in which they would normally arise, from initial concept to data presentation. This includes wind tunnel wall corrections related to high lift testing.

*British Aircraft Corp., Warton, U.K.

81 *Mavriplis, F.: **Aerodynamic Research on High Lift Systems.** In: AGARD-LS-43-71, Assessment of Lift Augmentation Devices, (N71-20051), Feb. 1971. A Lecture Series held at von Karman Institute, Rhode-Saint-Genèse, Belgium, Apr. 20-24, 1970, paper no. 16, 13 pp.

N71-20067#

Aspects of two dimensional flow research on high lift systems are discussed. A theoretical method is described for calculating two dimensional potential flow about multi-element high lift airfoils. The method is based on the distribution of vorticity on the airfoil contour. A wall blowing technique is also described which was developed for testing effectively complex high lift models in the wind tunnel. It was used to study the effect of leading edge and trailing edge devices on the aerodynamic characteristics of a 17% and a 10% thick airfoil. Finally, comparisons of calculated and experimental data obtained on some of the complex configurations tested are presented to demonstrate the usefulness of the methods described.

*Canadair, Ltd., P. O. Box 6087, Station A, Montreal PQ H3G 3G9, Canada

82 *Tyler, R. A.; and *Williamson, R. G.: **Observations of Tunnel Flow Separation Induced by an Impinging Jet.** NRC 11617; LR-537; Apr. 1970, 22 pp.

N71-13082#

Single jets were directed towards, and perpendicular to, the boundary of the 10-ft. x 20-ft. test section of the NRC V/STOL Propulsion Tunnel. The position of tunnel flow separation, arising from jet impingement and forward penetration, was determined from wool tuft observations for various conditions of jet geometry, jet velocity, and tunnel speed, relevant to V/STOL models involving discrete jets. The results indicated the separation position to be a simple function of the product of effective mainstream/jet velocity ratio and nozzle height/diameter ratio. A value of this product greater than 1.5 was found to be necessary to ensure tunnel flow separation downstream of the jet nozzle. An approximate extension to inclined jets, based on limited test data, is included.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

83 *Lo, C.-F.: **Wind Tunnel Boundary Interference on a V/STOL Model.** AIAA 5th Aerodynamic Testing Conference, Tullahoma, Tenn., May 18-20, 1970.

AIAA Paper 70-575 A70-29894#

Note: For a later form of this paper see no. 93 in this bibliography.

The wind-tunnel boundary interference on a V/STOL model is calculated in a test section with solid vertical and slotted horizontal walls. The method in the theory is the image method in addition to Fourier transforms with an equivalent homogeneous boundary condition on the slotted wall. The value of slot opening for zero interference is found as a function of model wake angle. The axial variation of the upwash interference suggests that certain variable slot widths in the stream direction will give zero upwash interference along the length of the test section.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.

84 *Lo, C.-F.; and **Oliver, R. H.: **Subsonic Lift Interference in a Wind Tunnel With Perforated Walls.** Journal of Aircraft, vol. 7, no. 3, May - June 1970, pp. 281-283, 8 refs.

A70-30869#

This Note presents an analytical solution of the boundary interference for wind tunnels with perforated walls. The method used in the calculation is the point-matching method in conjunction with Fourier transforms, which has been used previously in the slotted-wall tunnel. The material contained in the Note concerns the results for lift interference only. The lift interference is calculated using a horseshoe vortex to represent the wing model.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
**Univ. of Tenn. Space Institute, Tullahoma, TN 37388, U.S.A.
Contract F40(600)-69-C-0001

85 *Heyson, H. H.: **Theoretical Study of Conditions Limiting V/STOL Testing in Wind Tunnels With Solid Floor.** NASA TN D-5819, June 1970, 329 pp.

N70-31863#

Under sufficiently large wake deflections, the forward portion of the wake is found to flow forward along the floor leading to a vortex pattern which results in Rae's limits. Although wind-tunnel data cannot normally be corrected successfully beyond these limits, it may be possible to obtain ground-effect data for conditions more severe than those implied by Rae.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

86 *Michel, P.: **Wall Effect on a Helicopter Rotor in a Closed Circular Tunnel: Incompressible Flow Around a Doublet Placed in a Closed Circular Tunnel.** Translation into English by Translation Consultants, Ltd., Arlington, Va.: Effet de paroi sur un rotor d'helicoptere en veine fermee de section circulaire: ecoulement incompressible autour d'un doublet place dans une veine fermee circulaire, Nov. 1968. NASA TT F-13155, July 1970, 98 pp.

N70-33808#

Note: For the original report, in French, see no. 67 in this bibliography.

A method of calculating the interaction of a cylindrical wall with a circular straight section with the flow from a doublet placed in any way in this wall is described. This method is designed to be used in testing helicopter rotors. Although capable of more general applications, the calculations developed have a very definite goal in mind; i.e., to be used as a basis for elaboration of a method of wall correction for testing helicopter rotors in the S1MA wind tunnel. Annexes contain descriptions of Euler, hypergeometric Gauss and modified Bessel functions, as well as reference citations.

*ONERA, BP 72, 92322 Chatillon Cedex, France
Contract for translation NASw-2038

87 *Lo, C.-F.: **Test Section for a V/STOL Wind Tunnel.** Journal of Aircraft, vol. 7, no. 4, July - Aug., 1970, pp. 380-382.

A70-36461#

A test section having solid vertical and slotted horizontal walls with equal porosity has been studied by the author. The value of slot opening which results in zero interference has been found as a function of model wake angle. However, since the proper value of slot opening is a function of wake angle, it seems that one more variable is needed to achieve a configuration yielding zero upwash interference for all wake angles. Hence, a test section with solid vertical walls has been chosen for the present study. This did result in a configuration which gives nearly zero interference at the model position of every wake angle. The interference distributions along the streamwise and spanwise directions were determined by this selected configuration.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract F-40600-69-C0001 S/A 10(70)

88 *Jenny, R.; and *Hani, B.: **Wind Tunnel Wall Effects for V/STOL Airplanes With Lift Jets.** International Council of the Aeronautical Sciences, Congress, 7th Rome, Italy, Sept. 14-18, 1970. ICAS Paper 70-54, 12 pp.

A70-44150#

Lifting an aeroplane by vertically directed jets can lead to severe aerodynamic problems such as lift loss, loss of stability, hot gas ingestion, etc. Extended wind-tunnel testing of such configurations is therefore necessary. Although well established wind-tunnel techniques are commonly used, there still remain unclear important questions. Until now, not much quantitative information has been available on the importance of wall effects. Wall interference effects have been computed by using known theoretical effects for a jet penetrating vertically into a uniform parallel flow. After minor modifications of one of the jet models, it was possible to study more complex jet arrangements. In some cases, calculated boundary corrections have been compared with measurements in the wind tunnel.

*Swiss Federal Aircraft Factory, Emmen, Switzerland

89 *Lo, C.-F. **Upwash Interference on a Jet Flap in Slotted Tunnels.** Journal of Aircraft, vol. 7, no. 6, Nov. - Dec., 1970, pp. 572-574.

A71-12690#

This paper presents the upwash interference on a two-dimensional jet-flap wing in a slotted-wall tunnel. The formulation is based on the small disturbance theory and the linearized model of the jet-flap wing as derived by Spence. An analytical solution is developed for the upwash interference and some numerical results are shown in the graphical form.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract F40600-69-0001 S/A 10(70)

90 *Heyson, H. H.: **Approximate Treatment of V/STOL Wall Interference for Closed Circular Tunnels.** NASA TN D-6127, Feb. 1971, 33 pp.

N71-17367#

An approximate treatment of V/STOL wall interference in a circular tunnel indicates that the interference factors at the model for this tunnel should be of the same order of magnitude as those presently available for a square tunnel of equal cross-sectional area. There is a greater degree of uncertainty with respect to the lateral and longitudinal distributions of interference; however, the available results for the square tunnel should be reasonably close to those of the circular tunnel provided that the model is relatively small in comparison with the test section.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

91 *Hackett, J. E.; and *Justice, J. L.: **Aerodynamics of a Fixed Ground Plane for a Powered STOL Wind-Tunnel Model.** Presented at the AIAA 6th Aerodynamic Testing Conference, Albuquerque, New Mex., Mar. 10-12, 1971.

AIAA Paper 71-266 A71-21992#

Note: For another form of this paper see no. 116 in this bibliography.

Theoretical and experimental studies on a 0.10-scale C-130 STOL model, over a fixed ground plane, allowed a close examination both of ground boundary-layer effects and other aspects of such high-lift testing. Excellent experimental/theoretical agreement is demonstrated for both ground pressures (vortex-lattice techniques) and boundary-layer characteristics. Detailed prediction of ground boundary layers is shown to be feasible. Other aspects discussed include flow-breakdown criteria, contraction-lag effects, strut-fairing interference, and circulation around finite-chord ground planes.

*Lockheed-Georgia Company, Marietta, GA 30060, U.S.A.

92 *Tyler, R. A.; and *Williamson, R. G.: **Tunnel Flow Breakdown from Inclined Jets.** NRC-LR-545; NRC-11994; Mar. 1971, 53 pp.

N71-33491#

Inclined single and paired jets were operated through the regime of floor vortex formation in the NRC 10-ft. x 20-ft. V/STOL propulsion tunnel. Observed floor stagnation positions are correlated in terms of a jet force coefficient. Limiting conditions for vortex formation (incipient stagnation) are derived for a wide range of jet inclination to the vertical. The observations are discussed in relation to limited existing information on tunnel flow breakdown with models involving vertical jets, and used to infer the influence of jet inclination on testing limits. Correlated results for the single jet and tandem jet-pair were generally similar, at the same total nozzle area.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

93 *Lo, C.-F.: **Wind Tunnel Boundary Interference on a V/STOL Model.** Journal of Aircraft, vol. 8, no. 3, Mar. 1971, pp. 162-167.

A71-22029

Note: For an earlier form of this paper and an abstract see no. 83 in this bibliography.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract AF40600-69-C-0001

94 *Peake, D. J.; **Yoshihara, H.; ***Zonars, D.; and **Carter, W.: **The Transonic Performance of Two-Dimensional, Jet-Flapped Aerofoils at High Reynolds Numbers.** Presented at the Fluid Dynamics Panel Specialists' Meeting, Facilities and Techniques for Aerodynamic Testing at Transonic Speeds and High Reynolds Numbers, Apr. 26-28, 1971, Goettingen. In: AGARD-CP-83-71, (N72-11854#), Aug. 1971, Paper no. 7, 39 pp.

N72-11861#

Extensive surface pressure and wake data were obtained as well as three-component balance data. The tunnel is equipped with perforated upper and lower walls of 20% porosity, so that the correction for blockage is small, but significant "open jet type" angle of attack reduction must be expectéd. The latter correction is obtained by determining the effective angle-of-attack required that will resolve the axial and normal forces, as measured by the balance, to yield the drag as determined from the wake survey. Since boundary layer-shock wave interaction plays a central role, it is vital that the interaction of the shock is primarily with the aerofoil boundary layer rather than with the tunnel sidewall boundary layers. To ensure this, distributed suction is applied on the sidewalls in the vicinity of the model. Adequacy of the sidewall suction is gauged by the parallelism of the surface flow directions as indicated by the streaking of oil dots applied on the aerofoil surface. Some non-uniformity in the wake flow was found, particularly at high lift, which may be ascribed to the wake traverse being taken downstream of the area of sidewall boundary layer control. The absence of sidewall suction had a significant effect upon the upper surface flow, with the shock being displaced upstream by about 15% of the chord. In the range of Reynolds number tested, R.N. = 11 to 40 x 10^6 and M = 0.7 - 1.0, there was a noticeable effect of Reynolds number on the drag divergence, and a significant effect on buffet onset.

*National Aeronautical Establishment, National Research Council, Ottawa, ON-K1A-OR6
**Convair Aerospace Division of General Dynamics, San Diego, CA 92138, U.S.A.
***Flight Dynamics Lab., U.S. Air Force Systems; Command, Wright-Patterson AFB, OH 45433, U.S.A.

95 *Ferri, A.: **Engine Airplane Interference and Wall Corrections in Transonic Wind Tunnel Tests.** Presented at the Fluid Dynamics Specialists' Meeting, Facilities and Techniques for Aerodynamic Testing at Transonic Speeds and High Reynolds Numbers, Goettingen, Apr. 26-28, 1971. In AGARD-CP-83-71, (N72-11854#), Aug. 1971, Paper no. 25, 6 pp.

N72-11877#

Recent developments of high performance airplanes have generated requirements for the prediction for the aerodynamic performance of airplane designs with extremely high accuracy. A critical review of present experimental methods led to the initiation of two separate efforts related to experiments in transonic flows: (1) determination of Reynolds number effects and the design of high Reynolds number wind tunnels; and (2) correct representation in wind tunnel tests of the interaction between engine flow and airplane characteristics, and wall interference at high lift.

*Director, Aerospace Laboratory, New York, Univ., Bronx NY 10453, U.S.A.

96 *Hackett, J. E.; and *Evans, M. R.: **Vortex Wakes Behind High-Lift Wings.** Journal of Aircraft, vol. 8, no. 5, pp. 334-340, May 1971.

A71-28033#

At high wing lift coefficients pertinent to STOL operation, the conventional neglect of vortex roll-up effects can lead to errors when calculating downwash at the tail plane and in the presence of ground or wind-tunnel walls. A classical unsteady treatment in the cross-flow plane, which calculates the roll-up of an initial spanwise row of point vortices, has been 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 are 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 are additional to conventional estimates involving only the appropriate image system. Wind tunnel constraint is discussed in Section IV.

*Lockheed-Georgia Company, Marietta, GA 30060, U.S.A.

97 *Binion, T. W.: **An Investigation of Several Slotted Wind Tunnel Wall Configurations With a High Disc Loading V/STOL Model. Final Rept, July 1, 1966 - June 30, 1970.** AEDC-TR-71-77, May 1971, 66 pp.

AD-723294 N71-31894#

The investigation reported herein is the experimental portion of a unified theoretical and experimental search for a slotted wind tunnel wall configuration with minimal interference for conventional and V/STOL models. It is shown that theory and experiment are in excellent agreement for the classical case provided an appropriate expression is used to relate the wall geometry to the boundary condition. Classical data correction equations are not appropriate for the V/STOL case, however. An additional term, not predicated by theory, is needed to account for changes in the jet wake. Geometric parameters which influence the wall interference quantities are indicated. Wall configurations are shown which will produce interference-free force data to a jet-to-free-stream velocity ratio of 4.5.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract F40600-71-C-0002

98 *Schaub, U. W.; and *Bassett, R. W.: **Low-Speed Aerodynamic Testing of VTOL Models: A Method for the Compensation of Wind-Tunnel Interference Effects.** Canadian Aeronautics and Space Journal, vol. 17, no. 6, June 1971, pp. 245-249.

This note describes a simple method that can be used as a first approximation to estimate "equivalent" free air approach velocity and angle of attack by use of measured control pressures with the model under test conditions (in an unknown air stream) and a prior calibration of the same pressure orifices in a known air stream. The proposed method is restricted to steady, inviscid low-speed flows and simple models for which the flow over the pressure orifices is basically similar for both the known and unknown stream conditions. If the pressure coefficient characteristics of the model are well defined, the unknown stream properties can be calculated uniquely from measured pressures regardless of whether flow blockage exists, or whether the test section is open, closed or vented. The accuracy of the approximation of determining the equivalent free air conditions depends entirely on the degree of flow similarity and is consequently expected to be much better for two-dimensional blockage effects on two-dimensional models than for three-dimensional blockage effects on three-dimensional models.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

99 *Grunwald, K. J.: **Experimental Investigation of the Use of Slotted Test-Section Walls to Reduce Wake Interference for High-Lift Testing.** NASA TN D-6292, June 1971, 73 pp.

N71-28008#

An investigation of various test-section configurations with slotted sidewalls, both slotted and open lower boundaries, and slotted and closed upper boundaries was carried out in a small wind tunnel. Additional variables investigated include slot width and slot length. A full-span, jet-flap model with an aspect ratio of 4.0 was tested in a large test section to obtain essentially free-air conditions and in a small test section with closed walls as well as slotted walls to obtain a measure of the effectiveness of the slotted-wall configurations in reducing the wall effects. The model was also fitted with a horizontal tail to obtain a measure of the wall effects and the effectiveness of the slotted walls in reducing these wall effects at the tail. The results of the investigation indicated that the use of test-section configurations with three and four slotted walls resulted in a large reduction in the wall-interference effects.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

100 *Ferri, A.: **Conclusions and Recommendations on Engine Airplane Interference and Wall Corrections in Wind Tunnel Tests.** In: Engine-Airplane Interference and Wall Corrections in Transonic Wind Tunnel Tests, AGARD-AR-36-71, (N71-36400#), Part I. Aug. 1971, 5 pp.

N71-36401#

Conclusions and recommendations are presented concerning the correct representation in wind tunnel tests of the interaction between engine flow and airplane characteristics, and wall interference at high lift. A review of experimental methods in use for determining engine-airplane interference in transonic tests includes the following topics: (1) inlet airplane interference, (2) engine thrust with airplane drag and nozzle characteristics, (3) exhaust flow and airplane interference, and (4) determination of interference of the engine flow on the aerodynamic characteristics of the complete configuration. It is concluded that all of the approaches have important unknowns and shortcomings: action is required by research groups to develop new techniques and improve existing ones.

*Director, Aerospace Laboratory, New York Univ., Bronx, NY 10453, U.S.A.

101 *Heyson, H. H.: **General Theory of Wall Interference for Static Stability Tests in Closed Rectangular Test Sections and in Ground Effect.** NASA TR R-364, Sept. 1971, 331 pp.

N71-35386#

A theory is developed which predicts the interference velocities and interference velocity gradients caused by the walls of the tunnel. Large wake deflections are allowed in both the lateral and vertical directions. The theory includes V/STOL and conventional wall-interference theories and ground effect as special cases. Symmetry and interchange relationships between the interference factors are developed and extensive numerical results are presented. Use of the interference factors to correct data depends upon the availability of detailed aerodynamic treatments in nonuniform flow of the model under test. In most tests the available aerodynamic treatments will be found either inadequate or too time consuming for rigorous routine correction of data relating to lateral-directional stability.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

102 *Tyler, R. A.; and *Williamson, R. G.: **Wind Tunnel Testing of V/STOL Engine Models: Some Observed Flow Interaction and Tunnel Effects.** In AGARD-CP-91-71, (N72-16685), Inlets and Nozzles for Aerospace Engineering, Sept. 1971, paper no. 8, 12 pp.

N72-16693#

The interpretation of force measurements on V/STOL-related models incorporating inflows and/or outflows is discussed in relation to investigations concerned mainly with the transition performance of lift fan configurations. These utilize balance-mounted, powered models of about 1000 hp in the closed test section of a 10 ft. x 20 ft. V/STOL propulsion tunnel. With models producing strong downwash, an overriding testing limit arises in closed wind tunnels from the formation of a stable floor vortex system due to the interaction of stagnating model flow with the mainstream. An experimental study of this effect as it relates to downward directed jets is described. Vortex formation limits are correlated in terms of a jet force coefficient for a wide range of jet inclinations to the vertical, and for both single and paired jets. Interference velocity measurements, with limited data from the main program and other sources, are used to deduce corresponding tunnel flow breakdown limits. These testing limits are shown to be sensitive to model characteristics.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

103 *Heyson, H. H.: **Rapid Estimation of Wind-Tunnel Corrections With Application to Wind-Tunnel and Model Design.** NASA TN D-6416, Sept. 1971, 369 pp., 37 refs.

N71-36675#

A chart method is developed for the rapid estimation of wind-tunnel interference in closed and closed-on-bottom-only tunnels. In addition, testing-limit charts, based on varying degrees of correction, are developed. Applications of these results indicate very powerful effects of wing sweep and the degree of correction on the usable testing range of wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

104 *Schaub, U. W.; and *Bassett, R. W.: **Flow Distortion and Performance Measurements on a 12 Inch Fan-in-Wing Model for a Range of Forward Speeds and Angle of Attack Settings.** In: Quarterly Bulletin of the Division of Mechanical Engineering and the National Aeronautical Establishment, DME/NAE-1972(2), (N72-33964), June 30, 1972, pp. 15-32. Also in AGARD-CP-91-71 (N72-16685), Inlets and Nozzles for Aerospace Engineering, Dec. 1971, 13 pp.

N72-33966#

The performance of a typical fan-in-wing model was examined under representative transition conditions. The model, comprising a 12 in. diameter fan buried in a N.A.C.A. 0015 section wing with a constant chord of 40 in., was tested at various angles of attack and air speeds in the closed working section of a propulsion wind tunnel. Tunnel interference corrections were estimated. Typical corrections were indicated for the whole testing range which became limited at very low crossflow ratios as a result of uncertainty in the correction in angle of attack. Flow distortion, due to crossflow, occurred in both the inlet and exit planes. In the crossflow ratio range zero to 0.27, inflow distortion was observed to be velocity distortion at essentially constant total pressure, whereas outflow distortion appeared to be a distortion of the exit plane static pressure field. The fan thrust was seen to fall off with crossflow ratios greater than 0.2 and appeared to be a direct result of increasing distortion. However, it seems to be insensitive to relatively large changes in angle of attack. Input power measurements indicated little dependence of approach air speed or angle of attack.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

105 *Maskell, E. C.: **The Interference on a Three Dimensional Jet Flap Wing in a Closed Wind Tunnel.** In: ARC Aerodynamic Research, Including Heating, Airfoils, and Boundary Layer Studies, Vol. 1, 1971, (N73-24999), pp. 143-154. Also: Previously issued as British ARC R/M-3219; RAE-TN-Aero-2650; ARC-21598.

N73-25005

The theory of wind-tunnel interference is extended to cover interference on the effectiveness of a full-span jet flap issuing from the trailing edge of a high aspect ratio unswept wing. It is shown that, for small constraint, corrections ΔC_j 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 thrust coefficients. 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.

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

106 *Vayssaire, J.-C.: **Blockage Corrections in Wind Tunnel Tests of.. Effects of Take-off.** (Correction de Blocage dans les essais en soufflerie effets des decollements.) In: Fluid Dynamics of Aircraft Stalling, AGARD-CP-102 (N73-14998), held in Lisbon, April 25-28, 1972, 22 pp. In French.

N73-15006#

The application of blockage corrections to wind tunnel test measurements made on aircraft models is discussed. The procedure corrects the velocity to infinity upstream and restores to the wall-affected aerodynamic coefficients the values which are fairly equivalent to those obtained in the model placed in an unlimited fluid stream. The corrective blockage terms which modify the reference dynamic pressure are analyzed. The terms are affected by volume, wake, and separations. Each of them is usable in incompressible, compressible, two dimensional, and three dimensional flows on whole or half models.

*Avions Marcel Dassault-Breguet Aviation, 92210 Saint-Cloud, France

107 *Tyler, R. A.; and *Williamson, R. G.: **Experience With the NRC 10 ft. x 20 ft. V/STOL Propulsion Tunnel - Some Practical Aspects of V/STOL Engine Model Testing.** Presented at the Canadian Aeronautics and Space Institute Annual General Meeting held in Toronto, Canada, May 18, 1972. Rep. no. TR LTR-GD-13, and reprinted as DME/NAE-1973(2), 32 pp., 21 refs.

N75-10107#

Note: For other forms of this paper see nos. 109 and 127 in this bibliography.

Experience in the operation and use of the NRC 10 ft. x 20 ft. V/STOL propulsion tunnel is reviewed. This research facility, designed specifically for the investigation of problems relating to V/STOL engine systems, was first operated in December 1962. Representative experimental programs carried out in the tunnel since that time are used to illustrate general problem areas associated with the testing of high powered models. Wall constraint effects and model testing limits as well as tunnel flow breakdown are discussed.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

108 *Kroeger, R. A.: **Wind Tunnel Design for Testing V/STOL Aircraft in Transition Flight. Final Report,** ARO-OMD-TR-72-102; AEDC-TR-72-119; Sept. 1972, 103 pp.

AD-749154 N73-13278#

Wind tunnels have afforded the best potential for studying regions of aerodynamic uniqueness of V/STOL aircraft, but they have been of limited value because of the magnitude of the flow interference they introduce. A new wind tunnel concept is described for covering the spectrum of transition testing from hover throughout wing sustained flight. The wall interference corrections are physically produced by the structure of the wall. A small scale tunnel was designed, constructed, and tested employing this concept. Data from a small rotor model were obtained in the new tunnel and a large conventional one as a basis for comparative evaluation.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract F40600-71-C-0002

109 *Tyler, R. A.; and *Williamson, R. G.: **Experience With the NRC 10 ft. x 20 ft. V/STOL Propulsion Tunnel - Some Practical Aspects of V/STOL Engine Model Testing.** In: Canadian Aeronautics and Space Journal, vol. 18, Sept. 1972, pp. 191-199, 21 refs.

A72-44247#

Note: For other forms and an abstract of this paper see nos. 107 and 127 in this bibliography.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

110 *Rae, W. H., Jr.: **Some Comments on V/STOL Wind Tunnel Testing in the Transition Flight Region.** In: Status of Testing and Modeling Techniques for V/STOL Aircraft; Proceedings of the Mideast Region Symposium, Essington, Pa., Oct. 26-28, 1972, (A74-22451), Philadelphia, Pa., Boeing Vertol Co., 1973, 13 pp.

A74-22477

Flow breakdown and flow distortion are discussed as the two limitations to wind tunnel testing of V/STOL models at speeds within or near the transition region. It is shown that a very large wind tunnel would be most useful for research into basic aerodynamic phenomena associated with V/STOL aircraft. The large tunnel will not be able to meet the requirements of all the desired testing of V/STOL models, and smaller existing tunnels will continue to be used. There is need for more work, both experimental and theoretical, to bring about a more correct use of the smaller wind tunnels. The large tunnel would be a most useful tool in this work.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
DA-ARO-(D)-31-124-G1144
NGR-48-002-035

111 *Hackett, J. E.; and *Praytor, E. B.: **Ground Effect for V/STOL Aircraft Configurations and Its Simulation in the Wind Tunnel.** Part 1: **Introduction and Theoretical Studies,** NASA, CR-114495, 1972, 50 pp.

N73-12283#

Theoretical studies are made of three dimensional turbulent boundary layer behavior on fixed grounds and on moving grounds of the type used in wind tunnel tests. It is shown that for several widely-varying STOL configurations, the ground static pressure distributions possess a remarkable degree of fore-aft symmetry about the center of lift. At low Reynolds number, corresponding to small-tunnel testing, the boundary layer displacement surface reflected to a large degree the symmetry of the pressure distribution. For this reason, induced incidence at the model is small for unseparated ground flow. At high Reynolds number, the displacement thickness decreases aft of the static pressure maximum is noticeably more rapid than the corresponding rise. This is attributed to trailing-vortex-induced spanwise pumping within the boundary layer.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.
Contract NAS2-6690

112 *Hackett, J. E.; *Boles, R. A.; and *Praytor, E. B.: **Ground Effect for V/STOL Aircraft Configurations and Its Simulation in the Wind Tunnel. Part 2: Experimental Studies,** NASA CR-114496, 1972, 76 pp.

N73-12284#

Wind tunnel tests on a finite, knee-blowing-flapped wing and on a direct jet lift configuration were performed in a 30 x 42 inch wind tunnel. The objective of these tests were, in experimental order: (1) to obtain definitive fixed-versus-moving ground comparisons on a powered, high-lift finite wing and on a lifting jet configuration as a function of model height and lift, (2) to understand the flow mechanism which lead to observed differences between moving and fixed-ground results, (3) to discover whether the above effects of a moving ground plane can be simulated by tangential-blowing boundary layer control at the wind tunnel floor, and (4) to check the form and the numerical constants for the wall jet blowing equation derived theoretically in Part 1 of this report. This relates wall jet blowing quantities to model lift coefficient.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.
Contract NAS2-6690

113 *Joppa, R. G.: **Wind Tunnel Interference Factors for High-Lift Wings in Closed Wind Tunnels.** Ph.D. Thesis- Princeton Univ., NASA CR-2191, Feb. 1973, 126 pp.

N73-19269#

Note: This thesis is also available by Order No. 72-29794 from University Microfilms.

A problem associated with the wind tunnel testing of very slow flying aircraft is the correction of observed pitching moments to free air conditions. The most significant effects of such corrections are to be found at moderate downwash angles typical of the landing approach. The wind tunnel walls induce interference velocities at the tail 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. The effect of the relocated vortex and the walls is to cause important changes in the measured pitching moments in the wind tunnel.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Contract NGL-48-002-010

114 Albrecht, C. O.: **Factors in the Design and Fabrication of Powered Dynamically Similar V/STOL Wind Tunnel Models (Appendix 1).** In: AGARD Helicopter Aerodynamics and Dynamics, (N73-22948), Mar. 1973, 24 pp.

N73-22956

The factors involved in the design of a wind tunnel for testing V/STOL aircraft models are discussed. Mach-scaled rotor systems are analyzed to show development and construction. A review of Mach-scaling and Froude-scaling is included to show the relative advantages of each method. Techniques for constructing the models are illustrated. The construction of the test stands and specialized test equipment is explained.

*Boeing Helicopters, Boeing Center, P. O. Box 16858, Philadelphia, PA 19142, U.S.A.

115 *Harris, F. D.: **Aerodynamic and Dynamic Rotary Wing Model Testing in Wind Tunnels and Other Facilities.** In: AGARD Helicopter Aerodynamics and Dynamics, Mar. 1973, (N73-22948), 62 pp.

N73-22955

Procedures for testing models of rotary wing aircraft in wind tunnels are discussed. The test objectives involved in rotary wing tunnel tests are described. The characteristics of various testing facilities are analyzed and compared. Methods for obtaining and reducing wind tunnel data are presented. Cost considerations for models and test facilities are analyzed to provide basis for decision on construction and modification. Examples of typical wind tunnel tests conducted with rotary wing models are included.

*Boeing Helicopters, Boeing Center, P. O. Box 16858, Philadelphia, PA 19142, U.S.A.

116 *Hackett, J. E.; and *Justice, J. L.: **Aerodynamics of a Fixed Ground Plane for a Powered STOL Wind-Tunnel Model.** Journal of Aircraft, vol. 10, Mar. 1973, pp. 137-142.

Note: For an earlier form of this paper and an abstract see no. 91 in this bibliography.

*Lockheed-Georgia Company, Marietta, GA 30060, U.S.A.

117 *de Vos, D. M.: **Low Speed Wind Tunnel Measurements on a Two-Dimensional Flapped Wing Model Using Tunnel Wall Boundary Layer Control at the Wing-Wall Junctions.** NLR-TR-70050-U, Apr. 9, 1973, 58 pp.

N74-33440#

An investigation on a two-dimensional wing model with a double-slotted trailing edge flap is described where tunnel wall boundary layer control by blowing was applied to prevent premature flow separations at the junctions between the model and the tunnel walls. From the results it is concluded that tunnel wall boundary layer control at the wall junctions is necessary to obtain useful results from two-dimensional high-lift tests in wind-tunnels. It is shown that a relatively simple system of compressed air blowing slots in the tunnel walls gives a sufficient approximation of the desired two-dimensional flow pattern. The blowing system has already been applied on a routine basis to wing sections with trailing edge and also leading edge high-lift devices.

*National Aerospace Laboratory, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

118 *Wickens, R.; *South, P.; *Rangi, R. S.; and *Henshaw, D.: **Experimental Developments in V/STOL Wind Tunnel Testing at the National Aeronautical Establishment.** Canadian Aeronautics and Space Journal, vol. 19, Apr. 1973, pp. 145-154.

A73-36774#

Review of some developments in a low-speed wind tunnel that are related to the measurement of aerodynamic characteristics of high-lift systems. This includes work on moving belt ground boards, flow breakdown, drag measurements, and a simple jet engine simulator. The phenomenon of flow breakdown has been investigated with a normal floor, as well as a moving ground, and a simple criterion has been discovered that allows the prediction of this instability for three-dimensional models. An experimental research program has been undertaken on a small scale, to determine the size of moving belt ground boards that would be suitable for use in a 30 x 30 ft. wind tunnel. A jet flap model was used to simulate a powered lift system, and the effects of belt length and speed and model/tunnel configuration upon ground effect and flow breakdown limits were observed.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

119 *Carbonaro, M.: **Review of Some Programs Related to the Design and Operation of Low Speed Wind Tunnels for V/STOL Testing.** In: AGARD Rep. no. 601, Problems in Wind Tunnel Testing Techniques, (N73-26239), Apr. 1973, Paper no. 1, 24 pp., 58 refs.

N73-26240

Note: For an Addendum to this paper and an Errata see no. 131 in this bibliography.

A review is made of a number of operational problems associated with the wind tunnel testing of V/STOL aircraft including helicopters. The following subjects are discussed: (1) wall constraints, (2) use of ventilated walls, (3) testing for ground effect, and (4) flow disturbances in the tunnel circuit. Mathematical models are developed to clarify the theoretical aspects of wind tunnel operation.

*von Karman Institute for Fluid Dynamics, Chaussée de Waterloo 72, B-1640 Rhode-Saint-Genèse, Belgium

120 *Simons, T. A.; and **Derschmidt, H.: **Wind Tunnel Requirements for Helicopters.** In: AGARD Rept. no. 601, Problems in Wind Tunnel Testing Techniques, (N73-26239), Apr. 1973, paper no. 7, 10 pp., 21 refs.

N73-26246#

The sizes of model which are most suited to various aspects of wind tunnel tests of helicopters are defined. The scaling laws and associated constructional problems of small scale rotor systems are discussed. Tunnel sizes are suggested for various ranges of model size based on a consideration of interference effects.

*Westland Helicopters, Ltd., Yeovil Somerset, BA20 2YB, U.K.
**Helicopter Division, MBB, Ottobrun/Munchen, Germany

121 *Mokry, M.: **Calculation of the Flow Past Multi-Component Airfoils in Perforated Wind Tunnels.** Canadian Congress of Applied Mechanics, 4th Montreal, Canada, May 28 - June 1, 1973. CASI Transactions, vol. 7, March 1974, pp. 19-24.

A75-15194#

The method of incompressible flow calculation by Hess and Smith is extended to flows about two-dimensional airfoils located inside a wind tunnel with perforated walls. Contour distributions of sources and vortices, used in the free air calculation, are replaced by distributions of influence functions, whose analytic solutions are given in a domain between two parallel perforated walls. Application of the airfoil boundary condition leads to a Fredholm integral equation of the second kind. The solution is applicable to multicomponent airfoils of arbitrary shape and location between the walls. Computations for two test cases are presented to demonstrate the versatility and accuracy of the method.

*National Research Council, Ottawa, Ontario, K1A OR6, Canada

122 *Sears, W. R.: **Self-Correcting Wind Tunnels.** CALSPAN-RK-5070-A-2, July 1973, 48 pp.

AD 764 957 N73-32161#

Note: For a later form of this report see no. 129 in this bibliography.

The familiar technique of accounting for wind-tunnel boundary effects by correcting measured data falls in some of the most important flight regimes, such as the transonic and V/STOL. In such domains, typically strongly nonlinear, it seems necessary that the wind tunnel provide the same flow conditions in the vicinity of the model as in flight, since corrections are virtually impossible. Present-day slotted and perforated tunnels, for example, are intended to do this, but are often inadequate. However, unconfined flow is characterized by certain functional relationships among the flow variables at points on a surface within the tunnel; it is always possible to ascertain whether unconfined-flow conditions are actually present, by measuring such quantities and verifying that these relationships are indeed satisfied. These relationships are independent of the configuration being tested. It is proposed here that wind tunnels be provided with sensors to measure such selected quantities on a convenient surface and means to vary wall geometry so as to approach such conditions in an iterative process.

*Calspan Corp., Buffalo, NY 14221, U.S.A.
Contract N00014-72-C-0102

123 *Rae, W. H., Jr.; and *Shindo, S.: **An Experimental Investigation of Wind Tunnel Wall Corrections and Test Limits for V/STOL Vehicles. Final Rep., 1 July 1969 - 30 June 1972.** (AROD-4506-5-E), University of Wash., Rept. 73-2, July 12, 1973, 38 pp.

AD-764255 N73-30962#

The report deals with an experimental investigation of some of the problems associated with wind tunnel testing of V/STOL type aircraft. The models used in the study were either rotors or propellers acting as a rotor.

Various size and shape wind tunnel test sections were simulated by the use of inserts installed within a larger main wind tunnel test section. The study investigated the application of wind tunnel wall corrections to models with large values of downwash. A physical limit, called flow breakdown, to the size and allowable downwash for a given model-tunnel combination was also studied.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant DA-ARO(D)-31-124-G809

124 *Carbonaro, M.: **Wind Tunnel Corrections for STOL Models.** In: von Karman Institute for Fluid Dynamics' STOL Technology, Vol. 1, Sept. 1973, (N79-22996), 45 pp.

N79-22998#

A number of operational problems associated with the wind tunnel testing of V/STOL aircraft including helicopters are reviewed. Wall corrections, use of ventilated wall, testing for ground effect, and flow distributions in the tunnel circuit are discussed.

*von Karman Institute for Fluid Dynamics, Chaussée de Waterloo 72, B-1640 Rhode-Saint Genèse, Belgium

125 *Heyson, H. H.: **Theoretical and Experimental Investigation of the Performance of a Fan-In-Wing VTOL Configuration.** NASA TN D-7498, Dec. 1973, 75 pp.

N74-11823#

The incompressible-flow momentum theory is extended to the case of lifting fans. The resulting theory includes many of the known experimentally determined characteristics of fan-in-wing aircraft. These characteristics include the negligible effect of forward speed on fan thrust, the large momentum drag, and the generally inefficient performance throughout the transition speed range. Although mutual interference between the fans and the wing was totally neglected, the theory is confirmed by experimental results for the configuration tested. Examination of the results of an investigation of wall interference leads to the conclusion that the large fan-induced lift reported in many earlier investigations was largely the result of neglecting wall interference in the reduction of wind-tunnel data.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

126 *Hackett, J. E.; *Praytor, E. B.; and *Caldwell, E. O.: **Ground Effect for V/STOL Aircraft Configurations and Its Simulation in the Wind Tunnel. Part 3: The Tangentially Blown Ground as an Alternative to a Moving Ground: Application to the NASA-Ames 40 by 80-Foot Wind Tunnel.** NASA CR-114497, 1973, 59 pp.

N75-10005#

A set of conceptual drawings showing the application of slot-blowing boundary layer control to the 40- by 80-foot wind tunnel is presented. In small scale pilot experiments unswept slots were used, fed by a below-floor plenum. The model was sting mounted and its wing was unswept. However, design for the Ames tunnel was heavily constrained, both by under floor balance mechanisms and by a large turntable. An over floor supply system was therefore designed. A description of appropriate procedures for using the floor tangential blowing system is given. Though some of the operating graphs are specific to the design for the Ames tunnel, both nondimensional plots and the approach generally are widely applicable.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.
Contract NAS2-6690

127 *Tyler, R. A.; and *Williamson, R. G.: **Experience With the NRC 10 ft. x 20 ft. V/STOL Propulsion Tunnel - Some Practical Aspects of V/STOL Engine Model Testing.** NRC-NAW Quarterly Bulletin no. 2, 1973, pp. 43, 45-59, 61-75, 21 refs.

A73-40855#

Note: For other forms of this paper and an abstract see no. 107 and 109 in this bibliography.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

128 *Heyson, H. H.: **The Effect of Wind Tunnel Wall Interference on the Performance of a Fan-in-Wing VTOL Model.** NASA TN D-7518, Feb. 1974, 232 pp.

N74-18895#

A fan-in-wing model with a 1.07-meter span was tested in seven different test sections with cross-sectional areas ranging from 2.2 sq. meters to 265 sq. meters. The data from the different test sections are compared both with and without correction for wall interference. The results demonstrate that extreme care must be used in interpreting uncorrected VTOL data since the wall interference may be so large as to invalidate even trends in the data. The wall interference is particularly large at the tail, a result which is in agreement with recently published comparisons of flight and large scale wind tunnel data for a propeller-driven deflected-slipstream configuration. The data verify the wall-interference theory even under conditions of extreme interference. A method yields reasonable estimates for the onset of Rae's minimum-speed limit. The rules for choosing model sizes to produce negligible wall effects are considerably in error and permit the use of excessively large models.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

129 *Sears, W. R.: **Self-Correcting Wind Tunnels.** The Aeronautical Journal, vol. 78, Feb./Mar. 1974, pp. 80-89.

Note: For an earlier form of this paper and an abstract see no. 122 in this bibliography.

*Calspan Corp., Buffalo, NY 14221, U.S.A.

130 *Advisory Group for Aerospace Research and Development, NATO: **A Review Of Current Research Aimed at the Design and Operation of Large Windtunnels.** AGARD-AR-68, Mar. 1974, 55 pp.

N74-21899#

Note: For an update to this report see no. 140 in this bibliography.

The proceedings of a conference on wind tunnel design are presented. The subjects discussed are: (1) wind tunnel design and operation, (2) testing techniques, (3) special techniques for engine simulation, (4) techniques for high lift and V/STOL testing, (5) problems of testing at transonic speeds, and (6) fluid motion problems. There is a large bibliography, see pages 21-24.

*AGARD (Advisory Group for Aerospace R & D), NATO, 7 ru Ancelle, 92200 Neuilly sur Seine, France

131 *Carbonaro, M.: **Addendum to Paper No. 1 of AGARD-R-601 - Review of Some Problems Related to the Design and Operation of Low Speed Windtunnels for V/STOL Testing.** In: AGARD Rep. no. 615, Large Windtunnels: Required Characteristics and the Performance of Various Types of Transonic Facility, (N74-31733), pp. A-1 and A-2, June 1974.

N74-31741#

Note: For the paper discussed in the addendum see no. 119 in this bibliography.

Attention is drawn to some important references which had subsequently been published, main conclusions which could be drawn from the original paper are emphasized, and a list of errata is added.

*von Karman Institute for Fluid Dynamics, Chaussée de Waterloo 72, B-1640 Rhode-Saint-Genèse, Belgium

132 *Hackett, J. E.; and *Boles, R. A.: **High Lift Testing in Closed Wind Tunnels.** AIAA 8th Aerodynamic Testing Conference, Bethesda, Md., July 8-10, 1974, 12 pp.

AIAA Paper 74-641 A74-35405#

Note: For another form of this paper see no. 153 in this bibliography. (Title varies).

A new method for estimating blockage corrections is described which involves wall static pressure measurements at the test section entry and exit. Model, rig and power effects are included. Using this method, tests on a 20-inch jet flap model in a 42-inch wide tunnel correlated well with 'free air' results in a large tunnel. The highest test lift coefficient was 15 and a moving ground was used. Theoretical and experimental studies are described concerning the use of a tangentially-blown wind tunnel floor to replace a moving ground. Tests on the above model, at one chord altitude, confirm the feasibility of this approach. Applications of the new procedures are described and discussed.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

133 *Gentry, G. L., Jr.: **Wind-Tunnel Investigation of an Externally Blown Flap STOL Transport Model Including an Investigation of Wall Effects.** NASA TM X-3009, Sept. 1974, 174 pp.

N74-34462#

A wind-tunnel investigation was conducted in the Langley V/STOL tunnel and in a scaled version of the Ames 40- by 80-foot tunnel test section installed as a liner in the Langley V/STOL tunnel to determine the effect of test-section size on aerodynamic characteristics of the model. The model investigated was a swept-wing, jet-powered, externally blown flap (EBF) STOL transport configuration with a leading-edge slat and triple-slotted flaps. The model was an 0.1645-scale model of a 11.58-meter (38.0-ft.) span model designed for tests in a 40- by 80-foot tunnel. The data compare the aerodynamic characteristics of the model with and without the tunnel liner installed. Data are presented as a function of thrust coefficient over an angle-of-attack range of 0 deg to 25 deg. A thrust-coefficient range up to approximately 4.0 was simulated, most of the tests being conducted at a free-stream dynamic pressure of 814 Newtons/sq m (17 lb sq ft). The data are presented with a minimum of analysis.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

134 *Kraft, E. M.: **Analytical Study of Ventilated Wind Tunnel Boundary Interference on V/STOL Models Including Wake Curvature and Decay Effects. Final Rept. Feb. - Oct. 1973.** AEDC TR-74-51; NASA CR-142240, Nov. 1974, 59 pp.

AD-A000922 N75-18188#

The wind tunnel boundary interference on a V/STOL model is calculated in a rectangular test section with solid vertical walls and ventilated (perforated or slotted) horizontal walls. The interference is found by applying the small perturbation problem. The theory uses an image method in addition to Fourier transforms with an equivalent homogeneous boundary condition on the ventilated wall. The mathematical representation of the V/STOL model accounts for the curvature and decay of the wake. The assumption of a constant wake strength produced a paradox in that the initial jet velocity decreases. The most significant aspect of the analysis shows that nonlinear cross-flow effects at the tunnel boundary are important in the V/STOL case, and a quasi-linear approximation to these effects is introduced into the solution providing a good agreement with experimental data.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A. Sponsored by NASA.

135 *Bernstein, S.; and *Joppa, R. G.: **Development of Minimum Correction Wind Tunnels.** Presented at the AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., Jan. 20-22, 1975, 8 pp.

AIAA Paper 75-144 A75-18342#

Note: For another form of this paper see no. 150 in this bibliography.

The requirements to simulate flight vehicles at extreme lift coefficients with possible partial flow separation at hovering flight or at transition flight have imposed a new challenge for the wind-tunnel designers. The need to test large models results from several requirements. In order to match dynamic similarity rules, a high Reynolds number is required. Large models often are required also because of the difficulty in construction of small models with intricate components of high lift devices. Flow distortions due to wind-tunnel wall interference may be accounted for if the model-to-tunnel ratio is small, but the theory becomes less reliable as the model becomes larger. This paper presents a new approach to wind-tunnel simulation which may provide a complementary technique for improved tests of V/STOL models even in a large wind tunnel. The flow in the proposed tunnel is controlled so that the model is in an approximate free-flight condition during the test even for relatively large models at high lift coefficients.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant NGL-48-002-010

136 *Erickson, L. E.: **Calculations of Two-Dimensional Potential Flow Wall Interference for Multi-Component Airfoils in Closed Low Speed Wind Tunnels.** FFA-TN-AU-1116-Pt-1, Apr. 1975, 50 pp.

N76-16040#

The two-dimensional optimization of high lift devices requires the use of large models to obtain reliable results. The accommodation of these models in given wind tunnels necessitates advanced interference calculations, since classical wall correction methods are unsatisfactory. For attached flow it is thought that the total interference can be separated into a viscid wake blockage part and an inviscid potential flow part. A numerical method calculating the potential flow part was developed and tested. The airfoil and tunnel boundaries were simulated by a continuous surface vortex distribution, determined by the boundary conditions. The results for a simple airfoil between tunnel walls agree well with analytical methods where these apply. Analogous results for a wing-flap configuration show that the lift interference is nonlinear in lift coefficient. This effect is caused by the large vertical displacement of flap.

*Aeronautical Research Institute of Sweden, Stockholm, Sweden
Contract F-INK-82223-73-009-07001

137 *Foster, D. N.: **A Brief Flight-Tunnel Comparison for the Hunting H 126 Jet Flap Aircraft.** In: AGARD-CP-187, Flight/Ground Testing Facilities Correlation; the 46th Meeting of the Flight Mechanics Panel at Vallorie, France, June 9-13, 1975, (N76-25266), paper 18-A, 7 pp.

N76-25294

Flight measurements of the variation of lift with angle of incidence, for an aircraft with an internal-flow jet flap, were compared with results deduced from wind-tunnel tests of the aircraft itself, and of a one-seventh scale model of the aircraft. The correlation is shown to be unsatisfactory for large flap deflection and high values of the jet momentum. The effects of the wind-tunnel wall corrections, and of some uncertainties in the position error correction, were investigated in order to suggest areas where further work could lead to improvements in the flight-tunnel correlation.

*Royal Aircraft Establishment, Bedford MK41 6AE, U.K.

138 *Binion, J. W., Jr.: **An Experimental Study of Several Wind Tunnel Wall Configurations Using Two V/STOL Model Configurations -- Low Speed Wind Tunnels. Final Rep. Mar 10, 1972 - Apr. 16, 1974.** ARO-PWT-TR-75-4; AEDC-TR-75-36; NASA CR-145562, July 1975, 37 pp.

AD-A012000 N76-12086#

Experiments were conducted in the low speed wind tunnel using two V/STOL models, a jet-flap and a jet-in-fuselage configuration, to search for a wind tunnel wall configuration to minimize wall interference on V/STOL models. Data were also obtained on the jet-flap model with a uniform slotted wall configuration to provide comparisons between theoretical and experimental wall interference. A test section configuration was found which provided some data in reasonable agreement with interference-free results over a wide range of momentum coefficients.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A. AEDC Sponsored in part by NASA

139 *Mann, M. J.: **Low-Speed Upwash Interference on a Transport Model in a Rectangular Slotted-Wall Wind Tunnel.** NASA TM X-3218, Aug. 1975, 25 pp.

N75-28026#

A study was made of the upwash interference caused by the wind tunnel walls at a Mach number of 0.20. The wind tunnel has slotted horizontal walls and solid vertical walls and the wind tunnel model is a wing-fuselage combination typical of a short take-off and landing (STOL) transport. Measurements were made of the model forces and angle of attack. The experimental results are compared to theoretical solutions for the upwash interference. This comparison enabled an indirect determination of one of the constants in the slotted wall boundary condition. The magnitude of the experimental upwash interference is also compared to the accuracy of the data. This comparison indicates that it is difficult to make definite conclusions based on the experimental data. Suggestions are made for future research which could provide a practical means of accurately determining the wall-interference velocities in wind tunnels with rigid slotted walls.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

140 *Advisory Group for Aerospace Research and Development, NATO: **A Further Review of Current Research Aimed at the Design and Operation of Large Windtunnels.** AGARD-AR-83, Sept. 1975, 130 pp.

N76-11110#

This report updates AGARD-AR-68, which is no. 130 in this bibliography. Section 4 is entitled "Special Techniques for High-Lift and V/STOL Testing at Low Speeds."

*AGARD (Advisory Group for Aerospace R & D), NATO, 7 rue Ancelle, 92200 Neuilly sur Seine, France

141 *De Vries, O.; and *Schipholt, G. J. L.: **Two-Dimensional Tunnel Wall Interference for Multi-Element Aerofoils in Incompressible Flow.** In AGARD-CP-174, (N76-25213), Mar. 1976, Wind Tunnel Design and Testing Techniques, a symposium held in London, Oct. 6-8, 1975, paper no. 20, 7 pp.

N76-25233#

A singularity method has been applied to calculate two dimensional tunnel wall corrections for multi-element aerofoils. The calculations show that the well known corrections due to Glauert can be applied for a single aerofoil, except the pitching moment correction above 15 deg angle of attack; but that the Glauert approach fails in this case of trailing edge flap deflections. The results of the calculations agree with the strong non linear results found by De Jager and Van de Vooren for a hinged flat plate at zero incidence.

*National Aerospace Laboratory, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

142 *Hackett, J. E.; and *Wilsden, D. J.: **Determination of Low Speed Wake Blockage Corrections via Tunnel Wall Static Pressure Measurements.** In: AGARD-CP-174, (N76-25213), Mar. 1976, Wind Tunnel Design and Testing Techniques, a symposium held in London, Oct. 6-8, 1975, paper no. 22, 9 pp.

N76-25235#

A theoretical method has been defined for determining wind tunnel solid/bubble and viscous blockage from wind tunnel wall and roof pressure measurements involving lifting or non-lifting powered or unpowered models. Three finite span line sources are used which are defined by five geometric and two flow parameters. Matching these parameters to the measured tunnel surface pressures is recognized as a significant problem in solving sets of nonlinear simultaneous equations and an interim, engineering solution is suggested. The method has been applied successfully to blockage calculations for a series of normal flat plates. Other experimental results, involving more typical wind tunnel models are also discussed.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

143 *Carbonaro, M.: **Interference Problems in V/STOL Testing at Low Speeds.** In: AGARD-CP-174, (N76-25213), Mar. 1976, Wind Tunnel Design and Testing Techniques, a symposium held in London, Oct. 6-8, 1975, paper no. 40, 21 pp., 56 refs.

N76-25251#

When testing V/STOL models at low speeds several problems arise in connection with the sharp downward deflection of the wake originating from the highly loaded lifting systems. It is the purpose of this paper to define the various problems and to summarize and compare the obtained results. First, the inclined wake may impinge on the wind tunnel floor and cause a breakdown in the wind tunnel flow uniformity. The testing limitations associated with the occurrence of such phenomenon are discussed for the different cases of a rotor, a jet flap wing, or a single or multiple lifting jet configuration. Wind tunnel boundary corrections account for the real behavior of the wake and an upper limit of their validity has to be assessed. The various existing theories of wall corrections which take into account the deflection and eventually the curvature of the wake are summarized in the various cases of closed, open or ventilated test sections. Comparisons with existing experimental data are made. The limits proposed in the literature for the validity of wall corrections are discussed.

*von Karman Institute for Fluid Dynamics, 72, Chaussée de Waterloo, B-1640 Rhode St. Genèse, Belgium

144 *Hansford, R. E.: **The Removal of Wind Tunnel Panels to Prevent Flow Breakdown at Low Speeds.** In: AGARD-CP-174, (N76-25213), Mar. 1976, Wind Tunnel Design and Testing Techniques, a symposium held in London, Oct. 6-8, 1975, paper no. 41, 8 pp.

N76-25252

Note: For another form of this paper see no. 146 in this bibliography.

A model rotor was tested at low speed in a wind tunnel to study the problem of flow breakdown. This condition arises from the wake impingement on tunnel floor and wall panels to induce a recirculatory flow upstream. The phenomenon was first reproduced in the closed tunnel for various disc loadings and limiting operating conditions were established. Panels were then selectively removed and it was subsequently shown that it was possible to obtain a representative tunnel flow, free from recirculatory interference, at lower advance ratios compared to closed tunnel operation. By careful venting of a working section it is concluded that a substantial increase in maximum allowable downwash angle can be obtained.

*Westland Helicopters, Ltd., Yeovil, Somerset BA20 2YB, U.K.

145 *Cull, M. J.: **VSTOL Wind Tunnel Model Testing: An Experimental Assessment of Flow Breakdown Using a Multiple Fan Model.** In: AGARD-CP-174, (N76-25213), Mar. 1976, Wind Tunnel Design and Testing Techniques, a symposium held in London, Oct. 6-8, 1975, paper no. 42, 8 pp.

N76-25253

Tests have been made with a multifan VSTOL model in two different sized closed test section wind tunnels to investigate the problem of tunnel flow breakdown. The boundary condition of incipient stagnation where the high energy jet exhaust first penetrates the tunnel wall boundary layer has been identified for a range of model conditions. Correlation of results in both tunnels and with other work is good and the technique of establishing a flow breakdown boundary by investigating the behavior of the floor vortex, formed by the interaction of the model jet efflux and the tunnel mainstream flow, has been used successfully for a multifan configuration. In addition, model forces and moments are recorded in an attempt to estimate minimum testing conditions and to indicate the magnitude of wall constraint effect. Direct comparisons are made of longitudinal forces and moments using results from both wind tunnels and a sample of results are presented.

*Hawker Siddeley Aviation, Ltd., Hatfield, U.K.

146 *Hansford, R. E.: **The Removal of Wind Tunnel Panels to Prevent Flow Breakdown at Low Speeds.** Aeronautical Journal, vol. 79, Nov. 1975, pp. 475-479.

A76-15319

Note: For an earlier form of this paper and an abstract see no. 144 in this bibliography.

*Westland Helicopters, Ltd., Yeovil, Somerset BA20 2YB, U.K.

147 *Tyler, R. A.; and *Williamson, R. G.: **Crossflow Performance of Lift-Fans in Tandem -- for V/STOL Transport Aircraft.** In: International Symposium on Air Breathing Engines, 3rd, Proceedings, (A77-17226). Held at Munich, West Germany, Mar. 7-12, 1976, pp. 803-832.

A77-17265

Earlier work on the thrust behavior of isolated fans equipped with cowled intakes in crossflow is extended here to multiple lift-fans in tandem, as in recent designs of V/STOL transport aircraft incorporating wing pods or fuselage-mounted sponsons. The cowled fans are usually gimbal-mounted to allow limited thrust vectoring or inflow distortion control by fan tilting. A V/STOL propulsion tunnel designed for testing the models is described. A sponson model containing three cowled and tiltable lift-fans in tandem array was operated in crossflow. Tunnel flow breakdown and wall interference effects, shielding effects on inflow distortion from fans operating upstream, and inflow interaction effects were taken into account. The leading fan operates in the manner of an isolated fan, while trailing fans benefit from favorable interaction effects on inflow distortion.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

148 *Hackett, J. E.; *Boles, R. A.; and *Lilley, D. E.: **Ground Simulation and Tunnel Blockage for a Jet-Flapped, Basic STOL Model Tested to Very High Lift Coefficients.** NASA CR-137857, Mar. 1976, 133 pp.

N76-28227#

Ground effects experiments and large/small-tunnel interference studies were carried out on a model with a 20-inch (50.8 cm) span wing. The wing, which includes a highly deflected knee-blown flap can be fitted with unflapped tips and slats. A low-mounted tailplane can be fitted to the aft fuselage. Three-component balance measurements, made with a fixed ground equipped with a single boundary-layer blowing slot, were compared with datum, moving-ground results. Good comparisons were obtained up to model blowing momentum coefficients of approximately two, after which the particular floor blowing settings used proved insufficient to prevent floor separation in the vicinity of the model. Skin friction measurements, taken routinely along the floor centerline, proved invaluable during the analysis of results, and their use is recommended as input to determination of floor BLC setting. A careful investigation was made of pitching moments, including tail-on, close-to-ground cases, with favorable results. Drag proved the most sensitive to the change from a moving to the boundary-layer controlled ground.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

149 *Bernstein, S.; and *Joppa, R. G.: **Reduction of Wind-Tunnel Wall Interference by Controlled Wall Flow.** NASA CR-2654, Mar. 1976, 57 pp.

N76-18154#

Corrections for wind tunnel wall interferences are applied successfully to high lift models when the model to tunnel size ratio is small. The accuracy of the corrections becomes poorer when larger models are tested. An alternate method of testing was developed in which flow through the porous walls of the tunnel was actively controlled so as to approximate free air conditions in the neighborhood of the model during the test. The amount and distribution of the controlled flow through the walls is computed using a potential flow representation of the model based on the measured convergence of the method to free air conditions and to substantiate the general three dimensional theory of operation when the normal flow distribution is continuous. A two dimensional tunnel was constructed to evaluate the concept. Results show that substantial reduction of wall interference may be achieved with relatively low values of porosity of actively controlled walls.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Contract NGL-48-002-010

150 *Bernstein, S.; and *Joppa, R. G.: **Development of Minimum Correction Wind Tunnels.** Journal of Aircraft, vol. 13, no. 4 Apr. 1976, pp. 243-247.

Note: For an earlier form of this article and an abstract see no. 135 in this bibliography.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Contract NGL-48-002-010

151 *Maskew, B.: **A Quadrilateral Vortex Method Applied to Configurations With High Circulation.** In: NASA Langley Research Center Vortex-Lattice Utilization Workshop, NASA SP-405, (N76-28163#), Hampton, Va., May 17-18, 1976, pp. 163-186.

N76-28173#

A quadrilateral vortex-lattice method is briefly described for calculating the potential flow aerodynamic characteristics of high-lift configurations. It incorporates an iterative scheme for calculating the deformation of forcefree wakes, including wakes from side edges. The method is applicable to multiple lifting surfaces with part-span flaps deflected, and can include ground effect and wind-tunnel interference. Numerical results, presented for a number of high-lift configurations, demonstrate rapid convergence of the iterative technique. The results are in good agreement with available experimental data.

*Analytical Methods, Inc., Bellevue, WA 98009, U.S.A.

152 *Wilson, J. C.: **A General Rotor Model System for Wind-Tunnel Investigations.** In: AIAA 9th Aerodynamic Testing Conference in Arlington, Texas, (A76-38626). June 7-9, 1976, pp. 136-142.

A76-38641#

Note: For another form of this paper see no. 157 in this bibliography.

Persons using this bibliography may be interested in the description of the V/STOL tunnel at Langley. This tunnel is especially suitable for investigations of low-speed characteristics of lifting systems such as rotors. It is a closed-return atmospheric tunnel capable of producing forward speeds from 0 to 200 knots. The test section is 4.42 m (14.50 ft) high by 6.63 m (21.75 ft) wide. The wall configuration easily can be changed to reduce boundary influence through opening slots or by removing any or all of the two sidewalls or ceiling. The simulation of low-speed flight (both in and out of ground effect) can be enhanced further by use of a floor boundary-layer removal system or moving ground plane (endless belt).

*NASA Langley Research Center, Hampton, Virginia 23665-5225, U.S.A.

153 *Hackett, J. E.; and *Boles, R. A.: **Wake Blockage Corrections and Ground Effect Testing in Closed Wind Tunnels.** Journal of Aircraft, vol. 13, no. 8, Aug. 1976, pp. 597-604.

Note: For an earlier form of this report and an abstract see no. 132 in this bibliography. (Title varies).

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

154 *Gmelin, B.: **A Model for Wind-Tunnel Rotorcraft Research - Model Design and Test Objectives.** In: 2nd Deutsche Gesellschaft Fuer Luft-und Raumfahrt, European Rotorcraft and Powered Lift Aircraft Forum, Bueckeburg, West Germany, Sept. 20-22, 1976, paper no. 32, 17 pp.

DCAF A002799 A77-43363#

Factors underlying the design of components for a rotorcraft wind-tunnel test stand are discussed. Transferability of the data to full-scale helicopters, using model scaling laws, is investigated. The rotor drive system, geometrical scaling, handling of dimensionless ratios (Reynolds and Froude numbers, density and elasticity ratios), wind-tunnel interference effects, hover testing, and details of the wind-tunnel test program are covered. An outline of future DFVLR rotorcraft wind-tunnel test programs is presented.

*DFVLR, D-3300 Braunschweig, West Germany (FRG)

155 *Sears, W. R.; **Vidal, R. J.; **Erickson, J. C., Jr.; and **Ritter, A.: **Interference-Free Wind-Tunnel Flows by Adaptive-Wall Technology.** Presented at the 10th Congress of the International Council of the Aeronautical Sciences, Ottawa, Canada, Oct. 3-8, 1976, 13 pp. CALSPAN-RK-6040-A-1, Jan 1977, 25 pp.

ICAS Paper 76-02 A76-47351#
AD A034 889 N77-24155#

Note: For a later version of this paper see no. 158 in this bibliography.

The adaptive-wall or self-correcting wind tunnel has been proposed for such regimes as transonic and V/STOL where wall effects are large and cannot be corrected for. The power and generality of the concept are pointed out. In a two-dimensional transonic embodiment in the Calspan One-Foot Tunnel, the scheme has been shown to work at lower transonic Mach numbers. Several practical problems are cited, including instrumentation, the nature of the wall modification, and convergence of the iterative procedure. Moreover, questions of shock-wave neutralization at the wall and probable configuration of three-dimensional embodiments are discussed.

*Univ. of Arizona, Tucson, AZ 85721, U.S.A.
**Calspan Corp., Buffalo, NY 14221, U.S.A.
Contracts N00014-72-C-0102, N00014-77-C-0052, and NAS2-8777

156 *Hackett, J. E.; and *Boles, R. A.: **Ground Simulation and Tunnel Blockage for a Swept, Jet-Flapped Wing Tested to Very High Lift Coefficients.** NASA CR-152032, June 1977, 159 pp.

N78-13008#

Ground effects experiments and large/small tunnel interference studies were carried out on a model with a 20 inch (50.8 cm) 25 degree swept wing. The wing is slatted, has a 60 degree knee-blown flap and can be fitted with unflapped tips. A tail rake of pitch-yaw probes can be fitted to the fuselage. Certain check tests were also made with a very similar straight-wing model.

*Lockheed Missiles and Space Co., Huntsville, AL, U.S.A.
Contract NAS2-9155

157 *Wilson, J. C.: **A General Rotor Model System for Wind-Tunnel Investigations.** Journal of Aircraft, vol. 14, no. 7, July 1977, pp. 639-643.

Note: For an earlier version of this paper see no. 152 in this bibliography.

A complex rotorcraft model system has been developed for the NASA Langley Research Center and the U.S. Army Air Mobility R&D Laboratory, Langley Directorate, for aerodynamic and acoustic experimental investigations in the NASA Langley V/STOL tunnel. This generalized rotor model system has a powered main rotor, tail rotor, and auxillary engine capability. It may be configured to represent a variety of rotorcraft configurations. The first investigation was conducted to determine the performance, acoustic, stability, and control characteristics of the NASA/Army Rotor Systems Research Aircraft with an articulated rotor. In a second investigation, a 1/4-scale AH-1G configuration with a teetering rotor is being represented to determine if a V-tail will improve the directional characteristics. Future programs are planned to investigate advanced rotor blade airfoils for improved performance and acoustic characteristics.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

158 *Sears, W. R.; **Vidal, R. J.; **Erickson, J. C., Jr.; and *Ritter, A.: **Interference-Free Wind-Tunnel Flows by Adaptive-Wall Technology.** Journal of Aircraft, vol. 14, no. 11, Nov. 1977, pp. 1042-1050.

Note: For an earlier version of this article and an abstract see no. 155 in this bibliography.

*Univ. of Arizona, Tucson, AZ 85721, U.S.A.
**Calspan Corp., Buffalo, NY 14221, U.S.A.
Contract N00014-72-C-0102
Grant NAS-2-8777

159 *Dietz, W. E., Jr.; and *Altstatt, M. C.: **Experimental Investigation of Support Interference on an Ogive Cylinder at High Incidence.** Presented at the AIAA 16th Aerospace Sciences Meeting, Huntsville, Ala., Jan. 16-18, 1978, 8 pp.

AIAA Paper 78-165 A78-20717#

Note: For another form of this paper see Journal of Spacecraft and Rockets, vol. 16, 1979, pp. 67-68.

A wind tunnel test was conducted to determine the support and tunnel wall interference on an ogive-cylinder model at high angles of attack in transonic flow. The model was supported by either a base-mounted sting or a strut attached to the leeside of the model. The strut support acted as a splitter plate and generally reduced the normal-force coefficient, whereas the sting support increased the normal-force coefficient slightly. The support interference diminished with increasing Mach number. A simple algebraic method of estimating support interference was postulated. Two semi-empirical methods for calculation of aerodynamic coefficients were compared with test results.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.

160 *Alstatt, M. C.; and *Dietz, W. E.: **Support Interference on an Ogive-Cylinder Model at High Angle of Attack in Transonic Flow; Final Report, 1 July 1976 -- 30 Sept. 1977.** AEDC-TR-78-8, March 1978, 66 pp.

AD-A051689 N78-24088#

A combined experimental and analytical study was conducted to determine the relative magnitude of the support and tunnel wall interferences on an ogive-cylinder model at a high angle of attack in transonic flow. The tests were conducted in the AEDC Aerodynamic Wind Tunnel (4T). The results indicate that the strut support causes large reductions in the normal force on the model, while the effect attributable to the sting support is much smaller. A correction procedure applied to the data to remove support interference gives consistent results. The test data, combined with an inviscid analytic study, indicate that the wall interference effects were negligible. Solutions obtained using two computational methods compare well with experimental results.

*ARO, Inc., Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.

161 *Peitzman, F. W.: **Determination of High Attitude Wall Corrections in a Low Speed Wind Tunnel.** Presented at the AIAA 10th Aerodynamic Testing Conference held in San Diego, Calif., Apr. 19-21, 1978. In: Technical Papers, pp. 297-300.

AIAA Paper 78-810 A78-32364#

Note: For experimental data referred to in this report see no. 164 in this bibliography.

An investigation was conducted to determine the validity of wall corrections currently in use at high angles of attack, and develop improved corrections when necessary. Literature survey and theory study did not yield a method considered acceptable for use. An experimental investigation was performed using models of identical configuration but different scale. This investigation revealed that the conventional low attitude wall corrections are adequate at low attitudes (under $\alpha = 40°$), and the continuity equation using model planform area provides good correlation at $\alpha = 90°$. Between 40° and 90°, correction techniques were developed to provide correlation between the two models.

*Northrop Corporation, Aircraft Division, 3901 West Broadway, Hawthorne, CA 90250, U.S.A.

162 *Shindo, S.; and *Rae, W. H., Jr.: **Low-speed Test Limit of V/STOL Model Located Vertically Off-Center.** Journal of Aircraft, vol. 15, Apr. 1978, pp. 253-254.

A78-29642#

A vertically off-centered V/STOL model - a 2 ft. diameter three-bladed aluminum propeller operating in a rotor mode - is tested in an 8 by 12 ft. wind tunnel with and without ground plane along with an associated 3 by 4.5 ft. test section insert. The objective was to assess the effect of the vertically off-centered model on the low-speed test limit. The aerodynamic data of the model at a constant negative angle of attack (-3 deg) are recorded at selected tunnel dynamic pressures to provide adequate data points to define the model lift variation with respect to the tip speed ratio. The adverse effect of the rotor low-speed test limit is observed in the form of lift change with respect to the tip speed ratio. A major conclusion is that for rotors tested with a ground plane or in the vicinity of the floor, the ratio of distance between floor and model to rotor radius defines the low-speed test limits.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
This work was sponsored by the U.S. Army Research Office, Durham, N.C., under Grant DA-ARO-D-31-124-G1144, and NASA Grant No. NGR-48-002-035.

163 *Seidel, M; and **Jaarsma, F.: **The German-Dutch Low Speed Wind Tunnel DNW.** The Aeronautical Journal, April 1978, pp. 167-173. Lecture given at the Royal Aeonautical Society Feb. 3, 1977. (Updated in Jan. 1978).

A78-36447

A jointly financed German-Dutch wind tunnel is under development to provide aeronautical testing facilities in the speed range 62-145 m/sec. The flow characteristics of the 6- to 9.5-m cross section wind tunnel include: relative deviation of stationary and dynamic pressure across the tunnel section of + or - 0.3% and the local deviation of flow direction of + or - 0.1 deg; turbulence of 0.1-0.2%; and local temperature fluctuations of + or - 1C. Among the applications of the facility are studies to improve low-speed characteristics of aircraft, and investigations of engine/airframe interference, aircraft noise, helicopter rotor dynamics, flutter characteristics and the performance of full-scale aircraft components.

*German-Dutch Wind Tunnel, Noordoostpolder, The Netherlands
**National Aerospace Laboratory NLR, Noordoostpolder, The Netherlands

164 *Peitzman, F. W.: **Low Speed Wind Tunnel Investigation to Develop High Attitude Wall Corrections in the Northrop 7 x 10-Foot Low Speed Wind Tunnel.** Rep. no. NOR-78-20, May 1978, 76 pp., including figures, etc.

Note: For a companion report see no. 161 in this bibliography.

Results are presented of a low speed wind tunnel investigation of two models of differing sizes but identical configuration. The purpose of this investigation was to determine if currently used tunnel blockage correction factors through the entire angle of attack range to 90° were adequate, and to develop empirical correction factors if they were not. A secondary objective was to compare low speed data obtained with the same model in both the 7x10 and 2x2-foot wind tunnels. The experimental investigation provided confidence in the traditional low attitude corrections for angles of attack to 40°, and also showed that the continuity equation, based on planform area, adequately corrected the data at angle of attack of 90°. However, between 40° and 90°, neither low nor high attitude corrections were sufficient. The simple device of a linear combination of low and high attitude corrections in the range from 40° to 90° gives adequate results, and has been selected as the technique for reducing data in that angle of attack range.

*Northrop Corporation Aircraft Division, 3901 West Broadway, Hawthorne, CA 90250, U.S.A.

165 *Atkinson, A. J.: **Three-Dimensional Low Speed Minimum Interference Wind Tunnel Simulation Based on Potential Modeling.** M.S. Thesis, Dept. of Aeronautics and Astronautics, Univ. of Washington, May 1978, 150 pp. (Microfiche available from Univ. of Washington).

The purpose of the minimum interference wind tunnel is to closely match the free air flow field inside the tunnel test section. Consequently, the validity of the experimentally obtained test data for high lift vehicles is significantly improved. A computer model is developed to simulate a three-dimensional low speed minimum interference wind tunnel. The wind tunnel interference is minimized by controlling the flow through the active portions of the tunnel walls. It is believed that control need be exerted over only part of the tunnel walls to closely approximate free air flow conditions inside the tunnel. Results from the analytical study of the actively controlled wall tunnel, matching free air flow boundary conditions at the active wall portions of the tunnel, demonstrate that it is possible to substantially reduce the amount of tunnel wall interference and apply corrections to account for the small remaining effects. In particular, the pitching moment correction attributed to the reduced wall interference is minor and may be ignored in most instances.

*Univ. of Washington, Seattle, WA 98195, U.S.A.

166 *Heyson, H. H.: **Wind-Tunnel Testing of VTOL and STOL Aircraft.** NASA TM-78750. Presented at the Seminar on Aerodynamics of V/STOL Aircraft and Helicopters, University Park, Pa., July 31 - Aug. 4, 1978, 81 pp.

N78-30040#

The basic concepts of wind-tunnel boundary interference are discussed and the development of the theory for VTOL-STOL aircraft is described. Features affecting the wall interference, such as wake roll-up, configuration differences, recirculation limits, and interference nonuniformity, are discussed. The effects of the level of correction on allowable model size are shown to be amenable to generalized presentation. Finally, experimental configuration of wind-tunnel interference theory is presented for jet-flap, rotor, and fan-in-wing models.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

167 *Jaarsma, F.; and *Seidel, M.: **The German-Dutch Wind Tunnel DNW - Design Aspects and Status of Construction.** In: International Council of the Aeronautical Sciences Congress, 11th Lisbon, Portugal, Sept. 10-16, 1978, Proceedings, vol. 1, (A79-20076), 1978, pp. 449-460.

A79-20115#

As a cooperative project of DFVLR and NLR the German-Dutch wind tunnel DNW is under construction in the Noordoostpolder, The Netherlands. The DNW will belong to the largest and most efficient low-speed wind tunnels in Europe and contribute to aircraft development work. Typical design features are: closed and cooled circuit, three interchangeable atmospheric test sections with cross sections of 9.5m x 9.5m, 8m x 6m and 6m x 6m with maximum air speeds of 62, 110 and 145 m/s, air exchange system. The equipment includes: model sting support, external balance, computers for data handling and controls, compressed air plant, moving belt ground plane, q-stopper, and scoop for hot gas removal. The DNW will cover a wide range of testing capabilities including aeroacoustic (open test section) and testing with real engines. This paper specially refers to overall and aerodynamic design aspects and the development of selected components.

*German-Dutch Wind Tunnel, Noordoostpolder, The Netherlands

168 *Parkinson, G. V.; **Williams, C. D.; and **Malek, A.: **Development of a Low-Correction Wind Tunnel Wall Configuration for Testing High-Lift Airfoils.** In: International Council of the Aeronautical Sciences Congress, 11th, Lisbon, Portugal, Sept. 10-16, 1978. Proceedings, vol. 1, 1978, pp. 355-360, 6 refs.

A79-20108#

A recent innovation in wind tunnel test section design intended to reduce wall corrections in high-lift airfoil testing to negligible values is described. The test-section wall opposite the pressure side of the test airfoil is solid as in conventional tunnels, but the wall opposite the suction side consists of uniformly spaced transverse slats of symmetrical airfoil profile. This configuration permits the streamline pattern near the test airfoil to approach free-air conditions, so that the loading on the airfoil approaches its free-air values. Parameters for the wall configuration are chosen on the basis of potential-flow modeling, and some of the theoretical predictions and experimental comparisons are presented in the paper. The results are encouraging.

*Univ. of British Columbia, Vancouver, B.C., Canada
**National Aeronautical Establishment, National Research Council, Montreal Rd., Ottawa, Ontario K16 OR6, Canada
NRC of Canada Grant No. A-586

169 *Bucciantini, G.; *DeSilvestra, R.; and *Fornaster, L.: **In: High Angle of Attack Aerodynamics,** AGARD-CP-247, Jan. 1979, (N79-21996), a Symposium held in Norway Oct. 4-6, 1978, paper OD8, 4 pp.

N79-22034#

This paper illustrates the present status of investigation at Aeritalia on wind tunnel testing techniques at high angles of attack and on stall/post stall characteristics of configurations typical of modern combat aircraft. Validation tests in the Aeritalia low speed wind tunnel have shown a good accuracy in testing at high incidences, with small adjustment of the wall interference correction and proper design of the model mounting.

*Aeritalia S.p.A., Combat Aircraft Division, Torino, Italy

170 Byrkin, A. P.; and Mezhirov, I. I.: **The Induction Problem for the Permeable Walls of the Useful Length of a Low-speed Wind Tunnel.** In: TsAGI, Uchenye Zapiski, vol. 9, no. 5, 1978, pp. 11-20. In Russian.

A80-21318#

A method of designing minimum-correction low-speed wind tunnels with rectangular useful lengths is proposed for plane high-lift models. Numerical calculations are given for the boundary interference of walls with a mere one to four slots on the upper and lower walls of the useful length, using a pi-shaped vortex as the model, which is a schematic representation of the vortex system generated by a wing of finite span. It is shown that satisfactory results can be obtained with a very small number of slots at slot spacing on the order of the distance between the model and the wall.

171 *Margason, R. J.; and **Hoad, D. R.: **Critical Considerations for Wind-Tunnel Testing V/STOL Aircraft Models.** Presented at the AIAA 17th Aerospace Sciences Meeting, New Orleans, La., Jan. 15-17, 1979, 9 pp., 33 refs.

AIAA Paper 79-0332 A79-19671#

Note: For a later version of this paper see no. 177 in this bibliography.

Low-speed wind-tunnel testing of V/STOL aircraft concepts to determine the aerodynamic-propulsion interaction effects during the transition between hover and wingborne flight is a necessary step in the development cycle of this type of aircraft. The paper examines factors which must be dealt with to assure that the information obtained in experiments is accurate and representative of the full-scale aircraft modeled. Areas of discussion include: (1) Proper engine simulation selection and model size constraints as a result of the selection; (2) selection of reference power-off condition for determining propulsion interaction effects; (3) modeling of realistic flight conditions to obtain a comprehensive evaluation of the entire transition performance; and (4) wind-tunnel boundary interferences and how these are highly configuration dependent.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.
**U.S. Army Structures Lab., (AVRADCOM), Hampton, VA 23665-5225, U.S.A.

172 *Hackett, J. E.; *Wilsden, D. J.; and *Lilley, D. E.: **Estimation of Tunnel Blockage from Wall Pressure Signatures: A Review and Data Correlation.** NASA CR-152241, Mar. 1979, 170 pp.

N79-32219#

A method is described for estimating low speed wind tunnel blockage, including model volume, bubble separation and viscous wake effects. A tunnel-centerline source/sink distribution is derived from measured wall pressure signatures using fast algorithms to solve the inverse problem in three dimensions. Blockage may then be computed throughout the test volume. Correlations using scaled model or tests in two tunnels were made in all cases. In many cases model reference area exceeded 10% of the tunnel cross-sectional area. Good correlations were obtained regarding model surface pressures lift, drag, and pitching moment. It is shown that blockage-induced velocity variations across the test section are relatively unimportant but axial gradients should be considered when model size is determined.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.
Contract NAS2-9883

173 *Erickson, J. C., Jr.: **Adaptive-Wall Technology for V/STOL Testing.** Proceedings of a Workshop on V/STOL Aerodynamics, Vol. 1, Monterey Calif, May 16-18, 1979.

AD A079 115 N80-19074, pp. 444-461

The adaptive-wall wind tunnel concept has been proposed for both V/STOL and transonic testing where wall interference effects are large and corrections cannot be made. The tunnel walls are used actively to control the flow field, and a theoretical calculation is used in conjunction with flow-field measurements to confirm that wall interference has been minimized, if not eliminated. For the transonic case, a 2-dimensional, adaptive-wall test section is under investigation in the Calspan One-Foot Wind Tunnel. This test section is described and experimental results with a 6% blockage airfoil model are presented to demonstrate that iterative application of wall control effectively eliminates wall interference. The V/STOL application is based on the same principles as the transonic.

*Calspan Advanced Technology Center, Buffalo, NY 14221, U.S.A.

174 *Olson, L. E.; and **Stridsberg, S.: **Effect of Viscosity on Wind-Tunnel Wall Interference for Airfoils at High Lift.** Presented at the AIAA 12th Fluid and Plasma Dynamics Conference, Williamsburg, Va., July 23-25, 1979, 7 pp.

AIAA Paper 79-1534 A79-46715#

The effect of the walls of a wind tunnel on the subsonic, two-dimensional flow past airfoils at high angles of attack is studied theoretically and experimentally. The computerized analysis, which is based on iteratively coupled potential-flow, boundary-layer, and separated flow analyses, includes determining the effect of viscosity and flow separation on the airfoil/wall interaction. Predictions of the effects of wind-tunnel wall on the lift of airfoils are compared with wall corrections based on inviscid image analyses, and with experimental data. These comparisons are made for airfoils that are large relative to the size of the test section of the wind tunnel. It is shown that the inviscid image modeling of the wind-tunnel interaction becomes inaccurate at lift coefficients near maximum lift or when the airfoil/wall interaction is particularly strong. It is also shown that the present method of analysis (which includes boundary-layer and flow-separation effects) will provide accurate wind-tunnel wall corrections for the lift coefficients up to maximum lift.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.
**Flygtekniska Forsoksanstalten, Bromma, Sweden

175 *Seidel, M.; **Maarsingh, R. A.: **Test Capabilities of the German-Dutch Wind Tunnel DNW for Rotors, Helicopters, and V/STOL Aircraft.** Presented at the 5th European Rotorcraft and Powered Lift Aircraft Forum, Sept. 4-7, 1979, paper no. 17, 22 pp., 18 refs.

Langley Research Center library number CN-154,733

This paper describes some typical design features of interchangeable atmospheric test sections with cross sectional areas between 36m^2 and 90m^2 and maximum air speeds in the range of 65 to 150 m/s, slotted working sections and an air exchange system. Special attention has been given to comprehensive possibilities of aerodynamical and performance tests of rotors, helicopters and V/STOL aircraft. In view of prospective high-speed helicopters the size of the test sections had been determined in such a way that sufficiently large rotors can be tested in the whole range of actual forward speeds. The assessment of rotor testing capabilities has been supported by studies on wall interference effects taking into account such parameters as incidence correction, disc loading, model position and flow breakdown conditions. Examples are given for several V/STOL and rotor test set-ups considering different testing objectives.

*German-Dutch Wind Tunnel, Noordoostpolder, The Netherlands
**National Aerospace Laboratory NLR, Noordoostpolder, The Netherlands

176 *Shindo, S.; and *Rae, W. H., Jr.: **Recent Research on V/STOL Test Limits at the University of Washington Aeronautical Laboratory.** Final Report. NASA CR-3237, Feb. 1980, 27 pp.

N80-16068#

The occurrence of flow breakdown during the wind tunnel testing of a powered V/STOL aircraft was studied. Flow breakdown is the low forward speed test limit in a solid wall wind tunnel and is characterized by a vortex which forms on the floor and walls of the wind tunnel thereby failing to simulate free air conditions. The flow is caused by the interaction of the model wake and tunnel boundary layer and affects the model's aerodynamic characteristics in such fashion as to negate their reliability as correctable wind tunnel data. The low speed test limit was examined using a model that possessed a discretely concentrated powered lift system using a pair of lift jets. The system design is discussed and the tests and results which show that flow breakdown occurs at a velocity ratio of approximately 0.20 are reported.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Contract NGL-48-002-035

177 *Margason, R. J.; and **Hoad, D. R.: **V/STOL Aircraft Model in Wind-Tunnel Testing From Model Design to Data Reduction.** Journal of Aircraft, vol. 17, no. 3, Mar. 1980, pp. 129-135, 33 refs.

AIAA Paper 79-0332

Note: For an earlier form of this paper and an abstract see no. 171 in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.
**U.S. Army Structures Lab., Hampton, VA 23665-5225, U.S.A.

178 *Mokry, M.: **Canadian Studies of Wind Tunnel Corrections for High Angle of Attack Models.** Presented at a round table discussion following the AGARD Fluid Dynamics Symposium, Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 1, 11 pp.

N81-24121#

Wind tunnel interference studies, relating to testing of high angle of attack models, carried out in Canada during the last decade are briefly reviewed. A test section was developed which produces adequately low corrections to test data for a wide range of sizes, shapes, and angles of attack of test airfoil.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

179 *Hackett, J. E.; *Wilsden, D. J.; and *Stevens, W. A.: **A Review of the Wall Pressure Signature and Other Tunnel Constraint Correction Methods for High Angle-of-Attack Tests.** Presented at a round table discussion following the AGARD Fluid Dynamics Panel Symposium, Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angles of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 2, 16 pp.

N81-24122#

Recent developments concerning correction techniques for high angle of attack testing are reviewed and the results are presented of a letter survey on the methods now in use. The application of the wall pressure signature technique is demonstrated in experiments on several types of models. The method is shown to provide good estimates of tunnel blockage effects and extension to lift interference is discussed. It appears that correctability is limited more by the problem of determining the effects of tunnel induced velocity gradients than by ability to determine the flow field. It is suggested that passive boundary measurement technology diffuses first into high angle of attack production testing, possibly followed by partially adaptive tunnel techniques. An extensive bibliography is included.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

180 *Vaucheret, X.: **Expected Improvements on High Angle of Attack Model Testing.** (Améliorations envisagés pour résoudre les problèmes rencountrés au cours d'essais à grande incidence de maquettes en soufflerie.) Presented at a round table discussion following the AGARD Fluid Dynamics Symposium, Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 3, 22 pp. (in French). Also, Rep. no. ONERA TP-1980-36 (in French).

A80-40804# or N81-24123#

Several problems were encountered during tests at high angle of attack in wind tunnels. Selected for discussion are: wall interference, sting interference and vibrations beyond stall. State of the art wall interference correction methods, systematically applied to industrial wind tunnel walls are explained using numerous comparisons between wind tunnel data or between wind tunnel and flight data. The necessary representation of the models in free air are shown to be deficient for the case of apex vortices and jet exhausts. Simultaneously, other correction methods have been developed in France to overcome the assumptions and limitations of the classical method. Thus AMD-BA works on the vortex lattice method and ONERA on a method which uses model signatures on the test section walls. This method, already being used in 2D tests using ventilated cylindrical test sections, is extended to the 3-D case. The application of the method is further extended to deformable test section walls as a first stage toward self-streamlining test sections. In conclusion, the importance of controlled methods to evaluate the validity of wall interference correction methods is emphasized.

*ONERA, BP 72, 92322 Chatillon Cedex, France

181 *Holst, H.: **German Activities on Wind Tunnel Corrections.** Presented at a round table discussion following the AGARD Fluid Dymnamics Symposium, Munich, Germany, May 8, 1980, In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 4, 23 pp.

N81-24124#

Wind tunnel interference factors were calculated for open, closed, slotted, and perforated walls using the vortex lattice method with a homogeneous boundary condition. A more realistic pitching moment correction is obtained when the lift dependent relocation of the trailing vortices is taken into account. The inhomogeneities of lift and blockage interference parameters throughout the test section were investigated for models large in comparison to the test section dimensions. A method was developed using measured wall pressures for the correction of drag in transonic wind tunnels. For closed test sections, the image method and a modified vortex lattice method were used to evaluate wall pressure signals for correction purposes.

*DFVLR, Bunsenstrasse 10, D-3400 Goettingen, West Germany (FRG)

182 *Maarsingh, R. A.: **A Review of Research at NLR on Wind-Tunnel Corrections for High Angle of Attack Models.** Presented at a round table discussion following the AGARD Fluid Dynamics Symposium, Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692, (N81-24120), Feb. 1981, paper no. 5, 11 pp. Also, Rep. no. NLR-MP-80016-U, 19 refs.

N81-24125# or N81-27067#

A survey is given of past, current, and planned work at NLR in the field of wind tunnel wall interference on models at high angles of attack at low subsonic speeds. Among long term research activities those concerning slotted wall test sections play a dominant part. It is felt that an approach which makes use of measured distributions of flow quantities near the walls is the most promising one. It may be recommended also as a short term solution for some special wall correction problems arising from modern low speed wind tunnel testing in closed test sections.

*National Aerospace Lab., 1059 CM, Anthony Fokkerweg 2, Amsterdam, The Netherlands

183 *Nyberg, S.-E.: **A Review of Some Investigations on Wind Tunnel Wall Interference Carried Out in Sweden in Recent Years.** Presented at a round table discussion following the AGARD Fluid Dynamics Symposium in Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 6, 9 pp., 16 refs.

N81-24126#

For subsonic incompressible flow the mutual circulation induced model wind tunnel interference was calculated by panel methods for large multicomponent two dimensional airfoils for three dimensional swept wings, full or half models, and for wing-tail configurations. Wake blockage effects from a swept wing with and without high lift devices were studied experimentally. The effects of air flow leakage between half model fuselage and reflection wall were investigated. For transonic flow the flow properties of slotted walls and the influence of wall boundary layer were studied. Based on these results a numerical method was developed and axisymmetric calculations were carried out. The results were compared with experimental results for large blockage models.

*Aeronautical Research Institute of Sweden, P. O. Box 11021, S161 11 Bromma, Sweden

184 *Young, A. D.: **Wind Tunnel Corrections for High Angles of Attack: A Brief Review of Recent UK Work.** Presented at a round table discussion following the AGARD Fluid Dynamics Symposium, Munich, Germany, May 8, 1980. In: Wind Tunnel Corrections for High Angle of Attack Models, AGARD-R-692 (N81-24120), Feb. 1981, paper no. 7, 11 pp.

N81-24127#

The use of adaptive walls, a panel method of model and wake representation for a two dimensional model in a wind tunnel with solid walls, the use of measured pressure distributions on tunnel floor and roof also for a two dimensional model and solid walls, a vortex lattice representation of the tunnel walls to take account of wake curvature, interference limitations on tests on V/STOL models with lifting jets, and work on blockage corrections on models with reverse thrust are discussed. Some discussion is offered on the limitations on the validity of current methods for determining wind tunnel corrections and it is argued that these limitations are least severe with the use of adaptive walls.

*Queen Mary College, London University, Mile End Road, London, U.K.

185 *Gruen, N.: **Theoretical and Experimental Investigations of Wind Tunnel Interference Due to Angle of Attack.** Rep. no. MBB-FE-124/S/PUB/34, Aug. 29, 1980, 145 pp. (in German).

N82-21226#

Using wall pressure measurements, recorded simultaneously with model tests, corrections for model surface pressures are calculated. The difference between experimental wall pressure coefficients and computed free flight pressure coefficient distributions is used as a criterion for the wall interference on the tunnel flow. An evaluation of the wall pressure curves shows that their general shape is predetermined by the empty tunnel and the model support, respectively. Increasing the model angle of attack primarily causes a shift and a change in the gradient of these curves. The calculated free flight pressure coefficients are found to be very small compared to measured values. In order to find the pressure coefficient differences along the tunnel axis, a flow model is established which shows the previously computed differences in pressure coefficients on an imaginary wall at the location of the tunnel wall. The propagation of these disturbances to the tunnel axis is calculated using the finite element method. Results are used to correct measured coefficients for lift, drag and pitching moment.

*Messerschmitt-Boelkow-Blohm G.m.b.H., Ottobrunn Postf. 801220, D-8000 Munchen 80, West Germany

186 *Shindo, S.; and *Joppa, R. G.: **An Experimental Investigation of Three Dimensional Low Speed Minimum Interference Wind Tunnel for High Lift Wings.** NASA CR-164439, Sept. 1980, 24 pp.

N81-25037#

As a means to achieve a minimum interference correction wind tunnel, a partially actively controlled test section was experimentally examined. A jet flapped wing with 0.91 m (36 in.) span and AR = 4.05 was used as a model to create moderately high lift coefficients. The partially controlled test section was simulated using an insert, a rectangular box 0.96 x 1.44 m (3.14 x 4.71 ft.) open on both ends in the direction of the tunnel air flow, placed in the University of Washington Aeronautical Laboratories (UWAL) 2.44 x 3.66 m (8 x 12 ft) wind tunnel. A tail located three chords behind the wing was used to measure the downwash at the tail region. The experimental data indicates that, within the range of momentum coefficient examined, it appears to be unnecessary to actively control all four sides of the test section walls in order to achieve the near interference free flow field environment in a small wind tunnel. The remaining wall interference can be satisfactorily corrected by the vortex lattice method.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant NsG-2260

187 *Seidel, M.: **The German-Dutch Wind Tunnel. (Stichting Duits-Nederlandse Windtunnel Emmeloord, Netherlands).** Presented at Bundesministerium fuer Forschung und Technologie, Statusseminar zur Luftfahrtforschung und Luftfahrttechnologie, 2nd, Garmisch-Partenkirchen, West Germany, Oct. 8, 9, 1980, DCAF A002631, 27 pp. (in German).

A81-37652#

The German-Dutch Wind Tunnel is Europe's largest and most modern subsonic wind tunnel. It was completed in August 1980, after a construction period of four years. The wind tunnel was developed in the first joint project in Europe related to the area of large-scale aerodynamic testing installations. Characteristic features of the wind tunnel are its four exchangeable test sections with measuring cross sections in the range from 36 to 90 m. Wind velocities up to 540 km/h can be employed. The tunnel is, therefore, eminently suited for studies concerning the start and landing phase of large airliners and for investigations involving helicopters and the conduction of dynamic measurements. The standard sting allows for models to be placed at extreme positions, angle of attack ±45°, angle of yaw ±30°, and can be used in connection with a movable belt ground plane. Maximum vertical loads are ±65kN.

*German-Dutch Wind Tunnel, Noordoostpolder, The Netherlands
Research supported by the Bundesministerium fuer Forschung und Technologie

188 *Chan, Y. Y.: **Lift Effect on Transonic Wind-Tunnel Blockage.** Journal of Aircraft, vol. 17, no. 12, Dec. 1980, pp. 915-916.

A81-15883#

Perturbation analysis of wind-tunnel wall interference to the airfoil in transonic flows is used to determine an effective flow displacement due to lift as induced by the nonlinear compressibility condition. This effective flow displacement is significant compared to that due to the geometrical area of the airfoil, especially at high lift and a freestream Mach number close to unity. An approximate relation in the form of an effective doublet is derived for this effect; it can be applied directly in the blockage calculation.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

189 *Hackett, J. E.; *Sampath, S.; and Phillips, C. G.: **Determination of Wind Tunnel Constraint Effects by a Unified Pressure Signature Method. Part 1: Applications to Winged Configurations. Final Rept. Oct. 1980 - Nov. 1981.** NASA CR-166186, LG81ER0166-pt.1, June 1981, 185 pp.

N82-23234#

A new, fast, non-iterative version of the 'Wall Pressure Signature Method' is described and used to determine blockage and angle-of-attack wind tunnel corrections for highly-powered jet-flap models. The correction method is complemented by the application of tangential blowing at the tunnel floor to suppress flow breakdown there, using feedback from measured floor pressures. This tangential blowing technique was substantiated by subsequent flow investigations using an LV. The basic tests on an unswept, knee-blown, jet flapped wing were supplemented to include the effects of slat-removal, sweep and the addition of unflapped tips. C_{mu} values were varied from 0 to 10 free-air C_l's in excess of 18 were measured in some cases. Application of the new methods yielded corrected data which agreed with corresponding large tunnel 'free air' results to within the limits of experimental accuracy in almost all cases. A program listing is provided, with sample cases.

*Lockheed Georgia Co., Marietta, GA 30060, U.S.A.
Contract NAS2-9883

190 *Margason, R. J.: **Jet V/STOL Wind Tunnel Simulation and Groundplane Effects.** In: Proceedings of the Symposium on Fluid Dynamics of Jets With Applications to V/STOL, AGARD-CP-308, (N82-23150), held at Lisbon, Nov. 2-5, 1981, paper no. 15, 21 pp.

N82-23165#

Note: This complete symposium is included as no. A28 in this bibliography.

The pretest preparation necessary to define the objectives of an appropriate investigation into the jet V/STOL wind tunnel simulation and ground plane effects were examined. Low speed wind tunnel testing of V/STOL aircraft concepts to determine the aerodynamic propulsion interaction effects during the transition between hover and wingborne flight is a necessary step in the development cycle of this type of aircraft. Powered models are normally used to determine the aerodynamic performance characteristics. Several factors which influence the selection of the model concept and the engine simulator are discussed. Some of the test techniques important for this class of aircraft model are examined. Wind tunnel wall effects important to this aircraft testing with special emphasis on groundplane effects are reviewed.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.

191 *Hackett, J. E.: **Living With Solid-Walled Wind Tunnels.** AIAA 12th Aerodynamic Testing Conference, Williamsburg, Va., Mar. 21-24, 1982, 40 pp., 24 refs. (Invited paper).

AIAA Paper 82-0583

The effectiveness of existing, solid-walled low-speed wind tunnels can be increased substantially if tunnel constraint effects can be calculated reliably for unusually large models and for 'problem' flow conditions such as tunnel flow breakdown. Tests on basic models are described which demonstrate that constraint corrections may be estimated accurately using wall pressure 'signatures' for frontal area ratios up to 10%. Application of these methods to highly-powered knee-blown jet-flap models was successful to lift levels somewhat above the accepted flow breakdown limit. Beyond this, it is shown that the addition of tangential blowing, along the tunnel floor, eliminates the separation described of a new, curved-plume, vortex-force-doublet flow model for estimating the constraint effects for jets-in-crossflow. It is shown that, unlike existing jet-constraint flow models, tunnel wall pressures (and by implication tunnel constraint effects) are predicted successfully by the new model. The effects of aerodynamic "stiffness," observed for highly powered plumes and wakes, are discussed in relation to the constraint correction process.

*Lockheed Georgia Co., Marietta, GA 30060, U.S.A.

192 *Schulz, G.: **A Universal Three-Dimensional Wall Pressure Correction Method for Closed Rectangular Subsonic Wind Tunnel Test Sections. (Displacement, Downwash, Stream Line Curvature).** DFVLR-FB-82-19, Apr. 1982, 76 pp. (In German.)

N83-17516#

Note: For an English translation and an abstract see no. 199 in this bibliography.

*Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Oberpfaffenhofen (West Germany)

193 *Vaucheret, X.: **Corrections for Wall Effects in ONERA Industrial Wind Tunnels.** (Améliorations des calculs des effets de parois dans les souffleries industrielles de l'ONERA). Presented at the NATO, AGARD Meeting on Prediction of Aerodynamic Loads on Rotorcraft, London, England, May 17-19, 1982. ONERA-TP-1982-34, 1982, 13 pp., 11 refs. In French. Also: Presented at the AGARD Fluid Dynamic Specialists' Meeting on May 19-20, 1982 and published in AGARD-CP-335, Paper no. 11 (N83-20968#), 12 pp. In French.

A82-42810# or N83-20968

Note: For an English translation and an abstract see no. 195 in this bibliography.

*ONERA, BP 72, 92322 Chatillon Cedex, France

194 *Sears, W. R.: **Wind-Tunnel Testing of V/STOL Configurations at High Lift.** Presented at the 13th Congress of International Council of the Aeronautical Sciences (ICAS)/AIAA Aircraft Systems & Technology Meeting, Seattle, Wash., Aug. 22-27, 1982. In: Proceedings, vol. 1. (A82-40876); AIAA, 1982, pp. 720-730.

ICAS-82-5.4.1 A82-40949#

Note: For a later version of this paper see no. 201 in this bibliography.

The concept of adaptive wind-tunnel walls is utilized to eliminate, along with boundary interference, the inaccuracies of the usual tunnel calibration. Some numerical models of adaptive-wall tunnels are described and it is shown that the undisturbed stream direction and magnitude, arbitrarily chosen, are achieved by the iterative process of such a tunnel. The use of this type of tunnel in an extreme case is demonstrated by constructing and model testing an approximate panel representation of a jet-flap wing of finite span. The demonstration is completely successful, suggesting that the new tunnel would solve the recurring problem of V/STOL testing.

*Univ. of Arizona, Tuscon, AZ 85721, U.S.A.
Contract N00014-79-C-0010

195 *Vaucheret, X.: **Wall Interference Correction Improvements for the ONERA Main Wind Tunnels.** This is an English translation of a paper presented at NATO AGARD Meeting on Prediction of Aerodynamic Loads on Rotorcraft, London, England, May 17-19, 1982. Translation by Kanner (Leo) Associates, Redwood City, Calif.; NASA TM-76971, Aug. 1982, 24 pp.

N83-33908#

Note: For the original French form see no. 193 in this bibliography.

This paper describes improved methods of calculating wall interference corrections for the ONERA large windtunnels. The mathematical description of the model and its sting support have become more sophisticated. An increasing number of singularities is used until an agreement between theoretical and experimental signatures of the model and sting on the walls of the closed test section is obtained. The singularity decentering effects are calculated when the model reaches large angles of attack. The porosity factor cartography on the perforated walls deduced from the measured signatures now replaces the reference tests previously carried out in larger tunnels. The porosity factors obtained from the blockage terms signatures at zero lift) and from the lift terms are in good agreement. In each case (model + sting + test section) wall corrections are now determined, before the tests, as a function of the fundamental parameters M, C_X, C_Z. During the windtunnel tests, the corrections are quickly computed from these factors.

*ONERA, BP 72, 92322 Chatillon Cedex, France
Contract NASw-3541

196 *Mueller, B.: **Singularity Model for the Analysis of Wall Interference in Closed Wind Tunnels According to the Wall Pressure Signature Method (Blockage and Lift).** Singularitaeten-Modell zur Analyse der Wandinterferenz in geschlossenen Windkanaelen auf der Grundlage von Wanddruckmessungen. (Blockier- ung und Auftrieb). Rep. no. FW-FO-1612, Sept. 2, 1982, 91 pp. In German.

N85-12874#

Correction methods for wall influence in large wind tunnels are considered. Tunnel blockage up to any desired angle of attack was determined by mathematically modeled wall pressure signatures. A qualitative definition of blockage and lift correction is obtained by a swell/drop and vortex modeling for typical aircraft models.

*Versuchs- und Forschungsanlage, Eidgenoessisches Flugzeugwerk, Emmen, Switzerland

197 *Wilsden, D. J.; and *Hackett, J. E.: **Tunnel Constraint for a Jet in Crossflow.** In: Wind Tunnel Wall Interference Assessment and Correction, 1983. A workshop at NASA Langley Research Center, Hampton, Va., Jan. 25-26, 1983. NASA CP-2319, (N85-12011#), pp. 273-290.

N85-12027#

A facet of a unified tunnel correction scheme which uses wall pressures to determine tunnel induced blockage and upwash is described. With this method, there is usually no need to use data concerning model forces or power settings to find the interference; it follows directly from the pressures and tunnel dimensions. However, highly inclined jets do not produce good pressure signatures and are highly three dimensional, so they must be treated differently. Flow modeling is also discussed.

*Lockheed-Georgia Co., Marietta, GA 30060, U.S.A.

198 *Vogelaar, H. L. J.: **Description and Validation of the Two Dimensional Test Setup for Multiple Airfoils in the Pressurized Wind Tunnel HST.** NLR-TR-83031-U, March 18, 1983, 36 pp.

N84-29892#

The two-dimensional setup in the pressurized wind tunnel (HST) for the testing of multiple airfoils at high Reynolds numbers is described. Results of tests with this setup were validated by tests performed in the HST and in an atmospheric wind tunnel. The tunnel wall boundary layer control system and the tunnel wall correction method are outlined. Results of model deformation tests are discussed.

*National Aerospace Laboratory, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

199 *Schulz, G.: **A Universal 3-Dimensional Wall Pressure Correction Method for Closed Rectangular Subsonic Wind Tunnel Test Sections (Displacement, Downwash, Streamline Curvature).** Translation into English of the German Rep. no. DFVLR-FB-82-19. ESA-TT-800, June 1983, 74 pp.

N84-22588#

Note: For the original German form see no. 192 in this bibliography.

A wall pressure correction method for closed rectangular subsonic test sections, which corrects displacement, downwash, and streamline curvature for models of arbitrary size, shape, position and bulkiness is presented. The number of wall measuring points required is kept small so that the test duration need not be increased because of the correction. This is achieved by the selection of special wall pressure locations. The method can be extended to tunnels of any cross section. Experimental results are good for high lift measurements, and especially so for blockage correction in the presence of large wake regions behind the model.

*Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Oberpfaffenhofen, West Germany

200 *Mueller, B.: **Wall Influence Corrections in Wind Tunnels: Blockage Correction According to the Wall Pressure Signature Method.** (Wandeinfluss-korrekturen in Windkanaelen: Blockierungskorrektur nach der Wandrucksignatur-Methode) Rep. no. FW-FO-1613; Sept. 14, 1983, 60 pp. In German.

N85-12875#

Blockage correction methods for large models or high angles of attack in closed wind tunnels are discussed. The wall pressure signature method based on a FORTRAN program was used. A correction calculation without computing of problem parameters is outlined.

*Versuchs- und Forschungsanlage, Eidgenoessisches Flugzeugwerk, Emmen, Switzerland

201 *Sears, W. R.: **Adaptable Wind Tunnel For Testing V/STOL Configurations at High Lift.** Journal of Aircraft, vol. 20, Nov. 1983, pp. 968-974.

A84-11048#

For an earlier form of this paper and an abstract see no. 194 in this bibliography.

*Univ. of Arizona, Tucson, AZ 85721, U.S.A.
Contract N00014-79-C-0010

202 *Snyder, L. D.; and **Erickson, L. L.: **PAN AIR Prediction of NASA Ames 12-Foot Pressure Wind-Tunnel Interference on a Fighter Configuration.** Presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nev., Jan 9-12, 1984, 17 pp.

AIAA Paper 84-0219 A84-19243#

Models tested in the NASA Ames 12-Foot Pressure Wind Tunnel over an angle of attack range from 0 deg to 90 deg are mounted on a floor strut that protrudes from a fairly large support bump. In high-angle-of-attack tests (angle of attack = 40 deg to 90 deg), for which the floor support was originally designed, the effects of the flow angularities produced by the bump are often negligible. This is not so for low-angle-of-attack tests (0 deg to 40 deg). Since there are no standard means for correcting test data for this bump effect, low-angle-of-attack testing with the bump is not recommended by the Ames wind-tunnel staff. This paper presents an exploratory study of a technique for correcting balance forces and experimental pressures for combined wall and bump effects. This is done by modeling the aircraft, wind-tunnel walls, and bump, with PAN AIR. The wall-and-bump-induced increments in the lift coefficient and pitching-moment coefficient predicted by PAN AIR are compared with increments obtained from the Ames 12-foot tunnel with the bump and an 8 x 12 low speed wind tunnel which has no bump.

*General Dynamics Fort Worth Division, P. O. Box 748, Fort Worth, TX 76101, U.S.A.
**NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

203 *Loeffler, A. L., Jr.; and **Steinhoff, J. S.: **Computation of Wind Tunnel Wall Effects in Ducted Rotor Experiments.** Presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nev., Jan. 9-12, 1984, 7 pp., 9 refs.

AIAA Paper 84-0241 A84-17969#

Note: For a later version of this paper see no. 214 in this bibliography.

It is pointed out that ducted propulsion and power extraction systems are particularly sensitive to wind tunnel wall interference effects because much of their effectiveness depends on streamtube shapes before and behind the duct. In the case of 'open' bodies such as ducted propellers, flow blockage effects due to both the ducted rotor body and its wake should be taken into consideration. The present investigation is concerned with the use of the method of multiple images to predict closed wind tunnel interference effects which occur in testing models of two advanced ducted rotor concepts. The considered concepts include a diffuser augmented propeller propulsion system and a diffuser augmented turbine wind energy conversion system.

*Grumman Aerospace Corp., 1111 Stewart Ave., Bethpage, NY 11714, U.S.A.
**Univ. of Tennessee, Tullahoma, TN 37388, U.S.A.

204 *Starr, R. F.; and *Varner, M. O.: **Application of the Adaptive Wall to High-Lift Subsonic Aerodynamic Testing -- An Engineering Evaluation.** Presented at the AIAA 13th Aerodynamic Testing Conference, San Diego, Calif., Mar. 5-7, 1984. In: Technical Papers, (A84-24176), pp. 284-291.

AIAA Paper 84-0626 A84-24204#

The streamline curvature around high-lift airfoils at low-speed conditions is reviewed to assess adaptive wall requirements for a three-dimensional test section. High-lift flapped airfoil cases ($C_L \sim 4$) with large flow separation zones and an extreme blown flap airfoil ($C_L \sim 12$) are considered. An engineering configuration for the adaptive wall test section, accounting for model to tunnel span, wind chord to tunnel height, lifting area to test section cross sectional area, and test section to wing chord length ratio, is developed. The multi-element adaptive wall selected is shown to meet deflection and radius of curvature requirements for the extreme lift, low advance ratio cases evaluated. Test sections about one-quarter of the cross sectional area of present moderate lift, low-speed testing tunnels can be utilized without blockage induced errors. Preliminary results indicate that blockage induced errors can be minimized even with flow impingement at the test section wall.

*Sverdrup Technology, Inc., 600 William Northern Blvd., P. O. Box 884, Tullahoma, TN 37388, U.S.A.

205 *Proctor, J. G.: **Wall Pressure Signature Wind-Tunnel Wall-Constraint Correction Methods.** BAe-ARG-188, Apr. 1984, 42 pp.

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Three methods of wall-constraint correction using boundary measurements of static pressure are assessed. The procedures offer an alternative to conventional theoretical techniques in areas of relative uncertainty such as very high incidence testing. It is recommended that a short test program to study the practicalities of an on-line matrix method be implemented in a 2.7 x 2.1m low speed wind tunnel.

*British Aerospace Aircraft Group, Wind Tunnel Dept., Warton Aerodrome, Preston, PR4 1AX, Lancashire, U.K.

206 *Ransom, E. C. P.; and *Smy, J. R.: **Introduction and Review of Some Jet Interference Phenomena Relevant to V/STOL Aircraft.** In: Special Course on V/STOL Aerodynamics, AGARD-R-710, (N84-25625), Apr. 1984; held at Rhode St. Genèse, Belgium, May 14-18, 1984; and at NASA Ames Research Center, Moffett Field, Calif., June 4-8, 1984; paper no. 2, 23 pp.

N84-25626#

This introductory paper summarizes and discusses aspects of some fluid flows relevant to V/STOL aircraft. The principal sources of reference are the contributions to AGARD conferences which have been specifically concerned with V/STOL aerodynamics. Initially, consideration has been given to the behavior of single axisymmetric jets discharging into stationary surroundings and the creation of the corresponding flow field. The effect that a change of fluid properties has on the flow field and plume development is then described and is extended to include jets discharging into a cross flow and into a coflowing stream. The aerodynamics of jets impinging on adjacent surfaces are reviewed with particular reference to induced lift losses generated during hovering in ground effect, to ground erosion and to recirculation. Internal fluid flows in thrust augmentors are described including the effect of losses, and the generation of unsteady flows which are used to enhance mixing rates. The paper concludes with a brief discussion of modelling techniques and wind tunnel methods including interference effects.

*Kingston Polytechnic, Canbury Park, Rd., Kingston-Upon-Thames, KT2 6LA, U.K.

207 *Koenig, D. G.: **V/STOL Wind-Tunnel Testing.** In: Special Course on V/STOL Aerodynamics, AGARD-R-710, (N84-25625), Apr. 1984; held at Rhode St. Genèse, Belgium, May 14-18, 1984; and at NASA Ames Research Center, Moffett Field, Calif, June 4-8, 1984; paper no. 9, 74 pp., 135 refs. Also published as NASA TM-85936, May 1984.

N84-25633# or N84-24528

Factors influencing effective program planning for V/STOL wind-tunnel testing are discussed. The planning sequence itself, which includes a short checklist of considerations that could enhance the value of the tests, is also described. Each of the considerations, choice of wind tunnel, type of model installation, model development and test operations, is discussed, and examples of appropriate past and current V/STOL test programs are provided. A short survey of the moderate to large subsonic wind tunnels is followed by a review of several model installations, from two-dimensional to large-scale models of complete aircraft configurations. Model sizing, power simulation, and planning are treated, including three areas in test operations: data-acquisition systems, acoustic measurements in wind tunnels, and flow surveying.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

208 *Joppa, R. G.; and **Parikh, P. C.: **Numerical Simulation of Controlled Flow Tunnel for V/STOL Testing.** Presented at the AIAA 2nd Applied Aerodynamics Conference, Seattle, Wash., Aug. 21-23, 1984, 10 pp.

AIAA Paper 84-2152 A84-41330#

Note: For a later form of this paper see no. 222 in this bibliography.

A 'smart' wind tunnel concept for V/STOL transition regime studies is presented and performance is projected with numerical simulations. The wind tunnel would provide a flow that faithfully represents free air flow and thereby permits accurate lift calculations for V/STOL aircraft. The design concept is based on free-air tunnels used for planar wings. Modifications are necessary to account for the highly deflected, vortical wake produced in low-speed take-off and landing situations. A three-step numerical procedure covering the potential flow of a high lift system in free air, controlled flow data with a model in a wind tunnel and addition of the wall conditions to the simulation as a feedback loop to correct the closed-tunnel is described. The initial simulation is for three-dimensional full span jet flapped wings, and is derived from extended two-dimensional calculations. The results indicate that only partial control of the tunnel flow is sufficient to serve as a valid environment for V/STOL studies.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant NSG-2260

209 *National Aerospace Lab., Tokyo, Japan: **Low-Speed Wind Tunnel Tests of the NAL Fan-Jet STOL Research Aircraft Model With Ground Simulation by Tangential Blowing.** NAL-TR-828, Aug. 1984, 109 pp. In Japanese.

ISSN-0389-4010 N85-18976#

To investigate the basic aerodynamic characteristics of the turbofan powered lift STOL aircraft near the ground, wind tunnel tests were made on a the 8% NAL Quiet STOL Research Aircraft complete with an upper surface blowing flap system in the NAL 6.5 m x 5.5 m low speed wind tunnel. The wind tunnel tests were conducted using a fixed ground plane with tangential blowing boundary layer control instead of a moving belt ground plane. The tests covered the effects on longitudinal and lateral static stability produced by variations of flap angle and engine thrust, and by ground proximity. It appears that the report discusses the simulation of ground effect and the application of wall corrections to ground effect data.

*National Aerospace Laboratory, 1880 Jindaiji-machi, Chofu-shi, Tokyo 182, Japan

210 *Labrujere, Th.E.; *Maarsingh, R. A.; and *Smith, J.: **Wind Tunnel Wall Influence Considering 2D High Lift Configurations.** International Council of the Aeronautical Sciences, Congress, 14th Toulouse, France, Sept. 9-14, 1984, Proceedings, Vol. 1, (A84-44926), 1984, pp. 76-84.

A84-44935#

Note: For a later form of this report see no. 219 in this bibliography.

Two alternative correction methods are described for wall interference based on measured boundary conditions. In both methods it is assumed that at or near the tunnel boundary the flow velocity will be measured in magnitude and direction and the main part of the flowfield may be considered irrotational and subsonic. One method aims at a correction in terms of changes in free velocity and angle of attack; the other at corrections of the velocity distribution along the model. The application of both methods is demonstrated numerically for single- and multiple-airfoil cases in a solid wall test section.

*National Aerospace Laboratory, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

211 *Li, J.; and *Qi, M.: **Wall Lift Interference Corrections in Ground Effect Testing.** In: Acta Aerodynamica Sinica, no. 4, 1984, pp. 93-97, 6 refs. In Chinese.

85-35781# or N86-23575 (English)

Note: For an English translation see no. A37 in this bibliography.

The wall lift interference parameters on ground effects for octagonal closed wind tunnels has been derived using image vortex systems. The fillet vortex system can be added to rectangular tunnel vortex system. The vortex lattice method can be used to determine fillet vortex strength. It has been found that the wall lift interference corrections on ground effect have related to not only the wall upwash and streamline curvature effects, but also the normal gradient of the upwash velocity at the horizontal tail. (Includes mathematical equations and graphs.)

*Nanjing, Aeronautical Intitute, Nanjing, People's Republic of China

212 *Parikh, P. C.: **A Numerical Study of the Controlled Flow Tunnel for a High Lift Model.** NASA CR-166572, 1984, 120 pp. (Also Ph.D. Thesis, Univ. of Washington, 1984, Available from Univ. Microfilms, Order No. DA8404937.)

N84-25642#

A controlled flow tunnel employs active control of flow through the walls of the wind tunnel so that the model is in approximately free air conditions during the test. This improves the wind tunnel test environment, enhancing the validity of the experimentally obtained test data. This concept is applied to a three dimensional jet flapped wing with full span jet flap. It is shown that a special treatment is required for the high energy wake associated with this and other V/STOL models. An iterative numerical scheme is developed to describe the working of an actual controlled flow tunnel and comparisons are shown with other available results. It is shown that control need be exerted over only part of the tunnel walls to closely approximate free air flow conditions. It is concluded that such a tunnel is able to produce a nearly interference free test environment even with a high lift model in the tunnel.

*Univ. of Washington, Seattle, WA 98195, U.S.A.
Grant NSG-2260

213 *Gaffney, R. L., Jr.; *Hassan, H. A.; **Salas, M. D.: **Assessment of Wind Tunnel Corrections for Multielement Airfoils at Transonic Speeds.** In: Symposium on Numerical and Physical Aspects of Aerodynamic Flows, 3rd, Long Beach, Calif., Jan. 21-24, 1985. Proceedings, (A85-42951), California State Univ., Long Beach, Calif., 1985, pp. 4-35 to 4-41.

A85-42968#

A finite volume formulation of the Euler equations using Cartesian grids is used to calculate the transonic flow over multielement airfoils and to use the resulting solutions to assess wall interference effects in wind tunnels. Available methods and recommendations for evaluating such effects, which are based on shifts in Mach number and angle of attack, are examined and the results are compared with measurements using the flapped supercritical SKF 1.1 airfoil. Based on the calculations, it is concluded that shifts in Mach number and angle of attack cannot by themselves account for viscous and wall effects on multielement airfoils at transonic speeds.

*North Carolina State Univ., Raleigh, NC 27695, U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.
Grant NCC1-22

214 *Loeffler, A. L., Jr.; and **Steinhoff, J. S.: **Computation of Wind Tunnel Wall Effects in Ducted Rotor Experiments.** Journal of Aircraft, vol. 22, Mar. 1985, pp. 188-192, 9 refs.

A85-26755#

Note: For an earlier form of this paper and an abstract see no. 203 in this bibliography.

*Grumman Aerospace Corp., Bethpage, NY 11714, U.S.A.
**Univ. of Tennessee, Tullahoma, TN 37388, U.S.A.

215 *Rossow, V. J.: **Effect of Ground and/or Ceiling Planes on Thrust of Rotors in Hover.** NASA TM-86754, July 1985, 41 pp.

Note: See the following entry for another form of this report.

The thrust produced by a helicopter rotor hovering near ground and/or ceiling planes is investigated experimentally and theoretically. In the experiment, the thrust was measured on the 0.324-m-diam. rotor operating between floor and ceiling planes which were located from 6 to 0.08 diam. from the rotor disk. In the first theoretical model studied, the incompressible and inviscid flow induced by a sequence of vortex cylinders, located above and below the rotor to simulate the rotor wake and its interaction with the floor and ceiling planes, was considered. Comparison with experiment showed that this model overpredicts the change in thrust caused by the proximity of the walls. Therefore, a second arrangement of vortex cylinders was introduced which provides a more accurate prediction of the ground and ceiling effects on the thrust of the rotor in hover. The applicability of these results to a vented wind tunnel is also discussed.

*NASA Ames Research Center, Moffet Field, CA 94035, U.S.A.

216 *Rossow, V. J.: **Thrust Changes Induced by Ground and Ceiling Planes on a Rotor in Hover.** Journal of the American Helicopter Society, vol. 30, July 1985 pp. 53-55.

ISSN 0002-8711 A85-43223

Note: See the previous entry in this bibliography for another form of this paper.

The thrust produced by a helicopter motor in hover has been studied by measuring the thrust on a model rotor 0.234 meters in diameter operating between ground and ceiling planes. The distance between the two planes and the rotor disk was in the range of 0.08-6.0 rotor diameters. It was found that the confining surfaces changed the rotor thrust almost linearly with the logarithm of the distance from the confining surface. When both planes were near the rotor the variation was no longer linear. The measured thrust of the rotor was compared to predictions based on the theoretical calculations of Rossow (1985), and the results are given in a table.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

217 *Ashill, P. R.; and *Keating, R. F. A.: **Calculation of Tunnel Wall Interference From Wall-Pressure Measurements.** RAE TR 85086; Aero 3615; Oct. 1985, 65 pp., 18 refs.

A method is described for calculating wall interference in solid-wall wind tunnels from measurements of static pressures at the walls. Since it does not require a simulation of the model flow, the technique is particularly suited to determining wall interference for complex flows such as those over VSTOL aircraft, helicopters and bluff shapes (eg. cars and trucks). An experimental evaluation shows that the method gives wall-induced velocities which are in good agreement with those of existing methods in cases where these techniques are valid, and illustrates its effectiveness for inclined jets which are not readily modelled.

*Royal Aircraft Establishment, Bedford, Beds, U.K.

218 *Zhou, C.: **An Integral Method of Wall Interference Correction for Low Speed Wind Tunnel.** Acta Aerodynamica Sinica, no. 2, 1985, pp. 1-9. In Chinese.

A85-38962#

The analytical solution of Poisson's equation, derived from the definition of vortex, has been applied to the calculations of interference velocities due to the presence of wind tunnel walls. This approach, called the Integral Method, allows an accurate evaluation of wall interference for separated or more complicated flows without the need for considering any features of the model. All the information necessary for obtaining the wall correction is contained in wall pressure measurements. The correction is not sensitive to normal data-scatter, and the computations are fast enough for on-line data processing.

*Shenyang Aeronautics and Aerodynamics Research Institute, Shenyang, People's Republic of China

219 *Labrujere, Th. E.; *Maarsingh, R. A.; and *Smith, J.: **Wind Tunnel Wall Influence Considering Two-Dimensional High-Lift Configurations.** Journal of Aircraft, vol. 23, Feb. 1986, 7 pp., 4 refs.

A86-23187#

Note: For an earlier form and an abstract of this paper see no. 210 in this bibliography.

*National Aerospace Laboratory, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

220 *Mort, K. W.; *Soderman, P. T.; and *Meyn, L. A.: **Optimum Full-Scale Subsonic Wind Tunnel.** Presented at AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., Mar. 5-7, 1986, 64 refs.

AIAA-86-0732

The needs and reasons for performing full-scale subsonic research have been studied. Full-scale wind tunnel requirements are described; recommended size, airspeed, acoustic capabilities, and flow quality are developed; and data- acquisition systems, productivity, automation, and some cost elements are discussed. It is proposed that the optimum full scale, subsonic wind tunnel be large enough to accommodate aerodynamic and acoustic investigations on most advanced aircraft, which exhibit complex engine/lifting-surface flow-field interactions, including advanced rotorcraft.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

221 *Wood, N. J.; and **Rogers, E. O.: **An Estimation of the Wall Interference on a Two-Dimensional Circulation Control Airfoil.** AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., Mar. 5-7, 1986. Technical Papers, pp. 57-63.

AIAA Paper 86-0738 A86-24732#

Tests in two different wind tunnels of the same series of circulation control airfoils has provided insight into the nature of tunnel wall interference on the data obtained from high lift airfoils. In particular, strong influence of the chord-to-height ratio is shown - in this case a 23 percent difference in the apparent (uncorrected) sensitivity of lift to jet momentum level. These performance changes are found to arise from differences in effective incidence and a correlation with existing interference theory is established. Substantiation of a simple technique (inviscid pressure distribution matching) for identifying the effective angle of attack directly from airfoil data is obtained by demonstrating a collapse of data from the two wind tunnels. As an important contribution to the aerodynamics of circulation control airfoils, the correction of the angle of attack to free air conditions has indicated that the mid-chord pitching moment is essentially decoupled from the blowing momentum.

*Stanford Univ., Palo Alto, CA 94305-2186, U.S.A.
**David W. Taylor Naval Ship Research and Development Center, Bethesda, MD 20084, U.S.A.

222 *Parikh, P. C.; and **Joppa, R. G.: **Numerical Simulation of a Controlled-Flow Tunnel for V/STOL Testing.** Journal of Aircraft, Vol. 23, Mar. 1986, pp. 186-191, 14 refs.

ISSN 0021-8669 A86-28561#

Note: For an earlier form of this report see no. 208 in this bibliography.

A controlled-flow tunnel employs active control of flow through the walls of the wind tunnel so that the model is in approximate free-air conditions during the test. This is achieved by injecting into or extracting from the test section walls the required quantity of air to match the free-air conditions. In the present study, this concept is explored for a three-dimensional jet flapped wing using numerical simulations. An iterative scheme is developed to simulate the working of a controlled-flow tunnel and comparisons are made with other results where available. It is shown that control need be exerted over only part of the tunnel walls to closely approximate free-air flow conditions. The attractiveness of the scheme lies in its ability to provide a low-interference test environment for V/STOL testing.

*Vigyan Research Associates, Inc., 28 Research Drive, Hampton, VA 23666, U.S.A.
**Univ. of Washington, Seattle, WA 98195, U.S.A.
NASA Grant 2260

223 *Nyberg, S. E.; and *Sorensen, H.: **Experimental Investigation of the Interference-Free Flow Field Around a Lifting Wing-Body Model to Establish Cross Flow Characteristics for Ventilated Wind Tunnel Walls at Low Supersonic Mach Numbers.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colo., Mar. 18-20, 1980. In Technical Papers (A80-26929) pp. 172-182.

AIAA Paper 80-0444 A80-26948#

The interference-free flow field around a lifting delta-wing-body configuration has been measured with a probe in wind tunnel tests. Pressure and flow deflection were determined at Mach numbers 1.15, 1.20 and 1.30, at nominal incidences of 0, 5, 15, and 25 deg and at radial locations in relation to the model, where in wind tunnel tests the walls are normally situated. Some comparisons with theoretical calculations are made. The results indicate that the required relationship between pressure drop and cross flow for a minimum interference wind tunnel wall is quite different from hitherto widely used criteria based on the flow field around a cone-cylinder at zero angle of attack.

*Flygtekniska Forsokanstalten, Bromma, Sweden

APPENDIX

The following entries may not deal directly with V/STOL and high lift wall interference, but are included here because they could be useful to persons using this bibliography. These publications are included in the indexes and are identified by the "A" in their citation numbers.

A1 *Theodorsen, T.: **The Theory of Wind-Tunnel Wall Interference.** NACA TR No. 410, 1931, 11 pp.

This paper outlines the development of a general theory for the calculation of the effect of the boundaries of the air stream on the flow past an airfoil. An analytical treatment of the conventional closed and open jet types of rectangular wind tunnels disclosed the possiblity of devising three distinctly new types: Tunnels with horizontal boundaries only, with vertical boundaries only, and with a bottom boundary only. Formulas are developed for the tunnel wall interference in each case for an airfoil located at the center of the tunnel. The correction is given as a function of the width to height ratio of the tunnel. The formulas are exact for infinitely small airfoils only, but give good approximations for spans up to about three-quarters of the tunnel width. The surprising result is obtained that the three last-mentioned nonconventional types of wind tunnels all are superior to the conventional open or closed tunnels as regards wall interference; namely, a square tunnel with horizontal boundaries and no side walls, a rectangular type of a width to height ratio of slightly less than 2:1 and equipped with vertical boundaries only, and one of a ratio of 2:1 and equipped with one horizontal boundary. The author goes on to show that instabilities in the flow may occur for the free jet and the open bottom type tunnels, impairing the predictability of the tunnel wall corrections. A tunnel with a jet free on three sides and restricted only by a lower horizontal boundary extending along the test section from the entrance to the exit cone, is finally recommended as the most promising choice.

*Langley Memorial Aeronautical Laboratory, National Advisory Committee for Aeronautics, Langley Field, Virginia, U.S.A.

A2 *Pope, A.: **Wind-Tunnel Testing**, John Wiley and Sons, Inc., New York and Chapman and Hall, Ltd., London, 319 pp. Two editions, 1947 and 1954, pp. 303-304.

TL567.W5P7

This is the first integrated work embracing design, procedures, and corrections to be applied to wind tunnel data.

*Daniel Guggenheim School of Aeronautics, Georgia School of Technology, Atlanta, Georgia, U.S.A.

A3 *Katzoff, S.; *Gardner, C. S.; *Diesendruck, L.; and *Eisenstadt, B. J.: **Linear Theory of Boundary Effects in Open Wind Tunnels With Finite Jet Lengths.** NACA Report 976, 1950, 36 pp., 17 refs.

The boundary conditions for an open wind tunnel (incompressible flow) are examined with special reference to the effects of the closed entrance and exit sections. Basic conditions are that the velocity must be continuous at the entrance lip and that the velocities in the upstream and downstream closed portions must be equal. For the two-dimensional open tunnel, interesting possibilities develop from the fact that the pressures on the two free surfaces need not be equal. Electrical analogies that might be used for solving the flow in open wind tunnels are outlined. Two types are described -- one in which electrical potential corresponds to velocity potential, and another in which electrical potential corresponds to acceleration potential. The acceleration-potential analogies are probably experimentally simpler than the velocity-potential analogies. Solutions are derived for four types of two-dimensional open tunnels, including one in which the pressures on the two free surfaces are not equal. Numerical results are given for every case. In general, if the lifting element is more than half the tunnel height from the inlet, the boundary effect at the lifting element is the same as for an infinitely long open tunnel. A general method is given for calculating the boundary effect in an open circular wind tunnel of finite jet length. Numerical results are given for a lifting element concentrated at a point on the axis.

*Langley Aeronautical Laboratory, Langley Field, Virginia, U.S.A.

A4 *Pankhurst, R. C.; and **Holder, D. W.: **Wind Tunnel Technique.** Pitmans, London; Chapter 8, **Tunnel Interference Effects**, pp. 327-427, 1952.

TL567.W5P3 (1952)

This section is also in the newer edition of 1965. Misprints and other errors are corrected in the later reprint. A large bibliography is included at the end of each chapter.

*National Physical Laboratory, Teddington, Middlesex, TW11 OLW, U.K.
**Univ. of Oxford, Parks Road, Oxford, OX1 3PJ, U.K.

A5 *Werle, H.: **Ground-Effect Simulation at the Water-Tunnel.** (Simulation de l'effet de sol au tunnel hydrodynamique). La Recherche Aérospatiale, no. 95, July - Aug. 1963, pp. 7-15, ONERA-TP-63, 1963, in French.

N66-83092

Note: For an English translation and an abstract see no. A17 in this bibliography.

ONERA, BP 72, 92322 Chatillon Cedex, France

A6 *Pankhurst, R. C.; and **Holder, D. W.: **Wind Tunnel Technique - An Account of Experimental Methods in Low- and High-Speed Wind Tunnels.** Pitman and Sons, Ltd., London, 1965 reprint, 702 pp. Chapter 8, **Tunnel Interference Effects**, pp. 327-427, 67 refs.

TL567.W5P3, pp. 327-427

This is a reprint of the 1952 publication. Misprints and other errors have been corrected. A bibliography is included at the end of each chapter. Pages 349-379 are devoted chiefly to the 'lift effect.' There is also a section on corrections for models with propellers.

*National Physical Laboratory, Teddington, Middlesex, TW11 OLW, U.K.
**Univ. of Oxford, Parks Road, Oxford, OX1 3PJ, U.K.

A7 *Pope, A.; and *Goin, K. L.: **High-Speed Wind Tunnel Testing**, John Wiley and Sons, Inc., New York, London, Sydney, 1965.

TL567.W5P69

Note: Pages 119-126, 323-324, and 369-371 may be of special interest to the users of this bibliography.

The extension of the field of wind tunnel testing into the high-speed regimes has made it advisable to revise Wind Tunnel Testing into low- and high-speed coverages. In this, the high-speed edition, the design, calibration, and operation of nearsonic, transonic, supersonic, and hypersonic tunnels are covered. This book is a separate entity for all but the relatively rare field of nearsonic testing, where low-speed wall corrections may have to be obtained from Wind Tunnel Testing. The purpose of High-Speed Wind Tunnel Testing remains the same as that of its parent book: to furnish a reference for engineers using tunnels, to help students taking laboratory wind tunnel courses, and to aid beginners in the field of wind tunnel design.

*Sandia Corporation, P. O. Box 5800, Albuquerque, NM 87185

A8 *Conference on V/STOL and STOL Aircraft. NASA SP-116, held at Ames Research Center, Moffett Field, Calif., April 4-5, 1966, 461 pp.

N66-24606#

Conference papers on aerodynamics and propulsion, handling qualities, feasibility studies, and research testing techniques for STOL and V/STOL aircraft are presented. Three of the most relevant papers are included separately in the main part of this bibliography as nos. 45, 46, and 47.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

A9 *Garner, H. C., editor; *Rogers, E. W. E.; *Acum, W. E. A.; and *Maskell, E. C.: **Subsonic Wind Tunnel Wall Corrections.** AGARDOGRAPH 109, Oct. 1966, 476 pp., 398 refs.

N67-34612#

Developments in the formulation, calculation, and application of interference corrections are detailed for subsonic wind tunnel walls. A general review of interference effects is presented; and numerical data, principal formulas, and experimental results are detailed for lift interference on two-dimensional and three-dimensional wings, as well as for interference effects in unsteady experiments, blockage effects in closed or open tunnels, wall interference in tunnels with ventilated walls and bluff bodies and high lift systems.

*National Physical Laboratory, Teddington, Middlesex, U.K.

A10 *Pope, A.; and **Harper, J. J.: **Low-Speed Wind Tunnel Testing.** John Wiley and Sons, New York, 1966.

ATL567.W5P694, 1966

Note: For the second edition of this book see no. A36 in this bibliography.

Chapter 6, Wind Tunnel Boundary Corrections, pages 300-377, contains discussions on corrections for wing flapped models, propeller tests, and V/STOL aircraft. A large bibliography is included.

*Director of Aerospace Projects, Sandia Corp., Albuquerque, New Mexico, U.S.A.
**Georgia Institute of Technology, Atlanta GA 30332-1992, U.S.A.

A11 New York Academy of Sciences, **International Congress on Subsonic Aeronautics, Part VIII - Facilities and Techniques,** New York, N. Y., Apr. 3-6, 1967. In: New York Academy of Sciences, Annals, vol. 154, Nov. 22, 1968, pp. 1036-1117.

Q11.N5, Vol. 154-2 or A69-15541

The section of this compilation that will be of most interest to persons using this bibliography contains the following papers:

Part VIII. Facilities and Techniques

Factors Influencing the Choice of Facilities and Techniques for Aeronautical Development. By *Richard E. Kuhn, 25 refs., pp. 1036-1054, (A69-15572).

Recent Trends in Low-Speed Wind-Tunnel Design and Techniques. By **R. J. Templin, 9 refs., pp. 1055-1073, (A69-15573).

Wind-Tunnel Wall Effects at Extreme Force Coefficients. By *Harry H. Heyson, 37 refs., pp. 1074-1094, (A69-15574).

A Review of Facilities and Test Techniques Used in Low-Speed Flight. By ***Seth B. Anderson and ***Laurel G. Schroers, 11 refs., pp. 1094-1114, (A69-15575).

Summary of General Discussion that Followed Session 8, pp. 1115-1117.

*NASA Langley Research Center, Hampton, VA 23665-5225, U.S.A.
**National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada
***NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

A12 *Foster, D. N.; and *Lawford, J. A.: **Experimental Attempts to Obtain Uniform Loading Over Two-Dimensional High-Lift Wings.** RAE-TR-68283, Dec. 1968, 16 pp. (U.S. Gov't. & Contractors Only).

X69-14929#

*Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, U.K.

A13 **Aerodynamics of Rotary Wing and V/STOL Aircraft,** Cornell Aeronautical Laboratory and U.S. Army Aviation Materiel Laboratories, Symposium, 3rd, Buffalo, N. Y., June 18-20, 1969. **Proceedings Vol. 2 - Wind Tunnel Testing, New Concepts in Rotor Control.** Published by Cornell Aeronautical Laboratory, Inc., 1969, 318 pp.

A69-35226#

Note: Three papers from this conference are included separately in the main part of this bibliography. They are numbers 73, 74, and 75.

A14 *Advisory Group for Aerospace Research and Development, NATO: **Assessment of Lift Augmentation Devices.** A Lecture Series held at the von Karman Institute, Rhode Saint Genèse, Belgium, Apr. 20-24, 1970. AGARD-LS-43-71, Feb. 1971, 284 pp.

N71-20051#

Note: Three papers from this conference, numbers 79, 80, and 81, are included in the main part of this bibliography. There are 16 papers in all.

*AGARD (Advisory Group for Aerospace R & D), NATO 7 rue Ancelle, 92200 Neuilly sur Seine, France

A15 *Traybar, J. T.: **An Analysis and Comparison of VTOL-Type Aerodynamic Data Obtained in a Large Wind Tunnel and on a Model/Track Facility.** Presented at the AIAA 5th Aerodynamic Testing Conference, Tullahoma, Tenn., May 18-20, 1970, 15 pp.

AIAA Paper 70-574 A70-29895#

A study is made of static aerodynamic data obtained in the Langley Full Scale Wind Tunnel and Princeton Dynamic Model Track on an identical, general tilt-wing/propeller VTOL model. The experiments included test conditions corresponding to freestream velocities from transition to hovering and angles of attack through 90 degrees. Comparisons are made of the NASA data with the Princeton data using coefficient forms based on free stream as well as slipstream dynamic pressures. The separate effects of the wing forces are shown by subtracting the known propeller thrust forces from the total measured forces. Analysis of the data is made using wind-axis coefficients and drag polars. Additional new comparisons are made using wing body-axis coefficients and polars.

*Princeton University, Princeton, NJ 08540, U.S.A.

A16 *Pindzola, M.; and *Lo, C.-F.: **Boundary Interference at Subsonic Speeds in Wind Tunnels With Ventilated Walls, Final Rep. Oct. 1968 - Jan. 1969.** AEDC-TR-69-47, May 1969, 135 pp.

AD-687440 N69-34197#

Equations and charts as obtained by theoretical analyses are presented for the evaluation of corrections which must be applied to test data as obtained from wind tunnels because of the presence of the test section boundaries. Results are presented for two-dimensional, circular, and rectangular tunnels with boundaries of the completely closed, completely open, slotted, or perforated variety. Interference factors accounting for the direct effects of model and wake blockage on the longitudinal velocity and of model lift on the upwash velocity are enumerated. In addition, consideration is given to the variation of the longitudinal and vertical velocity components along the tunnel axis leading to buoyancy and streamline-curvature corrections.

*Arnold Engineering and Development Center, Arnold Air Force Station, Tullahoma, TN 37389, U.S.A.
Contract F40600-69-C-0001

A17 *Werle, H.: **Simulation of the Ground Effect in the Hydrodynamic Tunnel.** (Simulation de l'effet de sol au tunnel hydrodynamique.) NASA TT F-13799, Aug. 1971, 18 pp. Translated from the French by Scientific Translation Service, Santa Barbara, Calif.

N71-33494#

Note: For the original French form of this report see no. A5 in this bibliography.

The ground effect on the flow around models in the water-tunnel has been simulated by various devices: fixed plates, endless belts, image-models, etc... It has been analysed by visualizations. A systematic study has been done in two-dimensional flow (without and with jet effect); a few three-dimensional examples have also been studied (low aspect-ratio wings, simulated engine intakes and exhausts).

*ONERA, BP 72, 92322 Chatillon, Cedex, France
Contract (for translation) NASw 2035

A18 *Lukasiewicz, J.; editor: **Aerodynamic Test Simulation: Lessons From the Past and Future Prospects.** AGARD Rep. No. 603, Dec. 1972, 88 pp.

N73-18250

A record of proceedings of discussion at the 10th Aerospace Sciences Meeting of AIAA. Topics discussed are: Assessment of past experience (ad-hoc developments, deficiencies in technical judgement, information dissemination); present status and future prospects of aerodynamic and air-breathing propulsion testing in all speed regimes; ground test - flight comparisons; free-flight technique; the politics of the development of aerodynamic testing, from early beginnings to plans for the future. Appendices give a review of major west-European wind tunnels and a discussion of American aerodynamic test facilities. This Report was sponsored by the Fluid Dynamics Panel of AGARD. (Much emphasis is placed on the development and testing requirements of helicopters, V/STOL, and other high lift aircraft.)

*Carleton Univ. Ottawa, Canada

A19 *Von Karman Institute for Fluid Dynamics: **STOL Technology, Volume 1**, VKI Lecture Series-60-Vol. 1, Rhode-Saint-Genèse, Belgium, Sept. 10-14, 1973, 198 pp.

N79-22996#

Note: One paper in this lecture series is included separately in the main section of this bibliography as no. 124.

Airworthiness and certification of civil aircraft, wind tunnel corrections for STOL models, large low speed wind tunnel requirements, transport aircraft, and takeoff and landing ground rules are discussed. For individual titles, see N79-22997 through N79-23001.

*von Karman Institute for Fluid Dynamics. Chaussée de Waterloo, 72 B-1640 Rhode-Saint Genèse, Belgium

A20 *Von Karman Institute for Fluid Dynamics: **STOL Technology**, VKI Lecture Series-60-Vol. 2, Rhode-Saint-Genèse, Belgium, Sept. 10-14, 1973, 344 pp.

N79-23002#

This is Volume 2 of a two volume lecture series. The following topics are discussed: flight dynamic problems with STOL operations; aerodynamics and performance characteristics of direct lift schemes; engine integration and noise considerations for STOL aircraft; and special ground testing facilities and testing techniques for STOL aircraft. For individual titles, see N79-23003 through N79-23007.

*von Karman Institue for Fluid Dynamics, Chaussée de Waterloo 72, B-1640 Rhode-Saint-Genèse, Belgium

A21 *Halsey, N. D.: **Methods of the Design and Analysis of Jet-Flapped Airfoils.** Presented at the AIAA 12th Aerospace Sciences Meeting held in Washington, D.C., Jan. 30 - Feb. 1, 1974.

AIAA Paper 74-188 A74-18833#

Note: This paper was also published in the Journal of Aircraft, vol. 11, #9, Sept. 1974, pp. 540-546.

Methods for solving both the direct and inverse jet flap airfoil potential flow problems are described. The direct airfoil analysis method is a completely nonlinear iterative method which is applicable to either thick or thin airfoils of arbitrary shape. The very general surface singularity formulation has been extended to include multielement airfoils, ground effects, nonuniform freestreams, inlet flows, jet entrainment effects, etc. Comparisons are given with the results of previous linear and nonlinear methods as well as with experimental data. The inverse (design) method is a more approximate method in which camber and thickness distributions are designed separately. Section shapes are shown for several airfoils designed to have only very small regions of adverse pressure gradient.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846, U.S.A.

A22 *Advisory Group for Aerospace Research and Development, NATO: **Wind Tunnel Design and Testing Techniques.** Proceedings of the Fluid Dynamics Panel Symposium, London, Oct. 6-8, 1975, AGARD-CP-174, Mar. 1976, 488 pp.

N76-25213#

Fluid dynamics in wind tunnel model design, testing, and interference problems for subsonic and transonic ground test facilities are detailed. For individual titles, see N76-25214 through N76-25259. Five papers from this conference are included in the main part of this bibliography as nos. 141-145. There are 48 papers in all.

*AGARD (Advisory Group for Aerospace R & D), NATO 7 rue Ancelle, 92200 Neuilly sur Seine, France

A23 **V/STOL Conference**, sponsored by AIAA and NASA, Palo Alto, Calif. June 6-8, 1977. Technical Papers, 1977, 325 pp.

A77-34926#

Papers, A77-34927 - A77-34966, are presented on practical aspects of commercial STOL operations, a Vertical Attitude Takeoff and Landing (VATOL) program, powered-lift STOL ground effects, conceptual design studies of Navy Type A V/STOL aircraft, and a V/STOL shaft propulsion system analytical performance model. Also considered are the management of swirling flows with application to wind tunnel design and V/STOL testing, flight control testing of the VAK-191B, and surface fluctuating pressure measurements on a 1/4-scale YC-14 boilerplate model.

This conference volume contains AIAA Paper 77-587, (A77-34944), by *K. W. Mort, *P. T. Soderman, and *W. T. Eckert, Improving Large-Scale Testing Capability by Modifying the 40 x 80 ft. Wind Tunnel; a later version of which is in the Journal of Aircraft, vol. 16, no. 8, Aug. 1979, pp. 571-575.

*NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

A24 *Fromme, J.; *Golberg, M.; and *Werth, J.: **Two-Dimensional Aerodynamic Interference Effects on Oscillating Airfoils With Flaps in Ventilated Subsonic Wind Tunnels.** NASA CR-3210, Dec. 1979, 149 pp.

N80-14047#

The numerical computation of unsteady airloads acting upon thin airfoils with multiple leading and trailing-edge controls in two-dimensional ventilated subsonic wind tunnels is studied. The foundation of the computational method is strengthened with a new and more powerful mathematical existence and convergence theory for solving Cauchy singular integral equations of the first kind, and the method of convergence acceleration by extrapolation to the limit is introduced to analyze airfoils with flaps. New results are presented for steady and unsteady flow, including the effect of acoustic resonance between ventilated wind-tunnel walls and airfoils with oscillating flaps. The computer program TWODI is available for general use and a complete set of instructions is provided.

*Univ. of Nevada, 4505 Maryland Parkway, S., Las Vegas, NV 89154, U.S.A.
Contract NSG 2140

A25 *Dietz, R. O.; and **Laster, M. L. (Editors): **Wind Tunnel Corrections for High Angle of Attack Models.** AGARD-R-692, Feb. 1981, 124 pp. Round table discussion in Neubierg, Germany on May 8, 1980.

ISBN 92-835-0283-3 N84-24120#

Note: The seven papers presented are entered separately in this bibliography as nos. 178 through 184.

Several wind tunnel wall correction methods in use or under study are presented for closed, open, and ventilated wall wind tunnels. The Mach number range is generally limited up to high subsonic speeds with some techniques only useful for incompressible flow. Wall correction techniques discussed along with their attributes and disadvantages include vortex lattice, panel, system of images, wall pressure, and adaptive walls. The adaptive wall technique is a method to actively reduce or eliminate the need for wall correction and is becoming more favorable as development problems are solved.

*Sverdrup/ARO, Inc., AEDC Division, Tullahoma, TN 37389, U.S.A.
**Arnold Engineering & Development Center, Arnold AFB, TN 37389, U.S.A.

A26 *Covert, E. E.: **Separation of Laminar Boundary Layer Induced by Aerodynamic Interference.** AIAA Journal, vol. 18, no. 12, Dec. 1980, pp. 1537-1538.

A81-15897#

A theoretical analysis is presented of separation on a surface covered by a laminar boundary layer. A nearby body causes a pressure gradient on the first surface that, under circumstances, will lead to boundary layer separation on the first surface. For the case of flow in a wind tunnel containing a large model, when self-streamlined wind tunnel walls are used to reduce wall interference, the induced separation is most likely at high-induced pressure gradients near the angle of attack where the airfoil stalls. The study is based on the use of simple shapes with laminar boundary layers on the extended surface and is conducted for two-dimensional incompressible flow. Results are presented which show the conditions under which external-flow-induced separation is possible.

*Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.

A27 *Sawada, H.; *Sakakibara, S.; *Sato, M.; *Kanda, H.; and *Karasawa, T.: **A New Method of Estimating the Lateral Wall Effect on the Airfoil Incidence Due to the Suction at Side Walls.** NAL-TR-680, Aug. 1981, 20 pp. In Japanese.

ISSN-0389-4010 N82-17123#

Note: For an English translation and an abstract see no. A35 in this bibliography.

*National Aerospace Laboratory, 1880 Jindaiji-Machi, Chofu-shi, Tokyo, Japan

A28 Advisory Group for Aerospace Research and Development, NATO: **Fluid Dynamics of Jets With Applications to V/STOL.** Proceedings of a Symposium held at Lisbon, Nov. 2-5, 1981. AGARD-CP-308, Jan. 1982, 433 pp.

ISBN-92-835-0308-2 N82-23150#

Note: One paper in this symposium is included separately in the main part of this bibliography as citation no. 190.

This paper discusses the fluid dynamics of vertical and short take-off and landing aircraft which employ thrust vectoring or lift augmentation. Jet interactions with neighboring surfaces, jet structure and development, wind tunnel simulation, injection and thrust augmentation, and theoretical models were considered. In addition, a summary of important features of the meeting, made by Dr. Ir. B. M. Spee, is included following the papers. A more comprehensive Technical Evaluation report is available as N83-10403#.

*AGARD (Advisory Group for Aerospace R & D) NATO., 7 rue Ancelle, 92200 Neuilly sur Seine, France

A29 *Haftmann, B.: **Jet Effects on Forces and Moments of a V/STOL Fighter Type Aircraft.** In: AGARD-CP-308, Jan. 1982, a symposium held at Lisbon, Nov. 2-5, 1981, (N82-23150#), 13 pp.

N82-23168#

Results of jet effects on forces and moments of the VAK-191 B were compiled. The jet induced effects were investigated during the Vertical Short Take Off and Landing (VSTOL) mode in and out of ground effect, in yawed flight, during hover and transition right up to aerodynamic flight. The flight test results were compared with wind tunnel measurements performed during the VAK-191 B development phase and used for preparation of simulation and automatic flight control system development. Trends and deviations between aircraft and model test results are verified. The adequacy of wind tunnel data preparation is questioned. The practicability of wind tunnel data for the assessment of VSTOL aircraft design and determination of flight characteristics and performance is discussed. Recommendations of the measurements of jet induced forces and moments on VSTOL aircraft are outlined.

*Vereinigte Flugtechnische Werke G.m.b.H., Bremen, West Germany

A30 *Advisory Group for Aerospace Research and Development, NATO: **High Angle-of-Attack Aerodynamics,** AGARD-LS-121, Lectures held in Hampton, Va, Mar. 10-11, 1982 and in Goettingen, West Germany, March 22-23, 1982, 411 pp.

ISBN-92-835-0322-8 N83-18683#

Three dimensional flows on simple components including separation and reattachment are reviewed. Vortex breakdown, vortex control, and the effect of compressibility on these three dimensional flows are discussed. For individual titles, see N83-16684 through N83-18696.

*AGARD (Advisory Group for Aerospace R & D) NATO 7 rue Ancelle, 92200 Neuilly sur Seine, France

A31 *Advisory Group for Aerospace Research and Development, NATO: **Wall Interference in Wind Tunnels.** 50th Meeting of the Fluid Dynamics Panel Specialists' Meeting, London, May 19-20, 1982, AGARD-CP-335, 228 pp.

ISBN-92-835-0321-X N83-20957#

Note: For a Technical Evaluation Report of this meeting see AGARD-AR-190, (N83-29277#) March 1983. Also, see N84-23570#, Sept. 26-29, 1983 for another "summary" report, paper #6 in AGARD-CP-348.

Current usage and basic developments for wind tunnel wall corrections are addressed including Reynolds number corrections, wall and support interference, flow quality and aeroelasticity. Solid wall, ventilated wall, and adaptive wall wind tunnels are among the topics discussed. Progress in the area of wind tunnel correction is evident with adaptive walls to reduce or eliminate wall interference.

*AGARD (Advisory Group for Aerospace R & D), NATO 7 rue Ancelle, 92200 Neuilly sur Seine, France

A32 *Steinle, F.; and **Stanewsky, E.; edited by ***Dietz, R. O.: **Wind Tunnel Flow Quality and Data Accuracy Requirements.** AGARD-AR-184, Nov. 1982 35 pp. 33 refs.

ISBN-92-835-1440-8 N83-23276#

Flow quality and data accuracy requirements for wind tunnel testing are discussed. The emphasis is on transonic test conditions. The current level of testing technology, the requirements for the future, and what needs to be done were considered. To aid in understanding the impact of flow quality and data accuracy, a detailed examination of their contributions to the test results of a transport-type configuration is included. The approach can be adapted to other types. The results of this effort correlate well with what is generally accepted. The result of this effort brought focus on the need to document the flow quality in each facility and that the measurements should include a standard set of both instrumentation and data reduction methods. Aside from the already well known need to improve angle of attack measuring capability, the need to understand the role of aeronoise on Reynolds number effects was highlighted. (Users of this bibliography may find pages 9 and 11 of special interest.)

*NASA, Ames Research Center, Moffett Field, CA 94035, U.S.A.
**DFVLR, Bunsenstrasse 10, D-3400 Goettingen, West Germany (FRG)
***Route 1, Manchester, TN 37355, U.S.A.

A33 *Mokry, M.; *Chan, Y. Y.; and *Jones, D. J., edited by *Ohman, L. H.: **Two-Dimensional Wind Tunnel Wall Interference,** AGARD-AG-281, Nov. 1983, 195 pp.

AD-A138964 N84-20499#
ISBN-92-835-1463-7

A description and analysis is presented of the more important developments during the past decade in the understanding of the wall interference problem associated with two-dimensional wind tunnel testing at subsonic and transonic speeds. Discussed are wall boundary conditions, asymptotic analysis of wall interference, classical and extended wall interference theories, wall interference corrections from boundary measurements, integral equation formulation of subcritical wall interference, and effects of side wall boundary layer on two-dimensional tests. Unsteady wall interference at subsonic and supersonic flow conditions is reviewed. Recent advances in the adaptive wall technique, which actively reduces or eliminates wall interference, are also described.

*National Aeronautical Establishment, National Research Council, Ottawa, ON K1A OR6, Canada

A34 *Advisory Group for Aerospace Research and Development, NATO: **Special Course on V/STOL Aerodynamics.** AGARD-R-710, Apr. 1984, held at the von Karman Institute, Belgium on May 14-18, 1984, and at NASA, Ames Research Center on June 4-8, 1984, 386 pp.

IBSN 92-835-1489-0 N84-25625#

Note: Two papers from this Special Course are included separately in the main section of this bibliography as nos. 206 and 207.

The aim of the Special Course on V/STOL Aerodynamics was to outline and discuss the additional knowledge of aerodynamics needed to embark on the design of V/STOL aircraft. The influence of V/STOL features on wing design, layout considerations, engine and air intake considerations, effects of jet effluxes, wind tunnel and flight testing maneuverability and control, performance assessment and special aspects of flight aerodynamics were discussed by nine lecturers.

*AGARD (Advisory Group for Aerospace R & D), NATO, 7 rue Ancelle, 92200 Neuilly sur Seine, France
Sponsored by the VKI, NASA and the Fluid Dynamics Panel of AGARD

A35 *Sawada, H.; *Sakakibara, S.; *Sato, M.; *Kanda H.; and *Karasawa, T.: **A New Method of Evaluating the Side Wall Interference Effect on Airfoil Angle of Attack by Suction from the Side Walls.** NASA TM-77722, Aug. 1984, 39 pp. English Translation by the Scientific Translation Service, Santa Barbara, Calif. from the Japanese NAL-TR-680, Aug. 1981

N82-17123# (In Japanese)
N84-34432# (In English)

Note: For original language document see no. A27 in this bibliography.

A quantitative evaluation method of the suction effect from a suction plate on side walls is explained. It is found from wind tunnel tests that the wall interference is basically described by the summation form of wall interference in the case of two dimensional flow and the interference of side walls.

*National Aerospace Laboratory, 1880 Jindaiji-Machi, Chofu-shi, Tokyo, Japan

A36 *Rae, W. H., Jr.; and **Pope, A.: **Low-Speed Wind Tunnel Testing**, Second Edition. Wiley-Interscience, 1984. 545 pp. 247 refs.

ISBN 0-471-87402-7 TL567.W5P94, 1984 or A85-35804

The design, operation and applications of low-speed wind tunnels (WTs) are discussed and illustrated in an introductory and reference text for engineers and engineering students. Chapters are devoted to WT design; test-section calibration and instrumentation; measurements of model force, moment, and pressure; test procedures; WT boundary corrections; the use of WT data; small WTs and nonaeronautical applications of WTs. Photographs, graphs, drawings, and tables of numerical data are provided. The chapter on boundary corrections, pages 344-444, includes "Boundary Correction for Propeller Tests" and "Tunnel Boundary Effects on V/STOL Models."

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A37 *Li, J.; and *Qi, M.: **Wall Lift Interference in Ground Effect Testing.** English translation of Acta Aerodynamic Sinica (selected articles) #4, 1984. Air Force Systems Command, Wright-Patterson AFB, Ohio; Foreign Technology Division, Dec. 5, 1985. Rep. no. FTD-ID(RS)T-0639-85, pp. 88-97.

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Note: For the Chinese form of this report see no. 211 in this bibliography.

The wall lift interference parameters on ground effects for octagonal closed wind tunnels has been derived using image vortex systems. The fillet vortex system can be added to rectangular tunnel vortex system. The vortex lattice method can be used to determine fillet vortex strength. It has been found that the wall lift interference corrections on ground effect have related to not only the wall upwash and streamline curvature effects, but also the normal gradient of the upwash velocity at the horizontal tail.

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AUTHOR INDEX

SUBJECT INDEX

NOTE: The following index, although in no way complete, might be useful by giving an indication of where some material on definite subject areas may be found. Generally, surveys and summaries are not indexed in depth.

Entry

CORPORATE SOURCE INDEX
(Affiliation of Authors)