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**AERODYNAMIC CHARACTERISTICS OF RING WINGS
A BIBLIOGRAPHY**

by

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ABSTRACT

The cited references pertain primarily to the following aerodynamic information on ring wings, also known as annular wings or circular wings: calculation of circumferential velocity and pressure distribution, studies on flow separation phenomena at the wing leading and trailing edges, measurement of lift, drag and pitching moment, application of linearized theory to subsonic and supersonic gas flow, theory and measurement of vortex drag, measurement of three-dimensional turbulent boundary layer, determination of flutter using linearized equations, theory of stationary, inviscid, incompressible flow around the wing, studies on drag reduction, studies on interference effects of an axisymmetric fuselage or a strut on wing pressure distributions, wind tunnel tests of wings with and without a fuselage, and determination of optimum shape.

FOREWORD

This bibliography consists of 69 entries on the aerodynamic characteristics of ring wings, also referred to as annular wings or circular wings. Information sources for the period 1950 to June 1964 were searched.

The material was obtained from information sources available at the Redstone Scientific Information Center. Searches were made of Engineering Indexes, International Aerospace Abstracts, Index Aeronauticus, Applied Science and Technology Indexes, document card files, the Defense Documentation Center (DDC), and NASA tape search which includes references on Scientific and Technical Aerospace Reports and International Aerospace Abstracts.

The references are arranged alphabetically either by corporate author or personal author. Documents and papers are arranged by corporate author, and journal citations are arranged by personal author. A personal author index is included after the bibliography.

SUMMARY

Considerable interest has been shown since 1955 in ring wing-body configurations as a means of reducing the wave drag. Many theoretical studies for this configuration indicate that with proper wing-body design, zero wave drag may be possible. Results of various experimental investigations on ring-wing configurations also provide data which show some drag reduction due to favorable interference effects. However, in all of these investigations, only a few measurements were made on ring wing-body configurations which included friction drag as well as wave drag. Some indication is found in the literature⁴⁴ that the magnitude of friction drag may be sufficiently large to cancel the savings in wave drag. Thus, the overall configuration may offer little drag advantage over a conventional wing-body configuration.

The literature search reveals that extensive work has been performed on ring wings not only in the United States, but also in Germany, Great Britain, and France. Some studies were found in the literature from the Netherlands and Russia. Less than half the entries were from studies performed in the United States. Most of the work in this country appears to have been performed by Douglas Aircraft Company, Incorporated, and Rand Corporation.

Several of the referenced documents and articles are in the original foreign language; some have been translated to English and are in the DDC collection. Over half of the entries are available in the DDC.

BIBLIOGRAPHY

1. Aeronautical Research Council Reports and Memorandums, Great Britain
"A Method Of Calculating The Velocity Distribution On Annular Aerofoils In Incompressible Flow." Bagley, J. A., Kirby, N. B., Marcer, P. J. Report and Memo 3146/ARC 20597, 1961.

The method is for aerofoils of moderate thickness to chord ratio and camber, and reasonably large radius to chord ratio (the order of 1 or greater), and is based on the use of distributions of singularities on a cylinder whose velocity fields are tabulated. The annular wing at zero incidence is treated first, and then the wing at incidence. Examples of the calculated velocity distributions on various aerofoils are given.

2. Advisory Group for Aeronautical Research and Development, Paris, France.
"Interaction Of Separation At The Trailing Edge At The Leading Edge In Three-Dimensional Flow." Eichelbrenner, Ernest A. Report No. 275, April 1960. AD-294 173.
Papers presented at the Boundary Layer Research Meeting of the AGARD Working Group on Fluid Dynamics, 25-29 April 1960, London, England.

Wings with sharp leading edge or very small radius of curvature exhibit, even at low incidence, separation phenomena at the leading edge which are known as "excrescences" and which have been classified as essentially three-dimensional. As in the case of separation at the trailing edge investigated for obstacles which are in fact three-dimensional, it would appear therefore necessary to deal first of all with the problem of three-dimensional excrescences, starting with particularly simple obstacles and then pass to the two-dimensional limit. Such obstacles are the annular wings produced by the rotation of an aerodynamic profile around an axis parallel to its chord. The development of excrescences on these wings, and in particular on the outer side of their upper surface, has been studied in relation to incidence, and checked by wind dimensional wing between panels made it possible

to establish a comparison confirming that passing to the two-dimensional limit leads to conclusions which are qualitatively correct.

3. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio
"A Method For The Calculation Of The Pressure Distribution Of A Thin Ring Wing In Supersonic Flow." Tate, Stanley E. Report No. GAE-54, March 1954. AD-26 446.

An approximate method is presented for the calculation of the external pressure coefficient of an open-nose ring wing in supersonic flow. A verification of the solution for the case of axially symmetric flow is made, and a solution for the transverse component due to the small angle of attack is determined. A review of the theory on which the method is based and a physical interpretation of the mathematical model are also presented.

4. Bobrov, G. E.
"On The Theory Of The Annular Wing In A Supersonic Flow." *Aviatsionnaya Tekhnika*, No. 3, pp. 3-8, 1959. (In Russian)

Assuming the validity of the assumptions of the linear theory of supersonic gas flows, the solution is obtained for the lift and aerodynamic moment due to the pressure of the supersonic flow on the interior surface of an annular wing. For the sake of simplification, a flow past a cylindrical annular wing with zero profile thickness is considered. The vortex sheet behind the wing is regarded as a hard cylindrical surface forming the continuation of the wing. The flows within and without the wing are considered separately.

5. Bobrov, G. E.
"On The Possibility Of Using Aerodynamic Interference To Reduce The Wave Drag Of Annular Wing With A Wedge Profile In A Supersonic Flow." *Aviatsionnaya Tekhnika*, No. 4, pp. 3-9, 1960. (In Russian)

Presents the solution of a linear problem of the internal wave drag of a wedge-profiled annular wing in a supersonic flow at zero incidence. The solution holds for all wing parameters and the parameters of the flow consistent with the linear theory of supersonic flow.

6. Brown University, Providence, R. I.
"Aerodynamic Characteristics Of Ring Wings And Wing-Body Combinations." Degen, M., Johnson, A. R., and Thompson, W. E. WADC TN 56-442, March 1957. AD-135 082. Contract AF 33(616)2319.

An isolated ring wing and three wing-body combinations were tested in the Brown University 9 x 12 inch transonic wind tunnel. The fuselages were compensated for the presence of three ring supporting struts by a form of area rule. Three-component balance measurements providing values of lift, drag and pitching moment were made in the range $0.08 \leq M_\infty \leq 1.10$ and for geometrical angles of attack up to 12° for the isolated ring wing and for Models A and C. Limited tunnel operating time prevented making equally complete measurements for Model B. These data in terms of lift, drag and moment coefficients are presented graphically. To correlate the experimental results, a group of simplified theories for an infinitely thin ring wing were devised to cover a large speed range. At low subsonic speeds, lifting line theory was applied; slender body theory was used for high subsonic speeds and linearized supersonic theory was utilized at high supersonic speeds. The theoretical developments consistently predict the qualitative trends of the experimental data and they establish the basis for the choice of πRC for the reference area of the annular airfoil. Comparison between minimum drag measurements previously obtained on an F-86E model, on an F-86E model redesigned for drag reduction of 41 and the measurements of the present program shows that at $M_\infty = 1.10$, a drag reduction of 41 and 19% was obtained for Model B over the F-86E and the redesigned version respectively, while all models show smaller drags above $M_\infty = 0.98$ than the conventional F-86E. Below $M_\infty = 0.90$, the ring wing models tested show larger drags than the F-86 models but for high-speed aircraft this may be unimportant.

7. Brown University, Providence, R. I.
"Analysis of Annular Wings And Annular Wing-Body Combinations At Subsonic, Transonic, and Supersonic Speeds."
Maeder, P. F. TR W7-26; WADC TN 57-169, June 1957.
AD-118 302. Contract AF 33(616)2319.

A linearized theory is applied to ring wing-body combinations at small angles of incidence, yielding theoretical results which are applicable for the entire Mach number range from incompressible to linearize supersonic. The partial differential equation is solved by first applying an exponential Fourier transform over one coordinate, and then solving this reduced partial differential equation by the method of separation of variables. Expressions for the velocity potential throughout the flow field are found in terms of the load and area distributions of the configuration. The solution of the direct problem, in which the pressure distribution is to be found for an airfoil section of known centerline, is discussed and shown to depend on the solution of an integral equation for the load distribution. Expressions for the force coefficients, also in terms of the load and area distribution, are determined by retaining only the terms of greatest order.

The special cases of linearized subsonic and supersonic flows are considered in some detail, and an expression which is essentially the area rule for linearized supersonic flows is derived. The minimum drag problem is investigated by the application of a variational procedure, which results in an integral equation for the load distribution. This integral equation is solved for the special case of Mach numbers near unity, and the wing contour in the absence of a fuselage is investigated. (See also AD-135 082.)

8. Brown University, Providence, R. I.
"Aerodynamic Characteristics Of Ring Wings And Ring Wing-Body Combinations At Transonic Speeds." Johnson, A. R. and Thompson, W. E. WADC TR No. 57-263, September 1957. AD-118 303. Contract AF 33(616)2319.

Two basic models of ring wing-body combinations were tested for interference drag reduction. The models differed only in fuselage diameter and length; each was fitted with interchangeable fuselage sections and annular wings. The models were constructed so that only forces on the basic assembly of the fuselage section and ring wing were measured.

On the basis of drag measurements at zero angle of attack, all of the compensated wing-body combinations exhibited a compressibility drag reduction over the uncompensated models. Some of the drag reduction appeared to be due in part to favorable pressure gradients over the indentations which delay separation. The combination of the $M = 1.15$ compensated fuselage and ring wing (plano-convex profile of 4% thickness ratio) had the most desirable drag characteristic. Pressure transverse along the axial centerline of the isolated ring wing showed that above a certain free stream Mach number, the flow inside the ring is choked but that no shock-wave focusing effect occurs. (See also AD-135 082.)

9. Bureau Technique Zborowski, Paris, France

"Theoretical Investigation And Examination By Measuring Tests In What A Degree The Economy Of Flying Vehicles Is Influenced By Pre-Cambered Skeletons of Airfoils Closed in Themselves." 10 August 1959. AD-227 082. Contract DA 91-508-EUC-393.

Calculation and measurement of the aerodynamic coefficients of an annular wing of axisymmetric form.

Brief outline of the Wessinger method.

Computation of elementary cases.

Choice of the annular wing and of the wing profile.

Superposition and results.

Boundary-layer computation.

Review of the three-dimensional boundary-layer theory.

Numerical computation of the separation in laminar and turbulent flow.

Rheoelectric determination of an adapted center line for a given wing at given lift values.

Computation control and wind tunnel tests on efficiency of precambered profiles determined in the rheoelectric tank.

Computation control.

Representation of the 20%-adapted center line by limited Fourier developments.

Computation of c_L for zero incidence.

Determination of axial velocities for adapted profiles.

Calculation of turbulent boundary layer.

Description of the test model.

Aerodynamic values determined by wind tunnel tests.
Boundary-layer visualization.

10. Bureau Technique Zborowski, Paris, France
"Theoretical Investigation and Examination By Measuring Tests Of The Thrust Control By Rudders Uniformly Fitted At The Outlet Of A Duct." 10 August 1959. AD-228 106. Contract DA 91-508-EUC-394.

Theoretical approach to the thrust-control problem.
Thrust control at zero flight speed.
Thrust control under flight conditions.
Methods of calculation of the outlet-form parameter.
Calculation of jet-forms in plane and in rotational symmetric flow.
Estimation of the pressure at the trailing edge.
Boundary layer problems.
Description of model, test apparatus, and test procedures.
Wind tunnel.
Suspension of the model.
Measuring instrumentation.
Wind tunnel tests.
Velocity distributions.
Drag measurements.
Thrust measurements.
Thrust-control coefficient.

11. Bureau Technique Zborowski, Paris, France
"Theoretical Investigation And Control By Measuring Tests On The Three-Dimensional Turbulent Boundary Layer On An Annular Wing At Various Incidences." Eichelbrenner, Ernest A., Angioletti, Serge, et al. (Interim Technical Report, December 1961.) AD-297 809. Contract N62558-2526.

12. Bureau Technique Zborowski, Paris, France
"Theoretical Investigation And Control By Measuring Tests On The Behavior Of The Three-Dimensional Turbulent Boundary-Layer On An Annular Wing At Various Incidences." Eichelbrenner, Ernest A., Angioletti, Serge, et al. Interim Technical Report No. 2, 15 September 1962. AD-297 807. Contract N62558-2526.

13. Collins Radio Company, Cedar Rapids, Iowa
"Performance Calculation Of Aerodyne Systems in Cruising Flight." (U) Lippisch, A. M. Report No. CER-617, March 1957. AD-133 500. Contract Nonr-70100. Confidential Report.

14. Collins Radio Company, Cedar Rapids, Iowa
"Research On Wingless Aircraft." Final Report. Report No. CER-1014, 1 July 1959. AD-289 318. Contract Nonr-256600.

The Aerodyne test bed was modified for full scale wind tunnel testing by installation of the Lycoming 435 engines, alteration of test bed structures, and design and construction of outer skin and tail surfaces.

15. Cornell University Graduate School of Aeronautical Engineering, Ithaca, N. Y.
"Flutter Analysis Of A Supersonic Ring Wing." Crimi, Peter. Report No. AFOSR TN-59-685, June 1959. AD-227 075. Contract AF 18(600)1523.

The possibility of flutter of a supersonic ring wing is investigated by using linearized equations. The elastic system is limited to flexural deformations and piston theory is employed for aerodynamic pressures. By means of Lagrange's equations, the equations of motion are derived, and expressions for critical Mach number and flutter frequency obtained. Results are restricted to wings of moderately high aspect ratio by the simplified aerodynamics. A representative airfoil cross-section is chosen and flutter quantities calculated for various values of geometric parameters and mode number. Analytical and numerical results indicate that the system investigated is highly stable.

16. David Taylor Model Basin, Washington, D. C.
"On The Aerodynamics Of Ring Wings. I. The Pressure Distribution Of A Thin, Almost Axially Symmetric Wing In Subsonic Flow." Weissinger, J. Aero Report No. 899; Trans. from Deutschen Versuchsanstalt fuer Luftfahrt, Bericht 2, September 1955. AD-102 118.

A method for calculating the pressure distribution as well as the corresponding forces and moments on a thin, almost axially symmetric ring in incompressible flow is described. The assumptions and omissions correspond to those made in the theory of the lifting surface for ordinary wings. Finally, numerical observations and results are reported and gross lift and neutral point position as a function of length-diameter ratio of the ring wing subjected to inclined flow are communicated as principal results.

17. David Taylor Model Basin, Washington, D. C.
"Wind-Tunnel Tests Of A 1/4-Scale Model PA-2C VTOL Aircraft. Part IV. Power Tests Of The VTOL Configuration." Barnard, George A. and Harry, Charles W. AERO Report No. 935, March 1960. AD-235 473L.

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Results are presented of tests, under power, of a ring wing, VTOL aircraft model, in its VTOL configuration. The discussion covers power required and lift, drag, and stability characteristics for three constant-power settings. Results of static (hovering) tests are presented. It was found that the minimum power required exceeds the power available with one engine out, and that the power-off stall speed exceeds the maximum level-flight speed. The maximum rate of climb was found to be 1400 fpm at 44.5 Kn. Although the stabilizer will trim the aircraft, downwash at the tail causes pitch-up. The direct effects of power on stability are slight. The results of static tests are considered inapplicable to full-scale conditions because of excessive scale effects. All test results presented are influenced by uncorrected tunnel-wall effects. (See also AD-221 420.)

18. Deutsch Forschungsanstalt für Luftfahrt Berichte, German
"Aerofoil Theory For Subsonic Speed." Gersten, K. Report No. 115, 1958. (In German)

A broad survey is given of work over recent years for incompressible stationary flow. Mathematical foundations were established by J. Weissinger in 1955. Extensions of well-known methods and comparisons between theory and experiment are especially considered here. Problems still awaiting solution are emphasized. These include ring aerofoils, jet flap wings, and nonlinear theories of wings.

19. Deutsch Versuchsanstalt für Luftfahrt Berichte, Germany
"The Aerodynamics Of The Annular Wing: Pt. 2 - The Rudder Effect." Weissinger, J. Report No. 39, October 1957. (In German)

The formulae of Part I are summarized and tables derived for kernel functions, equivalent matrices and their inverses. The reciprocity rule of aerofoil theory is modified for the annular wing and formulae for the radial force and moment distribution derived. Results show that the annular wing parameter L/D has a strong influence on the rudder effect, but for a certain rudder height, in relation to the wing size, the effect of the ring shape may be slight.

20. Deutsch Versuchsanstalt für Luftfahrt Berichte, Germany
 "The Aerodynamics Of The Annular Wing: Pt 3 - The Influence of Profile Thickness." Weissinger, J. Report No. 42, October 1957. (In German)

To characterize an annular wing of thick profile by the method of singularities, a vortex distribution, as well as a source distribution, is necessary. The axial velocity for a circular cylinder, with super-imposed sources and vortices, is given in a suitable form for practical calculation. One term in the formula can be obtained by numerical integration by means of tabulated kernel functions, but can often be neglected in practice. Tables are given for the most important cases so that for a given profile and wing form only a superposition operation is required. It is shown that from the velocity on the circular cylinder that on the profile contour can be obtained.

21. Deutsche Versuchsanstalt für Luftfahrt, Mulheim an der Ruhr, W. Germany
 "About Aerodynamics Of The Ring Wing. IV: Ring Wing With Central Body." Weissinger, J. Report No. DVL-140, December 1960. (In German)

The stationary, inviscid, incompressible flow round a ring wing with an axialsymmetrical fuselage body on the ring axis is theoretically examined. The wing is represented by a layer of ring vortices, the fuselage by a covering of the axis with source-sinks and dipoles. From the usual linearizing exact theory which numerically is very irksome, more simple approximation methods are developed which correspond to the "supporting-line theory" and the "3/4 point-method." Numerical results for lift and moment of the fuselage and of the wing as well as for the wing circulation are given for four shapes of fuselage (infinitely long circular cylinder, ellipsoid of revo-

lution, fuselage with obtuse nose and pointed stern, fuselage reverse) which are dependent upon the position and thickness of the fuselage as well as upon the fineness of the parameters of the fuselages and of the wing.

22. Douglas Aircraft Company Incorporated, Santa Monica, California
"Drag Reduction At Supersonic Speeds For Bodies Of Revolution Within Cylindrical Shell Wing Systems." Beane, B. J. Report No. SM-19411, November 1955. AD-103 908.

It was shown by Ferrari that a certain type of wing-body combination can be designed to have zero wave drag at supersonic speeds. This arrangement consists of a circular cylindrical shell with axis in the streamwise direction and body of revolution placed on this axis. The wing carries radial forces (no net lift) and cancels out the wave system of the body. This report contains a preliminary study of the drag reductions obtainable using elliptic and rectangular cylindrical shells of zero thickness for the wing systems. These shapes are of interest primarily because they can be more easily attached to the fuselage than the circular cylindrical wing. The wave drag of the wing-body combination at zero lift is compared with that of an isolated Sears-Haack body having the same length and volume. For the wing-body combination the type of normal force distribution on the wing system is arbitrarily chosen. However, the magnitude of the normal force and the cross-sectional area distribution on the body are optimized. For a circular cylindrical wing a 100 percent drag reduction is obtained, corresponding to complete cancellation of the fuselage wave system. For an elliptical cylindrical shell with span three times the gap a 25 percent drag reduction is obtained. For the cases studied there appear to be large penalties in drag reduction for departing from the circular cylindrical wing when holding the chord constant. The drag reductions obtained are still substantial, and might be improved by an attempt to optimize the type of normal force distribution on the wing system, or by utilizing a chord that varies with polar angle in front view. (See also AD-75 212.)

23. Douglas Aircraft Company, Incorporated, Santa Monica, California
"Supersonic Drag Calculations For A Cylindrical Shell Wing Of Semi-Circular Cross-Section Combined With A Central Body Of Revolution." Beane, B. J. and Ryan, B. M. Report No. SM-22627, October 1956. AD-134 485.

A semi-circular ring wing with a body of revolution on the axis is studied to find the wave and the vortex drag for various chordwise lift distributions and for three values of a parameter describing the wing geometry

$\frac{\beta R}{c/2}$. Using the wave drag obtained from the chordwise loading that gives the least drag, together with the vortex and skin friction drags, the maximum lift to drag ratio for each wing geometry is computed. Compared to the estimates made by Lomax and Heaslet, somewhat lower drags are found.

24. Douglas Aircraft Company, Incorporated, Santa Monica, California
 "Minimum Drag At Supersonic Speeds For Cylindrical Ring Wings Of Specified Volume Or Base Area At Zero Lift." Licher, R. M. Report No. SM-22995, November 1957. AD-156 444.

Given a circular ring wing of constant chord which is required to contain a specified volume, the minimum drag for the given total volume is calculated for two cases: (1) a restricted optimum when no radial forced is carried, and (2) the optimum when radial forces (with no net lift) are allowed. Minimum drag values were determined for optimum configurations by working with artificial distributions of singularities which satisfy all conditions for the optimum in the combined flow. Since this is a spatial configuration, there can be favorable interference between the thickness and radial force distributions, and it is shown that under some optimum conditions it is possible to have a ring wing with zero drag. The details of the actual configuration and its thickness distribution and camber are more difficult to calculate. The minimum drag for a given base area is calculated for the ring wing, and it is shown that there is no interference drag between this case and previous cases.

25. Douglas Aircraft Company, Incorporated. Santa Monica, California

"Calculation Of The Thickness And Radial Force Distribution For A Ring Wing Having Zero Drag At Supersonic Speeds." Licher, R. M. Report No. SM-23579, 27 May 1959. AD-227 377.

A cylindrical ring wing with thickness and radial force is designed by linearized theory for supersonic flow, to have zero wave drag over a certain range of ring radius to wing chord values. The thickness and radial force distributions are computed. The flow field within the ring is calculated by taking a pair of parallel Mach planes of infinitesimal strengths and opposite signs and rotating them about an axis parallel to the free stream. Between such a pair of planes the flow is disturbed and the pressure changed; but, behind them, a uniform flow field has only been displaced from its initial position but not otherwise disturbed. A simple two-dimensional example to which this method can be applied is the zero drag Busemann biplane at zero angle of attack. It can be formed by streamlines from two sets of parallel Mach planes of finite strength, one rotated 180° with respect to the other. This method can be applied to some other cases such as a zero wave drag cylindrical wing carrying a net pitching moment and having some base area; this example is briefly discussed in an appendix.

- 26 Douglas Aircraft Company, Incorporated, Santa Monica, California

"Reduction Of Minimum-Drag Problems In Supersonic Flow To Two-Dimensional Potential Problems By Means Of The Combined Flow Field." Graham, M. E. and Lagerstrom, P. A. Report No. SM-23901, March 1960. AD-239 383.

Problems of finding the minimum drag of thin planar or nonplanar configurations in inviscid supersonic flow under the constraints of (1) a specified total lift, (2) a specified total lift, total pitching moment and lateral distribution of base area, (3) a specified total base area, and (4) a specified total volume and lateral distribution of base area are studied by means of Jones'

combined flow field concept. Particular attention is given to the minimum drag problems which include the constraint of a specified lateral distribution of base area. Specific numerical examples treated in detail are: (1) finding the drag of a ring wing optimized under the constraint of a specified total lift and total pitching moment and with closure at the trailing edge, and (2) finding the drag of a certain swept planar wing of specified volume and with closure at the trailing edge.

27. Ehlers, F. E.

"On The Lift, Drag, and Moment On A Ring Concentric To A Cylindrical Body In Supersonic Flow." *Journal of Aerospace Science*, Volume 28, No. 2, pp. 170-171, February 1961.

Formulae for lift and moment of ring wings in the author's earlier paper were restricted to a length l and ring radius R for which the M wave from the ring leading edge is not reflected back to the ring; here the analysis is extended to a length where multiple reflections of the M lines occur.

28. Eichelbrenner, E. A.

"Investigation On The Causes And Combating Of Break-Away Phenomena On Leading And Trailing Edges Of Ring-Wings." *Jb. Wissenschaftliche Gesellschaft für Luftfahrt*, pp. 119-123, 1959. (In German)

Experimental results obtained by the Bureau Technique Zborowski (BTZ) in wind tunnel and rheoelectric analogue facilities show the formation of separated flow at the wing extremities and explain the known favorable aerodynamic characteristics of the annular wing. The limits of modification of the leading edge, by introducing a curvative, are described in relation to theoretical and experimental flight polars. The mathematical treatment of the results has not yet been formulated.

29. Faure, G.

"Theoretical Study Of The Annular Wing." Techniques et Science Aeronautiques, Volume 6, pp. 293-297, 1956. (In French)

A review of experimental and theoretical results obtained at S. N. E. C. M. A. The theoretical part is restricted to subsonic incompressible flow but can be extended to compressible subsonic within the limits of validity of the linearized velocity potential. It is concluded that the vortex method of flow presentation is correct and permits the determination of pitching moments by introducing a local incidence based on the pitch velocity. Results are valid for take-off or launching. For lift and aerodynamic moment the case of the annular wing is basically the same as for a flat plate.

30. Foreign Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

"Determination Of The Profile Of Least Resistance Of An Annular Wing." Borisov, B. I. FTD TT63 397, 11 June 1963. AD-410 936.

A thin axisymmetric wing in a supersonic flow is studied to determine the profile of least resistance of an annular wing.

31. Levey, H. C. and Wynter, P. E.

"The Circular Wing And Related Problems." Proceedings of the Royal Society of London, Ser. A, Volume 268, pp. 390-404, 24 July 1962.

Development of a method for the solution of the mixed boundary-value problem in which a harmonic function is to be determined in a semi-infinite region with a plane boundary, when the value of the function is zero on the part of the plane outside a certain circle and the normal derivative has prescribed values inside this circle. By this method, which depends on a repeated use of Abel's integral equation, the values anywhere on the boundary plane of the function and its normal derivative within the circle. In linearized aerodynamic theory the acceleration potential of the flow of an incompressible fluid about a wing of circular planform satisfies this type of boundary condition. The preceding theory provides an infinite set of solutions that satisfy null boundary

conditions, that is whose normal derivatives vanish within the circle. These are combined to satisfy the upwash and Kutta-Joukowski conditions for the flat plate at incidence, and values are obtained for the lift and moment coefficients. The connection of the present method with some earlier methods for the solution of this type of problem is examined.

32. Massachusetts Institute of Technology, Naval Supersonic Laboratory

"Supersonic Drag Characteristics Of Partial-Ring Wings."
Beane, B. J. TR 444, September 1960.

Study of the problem of determining the minimum drag of lifting, partial-ring wings, with and without fuselage. The study is based on the linearized theory of small perturbations in supersonic flow. Two methods of approach are used. Both methods expand the loading on the partial-ring in a Fourier series about a complete ring. Thus, the force on the real wing is expressed as a sum of elementary simple harmonic loadings on an imaginary complete ring wing. The first method of approach seeks only to approximate the solution of the minimum drag problem by using a wing loading and a fuselage volume distribution which give nearly-optimum wave drag for the lowest order Fourier components and low wave drag for the higher order components. In the second method of approach, combined flow field techniques are used to optimize each of the elementary loadings within the Mach envelope of a complete ring wing.

33. Ministry of Aviation, Great Britain

"Study By An Electrical Analogue Of Lifting Surfaces In An Unsteady Flow." Duquenne, R. Trans. No. TIL/T. 5323 from ONERA Publication No. 98, 1960. January 1963. AD-298 816.

34. Mississippi State University, State College

"The Marvel Project. Part B. Report Of Preliminary Flight Testing Of Marvelette XAZ-1." Bryant, Glenn, and Roberts, Sean. Aerophysics Research Report No. 46, November 1963. ATRECOM TR 63 66. AD-425 788. Contract DA44 177 AMC892.

An interim test-bed aircraft, the Marvelette, was built to evaluate functionally the compatibility of the various features of the Marvel design (boundary-layer control, cambered wing, ducted propeller, fiberglass structure). Also, the Marvelette, designated XAZ-1, will provide information for the refinement of the Marvel design and be a readily available laboratory for exploration of low-speed aerodynamics in flight. Pilot evaluation and flight data on the Marvelette are presented for the first ten aircraft checkout flights.

35. Mississippi University

"Three-Dimensional Separation And Reattachment In Turbulent Flow." Eichelbrenner, Ernest A. Research Note No. 15, 14 December 1961. AD-271 568. Lecture presented on September 24, 1961 at Mississippi State University by the Aerophysics Department.

The concept of wall-streamlines is shown to be a very powerful and appropriate tool for studying the behavior of laminar three-dimensional boundary-layers on convex bodies. This conception is generalized and applied to the turbulent case. The mathematical development is then applied to the case of ring airfoils.

36. Moiseyenko, A. F.

"The Aggregate Effect Of The Annular Wing And The Fuselage In A Compressible Fluid." *Aviatsionnaia Tekhnika*, No. 3, pp. 163-180, 1961. (In Russian)

Study of the steady motion of an annular wing and an infinite cylinder (fuselage) in an ideal, incompressible fluid. The interaction of the wing and fuselage is also considered. The method of calculation, obtained for low velocities, is extended to cover the case of high subsonic speeds, taking into account the compressibility of the fluid. The calculation of the aerodynamic characteristics of the annular wing - fuselage combination in a compressible flow is reduced to the calculation of a certain fictitious combination in incompressible flow. The problem is solved linearly, the basic assumption being that the perturbations generated by the body are

small in relation to the flow velocity. The theoretically calculated aerodynamic characteristics are compared with experimental data.

37. Murphy, C. H. and Piddington, M. J.
"Aerodynamic Properties Of Ring Airfoils In Supersonic Flight." Journal of Aerospace Science, Vol. 27, No. 12, pp. 945-955, December 1960.

The linearized theory for thin rings with low-fineness ratio is similar to that developed for thin aerofoils by H. Mirels. A series of ring aerofoils was flight tested up to Mach 3.7 and found to be statistically stable for Mach numbers above 1.7. A plot is given of pitching-moment coefficient versus thickness ratio at Mach 3.1. The drag coefficient is constant for the Mach range 1.7 to 3.7.

38. National Advisory Committee for Aeronautics, Washington, D. C.
"Experimental Investigation Of Lift, Drag, And Pitching Moment Of Five Annular Airfoils." Fletcher, Herman S. Technical Note TN 4117, October 1957. AD-144 813.
Notice: Available to U. S. Military Organizations
Others direct requests to NACA, Washington, D. C.

An investigation was carried out in the Langley stability tunnel to determine the lift, drag, and pitching-moment characteristics of a family of annular airfoils. The five annular airfoils had equal projected areas but had varying chords and diameters which covered aspect ratios of $1/3$, $2/3$, 1.0, 1.5, and 3.0. The results showed that the effects of aspect ratio on the aerodynamic-center location were similar for annular and unswept airfoils and that annular airfoils had larger maximum lift-drag ratios below an aspect ratio of 2.4 than did plane rectangular airfoils with faired tips. The lift-curve slope was twice the lift-curve slope for a plane unswept airfoil of the same aspect ratio, and the induced drag coefficient was one-half the induced drag coefficient of an elliptic airfoil. The characteristics of the flow in the wake of the annular airfoils having lower aspect ratios ($1/3$, $2/3$, and 1.0) were similar to the wake characteristics of low-aspect ratio or highly swept airfoils.

39. National Aeronautical Research Institute, Netherlands.

"Determination Of The Aerodynamic Characteristics At Supersonic Speeds Of Ringwings Combined With Axially-Symmetric Fuselages." van der Walle, F. TN G. 2, February 1958.

Development of a method for determining, from the velocity distribution of the fuselage alone, the optimum shape and the aerodynamic characteristics of ring wings placed around an axisymmetric fuselage. The velocity distribution is determined by means of a graphical linearized characteristics method due to Erdmann and Oswatitsch. The method affords insight into the flow phenomena that determine the optimum shape and aerodynamic characteristics of a ring wing. It is found that, for suitable ring wing shapes, the fuselage drag can be reduced by approximately 30%.

40. National Aeronautical Research Institute, Netherlands

"Determination Of The Influence Of A Fuselage On The Characteristics Of A General Wing System And Comparison Between The Properties Of A Ring Wing And A Plane Wing." van der Walle, F. TN G. 3, July 1958.

Discussion of the various flow-phenomena that govern the interference effects of a fuselage on the wing pressure distributions. The general results are applied to a comparison of a fuselage equipped with either a ring wing, a straight midwing, or a cruciform wing.

41. National Aeronautical Research Institute, Netherlands.

"Determination of the Interference-Effects Between A Ringwing And An Axi-Symmetric Fuselage." van der Walle, F. TN G. 7, September 1958.

Extension of a previously published method for calculating ring-wing characteristics, to include the effect of ring-wing downwash in fuselage pressure distribution. The method permits rapid and easy calculation of the optimum characteristics of a ring wing with an axisymmetric fuselage, and affords particularly accurate drag calculation. It is shown that the effects on fuselage pressure distribution are always unfavorable with respect to the normal forces, but can also be favorable when the tangential force is considered. Especially at high supersonic Mach numbers, considerable drag reduction appears to be possible if the ring wing is suitably shaped.

42. National Aeronautical Research Institute, Netherlands.
"Graphical Determination Of The Stationary Forces On Body-Annular Wing Configurations With Circular Cross-Sections In Linearized Supersonic Flow." van der Walle, F. TN G. 9, January 1960.

Presentation of a characteristics method for determining the flow field around ring-wing-body configurations of circular cross section in linearized supersonic flow. The effects of thickness and body and ring-wing axis curvature are taken into account. The method, which is an extension of the Erdmann-Oswatitsch technique, is completely graphical except for the determination of the velocities on the boundaries. It is applicable to those cases in which linearization of the equations is permissible, and to all configurations of circular cross section having centerlines which deviate only slightly from a straight line.

43. National Aeronautics and Space Administration, Washington, D. C.
"Wind-Tunnel Tests Of A Circular Wing With An Annular Nozzle In Proximity To The Ground." Greif, R. K., Kelly, M. W., and Tolhurst, W. H., Jr. NASA Technical Note, D-317, May 1960.

Exploratory tests were conducted to determine the effects of forward speed and ground proximity on the vertical thrust of an annular nozzle exhausting from the lower surface of a thin circular wing. Lift, drag, and pitching-moment data are presented with nozzle airflow data over ranges of altitude, nozzle pressure ratio, free-stream dynamic pressure, and wing angle of attack. Pressure distributions on the wing lower surface and on the ground are also included.

44. National Aeronautics and Space Administration, Washington, D. C.
"Aerodynamic Characteristics In Pitch Of Several Ring-Wing-Body Configurations At A Mach Number Of 2.2." Morris, Odell. NASA TN D-1272, April 1962.

Wind-tunnel investigation of the aerodynamic characteristics for bodies alone and for ring wing and body combinations. The tests are conducted through an angle-of-attack range from -4° to 11° . The data indicate that sizable reductions in body wave drag are obtained for the concave-afterbody configuration as a result of the favorable interference produced by the ring wing. However, a large percentage of the total drag is produced

by the ring wing and struts, and thus the ring-wing configurations of these tests appear to offer no drag advantage over a conventional wing-body configuration. Of the three configurations tested, the half-ring wing in combination with a body having a parabolic afterbody has the lowest drag (0.35) and the highest maximum lift-drag ratio (4.9).

45. Nordström, L. E.

"Some Preliminary Results From Wind Tunnel Measurements On Models With Annular Wings At Supersonic Speeds." Zeitschrift für Flugwissenschaften, Volume 4, No. 8, pp. 272-276, August 1956. (In German)

Discusses some tests on wings mounted on cone-cylindrical bodies of revolution, in the KTH 22 x 22cm supersonic, blow-down tunnel, at Mach 2 and 3. Tests are incomplete but preliminary results are given for three-component measurements on wings of different chord to diameter ratios, varied position of the body nose in relation to the wing leading edge, but with constant wing and body diameters. Lift distribution on a cylindrical body due to annular wing interference at Mach 3 is shown for incidences from 3 to 12 degrees. Some schlieren and point film illustrations of boundary-layer flow are included.

46. Crimi, P. and Ordway, D. E.

"Flutter Analysis Of A Supersonic Ring Wing." Journal of Aerospace Science, Volume 29, No. 5, pp. 578-582, May 1962.

Flutter of a supersonic ring wing with symmetrical thickness distribution is investigated using linearized equations which limit the elastic system to inextensional deformations. First-order piston theory is employed for the aerodynamic pressures. The system is analyzed by means of Lagrange's equations. Explicit expressions for the critical Mach number and flutter frequency are obtained, and a general flutter criterion is also established. For a representative airfoil cross section, the variation of the critical Mach number with aspect ratio is calculated for several modes.

47. Pirko, S.

"Scientific Session of the Society for Applied Mathematics and Mechanics (GAMM) in Stuttgart 22-26. 5. 1956: Mechanics Of Fluids." Zeitschrift für Angewandte Mathematik und Mechanik, Volume 36, No. 7/8, pp. 296-312, July-August 1956. (In German)

On the estimation of the aerodynamic properties of the thin, circular cylinder annular wing in oblique flow.

48. Pivko, S.

"The Annular Aerofoil With Central Body and Propeller." Aircraft Engineering, Great Britain, Volume 29, No. 345, pp. 353-357, November 1957.

The method of combining several standard elementary types of flow is used to represent the parallel flow past an annular aerofoil with central body of revolution and propeller.

49. Portnoy, H.

"The Quasi-Cylinder Of Specified Thickness And Shell Loading In Supersonic Flow." Aeronautical Quarterly, Great Britain, Volume 11, Part 4, pp. 387-395, November 1960.

By use of the methods of operational calculus a linear approximation is obtained to the shape of the mean camber surface in terms of the shell thickness and loading distributions. The quasi-cylinder need not possess axial symmetry and may be within the small disturbance field of other components, e. g. a centre body. The solution is invalid close to and beyond the position where the first reflected characteristic cone meets the mean cylinder. From the present work the camber shapes of ring wings, used theoretically to reduce wave drag of a central body, can be deduced. An example illustrates the method.

50. Hacques, G.

"Problèmes de la Surface Portante Annulaire Traité par l'Analogie Rhéoelectrique." Publication scientifiques et techniques du Ministère de l'Air, Bulletin des Services Techniques, BST 358, 1960. (In French)

The principal aerodynamic characteristics of the annular wing determined by analogical calculation are obtained within the framework of the linearized theory of lifting surfaces. The different aerodynamic forces due to geometric variations of the wing, or its profile, could thus be analyzed separately. Comparison between the analogical results and theoretical and experimental results shows that they agree closely.

51. Rand Corporation, Santa Monica, California

"Achievement Of Very High Lift-Drag Ratios At Supersonic Speeds Through Drag Transformation And Reduction (U)."

Johnson, Roger P. Report on Possible Circumnavigation of the Earth with Unrefueled Strategic Bombardment Aircraft, and Other Applications: Abridged Edition, Secret Report, 10 April 1958. Research Memorandum No. RM-2154. AD-150 694. Contract AF 33(038)6413.

A discussion is given of a novel aerodynamics concept-drag transformation and reduction as it would apply to a family of ring-body configurations, representing, by reason of their very high lift-drag ratios, a possible breakthrough in the range of air-breathing strategic weapon systems. Examples of specific applications of the concept are given.

52. Rand Corporation, Santa Monica, California
"Aerodynamic Characteristics and Geometric Properties of Half- and Complete-Ring-Body Configurations For Supersonic Design Mach Number (U)." Johnson, Roger P. Research Memorandum RM-2208, Confidential Report, 9 July 1958. AD-156 016. Contract AF 33(038)6413.

A presentation of the optimum aerodynamic characteristics and the associate nondimensional geometries for half- and complete-ring-body configuration as functions of three parameters; design point Mach number, reduced aspect ratio of the wing planview, and average skin friction coefficient. These configurations use thickness drag cancellation, skin friction reductions, and drag-due-to-lift reductions to effect high lift-drag ratios.

53. Rand Corporation, Santa Monica, California
"Theoretical Development For Lifting Ring-Body Configurations." Johnson, Roger P. Research Memorandum No. RM-2260, 9 September 1958. AD-207 751. Contract AF 33(038)6413.

The development of the theoretical concept for the ring-body configuration is presented. Also presented are the formulation of the general aerodynamic and geometric parameters from which the lift-drag relations and the geometry formulas and their associated numerical values were determined. The direct results of this report are: (1) The expressions and plotted curves for the wave drag-due-to-lift factor and for the vortex drag-due-to-lift factor for both half- and complete-ring-body configuration; (2) The distribution of the central-body cross-sectional-area; the total volume of the body and the volume-lift relation, all of which are required uniquely for the half-wing

configurations in order to achieve the proper effects. (See also AD-150 694.)

54. Rand Corporation, Santa Monica, California
"The Design and Test of a Zero-Wave-Drag Ring-Wing Configuration." Browand, Frederick K. Research Memorandum RM-2638, 15 June 1960. Contract AF 49(638)-700.
55. Rand Corporation, Santa Monica, California
"Verification of Ring-Wing Theory." Johnson, Roger P. U. S. Air Force Project RAND Briefing B-224, 4 January 1961. Contract 49(638)-700.
56. Rand Corporation, Santa Monica, California
"The Design And Test At Mach Number 2.5 of Two Low-Wave-Drag. Ring-Wing Configurations Of Aspect Ratio 1.3 and 2.6." Browand, Frederick K., Beane, Beverly J., and Nowlan, Daniel T. Report No. RM-2933-PR, June 1962. Contract AF 49(638)-700; Work performed at Aerophysics Laboratory, MIT, under Subcontract 58-25; Project RAND.

Notice: Available to NASA offices and NASA centers only.

An approximate scheme for the design of ring-wing configurations which have almost no supersonic wave drag (at zero angle of attack and design Mach number 2.5) is described. This method is based on the Whitham correction to linearized small-perturbation theory. Wind-tunnel tests of two configurations designed by this method tend to verify the predicted wave-drag reduction. Discrepancies with the theoretical calculations are due mainly to their assumption of inviscid, isentropic flow. It appears probable that the design method could be improved by allowing for boundary-layer growth and for shock formation. The results of measurements of the lift, drag, and pitching moment of the test models at angle of attack are included. All tests were conducted at the design Mach number 2.5. Whenever possible, the measured results are compared with theoretical predictions and the agreement is generally good.

57. Royal Aircraft Establishment, Great Britain
"Quasi-Cylindrical Surfaces With Prescribed Loadings In The Linearized Theory Of Supersonic Flow." Jones, J. G. Technical Note No. Aero 2769, June 1961. AD-261 558.

A formula for the velocity field in terms of a given surface distribution of vorticity is applied to points lying on the surface. An equation giving the shape of a quasi circular-cylindrical surface in terms of a prescribed loading is derived. As an example a half ring wing with prescribed loading is discussed.

58. Royal Aircraft Establishment, Great Britain

"Quasi-Cylindrical Surfaces With Prescribed Thickness Distributions." Moore, K. C. and Jones, J. G. Technical Note No. Aero 2815, March 1962. AD-281 784.

A formula for the supersonic velocity field in terms of a given surface distribution of sources is applied to points lying in the surface. An equation giving the camber shape of a quasi circular-cylindrical surface in terms of a prescribed thickness distribution is derived and the half ring wing with prescribed thickness distribution is discussed as an example.

59. Royal Aircraft Establishment, Great Britain

"Some Aspects Of The Design Of Half-Ring Wing-Body Combinations With Prescribed Wing Loadings." Moore, K. C. and Jones, J. G. Report No. Aero 2860, December 1962. AD-402 740.

The design of half-ring wing-body combinations with prescribed wing loadings at supersonic speeds is discussed. A particular load distribution, that behaves near a side edge like the square of the distance from the edge, is considered in detail. In addition to finding wing and optimum body shapes, wave and vortex drag and wing pressure distributions are determined and discussed. Nonlinear effects such as the focussing of the wing leading edge shock are described with reference to experimental work using flow visualization techniques.

60. Royal Aircraft Establishment, Great Britain

"Wind Tunnel Force And Moment Investigation At $M = 4.3$ Into The Application Of Various Devices For The Control Of A Cone-Cylinder-Flare Configuration (U)." Pecover, B. E. Report No. AERO 2673, January 1963, Confidential MHA Report. AD-337 631.

Measurements were made in the supersonic wind tunnel of the six components of force and moment on a basic cone-cylinder-flare configuration fitted individually with ten different devices to produce aerodynamic control. In addition, some measurements

of three components of force and moment on a flap or panel in the flare tail are given.

61. Technisch Hochschule, Karlsruhe, Germany

"The Ring Airfoil With Deflected Control Surface In Steady Incompressible Flow." Weissinger, Johannes. Report No. AFOSR TR-57-8, Part 1, January 1957. AD-115 097. Contract AF 61(514)904.

A short review is given of previous work by the author (Z. Flugwiss 4:141-150, 1956), and new numerical material is added. The new material comprises tables of kernel functions and tables of Birnbaum coefficients of the vorticity distributions induced by the distributions of the incidence angle. The reciprocity theorem of wing theory in the special form for ring airfoils is used in deriving formulas for the distribution of radial force and pitching moment along the circumference and for the total lift and pitching moment caused by the deflection of a control surface. The numerical results show a strong influence of ring shape, characterized by the length-diameter ratio, on the effectiveness of the control surface.

62. Technische Hochschule, Karlsruhe, Germany

"The Influence Of Profile Thickness On Ring Airfoils In Steady Incompressible Flow." Weissinger, Johannes. Report No. AFOSR TR 57-8, Part 2, January 1957, AD-120 424. Contract AF 61(514)904.

In order to produce profile thickness for ring airfoils contrary to two-dimensional theory, not only a source distribution is needed, but also a vortex distribution. This vortex distribution is determined by an integral equation the kernel of which has been tabulated. The axial velocity at a cylinder covered with sources and vortices in such a way as to produce ring airfoils is given in a form suitable for practical computation; these formulae have an explicit term and a second term, which must be calculated by numerical quadrature using tabulated kernel functions, in most cases however, this second term can be neglected because of its smallness. The values of these integrals have been tabulated for the most interesting cases so that for actual computations only a superposition of explicit and tabulated terms is necessary. Finally it is shown how, from these velocities at the circular cylinder, the velocity at the profile may be calculated. (See also AD-115 097.)

63. Technische Hochschule, Karlsruhe, Germany

"Remarks On Ring Airfoil Theory." Weissinger, Johannes.
Report No. AFOSR TN-58-224, January 1958. AD-154 127.
Contract AF 61(514)1207.

An investigation was conducted on ring airfoils in (incompressible) potential flow. The circumferential velocity at the ring surface was calculated for application to the three-dimensional boundary layer calculations and for stress analysis. Pitching moments of ring airfoils were also calculated. The influence of a central body on pressure distribution, lift and pitching moment was investigated. Boundary layer effects were studied, in particular drag and separation.

64. Technische Hochschule, Karlsruhe, Germany

"Ring Airfoil Theory Problems Of Interference And Boundary Layer." Weissinger, Johannes. Report No. AFOSR TN 59-226, January 1959. AD-211 809. Contract AF 61(514)1207.

The investigations of the preceding report (AD-154 127) were continued. As a new subject the interference of the ring with a strut (of small chord length) is studied. The theory of ring body interference is extended to (slender) bodies of finite length whose diameter is small compared with the ring diameter. In this report also the shape parameter $\lambda = L/D$ is assumed to be small. The lift of the body and of the wing as well as the pitching moment of the body were determined; explicit formulas and numerical results are given for ellipsoids of revolution. In boundary layer theory the methods were improved by introducing the Mangler transformation and some minor refinements.

65. Technische Hochschule, Karlsruhe, Germany

"Theoretical Investigations On Ring Airfoils." Weissinger, Johannes. January 1960. AD-234 517. Contract AF 61(514)1207.

The effects of interference between a ring airfoil and a slender central body are studied. Simple formulas for the lift and the pitching moment are derived from a more thorough theory by considerations taken from lifting line and three quarter point theory. Numerical results are given for ellipsoidal bodies. Two methods for computing the three-dimensional laminar boundary layer on ring airfoils are developed. The first is based on an expansion with respect to the angle of attack, the second is an iteration procedure. In both methods a v. Karman-Pohlhausen procedure is used. The wall streamlines and the separation line are shown.

66. Weissinger, J.

"On The Aerodynamics Of The Annular Wing In Incompressible Flow." Zeitschrift für Angewandte Mathematik und Mechanik. Germany, Volume 4, No. 3/4, pp. 141-150, March-April 1956. (In German)

Presents the development of a method for calculating the pressure distribution over thin, nearly axisymmetrical annular wings, and the appropriate forces and moments. The assumptions are those used for conventional aerofoils. Results are given for total lift and the position of the aerodynamical centre of the wing at incidence, as a function of the chord-diameter ratio.

67. Wichita University, School of Engineering, Kansas

"Shrouded Propeller Investigations: Wind Tunnel Tests Of A Shrouded Propeller Model With An Elliptical Shroud Exit." Hoehne, Vernon O. Engineering Report No. 213-16, December 1960. AD-248 804. Contract Nonr-20101.

Wind tunnel tests were made on a shrouded propeller model with a shroud whose cross-section changed from circular at the propeller plane to elliptical at the exit. The major axis of the ellipse was parallel to the model pitching axis. The transition from circular to elliptical cross-section was achieved with no change in cross-sectional areas so that this shroud can be considered as being nondiffused. A comparison model with a configuration identical to the above model except for a circular shroud exit was also tested. Performance of both models was measured throughout an advance ratio range from zero to roughly 2.5 at several blade pitch angles and at angles of attack to 90 degrees. A comparison of the performance of the two models indicates that the circular exit model is superior to the elliptical exit model.

68. Zandbergen, P. J.

"The Complete Solution For The Problem Of A Ring Wing Around A Circular Cylindrical Fuselage In A Stationary Supersonic Flow." Netherland N. L. R. Technical Report No. G. 6, September 1959. (In English)

The linearized supersonic flow around a ring wing which is concentric to a circular cylindrical fuselage is considered. Use has been made of the Laplace-transform method. The wing has an arbitrary rotationally symmetrical shape and in addition

axis curvature the vertical plane. The fuselage and the wing can have different angles of attack. The solution for the general case is derived by the super-position of the solutions of four more elementary problems.

69. Zierep, J.

"On The Lift Of An Annular Wing In Accelerating Or Decelerating Supersonic Flight." Zeitschrift für Flugwissenschaften, Volume 4, No. 8, pp. 269-272, August 1956. (In German)

A method of characteristics is used for estimating the lift of a stabilizing ring. For time-constant speeds of flight the method converges to that of Haack. Effects of acceleration and deceleration on the lift and stabilizing properties of the control surface are discussed.

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13. ABSTRACT The cited references pertain primarily to the following aerodynamic information on ring wings, also known as annular wings or circular wings: Calculation of circumferential velocity and pressure distribution, studies on flow separation phenomena at the wing leading and trailing edges, measurement of lift, drag and pitching moment, application of linearized theory to subsonic and supersonic gas flow, theory and measurement of vortex drag, measurement of three-dimensional turbulent boundary layer, determination of flutter using linearized equations, theory of stationary, inviscid, incompressible flow around the wing, studies on drag reduction, studies on interference effects of an axisymmetric fuselage or a strut on wing pressure distributions, wind tunnel tests of wings with and without a fuselage, and determination of optimum shape.		

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