OFFICE OF NAVAL RESEARCH

Contract N7onr-35810

NR-360-003

Technical Report No. 19

THE RESPONSE OF A SUBMERGED CYLINDRICAL SHELL
TO AN AXIALLY PROPAGATING ACOUSTIC WAVE

by

G. F. Carrier

GRADUATE DIVISION OF APPLIED MATHEMATICS

BROWN UNIVERSITY

PROVIDENCE, R. I.

October, 1953

B11-19/7
The Response of a Submerged Cylindrical Shell to an Axially Propagating Acoustic Wave

By G. F. Carrier, Harvard University

1. Introduction. In this report, we shall discuss the dynamic response of a submerged elastic cylindrical shell when a plane acoustic wave propagates relative to the shell as indicated in Fig. 1. We shall be concerned only with the deformation and stress in certain localities where these quantities are large. The results are found in a very concise form and are of more general applicability than is implied by the title.

2. The interaction problem. The motion of the shell indicated in Fig. 1 is governed by the usual conservation laws as applied to the shell and to the surrounding fluid. For axially symmetric deformations of the shell, the conservation of momentum requirements imply that

\[ EIu^{IV} + chu'' + phu_{tt} - pIu_{tt} \\
+ \frac{Eh}{R^2}u = - p(R, x, t). \tag{2.1} \]

Here, \( E, \rho, h, R, u \) are, respectively, the elastic modulus, density, thickness, radius, and radial displacement of the shell; \( \sigma \) is the average over the shell thickness of the axial compressive stress \[ \sigma = - \frac{Eh}{R^2} \int_{R-h/2}^{R+h/2} (\sigma_x/h) \, dr, \quad I = h^3/12, \]

\( p \) is the externally applied over-pressure, and primes denote differentiation with regard to the axial coordinate \( x \). It is to
be noted that we have retained the rotational inertia terms in the bending theory. Our object, in doing so, is to demonstrate that this term has no appreciable effect on the results even in high-speed impact problems. It should also be noted that these equations are pertinent to an unstiffened shell. We shall consider the stiffened shell in a later section.

The pressure $p$ is associated with the acoustic field surrounding the shell. This consists of a contribution from the incident wave plus that associated with the shell motion. Although we could readily formulate the problem in a form which accounts for the detailed acoustic field, it is convenient to approximate $p(R, x, t)$ by

$$p = p_0 + \rho_f a u_t(x, t)$$

(2.2)

where $\rho_f$ is the fluid density, $a$ the fluid acoustic speed, and $p_0$ is the overpressure in the incident acoustic wave. The justification of this approximate formula is found in the fact that the pressure associated with the motion of a plane obstacle normal to itself is $\rho_f a F(t)$, where $F(t)$ is the normal velocity.

The equation governing $u(x, t)$ then becomes

$$EIu'''' + \sigma u'' + \rho u_{tt} - \rho I u_{tt} + \rho_f a u_t + \left(\frac{Eh}{R^2}\right) u = - p_0 S(t - x/a)$$

(2.3)

where $S(t - x/a)$ is the conventional step function.

We shall be interested in two basic solutions of this equation. The first is that for which $u(x, t) \equiv w(t - x/a)$. 

This function must satisfy the ordinary differential equation
(where $\xi = t - x/a$)

\[
\left( \frac{EI}{a^4} - \frac{pI}{a^2} \right) w^{IV} + h(\rho + \frac{a^2}{c^2}) w'' + \rho f a w' + (\frac{Eh}{R^2}) w = - p_o S(\xi). \quad (2.4)
\]

The desired solution has the form

\[
w = \begin{cases} 
-\left( \frac{p_o R^2}{Eh} \right) \left[ 1 + a_1 e^{\lambda_1 \xi} + a_2 e^{\lambda_2 \xi} \right], & \xi > 0 \\
\left( \frac{p_o R^2}{Eh} \right) \left[ a_3 e^{\lambda_3 \xi} + a_4 e^{\lambda_4 \xi} \right], & \xi < 0.
\end{cases} \quad (2.5)
\]

The $\lambda_j$ are the roots of

\[
\left( \frac{EI}{a^4} - \frac{pI}{a^2} \right) \lambda^4 + h(\rho + \frac{a^2}{c^2}) \lambda^2 + \rho f a \lambda + (\frac{Eh}{R^2}) = 0, \quad (2.6)
\]

and the $a_j$ are given by\textsuperscript{1}

\[
a_j = \frac{\gamma}{k^2 j} \frac{\lambda k}{\lambda_j - \lambda_k}. \quad (2.7)
\]

Equations (2.5) and (2.7) are valid, of course, only if the $\lambda_j$ are distinct and are such that $\lambda_1$, $\lambda_2$ have negative real parts, and $\lambda_3$, $\lambda_4$ have positive real parts.

An example of some interest is one for which:

$R = 8'$, $h = 1''$, $a = 5000'/\text{sec}$, $E/\rho = (17,000'/\text{sec})^2$,

$\sigma = 25,000 #'\text{in}^2$, $\rho_f/\rho = 1/8$, $E = 3.10^7 #'\text{in}^2$.

For these dimensions (in units, sec\textsuperscript{-1}), $\lambda_1 = -650$,

$\lambda_2 = -7500$, $\lambda_3, \lambda_4 = 7300 \pm 66000i$. The coefficient, $-a_1$, is

\textsuperscript{1} These are chosen so that $u$, $u'$, $u''$, $u'''$, are continuous at $\xi = 0$. 
near unity and $|a_2| = O(|\lambda_1/\lambda_2|)$, $|a_3| = O(|\lambda_1\lambda_2/2\lambda_3^2|)$.

The quantities of interest are $w$ and $w''/a^2$ since these are directly related to the hoop and bending stresses, respectively. The orders of magnitude of these terms are given by

$$|w|_{\text{max}} = -\frac{p_0 R^2}{Eh}$$
$$|w''/a^2|_{\text{max}} = O[\lambda_1\lambda_2 p_0 R^2/Eha^2].$$

It is now convenient to turn to the second basic solution of Eq. (2.3). We wish, in fact, to find the deformation of the shell which is associated with the conditions $p_0 = 0$, $u(x,t) = 0$ for $t < 0$, $u(0,t) = f(t)$, and $u'(0,t) = 0$. It is evident that a combination of this solution with the foregoing will allow a treatment of practical problems wherein the shell is supported in one manner or another.

Our purpose is most readily accomplished by introducing the Laplace transform of $u$, 

$$\bar{u}(x,s) = \int_0^\infty e^{-st} u(x,t) dt.$$ 

The conventional use of this transform leads to the equation

$$EI\bar{u}'' + (\rho h - \rho Is^2)\bar{u}'' + (\rho h s^2 + \rho a s + Eh/R^2)\bar{u} = 0.$$ 

The pertinent solution of this ordinary differential equation is

$$\bar{u}(x,s) = \frac{\bar{f}(s)}{\eta_2 - \eta_1} \left[ \eta_2(s) e^{-\eta_1 x} - \eta_1(s) e^{-\eta_2 x} \right]. \quad (2.8)$$

Here, $\bar{f}(s)$ is the transform of the given motion $u(0,t)$, and

$$\eta_1,2(s) = [M \pm (N^2 - N)^{1/2}]^{1/2},$$
where
\[-M = (\rho h - \rho I s^2)/2EI, \quad N(s) = (\rho h s^2 + \rho f a s + \frac{Eh}{R^2})/EI.\]

This transform would be rather difficult to invert with any degree of precision but the most useful piece of information is readily extracted. The deformation (and stress) of major concern is that associated with the bending near \(x = 0\). However, using Eq. (2.8),
\[\bar{u}_{xx}(0,s) = -N^{1/2}I \quad (2.9)\]
and this can be inverted to give
\[u_{xx}(0,t) = -(\rho h/EI)^{1/2}L[f(t)], \quad (2.10)\]
where \(L[f(t)]\) can be written
\[L[f(t)] = f_t + \alpha f - k^2 \int_0^t e^{-\alpha(t-\tau)} \frac{I_1[k(t-\tau)]}{k(t-\tau)} f(\tau) d\tau \]
\[= f_t + \alpha f + k \int_0^t e^{-\alpha(t-\tau)} (I_0[k(t-\tau)] + I_1[k(t-\tau)]) \frac{f'(\tau) + \epsilon f(\tau)}{\epsilon} \tau. \quad (2.11)\]

The essential feature of this result is that each of the integrals in Eqs. (2.11) is positive when \(f(t)\) and \(f'(t)\) are positive in the time interval of interest, e.g., for \(0 < t < t_o\). Thus,
\[-(EI/\rho h)^{1/2}u_{xx}(0,t)\]
lies between the values \(f_t + \epsilon f\) and \(f_t + \alpha f\) where \(\epsilon\) is the smaller root of \(N(s) = 0\), \(2\alpha\) is the positive difference of the two roots, and \(2\alpha\) is the sum of the roots, i.e., \(\rho f a/\rho h\). In the example used earlier, \(a \approx 3750 \text{ sec}^{-1}\) and \(\epsilon \approx 650 \text{ sec}^{-1}\).
3. **Properties of the foregoing results.** Some general observations associated with the work of section (2) can now be stated. We note first that the rotational inertia term has a negligible effect on the solution of the first problem. In fact, its inclusion affects the size of $\lambda_3$ and $\lambda_4$ by about 5% and $\lambda_1$ and $\lambda_2$ not at all. In the latter result, this term has no effect whatever (rigorously). The deformation at $x \neq 0$ may be affected by this term (must be, in fact) but at $x = 0$, no contribution of this item is present. As a matter of fact, a simple boundary layer type analysis will demonstrate that only near $x = (E/\rho)^{1/2} t$ and for $x > (E/\rho)^{1/2} t$ can this term seriously modify the result.

We should also note that, for a beam vibration problem of this type, the terms in $u$ and $u_t$ would be absent and $u_{xx}(0,t)$ is precisely given by

$$u_{xx}(0,t) = - (\rho h/EI)^{1/2} u_t(0,t).$$

(3.1)

We should also note that the term representing the axial membrane contribution (i.e., $cu''$) plays a completely negligible role. This is fortunate for the investigator since, in many problems of interest, $\sigma$ will vary considerably during the interesting time interval$^2$. If $\sigma$ were to exceed the yield stress, of course, this remark (and the foregoing analysis, as well) would be invalid. Note, however, that during the deformation, the axial membrane deformation contributed by the bending is such as to decrease the value of $\sigma$.

$^2$ As implied earlier, all of our remarks apply to the time interval where $u$ and $u_t$ are positive.
Fig. 1

advancing wave front

r

shell

h

R

x
Distribution List
for
Technical and Final Reports Issued Under
Office of Naval Research Project NR-360-364, Contract N7onr-35810

I: Administrative Reference and Liaison Activities of ONR

Chief of Naval Research
Department of the Navy
Washington 25, D. C.
Attn: Code 438 (2)
Code 432 (1)
Code 466 (via Code 103) (1)

Director, Naval Research Lab.
Washington 25, D. C.
Attn: Tech. Info. Officer (1)
Technical Library (1)
Mechanics Division (2)

Commanding Officer
Office of Naval Research
Branch Office
495 Summer Street
Boston 10, Mass. (2)

Commanding Officer
Office of Naval Research
Branch Office
346 Broadway
New York 13, New York (1)

II: Department of Defense and other interested Gov't. Activities

a) General

Research & Development Board
Department of Defense
Pentagon Building
Washington 25, D. C.
Attn: Library (Code 3D-1075) (1)

Armed Forces Special Weapons Project
P.O. Box 2610
Washington, D. C.
Attn: LtCol. G.F. Blunda (2)

Joint Task Force 3
12St & Const. Ave., N.W.
(Temp. U)
Washington 25, D.C.
Attn: Major B.D. Jones (1)

b) Army

Chief of Staff
Department of the Army
Research & Development Div.
Washington 25, D. C.
Attn: Chief of Res. & Dev. (1)

Office of the Chief of Engineers
Assistant Chief for Works
Department of the Army
31Dg. T-7, Gravelly Point
Washington 25, D.C.
Attn: Structural Branch
(R.L. Bloor) (1)

Engineering Research and Development Laboratory
Fort Belvoir, Virginia
Attn: Structures Branch (1)
Distribution List

Army (cont.)

Office of the Chief of Engineers
Asst. Chief for Military
Construction
Department of the Army
Bldg. T-3, Gravelly Point
Washington 25, D.C.
Attn: Structures Branch
(N. F. Carey)
Protective Construction
Branch (I. O. Thornley)

Office of the Chief of Engineers
Asst. Chief for Military
Operations
Department of the Army
Bldg. T-7, Gravelly Point
Washington 25, D.C.
Attn: Structures Development
Branch (W. F. Woollard)

U.S. Army Waterways Experiment Station
P. O. Box 631
Halls Ferry Road
Vicksburg, Mississippi
Attn: Col. H. J. Skidmore

The Commanding General
Sandia Base, P. O. Box 5100
Albuquerque, New Mexico
Attn: Col. Canterbury

Operations Research Officer
Department of the Army
Ft. Lesley J. McNair
Washington 25, D.C.
Attn: Howard Brackney

Office of Chief of Ordnance
Office of Ordnance Research
Department of the Army
The Pentagon Annex 4-2
Washington 25, D.C.
Attn: ORDTB-PS

Ballistics Research Laboratory
Aberdeen Proving Ground
Aberdeen, Maryland
Attn: Dr. C. V. Lampson
Chief of Naval Operations
Department of the Navy
Washington 25, D.C.
Attn: OP-31
OP-363

Chief, Bureau of Ships
Department of the Navy
Washington 25, D.C.
Attn: Director of Research (2)
Code 423 (1)
Code 442 (1)
Code 421 (1)

Director, David Taylor Model Basin
Department of the Navy
Washington 7, D.C.
Attn: Code 720, Structures Division
Code 740, Hi-Speed Dynamics Div. (1)

Commanding Officer
Underwater Explosions Research Div.
Code 290
Norfolk Naval Shipyard
Portsmouth, Virginia (1)

Commander
Portsmouth Naval Shipyard
Portsmouth, N.H.
Attn: Design Division (1)

Director, Materials Laboratory
New York Naval Shipyard
Brooklyn 1, New York (1)

Chief, Bureau of Ordnance
Department of the Navy
Washington 25, D.C.
Attn: Ad-3, Technical Library (1)
Rec, P. H. Girouard (1)

Naval Ordnance Laboratory
White Oak, Maryland
RFD 1, Silver Spring, Maryland
Attn: Mechanics Division (1)
Explosive Division (1)
Mech. Evaluation Div. (1)

Commander
U.S. Naval Ordnance Test Station
Inyokern, California
Post Office - China Lake, Calif.
Attn: Scientific Officer (1)

Naval Ordnance Test Station
Underwater Ordnance Division
Pasadena, California
Attn: Structures Division (1)
Distribution List

Navy (cont.)

Chief, Bureau of Aeronautics
Department of the Navy
Washington 25, D.C.
Attn: TD-41, Technical Library (1)

Chief, Bureau of Ships
Department of the Navy
Washington 25, D.C.
Attn: Code P-314
Code C-313 (1)

Officer in Charge
Naval Civil Engr. Research & Evaluation Laboratory
Naval Station
Port Hueneme, California (1)

Superintendent
U.S. Naval Post Graduate School
Annapolis, Maryland (1)

Air Forces

Commanding General
U.S. Air Force
The Pentagon
Washington 25, D.C.
Attn: Res. & Development Div. (1)

Deputy Chief of Staff, Operations
Air Targets Division
Headquarters, U.S. Air Force
Washington 25, D.C.
Attn: APO IN-T/PV (1)

Office of Air Research
Wright-Patterson Air Force Base
Dayton, Ohio
Attn: Chief, Applied Mechanics Group (1)

Other Government Agencies

U.S. Atomic Energy Commission
Division of Research
Washington, D.C. (1)

Director, National Bureau of Standards
Washington 25, D.C.
Attn: Dr. V.H. Ramberg (1)

Supplementary Distribution List

<table>
<thead>
<tr>
<th>Addressee</th>
<th>No. of Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified Reports</td>
<td>Classified Reports</td>
</tr>
</tbody>
</table>

Professor Lynn Beadle
Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania 1

Professor R.L. Bisplinghoff
Dept. of Aeronautical Engineering
Massachusetts Institute of Technology
Cambridge 39, Massachusetts 1

Professor Hans Bleich
Dept. of Civil Engineering
Columbia University
Broadway at 117th St.
New York 27, New York 1
<table>
<thead>
<tr>
<th>Addressee</th>
<th>Unclassified Reports</th>
<th>Classified Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professor B. A. Boley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dent. of Aeronautical Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohio State University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbus, Ohio</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Professor G. F. Carrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>309 Pierce Hall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvard University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cambridge, Massachusetts</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Professor R. J. Dolan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dept. of Theoretical &amp; Applied Mechanics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Illinois</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urbana, Illinois</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Professor Lloyd Donnell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Department of Mechanics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicago 16, Illinois</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Professor A. C. Eringen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Department of Mechanics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicago 16, Illinois</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Professor B. Fried</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dept. of Mechanical Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington State College</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pullman, Washington</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Mr. Martin Goland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midwest Research Institute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4049 Pennsylvania Avenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kansas City 2, Missouri</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Dr. J. N. Goodier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>School of Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford, California</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Professor R. M. Hermes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>College of Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Santa Clara</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Clara, California</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Professor R. J. Hansen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dept. of Civil &amp; Sanitary Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cambridge 39, Massachusetts</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Addressee</td>
<td>Unclassified Reports</td>
<td>Classified Reports</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------</td>
<td>--------------------</td>
</tr>
</tbody>
</table>
| Professor M. Hetenyi  
Walter P. Murphy Professor  
Northwestern University  
Evanston, Illinois | 1 | - |
| Dr. N.J. Hoff, Head  
Department of Aeronautical Engineering & Applied Mechanics  
Polytechnic Institute of Brooklyn  
Brooklyn 2, New York | 1 | 1 |
| Dr. J.H. Hollomon  
General Electric Research Laboratories  
1 River Road  
Schenectady, New York | 1 | - |
| Dr. W.H. Hoppmann  
Department of Applied Mechanics  
Johns Hopkins University  
Baltimore, Maryland | 1 | 1 |
| Professor L.S. Jacobsen  
Department of Mechanical Engineering  
Stanford University  
Stanford, California | 1 | 1 |
| Professor J. Kempner  
Department of Aeronautical Engineering and Applied Mechanics  
Polytechnic Institute of Brooklyn  
99 Livingston Street  
Brooklyn 2, New York | 1 | 1 |
| Professor George Lee  
Department of Aeronautical Engineering  
Renssalaer Polytechnic Institute  
Troy, New York | 1 | - |
| Professor Paul Lieber  
Department of Aeronautical Engineering  
Renssalaer Polytechnic Institute  
Troy, New York | 1 | 1 |
| Professor Glen Murphy, Head  
Department of Theoretical & Applied Mechanics  
Iowa State College  
Ames, Iowa | 1 | - |
| Professor N.M. Newmark  
Department of Civil Engineering  
University of Illinois  
Urbana, Illinois | 1 | 1 |
<table>
<thead>
<tr>
<th>Address</th>
<th>Unclassified Reports</th>
<th>Classified Reports</th>
</tr>
</thead>
</table>
| Professor Jesse Ormondroyd  
University of Michigan  
Ann Arbor, Michigan | 1 | - |
| Dr. W. Osgood  
Armour Research Institute  
Technology Center  
Chicago, Illinois | 1 | - |
| Dr. R.P. Petersen, Director  
Applied Physics Division  
Sandia Laboratory  
Albuquerque, New Mexico | 1 | 1 |
| Dr. A. Phillips  
School of Engineering  
Stanford University  
Stanford, California | 1 | - |
| Dr. W. Prager  
Graduate Division of Applied Mathematics  
Brown University  
Providence 12, R. I. | 1 | 1 |
| Dr. S. Raynor  
Armour Research Foundation  
Illinois Institute of Technology  
Chicago, Illinois | 1 | - |
| Professor E. Reissner  
Department of Mathematics  
Massachusetts Institute of Technology  
Cambridge 30, Massachusetts | 1 | - |
| Professor M.A. Sadowsky  
Illinois Institute of Technology  
Technology Center  
Chicago 16, Illinois | 1 | - |
| Professor V.L. Salerno  
Department of Aeronautical Engineering  
Renssalaer Polytechnic Institute  
Troy, New York | 1 | 1 |
| Professor M.G. Salvadori  
Department of Civil Engineering  
Columbia University  
Broadway at 117th Street  
New York 27, New York | 1 | - |
| Professor J.R. Stallmeyer  
Talbot Laboratory  
Department of Civil Engineering  
University of Illinois  
Urbana, Illinois | 1 | 1 |
## Distribution List

<table>
<thead>
<tr>
<th>Addressee</th>
<th>Unclassified Reports</th>
<th>Classified Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professor E. Sternberg</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicago 16, Illinois</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor R. G. Sturm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Purdue University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lafayette, Indiana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor F. K. Teichmann</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Department of Aeronautical Engine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University Heights, Bronx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York, N. Y.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor C. T. Wang</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Department of Aeronautical Engine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University Heights, Bronx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York, N. Y.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project File</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Project Staff</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>For possible future distribution</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>by the University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To ONR Code 438, for possible</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>future distribution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>