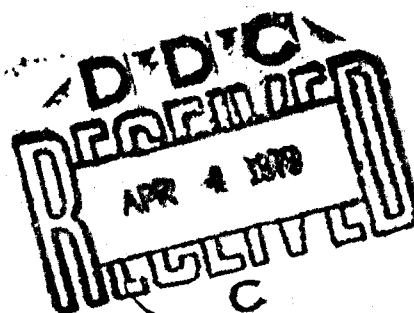


A066797

XXXXXX 75 C-1015

TOLERANCE OF THE NECK TO INDIRECT IMPACT

A. I. KING
WAYNE STATE UNIVERSITY
BIOENGINEERING CENTER
418 HEALTH SCIENCES BUILDING
DETROIT, MICHIGAN 48202



MARCH 5, 1979

TECHNICAL REPORT NO. 9

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
STRUCTURAL MECHANICS PROGRAM (CODE 474)
ARLINGTON, VIRGINIA 22217

Best Available Copy

70 04 09 06 4

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER N00014-75-C-1015	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Tolerance of the Neck to Indirect Impact	5. TYPE OF REPORT & PERIOD COVERED Technical Report, No. 9	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Albert I. King (Principal Investigator) Voigt R. Hodgson	8. CONTRACT OR GRANT NUMBER(s) N00014-75-C-1015	9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 064-524/12-10-75
10. PERFORMING ORGANIZATION NAME AND ADDRESS Wayne State University, Bioengineering Center 418 Health Sciences Building Detroit, Michigan 48202	11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy, Office of Naval Research Structural Mechanics Program (Code 474) Arlington, VA 22217	12. REPORT DATE Mar 1979
13. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) TR-1 same as above	14. NUMBER OF PAGES 14	15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) biodynamic response, indirect impact, auto crash simulation, peak neck loads neck injury environments, impact tolerance curves		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The literature has been reviewed to determine available neck tolerance criteria for indirect impact. Seven sources of information were found, along with four papers containing supporting information. Four of the seven papers contain neck load data for inertia loading of the heads of volunteers (up to AIS 1 rating), embalmed cadavers and Hybrid III dummy, during auto crash simulation tests. One reference contains crown impact peak force limits for cervical spinous process fracture (AIS 3). Two references, both related to the same study, published peak neck loads and axial force-time tolerance curves for crown impact to		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

Block Number 20

the Hybrid III dummy, based upon simulation of catastrophic fracture-dislocation football neck injury environment. Despite the differences in the subjects and environments, there is a general coherence among the data showing increasing loads with increasing levels of injury severity.

ACCESSION for		File Section <input checked="" type="checkbox"/>
NTIS		Ext. Section <input type="checkbox"/>
DSC		
UNANNOUNCED		
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CODES		
Dist.	AVAIL	SPECIAL
A		

TOLERANCE OF THE NECK TO IMPACT ACCELERATION

by

Voigt R. Hodgson, Ph.D.

ABSTRACT

The literature has been reviewed to determine available neck tolerance criteria for indirect impact. Seven sources of information were found, along with four papers containing supporting information. Four of the seven papers contain neck load data for inertia loading of the heads of volunteers (up to AIS 1 rating), embalmed cadavers and Hybrid III dummy, during auto crash simulation tests. One reference contains crown impact peak force limits for cervical spinous process fracture (AIS 3). Two references, both related to the same study, published peak neck loads and axial force-time tolerance curves for crown impact to the Hybrid III dummy, based upon simulation of catastrophic fracture-dislocation football neck injury environment. Despite the differences in the subjects and environments, there is a general coherence among the data showing increasing loads with increasing levels of injury severity.

1.0 Introduction

Until very recently, tolerance data for indirect loading of the neck was virtually non-existent. A paper by Melvin (1) to be presented at the 1979 SAE Congress concurs with this statement. A new SAE Information Report J885b (2) has been prepared for publication. It describes current (as of December 1976) knowledge in human loading behavior under impact conditions typical of automobile collisions. It is intended as a review of quantitative tolerance data but no specific limits are recommended. The neck data cited (3-5) apply to adult males and are limited to: volunteer studies of static strength tests for reactions at the occipital

condyles to loads applied directly to the head, and; dynamic neck reactions calculated at the occipital condyles for volunteers and cadavers strapped to a chair on an accelerator sled.

Only in the dynamic tests was the injury threshold reached. One of the volunteers achieved an AIS 1 rating (pain but no injury), and ligamentous damage (AIS 3) was produced in one cadaver.¹ Their results indicated that the neck appears to be at least three times stronger in resisting flexion than extension. Not included in the above Report was the work of Gadd, et al, (6) who determined the angular limits short of significant injury in unembalmed subjects loaded statically and dynamically through the head similar to tests in References 3-5.

Since the December 1976 cutoff date for the J885b report three additional papers relating to neck injury tolerance to indirect loads have been published. Two studies of injury environments have been made with the Hybrid III dummy (9) and the third delivered impulses to the crowns of fresh intact human cadavers (10). In chronological order, the experimental investigations into the tolerance of the neck to indirect loading are described below.

2.0 Description of Experiments

2.1 Inertial Loading of the Heads of Volunteers (3, 4)

The subjects were restrained in a rigid chair which was mounted on an impact sled. The sled traveled on two horizontal rails and was accelerated

¹ Abbreviated Injury Scale (AIS) for injury severity (7):

<u>Code</u>	<u>Category</u>
0	no injury
1	minor
2	moderate
3	severe (not life threatening)
4	serious (life threatening, survival probable)
5	critical (survival uncertain)
6	maximum (currently untreatable)
9	unknown

pneumatically over a distance of 1.8 m (6 ft) to a prescribed velocity. During the acceleration stroke, a headrest was used to maintain the head in an upright position. After reaching its prescribed velocity, the sled coasted for a short distance before being stopped by an approximately square deceleration pulse.

The restraint system consisted of lap belt and two individual shoulder harnesses which criss-crossed the chest at midsternum. Each belt was made of nominally 5 cm (2 in) wide, standard automotive webbing material fastened with a standard automotive seat belt buckle. The upper shoulder harness mounts were adjustable so that this portion of the harness could be kept horizontal, independent of the size of the subject. In addition, to these restraints the subject's feet were securely fastened to the foot support and his wrists were strapped to the arm rest to prevent flailing of these appendages during the run. Two pairs of accelerometers were mounted in the mouth and on a light weight fiberglass helmet which was securely fastened to the subject's head.

The object of the research project discussed in Reference 3 was to determine the kinetic, kinematic, and physiological effects produced by varying the mass, center of gravity and mass motion of inertia of the head by the addition of a helmet. Consequently, tests were conducted only in forward flexion with lead weights attached to the fiberglass helmet in various configurations. In a later work (4) four volunteers were subjected to similar test conditions but with the addition of rearward extension, lateral and oblique flexion and without helmets or lead weights.

2.2 Direct Impact to the Crown of the Hybrid III Dummy (8, 9)

The purpose of these tests was to simulate several accidents which were alleged to have happened in football blocking and tackling drills when the players were struck on the crown of the helmet by a dynamic blocking machine. The dummy was strapped in a stationary supine position to a sled which was free to move on a conveyor after being struck by the

moving tackling block which had been involved in a field accident. The 25 kg (55 lb) padded bag was propelled at velocities of 2, 4.1, 5.2 and 7 m/s (10, 14, 17, and 23 ft/s) into impact with the crown of several types of football helmets worn on the head of the dummy. The majority of the impacts delivered almost purely axial loads but a few were delivered with the shoulder raised (flexion) and buttocks raised (extension). The dummy was instrumented with a triaxial accelerometer mounted at the center of gravity of the head, a load cell at the atlanto-occipital junction to record axial force, shear force and bending moment, and a uniaxial accelerometer mounted in the thorax aligned along a superior-inferior axis.

2.3 Inertial Loading of the Head of the Hybrid III Dummy (10)

The dummy was "calibrated" relative to a field accident injury data base from Sweden for three-point lap-shoulder belt occupants involved in frontal crashes. The field accident data base used in this study is fully described in the publications of Patrick, et al., (11). It consists of 128 cases of Volvo accidents in Sweden, ninety-eight of which satisfied the criteria of the study and thirty-two of which were rated on the AIS Injury Scale of at least one. Sixty-six of the ninety-eight cases had no injury. The barrier equivalent velocity (BEV) ranged from 3-64 m/s (2-40 mph). There were twenty-nine females and sixty-nine males in the group ranging in age from 18-84 years. In the field accident study group were five AIS 1 neck injuries.

The Wayne State University WHAM III sled facility was utilized to simulate the field accidents. This device towed a modified 1970 Volvo sedan with a Hybrid III dummy restrained in the right front passenger seat by a standard three-point single loop belt system. A pneumatic propulsion mechanism accelerated the car and sled to the desired speed, after which the combination is stopped by a programmable hydraulic snubber set for a slightly skewed half sine pulse, the duration of which ranged from 112 to 135 ms. The dummy was extensively instrumented for these tests but with

respect to the head it had a triaxial accelerometer (AP, SI, and Lateral sensors), and at the head-neck interface the loads monitored were axial force (SI), shear force (AP) and bending moment (flexion-extension). Three tests were run at 32.2 km/h (20 mph) BEV and three tests at 43.4 km/h (30 mph) BEV. There were no direct impacts to the head in any of these tests.

2.4 Direct Impact to the Crown of Fresh Cadavers (12)

Six males and five female fresh cadavers were used in this study. The subjects were placed in a supine position and the cervical spine was aligned along the impactor axis. Using axial alignment the investigators were attempting to achieve the maximum load carrying capability of the spine, thereby improving chances for basal skull fracture. The machine which was used to deliver the impacts consisted of an air cylinder and a ground and honed cylinder and transferred its momentum to the impact piston. Instrumentation for this series consisted of a piston accelerometer which yields an inertially compensated piston force as a function of time. Resultant, horizontal and vertical displacement and their first and second derivatives were obtained by analysis of high-speed movies taken at 3000 frames/s.

3.0 Results

3.1 Inertial Loading of the Heads of Volunteers

The results obtained from References 3 and 4 for forward flexion, rear extension and various degrees of lateral flexion are given in Table 1. No injuries were produced, but pain was experienced by one volunteer and an AIS rating of one was assigned. Similar tests were carried to higher levels in cadavers, with results given in Table 1 for forward flexion and rearward extension. Damage was experienced in only one case which was assigned AIS rating of 3, designating ligamentous damage. In Table 1 the neck torque given for forward flexion included the moment of the chin force taken with respect to the occipital condyles. The authors found that the resultant torque was an excellent indicator of neck strength. Based on their

cadaver data, they suggested tolerance levels for 50th percentile adult male. For flexion a resultant torque of 190 N·m (140 ft-lb) was proposed as a lower bound for an injury tolerance limit. This torque level did not produce any discernable ligamentous damage to a human cadaver. Comparing the Table 1 torque data, the neck appears to be at least three times stronger in resisting flexion than extension. It was noted that this is consistent with the anatomical fact that there are more muscles located posterior to the cervical spine, and these muscles should generate forces in resisting flexion than those produced by the limited number of anterior muscles in resisting extension. In addition, there is a sizable increase in the effective moment arm of the posterior muscles and ligaments when the chin contacts the chest.

3.2 Direct Impact to the Crown of the Hybrid III Dummy (8, 9)

Shown in Table 1 are the peak neck loads measured at the atlanto-occipital junction and the SI head accelerations measured at the head CG of the Hybrid III dummy under field accident paralyzing neck injury crown impact conditions. Since most biological tissues have time dependent properties which result in an increase in their load carrying capacity as the duration of loading decreases, the authors published two injury reference curves for axial compression neck loading. One curve is applicable to the general adult population and the other tolerance curve which is higher, applies to high school football players. Both references apply to measurements made on the Hybrid III dummy. Explanations and restrictions on the use of the curve are given in Reference 9.

3.3 Direct Impact to the Crown of Fresh Cadavers (12)

The primary skeletal injuries in this series of tests were spinous process fractures. The type of fracture and high speed movie analysis indicated a compressive arching of the cervical spine. HSRI investigators found that the arching followed the normal lordotic curvature of the cervical spine and appeared to depend on the initial rotation of the head

and axial alignment of the spine. They found that if the head is rotated rearward or the head placed above the axis of the spine, the arching is increased. No dislocations, no anterior compressive fracture of the bodies of the vertebrae, nor any basal skull fractures were found. This was a pilot study and its utility is limited, but the data indicated that peak impact force of 5.7 kN (1280 lb) is a level above which cervical spine fracture will begin to occur for an average cadaver under conditions of their experiment.

CONCLUSIONS

1. There is a small but significant body of data for tolerable and injurious neck loading that is beginning to accumulate.
2. Most of the available tolerance data for indirect loading of the neck has been obtained from inertia loadings of the heads of volunteers and cadavers.
3. Inertia loading of the head in car crash field accident studies has provided some measured and calculated data, and impact environment conditions up to the level of pain - no injury (AIS 1) for forward flexion in the volunteer; up to ligamentous damage in embalmed cadavers for rear extension, and; measured neck loads for AIS 1 in forward flexion of the Hybrid III dummy.
4. Neck loads for direct impact to the crown of the helmeted head of the Hybrid III dummy in an assumed catastrophic cervical fracture-dislocation environment (AIS 5) have been measured and tolerance curves for axial compressive neck loads measured in this dummy have been published.
5. Peak forces have been measured during impact with a piston on the crowns of head of fresh cadavers during which several spinous process fractures occurred.

6. For inertia loading pain - no injury (AIS 1) in the volunteer produced shear forces (797 N) calculated to be roughly one-half as high as those in the cadaver (no damage observed), which were in turn roughly one half as high as those measured in the Hybrid III dummy (AIS 1 simulation) for forward flexion.
7. For direct loading, peak axial loads in the fresh cadaver to produce spinous process fracture (AIS 3) were lower than those measured in the Hybrid III dummy under catastrophic fracture dislocation (AIS 5) injury environment.
8. There is intense activity in the study of mechanisms of neck injury to indirect impact and should be monitored closely for input to the head and neck protection problem.

TABLE 1

COMPARISON OF PEAK NECK LOAD DATA FOR INERTIA AND DIRECT IMPACT LOADING
OF THE HEADS OF VOLUNTEERS, CADAVERS, AND THE HYBRID III DUMMY

LOADING CONFIGURATION	Torque		Shear Force (N)	Force lb	Axial Force (N)	Force lb	AIS Rating	COMMENTS
	(N·m)	ft-lb						
<u>Inertia Loading - Volunteers (2, 3):</u>								
Forward Flexion 0°	88.2	(65.0)	787	(177)	--	--	1	Pain no injury
Rearward Extension 180°	30.5	(22.5)	231	(52)	249	(56T) [~]	0	No injury
Lateral Flexion 90°	45.2	(33.5)	792	(178)	--	--	0	No injury
Lateral Flexion 135°	18.0	(13.3)	311	(311)	356	(80T)	0	No injury
Lateral Flexion 45°	31.2	(23.0)	440	(440)	165	(37T)	0	No injury
<u>Inertia Loading - Cadavers (2, 4):</u>								
Forward Flexion 0°	190	(140)	1588	(357)	--	--	0	No damage
	176	(130)	1944	(437)	--	--	0	No damage
Rearward Extension 180°	47	(35)	--	--	--	--	0	No damage
	57	(42)	--	--	--	--	3	Ligamentous damage
<u>Inertia Loading - Hybrid III Dummy (9):</u>								
Forward Flexion 0°	76	(56)	1180	(265)	850	(190T)	*	mean of 3 replications v=32.2 km/h (20 mph) BEV
	152	(112)	2970	(670)	3290	(740T)	*	mean of 3 replications v=48.3 km/h (30 mph) BEV
<u>Direct Loading - Fresh Cadavers (11):</u>					<u>Impact Force[†]</u>			
					lb	(N)		
Crown Impact					3600	(809C)	3	long thin necks, little musculature Cervical spine fracture
					5700	(1280C)	3	Cervical spine fracture
<u>Direct Loading - Hybrid III Dummy (7, 8):</u>								
Crown Impact	30 ^T	(22)	1330	(300)	4000	(900C)	5	Catastrophic cervical fracture/dislocation-adults
	39	(28)	2220	(500)	6670	(1500C)	5	Catastrophic cervical fracture/dislocation-High School football players

*There was a total of 5 AIS 1 neck injuries in the (98) field accident cases being simulated by the dummy. Two occurred at a lower BEV and three at the 48.3 km/h (30 mph) appears to be a 14 percent probability of an AIS 1 maximum neck injury when the 48.3 km/h (30 mph) BEV data levels are reached.

†The neck axial loads would be lower by the amount of the head SI inertia force which is not available.

^TTorque deliberately minimized to achieve near-axial loading.

^TT-Tension; C-Compression

REFERENCES

1. Melvin, J. W., "Human Neck Injury Tolerance." SAE No. 790136, to be presented at 1979 SAE Congress and Exposition.
2. SAE Information Report J885b - Human Injury Criteria as Related to Motor Vehicle Injuries (In Print). Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096
3. Mertz, H. J. and Patrick, L. M., "Investigation of the Kinematics and Kinetics of Whiplash," SAE 670919, Eleventh Stapp Car Crash Conference October, 1967.
4. Patrick, L. M. and Chou, C. C., "Response of the Human Neck in Flexion Extension and Lateral Flexion," SAE Vehicle Research Institute Final Report No. VRI 7.3, April, 1976.
5. Mertz, H. J. and Patrick, L. M., "Strength and Response of the Human Neck," SAE 810855, Fifteenth Stapp Car Crash Conference, November, 1971, Coronado, CA.
6. Gadd, C. W., Culver, C. C. and Nahum, A. M., "A Study of Responses and Tolerances of the Neck," SAE No. 710856, Fifteenth Crash Conference, November, 1971; Coronado, CA.
7. Proceedings of the Nineteenth Conference of the American Association for Automotive Medicine - The abbreviated Injury Scale, San Diego, CA, November, 1975. American Association for Automotive Medicine, 801 Green Bay Road, Lake Bluff, IL 60044.
8. Hodgson, V. R. and Thomas, L. M., "Investigation of Forces and Moments at the Atlanto-Occipital Junction Under Known Cervical Fracture Dislocation in Head Impact Conditions." Final Report Environmental Activities Staff General Motors Corporation, March, 1978.
9. Mertz, H. J., Hodgson, V. R., Thomas, L. M. and Nyquist, G. W., "An Assessment of Compressive Neck Loads Under Injury Producing Conditions." The Physician and Sportsmedicine, Volume 6, Number 11, November, 1978.
10. Nyquist, G. W., Begeman, P. C., King, A. I., Mertz, H. J., "Correlation of Field Injuries and G.M. Hybrid III Dummy at Response for Lap-Shoulder Belt Restraints," To be presented at ASME Applied Mechanics/Bioengineering/Fluid Engineering Conference, Niagara Falls, NY, June, 1979.
11. Patrick, L. M., Bohlin, N., and Andersson A., "Comparison of Three-Point Harness Accident and Laboratory Data." Final report submitted to the MVMA, Wayne State University, August 20, 1974.
12. Culver, R. H., Bender M., and Melvin, J. W., "Mechanisms, Tolerance, and Responses Obtained Under Dynamic Superior-Inferior Head Impact." OSHA Final Report, May, 1978.

PAGE 1 - GOVERNMENT

Main Activities & Liaison Activities

Chief of Naval Research
Department of the Navy
Arlington, Virginia 22217
Attn: Code 874 (2)
411
222

Director
ONR Branch Office
401 Summer Street
Boston, Massachusetts 02210

Director
ONR Branch Office
315 S. Dearborn Street
Chicago, Illinois 60604

Director
Naval Research Laboratory
Attn: Code 26.9 (ONRL)
Washington, D.C. 20390 (6)

U.S. Naval Research Laboratory
Attn: Code 2627
Washington, D.C. 20390

Director
ONR - New York Area Office
715 Broadway - 5th Floor
New York, N.Y. 10003

Director
ONR Branch Office
1030 S. Green Street
Pasadena, California 91101

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22304 (12)

Army

Commanding Officer
U.S. Army Research Office Durham
Attn: Mr. J. J. Murray
CRO-AM-SP
Box CM, Duke Station
Durham, North Carolina 27706 (2)

Commanding Officer
AMNH-ATL
Attn: Mr. R. Shea
US Army Materiel Res. Agency
Weymouth, Massachusetts 02122

Director
ONR Research Center
Director, New York 12189
Attn: Director of Research

Technical Library

Systems Scientific Info. Center
Chief, Document Section
U.S. Army Missile Command
Redstone Arsenal, Alabama 35899

Army R&D Center
Fort Belvoir, Virginia 22060

NAVY

Commanding Officer and Director
Naval Ship Research & Development Center
Bethesda, Maryland 20016
Attn: Code 042 (Tech. Lib. Br.)

17 (Struc. Mech. Lab.)
172
176
177
1800 (Appl. Math. Lab.)
34125 (Dr. W.D. Bates)
19 (Dr. W.M. Smith)
1901 (Dr. W. Strassberg)
1943
196
1962 (Dr. D. Veit)

Naval Weapons Laboratory
 Dahlgren, Virginia 22448

Naval Research Laboratory
Washington, D.C. 20375
Attn: Code 9400
9410
9430
9440
9500
9590
9600

Undersea Explosion Research Div.
Naval Ship R&D Center
Berkeley Naval Shipyard
Portsmouth, Virginia 23709
Attn: Dr. S. Palmer
Code 780

Naval Ship Research & Development Center
Annapolis Division
Annapolis, Maryland 21402
Attn: Code 2768 - Dr. T.F. Wang
28 - Mr. B.J. Wolfe
281 - Mr. B.V. Hinderberger
2814 - Dr. H. Vandervort

Technical Library

Naval Underwater Weapons Center
Pasadena Annex
3202 S. Foothill Blvd.
Pasadena, California 91107

U.S. Naval Weapons Center
China Lake, California 93557
Attn: Code 4042 - Mr. V. Werbach
4520 - Mr. Sam Blackall

Commanding Officer
U.S. Naval Civil Engr. Lab
Code L32
Port Hueneme, California 93041

Technical Director
U.S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland 20910

Technical Director
Naval Undersea R&D Center
San Diego, California 92132

Supervisor of Shipbuilding
U.S. Navy
Norfolk Navy, Virginia 23607

Technical Director
Hare Island Naval Airyard
Vallejo, California 94592

U.S. Navy Underwater Sound Ref. Lab.
Office of Naval Research
PO Box 8337
Orlando, Florida 32806

Chief of Naval Operations
Dept. of the Navy
Washington, D.C. 20350
Attn: Code 0p071

Strategic Systems Project Office
Department of the Navy
Washington, D.C. 20390
Attn: NSP-001 Chief Scientist

Deep Submergence Systems
Naval Ship Systems Command
Code 2912
Department of the Navy
Washington, D.C. 20360

Engineering Dept.
US Naval Academy
Annapolis, Maryland 21402

Naval Air Systems Command
Dept. of the Navy
Washington, D.C. 20360
Attn: NAVAIR 1501 Aero & Structures
2308 Structures
23031F Structures
604 Tech. Library
2308 Structures

Director, Aero Mechanics
Naval Air Development Center
Johnsville
Harrisburg, Pennsylvania 17174

Technical Director
U.S. Naval Undersea R&D Center
San Diego, California 92132

Engineering Department
U.S. Naval Academy
Annapolis, Maryland 21402

Naval Facilities Engineering Command
Dept. of the Navy
Washington, D.C. 20360
Attn: NAVFAC 03 Research & Development
04
14416 Tech. Library

Naval Sea Systems Command
Dept. of the Navy
Washington, D.C. 20360
Attn: NAVSHIP 03 Res. & Technology
031 Ch. Scientist for R&D
03415 Hydrodynamics
037 Ship Silencing Div.
035 Weapons Dynamics

Naval Ship Engineering Center
Prince Georges' Plaza
Bryantown, Maryland 20782
Attn: NAVSEC 6100 Ship Sys. Engr. & Des. Ctr.
6102C Computer-Aided Ship Des.
6105G
6110 Ship Concept Design
6120 Hull Div.
6120D Hull Div.
6128 Surface Ship Struct.
6129 Submarine Struct.

Air Force

Commander WADD
Wright-Patterson Air Force Base
Dayton, Ohio 45433
Attn: Code WADD
AFDOL (PDOS)
Structures Division
AFLE (DCSLA)

Chief, Applied Mechanics Group
U.S. Air Force Inst. of Tech.
Wright-Patterson Air Force Base
Dayton, Ohio 45433

Chief, Civil Engineering Branch
WADD, Research Division
Air Force Weapons Laboratory
Wright-Patterson Air Force Base
Dayton, Ohio 45433

Air Force Office of Scientific Research
1400 Wilson Blvd.
Arlington, Virginia 22209
Attn: Mechanics Div.

NSA

Structures Research Division
National Communications & Space Admin.
Langley Research Center
Langley Station
Hampton, Virginia 23365

National Aeronautic & Space Admin.
Associate Administrator for Advanced
Research & Technology
Washington, D.C. 20546

Scientific & Tech. Info. Facility
NSA Representative (S-AM/DL)
P.O. Box 5700
Bethesda, Maryland 20814

Other Government Activities

Commandant
Chief, Testing & Development Div.
U.S. Coast Guard
1300 S. Street S.W.
Washington, D.C. 20226

Technical Director
Naval Corps Dev. & Educ. Command
Quantico, Virginia 22134

Director
National Bureau of Standards
Washington, D.C. 20334
Attn: Mr. S.L. Wilson, EN 119

Dr. H. Case
National Science Foundation
Engineering Division
Washington, D.C. 20550

Science & Tech. Division
Library of Congress
Washington, D.C. 20540

Director
Defense Nuclear Agency
Washington, D.C. 20305
Attn: SP25

Commander Field Command
Defense Nuclear Agency
Sandia Base
Albuquerque, New Mexico 87115

Director Defense Research & Engr.
Technical Library
Room M-118
The Pentagon
Washington, D.C. 20301

Chief, Airframe & Equipment Branch
PS-125
Office of Flight Standards
Federal Aviation Agency
Washington, D.C. 20551

Chief, Research and Development
Maritime Administration
Washington, D.C. 20225

Deputy Chief, Office of Ship Constr.
Maritime Administration
Washington, D.C. 20225
Attn: Mr. U.S. Russ

Atomic Energy Commission
Div. of Reactor Devel. & Tech.
Germantown, Maryland 20775

Ship Hull Research Committee
National Research Council
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20018
Attn: Mr. A.B. Lytle

PAGE 2 - CONTRACTORS AND OTHER
TECHNICAL COLLABORATORS

Universities

Dr. J. Stanley Odum
University of Texas at Austin
365 Eng. Science Bldg.
Austin, Texas 78712

Prof. Julius Hilsenrath
California Institute of Technology
Div. of Engineering & Applied Sciences
Pasadena, California 91109

Dr. Harold Liebowitz, Dean
School of Engr. & Applied Science
George Washington University
725 22nd St. N.W.
Washington, D.C. 20004

Prof. Eli Sternberg
California Institute of Technology
Div. of Engr. & Applied Sciences
Pasadena, California 91109

Prof. Paul H. Raghel
University of California
Div. of Applied Mechanics
Berkeley, California 94720

Professor P. S. Lyonde
Brown University
Division of Engineering
Providence, R.I. 02912

Prof. A.J. Durall
The Catholic University of America
Civil/Mechanical Engineering
Washington, D.C. 20017

Prof. R.B. Testa
Columbia University
Dept. of Civil Engineering
S.W. Mudd Bldg.
New York, N.Y. 10027

Prof. R.H. Bleich
Columbia University
Dept. of Civil Engineering
Amsterdam & 120th St.
New York, N.Y. 10027

Librarian
Hull Institute of Naval Architecture
Greenwich Beach Road, Glen Cove
Long Island, New York 11542

Prof. Daniel Frodoth
Virginia Polytechnic Institute
Dept. of Engineering Mechanics
Blacksburg, Virginia 24061

Prof. A.C. Erlangen
Dept. of Aerospace & Mech. Sciences
Princeton University
Princeton, New Jersey 08540

Dr. S.L. Koh
School of Aero., Astro. & Engr. Sci.
Purdue University
Lafayette, Indiana

Prof. R.B. Lee
Div. of Engr. Mechanics
Stanford University
Stanford, California 94305

Prof. R.D. Mindlin
Dept. of Civil Engineering
Columbia University
S.W. Mudd Building
New York, N.Y. 10027

Prof. R.B. Doug
University of California
Dept. of Mechanics
Los Angeles, California 90024

Prof. Bert Paul
University of Pennsylvania
Yenching Institute of Civil & Mech. Engr.
36-111 - Town Building
220 S. 33rd Street
Philadelphia, Pennsylvania 19104

Prof. S.U. Liu
Dept. of Chemical Engineering & Metall.
Syracuse University
Syracuse, N.Y. 13210

Prof. S. Sadener
Yeshiva Rabbinical Foundation
Brooklyn, Israel

Prof. S.J.B. Ballard
Chairman, Aeronautical Engr. Dept.
107 Sigmund Hall
University of Washington
Seattle, Washington 98195

Prof. P.L. D'Ameglio
Columbia University
Dept. of Civil Engineering
610 Mudd Building
New York, N.Y. 10027

Prof. H. Proudenthal
George Washington University
School of Engineering & Applied Sciences
Washington, D.C. 20004

R.C. Evans
University of Utah
Computer Science Division
Salt Lake City, Utah 84112

Prof. Norman Jones
Massachusetts Inst. of Technology
Dept. of Naval Architecture & Marine Engr.
Cambridge, Massachusetts 02139

Professor Albert E. King
Strombolini Research Center
Wayne State University
Detroit, Michigan 48202

Dr. V.R. Sadayappan
Wayne State University
School of Medicine
Detroit, Michigan 48202

Dean R.A. Bailey
Northwestern University
Technological Institute
2145 Sheridan Road
Evanston, Illinois 60201

Prof. P.G. Rodger, Jr.
The University of Minnesota
Dept. of Aerospace Engr. & Mechanics
Minneapolis, Minnesota 55455

Dr. D.C. Bruecher
University of Illinois
Dept. of Engineering
Urbana, Illinois 61801

Prof. R.M. Newmark
University of Illinois
Dept. of Civil Engineering
Urbana, Illinois 61801

Prof. E. Reissner
University of California, San Diego
Dept. of Applied Mechanics
La Jolla, California 92037

Prof. G.B. Baller
Division of Engineering
Brown University
Providence, Rhode Island 02912

Prof. Warner Goldsmith
Dept. of Mechanical Engineering
Div. of Applied Mechanics
University of California
Berkeley, California 94720

Prof. J.B. Rice
Division of Engineering
Brown University
Providence, Rhode Island 02912

Prof. R.S. Rivlin
Center for the Application of Mathematics
Lehigh University
Bethlehem, Pennsylvania 18015

Library (Code 0184)
U.S. Naval Postgraduate School
Monterey, California 94043

Dr. Francis Casaroli
Div. of Interdisciplinary Studies & Research
School of Engineering
State University of New York
Buffalo, N.Y. 14214

Industry and Research Institution

Library Services Department
Support Section Bldg. 10-1
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60460

Dr. W.C. Jungst
Cambridge Acoustical Associates
119 Mount Auburn St.
Cambridge, Massachusetts 02138

Dr. L.H. Chen
General Dynamics Corporation
Electric Boat Division
Groton, Connecticut 06340

Dr. J.B. Greenbaum
J.C. Engineering Research Associates
3031 Main Drive
Baltimore, Maryland 21215

Dr. S. Huford
The Aerospace Corp.
P.O. Box 92957
Los Angeles, California 90009

Prof. William A. Bush
University of Massachusetts
Dept. of Mechanical & Aerospace Engr.
Amherst, Massachusetts 01002

Library (Code 0184)
U.S. Naval Postgraduate School
Monterey, California 94043

Prof. Arnold Allentuch
Rutgers College of Engineering
Dept. of Mechanical Engineering
121 High Street
Newark, New Jersey 07102

Dr. George Herrmann
Stanford University
Dept. of Applied Mechanics
Stanford, California 94305

Prof. J.D. Achenbach
Northwestern University
Dept. of Civil Engineering
Evanston, Illinois 60112

Director, Applied Research Lab.
Pennsylvania State University
P.O. Box 30
State College, Pennsylvania 16801

Prof. Eugene J. Shadrava
Pennsylvania State University
Applied Research Laboratory
Dept. of Physics - P.O. Box 30
State College, Pennsylvania 16801

Prof. J. Samner
Polytechnic Institute of Brooklyn
Dept. of Aero. Engr. & Applied Mech.
333 Jay Street
Brooklyn, N.Y. 11201

Prof. J. Kleener
Polytechnic Institute of Brooklyn
Dept. of Aerospace & Appl. Mech.
333 Jay Street
Brooklyn, N.Y. 11201

Prof. R.A. Schapery
Texas A&M University
Dept. of Civil Engineering
College Station, Texas 77840

Prof. W.D. Pilkey
University of Virginia
Dept. of Aerospace Engineering
Charlottesville, Virginia 22901

Dr. R.C. Park
Lockheed Palo Alto Research Laboratory
Dept. 2233, Bldg. 205
3251 Hanover Street
Palo Alto, California 94304

Library
Newport News Shipbuilding and Dry Dock Co.
Newport News, Virginia 23607

Dr. W.F. Busch
McDonnell Douglas Corporation
3101 Boise Ave.
Burlington Beach, California 92007

Dr. H.B. Abrahamson
Southwest Research Institute
Technical Vice President
Mechanical Sciences
P.O. Drawer 28310
San Antonio, Texas 78284

Dr. R.C. Doherty
Southwest Research Institute
Dept. of Structural Research
P.O. Drawer 28310
San Antonio, Texas 78284

Dr. H.L. Baron
Widlinger Associates,
Consulting Engineers
110 East 57th Street
New York, N.Y. 10022

Dr. W.A. von Bloembergen
Sandia Laboratories
Sandia Road
Albuquerque, New Mexico 87115

Dr. T.L. Goss
Lockheed Missiles & Space Co.
Palo Alto Research Laboratory
3251 Hanover Street
Palo Alto, California 94304

Dr. J.L. Fox
Sams Computer Services, Inc.
P.O. Box 7444
Seattle, Washington 98124

Dr. William Corwood
Code 888, Applied Physics Laboratory
9421 Georgia Avenue
Silver Spring, Maryland 20914

Dr. H.C. Schaeffer
University of Maryland
Aerospace Engineering Dept.
College Park, Maryland 20742

Prof. S.D. Utinur
University of Maryland
Dept. of Mechanical Engineering
Potsdam, N.Y. 13155

Dr. J.A. Strickland
Texas A&M University
Aerospace Engineering Dept.
College Station, Texas 77843

Dr. L.A. Schmitz
University of California, LA
School of Engineering & Applied Science
Los Angeles, California 90024

Dr. R.A. Kramel
The University of Arizona
Aerospace & Mech. Engineering Dept.
Tucson, Arizona 85721

Dr. E.C. Berger
University of Maryland
Dept. of Mechanical Engineering
College Park, Maryland 20742

Prof. C.B. Irwin
Dept. of Mechanical Engineering
University of Maryland
College Park, Maryland 20742

Dr. S.J. Fawcett
Carnegie-Mellon University
Dept. of Civil Engineering
Schaefer Park
Pittsburgh, Pennsylvania 15213

Dr. Ronald L. Huston
Dept. of Engineering Analysis
Mail Box 117
University of Cincinnati
Cincinnati, Ohio 45221

Prof. George Sih
Dept. of Mechanics
Lehigh University
Bethlehem, Pennsylvania 18015

Prof. A.S. Eshvashili
University of Washington
Dept. of Mechanical Engineering
Seattle, Washington 98195

Mr. P.C. Durup
Lockheed-California Company
Aeronautics Dept., 74-43
Burbank, California 91523