

AD-A071 639

AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA)

F/G 20/11
SIMPLE FORMULAE FOR CALCULATING THE VIBRATIONAL FREQUENCIES OF --ETC(U)

JUN 78 R JONES

UNCLASSIFIED

ARL/STRUC-371

NL

1 OF 1

AD
A071639



END
DATE
FILMED
8-79

DDC

LEVEL II



AD A 071 639

**DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES**

MELBOURNE, VICTORIA

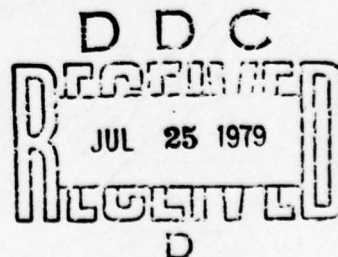
STRUCTURES REPORT 371

**SIMPLE FORMULAE FOR CALCULATING THE
VIBRATIONAL FREQUENCIES OF PLATES, SHELLS
AND MEMBRANES**

by

R. JONES

Approved for Public Release.



© COMMONWEALTH OF AUSTRALIA 1978

COPY No 11

JUNE 1978

79 07 24 017

DDC FILE COPY

APPROVED
FOR PUBLIC RELEASE

THE UNITED STATES NATIONAL
TECHNICAL INFORMATION SERVICE
IS AUTHORIZED TO
REPRODUCE AND SELL THIS REPORT

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

(9) STRUCTURES REPORT 371

(6) **SIMPLE FORMULAE FOR CALCULATING THE
VIBRATIONAL FREQUENCIES OF PLATES, SHELLS
AND MEMBRANES.**

by

(10) R. JONES

(11) Jun 78

(12) 24p.

(14) ARL/STRUC-371

SUMMARY

Simple approximate formulae for estimating the vibrational frequencies of plates, shells and membranes are presented. These formulae take the general form $F = A/W_{\max}$ where F is a frequency parameter, A is a numerical parameter having a constant value for many different problems, and $W_{\max}$ is the maximum deflection of an associated static deflection problem.

The approach is particularly simple and the agreement between the frequencies calculated using the approximate formulae and those calculated using standard vibration analyses is excellent.

W sub max

DDC
RECEIVED
JUL 25 1979
D

008 650

500

CONTENTS

	Page No.
NOTATION	
1. INTRODUCTION	1
2. FORMULA FOR PLATES	1
3. FORMULA FOR MEMBRANES AND SHEELS	4
4. FORMULA FOR ANISOTROPIC PLATES	9
5. CONCLUSIONS	10
REFERENCES	
DOCUMENT CONTROL DATA	
DISTRIBUTION	

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification _____	
By _____	
Distribution/ _____	
Availability Codes	
Dist A	Avail and/or special

NOTATION

ρ	Mass per unit area
h	Thickness of the plate, membrane or shell
ν	Poisson's ratio
ω	Frequency
$W'_{\max}$	Maximum deflection due to a uniformly distributed load
$\hat{W}_{\max}$	Maximum deflection due to a load varying linearly with the distance from the centroid
k	Curvature of a shallow cylindrical or spherical shell
ω_0	Frequency parameter for a flat plate with Poisson's ratio equal to zero
E	Young's Modulus
D_x, D_y, H	Flexural rigidities for an orthotropic plate
δ	Aspect ratio

1. INTRODUCTION

Static deflection modes, due to particular pressure distributions, have long been used for vibration and flutter analysis, and are commonly used in conjunction with the Ritz method to obtain estimates of the vibrational frequencies. However, in a recent paper, Jones¹ proposed a new procedure which related the fundamental frequency of a vibrating plate to the maximum deflection of the corresponding, uniformly loaded plate. Unlike the Ritz method, this technique has the advantages that it is not necessary to perform any integration, and that the approximation is explicitly independent of the support conditions.

The aim of the present report is to discuss the developments of this technique, which have enabled the method to be extended so as to predict the frequencies of several higher modes as well as the frequencies of membrane and shell structures.

2. FORMULA FOR PLATES

In a recent article, Jones¹ presented an approximate expression for the fundamental frequency of a vibrating plate: viz.

$$\rho h \omega^2 = (10 \cdot 2151)^2 / 64 W'_{\max} \quad (1)$$

where ρ is the mass per unit area, h is the plate thickness, ω the frequency of vibration and $W'_{\max}$ is the maximum deflection under unit loading of the corresponding uniformly loaded plate. Although the accuracy of this expression was clearly shown in Reference 1, this paper will include a more detailed investigation into its accuracy. In Table 1, the predicted values of the frequency, along with corresponding values obtained from the literature are shown for a large range of plates of various geometrical shapes and subject to a combination of boundary conditions.

TABLE 1

Frequency Parameter $\omega a^2 \sqrt{\rho h / D}$ for Fundamental Mode for Various Plate Problems,
 $\nu = 0 \cdot 3$ (unless otherwise stated)

Problem	Equation (1)	Literature, e.g. Ref. 3
Simply supported equilateral triangle, sides of length $2a/\sqrt{3}$	39·80	39·48
Clamped rectangular plate, sides of length a, b $b/a = 1 \cdot 0$	35·97	35·99
$= 1 \cdot 5$	27·22	26·59
$= 2 \cdot 0$	25·33	24·58
Simply supported rectangular plate $b/a = 1 \cdot 0$	20·04	19·74
$= 1 \cdot 5$	14·53	14·26
$= 2 \cdot 0$	12·67	12·34
Clamped semicircular plate radius a	28·40	27·? (too inaccurate)

TABLE 1—continued

Problem	Equation (1)	Literature, e.g. Ref. 3
Clamped elliptic plate, semi major axis of length a , semi minor axis of length b $a/b = 1.0$ $= 1.5$ $= 2.0$ $= 3.0$	10.22 17.20 27.74 58.68	10.22 17.20 27.74 58.68
Clamped rhombic plate, sides of length a , an included angle of θ $\theta = 75^\circ$ $= 60^\circ$ $= 45^\circ$ $= 30^\circ$	38.10 46.03 65.77 122.79	38.19 46.17 65.59 121.29
Simply supported rhombic plate $\theta = 60^\circ$ $= 45^\circ$	24.23 33.31	23.70 31.90
Rectangular plate, two opposite edges simply supported, two clamped. Length of clamped sides a , simply supported sides of length b $b/a = 1.0$ $= 1.5$ $= 2.0$ $= 3.0$	29.14 17.52 13.90 11.82	28.95 17.37 13.69 11.36
Circular plate of radius a clamped on the boundary over angle θ , remaining boundary simply supported $\theta = 0^\circ$ $= 45^\circ$ $= 90^\circ$ $= 135^\circ$ $= 180^\circ$ $= 225^\circ$ $= 270^\circ$ $= 315^\circ$ $= 360^\circ$	4.98 6.01 6.49 7.00 7.59 8.31 9.13 9.72 10.22	($\nu = 0.25$) 4.87 5.87 6.35 6.88 7.51 8.23 9.12 9.88 10.22

TABLE 1—continued

Problem	Equation (1)	Literature, e.g. Ref. 3
Annular plate free on the inner edge $r = b$ and either (a) clamped on outer edge $r = a$, $a/b = 1.25$ $= 2.00$ $= 4.00$ $= 5.00$ or (b) simply supported on outer edge $r = a$ $a/b = 1.25$ $= 2.00$ $= 4.00$ $= 5.00$	93.49 17.39 10.36 9.97 9.72 5.117 4.58 4.625	85.32 17.51 10.86 10.34 9.43 5.04 4.625 4.726
Square plate, sides simply supported, free, simply supported and clamped (SS-F-SS-C)	12.01	12.69
Square plate, three sides simply supported, the other free (SS-SS-SS-F)	11.26	11.68

It is interesting to note that Equation (1) does not depend explicitly upon the geometry or the support conditions at the edges of the plate. Furthermore it should also be noted that, in order to obtain an estimate of the frequency, it is not necessary to perform any integration. For example, let us consider a square plate clamped on all of its sides. In this case the value of $W'_{\max}$ is given by Timoshenko² as

$$W'_{\max} = 0.00126 \frac{a^4}{D} \quad (2)$$

where a is the total length of a side of the plate. Substituting for $W'_{\max}$, as given in Equation (2), into Equation (1), yields

$$\rho h \omega^2 = \frac{D(10.2151)^2}{(64a^4) \cdot 0.00126} \quad (3)$$

and this subsequently gives

$$\omega a^2 \sqrt{\frac{\rho h}{D}} = 35.97 \quad (4)$$

which differs from the value of 35.99 given by Leissa,³ by less than 0.1%.

As a second illustration, let us consider the same rectangular plate but with two opposite sides clamped and the remaining sides simply supported. In this case the value of $W'_{\max}$ given in Reference 2 is

$$W'_{\max} = \frac{0.00192a^4}{D} \quad (5)$$

Substituting for $W'_{\max}$ in Equation (1) now gives

$$\omega^2 a \sqrt{\frac{\rho h}{D}} = 29.14 \quad (6)$$

which differs by less than 1% from the value of 28.95 as given by Leissa.³

The two illustrative examples considered above clearly indicate the ease of applying the method, while Table 1 shows its remarkable accuracy.

It should be mentioned that the formula—Equation (1)—was discovered when the author was investigating the vibration of elliptical plates, and the constant was chosen so as to give the exact value of the fundamental frequency for the case of a clamped circular plate.

The ease and accuracy of this technique prompted Johns⁴ to extend the method to the calculation of the frequency parameter for the first anti-symmetric mode. In this case the approximate expression

$$\rho h \omega^2 = \frac{40}{25\sqrt{5} \hat{W}_{\max}} \quad (7)$$

was found to hold where $\hat{W}_{\max}$ is the maximum deflection of the plate due to a load distribution which is proportional to the distance from the centroid. The accuracy of this approximation can also be judged by examining Table 2.

TABLE 2
Frequency Parameter $\omega a^2 \sqrt{\rho h/D}$ for the First Anti-symmetric Mode
for Various Plate Problems

	Equation (7)	Literature, e.g. Ref. 3
Circular plate of radius a		
(1) clamped	21.90	21.20
(2) simply supported	14.00	13.90
Square plate sides of length a		
(1) clamped	75.30	73.40
(2) simply supported	47.60	49.30

3. FORMULA FOR MEMBRANES AND SHELLS

Following the success of Johns⁴ extension of Jones¹ original work, Jones^{5,6} subsequently extended the approximation so as to predict the fundamental frequencies of membranes and shells of arbitrary shape. The governing equation was found to take the following generalized form

$$\rho h \omega^2 = A/W_{\max} \quad (8)$$

where $W_{\max}$ is the maximum value of the corresponding static deflection mode, and A is a constant dependent upon the particular problem and the mode under consideration.

For plates and shallow shells, $A = (10.2151)^2/64$, for the fundamental mode, and $A = 40/25\sqrt{5}$ for the first antisymmetric mode, while when predicting the fundamental frequency of a membrane of arbitrary shape,

$$A = (2.4048)^2/4. \quad (9)$$

When predicting the fundamental frequencies of membranes, plates and shells, $W_{\max}$ is the maximum deflection which the structure would experience when subjected to a uniform loading of unity. When predicting the frequency of the first antisymmetric mode, the load distribution is to be taken as proportional to the distance from the centroid.

The accuracy of Equation (7) in predicting the frequencies of plates has already been established in Tables 1 and 2. Its accuracy in predicting the fundamental frequency of membranes can be seen in Table 3 while Table 4 shows the accuracy of the method in predicting the fundamental frequency of a simply supported cylindrical shell of curvature k . Here the fundamental

frequency ω has been compared to the exact frequency in the special case for which $k = 0$ and $\nu = 0$. The accuracy of the method can also be judged from Figures 1, 2 and 3 which show plots of the fundamental frequency of a shallow spherical shell versus the non-dimensional parameter $ka^2/2h$, where h is the shell thickness, a is the radius of the base of the shell and k is the curvature

TABLE 3
Fundamental Frequency $\omega a^2 \sqrt{\rho h/E}$ of Various Shaped Membranes

Problem	Equation (9)	% difference from the literature
Elliptical membrane major axis length a minor axis length b $b/a = 1.0$ $= 1.2$ $= 1.5$ $= 2.0$ $= 5.0$ $= \infty$	2.405 2.134 2.044 1.792 1.734 1.701	0.0 0.0 0.0 0.0 0.0 0.0
Rectangular; sides of length $2a, 2b$ $b/a = 1.0$ $= 1.1$ $= 1.2$ $= 1.5$ $= 2.0$ $= 3.0$ $= 4.0$	2.223 2.117 2.041 1.894 1.787 1.716 1.707	0.0 0.2 0.2 0.3 1.8 3.7 5.4
Semicircular radius a Equilateral triangle	3.848 6.248	0.3 0.6

TABLE 4
Fundamental Frequency Parameter $\omega a^2 \sqrt{\frac{12\rho}{E\pi^4 h^2(1 + a^2/b^2)^2}}$ for a Cylindrical Shallow Shell

ka^2/h	1		2		3		4		5	
a/b	Pred.	Exact	Pred.	Exact	Pred.	Exact	Pred.	Exact	Pred.	Exact
1	1.519	1.520	1.062	1.063	1.076	1.081	1.095	1.105	1.108	1.136
$\frac{1}{2}$	1.072	1.072	1.136	1.140	1.221	1.246	1.308	1.381	1.389	1.536
$\frac{1}{3}$	1.089	1.086	1.198	1.193	1.341	1.351	1.513	1.545	1.674	1.766
$\frac{1}{4}$	1.098	1.093	1.234	1.219	1.387	1.403	1.647	1.627	1.880	1.875

of the shell. Exact values of the frequency are shown as given by Reissner⁷ as well as the corresponding Ritz approximation (also given by Reissner⁷). In calculating the fundamental frequency of the spherical shell, exact values of the maximum deflection were not available and so use was made of the approximate expression, given in Reference 4, of

$$W'_{\max} = \frac{a^4}{128D} \left\{ \frac{1}{[1 + k^2 a^4(1 + \nu)/8h^2]} + \frac{1}{(1 + 72k^2/6h^2) a^4(1 + \nu)^2 [0.1 + (1 + \nu)/18(1 - \nu)]} \right\} \quad (10)$$

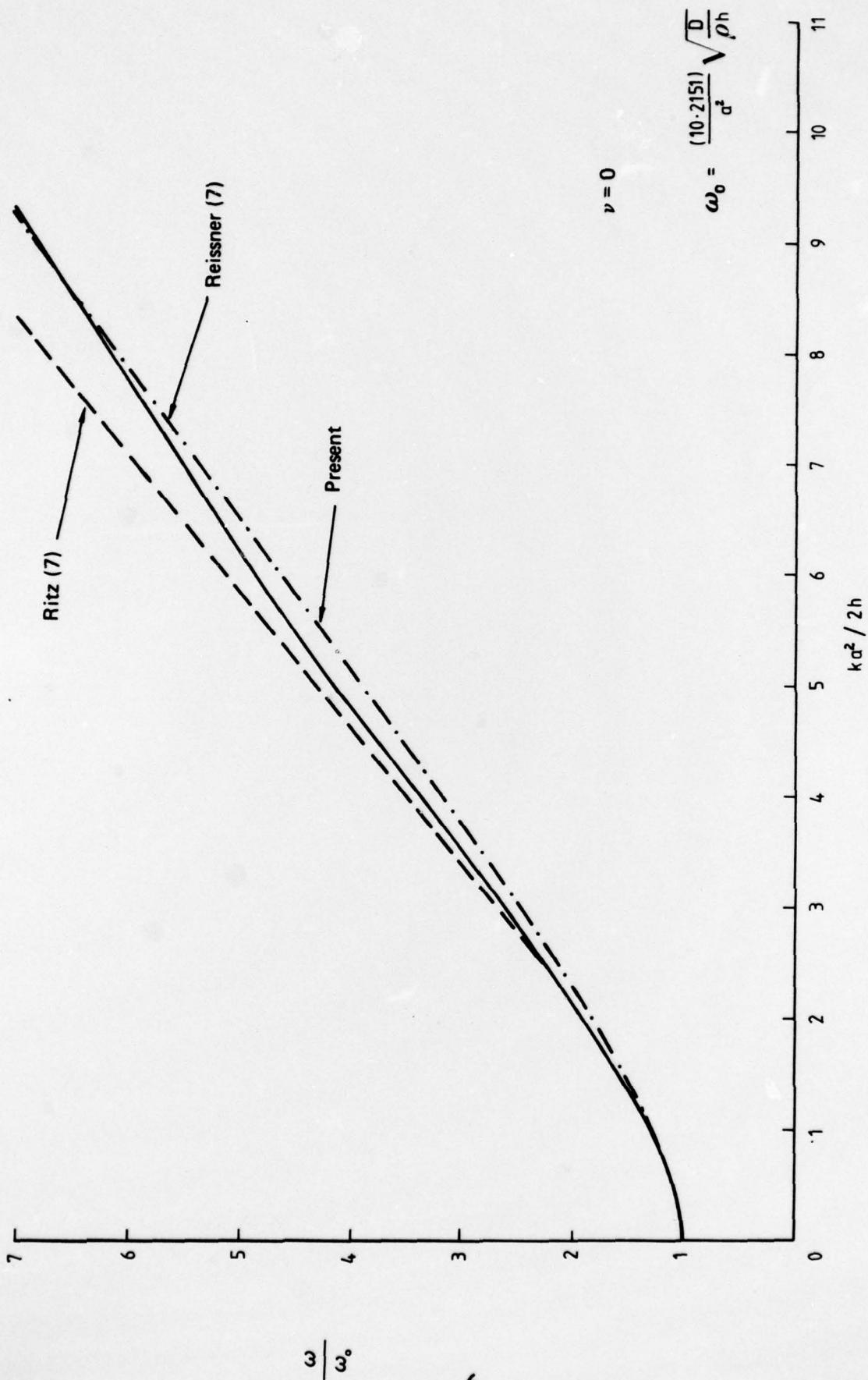


FIG. 1. FUNDAMENTAL FREQUENCY OF A SHALLOW SPHERICAL SHELL: $\nu = 0$

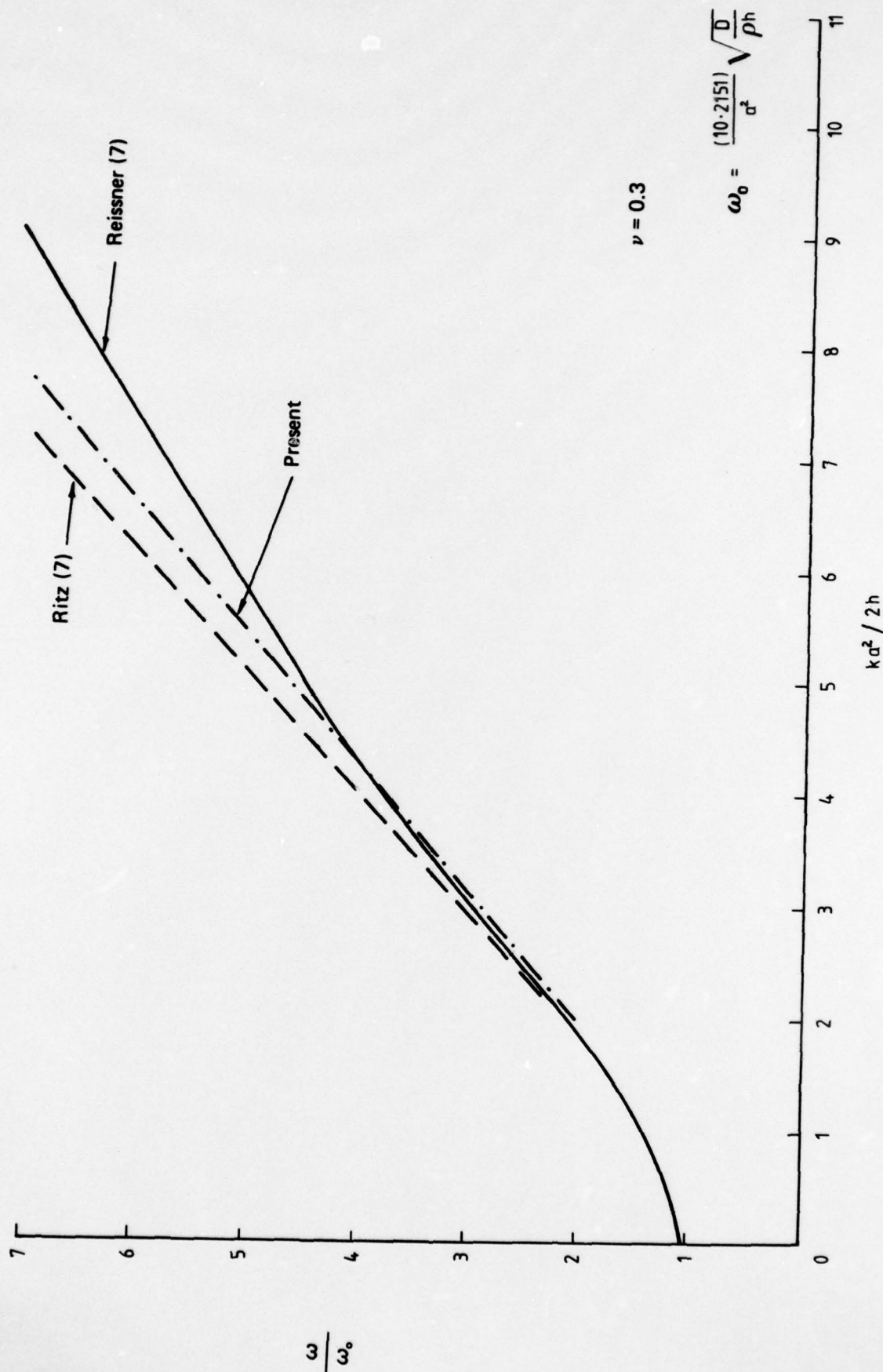


FIG. 2. FUNDAMENTAL FREQUENCY OF A SHALLOW SPHERICAL SHELL: $\nu = 0.3$

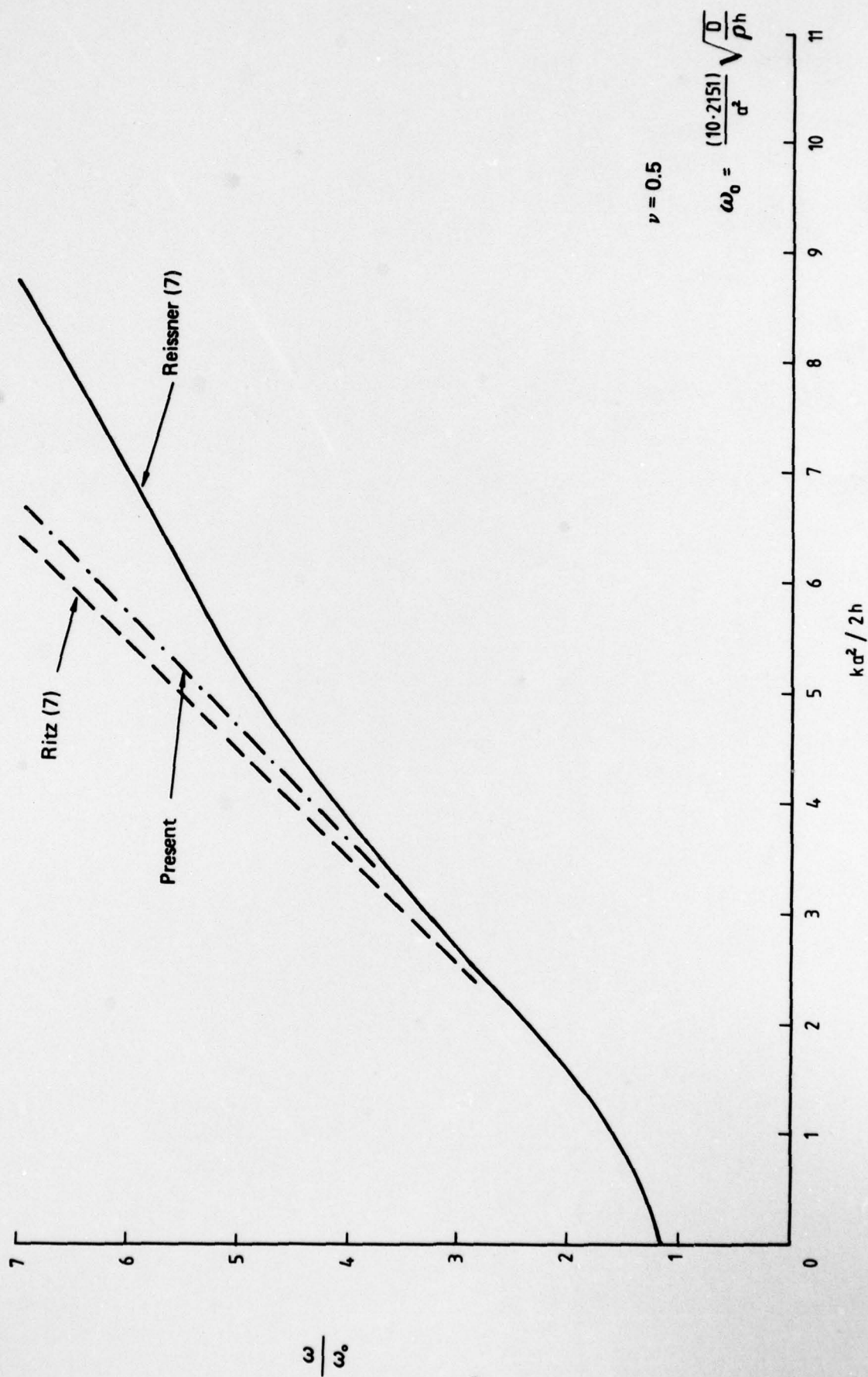


FIG. 3. FUNDAMENTAL FREQUENCY OF A SHALLOW SPHERICAL SHELL: $\nu = 0.5$

Tables 3 and 4 and Figures 1, 2 and 3 can be found in either Reference 5 or in Reference 6. We thus see that Equation (8) represents an exceptionally simple means of estimating the fundamental frequency of plates, shells and membranes.

4. FORMULAE FOR ANISOTROPIC PLATES

One very important structural form which has not yet been discussed is that of a plate consisting of orthotropic material. Let us now apply the approximate Equation (8) to the problem of a clamped elliptical plate made of composite material. In this case

$$W_{\max} = \frac{a^4}{8(3D_x + 3\delta^4 D_y + 2\delta^2 H)} \quad (11)$$

where $\delta = a/b$ is the aspect ratio of the ellipse, a, b are the lengths of the major and minor axes of the ellipse and D_x, D_y, H are the rigidities of the plate. This yields

$$\omega a^2 \sqrt{\rho h} = (10.2151) \left(\frac{3D_x}{8} + \frac{3\delta^4 D_y}{8} + \frac{2\delta^2 H}{8} \right) \quad (12)$$

which is in exact agreement with the recent analytical results of Dharmarajan and Fang Hui Chou.⁸ As a second illustration, let us consider the case of a simply supported rectangular composite plate with sides of length a and b respectively. In this case the fundamental frequency is known to be given by the relationship

$$\rho h \omega^2 = D_y \pi^4 (D_x/D_y a^4 + 2H/a^2 b^2 D_y + 1) \quad (13)$$

while the values of $W'_{\max}$ are found in Reference 3 for the particular case $H = \sqrt{D_x D_y}$. The values of the fundamental frequency $\omega b^2 \sqrt{\rho h/D_y}$ thus predicted are shown in Table 5 along with exact values given by Equation (13) above. As in all previous cases, the agreement between these two sets of values is excellent.

TABLE 5
Fundamental Frequency.
Parameter $\omega b^2 \sqrt{\rho h/D_y}$ for an Orthotropic, Simply Supported Rectangular Plate;
 $\epsilon = a/b \sqrt{D_y/D_x}$

ϵ $\omega b^2 \sqrt{\rho h/D_y}$	1.0	1.5	2.0	3.0
Predicted	20.01	14.53	12.68	11.54
Exact	19.74	14.22	12.33	10.96

We thus see that the initial work of Jones¹ has led to a new technique for estimating the fundamental frequency of common structural elements. As can be seen in the recent review article of Leissa,⁹ this procedure is one of the few new techniques which may be applied to plates of arbitrary plan form with mixed support conditions.

Although we have concentrated on the positive aspects of this technique, there are two areas in which the technique is lacking.

The most important lack is the development of a rigorous mathematical basis for the approximation. So far, the only work in which this has been attempted is that of Sundarajan.¹⁰ Unfortunately it is the opinion of the author that Reference 10 fails to provide this mathematical basis.

Again, the approximation fails in the field of large amplitude vibrations. The author has attempted to apply the approximation to the large amplitude vibration of plates but found that the predicted frequencies were in considerable disagreement with the values given in Reference 3. The method at present can only be applied when vibration amplitudes are small.

5. CONCLUSIONS

We have seen that the initial approximation developed by Jones¹ can be significantly extended so that it now provides a very simple, yet accurate, means for calculating the fundamental frequencies of membranes, plates and shallow shells vibrating at small amplitudes.

REFERENCES

1. Jones, R. An approximate expression for the fundamental frequency of vibration of elastic plates. *J. Sound and Vibration* **38**, 503-504, 1975.
2. Timoshenko, S. P., and Wornowsky Krieger, S. Theory of plates and shells. McGraw Hill, 2nd edition, 1959.
3. Leissa, A. W. Vibration of plates. NASA SP-160, 1969.
4. Johns, D. J. Comments on "An approximate expression for the fundamental frequency of vibration of elastic plates". *J. Sound and Vibration* **41**, 385, 1975.
5. Jones, R. Approximate expressions for the fundamental frequency of vibration of several dynamic systems. *J. Sound and Vibration* **44**, 475-78, 1976.
6. Jones, R. Approximate methods for the linear and non-linear analysis of plates and shallow shells. *J. Structural Mechanics* **3**, 5, 1977.
7. Reissner, E. On axisymmetrical vibrations of shallow spherical shells. *Q. Appl. Maths.* **13**, 279-90, 1955.
8. Dharmarajan, S. and Fang Hui Chou. Vibration of composite plates of arbitrary shape by the method of constant deflection lines. *Shock and Vibration Bulletin*, Part 2, 99-106 September 1977.
9. Leissa, A. W. Recent research in plate vibrations: classical theory. *The Shock and Vibration Digest* **9**, 13-24, October 1977.
10. Sundarajan, C. Relationship between the fundamental frequency and the static response of elastic systems. *J. Sound and Vibration* **51**, 4, 493-499, 1977.

DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers (a) AR Number: AR-001-290 (b) Document Series and Number: Structures Report 371 (c) Report Number: ARL-Struc.—Report-371		2. Security Classification (a) Complete document: Unclassified (b) Title in isolation: Unclassified (c) Summary in isolation: Unclassified										
3. Title: SIMPLE FORMULAE FOR CALCULATING THE VIBRATIONAL FREQUENCIES OF PLATES, SHELLS AND MEMBRANES												
4. Personal Author(s): R. Jones		5. Document Date: June, 1976										
6. Type of Report and Period Covered:												
7. Corporate Author(s): Aeronautical Research Laboratories		8. Reference Numbers (a) Task: (b) Sponsoring Agency:										
9. Cost Code: 21 6901												
10. Imprint Aeronautical Research Laboratories, Melbourne		11. Computer Program(s) (Title(s) and language(s)):										
12. Release Limitations (of the document) Approved for public release												
<table border="1"> <tr> <td>12-0. Overseas:</td> <td>No.</td> <td>P.R.</td> <td>1</td> <td>A</td> <td>B</td> <td>C</td> <td>D</td> <td>E</td> </tr> </table>				12-0. Overseas:	No.	P.R.	1	A	B	C	D	E
12-0. Overseas:	No.	P.R.	1	A	B	C	D	E				
13. Announcement Limitations (of the information on this page): No limitation												
14. Descriptors: Vibration Frequencies Shells (Structural forms) Plates (Structural members)		15. Cosati Codes: 2011 1201 1313 Membranes Formulae (Mathematics) Computation Vibration analysis										

16.

ABSTRACT

Simple approximate formulae for estimating the vibrational frequencies of plates, shells and membranes are presented. These formulae take the general form $F = A/W_{\max}$ where F is a frequency parameter, A is a numerical parameter having a constant value for many different problems, and $W_{\max}$ is the maximum deflection of an associated static deflection problem.

The approach is particularly simple and the agreement between the frequencies calculated using the approximate formulae and those calculated using standard vibration analysis is excellent.

DISTRIBUTION

Copy No.

AUSTRALIA

DEPARTMENT OF DEFENCE

Central Office

Chief Defence Scientist	1
Executive Controller, ADSS	2-3
Superintendent, Defence Science Administration	4
Australian Defence Scientific and Technical Representative (UK)	5
Counsellor Defence Science (USA)	6
Defence Library	7
Assistant Secretary, DISB	8-23
JIO	24

Aeronautical Research Laboratories

Chief Superintendent	25
Library	26
Superintendent, Structures Division	27
Divisional File, Structures Division	28
Author: R. Jones	29

Materials Research Laboratories

Library	30
---------	----

Defence Research Centre

Library	31
---------	----

Central Studies Establishment

Library	32
---------	----

Engineering Development Establishment

Library	33
---------	----

RAN Research Laboratory

Library	34
---------	----

Defence Regional Office

Library	35
---------	----

Air Office

Air Force Scientific Adviser	36
Engineering (CAFTS) Library	37
D. Air Eng.	38
RAAF Point Cook	39
Aircraft Research and Development Unit	40

Army Office

Army Scientific Adviser	41
Royal Military College	42
US Army Standardisation Group	43

Navy Office

Naval Scientific Adviser	44
--------------------------	----

DEPARTMENT OF PRODUCTIVITY

Government Aircraft Factories, Library 45

DEPARTMENT OF TRANSPORT

Secretary/Library 46

Airworthiness Group (Mr. R. Ferrari) 47

STATUTORY, STATE AUTHORITIES AND INDUSTRY

Australian Atomic Energy Commission, Director 48

CSIRO Central Library 49

CSIRO Division of Mechanical Engineering, Chief 50

CSIRO Materials Science Division, Director 51

Applied Engineering Pty. Ltd. 52

Commonwealth Aircraft Corporation, Manager 53

Commonwealth Aircraft Corporation, Manager of Engineering 54

Conzinc Riotinto of Australia (Dr. Worner) 55

Hawker de Havilland Pty. Ltd., Librarian, Bankstown 56

Hawker de Havilland Pty. Ltd., Manager, Lidcombe 57

ICI Australia Ltd., Library 58

Rolls Royce of Australia Pty. Ltd. (Mr. O. Mosley) 59

UNIVERSITIES AND COLLEGES

Adelaide Barr Smith Library 60

Prof. J. Mazundar, Applied Mathematics 61

Australian National Library 62

Flinders Library 63

James Cook Library 64

La Trobe Library 65

Melbourne Engineering Library 66

Monash Library 67

Newcastle Library 68

New England Library 69

New South Wales Library 70

Assoc. Prof. R. W. Traill-Nash 71

Sydney Engineering Library 72

Dr. W. B. Fraser, Applied Mathematics 73

Queensland Library 74

Dr. V. G. Hart 75

Tasmania Engineering Library 76

Western Australia Library 77

Dr. P. B. Chapman 78

RMIT Library 79

CANADA

Physics and Metallurgy Research Labs. (Dr. A. Williams) 80

CAARC Co-ordinator, Structures 81

National Aeronautical Establishment NRC, Library 82

Division of Mechanical Engineering NRC, Director 83

Universities and Colleges

McGill Library 84

Toronto Institute of Aerophysics 85

FRANCE

ONERA, Library 86

AGARD, Library 87

Service de Documentation, Technique de l'Aeronautique 88

GERMANY	
ZLDI	89
INDIA	
CAARC Co-ordinator, Structures	90
Civil Aviation Department, Director	91
Defence Ministry, Aero Development Establishment, Library	92
Hindustan Aeronautics Ltd., Library	93
Indian Institute of Science, Library	94
Indian Institute of Technology, Library	95
National Aeronautical Laboratory, Director	96
ISRAEL	
Technion—Israel Institute of Technology, Prof. J. Singer	97
ITALY	
Fiat Co., Dr. G. Gabrielli	98
Associazione Italiana di Aeronautica e Astronautica (Prof. A. Evla)	99
JAPAN	
National Aerospace Laboratory, Library	100
Universities	
Tohoku (Sendai) Library	101
Tokyo Institute of Space and Aerospace	102
NETHERLANDS	
Central Org. for Applied Science Research TNO, Library	103
National Aerospace Laboratory (NLR) Library	104
NEW ZEALAND	
Air Department, RNZAF Aero Documents Section	105
Universities	
Canterbury Library	106
SWEDEN	
Aeronautical Research Institute	107
Chalmers Institute of Technology, Library	108
Kungl. Tekniska Hogskolans	109
SAAB, Library	110
Research Institute of the Swedish National Defence	111
SWITZERLAND	
Brown Boverie, Management Chairman	112
Escher-Wyss Ltd., Manager	113
Institute of Aerodynamics ETH	114
UNITED KINGDOM	
CAARC NPL, Secretary	115
Royal Aircraft Establishment, Library, Farnborough	116
Royal Aircraft Establishment, Library, Bedford	117
Military Vehicles and Experimental Establishment	118
National Engineering Laboratories, Superintendent	119
British Library, Science Reference Library	120
British Library, Lending Division	121
Naval Construction Research Establishment, Superintendent	122
CAARC Co-ordinator, Structures	123

Fulmer Research Institute Ltd., Research Director	124
Ricardo ii. Co., Manager	125
Rolls Royce (1971) Ltd., Aeronautics Div. (Chief Librarian)	126
Science Museum (Library)	127
British Aircraft Corporation (Holdings) Ltd., Military Aircraft Div.	128

Universities and Colleges

Bristol	Library, Engineering Dept.	129
	Dr. W. Chester, Mathematics Dept.	130
Cambridge	Library, Engineering Dept.	131
	Sir William Hawthorne, Engineering Dept.	132
Manchester	Professor of Applied Mathematics	133
Nottingham	Library	134
Southampton	Library	135
Strathclyde	Library	136
Cranfield Institute of Technology	Library	137
Imperial College	The Head	138
	Prof. B. G. Neal, Struct. Engineering	139
Loughborough Uni. of Technology	Prof. D. J. Johns, Dept. of Transport Engineering	140

UNITED STATES OF AMERICA

NASA Scientific and Technical Information Facility	141
Sandia Group Research Organisation	142
American Institute of Aeronautics and Astronautics	143
Applied Mechanics Review	144
The John Crerar Library	145
Allis Chalmers Inc. (Director)	146
Boeing Co., Industrial Production Division	147
Esso Research Laboratories (Director)	148
Westinghouse Laboratories (Director)	149
United Technologies Corp. Pratt and Whitney Aircraft Group	150
Battelle Memorial Institute (Library)	151

Universities and Colleges

Brown	Prof. R. E. Meyer	152
Cornell (New York)	Library, Aeronautical Laboratories	153
Florida	Aero. Engineering Department	154
Harvard	Prof. G. F. Carrier, Applied Mathematics	155
	Dr. S. Goldstein	156
Johns Hopkins	Prof. S. Corrsin	157
Iowa State	Dr. G. K. Serory, Mech. Eng. Dept.	158
Princeton	Prof. G. L. Mellor, Mechanics Department	159
George Washington	Prof. Freudenthal	160
Brooklyn	Library, Polytech. Aero. Lab.	161
California	Library, Guggenheim Aero. Lab.	162
	Dr. M. Holt, Dept. of Aerosciences	163
Ohio State	Prof. A. W. Leissa, Dept. of Mech. Eng.	164
Illinois	Prof. N. M. Newmark, Talbot Laboratories	165
Massachusetts	Prof. W. A. Nash, Dept. of Civil Engineering	166
Stanford	Dept. of Aeronautics, Library	167
Wisconsin	Memorial Library, Serials Dept.	168