AMPEX

N68 37198
(ACCESSION NUMBER)
(THRU)
25
(PAGES)
1
(CODE)
CR-97260
(NASA CR OR TMX OR AD NUMBER)
12
(CATEGORY)
FACILITY FORM 602

ON FLUID INERTIA EFFECTS IN INFINITELY WIDE FOIL BEARINGS

RR 68-15

July 15, 1968

Ampex Corporation
Research and Advanced Technology Division

UNCLASSIFIED

Prepared under

Contract No. Nonr-3815(00)(X)
Task NR 062-297

Supported jointly by

Department of Defense
Atomic Energy Commission
National Aeronautics and
Space Administration

Administered by

S. Doroff
Fluid Dynamics Branch
Office of Naval Research
Department of the Navy

ON FLUID INERTIA EFFECTS IN INFINITELY WIDE FOIL BEARINGS

Prepared by: A. Eshel
A. Eshel
Member of the Research Staff

Approved by: M. Wildmann
M. Wildmann
Manager, Mechanics Section

Approved by: W. A. Gross
W.A. Gross
Vice President, Research &
Advanced Technology,
Director of Research

Ampex Corporation
Research and Advanced Technology Division

ACKNOWLEDGEMENTS

This work was sponsored by the Office of Naval Research, Fluid Dynamics Branch, under Contract Nonr 3815(00)(X) administered by Mr. S. Doroff.

Thanks are due to Miss T. Woo for assistance in programming.

ABSTRACT

Equations for a foil over a lubricating film in which the effects of fluid inertia are taken into account are derived. Approximate solutions showing the effect of inertia and fluid compressibility are obtained. The effect of inertia is to increase the fluid film thickness.

NOMENCLATURE

C	Compresibility Parameter $\frac{p_a r_o}{T}$
C^*	Normalized Compressibility Parameter $(1 + C)H^*$
f	Shape Factor for Velocity Profile
h	Radial Clearance
H	Dimensionless Clearance $= \frac{h}{r_o}\epsilon^{-2/3}$
$\bar{H}$	Normalized Clearance = H/H^*
I	Inertia Parameter $1/2\rho_a U^2/(T/U_o)$
I^*	Normalized Inertia Parameter IH^*
k, m, n	Exponential Measures
L	Distance of Guide from Point of Tangency
p	Pressure under the Foil
p_a	Atmospheric Pressure
r	Polar Angle
r_o	Spindle Radius
R	Local Radius of Curvature
t	Temperature
t_a	Ambient Temperature
T	Tension per Unit Width of Foil
$\dot{v}_\theta$	Velocity Component in the Angular Direction
v_r	Velocity Component in the Radial Direction
$\hat{v}$	Dimensionless Radial Component of Velocity

NOMENCLATURE (Cont)

$\hat{u}$	Dimensionless Angular Component of Velocity
U	Speed of Foil or Shaft
ϵ	Dimensionless Parameter $\frac{6\mu U}{T}$
φ	Small Perturbation of Clearance
μ	Air Viscosity
ρ	Air Density at (p, t_a)
ρ_a	Air Density at Ambient Conditions (p_a, t_a)
π	Dimensionless Pressure $= (p - p_a)/(T/r_o)$
θ	Polar Angle
Θ	Wrap Angle
ξ	Dimensionless Polar Angle
$\bar{\xi}$	Normalized Polar Angle
η	Dimensionless Radial Distance from Spindle

CONTENTS

LIST OF FIGURES

ON FLUID INERTIA EFFECTS IN INFINITELY WIDE FOIL BEARINGS

1.0 INTRODUCTION

Recent applications of foil bearings (Fig. 1) in high speed tape transports and in high speed rotor supports necessitate the study of fluid inertia effects. This report is devoted to an approximate treatment of these effects.

2.0 ANALYSIS

We start with the steady, two-dimensional, compressible Navier-Stokes equations in polar coordinates:

$$\rho\left[v_r \frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} - \frac{v_\theta^2}{r}\right] = -\frac{\partial p}{\partial r} + \mu\left[2\frac{\partial^2 v_r}{\partial r^2} - \frac{2}{3}\left\{\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial r v_r}{\partial r} + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta}\right)\right\} + \right.$$

$$\left. + \frac{1}{r}\frac{\partial}{\partial \theta}\left\{\frac{1}{r}\frac{\partial v_r}{\partial \theta} + \frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r}\right\} + \frac{2}{r}\left(\frac{\partial v_r}{\partial r} - \frac{1}{r}\frac{\partial v_\theta}{\partial \theta} - \frac{v_r}{r}\right)\right] \qquad (1)$$

$$\rho\left[v_r \frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r v_\theta}{r}\right] = -\frac{1}{r}\frac{\partial p}{\partial \theta} + \mu\left[\frac{2}{r}\frac{\partial}{\partial \theta}\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta}\right) - \frac{2}{3r}\frac{\partial}{\partial \theta}\left\{\frac{1}{r}\frac{\partial r v_r}{\partial r} + \right.\right.$$

$$\left. \left. + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta}\right\} + \frac{\partial}{\partial r}\left\{\frac{1}{r}\frac{\partial v_r}{\partial \theta} + \frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r}\right\} + \frac{2}{r}\left\{\frac{1}{r}\frac{\partial v_r}{\partial \theta} + \frac{\partial v_\theta}{\partial r} - \frac{v_\theta}{r}\right\}\right] \qquad (2)$$

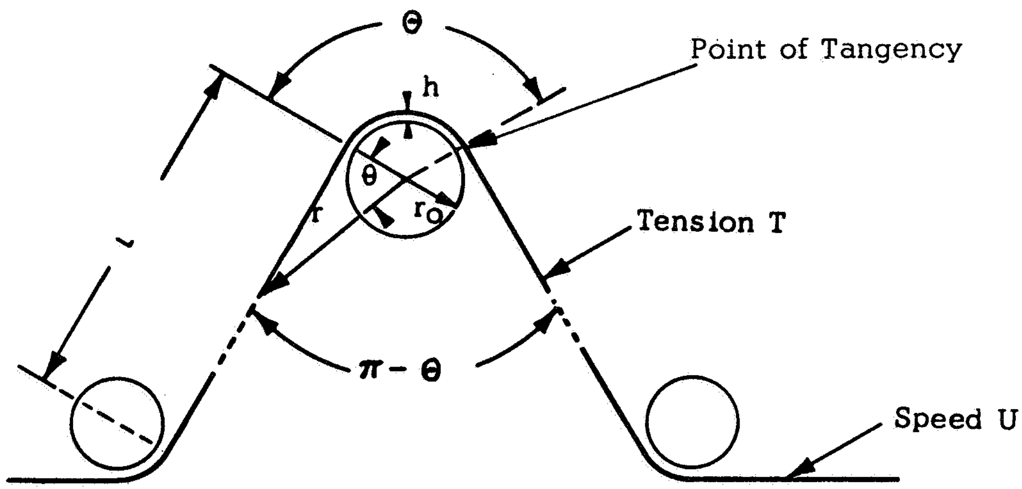

Fig. 1 Schematic View of Problem under Consideration

The continuity equation is

$$\frac{\partial(\rho v_r r)}{\partial r} + \frac{\partial(\rho v_\theta)}{\partial \theta} = 0 \tag{3}$$

The perfectly flexible foil equation is

$$p - p_a = \frac{T}{R} \tag{4}$$

The isothermal equation of state is

$$\frac{p}{p_a} = \frac{\rho}{\rho_a} \tag{5}$$

The curvature in polar coordinates is

$$\frac{1}{R} = \frac{2\left(\frac{dr}{d\theta}\right)^2 - r\frac{d^2 r}{d\theta^2} + r^2}{\left[\left(\frac{dr}{d\theta}\right)^2 + r^2\right]^{3/2}} \tag{6}$$

and the clearance

$$h = r - r_o \tag{7}$$

In previous analyses of foil bearings [1], a small parameter expansion was used to formally discard terms of higher order. In the following, the same expansion is used for the Navier-Stokes equations. This will yield a consistent set of equations, including the effect of inertia. This reduction may not be correct in the large gap inlet and exit regions of the flow since the expansion is incomplete in terms of boundary conditions. It is expected, however, that for small inertia parameters, the effect of the boundary conditions will not penetrate into the small gap regions. Due to this rather heuristic character of the derivation, the results must be viewed as estimates only.

We introduce the dimensionless parameters

$$\epsilon = \frac{6\mu U}{T} \qquad \text{foil bearing number} \tag{8}$$

$$C = \frac{p_a}{T/r_o} \qquad \text{compressibility parameter} \tag{9}$$

$$I = \frac{\frac{1}{2}\rho_a U^2}{T/r_o} \qquad \text{inertia parameter} \tag{10}$$

and the dimensionless variables

$$\hat{v} = \frac{v_r}{U}\epsilon^{-k} \tag{11}$$

$$\hat{u} = \frac{v_\theta}{U} \tag{12}$$

$$\Pi = \frac{p - p_a}{T/r_o} \tag{13}$$

$$\xi = \theta \epsilon^{-m} \tag{14}$$

$$\eta = \frac{y}{r_o} \epsilon^{-n} \tag{15}$$

$$H = \frac{h}{r_o} \epsilon^{-n} \tag{16}$$

where k, m, n are constants to be determined.

In accordance with conventional foil bearing theory, the following requirements are imposed on the equations for the purpose of the determination of k, m, n: (a) The expansion of equation (6) has to retain the capability of satisfying the condition that the tape becomes flat at infinity. (b) The purpose of this work is to study cases in which inertia effects are significant. It will be required, therefore, that at least some inertia term will be of the order of some viscous term. (c) Finally, it is required that the lateral and longitudinal terms in the continuity equations will be of the same order. These three requirements result in the conditions

$$n = 2/3 \quad ; \quad m = 1/3 \quad ; \quad k = 1/3 \tag{17}$$

With these results, the equations can be shown to degenerate, to the zeroth approximation, into Prandtl's boundary layer equations.

$$I\left(1+\frac{\pi}{c}\right)\left[\hat{u}\frac{\partial\hat{u}}{\partial\xi}+\hat{v}\frac{\partial\hat{u}}{\partial\eta}\right]=-\frac{1}{2}\frac{d\pi}{d\xi}+\frac{1}{12}\frac{\partial^2\hat{u}}{\partial\eta^2} \tag{18}$$

$$\frac{\partial}{\partial\eta}\left\{(c+\pi)\hat{v}\right\}+\frac{\partial}{\partial\xi}\left\{(c+\pi)\hat{u}\right\}=0 \tag{19}$$

$$\pi = 1 - H'' \tag{20}$$

We assume that the velocity profile is parabolic. The profile which satisfies the boundary conditions

$$\hat{u}=1 \qquad \eta=0 \tag{21}$$

$$\hat{u}=0 \qquad \eta=H \tag{22}$$

is

$$\hat{u}=-f\left(\frac{\eta}{H}\right)^2+(f-1)\left(\frac{\eta}{H}\right)+1 \tag{23}$$

where f is to be determined.

The three unknown functions π, H, f will be determined from the momentum and continuity integrals between $\eta = 0$ and $\eta = H$ and from the elastic equation.

The momentum integral becomes

$$I\left\{\left(f+\frac{5}{2}\right)\frac{df}{d\xi} - \frac{1}{(\pi+C)H}\,\frac{d[(\pi+C)H]}{d\xi}\,\frac{(f-5)}{2}\right\} = -15\frac{d\pi}{d\xi} + \frac{5f}{H^2} \qquad (24)$$

The continuity integral is

$$\frac{d}{d\xi}\left[(\pi+C)\,H\left(\frac{1}{2}+\frac{f}{6}\right)\right] = 0 \qquad (25)$$

Equations (20), (24), and (25) constitute the approximate formulation of the problem. The first integral of Eq. (25) is

$$(\pi+C)\,H\left(1+\frac{f}{3}\right) = (1+C)\,H^* \qquad (26)$$

where $(1 + C)\,H^*$ denotes the integration constant. The physical interpretation of H^* is the value of H in the central or uniformity region of the bearing. It is also a measure of the flow rate through the bearing.

From previous analyses [1], the boundary conditions representing the straight asymptotic behavior of the foil far from the spindle are:

$$H \sim \xi^2/2 + \dots \tag{27}$$

$$H' \sim \xi + \dots \tag{28}$$

as $\xi \to \pm\infty$

The formulation is, thus, a function of three parameters: I, C, H*. It is convenient to eliminate H* from Eq. (26) For this purpose, the transformation

$$\frac{H}{H^*} = \bar{H} \ ; \quad \frac{\xi}{H^*} = \bar{\xi} \ ; \ (1+c)H^* = C^* \ ; \ I H^* = I^* \tag{29}$$

is used. The equations become

$$f = \frac{3C^*}{(C^* - \bar{H}'')\bar{H}} - 3 \tag{30}$$

$$\bar{H}''' = \frac{\dfrac{5f}{\bar{H}^2} - I^* \dfrac{f^2+6f+5}{\bar{H}} \bar{H}'}{15 - I^* \dfrac{(f^2+6f+5)(f+3)}{3C^*}} \tag{31}$$

with

$$\begin{aligned} \bar{H}' &\sim H^* \bar{\xi} \\ \bar{H}'' &\sim H^* \end{aligned} \tag{32}$$

as $\bar{\xi} \to \infty$

Following the procedure of[1], the solution is started from the central region towards the exit with a matched H* at the central region. This is done by a linearized approach

$$\begin{aligned} \bar{H} &= 1 + \varphi \\ \bar{H}' &= \varphi' \\ \bar{H}'' &= \varphi'' \end{aligned} \tag{33}$$

where $\varphi \ll 1$

The linearized continuity and momentum equations become

$$f = 3\left(\frac{\varphi''}{C^*} - \varphi\right) \qquad (34)$$

$$\varphi'''\left(1 - \frac{I^*}{3C^*}\right) - \frac{\varphi''}{C^*} + \frac{I^*}{3}\varphi' + \varphi = 0 \qquad (35)$$

The roots of the characteristic equation are graphically shown in Fig. 2.

3. ASYMPTOTIC BEHAVIOR

It can be observed that as

$$\bar{H} \to \infty \qquad f \to -3$$

$$\bar{H}''' \sim -\frac{4}{15}\frac{\bar{H}'}{\bar{H}} = -\frac{4}{15}\frac{d(\ln \bar{H})}{d\xi} \qquad (36)$$

Thus, the boundary conditions cannot be satisfied since $\bar{H}''$ does not approach a constant as required by Eq. (32). It must be observed, however, that in the region of interest $\bar{H}'''$ is fairly small. $\bar{H}$ is, therefore, nearly parabolic, until finally the logrithmic contribution becomes overwhelming. Thus, one may consider that the boundary condition of asymptotically straight tape is approximately satisfied. *

*This interpretation of the results is due to Prof. H. G. Elrod Jr.

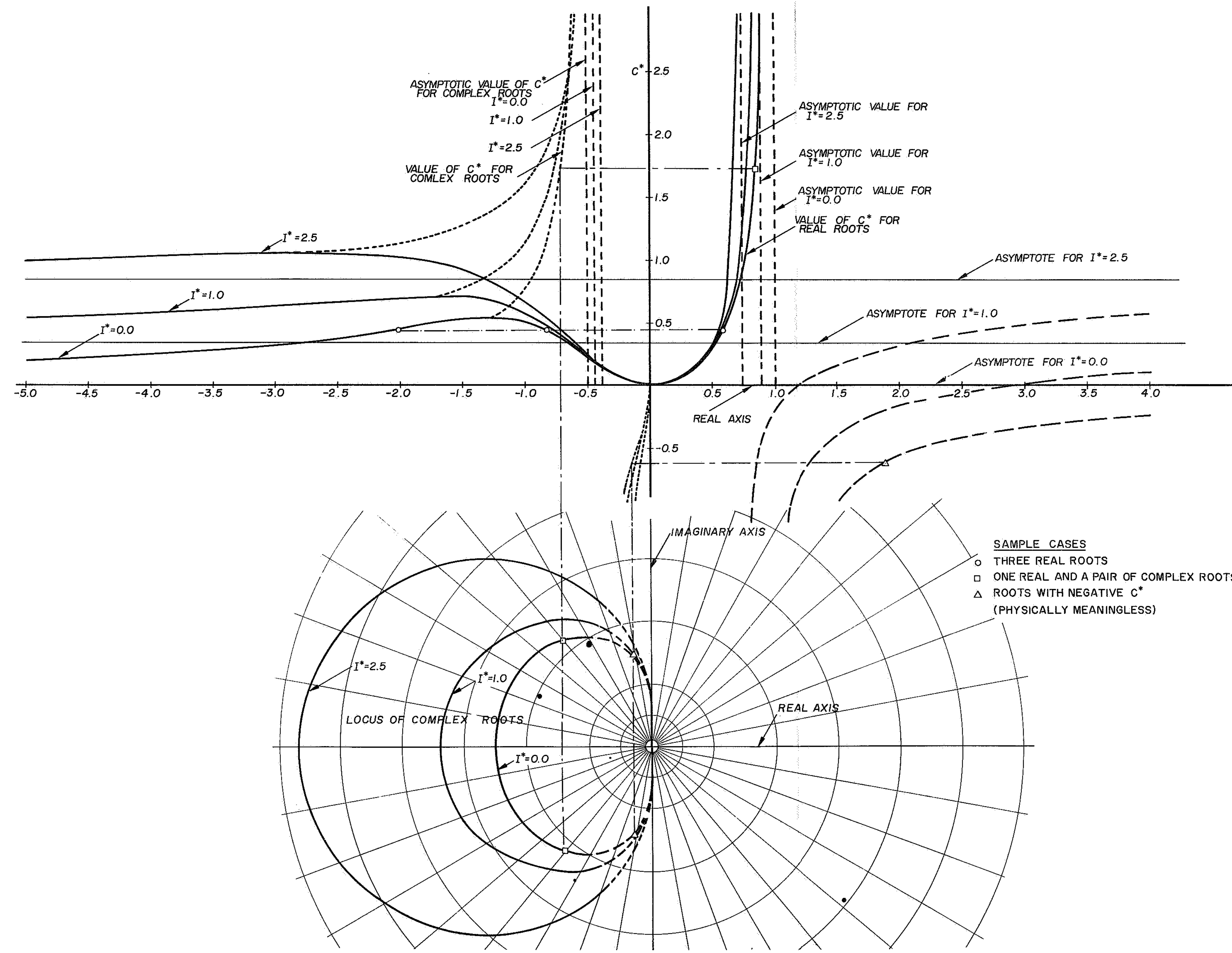

Fig. 2 Roots of Characteristic Equation

Due to the imperfect satisfaction of the boundary conditions, a degree of uncertainty is involved which increases with the inertia parameter I and vanishes for $I \to 0$. In the actual computation work the point at which the logrithmic behavior takes over was assumed to lie between $\bar{H} = 20$ and $\bar{H} = 1000$. The value of H* taken as "correct" was chosen as that corresponding to $\bar{H} = 100$.

Figure 3 shows the corresponding range of uncertainty in H*. The main result of this work is given in Fig. 4. Here, the values of H* as a function of the compressibility and inertia parameters is given. A similar chart, where H* is expressed in terms of C and I* which naturally appear in the equations, is given in Fig. 5.

For the purpose of practical calculations, an analytical formula was fitted to the results of Fig. 4:

$$H^* = 0.643 + 0.286\, I + 1.905\, I^2 - \frac{0.183}{C}$$

The formula approximates the results well in the region

$$0 < \frac{1}{C} < 1$$

$$0 < I < 0.5$$

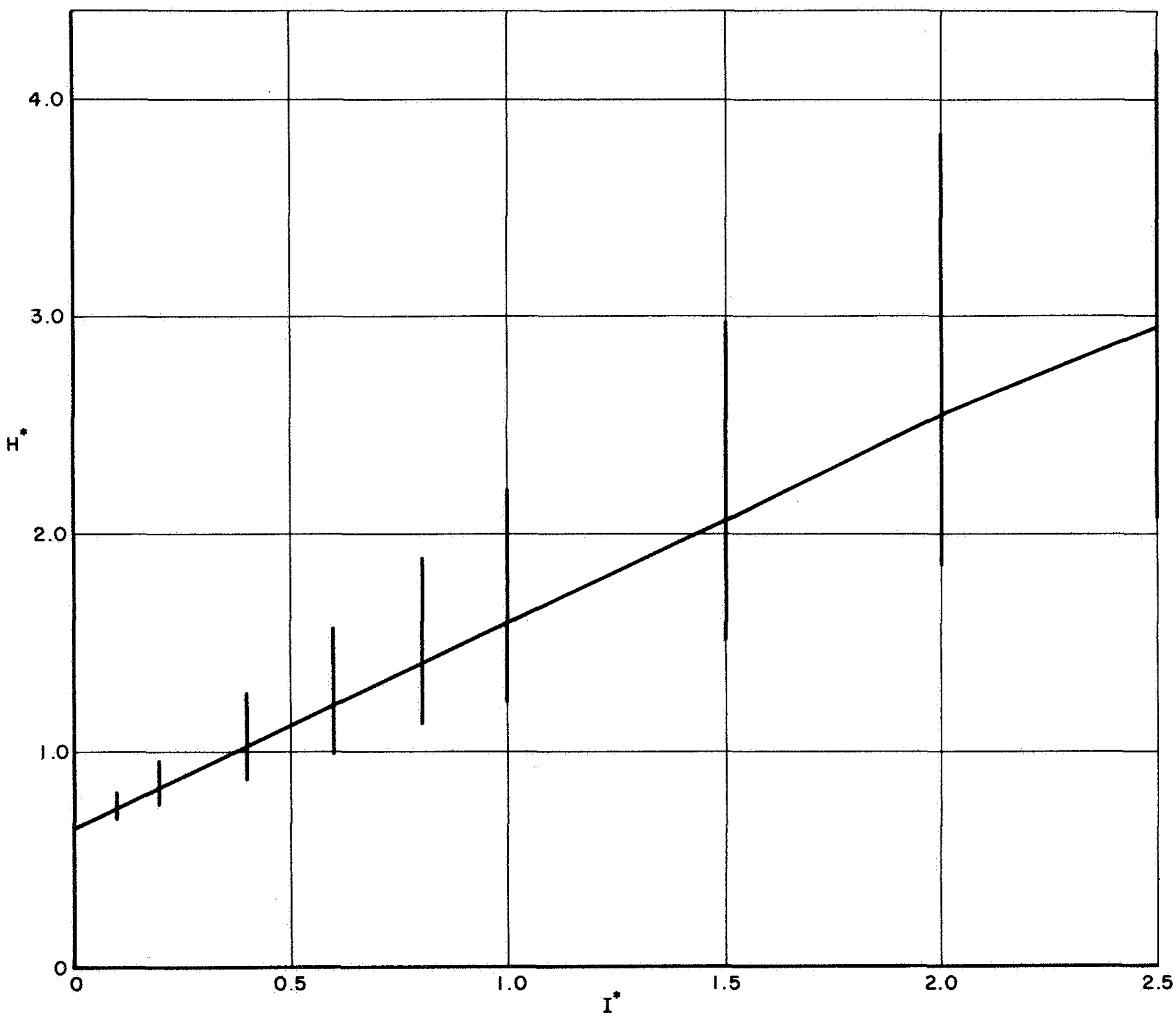

Fig. 3. Bounds of Uncertainty in the Evaluation of H* (C*= ∞)

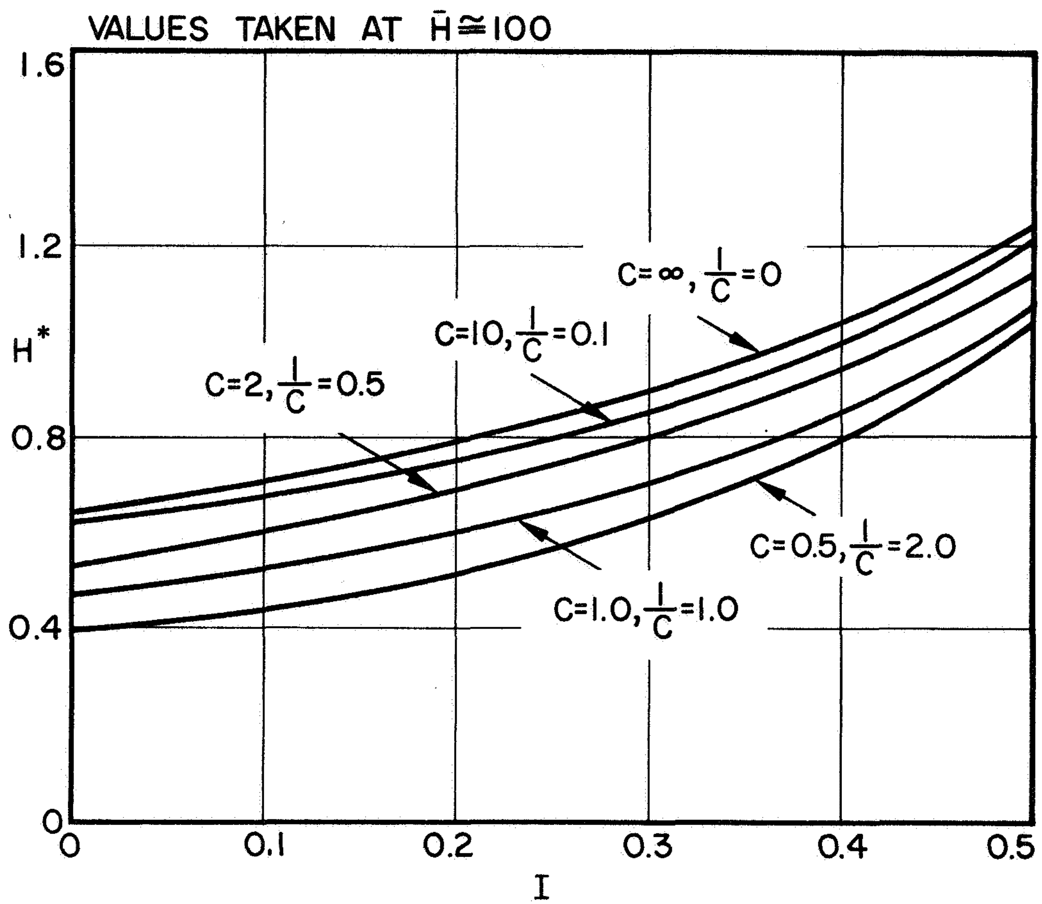

Fig. 4 Nominal Clearance H* as a Function of Compressibility (C) and Inertia (I) Parameters

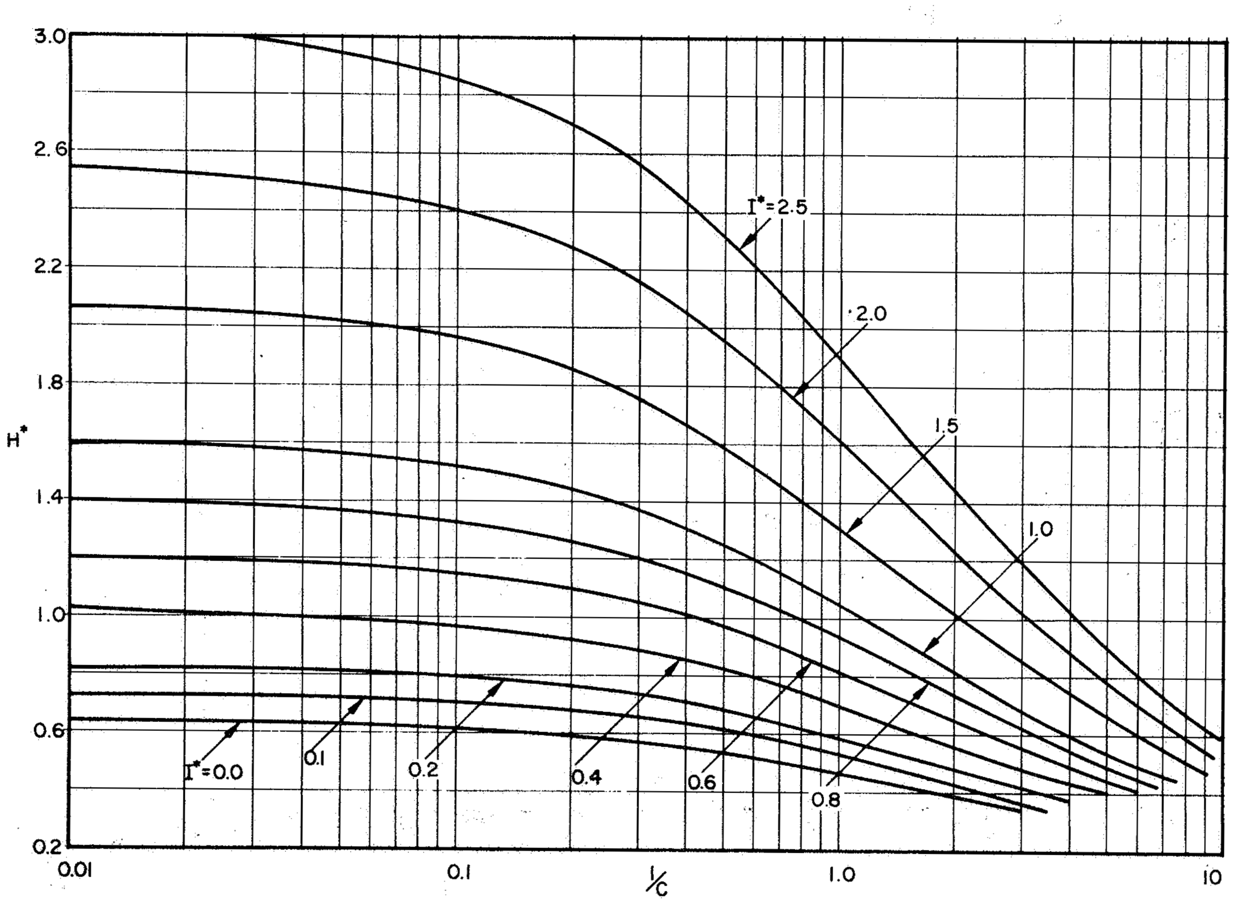

Fig. 5 Nominal Clearance H* as a Function of Compressibility (C) and the Normalized Inertia (I*) Parameters

REFERENCES

1. A. Eshel and H. G. Elrod Jr., "The Theory of the Infinitely Wide, Perfectly flexible Self-Acting Foil Bearing," Journal of Basic Engineering, Trans. ASME, Series D, Vol. 87, Dec. 1965, pp. 831 - 836.

APPROVED DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL REPORTS ISSUED UNDER CONTRACT NONR 3815(00), NR 062-297

Defense Documentation Center
Cameron Station
Alexandria, Virginia (20)

Mr. Stanley L. Zedaker
Department 244-2, Building 71
Autonetics
P. O. Box 4181
Anaheim, California 92803

Officer in Charge
Annapolis Division
Naval Ship Research and Development Center
Attn: Mr. Watt V. Smith (1)
Code 800 (1)
Annapolis, Maryland 21402

Superintendent
Naval Academy
Attn: Library
Annapolis, Maryland 21402

Air Force Office of Scientific Research
Attn: Code SREM
1400 Wilson Boulevard
Arlington, Virginia 22209

Mr. David Craig, Jr.
Mechanical Design Section
Grumman Aircraft Engineering Corporation
Bethpage, New York 11714

Director
Office of Naval Research Branch Office
495 Summer Street
Boston, Massachusetts 02210

Commander
Boston Naval Shipyard
Boston, Massachusetts 02129

Cryogenic Data Center
National Bureau of Standards
Boulder, Colorado 80302

Massachusetts Institute of Technology
Instrumentation Laboratory
Attn: Library
68 Albany Street
Cambridge, Massachusetts 02139

Professor Herbert H. Richardson
Room 3-461
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Mr. Robert S. Siegler
Rocketdyne
Nucleonics Subdivision
6633 Canoga Avenue
Canoga Park, California 91304

Commander
Charleston Naval Shipyard
Naval Base
Charleston, South Carolina 29408

Dr. Edgar J. Gunter, Jr.
University of Virginia
School of Engineering and Applied Science
Charlottesville, Virginia 22903

Director
Office of Naval Research Branch Office
219 South Dearborn Street
Chicago, Illinois 60604

Professor L. N. Tao
Illinois Institute of Technology
Chicago, Illinois 60616

Commander
Naval Weapons Center
Attn: Code 753
China Lake, California 93555

Mr. Robert H. Josephson, Manager
Clevite Corporation
Mechanical Research Division
540 East 105th Street
Cleveland, Ohio 44108

Director, Lewis Research Center
National Aeronautics and Space
Administration
Attn: Mr. E. E. Bisson
Cleveland, Ohio 44871

NASA Scientific and Technical
Information Facility
P. O. Box 33
Attn: Acquistions Branch (S-AK/DL)
College Park, Maryland 20740

Battelle Memorial Institute
505 King Avenue
Attn: Dr. Russell Dayton (1)
Mr. J. W. Kannel (1)
Columbus, Ohio 43201

Dr. John E. Mayer, Jr.
Research & Engineering Center
Ford Motor Company
P. O. Box 2053
Dearborn, Michigan 48123

Mr. Henry J. Elwertowski
Admiralty Compass Observatory
Ditton Park, Slough, Bucks, England

Commanding Officer
Army Research Office
Attn: ESD-AROD
Box CM, Duke Station
Durham, North Carolina 27706

Professor A. Charnes
The Technological Institute
Northwestern University
Evanston, Illinois 60201

C. C. Moore, Manager
Advance Bearing & Seal Technology
General Electric Company
Flight Propulsion Division
Mail Drop H25
Evendale, Ohio 45215

Mr. L. R. Manoni
Manager, Advanced Programs
United Aircraft Corporation Systems Center
1690 New Britain Avenue
Farmington, Connecticut 06032

Commanding General
Army Engineering Research and
Development Laboratories
Attn: Mr. W. M. Crim (1)
Technical Documents Center (1)
Fort Belvoir, Virginia 22060

Mrs. Hisaw, Engineering Librarian
The LaFLEUR Corporation
16659 South Gramercy Place
Gardena, California 90247

Mr. W. G. Wing
Sperry-Gyroscope Company
2T120
Great Neck, New York 11020

Mr. H. Walter
Vice President, Research & Development
Worthington Corporation
Harrison, New Jersey 07029

Dr. Charles C. W. Ng
Pratt and Whitney Aircraft Corporation
E. Hartford, Connecticut 06108

Mr. Stanley Abramovitz, Director
Industrial Tectonics, Inc.
Fluid Film Bearing Division
New South Road and Commercial Street
Hicksville, New York 11803

Mr. P. H. Broussard, Jr.
Guidance and Control Division
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Professor J. F. Kennedy, Director
Iowa Institute of Hydraulic Research
University of Iowa
Iowa City, Iowa 52240

Commanding Officer
Naval Avionics Facility
21st and Arlington Avenue
Attn: Mr. J. G. Weir RDM-4
Indianapolis, Indiana 46218

Dr. H. N. Linhardt
Director of Engineering
Cryogenic Division
Aireduction Company
1900 Lane Road
Irvine, California 92664

Captain L. S. McCready
Merchant Marine Academy
Kings Point, New York 11024

Professor J. Modrey
School of Mechanical Engineering
Purdue University
Lafayette, Indiana 47907

Dr. B. Sternlicht
Mechanical Technology Incorporated
968 Albany-Shaker Road
Latham, New York 12110

Mr. P. Eisenberg
Hydronautics, Incorporated
Pindell School Road
Howard County, Laurel, Maryland 20810

Mr. Walter Carow
Kearfott Division
General Precision Incorporated
1150 McBride Avenue
Little Falls, New Jersey 07425

Mr. J. Levine
Ford Instrument Company
31-1 Thomson Avenue
Long Island City, New York 11101

Commander
Long Beach Naval Shipyard
Long Beach, California 90802

Mr. Jerry Glaser
Senior Project Engineer (Dept. 37)
The Garrett Corporation
9851 S. Sepulveda Boulevard
Los Angeles, California 90009

Mr. Howard F. Traeder
Instruments Engineering Department
AC Electronics Division
General Motors Corporation
Milwaukee, Wisconsin 53201

Mr. J. W. Lower, Chief
Engineer-Inertial Components
Honeywell Aero Division
2600 Ridgway Road
Minneapolis, Minnesota 55455

Superintendent
Naval Postgraduate School
Attn: Library
Monterey, California 93940

Professor Paul F. Pucci
Mechanical Engineering Department
Naval Postgraduate School
Monterey, California 93940

Research Committee in Information
The American Society of Mechanical
Engineers
345 East 47th Street
New York, New York 10017

Engineering Societies Library
345 East 47th Street
New York, New York 10017

Office of Naval Research
New York Area Office
207 W. 24th Street
New York, New York 10011

Commanding Officer
Office of Naval Research Branch Office
Box 39 FPO New York 09510 (25)

Columbia University
Department of Mechanical Engineering
Attn: Professor V. Castelli (1)
Professor H. Elrod (1)
New York, New York 10027

Mr. Gerald E. Speen, Division Manager
Conductron
P. O. Box 844
Northridge, California 91324

Ralph F. De Angelias
Norden Division of United
Aircraft Corporation
Helen Street
Norwalk, Connecticut 06852

Mr. E. L. Swainson
Precision Products Department
Nortronics
100 Morse Street
Norwood, Massachusetts 02062

United States Atomic Energy Commission
Division of Technical Information
Extension
P. O. Box 62
Oak Ridge, Tennessee 37830

Mr. R. E. MacPherson
Oak Ridge National Laboratory
P. O. Box Y
Oak Ridge, Tennessee 37831

Mr. R. G. Jordan
Oak Ridge Gaseous Diffusion Pl.
Union Carbide Corporation - Nuclear
Division
P. O. Box P
Oak Ridge, Tennessee 37830

National Research Council
Aeronautical Library
Attn: Miss O.M. Leach, Librarian
Montreal Road
Ottawa 7, Canada

Dr. Calus G. Goetzel, Orgn 52-30
Bldg. 201, Plant 2
Lockheed Missiles and Space Company
3251 Hanover Street
Palo Alto, California 94304

Director
Office of Naval Research Branch Office
1030 E. Green Street
Pasadena, California 91101

Dr. E. E. Sechler
Executive Officer for Aero
California Institute of Technology
Pasadena, California 91109

Mr. Carl F. Graesser, Jr.
Director of Research
New Hampshire Ball Bearings, Inc.
Peterborough, New Hampshire 03458

Professor D. D. Fuller
Laboratories for Research & Development
The Franklin Institute
Philadelphia, Pennsylvania 19104

Mr. Otto Decker, Manager
Friction and Lubrication Laboratory
Franklin Institute
20th and Parkway
Philadelphia, Pennsylvania 19103

Professor P. R. Trumpler
Towne School of Civil and Mechanical
Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Commander
Philadelphia Naval Shipyard
Attn: Technical Library (Code 249b)
Philadelphia, Pennsylvania 19112

Mr. John Boyd
Westinghouse Research Incorporated
Churchill Boro
Pittsburgh, Pennsylvania 15235

Professor M. C. Shaw, Head
Department of Mechanical Engineering
Carnegie Institute of Technology
Pittsburgh, Pennsylvania 15213

Dr. F. Osterle
Department of Mechanical Engineering
Carnegie Institute of Technology
Pittsburgh, Pennsylvania 15213

Commander
Naval Missile Center
Attn: Technical Library
Point Mugu, California 93041

Commander
Portsmouth Naval Shipyard
Portsmouth, New Hampshire 03801

Commander
Norfolk Naval Shipyard
Portsmouth, Virginia 23709

Mr. Phillip J. Mullan
Staff Engineer-Advanced Tapes
IBM Data Systems Division
Development Laboratory- Box 390
Poughkeepsie, New York 12602

Redstone Scientific Information Center
Army Missile Command
Attn: Chief, Document Section
Redstone, Arsenal, Alabama 35809

Dr. W. A. Gross (1)
Dr. J. Licht (1)
Ampex Corporation
401 Broadway
Redwood City, California 94063

Editor
Applied Mechanics Reviews
Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206

Office of Naval Research
San Francisco Area Office
1076 Mission Street
San Francisco, California 94103

Technical Library, Code H245C-3
Hunters Point Division
San Francisco Bay Naval Shipyard
San Francisco, California 94135

Mr. G. R. Fox
Research and Development Center
General Electric Company
P. O. Box 8
Schenectady, New York 12301

Fenton Kennedy Document Library
The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910

Commander
Naval Ordnance Laboratory
Attn: Librarian
Silver Spring, White Oak, Maryland 20910

Dr. H. S. Grassam
University of Southampton
Department of Mechanical Engineering
Southampton, England

Professor J. Foa
Department of Aeronautical Engineering
Rensselaer Polytechnic Institute
Troy, New York 12180

Professor R. C. DiPrima
Department of Mathematics
Rensselaer Polytechnic Institute
Troy, New York 12180

Walt Tucker
Nuclear Engineering Department
Brookhaven National Laboratory
Upton, Long Island, New York 11973

Shipyard Technical Library
Code130L7 Bldg 746
San Francisco Bay Naval Shipyard
Vallejo, California 94592

Mr. E. Roland Maki
Mechanical Development Department
General Motors Corporation
12 Mile and Mound Roads
Warren, Michigan 48090

Chief of Naval Research
Department of the Navy
Attn: Code 438 (3)
Code 473 (1)
Code 463 (1)
Washington, D. C. 20360

Director
Naval Research Laboratory
Attn: Code 2027 (6)
Code 5230 (1)
Washington, D. C. 20390

Director
Special Projects Office
Department of the Navy
Washington, D. C. 20360

Director, Special Projects Office
Department of the Navy
Attn: Code SP230
Washington, D. C. 20360

Commander
Naval Ship Systems Command
Department of the Navy
Attn: Code 6340 (1)
Code 6345 (1)
Code 6644C (1)
Washington, D. C. 20360

Commanding Officer and Director
Naval Ship Research and Development Center
Attn: Code 042 (1)
Code 513 (1)
Washington, D. C. 20007

Commander
Naval Air Systems Command
Attn: AIR 52034 (1)
AIR 53651 (1)
Washington, D. C. 20360

Commander
Naval Ordnance Systems Command
Attn: ORD 03 (1)
ORD 913 (1)
Washington, D. C. 20360

Division of Engineering
Maritime Administration
441 G Street, N.W.
Washington, D. C. 20235

Librarian Station 5-2
Coast Guard Headquarters
1300 E Street, N.W.
Washington, D. C. 20226

Chief of Research and Development
Office of Chief of Staff
Department of the Army
The Pentagon, Washington, D. C. 20310

Chief of Staff
U.S. Air Force
The Pentagon
Attn: AFDRD-AS/M
Washington, D. C. 20330

Commander
Air Force Office of Scientific Research
Attn: SRHM
Washington, D. C. 20333

Science and Technology Division
Library of Congress
Washington, D. C. 20540

National Science Foundation
Engineering Division
1800 G Street, N.W.
Washington, D. C. 20550

Headquarters Library
Atomic Energy Commission
Washington, D. C. 20545

Mr. N. Grossman, Chief
Engineering Development Branch
Reactor Development Division
Atomic Energy Commission
Washington, D. C. 20545

Mr. Clarence E. Miller, Jr.
Division of Reactor Development and Technology
U.S. Atomic Energy Commission
Washington, D. C. 20545

Defence Research and Development Attache
Australian Embassy
1735 Eye Street, N. W.
Washington, D. C. 20006

Dr. W. T. Sawyer
Department of Mechanical Engineering
Catholic University
Washington, D. C. 20017

Mr. Don Moors (1)
Dr. J. S. Ausman (1)
Litton Systems, Inc.
5500 Canoga Avenue
Woodland Hills, California 91364

Mr. George H. Pedersen
Curtiss-Wright Corporation
Wright Aeronautical Division
Woodridge, New Jersey 07075

AF Flight Dynamics Laboratory
Attn: Mr. W.C. Buzzard (FDFM)
Wright-Patterson AFB, Ohio 45433

AF Aero Propulsion Laboratory
Attn: Mr. M.R. Chasman (APFL)
Wright-Patterson AFB, Ohio 45433

Commander, Research & Technology Division
Air Force Systems Command
Attn: L.M. Medgepeth (APIP-1) (1)
R.W. McAdory (AVNE) (1)
Wright-Patterson AFB, Ohio 45433

Hamilton Standard Systems Center
1690 New Britain Avenue
Attn: Librarian
Farmington, Connecticut 06032

Commanding Officer and Director
Naval Ship Research and
Development Center, Code 800
Washington, D.C. 20007

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

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

1. ORIGINATING ACTIVITY *(Corporate author)* Ampex Corporation, 401 Broadway, Redwood City, Calif.	2a. REPORT SECURITY CLASSIFICATION: Unclassified
	2b. GROUP

3. REPORT TITLE

On Fluid Inertia Effects in Infinitely Wide Foil Bearings

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

Technical Report

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

Eshel, A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 15, 1968	25	1

8a. CONTRACT OR GRANT NO. Contract No. Nonr-3815(00)(X)	9a. ORIGINATOR'S REPORT NUMBER(S) RR 68-15
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Department of the Navy, Office of Naval Research, Washington, D.C. 20360

13. ABSTRACT

Equations for a foil over a lubricating film in which the effects of fluid inertia are taken into account are derived. Approximate solutions showing the effect of inertia and fluid compressibility are obtained. The effect of inertia is to increase the fluid film thickness.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Foil Bearings						
Fluid Mechanics						
Reynolds Equation						
Fluid Films						
Mathematical Analysis						
Inertia Effects						

INSTRUCTIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

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

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

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

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

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

Unclassified

Security Classification