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UNITED STATES AIR FORCE

SUMMER RESEARCH PROGRAM -- 1992

SUMMER RESEARCH EXTENSION PROGRAM FINAL REPORTS

VOLUME 1B

ARMSTRONG LABORATORY

RESEARCH & DEVELOPMENT LABORATORIES

5800 UPLANDER WAY

CULVER CITY, CA 90230-6608

SUBMITTED TO:

LT. COL. CLAUDE CAVENDER
PROGRAM MANAGER

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

BOLLING AIR FORCE BASE

WASHINGTON, D.C.

MAY 1993

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6. AUTHOR(S)

Mr Gary Moore

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Research & Development Laboratoreis (RDL)
5800 Uplander Way
Culver City CA 90230-6600

8. PERFORMING ORGANIZATION REPORT NUMBER

AFOSR-TR-95
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AFOSR/NI
110 Duncan Ave., Suite B115
Bldg 410
Bolling AFB DC 20332-0001
Lt Col Claude Cavender

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13. ABSTRACT (Maximum 200 words)

The purpose of this program is to develop the basis for cintinuing research of interest to the Air Force at the institution of the faculty member; to stiumlate continuing relations among faculty members and professional peers in the Air Force to enhance the research interests and capabilities of scientific and engineering educators; and to provide follow-on funding for research of particular promise that was started at an Air Force laboratory under the Summer Faculty Research Program.

During the summer of 1992 185 university faculty conducted research at Air Force laboratories for a period of 10 weeks. Each participant provided a report of their research, and these reports are consolidated into this annual report.

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RESEARCH & DEVELOPMENT LABORATORIES

5800 Uplander Way

Culver City, CA 90230-6608

Program Director, RDL
Gary Moore

Program Manager, AFOSR
Lt. Col. Claude Cavender

Program Manager, RDL
Scott Licoscos

Program Administrator, RDL
Gwendolyn Smith

Submitted to:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Bolling Air Force Base

Washington, D.C.

May 1993

PREFACE

This volume is part of a five-volume set that summarizes the research of participants in the 1992 AFOSR Summer Research Extension Program (SREP). The current volume, Volume 1B of 5, presents the final reports of SREP participants at Armstrong Laboratory.

Reports presented in this volume are arranged alphabetically by author and are numbered consecutively -- e.g., 1-1, 1-2, 1-3; 2-1, 2-2, 2-3, with each series of reports preceded by a 22-page management summary. Reports in the five-volume set are organized as follows:

VOLUME	TITLE
1A	Armstrong Laboratory (part one)
1B	Armstrong Laboratory (part two)
2	Phillips Laboratory
3	Rome Laboratory
4A	Wright Laboratory (part one)
4B	Wright Laboratory (part two)
5	Air Force Civil Engineering Laboratory, Arnold Engineering Development Center, Frank J. Seiler Research Laboratory, Wilford Hall Medical Center

1992 SUMMER RESEARCH EXTENSION PROGRAM FINAL REPORTS

Armstrong Laboratory

Armstrong Laboratory (cont'd)

1992 SUMMER RESEARCH EXTENSION PROGRAM (SREP) MANAGEMENT REPORT

1.0 BACKGROUND

Under the provisions of Air Force Office of Scientific Research (AFOSR) contract F49620-90-C-0076, September 1990, Research & Development Laboratories (RDL), an 8(a) contractor in Culver City, CA, manages AFOSR's Summer Research Program. This report is issued in partial fulfillment of that contract (CLIN 0003AC).

The name of this program was changed during this year's period of performance. For that reason, participants' cover sheets are captioned "Research Initiation Program" (RIP), while the covers of the comprehensive volumes are titled "Summer Research Extension Program" (SREP). The program's sponsor, the Air Force Office of Scientific Research (AFOSR), changed the name to differentiate this program from another which also bore its original name.

Apart from this name change, however, the program remained as it has been since its initiation as the Mini-Grant Program in 1983. The SREP is one of four programs AFOSR manages under the Summer Research Program. The Summer Faculty Research Program (SFRP) and the Graduate Student Research Program (GSRP) place college-level research associates in Air Force research laboratories around the United States for 8 to 12 weeks of research with Air Force scientists. The High School Apprenticeship Program (HSAP) is the fourth element of the Summer Research Program, allowing promising mathematics and science students to spend two months of their summer vacations at Air Force laboratories within commuting distance from their homes.

SFRP associates and exceptional GSRP associates are encouraged, at the end of their summer tours, to write proposals to extend their summer research during the following calendar year at their home institutions. AFOSR provides funds adequate to pay for 75 SREP subcontracts. In addition, AFOSR has traditionally provided further funding, when available, to pay for additional SREP proposals, including those submitted by associates from Historically Black Colleges and Universities (HBCUs) and Minority Institutions (MIs). Finally, laboratories may transfer internal funds to AFOSR to fund additional SREPs. Ultimately the laboratories inform RDL of their SREP choices, RDL gets AFOSR approval, and RDL forwards a subcontract to the institution where the SREP associate is employed. The subcontract (see Attachment 1 for a sample) cites the SREP associate as the principal investigator and requires submission of a report at the end of the subcontract period.

Institutions are encouraged to share costs of the SREP research, and many do so. The most common cost-sharing arrangement is reduction in the overhead, fringes, or administrative changes institutions would normally add on to the principal investigator's or research associate's labor. Some institutions also provide other support (e.g., computer run time, administrative assistance, facilities and equipment or research assistants) at reduced or no cost.

When RDL receives the signed subcontract, we fund the effort initially by providing 90% of the subcontract amount to the institution (normally $18,000 for a $20,000 SREP). When we receive the end-of-research report, we evaluate it administratively and send a copy to the laboratory for a technical evaluation. When the laboratory notifies us the SREP report is acceptable, we release the remaining funds to the institution.

2.0 THE 1992 SREP PROGRAM

SELECTION DATA: In the summer of 1991, 170 faculty members (SFRP associates) and 142 graduate students (GSRP associates) participated in the summer program. Of those, 147 SFRPs and 10 GSRPs submitted SREP proposals; 88 SFRP SREPs and 7 GSRP SREPs were selected for funding (total: 95).

	Summer 1991 Participants	Submitted SREP Proposals	SREPs Funded
SFRP	170	147	88
GSRP	142	10	7

The funding was provided as follows:

Contractual slots funded by AFOSR	75
Laboratory-funded	13
Additional funding from AFOSR	7
Total	95

Seven HBCU/MI associates from the 1991 summer program submitted SREP proposals; five were selected (one was lab-funded; four were funded by additional AFOSR funds).

By laboratory, the applications submitted and selected show in the following table:

	Applied	Selected
Air Force Civil Engineering Laboratory	6	4
Armstrong Laboratory	34	20
Arnold Engineering Development Center	12	2
Frank J. Seiler Research Laboratory	5	3
Phillips Laboratory	30	18
Rome Laboratory	16	11
Wilford Hall Medical Center	1	1
Wright Laboratory	53	36
TOTAL	157	95

Note: Phillips Laboratory funded 2 SREPs; Wright Laboratory funded 11; and AFOSR funded 7 beyond its contractual 75.

ADMINISTRATIVE EVALUATION: The administrative quality of the SREP associates' final reports was satisfactory. Most complied with the formatting and other instructions RDL provided to them. In the final days of December 1992 and in the first two months of 1993, several associates called and requested no-cost extensions of up to six months. After consultation with our AFOSR Contracting Officer's Representative, RDL approved the requests but asked that all such associates provide an interim report to be included in this volume. That caused an AFOSR-approved delay beyond the 1 April 1993 submission of this report. The subcontracts were funded by $1,893,616 of Air Force money. Institutions' cost sharing amounted to $948,686.

TECHNICAL EVALUATION: The form we used to gather data for technical evaluation and the technical evaluations of the SREP reports are provided as Attachment 2. This summary evaluation is shown by SREP number. The average rating range was from 3.1 to 5.0. The overall average for those evaluated was 4.6 out of 5.00. The three rating factors with the highest average scores were:

- o The USAF should continue to pursue the research in this RIP report.
- o The money spent on this RIP report was well worth it.
- o I'll be eager to be a focal point for summer and RIP associates in the future.

Thus it is clear that the laboratories place a high value on AFOSR's Summer Research Program: SFRP, GSRP, and SREP.

3.0 SUBCONTRACTS SUMMARY

Table 1 lists contractually required information on each SREP subcontract. The individual reports are published in volumes as follows:

Laboratory	Volume
Air Force Civil Engineering Laboratory	5
Armstrong Laboratory	1
Arnold Engineering Development Center	5
Frank J. Seiler Research Laboratory	5
Phillips Laboratory	2
Rome Laboratory	3
Wilford Hall Medical Center	5
Wright Laboratory	4

TABLE 1: SUBCONTRACTS SUMMARY

Researcher's name / Institution / Location	Highest Degree	Subcontract Number / Department / Amount	Duration / Sharing
Abbott, Ben A Vanderbilt University Nashville, TN 37235	MS	135 Dept of Electrical Engineering 19966.00	01/01/92-12/31/92 0.00
Acharya, Raj State University of New York, Buffalo Buffalo, NY 14260	PhD	151 Dept of Electrical & Comp Engrg 20000.00	01/01/92-12/31/92 0.00
Adams, Christopher M Oklahoma State University Stillwater, OK 74078	PhD	68 Dept of Chemistry 20000.00	01/01/92-12/31/92 0.00
Anderson, Richard A University of Missouri, Rolla Rolla, MO 65401	PhD	50 Dept of Physics 20000.00	01/01/92-12/31/92 5000.00
Arora, Vijay K Wilkes University Wilkes-Barre, PA 18766	PhD	3 Dept of Electrical & Comp Engrg 19996.00	10/01/91-09/30/92 36208.00
Ball, William P Duke University Durham, NC 27706	PhD	71 Dept of Civil & Environmental Eng 20000.00	01/01/92-12/31/92 26747.00
Battles, Frank P Massachusetts Maritime Academy Buzzard's Bay, MA 025321803	PhD	152 Dept of Basic Sciences 20000.00	01/01/92-12/31/92 22000.00
Bieniek, Ronald J University of Missouri, Rolla Rolla, MO 65401	PhD	147 Dept of Physics 19945.00	01/01/92-12/31/92 4000.00
Blystone, Robert V Trinity University San Antonio, TX 78212	PhD	127 Dept of Biology 20000.00	01/01/92-12/31/92 14783.00
Cha, Soyoung S University of Illinois, Chicago Chicago, IL 60680	PhD	011 Dept of Mechanical Engineering 20000.00	01/01/92-12/31/92 3842.00
Chandra, D. V. Satish Kansas State University Manhattan, KS 66506	PhD	89 Dept of Electrical Engineering 20000.00	01/18/92-10/17/92 11170.00
Chenette, Eugene R University of Florida Gainesville, FL 32611	PhD	106 Dept of Electrical Engineering 20000.00	01/01/92-12/31/92 0.00
Christensen, Douglas A University of Utah Salt Lake City, UT 84112	PhD	83 Dept of Electrical Engineering 19999.00	01/01/92-12/31/92 5000.00

Chubb, Gerald P	Ohio State University	Columbus, OH 43235	PhD	26	01/01/92-12/31/92	Dept of Aviation	20000.00	7600.00
Courter, Robert W	Louisiana State University	Baton Rouge, LA 70803	PhD	8	10/01/91-09/30/92	Dept of Mechanical Engineering	20000.00	445.00
Dey, Pradip P	Hampton University	Hampton, VA 23668	PhD	120	01/01/92-12/31/92	Computer Science Department	19921.00	0.00
Draut, Arthur W	Embry Riddle Aeronautical University	Prescott, AZ 86301	PhD	133	01/06/92-05/08/92	Computer Science Dept	19431.00	0.00
Dreisbach, Joseph	University of Scranton	Scranton, PA 185104626	PhD	108	12/01/91-12/01/92	Dept of Chemistry	20000.00	4000.00
Dror, Itiel	Harvard University	Cambridge, MA 02138	BS	76	01/01/92-12/31/92	Dept of Psychology	20000.00	0.00
Drost-Hansen, W.	University of Miami	Coral Gables, FL 33124	PhD	124	12/01/91-12/01/92	Dept of Chemistry	20000.00	12000.00
Dunleavy, Lawrence P	University of South Florida	Tampa, FL 33620	PhD	41	01/01/92-12/31/92	Dept of Electrical Engineering	20000.00	6463.00
Evans, Joseph B	University of Kansas	Lawrence, KS 66045	PhD	96	01/01/92-12/31/92	Dept of Electrical & Comp Engrg	20000.00	0.00
Flowers, George T	Auburn University	Auburn, AL 368495341	PhD	73	01/01/92-12/30/92	Dept of Mechanical Engineering	19986.00	12121.00
Gantenbein, Rex E	University of Wyoming	Laramie, WY 82071	PhD	22	01/01/91-12/31/92	Dept of Computer Science	20000.00	26643.00
Garcia, Ephrarim	Vanderbilt University	Nashville, TN 37235	PhD	32	12/01/91-11/30/92	Dept of Mechanical Engineering	20000.00	9659.00
German, Fred J	Auburn University	Auburn University, AL 36830	PhD	49	01/01/92-12/31/92	Dept of Electrical Engineering	20000.00	0.00
Gould, Richard D	North Carolina State University	Raleigh, NC 276957910	PhD	87	01/01/92-12/31/92	Dept of Mech and Aerospace Engrg	20000.00	14424.00
Gove, Randy L	University of Alabama, Huntsville	Huntsville, AL 35899	MS	122	01/01/92-12/31/92	Dept of Physics	20000.00	3469.00
Grabowski, Marek	University of Colorado, Colorado Springs	Colorado Springs, CO 809337150	PhD	92	01/01/92-12/31/92	Dept of Physics	19700.00	0.00

Gunaratne, Manjriker University of South Florida Tampa, FL 33620	PhD	90	01/01/92-12/31/92	
	Dept of Civil Engrg & Mechanics			
	19994.00		10062.00	
Hall, Ernest L University of Cincinnati Cincinnati, OH 452210072	PhD	134	01/01/92-12/31/92	
	Dept of Robotics Research			
	19975.00		0.00	
Hamilton, William L Salem State College Salem, MA 01970	PhD	47	01/01/92-12/31/92	
	Dept of Geography			
	20000.00		32000.00	
Hamilton, Kirk L Xavier University of Louisiana New Orleans, LA 70125	PhD	57	01/01/92-12/31/92	
	Dept of Biology			
	20000.00		16100.00	
Harris, Harold H University of Missouri, St.Louis St. Louis, MO 63121	PhD	94	01/01/92-12/31/92	
	Dept of Chemistry			
	19300.00		8600.00	
Hartung, George H University of Hawaii Honolulu, HI 96822	PhD	46	01/01/92-12/31/92	
	Dept of Physiology			
	20000.00		7530.00	
Hatfield, Steven L University of Kentucky Lexington, KY 40506	BS	23	01/01/92-12/31/92	
	Dept of Materials Science & Engrg			
	20000.00		28625.00	
Hedman, Paul O'Dell Brigham Young University Provo, UT 84602	PhD	17	01/01/92-12/31/92	
	Dept of Chemical Engineering			
	19999.00		6928.00	
Heister, Stephen D Purdue University West Lafayette, IN 47907	PhD	5	01/01/92-12/31/92	
	School of Aero & Astronautics			
	20000.00		4419.00	
Hess, David J University of Texas, Austin Austin, TX 78713	BA	149	01/01/92-12/31/92	
	Dept of Psychology			
	19914.00		8784.00	
Hoffman, R. W Case Western Reserve University Cleveland, OH 44106	PhD	99	01/01/92-12/31/92	
	Dept of Physics			
	19770.00		0.00	
Huerta, Manuel A University of Miami Coral Gables, FL 33124	PhD	62	01/01/92-12/31/92	
	Dept of Physics			
	20000.00		1207.00	
Hui, David University of New Orleans New Orleans, LA 70148	PhD	116	01/01/92-12/31/92	
	Dept of Mechanical Engineering			
	20000.00		0.00	
Iyer, Ashok University of Nevada, Las Vegas Las Vegas, NV 89154	PhD	74	01/01/92-12/31/92	
	Dept of Electrical & Comp Engrg			
	20000.00		18549.00	
Khonsari, Michael M University of Pittsburgh Pittsburgh, PA 15260	PhD	53	01/01/92-12/31/92	
	Dept of Mechanical Engineering			
	20000.00		32958.00	
Kibert, Charles J University of Florida Gainesville, FL 32611	PhD	2	01/01/92-12/31/92	
	Dept of Fire Testing & Research			
	20000.00		6928.00	

Klarup, Douglas G University of Montana Missoula, MT 59812	PhD	84	01/01/92-12/31/92	
	Dept of Chemistry			
	20000.00		0.00	
Koblasz, Arthur J Georgia Institute of Technology Atlanta, GA 30332	PhD	145	01/01/92-09/30/92	
	Dept of Civil Engineering			
	19956.00		0.00	
Kornreich, Philipp Syracuse University Syracuse, NY 13244	PhD	35	10/01/91-09/30/92	
	Dept of Electrical & Comp Engrg			
	20000.00		0.00	
Kuo, Spencer P Polytechnic University Farmingdale, NY 11735	PhD	59	01/01/92-12/31/92	
	Dept of Electrical Engineering			
	20000.00		9916.00	
Langhoff, Peter W Indiana University Bloomington, IN 47402	PhD	115	01/01/92-12/31/92	
	Dept of Chemistry			
	20000.00		35407.00	
Lee, Byung-Lip Pennsylvania State University University Park, PA 16802	PhD	93	01/01/92-12/31/92	
	Dept of Engrg Science & Mechanics			
	20000.00		8173.00	
Leigh, Wallace B Alfred University Alfred, NY 14802	PhD	118	01/01/92-12/31/92	
	Dept of Electrical Engineering			
	19767.00		18770.00	
Liddy, Elizabeth Syracuse University Syracuse, NY 132444100	PhD	104	01/01/92-12/31/92	
	Dept of Information Studies			
	20000.00		0.00	
Liu, Cheng University of North Carolina, Charlotte Charlotte, NC 28270	PhD	6	11/01/99-12/31/92	
	Dept of Engineering Technology			
	20000.00		0.00	
Main, Robert G California State University, Chico Chico, CA 959290504	PhD	28	01/01/92-06/30/92	
	Dept of Communication Design			
	20000.00		7672.00	
Mains, Gilbert J Oklahoma State University Stillwater, OK 74078	PhD	52	01/01/92-12/31/92	
	Dept of Chemistry			
	19071.00		8746.00	
Marathay, Arvind S University of Arizona Tucson, AZ 85721	PhD	51	01/01/92-12/31/92	
	Dept of Optical Sciences			
	20000.00		0.00	
Martin, Charlesworth R Norfolk State University Norfolk, VA 23504	PhD	125	01/01/92-12/31/92	
	Dept of Physics & Engineering			
	20000.00		0.00	
Mayes, Jessica L University of Kentucky Lexington, KY 405034203	BS	16	01/01/92-12/31/92	
	Dept of Material Science & Engrng			
	20000.00		28625.00	
Mulligan, Benjamin E University of Georgia Athens, GA 30602	PhD	54	01/01/92-12/31/92	
	Dept of Psychology			
	19895.00		13677.00	
Munday, Edgar G University of North Carolina, Charlotte Charlotte, NC 28223	PhD	38	10/01/91-10/30/92	
	Dept of Mechanical Engineering			
	20000.00		11638.00	

Nurre, Joseph H Ohio University Athens, OH 45701	PhD 56 Dept of Electrical & Comp Engrg 19842.00	01/01/92-12/31/92 15135.00
Orkwis, Paul D University of Cincinnati Cincinnati, OH 452210070	PhD 14 Dept of Engineering Mechanics 19966.00	10/01/91-10/30/92 23017.00
Patra, Amit L University of Puerto Rico Mayaquez, PR 00681	PhD 69 Dept of General Engineering 20000.00	01/01/92-12/31/92 2750.00
Peters II, Richard A Vanderbilt University Nashville, TN 37235	PhD 160 Dept of Electrical Engineering 20000.00	01/01/92-12/31/92 0.00
Pollack, Steven K University of Cincinnati Cincinnati, OH 452200012	PhD 31 Dept of Materials Sci & Engrg 20000.00	01/01/92-12/31/92 14877.00
Prescott, Glenn E University of Kansas Lawrence, KS 66045	PhD 72 Dept of Electrical Engineering 20000.00	01/01/92-12/31/92 8000.00
Price, James L University of Iowa Iowa City, IA 52242	PhD 48 Dept of Sociology 20000.00	01/01/92-12/30/92 8600.00
Qazi, Salahuddin SUNY, Utica Utica, NY 13504	PhD 129 Dept of Electrical Engineering 20000.00	01/01/92-12/31/92 25000.00
Rappaport, Carey M Northeastern University Boston, MA 02115	PhD 58 Dept of Electrical & Comp Engrng 19999.00	01/01/92-06/30/92 0.00
Rawson, Jenny L North Dakota State University Fargo, ND 58105	PhD 144 Dept of Electrical Engineering 19997.00	01/01/92-12/31/92 19826.00
Riccio, Gary E University of Illinois, Urbana Urbana, IL 61821	PhD 80 Dept of Human Perception 20000.00	01/01/92-12/31/92 0.00
Rotz, Christopher A Brigham Young University Provo, UT 84602	PhD 136 Dept of Manufacturing Engineering 20000.00	12/01/91-12/31/92 11814.00
Schwartz, Martin University of North Texas Denton, TX 762035068	PhD 55 Dept of Chemistry 20000.00	01/01/92-12/31/92 18918.00
Senseman, David M University of Texas, San Antonio San Antonio, TX 78285	PhD 77 Dept of Information 20000.00	12/01/91-11/30/92 19935.00
Sensiper, Martin University of Central Florida Orlando, FL 32816	BS 15 Dept of Electrical Engineering 20000.00	11/01/91-05/31/92 0.00
Shamma, Jeff S University of Texas, Austin Austin, TX 78713	PhD 70 Dept of Electrical Engineering 20000.00	01/01/92-12/31/92 0.00

Shively, Jon H California State University, Northridge Northridge, CA 91330	PhD 140 01/01/92-12/31/92 Dept of CIAM 20000.00 14553.00
Singh, Sahjendra N University of Nevada, Las Vegas Las Vegas, NV 89014	PhD 79 01/01/92-12/31/92 Dept of Electrical Engineering 20000.00 20595.00
Smith, Gerald A Pennsylvania State University University Park, PA 16802	PhD 63 07/01/92-07/01/93 Dept of Physics 20000.00 0.00
Stephens, Benjamin R Clemson University Clemson, SC 29634	PhD 114 01/01/92-12/31/92 Dept of Psycology 19988.00 4250.00
Sudkamp, Thomas Wright State University Dayton, OH 45435	PhD 97 01/01/92-08/31/92 Dept of Computer Science 20000.00 18739.00
Sydor, Michael University of Minnesota, Duluth Duluth, MN 55804	PhD 11 01/01/92-12/31/92 Dept of Physics 20000.00 0.00
Tankin, Richard S Northwestern University Evanston, IL 60208	PhD 44 01/01/92-12/31/92 Dept of Mechanical Engineering 20000.00 29103.00
Taylor, Michael D University of Central Florida Orlando, FL 32816	PhD 141 05/01/92-07/31/92 Dept of Mathematics 20000.00 1587.00
Teegarden, Kenneth J University of Rochester Rochester, NY 14627	PhD 98 01/01/92-12/31/92 Dept of Optics 20250.00 60600.00
Tew, Jeffrey D Virginia Polytech Instit and State Univ Blacksburg, VA 24061	PhD 137 03/01/92-09/30/92 Dept of Industrial Engineering 17008.00 4564.00
Tipping, Richard H University of Alabama Tuscaloosa, AL 35487	PhD 81 01/01/92-05/31/92 Dept of Physics & Astronomy 20000.00 15000.00
Tripathi, Ram C University of Texas, San Antonio San Antonio, TX 78249	PhD 105 01/01/92-12/31/92 Dept of Mathematics 20000.00 2274.00
Wells, Fred V Idaho State University Pocatello, ID 83209	PhD 155 01/01/92-12/31/92 Dept of Chemistry 20000.00 8000.00
Whitefield, Phillip D University of Missouri, Rolla Rolla, MO 65401	PhD 25 01/01/92-12/31/92 Dept of Chemistry 19991.00 25448.00
Wolfenstine, Jeffrey B University California, Irvine Irvine, CA 92717	PhD 18 01/01/92-12/31/92 Dept of Mechanical Engineering 20000.00 11485.00
Wolper, James S Idaho State University Pocatello, ID 83209	PhD 138 01/15/92-09/30/92 Dept of Mathematics 20000.00 4828.00

Zavodney, Lawrence D Ohio State University Columbus, OH 43210	PhD 148 Dept of Engineering Mechanics 20000.00	01/01/92-12/31/92 0.00
Zimmerman, Wayne J Texas Women University Denton, TX 76204	PhD 111 Dept of Mathematics 19990.00	01/01/92-12/31/92 8900.00

ATTACHMENT 1:

SAMPLE SREP SUBCONTRACT

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
1993 SUMMER RESEARCH EXTENSION PROGRAM SUBCONTRACT 93-36

BETWEEN

Research & Development Laboratories
5800 Uplander Way
Culver City, CA 90230-6608

AND

University of Delaware
Sponsored Programs Admin.
Newark, DE 19716

REFERENCE: Summer Research Extension Program Proposal 93-36
Start Date: 01/01/93 End Date: 12/31/93
Proposal amount: $20000.00

(1) PRINCIPAL INVESTIGATOR: Dr. Ian W. Hall
Materials Science
University of Delaware
Newark, DE 19716

(2) UNITED STATES AFOSR CONTRACT NUMBER: F49620-90-C-09076

(3) CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER (CFDA): 12.800
PROJECT TITLE: AIR FORCE DEFENSE RESEARCH SOURCES PROGRAM

(4) ATTACHMENTS 1 AND 2: SREP REPORT INSTRUCTIONS

*** SIGN SREP SUBCONTRACT AND RETURN TO RDL ***

1. BACKGROUND: Research & Development Laboratories (RDL) is under contract (F49620-90-C-0076) to the United States Air Force to administer the Summer Research Programs (SRP), sponsored by the Air Force Office of Scientific Research (AFOSR), Bolling Air Force Base, D.C. Under the SRP, a selected number of college faculty members and graduate students spend part of the summer conducting research in Air Force laboratories. After completion of the summer tour participants may submit, through their home institutions, proposals for follow-on research. The follow-on research is known as the Research Initiation Program (RIP). Approximately 75 RIP proposals annually will be selected by the Air Force for funding of up to $20,000; shared funding by the academic institution is encouraged. RIP efforts selected for funding are administered by RDL through subcontracts with the institutions. This subcontract represents such an agreement between RDL and the institution designated in Section 5 below.

2. RDL PAYMENTS: RDL will provide the following payments to RIP institutions:

- 90 percent of the negotiated RIP dollar amount at the start of the RIP Research period.
- the remainder of the funds within 30 days after receipt at RDL of the acceptable written final report for the RIP research.

3. INSTITUTION'S RESPONSIBILITIES: As a subcontractor to RDL, the institution designated on the title page will:

a. Assure that the research performed and the resources utilized adhere to those defined in the RIP proposal.

b. Provide the level and amounts of institutional support specified in the RIP proposal.

c. Notify RDL as soon as possible, but not later than 30 days, of any changes in 3a or 3b above, or any change to the assignment or amount of participation of the Principal Investigator designated on the title page.

d. Assure that the research is completed and the final report is delivered to RDL not later than twelve months from the effective date of this subcontract. The effective date of the subcontract is one week after the date that the institution's contracting representative signs this subcontract, but no later than January 15, 1992.

e. Assure that the final report is submitted in the format shown in Attachment 1.

f. Agree that any release of information relating to this subcontract (news releases, articles, manuscripts, brochures, advertisements, still and motion pictures, speeches, trade association meetings, symposia, etc.) will include a statement that the project or effort depicted was or is sponsored by: Air Force Office of Scientific Research, Bolling AFB, D.C.

g. Notify RDL of inventions or patents claimed as the result of this research in a format specified in Attachment 1.

h. RDL is required by the prime contract to flow down patent rights and technical data requirements in this subcontract. Attachment 2 to this subcontract contains a list of contract clauses incorporated by reference in the prime contract.

4. All notices to RDL shall be addressed to:

RDL Summer Research Program Office
5800 Uplander Way
Culver City, CA 90230-6608

5. By their signatures below, the parties agree to the provisions of this subcontract.

____________________ Abe S. Sopher RDL Contracts Manager	____________________ Signature of Institution Contracting Official
	____________________ Typed/Printed Name
____________________ Date	____________________ Title
	____________________ Institution
	____________________ Date/Phone

Attachment 1
Final Report Format

1. All RIP Principal Investigators will submit a final report of the research conducted.

2. One copy of the report is due to RDL no later than twelve months after the effective date of the RIP subcontract. At the same time, submit one copy to the Air Force laboratory focal point.

3. The title page should contain the title of the research, the Principal Investigator and or other co-investigators, the month and year of issue, the university with department and address, and acknowledgement of sponsorship by AFOSR (see clause 3f of this subcontract).

4. For text, use a font that is 12 characters per inch (elite) and as close to letter quality as possible. Start with the title in all caps one and one-half inches from the top of the first page; if the title requires two or more lines, single space it. Double space below the title, and then center and type the researcher's title and name. Then space twice and begin the double-spaced text.

   Use a one-and-one-half-inch left margin and a one-inch right margin for the body of the text. Center page numbers at the foot of each page, one inch from the bottom. Each page should have a one-inch margin at the top. The format should be that of a standard research paper: it should begin with a one-paragraph abstract (on its own page) summarizing your work and should be followed by an introduction, a discussion of the problem, a results section, and a conclusion. Since multiple copies of your report may be required, assure that all pages can be readily copied to a black-and-white 8 1/2" by 11" page. (No colors, such as blue or green, that don't photocopy well, and no foldouts, please.)

5. The report must be accompanied by a separate statement on whether or not any inventions or patents have resulted from this research. If yes, use a DD Form 882 (supplied by RDL on request) to indicate the patent filing date, serial number, title, and a copy of the patent application, and patent number and issue date for any subject invention in any country in which the subcontractor has applied for patents.

Attachment 2

Contract Clauses

This contract incorporates by reference the following clauses of the Federal Acquisition Regulations (FAR), with the same force and effect as if they were given in full text. Upon request, the Contracting Officer or RDL will make their full text available (FAR 52.252-2).

FAR CLAUSES	TITLE AND DATE
52.202-1	DEFINITIONS (APR 1984)
52.203-1	OFFICIALS NOT TO BENEFIT (APR 1984)
52.203-3	GRATUITIES (APR 1984)
52.203-5	COVENANT AGAINST CONTINGENT FEES (APR 1984)
52.304-6	RESTRICTIONS ON SUBCONTRACTOR SALES TO THE GOVERNMENT (JUL 1985)
52.203-7	ANTI-KICKBACK PROCEDURES (OCT 1988)
52.203-12	LIMITATION ON PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS (JAN 1990)
52.204-2	SECURITY REQUIREMENTS (APR 1984)
52.209-6	PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT (MAY 1989)
52.212-8	DEFENSE PRIORITY AND ALLOCATION REQUIREMENTS (MAY 1986)
52.215-1	EXAMINATION OF RECORDS BY COMPTROLLER GENERAL (APR 1984)
52.215-2	AUDIT - NEGOTIATION (DEC 1989)
52.222-26	EQUAL OPPORTUNITY (APR 1984)
52.222-28	EQUAL OPPORTUNITY PREAWARD CLEARANCE OF SUBCONTRACTS (APR 1984)
52.222-35	AFFIRMATIVE ACTION FOR SPECIAL DISABLED AND VIETNAM ERA VETERANS (APR 1984)
52.222-36	AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS (APR 1984)

52.222-37	EMPLOYMENT REPORTS ON SPECIAL DISABLED VETERANS AND VETERANS OF THE VIETNAM ERA (JAN 1988)
52.223-2	CLEAN AIR AND WATER (APR 1984)
52.232-6	DRUG-FREE WORKPLACE (MAR 1989)
52.224-1	PRIVACY ACT NOTIFICATION (APR 1984)
52.224-2	PRIVACY ACT (APR 1984)
52.225-13	RESTRICTIONS ON CONTRACTING WITH SANCTIONED PERSONS (MAY 1989)
52.227-1	AUTHORIZATION AND CONSENT (APR 1984)
52.227-2	NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (APR 1984)
52.227-10	FILING OF PATENT APPLICATIONS - CLASSIFIED SUBJECT MATTER (APR 1984)
52.227-11	PATENT RIGHTS - RETENTION BY THE CONTRACTOR (SHORT FORM) (JUN 1989)
52.228-6	INSURANCE - IMMUNITY FROM TORT LIABILITY (APR 1984)
52.228-7	INSURANCE - LIABILITY TO THIRD PERSONS (APR 1984)
52.230-5	DISCLOSURE AND CONSISTENCY OF COST ACCOUNTING PRACTICES (SEP 1987)
52.232-23	ASSIGNMENT OF CLAIMS (JAN 1986)
52.237-3	CONTINUITY OF SERVICES (APR 1984)
52.246-25	LIMITATION OF LIABILITY - SERVICES (APR 1984)
52.249-6	TERMINATION (COST-REIMBURSEMENT) (MAY 1986)
52.249-14	EXCUSABLE DELAYS (APR 1984)
52.251-1	GOVERNMENT SUPPLY SOURCES (APR 1984)

DoD FAR CLAUSES	TITLE AND DATE
252.203-7001	SPECIAL PROHIBITION ON EMPLOYMENT (MAR 1989)
252.203-7002	STATUTORY COMPENSATION PROHIBITIONS AND REPORTING REQUIREMENTS RELATING TO CERTAIN FORMER DEPARTMENT OF DEFENSE (DoD) EMPLOYEES (APR 1988)
252.223-7500	DRUG-FREE WORK FORCE (SEP 1988)
252.225-7001	BUY AMERICAN ACT AND BALANCE OF PAYMENTS PROGRAM (APR 1985)
252-225-7023	RESTRICTION ON ACQUISITION OF FOREIGN MACHINE TOOLS (JAN 1989)
252.227-7013	RIGHTS IN TECHNICAL DATA AND COMPUTER SOFTWARE (OCT 1988)
252.227-7018	RESTRICTIVE MARKINGS ON TECHNICAL DATA (OCT 1988)
252.227-7029	IDENTIFICATION OF TECHNICAL DATA (APR 1988)
252.227-7034	PATENTS - SUBCONTRACTS (APR 1984)
252.227-7037	VALIDATION OF RESTRICTIVE MARKINGS ON TECHNICAL DATA (APR 1988)
252.231-7000	SUPPLEMENTAL COST PRINCIPLES (APR 1984)
252.231-7001	PENALTIES FOR UNALLOWABLE COSTS (APR 1988)
252.231-7003	CERTIFICATION OF INDIRECT COSTS (APR 1986)
252.251-7000	ORDERING FROM GOVERNMENT SUPPLY SOURCES (APR 1984)
252.271-7001	RECOVERY OF NONRECURRING COSTS ON COMMERCIAL SALES OF DEFENSE PRODUCTS AND TECHNOLOGY AND OF ROYALTY FEES FOR USE OF DoD TECHNICAL DATA (FEB 1989)

7 November 1991

AFOSR/PKO
Bldg. 410, Room C-124
Bolling AFB, DC 20332-6448

Attn: Ms. Kathleen Wetherell

Dear Ms. Wetherell:

Enclosed for your approval is the model subcontract for the Research Initiation Program under the Summer Research Programs (Contract F9620-90-C-0076). The blanks will be filled by merging information from our dBase IV database.

Sincerely,

Abe S. Sopher
Contracts Manager

cc: AFOSR/NI (Lt. Col. Cavendar)

ATTACHMENT 2:

SAMPLE TECHNICAL EVALUATION FORM AND TECHNICAL EVALUATION SUMMARY

1992 RESEARCH INITIATION PROGRAM TECHNICAL EVALUATION

RIP NO: 92-2
RIP ASSOCIATE: Dr. Charles Kibert

Provided are several evaluation statements followed by ratings of (1) through (5). A rating of (1) is the lowest and (5) is the highest. Circle the rating level number you best feel rates the statement. Document additional comments on the back of this evaluation form.

Mail or fax the completed form to:

RDL
Attn: 1992 RIP TECH EVALS
5800 Uplander Way
Culver City, CA 90230-6608
(Fax: 310 216-5940)

1.	This RIP report has a high level of technical merit	1 2 3 4 5
2.	The RIP program is important to accomplishing the lab's mission	1 2 3 4 5
3.	This RIP report accomplished what the associate's proposal promised	1 2 3 4 5
4.	This RIP report addresses area(s) important to the USAF	1 2 3 4 5
5.	The USAF should continue to pursue the research in this RIP report	1 2 3 4 5
6.	The USAF should maintain research relationships with this RIP associate	1 2 3 4 5
7.	The money spent on this RIP effort was well worth it	1 2 3 4 5
8.	This RIP report is well organized and well written	1 2 3 4 5
9.	I'll be eager to be a focal point for summer and RIP associates in the future	1 2 3 4 5
10.	The one-year period for complete RIP research is about right	1 2 3 4 5

****USE THE BACK OF THIS FORM FOR ADDITIONAL COMMENTS****

LAB FOCAL POINT'S NAME (PRINT): ______________________________

OFFICE SYMBOL: __________ PHONE: ______________

TECHNICAL EVALUATION SUMMARY

Subcontract no.	Technical Evaluation Questionnaire Rating Factors 1	2	3	4	5	6	7	8	9	10	Average
135	5	4	5	4	4	4	4	4	5	5	4.4
50	4	4	5	4	4	4	4	3	5	5	4.2
3	4	3	3	3	3	3	3	3	3	4	3.2
71	4	4	4	4	3	5	5	4	5	5	4.3
152	3	4	3	4	4	3	4	3	4	5	3.7
147	5	5	5	5	5	5	5	5	5	4	4.9
011	4	4	5	4	5	5	5	4	5	4	4.5
106	5	5	4	5	5	5	5	5	5	5	4.9
83	5	4	5	5	5	5	5	5	5	4	4.8
26	5	4	4	5	5	5	5	5	4	4	4.6
8	5	3	4	4	5	5	5	3	5	5	4.4
120	1	5	2	4	5	3	2	1	4	4	3.1
133	3	2	4	5	5	4	3	4	3	5	3.8
108	5	4	4	5	5	5	5	5	5	5	4.8
76	5	5	5	5	5	5	5	5	5	3	4.8
122	5	5	5	5	5	4	5	5	5	5	4.9
92	4	5	5	5	5	5	5	5	5	5	4.9
47	5	5	5	5	5	4	4	5	5	5	4.8
57	4	4	4	5	5	4	4	4	4	2	4.0
17	5	5	5	5	5	5	5	5	5	5	5.0
5	5	3	4	4	4	5	5	5	4	3	4.2
62	5	4	5	4	4	5	5	5	5	5	4.7
74	4	3	4	4	4	4	5	4	4	5	4.1
53	4	3	4	4	3	4	3	5	3	4	3.7
84	5	4	4	5	5	5	5	5	5	4	4.7
145	4	4	5	4	5	5	5	5	5	4	4.6
35	5	5	5	5	5	5	5	5	5	5	5.0

Subcontract no.	Technical Evaluation Questionnaire Rating Factors 1	2	3	4	5	6	7	8	9	10	Average
59	5	4	5	5	5	5	5	5	5	5	4.9
115	5	5	5	5	5	5	5	5	5	5	5.0
118	4	5	5	5	5	5	5	4	5	4	4.7
104	5	3	4	3	5	4	5	5	4	5	4.3
6	3	5	5	5	3	5	5	4	5	3	4.3
28	5	4	5	5	5	4	5	4	4	4	4.5
51	5	5	4	5	5	5	5	5	5	4	4.8
16	5	5	5	5	5	4	5	5	5	5	4.9
54	5	4	5	4	5	4	5	5	5	5	4.7
56	3	3	5	4	5	3	4	5	5	5	4.2
69	4	5	4	5	5	4	5	5	5	5	4.7
72	5	5	5	5	5	5	5	5	5	5	5.0
129	5	5	5	5	5	5	5	5	5	5	5.0
58	3	4	5	4	3	4	5	4	4	4	4.0
144	5	5	5	5	5	5	5	5	5	5	5.0
80	5	5	5	5	5	5	5	5	4	4	4.8
136	5	4	5	5	5	5	5	5	5	4	4.8
55	5	5	5	5	5	5	5	5	5	4	4.9
77	5	4	3	4	3	4	4	4	5	4	4.0
15	5	4	5	5	5	5	5	4	5	5	4.8
70	5	4	4	5	5	5	5	5	5	4	4.7
140	5	5	5	5	5	5	5	5	5	5	5.0
79	4	3	5	4	5	4	5	5	4	5	4.4
63	5	5	5	5	5	5	5	5	5	5	5.0
97	5	4	4	5	5	5	5	5	5	5	4.8
11	5	4	4	4	4	5	4	4	5	3	4.2
44	5	5	5	5	5	5	5	5	5	5	5.0
141	5	4	5	4	4	5	5	5	5	4	4.6
98	5	5	5	5	5	5	5	5	5	5	5.0

Technical Evaluation Questionnaire Rating Factors

Subcontract no.	1	2	3	4	5	6	7	8	9	10	Average
81	4	4	3	4	4	4	4	5	5	4	4.1
105	5	5	5	5	5	5	5	5	5	5	5.0
25	4	4	4	5	5	5	4	5	4	2	4.2
18	5	3	5	5	5	3	5	5	5	4	4.5
138	5	4	5	5	5	5	5	3	5	3	4.5
111	5	5	5	5	5	5	5	5	5	5	5.0
Avg by factor:	4.5	4.2	4.5	4.6	4.7	4.6	4.7	4.6	4.7	4.4	4.6

A DESIGN ADVISOR FOR THE ACQUISITION MANAGEMENT OF HAZARDOUS MATERIALS

Ernest L. Hall
Professor and Director
Department of Mechanical, Industrial and Nuclear Engineering
Center for Robotics Research

University of Cincinnati
ML 72
Cincinnati, Ohio 45221

"Final Report For:
Research Initiation Program
AFHS/HSD/AL/HRD/LRA, WPAFB
Wright Patterson AFB, OH 45433

March 1993

A DESIGN ADVISOR FOR THE ACQUISITION MANAGEMENT OF HAZARDOUS MATERIALS

Ernest L. Hall
Professor and Director
Department of Mechanical, Industrial and Nuclear Engineering
Center for Robotics Research
University of Cincinnati

Abstract

Protecting the environment is not only a common sense social goal but also an important national defense role. The U.S. Air Force Acquisition Management of Hazardous Materials Task Force was initiated to consider opportunities for minimizing hazardous materials usage in the early stage of system design. A hazardous materials for computer aided design (HASCAD) conceptual/software tool is described which would aid designers by indicating how and where the several databases which are available relating to hazardous materials could be used to anticipate and hopefully avoid problems with hazardous materials on future systems. A review of the very complicated problem facing the designer of minimizing hazards for humans and the environment has been made which shows that different databases would be of interest at the various design stages. The design advisor would permit easy access of these different databases to provide information on hazardous materials identification and alternative evaluation. The software tool would use a relational database and a distributed database system to aid in the identification of hazardous materials. The significance of such a software tool would lie in the improved ability for the designer to obtain appropriate information at the earliest stage of design.

TABLE OF CONTENTS

A DESIGN ADVISOR FOR THE ACQUISITION MANAGEMENT OF HAZARDOUS MATERIALS

Ernest L. Hall

1. Introduction

Acquisition management of hazardous materials is an important area of broad national concern. The life cycle of a weapon system starts from a conceptual design requirement and ends with the disposition of the system. There are several key points in the life cycle at which acquisition logistics could provide directions which should prevent most if not all environmental concerns. At the design stage when a tentative list of components is determined and their materials specified, one could identify the materials for possible hazardous effects and evaluate alternatives. The identification should consider not only the component materials but also any other materials needed to support the system such as fuel, cleaning materials, etc. and any possible compounds that may be generated. This is, of course, a burdensome task at least without some design aids. Several computer databases exist which could be used for such a test; however, a clear procedure needs to be developed that will show which databases to use, as well as the expected outcomes the limitations of the procedures. If a hazardous material is called for because of mission requirements, a thorough search for alternative materials which will still satisfy the requirements should also be made. Again, with the many databases available, it is possible that a clear procedure could be developed to search for these alternatives. Of course, one must also specify how to choose between the alternatives and evaluate the best or at least an acceptable solution. Again, if the hazardous material is the best alternative, then an entry into a tracking database is needed so that future direction may be provided. At this stage, it is also desirable to plan for material management and to estimate costs of the use of the hazardous material. Again, a computer tool to assist with these tasks is very desirable. Finally, a life cycle plan can be developed that incorporates these considerations. If the plan is acceptable, one can proceed with the acquisition with the knowledge that all reasonable alternatives have been investigated. During the process of system development and use of the system, the databases of hazardous materials should be continuously updated. However, the material collection and disposition may still be a major concern. The method for disposition and location of sites for storage must still be addressed. Constant attention perhaps over decades is required to ensure safe usage to humans and the environment.

The objective of this research was to conduct a state of the art assessment of the possible uses of existing databases which could provide guidance for hazardous materials minimization in future systems. This effort was directed at determining which of these are relevant databases for design acquisition, understanding the access requirements, data formats and usage for identifying and evaluating material selection and alternatives.

The purpose of this report is to provide an information aid for designers by introducing the available databases for identifying hazardous materials and substances, the procedures available in the Logistic Support Analysis for identifying hazardous materials, and methods for tracking hazardous materials throughout the life cycle. The considerations for hazardous materials must start at the pre-concept stage of a system design. Identification not only of hazardous materials which may be used directly in the system but also of hazardous waste products that may be generated in the operation or maintenance of the system should be made. Through use of resources such as the published literature and on-line databases, the designer may become aware of potential future problems at a stage in which they may be avoided.

Several questions may occur to the designer that are difficult to answer in a definitive manner. For example, questions such as the following are very natural to ask but may be very difficult to answer. Is this material hazardous? Is this material toxic? Is this material regulated? Is there an alternative material or procedure? What procedures must be followed? These questions are addressed in the following sections.

An introduction to hazardous materials definitions will first be given in Section 2. In Section 3, a literature review is presented for some past hazardous materials studies that demonstrate some of the primary issues and concerns. In Section 4, a brief description of related research is given. A description of available hazardous materials on-line databases is given in Section 5. A design advisor is presented in Section 6. Conclusions and recommendations for further research are described in Section 7.

2. Why Should Designers be Concerned about Hazardous Materials?

It may be argued that designers should not be concerned with the use of hazardous materials or the generation of hazardous waste since they may not be qualified as environmental engineers, lawyers, or physicians. A little knowledge may be a dangerous thing. However, the other side of this double edged sword is that ignorance of the law is no excuse for wrongdoing. Failure to comply with federal, state or local laws or regulations is possible with such complex issues as hazardous materials. Also, loss or damage to property or persons caused by negligence or willful acts of omissions are easily possible. The Acquisition Management of Hazardous Materials (AMHM) Task Force approach is a team approach which provides the opportunity to anticipate and avoid future hazardous materials problems several years before the material is to be used. In this approach, proper consideration can be given to materials selection and alternatives during the early stage of a system life cycle. As originators of technical information, the designers have the initial opportunity to identify a possible hazardous material use and initiate a risk assessment.

Engineers have traditionally been concerned with safety and health issues in design and in the workplace (ReVelle[5]). The workplace environment can be kept safe through the use of protective equipment, engineering controls, and administrative controls, or a combination of these approaches. Protective clothing such as gloves, glasses, face masks, etc. should be tailored to the materials and task. Engineering controls must eliminate the hazard at the source without relying on the workers' effectiveness and often offer the best and most reliable means for safeguarding against accidents or eliminating hazards. Administrative controls such as safety procedures, safety awareness training, special markings, etc. can also contribute to maintaining a safe working environment especially when management provides high quality leadership. The Acquisition Management of Hazardous Materials Program may be considered as a form of administrative control at the early stage of a system design which is the ideal time to anticipate and avoid future problems.

2.1 Definitions of Hazardous and Toxic Materials

Although everyone has some concept of some materials that are hazardous, there are several common and specific definitions in use. The dictionary definitions of hazardous and toxic materials are a good place to start. The **Condensed Chemical Dictionary** [8,21] provides the following.

> A hazardous material is "any material or substance which, if improperly handled, can be damaging to the health and well-being of man. Such materials cover a broad range of types which may be classified as follows.
>
> (1) Poisons or toxic agents, including drugs, chemicals and natural or synthetic products that are in any way harmful, ranging from those that cause death to skin irritants and allergens.
>
> (2) Corrosive chemicals that burn or otherwise damage the skin and mucous membranes on external contact or inhalation.
>
> (3) Flammable materials including (a) organic solvents, (b) finely divided metals or powders, (c) some classes of fibers, textiles, or plastics, and (d) chemicals that either evolve or absorb oxygen during storage, thus constituting a fire risk when in contact with organic materials.
>
> (4) Explosives and strong oxidizing agents such as peroxides and nitrates.
>
> (5) Materials in which dangerous heat build-up occurs during storage, either by oxidation or micro-biological action.
>
> (6) Radioactive chemicals that emit ionizing radiation."

Toxicity is defined in the same dictionary as:

> "The ability of a substance to cause damage to living tissue, impairment of the central nervous system, severe illness, or, in extreme cases, death when ingested, inhaled, or absorbed by the skin. The amounts required to produce these results vary widely with the nature of the substance and the time of exposure to it. 'Acute' toxicity refers to exposure of short duration, i.e., a single brief exposure; 'chronic' toxicity refers to exposure of long duration, i.e., repeated or prolonged exposures.
>
> The toxic hazard of a material may depend on its physical state and on its solubility in water and acids. Some metals that are harmless in solid or bulk form are quite toxic as fumes, power, or dust. Many substances that are intensely poisonous are actually beneficial when administered in micro amounts, as in prescription drugs."

Also, harmless materials which react when combined must also be considered. "Reactive materials are those which can enter into a chemical reaction with other stable or unstable materials. Some materials are capable of rapid release of energy by themselves, as by self-reaction or polymerization, or can undergo violent eruptive or explosive reaction upon contact with water or other extinguishing agents or within certain other materials." (NFPA[7])

Several more specific definitions are used in the Federal, State and local regulation concerning hazardous materials. Some of these are shown in Table 1.

Another variation of the definitions is used by the Defense Reutilization and Marketing Service (Kim[8]). DRMS terminology refers to "hazardous materials" as those classified as hazardous by the Department of Transportation and "hazardous waste" as those classified as hazardous by the EPA.

In 1989, the Air Force created the Acquisition Management of Hazardous Materials (AMHM) Program to institutionalize consideration of hazardous materials issues in the weapon system acquisition process with the aim of minimizing hazardous materials use and hazardous waste generation throughout the weapon system life cycle. As part of their effort, the MITRE Corporation, as an unbiased third party, has developed a systematic process for the identification and evaluation of hazardous materials. To clarify the definitions as they pertain to the AMHM program and to Air Force concerns, they have developed two additional definitions (Roberts[9]). The first is an administrative definition which reflects the scope of the AMHM program:

"A hazardous material of concern under the Acquisition Management of Hazardous Materials Program is any material which is mission-critical to weapon systems acquired by the Air Force and because of the material's physical, chemical, or biological characteristics; quality; or concentration may

(a) Cause or contribute to adverse effects in organisms or offspring

(b) Pose a substantial present of future danger to the environment

(c) Result in damage to or loss of equipment or property during the system's life cycle (development, testing, manufacture, operation, maintenance, modification, and disposal)."

The mission-critical elements are considered essential to perform the mission of the weapon system. Non-mission-critical agents, nonmaterials such as noise, biological agents, and radioactive materials are currently excluded from consideration under AMHM.

Roberts[9] also presented a second working definition to aid in their identification and evaluation. The "working" definition is as follows:

"A mission-critical material is considered hazardous in the context of AMHM if available information;

(a) States or suggests that the material itself, or any of its ingredients, pose a significant potential hazard in any of the following seven categories:

Acute health
Chronic health(non-cancer)
Cancer

Contact
Flammability
Reactivity
Environmental

or is insufficient to determine that a significant potential hazard does not exist in any of these categories,

and;

(b) The material is used in sufficient quantity to allow that potential hazard to be realized."

A recent note indicated that "ignitability" was also added to the categories. These definitions aid in reducing the scope and permitting evaluation of selected hazardous materials for the AMHM Program.

2.2 Responsibility for Hazardous Materials

The System Program Office (SPO) prime contractor and associated subcontractors have primary responsibility for identifying hazardous materials proposed for use and for evaluating the health and safety aspects associated with their use. This may require special expertise in toxicology, environmental engineering, analytical chemistry, etc. The SPO System Safety Manager may not have a formal mechanism in place to provide such assistance in a timely manner. However, a Logistic Support Analysis (LSA) provides a structured procedure.

Determining a particular hazard may require special expertise in environmental engineering, safety engineering, analytical chemistry, medicine or law. This expertise is unlikely to be available in the SPO but can be obtained. An acquisitions management of hazardous materials study may be used to identify sources and make them available to the SPO in a timely manner (Roberts, pp xi[9]). A life cycle cost estimation tool is being developed by TASC (Hilton[10])

2.3 Strategy for Environmental Concerns

Hazardous materials questions are complex for several reasons. There are over five million known and patented substances which are identified with more than seven million names. The lists of a few thousand of these materials that have been designated as extremely hazardous may not be complete. Many thousands of other hazardous waste materials may be generated from the use of these hazardous substances. Many of the mixtures of hazardous materials have not been thoroughly studied. The generation of hazardous waste materials may occur in an innocent appearing process such as using a fire extinguisher, stripping paint or cleaning a surface. A lack of training of personnel should be expected, since the field is very broad and based on both social and physical sciences.

Effective hazardous materials management must be a functional and flexible approach which is able not only to address existing concerns but also to lead to new discoveries of potential hazards or improved procedures. This requires the collection of appropriate technical data on materials and processes, decision making, evaluation, and reporting. This procedure provides a basis for material selection, evaluation of alternatives, and good system design decisions throughout the acquisition process.

A brief introduction to a strategy for environmental concerns during the life cycle of a system is shown in Table 2. The acquisition stage is the time at which new concepts, feasibility studies, design alternatives, and experimental studies are of primary concern. It is also the time that changes are easiest to accomplish. Therefore, major effort should be devoted during this stage to reducing hazardous materials usage, seeking safe alternatives, and initiating any required database to record and track usage of hazardous materials throughout the life cycle.

During the operation of a system, constant attention is given to safety. However, emergencies, accidents, and disasters have happened in the past such as those at Three Mile Island, Bhopal, and Chernoble. Minimizing hazardous materials usage should reduce the risk of such occurrences.

For a retired system, the problem of hazardous waste management is substantial. However, with proper material identification and management, the hand off from hazardous material to hazardous waste can be done in an orderly and controlled manner. Hazardous waste testing for ignitable, corrosive, reactive or toxic characteristics is much easier if the material is identified and controlled. Similarly, recycling of waste is easier if the waste is known and controlled. Finally, appropriate disposition of hazardous waste is also easier if the original source and process is known.

The successful management of a system in terms of hazardous materials requires both information and materials management. The need for both information and material management varies throughout a system's life cycle. The need for information management starts at the pre-concept stage of a system and is continuous throughout the life cycle. The need for material management is significant during system operation and maintenance and perhaps greatest at system retirement and post-retirement. Only when information and materials flow are coordinated can efficient system operation and control be expected. Currently, it appears that such control is being lost at one or more points in the life cycle.

Determining whether a material hazardous is not easy, as illustrated in Figure 1. Since the number of materials is large and increasing with new materials and compounds discovered daily, it is possible that a new hazardous material or a new hazard from an existing material could be discovered at any time. Of those known materials, several knowledge bases are available such as the Chemical Abstract Library which publishes more than 60,000 basic patents per year. (Skolnik, pp. vii[11]) Skolnik describes the Chemical Abstracts Service (CAS) and its chemical registry system. In this system a number is assigned to each unique substance. The foundation of the system is an algorithm that generates a unique description of each molecular structure in terms of atoms, bonds, spatial arrangement, etc. Over 5 million unique structures have been assigned CAS numbers and new structures are reported at the rate of about 350,000 per year. Skolnik also reports that for the 5 million registered substances there are 7.7 million names. For example, polyethylene has 945 names. Even conducting a literature search is complicated by the variety of names and applications. One suggested list of key words to conduct a complete search for the health effects of a hazardous material is shown in Table 3.

The number of hazardous materials is also difficult to determine and may change since problems with new materials may be discovered which may prompt new laws. For example, one list from the Clean Water Act contains 366 hazardous substances[13]. Historically, when the EPA list of extremely hazardous substances went into law, 406 chemicals were listed. Forty of these were deleted by Feb. 1988. Another list which is related to the transportation of hazardous materials is contained in Title 49 of the Code of Federal Regulations and contains about 740 radionuclides and about 1500 other chemicals[14]. The CHEMTOX database contains over 6000 hazardous substances[15]. Since new substances are constantly being synthesized, the new additions to the list are published in the Code of Federal Regulations as described in 40 CFR 261.30[16]. Some of the sources of lists of hazardous materials are shown in Table 4.

Not all materials known to man are used in the U.S.; however, the U.S. "right to know" laws require those who manufacture or use hazardous materials in sufficient quantities must provide Material Safety Data Sheets (MSDS). The Material Safety Data Sheet (MSDS) contains information on: physical data; fire and explosion data; transportation data; toxicity; health effects and first aid; storage and disposal; conditions to avoid; spill and leak procedures; and protective equipment. The entire set of MSDS's from U.S. manufacturers and users may be thought of as a large and important database. Unfortunately, this data has not been collected into a single database. For materials purchased by the U.S. Government, MSDS are required to be submitted to DoD. These have been used to form a computerized database called the Hazardous Materials Information System (HMIS). The Hazardous Materials Information System (HMIS) data elements by major category include: hazardous item description; hazardous components; transportation data; health and physical properties data; safety storage handling and fire fighting procedures; spill and leak procedures; and disposal information. The Hazardous Materials Information System (HMIS) provides useful information on over 30,000 hazardous records on products supplied to the Department of Defense. However, if an item is not in HMIS, one cannot assume that the item is nonhazardous. Additional research is required.

An important step in any research undertaking is the searching of relevant indexes and databases to identify the existing literature on the topic of research. No one single database exists which lists all the literature and knowledge of hazardous materials effects; however, a number of databases are available which offer wide coverage of the field. The serious designer/researcher would want to take advantage of all the databases to which he or she has access or can obtain access with the resources available.

In addition to the existing databases, the Logistics System Analysis Report (LSAR), provides a procedure for producing a database for major systems as part of the Logistics Systems Analysis [17,18]. This may be used to provide a database of hazardous materials used or associated with the system throughout its life cycle.

3. Literature Review

3.1 Logistic Support Analysis and Logistic Support Analysis Record

The Logistic Support Analysis (LSA)[17] is an iterative and interactive analytical process within systems engineering. The design engineer is provides with two major tools for acquisition management of hazardous materials. First is an identification which is contained in the considerations for System Safety and Hazardous Materials (pp. 7-13, 7-14). Secondly is the provision for a database record which may be used for tracking and reporting the use of hazardous materials throughout the system life cycle (pp. 7-3).

The Logistics System Analysis is a procedure used to evaluate an emerging system design to determine if it is adequate to accommodate operating and maintenance tasks, quickly, easily, with minimal skill levels and minimal special tools. The LSA is the procedure for following the recommendations given in MIL-STD-1388-1A[19] including the generation of a Logistic System Analysis Record (LSAR) database. The LSAR is the primary source of logistics data for many elements such as maintenance planning, design, interfaces, reliability, maintainability, safety, survivability and hazardous materials.

MIL-STD-1388-1A describes the tasks required to develop a LSAR. MIL-STD-1388-2A defines the formats and requirements of the data processing system. MIL-STD-1388-2B is a proposed new standard with greater emphasis on hazardous materials management.

The System Safety program requires continual effort throughout the system life cycle to identify the hazards of the system. Design requirements may be developed to prevent mishaps by eliminating hazards. Also, management controls may be imposed to eliminate or reduce the risks to a level acceptable to the managing activity.

During the Task Analysis, Task 401 is used to identify the logistics resources required. A B Record, card B06, block 3, provides a checklist of queries as to whether safety has been considered in the design provisions:

B06 Card (MIL-STD-1388-2A, Appendix A, pp.45) d. Safety. Have adequate design provisions been made to ensure the conservation of human life and effectiveness, and the prevention of damage to items, consistent with mission requirements?

Cards B13, block 10 and B16, block 7, contain the Safety Hazard Severity Code (DED 396). The C Record, C06, contains the Hazardous Maintenance Procedure Code (HMPC-DED 155):

MIL-STD-1388-2A, Appendix F, 155 describes the hazardous maintenance procedure code (HMPC) as follows:

> A code which denotes whether the performance of the maintenance action identified by the Task Code will potentially expose assigned maintenance personnel to hazardous conditions.
>
> Code A. Potential loss of life consequences resulting from the incorrect or improper performance of maintenance.

Code B. Potential severe injury resulting from the incorrect or improper performance of maintenance.

Code C. Potential minor injury resulting from incorrect or improper performance of maintenance.

Code D. No potential danger to maintenance personnel conducting maintenance.

These codes can be used in the development of the C and D records and the respective Technical Orders.

Since hazardous materials usage and disposal of hazardous waste can substantially increase system life cycle operations and maintenance costs, hazardous items and potentially hazardous waste streams must be identified early in the system acquisition process to decrease quantities or eliminate them altogether. The LSA can identify hazardous material items, generation of hazardous waste and hazardous waste disposal procedures/requirements by the following procedure (LSA Guide, pp 7-14).

1. By tailoring the Statement of Work, the contractor can identify all provisional items that are regulated hazardous according to MIL-STD-2073[20] and document these items in the LSAR. If data element "hazard code" has been ordered on the data element selection sheet (1949-1, Part 2), the LSAR can identify all items that are hazardous and display these items by LCN, Item Name, Reference Number, and Quantities in the LSA 036 report (Provisioning Requirements).

2. MIL-STD-1388-1A Task 301.2.4.3 and 401.2.1 can be tailored to require a contractor to identify all hazardous waste disposal tasks and requirements for the system under analysis. The data generated by this task feeds into the LSAR database, and can be retrieved in the LSA 015 report (DI-ILSS-80115).

3. A Hazardous Maintenance Procedure Code (HMPC) is utilized. The Hazardous Code (HC-DED 154) will be paired with the specific item on the H record, H07. This information appears on the LSA 025, 026 and 036 output summary reports. MIL-STD-1388-2A, Appendix F, 154 defines the HAZARDOUS CODE (HC) as a code which indicates whether the item is regulated or non-regulated. For applicable codes, see MIL-STD-2073 Series.

3.2 Related Reports

A literature search of the DTIC Technical Report Database was conducted to determine related past work. Selected reports will now be briefly described.

3.2.1 An Analysis of Army Hazardous Waste Disposal Cost Analysis[8].

This recent study is reported as the Army's first effort to compile and analyze representative hazardous waste disposal cost data. Disposal quantities, unit costs, and total costs were calculated and analyzed from data provided by the Defense Reutilization and Marketing Service (DRMS) from installations within the continental United States (CONUS) for FY 88. The DRMS database contains Contractor Line Item Numbers (CLIN) which categorize waste on the basis of type, amount, container, and other factors. The major CLIN list categories are shown in Table 5. The Master CLIN list provides a further breakdown of each category.

An important concept mentioned in this report is that by studying disposal data, it may be possible to trace hazardous waste to its source of generation. This would undoubtedly reveal a number of potential opportunities for reduction of hazardous waste generation. This may also be observed by study of the top 20 most costly CLIN's shown in Table 6. These data are for non- Army Material Command locations. The Army Material Command locations are involved in munitions. The item with the highest total disposal cost was lithium - sulfur dioxide batteries (CLIN 0501). This was followed with contaminated containers, PCP wood or debris, spill residues with RCRA contaminants, oil sludge, containers, paint wastes, decontaminant agents, compressed gas cylinders, sludge, paint removers, toxins, solvents, asbestos, PCB's, and medical waste.

Note that in addition to lithium - sulfur dioxide, several other types of batteries are listed on the CLIN list including: magnesium, nickel cadmium, mercury, potassium hydroxide and zincate, alkaline, lead acid, silver - zinc, zinc - alkali, nickel - iron, and thormal.

Several important recommendations are also made in this report. One was that hazardous waste management data covering a longer period of time be analyzed to provide a more accurate picture of disposal costs and the opportunity to trace data back to its source. Several recommendations for improving the DRMS HW database such as linking CLIN to EPA hazardous waste codes and to National Stock Numbers to provide some link between hazardous waste data and material data. It was also recommended that the Army conduct research on how to reduce the quantities and disposal costs of each specific waste stream item of high disposal cost.

3.2.2 An Expert System for the Management of Hazardous Materials at a Naval Supply Center[21]

This thesis analyzes, designs and implements an expert system for the management of hazardous materials at a Navy Supply Center (NSC). This system is part of a series of expert systems built by the Naval Postgraduate School to assist the Naval Supply Systems Command in automating its inventory management system at NSCs. Selecting the proper storage conditions and locations for newly received hazardous materials requires the NSC's expert in such matters, the safety and health manager, to research the primary database, the Hazardous Materials Information System (HMIS), and any other relevant information sources, and extract the pertinent information. He determines the best storage conditions for the material and passes this information to the warehouse worker. The Hazardous Materials Expert System (HASMAT ES) will facilitate making the storage decision and will allow a warehouse worker to safely store hazardous materials without the assistance of the safety and health manager. In addition, it can provide information on an item's flash point, reactivity, and disposal requirements.

The HASMAT ES does not query the HMIS database but rather asks its user questions to determine whether the material belongs in one of eight categories: acids, flammables, toxins, explosives, combustibles, alkalines, oxidizers, and poisons. A storage category of either "ok" or "information needed" is also determined. Information regarding the material's flash point, disposal or reactivity may be requested. Once the material's hazard category and storage variables are set, the expert system then displays the proper storage condition for the material. A storeroom location recommendation is then determined. This work indicates the feasibility of making a storage decision using an expert system.

3.2.3 Computer Generation of Hazardous Analyses[22]

This report identifies an automated process to develop a preliminary hazard analysis (PHA) for a standing operating procedure (SOP). The automation is done by an integrated database management and interactive program. Engineering and clerical personnel can save much time automating the PHA generation. When automating a hazard analysis, it is important not to sacrifice the quality of the analysis for time and cost savings. The automation process presented requires input from a safety engineer following a review of the draft SOP.

3.2.4 Hazard Response Modeling Uncertainty[23]

There are currently available many microcomputer-based models for calculating concentrations of hazardous chemicals in the atmosphere. The uncertainties associated with these models are not well-known and they have not been adequately evaluated and compared using statistical procedures where confidence limits are determined. The U.S. Air Force has a need for an objective method for evaluating these models, and this project provides a framework for performing these analyses and estimating the model uncertainties. As part of this research, available models and data sets were collected, methods for estimating uncertainties due to data input errors and stochastic effects were developed, a framework for model evaluation was put together, and preliminary applications using test data sets took place.

3.2.5 The 'Hazard Expertise' (HAZE) Knowledge Based System[24]

The 'Hazard Expertise' (HASE) program is a knowledge based system for military installation personnel working with hazardous materials/waste management. HASE is an easy, informal way to share problems, ideas for solutions, and information on the latest technologies and environmental management strategies. The system allows self contained updating, systematic analysis of alternatives, and selection of optimal technologies. The system provides a list of courses, meeting announcements, a personnel directory, a listing of pertinent literature and other special services. Example sessions demonstrate use of the commands.

3.2.6 Technology Assessment of Hazardous Waste Minimization Process Changes[25]

The objective of this study was to technically evaluate selected industrial process changes for application to Air Logistic Centers for hazardous waste minimization. Those processes evaluated were as follows: (a) Ion vapor deposition of aluminum as a replacement for cadmium electroplating, (b) Non-cyanide strippers to replace cyanide strippers, (c) Plasma spray of chromium to replace chromium electroplating, and (d) Nickel boron as a replacement for chromium electroplating. The study resulted in the recommendation to develop databases, test plans, pilot studies, and demonstrations of the effectiveness of processes (a) and (b), above, in minimizing hazardous waste generation. Processes (c) and (d) showed minimal potential for hazardous waste minimization, and were not recommended for further study.

3.2.7 Geotox Multimedia Compartment Model User's Guide[26]

This report describes how to use the GEOTOX programs. GEOTOX is a set of programs designed to calculate time-varying chemical concentrations in multiple environmental media and to estimate potential human exposures. The report provides a description of the partitioned environment that is modeled by GEOTOX, discusses the theoretical basis for compartment models, and presents the design criteria against which the model is judged. This is followed by a description of what the user must do to run the GEOTOX on a particular system. A step-by-step tutorial for running GEOTOX programs is provided. A discussion of the functions of the GEOTOX models is given. Finally, a discussion of model inputs and outputs is provided.

3.2.8 Evaluation/Selection of Innovative Technologies for Testing with Basin F Materials[27]

A study was conducted to determine promising hazardous materials treatment technologies for the Rocky Mountain Arsenal. Three technologies were selected for laboratory/pilot scale tests. These were: glassification; fluidized/circulating bed combustion; and soil washing. In actuality, these three technologies offer one the opportunity to evaluate a spectrum of processes, each offering potentially distinct advantages. Glassification destroys organics and fixes metals under controlled conditions whereby further treatment of residuals may be eliminated; circulating bed combustion destroys organics and offers in-situ acid gas removal, thereby eliminating wet scrubbing; and soil washing offers the possibility of removing organics from soil without having to heat considerable quantities of soil to very high temperatures.

3.2.9 A Health and Environmental Effects Database Assessment of U.S. Army Waste Material[28]

Substances used by the U.S. Army on a regular basis in accomplishing their missions of training, defense, and weapons development have a wide range of uses, storage and disposal methods. Humans and the environment may be exposed to them in varying amounts. Proper research planning requires knowledge of gaps in health and environmental data on those compounds. CARLTECH was contracted to develop a database on health and environmental effects of commonly encountered materials. A comparison database of sixty hazardous materials is presented.

3.2.10 Extremely Hazardous Substances: Superfund Chemical Profiles[29]

The Extremely Hazardous Substances list[29] contains the data profiles on 366 hazardous substances as listed in Feb. 1988 as extremely hazardous. Profiles are presented alphabetically with Chemical Abstract Service (CAS) numbers and other information. The CAS number was used to search the Toxicology Database (TDB) and Hazardous Substance Database (HSDB) from the National Library of Medicine. Approximately 65 % of the 366 chemicals were found listed in the TDB/HMDB files. For the others, standard references were used to construct profiles. The profile contains the chemical identity, CAS number, synonyms, chemical formula and molecular weight, regulatory information, physical chemical characteristics, health hazard data, fire and explosion hazard data, reactivity data, use information, precautions for safe handling and use, protective equipment for emergency situations, emergency treatment information and comments.

3.2.11 J. K. Webster, Toxic and Hazardous Materials, Greenwood Press, Westport, CT 1987

The Toxic and Hazardous Materials book[30] is an excellent general guide to information sources on toxic and hazardous materials. The fields covered include monitoring, disposal, effects on humans, air, land and water and more specific areas such as oil spills, acid rain and radiation.

Books, monographs, periodicals, reports and documents, proceedings, reviews, indexes and abstracts, databases, audiovisual materials, dissertations, government organizations, research centers, and industrial laboratories, libraries, information centers, and associations and societies are listed.

3.2.12. The Installation Restoration Program (IRP) Toxicology Guide[31]

This excellent guide provides detailed health and environmental information for 70 potential contaminants of drinking water supplies associated with USAF installations. For each chemical in the IRP Toxicology Guide, the environmental fate, exposure pathways, toxicity, sampling and analyzed methods and state and federal regulatory status are outlined. The 70 chemicals listed in Table 7 are described in four volumes. An additional volume on metals is also available.

4. On-line Databases

4.1 Databases Easily Available to USAF

4.1.1 Lessons Learned Database

The Air Force Acquisition Logistics Division (ALD) was formed to bridge the gap between the acquisition and logistics communities to improve reliability and supportability of new weapons systems coming into the Air Force inventory while lowering the cost of ownership for those systems. One valuable method of meeting this goal is by recording and sharing past program management experiences in the form of lessons learned. The Deputy for Integrated Logistics, ALD/LS, has been assigned the responsibility of the Lessons Learned Program. The Directorate of Lessons Learned and Systems Support, ALD/LSL, has the task of gathering, validating, storing and disseminating lessons within the Air Force.

Basically, the database contains two types of lessons learned - management and technical. The management lessons address program decisions and actions in such areas as program control, budget/financial control, contracting techniques, support planning, configuration management, maintenance concepts and data management. The technical lessons relate to systems, equipment and components, including hardware, software, support equipment, or the design factors that influence the performance of the system or equipment.

The Air Force Lessons Learned Data Bank is open to all government agencies and contractors engaged in military business. Access services are provided free of charge and requests can be made either by computer connection, phone or mail. Individual lessons may be requested by lessons learned call number, as identified in the abstract, or through a keyword search of the database which identify system, topic, commodity or functional area and compile a package of lessons. These lessons can be obtained by contacting ALD/LSL, WPAFB, OH 45433 at 255-3161.

4.1.2 HMIS

The Hazardous Materials Information System (HMIS)[36] data elements by major category include: hazardous item description; hazardous components; transportation data; health and physical properties data; safety storage handling and fire fighting procedures; spill and leak procedures; and disposal information. The Hazardous Materials Information System (HMIS) provides useful information on over 30,000 hazardous records provided on products supplied to the Department of Defense.

4.2 Commercial Databases

A variety of commercial databases for various aspects of chemicals including hazardous chemical materials are available. A list of several of these are given in the Appendix. Some of these databases are directed toward legal and regulatory considerations, such as LEXIS and WESTLAW. Others such as the CAS contain knowledge on every known substance. Others such as OHS and CHEMTOX are directed toward hazardous materials identification and reporting.

Some of these databases are available for large computer systems, CD ROM, and hard disk PC-based formats.

4.3 Sample PC Database Material

4.3.1 Sample 1:

Chemtox System - Dr. Wood
Div. of Resource Consultants, Inc.
P.O. Box 1848
Brentwood, TN 37024
(615) 373-5040

The CHEMTOX Database of regulated and hazardous materials is an IBM-PC and compatible database system which contains information on: physical properties, reactivity data, personnel protection, toxicological data, symptoms of exposure, spill/disposal data, information related to transportation and emergency response, and regulatory summaries. It contains data on more than 6000 hazardous substances with more than 42,000 synonym names. Data sheets can be generated on each. The database is updated quarterly. It is also supported by a toll free hotline, electronic bulletin board, and a 24 hour telefax service. It has 90 built in help screens which provide explanations and examples.

4.3.2 Sample 2:

Occupational Health Services, Inc. - Richard Cohen
450 7th Ave., Suite 2407
New York, NY 10123
(212) 789-3535

Product information and data disks were requested and received. On-line VAX, PC and CD-ROM products are available. This is used by the Los Alamos Purchasing and Waste Stream. Reference is Barbara Hargres of Los Alamos. They can also add
new components.

The OHS MSDS ON DISK(TM) demonstration software was examined. This menu driven PC based system permits access to 4 databases, the OHS MSDS Database, the OHS MSDS Summary Sheets Database, the Fisher Scientific Database, and the OHS MSDS Master Index. The databases also come on a CD-ROM. They are updated quarterly. The program installed on a hard drive using about 1.5 Mbytes of storage. The main menu presents four options, select database, file, print data and exit. The select database permits one to choose between the OHS MSDS, the OHS Summary Sheets, the Fisher Scientific and the OHS Master Index. A brief description of each can be obtained using the file option. The F2 Key is used to pull down a menu containing the query options. When query is selected a search menu permits the search by chemical name, CAS number, OHS number, or any text. If an item is not found a screen displays a message. If an item is found, then either the MSDS or Summary Sheet is displayed depending on the database selected. A word index is available to help with the chemical name and synonym fields.

OHS MSDS ON DISK also permits the creation and maintenance of up to 10 user lists and the ability to add and delete substances. A general help screen also makes the system easy to use. The OSH FORMULATOR software for creating and printing MSDS and other reports was also tested and worked fine.

4.3.3 Sample 3:

Logical Technology Inc.
P.O. Box 3655
Peoria, IL 61612
(309) 689-2900

New product information was received on LogiTrac. This is a flexible material tracking system, an MSDS module, and a chemical compliance monitor. The information is presented in an easy to use, menu driven package for comprehensive environmental tracking. Other products include HASMIN and the MSDS Solution.

4.3.4 Sample 4:

Environmental Informatics
7900 Ariel Way
McLean, VA 22102
(703) 847-6625

Experienced scientist whose accomplishments include planning and conducting technical and policy studies in biology and biotechnology. Current interests include establishing a network and database that unites the various information resources within the federal government dealing with environmental and waste management. The network could provide users with information on research, development, demonstration, testing and evaluation.

5. Design Advisor

At least four options can be considered at the design stage for the control of pollutants: eliminate the source, eliminate the waste, treat the waste to reduce the deleterious load, or augment the environmental capacity to assimilate the waste. All of the above options may be required; however, at the acquisition design stages the first option is of primary concern. What tool could be developed to guide the designer through the appropriate knowledge bases at each stage of design? An overview of the design advisor strategy is shown in Figure 2 and in Table 10. At each stage of design, certain key decisions must be made. Several databases are available which can aid in this decision making process. Also, some output could be expected at each stage from querying the database. At the pre-concept stage, one may consider a mapping from concept to a previous system to problems encountered.

Concept -- Previous system -- Problems

For example, one may consider fighter aircraft, look up the F - 16, and find the hydrazine use for emergency power unit.

At the concept exploration stage, the important mapping from compounds to component chemicals may be most important.

Compounds -- Component chemicals

Chemicals -- MSDS

Chemical -- DOD Usage

Chemical -- Regulations

For example, one may consider a composite material, and need to determine the chemicals used in the bonding. Once the components are known, the MSDS information could be determined.

At the design exploration stage, the mapping from materials to hazards and from hazards to actions may be most important.

Material -- Hazards

Hazards -- Protective Clothing

Hazards -- Toxicity

Hazards -- Procedures

For example, if hydrazine is the material, the hazards and protective clothing required to handle this toxic substance could be determined.

Finally, at the concept stage, tracking the hazardous materials and wastes may be the prime concern.

Materials -- How much, where

Waste -- How much, where

For example, the amount and location of hazardous materials and the generation of hazardous waste would be of prime concern.

5.1 Pre-concept Stage - Lessons Learned and Legal Databases

The designer's options are greatest at the pre-concept and concept exploration stages of a project. At the pre-concept stage, a entire system such as a helicopter or fighter is being considered. This might be the easiest time for the designer to examine past lessons as well as explore legal problems on similar systems.

(a) The designer could examine the "Lessons Learned" database to determine if problems had arisen with similar concepts and designs in the past. A contact for this database is:

Mr. Kerr (513) 255-9689
ALD/LSE
WPAFB, OH 45433-5000

(b) Legal issues could be explored through examination of such databases as LAWS, LEXIS or WESTLAW or the legal office to determine if past legal issues had been raised over a related system. A sample WESTLAW record is shown in Figure 3.

5.2 Concept Stage - Identification and Selection Databases

At the concept exploration stage of design, the main sub-systems would be defined. For example, the power plant, engine and airframe components of a helicopter would be considered. At some point a tentative bill of materials would be defined. At this point the designer could request MSDS for the items on the list from the HMIS or other database. A sample MSDS is shown in Table 11. Note that a properly completed MSDS provides a wealth of information.

If any hazardous materials are identified, a list of alternatives could be established and the HMTF requested to assist with the evaluation of the alternatives.

With a material list available, the identification search could begin.

1. For each material selected, an identification search could be made to determine:
   (a) Is the material hazardous? (To what extent?)
   e.g. halon
   (b) Does the manufacturing process use hazardous materials or produce hazardouswastes?
   e.g. electroplating
   (c) Does the maintenance require hazardous materials?
   e.g. composite material repair, stripping
2. During design analysis:
   (a) What interactions in the design may produce hazardous materials?
   (b) Could new compounds or mixtures be formed?
   (c) What alternatives could be considered?

It appears that a hazardous materials software tool could be created for computer aided design

(CAD) using RAMCAD as the vehicle to develop and test the module. Questions of what the designer needs to know and when he need hazardous materials information could be answered by an expert system which could provide guidance to the designer. Information would be provided to the designer on the implications of the use of hazardous materials on a real time basis through the use of appropriate on-line databases and expert systems. It would also be possible to track a design effort to determine when, where, how, who, what and possibly why hazardous materials were/are considered for use and document the alternatives which were considered.

5.3 Software Tool

Since several different databases are of interest at the various design stages, a software tool that could access these databases would be useful for the designer. Such a tool could save designers time by permitting a directed search that could provide important information for identification and evaluation of hazardous materials at the earliest design stage.

The software tool could be in the form of a menu driven communications tool similar to GRATEFUL MED[37] which may be used to search the National Library of Medicine databases. It could contain the following features.

1. Input screens to prompt the user with key words for developing a search strategy before connecting to the on-line databases.
2. Access to on-line databases with automatic dialing.
3. Automatic login.
4. Ability to conduct the on-line search and automatically download the results of the search.
5. Search up to 100 different databases.
6. Have an expert search mode for frequent users.
7. Help capability to explain key words.
8. Have a computer based training capability.

To use such a tool, accounts and passwords for all the component databases would need to be established. Also, some amount of training may be required. Several on-line search applications are shown in Table 12.

A communications program such as PROCOM could be used to log in and download information from any of the individual databases; however, a specific tool for designers would have several advantages in terms of ease of use. The computer tool could also save computer charges by permitting the search strategy to be formulated before logging in and automatically downloading the search results. A menu of the various databases categorized into appropriate categories such as lessons learned, legal, identification and evaluation, and archival would also reduce the search time. Each of these categories could be further subdivide into logical categories then into specific database acronyms with a help feature which describes each database.

The rates for on-line service include a subscription fee which varies from $25 to $300 plus an hourly connection fee that varies from $17 to $90 per hour. The on-line service has the advantage of charging in proportion to usage.

A PC based system may cost as little as $245 for CAMEO; however, one must be certain of the specific database which would be used. Several CD ROM systems are also available at costs of about $1,500. Again, a relatively high usage would be needed to make this type system cost effective.

The significance of such a software tool would lie in the ability of the designer to obtain appropriate information in a timely manner. This should permit correct logical decisions about future uses of hazardous materials. By increasing the ease of obtaining information about hazardous materials, the designer would have a greater chance of obtaining the right information at the right time in order to satisfy mission requirements and minimize hazards for humans and the environment.

5.4 Research Results

The following is a brief description of the research that was conducted during this study to examine the difficulty of preparing a software tool and demonstrate its use of a list of important materials to the Air Force.

Task Description

1. Develop database A relational database that will assist designers in developing a search strategy will be prepared. The databases required for the design advisor are distributed, i. e. not collected in a single database. Also, it is difficult to describe the databases as complete. The ones that are available are helpful. Since several databases are available, the research proceeded using those that are most easily available through Compuserve such as IQuest and Dialog.

2. Establish network A communications network was established using a standard PC and modem. Several software packages including PROCOM, and CIM were tested.

3. Establish accounts Login capability and accounts were established with several database vendors to provide testing of the design advisor. Several accounts were considered, some of which require special access such as the HMIS. However, for this study the readily available Compuserve account was used.

4. Obtain test materials list Test materials were selected from the previous research studies and examined.

5. Test with Important AMHM Materials A test was conducted with the selected items. Previous research indicated that less than 100% identification should be expected. The percentage found was less than 100% and is a measure of the databases' completeness and skill required in searching.

As an example, the legal and medical aspects of using halon were considered. One reference to a legal consideration was found. Also, references to the toxicology of halon was also identified. An example is shown in Table 13.

6. Final Report A final report was prepared and demonstrations may now be given to determine if a multi-user version should be prepared.

6. Conclusions and Recommendations

6.1 Conclusions

The proposal has developed from a research initiation project to determine which hazardous materials databases would be useful to a designer and permit the minimization of the use of hazardous materials by identifying and evaluating alternatives in the early design stage. Previous studies concerning hazardous materials and related programs were examined to understand the current situation. A variety of on-line databases are available; however, these do not appear to be currently used by designers. One reason is the complexity of the hazardous materials field. Another may be the cost. However, at least two of the most important databases for the Air Force, the Lessons Learned and HMIS are free to use for Air Force purposes. Several high quality commercial databases are available in either on-line, PC or CD ROM formats. It appears that further training in the importance of environmental concerns and more tools for designers are needed.

The design advisor concept shows how and where the databases could be used to anticipate and hopefully avoid being surprised by hazardous materials issues on future systems, by addressing these issues at the pre-concept phase of a system design.

Other fundamental problems in the current system have been noted.

1. There is no single definition of hazardous materials. Several definitions are available for toxic substance, hazardous material, and hazardous waste. Also there is the definition by the eight lists of hazardous materials.
2. There is no complete list of hazardous materials. At least eight different lists are available that cover transportation, land, air and water lists. New hazardous materials are listed in the Federal Register.
3. There is no single database of hazardous materials. Over 100 on-line databases are available each with its own coverage and characteristics.
4. There has been no survey of USAF uses of hazardous materials or ways to minimize uses of hazardous materials. Paint stripping of aircraft is one minimization process that has been studied. Composite material repair for aircraft is another important area.
5. Federal Stock numbers do not correspond to CAS numbers. A many to one mapping of Federal Stock numbers to CAS registered substances could be done. Also no mapping from hazardous materials to hazardous waste is available at present.
6. No software tool for the design advisor is available. At the present time a designer cannot easily answer the simple question: is this material hazardous?
7. No training aid for designers is available. A specific software tool for designers is not available. Greater training is needed.

The proposed software tool will permit users from the scientific and engineering communities to address one important issue by increasing the designers knowledge about possible hazardous materials concerns during the early stages of system design. However, the problem scope is one of national importance and a national effort may be required to provide the coordination, definition and standards required to implement a solution.

6.2 Recommendations for Future Research

Since there seems to be a definite need for access to environmental and other hazardous materials databases and no integrated network or database system at the federal level, a major effort will be required to establish one. This could be accomplished with a phased approach. During Phase 1, a working group would be established to access the current status and needs for a national effort. During Phase 2, a review of existing and desired databases could be made. This group could provide the specifications for the desired database. During Phase 3, the network and database would be implemented. During Phase 4, the system would be introduced to the wide group of potential users.

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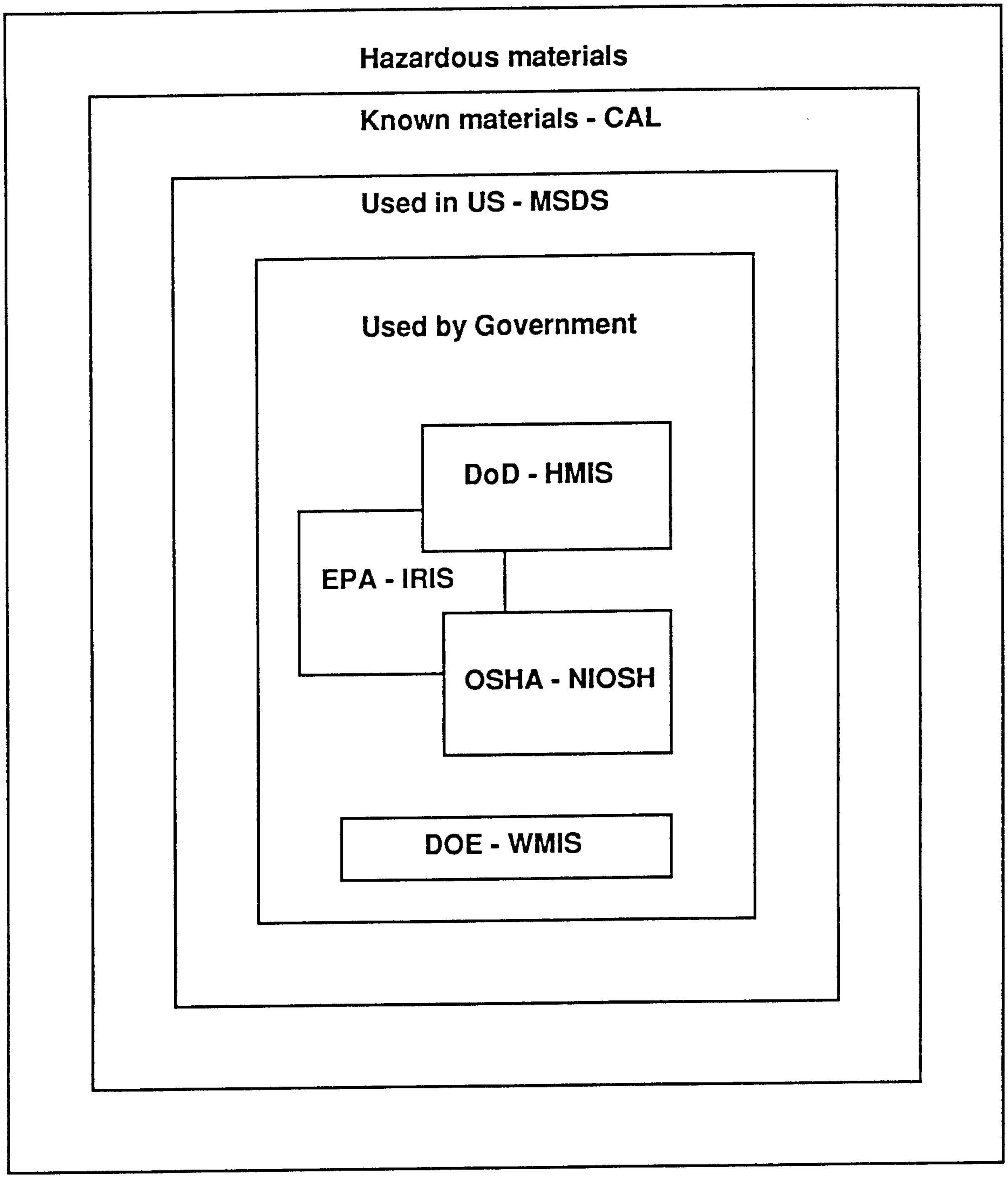

Figure 1. Hazardous materials database concept

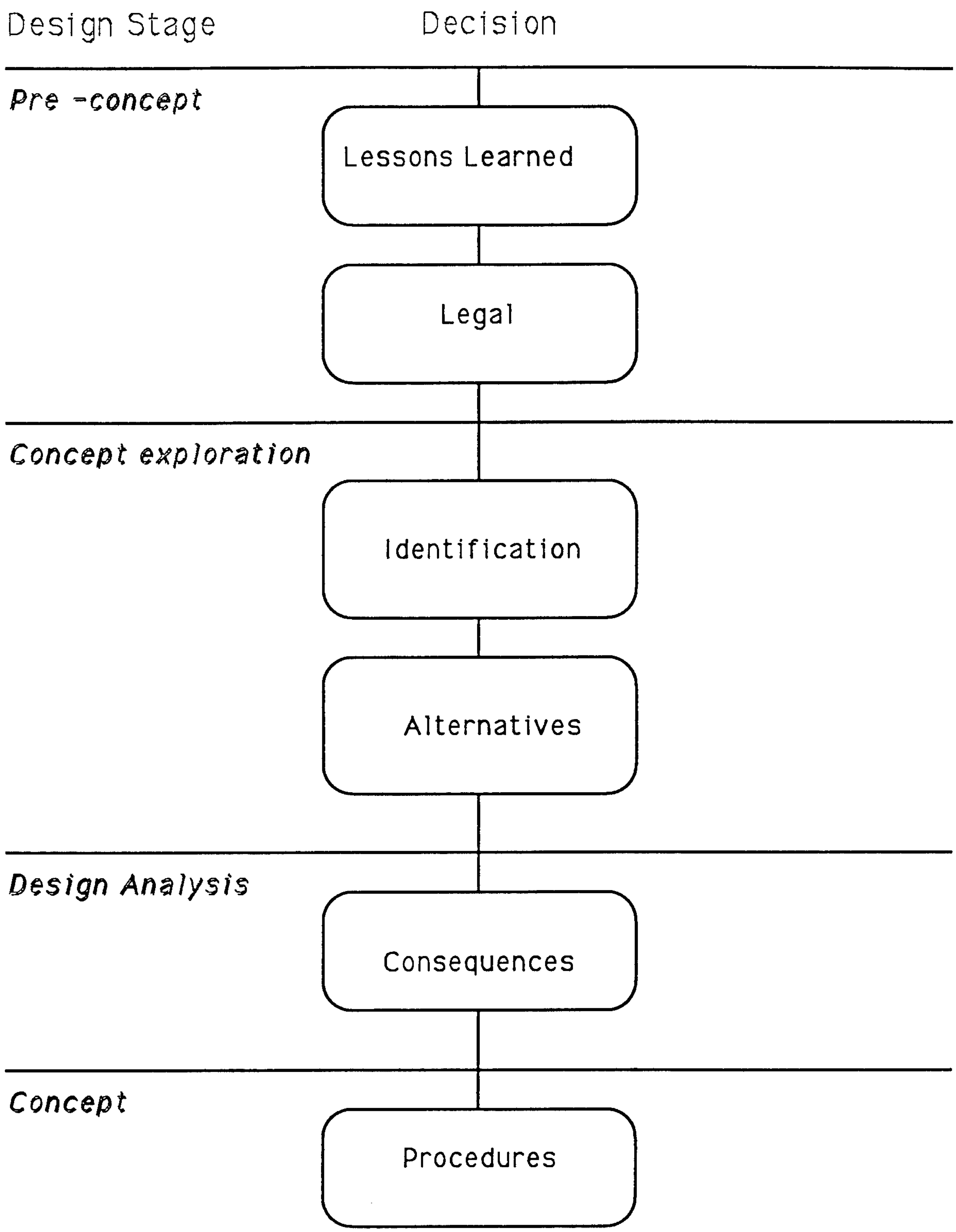

Figure 2. Design advisor strategy

6

The WESTLAW FEDERAL DATA BASE, available through West Publishing Company, contains full text of federal laws, regulations, executive documents, and court decisions.

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Citations                  Rank(R)        Page(P)       Database    Mode
107 S.Ct. 2971             R 1 OF 7       P 1 OF 110    ALLFEDS     T
 97 L.Ed.2d 427, 55 U.S.L.W. 5061, 3 U.S.P.Q.2d 1145

    SAN FRANCISCO ARTS & ATHLETICS, INC. and Thomas F. Waddell, Petitioners
                                   v.
     UNITED STATES OLYMPIC COMMITTEE and International Olympic Committee.

                              No. 86-270.
                         Argued March 24, 1987.
                         Decided June 25, 1987.

The United States Olympic Committee and the International Olympic Committee
brought suit under the Amateur Sports Act against a California corporation and
various individuals to restrain their use of the term "Olympics" to describe
athletic competition they sponsored.  The United States District Court for
the Northern District of California, John P. Vukasin, Jr., J., awarded summary
judgment and permanent injunction to the USOC and IOC.  Defendants appealed.
After consolidating appeals, the Court of Appeals, 781 F.2d 733, Alfred T.
Goodwin, Circuit Judge, affirmed the injunction, and vacated and remanded the
fee award.  On petition for rehearing and suggestion for rehearing en banc,
the panel voted to amend its opinion, denied petition for rehearing, and
rejected suggestion for rehearing en banc, at 789 F.2d 1319.  On certiorari,
the Supreme Court, Justice Powell, held that: (1) the statute granting the
United States Olympic Committee exclusive use of the word "Olympic" did not
require proof...
```

Figure 3. A sample WESTLAW record

Table 1. Hazardous Materials Definitions (Mavis [3])

Terminology	Regulation	Content
Hazardous Waste	RCRA 40 CFR 260.10	Wastes posing environmental or health hazards.
	40 CFR 261.20-261.24	Characteristics of ignitability, corrosivity, reactivity and EP toxicity.
	40 CFR 261.30-261.33	Listed wastes and discarded commercial products.
Hazardous Substances	CERCLA 40 CFR 302 Includes by reference:	List of hazardous substances and reportable quantities.
	Sections 102,307(a), 311(b)(2)(A) of the Federal Water Pollution Control Act	Toxic chemicals and carcinogens.
	Section 3008 of the Solid Waste Disposal Act	RCRA hazardous wastes.
	Section 112 of the Clean Air Act	Hazardous air pollutants.
	Section 7 of the Toxic Substances Control Act	Toxic substances
	DOT 49 CFR 172.101	Materials and mixtures transported in specific packaging and in quantities exceeding reportable limits.
Hazardous Chemicals	OSHA 29 CFR 1910.1200	Subpart Z list of toxic and hazardous substances; Appendix A definition of corrosive, toxic, highly toxic, irritant, sensitizer, carcinogens, and target organ effects of materials; and materials identified by manufacturers and importers.
Hazardous Material	DOT	Substances of material posing an unreasonable risk to health, safety, and property when transported in commerce.

Table 2. Strategy for Environmental Performance

Retired System	Operational System	New System
Stored but retired Bombs, ammunition	Emergency, accident, disaster Three Mile Island, Bhopal, Chernoble	Before year 2000 Recommendation to reduce hazardous material use, seek alternatives
Stored waste Single, mixed	Normal usage Monitored	After year 2000 Some chemicals forbidden by treaty
Dumped waste Single, mixed	Not measured Firefighting with Halon Paint stripping	

Table 3. Key words to conduct a complete literature search for health effects of hazardous materials (Webster [12]).

health hazards
occupational health
occupational hygiene
occupational exposure
carcinogens
mutagens
teratogens
toxicity
toxicology
reproductive hazards
industrial chemicals
chemical exposure
environmental health
specific causes of health hazards
    radiation, lead, uranium, asbestos, dust, dioxin, wood, etc.
specific diseases
    dermatitis, asthma, asbestosis, pneumoconiosis, etc.

Table 4. Lists of Hazardous and Toxic Materials (Mavis [3]).

Regulation	Description
1. 40 CFR 261.30-261.33	Listed hazardous wastes and discarded commercial products.
2. 40 CFR 302	CERCLA list of hazardous substances and reportable quantities.
3. Federal Water Pollution Control Act Sections 102,307(a),311(b)(2)(A)	Toxic chemicals and carcinogens
4. Solid Waste Disposal Act Section 3008	RCRA hazardous wastes
5. Clean Air Act Section 112	Hazardous air pollutants
6. Toxic Substances Control Act	Toxic substances
7. 49 CFR 172.101, DOT	Materials and mixtures transported in specified packaging and in quantities exceeding reportable limits.
8. 29 CFR 1910.1200, OSHA Section 7	Hazardous chemicals

Table 5. CLIN List Categories (Kim [8])

Category	CLIN	Note
Acute hazardous wastes	0001 - 0499	EPA P List
Batteries	0500 - 0599	
Compressed gas cylinders	0600 - 0799	
Container	1200 - 1299	
Corrosives - Acids	1300 - 1650	
Corrosives - Bases	1651 - 1999	
Extraction Procedure toxic	2000 - 2299	
Ignitable	2300 - 2700	
Medical items	2800 - 2899	
Metal plating	2900 - 3099	
Paints	3100 - 3399	
Pesticides	3400 - 3699	
Photographic wastes	3700 - 3899	
Petroleum oil and lubricant (POL)	3900 - 4199	
Reactives	4200 - 4499	
Solvents	4500 - 5499	
Spill residues	5500 - 5599	
Toxins	5600 - 5899	EPA U List
Chemical defense equipment	5900 - 5999	
Non-RCRA	6000 - 6500	Asbestos
PCBs	7000 - 7099	
Medical items (Non - RCRA)	8000 - 8099	

Table 6. Top 20 CLIN's in Total Disposal Costs.(Kim [8])

CLIN	Supplies/Services	Total Cost $
0501	Batteries, lithium-sulfur dioxide	588,614
1201	Containers, 1 gal or larger with more than 1 inch of the wastes described in CLIN 0500-0599	572,583
4720	Deleted - 4753	347,524
3921	Oil, contaminated	218,488
0031	Not listed on Master CLIN list	186,010
6033	Wood or debris with residual amounts of PCP, DDD, and/or DDE*	182,795
5500	Spill residues, RCRA contaminated	158,393
3911	Oil/oil sludge	148,169
6089	Containers, 1 gal or larger with less than 1 inch of wastes described in CLIN's 0500-0599	120,311
3300	Paint wastes	106,563
6049	Decon agent, STB, less than 39% chlorine	90,596
0600	Compressed gas cylinders, misc.	81,566
2133	Sludge, contaminated	78,000
4705	Paint removers	72,328
5604	Toxins, misc.	55,602
4704	Solvents and thinners	51,506
3905	POL, misc.	47,915
1309	Battery electrolyte (sulfuric acid)	45,851
3928	Petroleum fuels	43,616
7007	Transformers 500 ppm and over PCB	39,952

Table 7. 70 Potential Contaminants of Drinking Water (Fisher [31]).

1. Methylene Chloride
2. Dibromomethane
3. Dibromochloromethane
4. Chloroform
5. Trichlorofluoromethane
6. Carbon Tetrachloride
7. Chloroethane
8. 1,1-Dichloroethane
9. 1,2-Dichloroethane
10. 1,1,1-Trichloroethane
11. 1,1,2,2-Tetrachloroethane
12. 1,2-Dichloropropane
13. Vinyl Chloride
14. 1,1-Dichloroethylene
15. 1,2-Dichloroethylene
16. Trichloroethylene
17. Tetrachloroethylene
18. Benzene
19. Toluene
20. Ethyl Benzene
21. Xylene
22. 2,4-Dimethylphenol
23. 2,6-Dinitrotoluene
24. Chlorobenzene
25. 1,2-Dichlorobenzene
26. 1,3-Dichlorobenzene
27. 1,4-Dichlorobenzene
28. 1,2,4-Trichlorobenzene
29. Diethyl Phthalate
30. Di-n-Butl Phthalate
31. Di(2-ethylhexyl)phthalate
32. Naphthalene
33. Bis(2-chloroethyl)ether
34. N-Nitrosodimetylamine
35. N-Nitrosodiphenylamine
36. Phenol
37. O-Chlorophenol
38. 2,6-Dichlorophenol
39. Pentachlorophenol
40. Acetone
41. Methyl Ethyl Keytone
42. Methyl Cellosolve(R)
43. Ethylene Glycol
44. Bromochloromethane
45. Ethylene Dibromide
46. Butyl Benzyl Phthalate
47. Lindane
48. Chlordane
49. TOCP
50. Malathion
51. Diazinon(R)
52. Aroclor(R) 1016,1242,1254,1260
53. Sodium Chromate
54. Tetraethyl Lead
55. Hydrazine
56. Cyanide
57. DDT
58. DDD
59. DDE
60. 2,4-D
61. 2,4,5-T
62. 2,4,5-TP
63. 2,3,7,8-Tetrachlorodibenzo-p-dioxin
64. JP-4 (Jet Fuel-4)
65. Automotive Gasoline
66. Fuel Oils
67. Stoddard Solvent
68. Hydraulic Fluid
69. Mineral Base Crankcase Oil
70. Synthetic Crankcase Oil

Table 8. Polymers for Laminated Panels. Polymers used in composite panels and plates are shown. A composite material may be composed of faces, a core, and bonding. The behavior of a laminated panel depends on its constituents, its geometry, and the applied technology during manufacturing. (Hussein[33])

Faces	Core
Phenolic-Asbestos Laminates	Fibre Glass
Epoxy-Glass Cloth Laminates	Expanded Polystyrene
Polyester-Glass Fiber Laminates	Expanded Polyurethane
PVC	Expanded PVC
PMMA	Acrylonitrile styrene
Laminated wood-plastic	Cellulose Acetate
FRP	Epoxy
Polyamide (nylon)	Methylmethacrylate styrene
Plastic Clad Plywood	Phenolic
	Polyethylene
	Polystyrene
	Polyvinyl Chloride
	Silicone
	Urea Formaldehyde
	Urethane

Bonding	
Latex	Phenlicneoprene
Neoprene base contact cement	Phenolicvinyl
Alkyd	Polyacrylonitrile
Acrylate	Polamide
Caselin	Polyethylene
Cellulosenitrate	Polyimide
Cellulosevinyl	Polyvinylacetate
Epoxy	Polyvinylbutyral
Epoxy-novalac	Resorcinolphenol
Epoxy-phenolic	Formaldehyde
Epoxy-polyamide	Silicone
Epoxy-polysulfide	Vinyl buyralphenolic
Epoxy-silicone	Vinyl copolymers
Melamine-formaldehyde	Urea formaldehyde
Phenolic	Urethane
Phenolic-butadience acrylonitrile	

Table 9. Cost Drivers For Operation and Support Costs From Three Sites (Hilton [10])

Personnel Protection	32.9%
Legal/Environmental	22.8
Medical	12
Procurement	11.2
Monitoring	8.4
Disposal	3.9
Handling	3.6

Table 10. Design Advisor

Design Stage	Databases	Output
Pre-concept	Lessons Learned	Previous problems
	Legal LEXIS WESTLAW	
Concept exploration	Identification	
	CAS	Synonyms
	OHS	MSDS
	HMIS	DOD Usage
	REGMAT	Regulated
Design analysis	Consequences HMIS	Hazards Reactivity Protection Warnings Transportation
Concept	Procedures LSAR	Tracking of hazardous materials
	CLIN	Tracking of hazardous wastes

Table 11. Sample MSDS

MATERIAL SAFETY DATA SHEET

CUPATIONAL HEALTH SERVICES, INC.
WEST 42ND STREET, 12TH FLOOR
W YORK, NEW YORK 10036
800-445-MSDS (1-800-445-6737) OR
212-789-3535

FOR EMERGENCY SOURCE INFORMATION
CONTACT: 1-615-366-2000

SUBSTANCE IDENTIFICATION

CAS-NUMBER 1330-20-7

BSTANCE: XYLENE

ADE NAMES/SYNONYMS:
BENZENE, DIMETHYL-; DILAN; DIMETHYLBENZENE; XYLOL;
HUMISEAL THINNER NO.33 (HUMISEAL DIV.);
HUMISEAL THINNER NO.SP 420 (HUMISEAL DIV.);
SOLVESSO XYLENE (HUMBLE OIL AND REFINING COMPANY);
TT-X-9166 REDUCER (ADVANCED COATINGS AND CHEMICALS);
DYNACHEM (R) DEVELOPER DCR (THIOKOL/DYNACHEM CORPORATION);
THINNER 2000 (KOP-COAT); SOL 9050 XYLENE (CHEMTECH INDUSTRIES, INC.);
HUMISEAL THINNER NO. 521 (M.W. RIEDEL AND COMPANY);
NEGATIVE TYPE DEVELOPING SOLUTION (GC ELECTRONICS); RCRA U239; STCC 4904350;
UN 1307; C8H10; OHS25150

EMICAL FAMILY:
DROCARBON, AROMATIC

LECULAR FORMULA: C6-H4-(C-H3)2

LECULAR WEIGHT: 106.16

RCLA RATINGS (SCALE 0-3): HEALTH=2 FIRE=3 REACTIVITY=0 PERSISTENCE=1
PA RATINGS (SCALE 0-4): HEALTH=2 FIRE=3 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

MPONENT: XYLENE (O-, M-, P-ISOMERS) PERCENT: 100
CAS# 1330-20-7

HER CONTAMINANTS: NONE

POSURE LIMITS:
LENE:
100 PPM (435 MG/M3) OSHA TWA; 150 PPM (655 MG/M3) OSHA STEL
100 PPM (435 MG/M3) ACGIH TWA; 150 PPM (655 MG/M3) ACGIH STEL
100 PPM (435 MG/M3) NIOSH RECOMMENDED 10 HOUR TWA; 200 PPM (870 MG/M3)
NIOSH RECOMMENDED 10 MINUTE CEILING

1000 POUNDS CERCLA SECTION 103 REPORTABLE QUANTITY
SUBJECT TO SARA SECTION 313 ANNUAL TOXIC CHEMICAL RELEASE REPORTING

PHYSICAL DATA

SCRIPTION: LIGHT COLORED OR COLORLESS MOBILE LIQUID WITH AN AROMATIC

Welcome to IQuest

Table No. 12

(c) 1992 Telebase Systems, Inc.
U.S. Patent No. 4,774,655

Logon 0960007 25Mar93 9:34 EST

COMPUTE THIS: *FREE* "Computer" SmartSCANs in March!
From telecommuting to corporate network computing, IQuest Computer scans
help you zero in on the information you need. Details, see NEW! This Month

F1=Help F10=Menu bar F5=Logging [OFF] F6=Printer [OFF]

Þ Terminal Emulation CONNECTED 0:08:09
File Edit Services Terminal Special

* ENTER LEGAL TOPIC *

SEARCH TIPS: Omit all punctuation and small, common words (examples: the, as, in, on, for, an, of).

SEARCH EXAMPLES: Constitution/ AND press leak/
classified OR national security
(civil OR legal) AND rights

Type H for more help and examples.

ENTER A LEGAL TOPIC
-> halon AND hazardous

Is:
HALON AND HAZARDOUS
Correct ? (Yes/No) -> y
F1=Help F10=Menu bar F5=Logging [OFF] F6=Printer [OFF]

Þ Terminal Emulation CONNECTED 0:08:21
File Edit Services Terminal Special
amount paid by the customer to Telebase.

****

'he scan is now in progress. Your query is being submitted to a selected ;roup of databases.

'hen the scan is completed, a results menu will display. This special :enu will show you which of the databases contains information on your opic. To help you select the appropriate databases to search, the menu 'ill indicate the format of items in each database and the main source of nformation, such as journals, books, or newspapers. You'll also be able o see database descriptions by typing H. Further assistance will be vailable from the results menu by typing SOS to access our online 'eference support facility.

ote that database searches conducted from the scan results menu incur ormal search charges. The scan process may take a few minutes. The :essage "Scanning, please wait..." will repeat until the scan is completed.

F1=Help F10=Menu bar F5=Logging [OFF] F6=Printer [OFF]

Þ Terminal Emulation CONNECTED 0:09:34

File Edit Services Terminal Special

RESS	TO SEARCH	Results	Format	Source Type
	Books in Print	0	reference	books
1	BNA Daily News......................	6	full text	newsletters
	Child Abuse & Neglect	0	abstract	multiple sources
2	Congress Information Service........	2	abstract	gov't reports
	Congressional Record Abstracts	0	reference	gov't reports
3	Criminal Justice Periodical.........	3	reference	journals
4	Federal Register..................	32	full text	gov't reports
	Federal Register Abstracts	0	reference	gov't reports
	LaborLaw I	0	abstract	gov't reports
	LaborLaw II	0	abstract	gov't reports
5	*Legal Resource Index...............	1	reference	journals

* Good choice for professional literature.

A ADDITIONAL CHOICES
H Database descriptions
M Main Menu
OS Online assistance

otal charges thus far: $5.00

\>

F1=Help F10=Menu bar F5=Logging [OFF] F6=Printer [OFF]

Þ Terminal Emulation CONNECTED 0:10:50

File Edit Services Terminal Special

electing Database..........Completed.
ubmitting Search...........Completed.

here are 1 item(s) which
atisfy your search phrase.

ou may wish to PRINT or CAPTURE this data if possible.

eading # 1 Searched: 03-25-1993 09:38

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07107293   DIALOG File 150: LEGAL RESOURCE INDEX
TITLE: Administrative law - interpreting 30 U.S.C. 902(f)(2): what are the
    "criteria" of the Black Lung Amendment of 1977?
AUTHOR: Vassallo, Richard A.
JOURNAL NAME: Western New England Law Review  10 n2 359-392 Spr, 1988
SOURCE FILE: LRI File 150
CODEN: WNERDZ  ISSN: 0190-6593

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REGIONAL OXYGEN PROFILE OF THE RAT BRAIN DURING G-INDUCED LOSS OF CONSCIOUSNESS DUE TO HIGH G-EXPOSURE

Kirk L. Hamilton, Ph.D.
Assistant Professor
Department of Biology

Xavier University of Louisiana
7325 Palmetto St.
New Orleans, LA 70125

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Kirk L. Hamilton, Ph.D.
Assistant Professor
Department of Biology
Xavier University of Louisiana

Abstract

A preliminary study was conducted to examine the feasibility of using metal oxygen electrodes to record the regional oxygen profile of the rat brain. Construction and testing of electrodes has been accomplished. Electrode reliability has been satisfactory. However, longevity of electrodes have been short lived. Experimental results indicate that 61% of the electrodes constructed responded to changes in local concentrations (levels) of oxygen and nitrogen. Response time of electrodes to changes in oxygen and nitrogen levels have been rapid.

REGIONAL OXYGEN PROFILE OF THE RAT BRAIN DURING G-INDUCED LOSS OF CONSCIOUSNESS DUE TO HIGH G-EXPOSURE

Kirk L. Hamilton, Ph.D.

INTRODUCTION

During recent years, officials of the U.S. Air Force (USAF) have been concerned about the loss of life of pilots of high performance aircraft due to gravity-induced loss of consciousness (G-LOC) (Burton, 1988). Under rapid flying manuevers, G-LOC can occur which results in disorientation, confusion and the inability of a pilot to properly control an aircraft. In order to assure the safety of pilots, efforts have focused on increased physical conditioning of pilots, development of G-suits, G-valves and the training of pilots of anti-G straining manuevers (Burton and Whinnery, 1985; Burton 1991). Unfortunately, even with improvements in physical conditioning and gear, the USAF still reports loss of pilot life and aircraft due to G-LOC. At present, G-LOC has been described by Burton (1988) as "a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of cerebral blood circulation (cerebral ischemia) caused by increased G force".

In humans, cerebral ischemia results in loss of consciousness (LOC) within seconds (Rossen et al., 1943).

Present dogma suggests that LOC in humans is due to decreased cerebral blood flow resulting in decreased delivery of oxygen and glucose to the brain. Recently, biochemical analyses of high energy phosphates during LOC have shown a shift from aerobic to anaerobic metabolism after the initiation of LOC caused by cerebral ischemia (Hansen, 1985; Siesjo and Wieloch, 1985). Likewise, Werchan has begun to examine the chronology of physiological and biochemical changes in the brain of rats and mice exposed to high G levels resulting in G-LOC simulated with a small animal centrifuge (Werchan, 1991; Werchan and Shahed, in preparation). Such a shift of types of metabolism during LOC and G-LOC suggest decreased levels of tissue oxygen. However, at present, little information is known about the regional oxygen profile of the brain of rats subjected to high sustained G force (+Gz) which results in G-LOC.

DISCUSSION OF PROBLEM

The present study was initiated to determine the feasibility of constructing and using metal oxygen electrodes to study regional oxygen levels of rats exposed to high sustained +Gz. The original phase of this project was to construct and test polargraphic metal oxygen electrodes (at Xavier University) which would be used to monitor regional oxygen levels of the brains of rats exposed to G-LOC with a small animal centrifuge at Armstrong Laboratory (at a later date).

METHODOLOGY

The initial phase of this project was to construct and test polarographic metal oxygen electrodes which would be used to examine regional oxygen levels of the brains of rats.

Electrode Construction

Polargraphic metal oxygen electrodes were constructed using modified methods of Halsey and Clark (1970) and Raffin et al. (1991). Electrodes were fabricated from platinum-iridium wire (90%-10%, # 10IR5T, Medwire, Mount Vernon, NY). Prior to construction of electrodes, the platinum-iridium wire was pulled to a diameter of less than 100 um and cut into 50 mm lengths. Afterwhich, each electrode wire was coated near the tip with a thin layer of glass to insulate and reduce the exposed surface area of polarization. Electrodes were examined under a dissecting scope to examine the evenness of the glass coating. After glass coating, the tip of the electrode was lightly sanded (135 grit) as to expose the tip surface of the electrode. Once the electrode wire was prepared, the electrode was mounted and soldered into a contact pin (#M39029/58-360, Arrow Electronics, Ronkonkoma, NY), and then the electrode was soldered to an insulated wire. To prevent short circuiting during electrode calibration and testing, the insulated wire - contact pin connection was covered with heat shrink tubing. Figure 1 shows the design of a polarographic metal oxygen electrode.

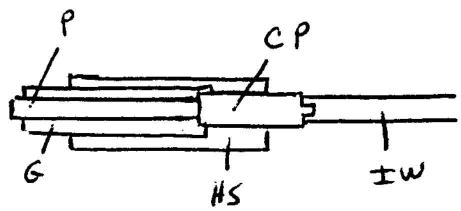

Figure 1. Diagram of a polarographic metal oxygen electrode. Symbols include: P - platinum-iridium wire, G - glass coating, CP = contact pin, IW - insulated wire, HS - heat shrink tubing.

Electrode Testing

Testing and calibration of electrodes were carried out with the use of an oxygen microsensor (Mo. 1201, Diamond General Corp., Ann Arbor, MI). Electrodes were immersed in a saline solution (160 mM NaCl) with a Ag-AgCl_2 reference electrode. The saline solution was bubbled with test gases of pure oxygen (100%), pure nitrogen (100%) or exposed to room air (21% oxygen). Electrodes were polarized with 0.75V and the output signal was noted. The output signal displays the partial pressure of oxygen (PO_2) in pressure units of millimeters of mercury (mmHg) or percentage of atmospheric pressure. A typical experiment was to first test an electrode with a saline solution exposed to room air, and then, bubble pure oxygen into the solution. Afterwhich, pure nitrogen was bubbled through the solution. Response time of the electrode was noted.

RESULTS

Electrode construction was very difficult at the initiation of this project. However, after a number of modifications, functional electrodes were constructed. Table 1 lists the number of electrodes constructed, electrodes tested and functional electrodes. An electrode was considered functional when response of the electrode to changing PO_2 was rapid (with bubbling of pure oxygen or pure nitrogen). Of the electrodes constructed, 93% of the electrodes were tested for performance. Of the electrodes tested, 61% of the electrodes were functional. Response time of electrodes ranged between 1-2 seconds. Response to changes in PO_2 ranged from 66-76%. PO_2 signals were not always stable, however, electrical coupling may have lead to the unstable signals.

Table 1. Results of electrode construction and testing.

# of electrodes constructed	# of electrodes tested	# of electrodes functional
58	54	33

Longevity and reliability of electrode performance has been examined. It appears that electrodes are less sensitive after two weeks of construction, however, experiments on rats will entail electrode implantation and use within a three day period. Therefore, longevity of electrode performance may not present a problem.

CONCLUSIONS

Results from experiments conducted to date suggest that the use of polarographic metal oxygen electrodes to measure partial pressure of oxygen is feasible. Implantation of electrodes into the brain of rats is the next logical step of this project. The potential results gained from this next series of experiments will give scientists additional data which will allow implementation of polarographic metal oxygen electrodes with animals which will be exposed to G-LOC on the small animal centrifuge.

RECOMMENDATIONS

Preliminary results suggest that electrode construction and reliability are satisfactory for implantation to the rat brain. Student participation from the MARC program will continue until May, 1993. The research student will continue with experiments which test implantation of electrodes in the brains of rats. Also, initiation of LOC with an aortic transection will be implemented to induce cerebral ischemia of the reat brain.

It is recommended that the current AFOSR project be continued without any additional funded from AFOSR.

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VALIDITY OF ESTIMATION OF AEROBIC FITNESS (MAXIMAL OXYGEN UPTAKE) IN WOMEN USING SUBMAXIMAL CYCLE ERGOMETRY

G. Harley Hartung
Professor
Department of Physiology
John A. Burns School of Medicine

University of Hawaii at Manoa
1960 East West Road
Honolulu, HI 96822

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G. Harley Hartung, Ph.D.
Professor
Department of Physiology
John A. Burns School of Medicine
University of Hawaii at Manoa

Abstract

Simple, valid and reliable methods of estimating maximal oxygen uptake(VO_{2max}) are needed to epidemiologic studies of physical activity and to assist in prescription of exercise. Such estimations in women have not received due research attention. Heart rate(HR) responses to submaximal cycle ergometry and VO_{2max} during treadmill testing were measured in 37 healthy women aged 19-47 yr(x=31.7± 7.9). The submaximal test was very reliable on retest(r=.92), overestimated measured VO_{2max}(x=2.42 vs 2.23 $L \cdot min^{-1}$; r=.76, SEE=.229). Stepwise multiple regression yielded an equation which included submaximal estimate of VO_{2max} and body weight. The R^2 was .74 and SEE .237. For VO_{2max} normalized for body weight, the equation included estimated VO_{2max}, rating of perceived exertion, a self rating of physical activity, and the total of 4 skinfolds, yielding an R^2 of .73 and SEE of 3.4 $ml \cdot kg^{-1} \cdot min^{-1}$. A simple submaximal exercise test is highly reliable as an estimate of VO_{2max} when used for women. It also provides a reasonably good estimate of measured VO_{2max}, especially if other easily measured variables are included in a prediction equation.

VALIDITY OF ESTIMATION OF AEROBIC FITNESS (MAXIMAL OXYGEN UPTAKE) IN WOMEN USING SUBMAXIMAL CYCLE ERGOMETRY

G. Harley Hartung

INTRODUCTION

Aerobic capacity (maximal oxygen uptake), the body's ability to do sustained heavy work is the most important indicator of physiological fitness and is positively correlated with cardiovascular health(1,2). Aerobic capacity is measured by determining the body's maximal rate of oxygen consumption (VO_{2max}), which is dependent on the cardiovascular system's ability to deliver blood to working muscles and the cellular ability to take up and utilize this oxygen in energy production.

Measurement of VO_{2max} is a laboratory procedure involving maximal treadmill or cycle ergometer exercise with analysis of expired air and requires a considerable amount of time and expensive equipment. Methods of easily and accurately estimating this important parameter would be valuable adjuncts to health and fitness evaluations(2,3). There are a number of methods of estimating VO_{2max} in common usage; heart rate response to a standard submaximal exercise on a cycle ergometer, treadmill, or stepping bench or box is perhaps the most widely used method(3). This prediction method is based on the assumption that there is essentially a linear relationship between heart rate(HR) and VO_2 or workload.

Distance run in a specified time(4), or conversely time required to run a set distance(5) is another commonly used method of predicting VO_{2max} from submaximal physical performance. This method is based on the known oxygen requirement for running at a given speed, ignoring the HR response. This test may involve as much risk as a maximal treadmill test, and the run results are also confounded by such factors as climate, running efficiency, motivation, and pacing skill.

A nomogram for predicting aerobic capacity from submaximal heart rate response to cycle or step test exercise was developed by Astrand and Ryhming(6). Using data from 58 young, well-trained male and female subjects the prediction had a standard error of estimate (SEE) of ~.28 l·min. The nomogram was revised in 1960 to account for differences in mechanical efficiency at lower workloads and in VO_2 at a given workload between men and women(7).

Little is known about the validity of submaximal cycle ergometry in the prediction of aerobic capacity in women and thus there is a need for additional studies. The only studies which have attempted to validate a submaximal cycle ergometer test in women have been conducted by I. Astrand(7) and Siconolfi, et al(8,9). Astrand (nee Ryhming) tested 44 women between the ages of 20 and 65 years in addition to the original 32 young females used to develop the nomogram(7). This sample was used to develop a correction factor for age and to make adjustments to the original nomogram. Siconolfi and others in two studies(8,9) found that the A-R method overpredicted VO_{2max} in subjects including women ranging from 19 to 70 years of age. In one study the difference was 5.5% and an r=0.86 and SEE of .25 $L \cdot min^{-1}$(8); in the other investigation, the difference was 3% with an r=0.92 and SEE of .29 $L \cdot min^{-1}$(9).

Getchell et al.(10) found a similar correlation (0.91) between the time to run 1.5 miles and measured treadmill VO_{2max} expressed as $ml \cdot kg^{-1} \cdot min^{-1}$ in 21 trained young women. The correlation, however, was only 0.46 when the VO_2 was expressed as $L \cdot min^{-1}$ indicating that weight was an important factor in this relationship in women.

The aerobic fitness level of personnel entering the military services is considered to be low initially and the sedentary nature of many jobs after the completion of basic training is not conducive to the attainment or maintenance of satisfactory levels of VO_{2max}. A reliable and practical method is needed to easily and accurately assess the aerobic fitness of Air Force personnel on a periodic basis without imposing a health risk on the individuals tested. The present 1.5 mi run test performed annually(5) requires a near maximal effort by young low-fit individuals, and may pose a danger to middle-aged and older personnel who are not accustomed to such exertion.

The level of aerobic fitness is an important factor in the ability of military personnel to carry out duties required of them both in peacetime and during times of emergency or actual combat conditions. Many Air Force personnel fill sedentary "desk jobs" during normal peacetime operations, but during war, many of them will be called on to perform tasks which require much higher levels of energy expenditure than they are able to perform except for short periods of time(11,12). Other personnel, such as firefighters and crash crews, have jobs which are mostly sedentary, but which may periodically require extremely heavy workloads under unfavorable environmental conditions(13).

The military duties of women are in a state of transition, with females increasingly serving in roles formerly reserved for men. The use of female pilots in combat roles is currently being considered by the military services.

The energy requirement for accomplishing a given submaximal work task is the same regardless of sex, body size, and fitness level. To do a given task, women, with generally lower maximal aerobic capacities, would have to work at a greater percentage of their capacity than men who have a higher VO_{2max}. With the advent of increasing roles for women in the military, it is imperative that more work tolerance data be collected which will assist in the assessment of safe guidelines for their transition into career categories formerly reserved for men.

The interaction between aerobic capacity and acceleration tolerance is of great interest to organizations and individuals responsible for safety in high performance combat and training aircraft. There is widespread belief within the aviation medicine hierarchy that there is an inverse relationship between aerobic capacity and positive G-tolerance (+Gz). Despite considerable interest in this issue, there is only limited and somewhat controversial research evidence with which to evaluate this hypothesis.

There also exists concern that enhanced aerobic capacity may increase a pilot's susceptibility to an inappropriate chronotropic and/or dysrhythmic response to +Gz stress. These concerns certainly point to the need for an accurate, easily conducted test to predict the aerobic capacity or VO_{2max} in the Air Force pilot population.

The purpose of this project was: 1) to assess the validity of a submaximal heart-rate dependent cycle ergometer exercise test as a predictor of maximal oxygen uptake in women, 2) to compare the cycle ergometry prediction in women with measured maximal oxygen uptake on both the treadmill and cycle ergometer,

3) to develop a mathematical prediction model to reduce the error of prediction using additional physiological and anthropometric variables.

METHODOLOGY

Thirty-eight healthy female subjects between the ages of 19 and 47 years were recruited from among the student body, faculty and staff of the University of Hawaii at Manoa and from the Honolulu community. A wide range of aerobic fitness levels were included in the study in order to approximate the range of fitness found in the USAF female population. All subjects met the weight for height requirements which the Air Force allows for women according to AFR 35-11.

Complete data (both submaximal CE tests and the maximal treadmill test) were obtained on 35 of the subjects, incomplete data were obtained on 2 subjects and unusable data were obtained on 1 subject. One elected not to continue due to scheduling problems, one left town unexpectedly for an extended business trip, and another did not complete the maximal treadmill test due to medical complications. Sixteen of the subjects were in the 19-29 year age range, 13 were 30-39 years, and 9 were 40-49.

The study was approved by the University's Institutional Review Board for Human Subjects and appropriate written informed consent was obtained from all study subjects prior to testing. An oral and written briefing was provided and each subject had an opportunity to ask questions pertaining to the study protocol and to her participation.

Aerobic fitness level was predicted using the submaximal cycle ergometer, heart rate method of Astrand and Ryhming (6,7) as modified for USAF use by Myhre (14,15). Maximal oxygen uptake was measured during both maximal treadmill and maximal cycle ergometer exercise in each subject according to a modification of the protocol of Saltin and Astrand (16).

Subjects reported to the laboratory 4 times, approximately one week apart, with the first day consisting of medical screening and administration of the first submaximal cycle ergometer test. The test was conducted on a friction braked ergometer (Monarck). Other measurements which were made at the first visit include: weight, height, leg length, triceps, suprailiac, subscapular and thigh skinfolds, hip, waist, thigh and calf circumferences, self-reported exercise habits, and resting heart rate.

A second submaximal cycle ergometer test was conducted within approximately one week of the first test. During this visit, the subjects were also acquainted with the methods of conducting the maximal tests, including walking and/or running on the treadmill, breathing through the expired air collection apparatus with a nose clip in place, and other instructions and expectations. The maximal treadmill and cycle tests were administered in counterbalanced order on the final 2 visits.

Maximal oxygen uptake on the treadmill was measured by indirect calorimetry during a continuous progressive walking or running protocol. The initial level speed was set to require approximately 75% of VO_{2max} as estimated from the cycle ergometer prediction. Each stage was 2 min in duration with the grade increased 2.5% for each subsequent stage. The maximal cycle ergometer test was conducted on an electronically braked instrument using a similar protocol with 2 minute stages. The beginning workload was calculated to require 75% of VO_{2max}, with increases in workload of 100 kilopond-meters each stage. These protocols are designed to elicit VO_{2max} in 8-12 min (16).

During both protocols, expired air was collected in 200 l Douglas bags and the volume was determined by drawing the air through a calibrated gas meter. A 100 ml sample was withdrawn from each bag and measures of O_2 and CO_2 concentration were made using calibrated paramagnetic oxygen and infra-red carbon dioxide analyzers.

For both submaximal cycle ergometer tests the subjects reported to the laboratory at least 3 hr following the last meal with no caffeine, tobacco or alcohol consumption in the same period. The subjects were also told not to exercise within 10 hours of the tests and it was determined that they were not taking medications which might influence the heart rate.

Analysis of variance was used to determine if there was a significant difference among the 3 methods (VO_{2max} predicted from cycle ergometry, maximal measured cycle, maximal measured treadmill). Where a significant main effect was found, the Tukey HSD post hoc test was used to determine where differences among means for the 3 methods existed. The p=0.05 level was used to evaluate the significance of the computed F ratios. Linear regression was used to determine the relationships among the 3 test methods. Regression coefficients for predicted and each measured VO_{2max} value were calculated along with standard errors of estimate (SEE). Stepwise multiple regression was employed to develop a mathematical model using additional variables which might significantly add to the ability to improve the precision of the predictive estimate for aerobic capacity.

RESULTS

Characteristics of the subjects are shown in Table 1. Results of the submaximal CE tests are presented in Table 2 and show that similar predictions of VO2max were obtained on retesting with a correlation of 0.92 between tests. There was not a significant difference ($p>.05$) between either of the predicted VO2max values on the two test administrations or the average heart rates used to calculate them.

The submaximal CE tests significantly ($p<.05$) overestimated VO_{2max} compared with that measured on both the treadmill and the the cycle ergometer. Figure 1 shows comparisons among the mean estimated VO_{2max} values obtained by submaximal CE and measured values obtained during maximal TM and cycle exercise.

Figures 2 and 3 show individual predicted values for CE (test 1) plotted against absolute and relative treadmill VO_{2max}. The correlation between the two was 0.76 and R^2=.58 with a SEE of .299 (SEE=4.07 for relative VO_{2max}). Multiple regression analysis showed that the addition of weight resulted in a multiple r of 0.86, R^2 of .74 and an SEE of .237 $L \cdot min^{-1}$. For prediction of VO_{2max} relative to body weight, regression analysis found that the CE prediction, rating of perceived exertion, current physical activity, and sum of 4 skinfolds resulted in a multiple r of 0.85, R^2 of .73 and an SEE of 3.42 $ml \cdot kg^{-1} \cdot min^{-1}$. The prediction equations for both follow:

VO_{2max} ($L \cdot min^{-1}$)= .4469*$CEVO_2$+.02365*Body wt(kg)-.27159

VO_{2max} ($ml \cdot kg \cdot min^{-1}$)= 29.525+.20908*$CEVO_2KG$+3.4696*PANOW-.9587RPE-.0697TOTSF

Where:

$CEVO_2$ is predicted VO_{2max}($L \cdot min^{-1}$) from the cycle ergometer test

$CEVO_2KG$ is predicted VO_{2max}($ml \cdot kg^{-1} \cdot min^{-1}$) from the cycle ergometer test

PANOW is a 1-4 scale rating of present physical activity level with 1=sedentary, 2=moderately active, 3=very active, 4=competitive athlete

RPE is rating of perceived exertion on the Borg 1-10 scale

TOTSF is sum of skinfold thickness at 4 sites, triceps, thigh, subscapular and suprailiac

DISCUSSION AND CONCLUSION

The cycle ergometry submaximal heart rate method of aerobic capacity estimation based on the A-R nomogram appears to be a valid predictor, with reservations. The method under-predicts treadmill measured VO_{2max} by about 20% in men but over-predicts by 8% in women in the present study. Important, however is its consistency; highly fit subjects by the predicted method have high measured values and less active persons tend to have lower measured values as is shown in Fig 2 and 3.

The simple correlation of 0.76 between the predicted and measured values is lower than that found by other investigators (17-19). The SEE (4.07 $ml \cdot kg \cdot min^{-1}$; .295 $L \cdot min^{-1}$), however, is similar to that found by several other investigators(8,9,20). There does not appear to be an effect of resting or maximal attainable HR on the predictive ability of the cycle ergometer test, which has been suggested previously.

Using a regression method to include the influence of other variables in a prediction model significantly improves the accuracy of the submaximal test. The addition of only one variable (weight) improved the multiple r to 0.86 for absolute VO_2 and accounts for 74% of the variance. The addition of 3 variables (physical activity rating and RPE, and sum of skinfolds) improves the r to 0.85 for relative VO_2 and accounts for 73% of the variance. The SEE using these equations has also been reduced to .237 $L \cdot min^{-1}$ and 3.42 $ml \cdot kg^{-1} \cdot min^{-1}$ which is lower than that found in some previous studies.

The Astrand-Ryhming test is not without drawbacks and sources of error, but it may have been criticized for deficiencies which it was not originally intended to accommodate(21,22). These include: 1) lack of an age correction extending its use beyond the original validation group consisting of young, fairly well-trained subjects; 2) lack of valid prediction at the upper range of VO_2 where the relation with heart rate may become nonlinear; 3) lack of a mechanism which would allow for adjustment of the exercising HR during the test if it did not reach acceptable levels; and 4) variability of submaximal HR due to such factors as temperature, meal ingestion, emotions, illness, dehydration, and fatigue. Most of the latter mentioned factors can be easily controlled, and an age correction factor has been developed(7). Lack of linearity of the HR-VO_2 relationship remains a source of error when a single or even dual HR determination is used as the basis for the prediction(21).

Although individual values may be subject to considerable error for what ever reason, the concept of using a submaximal test based on a HR determined prediction of aerobic capacity is valid. The test may be made more precise by better controlling for variables which may affect HR response to submaximal exercise. In addition, in field or mass testing situations, some subjects may respond with more valid results to a repeated test conducted under more controlled conditions. The level of experience of the test administrator is an important factor which can significantly affect test results.

Other methods of estimating VO_{2max} from submaximal exercise information involves the use of multiple regression techniques with several variables measured. Kline, et al. (23) used such a method with a 1.6 km(1 mi) walk, age, body weight, and gender as the criterion variables and attained a correlation of 0.93 and SEE of .325 $L \cdot min^{-1}$. Mastropaolo(24) found an r=0.93 and a SEE=.172 $L \cdot min^{-1}$ for respiration exchange ratio (RER), workload, diastolic blood pressure (DBP), expired volume, and expired CO2 as multiple regression variables. Jessup, et al.(25) used age, height, weight, DBP, leg length, 12-minute run time, and Astrand-Ryhming predicted VO_{2max} and obtained an r=0.81 and SEE of .188 $L \cdot min^{-1}$. Hermiston and Faulkner(26) found an r=0.90 for VO_{2max} from fat-free weight, submaximal treadmill HR, RER, age, expired CO_2, and tidal volume measurements. Ribisl and Kachadorian(27) used age, 2 mile run time, and body weight to predict VO_{2max} in middle-age men with an r=0.95 and SEE of 1.97 $ml \cdot kg^{-1} \cdot min^{-1}$.

We have recently determined that in over 600 cycle ergometer tests repeated within 1 week in male firefighters, the reliability was 0.91 with the second test yielding a slightly higher score (mean=1.0 $ml \cdot kg^{-1} \cdot min^{-1}$)(unpublished data). This is almost identical to the results of the present study in which an r of 0.92 was found with a mean difference between tests of 1.02 $ml \cdot kg^{-1} \cdot min^{-1}$ except that the first test was higher.

The use of the computer program developed at the Armstrong Laboratory at Brooks AFB is an important step toward standardizing test administration and thus minimizing the influence of differences in administrator proficiency. It does not, however, eliminate the need for adequately training those administering the test, since there is still the requirement for certain decisions and choices to be made prior to and during the test.

The elimination of emotionally driven elevations in HR will also reduce the error, but it must be recognized that some persons simply have an exaggerated HR response to exercise unrelated to level of aerobic capacity or state of physical training. These types of conditions might be partially corrected for by the introduction of other variables in the prediction, such as a physical activity index, rating of perceived exertion, or other factors. More thorough study is need on this topic which will include additional data on the validity and reliability of the test in older subjects, the effects of altitude and of various nonprescription alergy and asthma medications on test results.

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TABLE 1. Characteristics of Subjects

Variable	Mean	S.D.	Range
Age (yr)	31.7	7.9	19-47
Weight (kg)	59.8	7.6	40-74
Height (cm)	165.5	7.0	147-179
BMI	21.8	2.6	17-28
Sum Skinfold (mm)	81.7	22.5	47-134
% Fat	26.4	5.3	17-37
Waist/Hip ratio	0.78	0.05	.68-.85
Rest Heart Rate	70.6	10.7	52-95

TABLE 2. Reliability of Submaximal Cycle Ergometry

	Average Heart Rate	VO2max(L·min-1)
Test 1	136.9 ±12.9	2.42 ±.66
Test 2	137.9 ±13.1	2.36 ±.61
	r=0.89	r=0.92

values are mean ± s.d.

FIGURE 1
MEAN VO2max

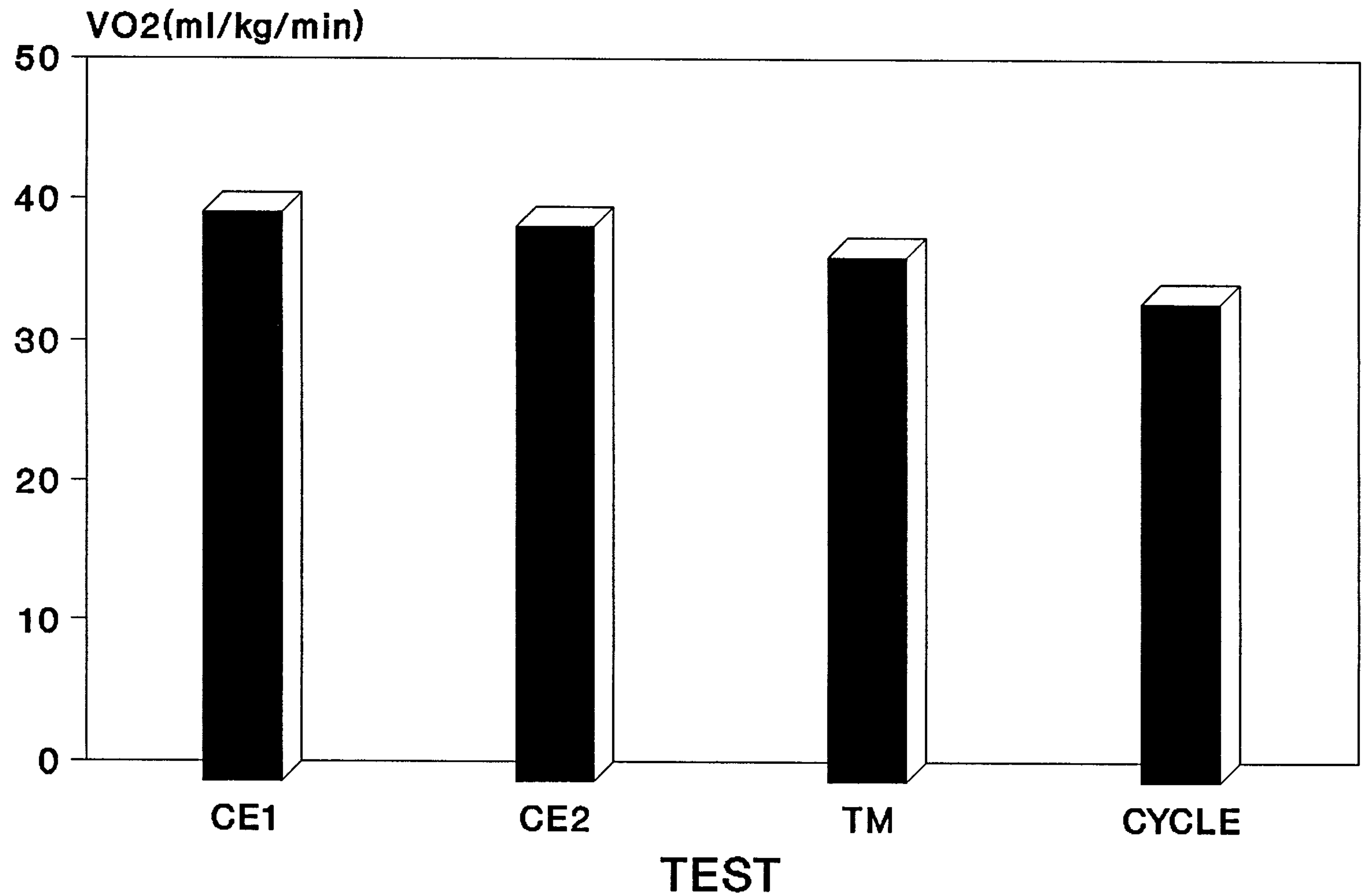


FIGURE 2

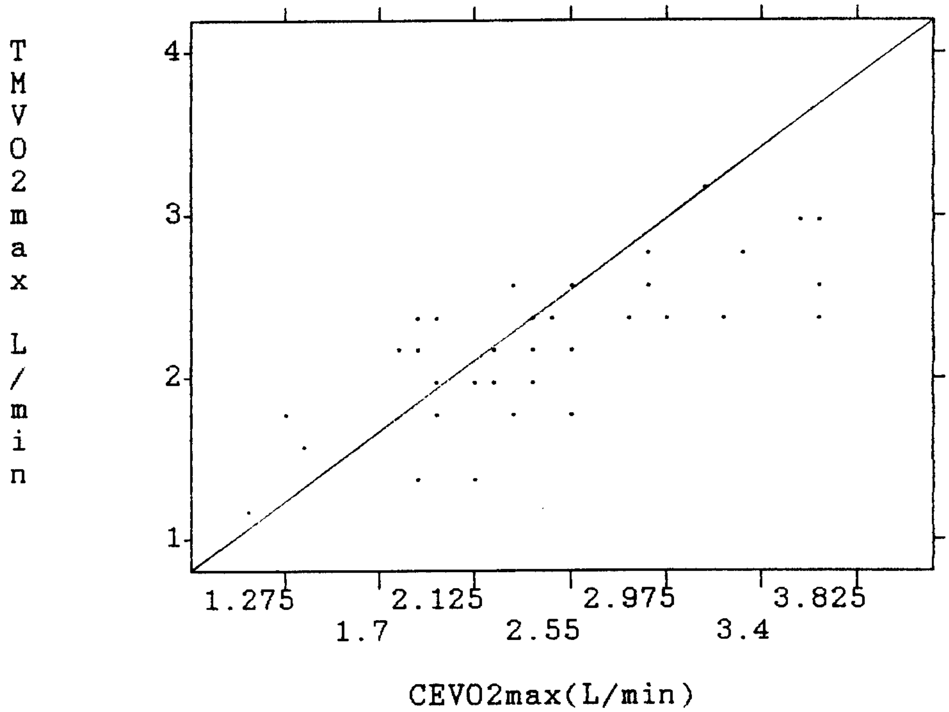
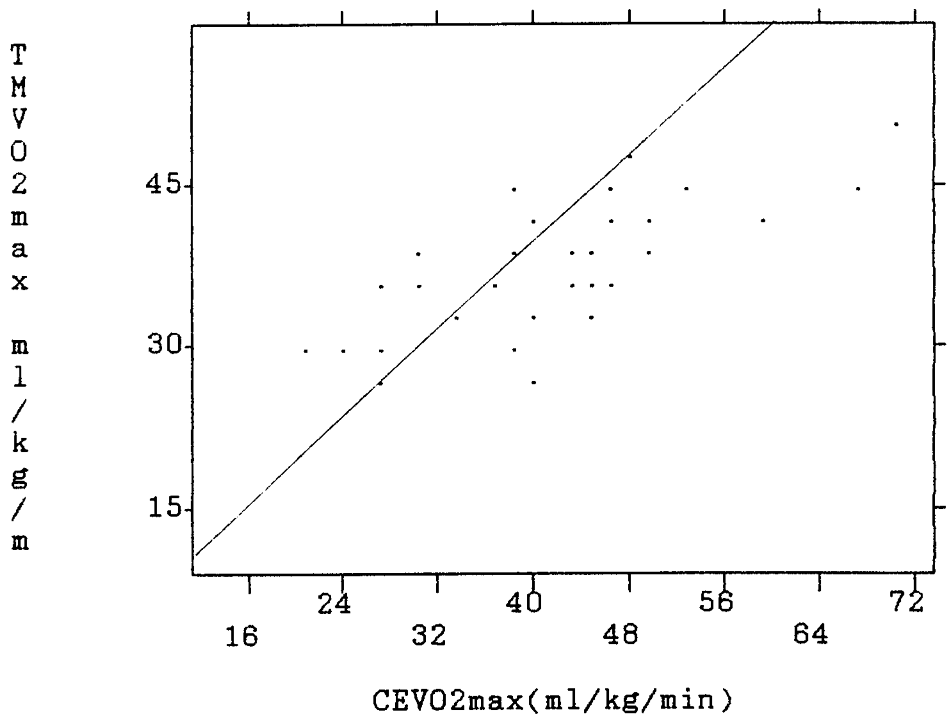


FIGURE 3



WORKING MEMORY AND CONTEXT EFFECTS IN WORD RECOGNITION

David J. Hess
Department of Psychology

The University of Texas at Austin
Austin, Texas 78712

Interim Report for:
Research Initiation Program
Armstrong Laboratory

Sponsored by:
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and

The University of Texas at Austin

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Interim report

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This report is an update on the status of the above-referenced project. While definite progress has been made, there have been a number of unavoidable delays in this project. In its initial stages, data collection was delayed because new hardware had to be ordered. Once we began running the study, constraints on laboratory access at Lackland AFB limited the speed with which data could be collected.

Our first study looked at the relationship between working memory capacity and context effects in word recognition. Earlier work in the area of context effects on word recognition has identified two processes in the facilitation of word recognition. The first process is an automatic and fast spreading activation between semantically related lexical items. The second is a slower, more resource consuming process attributable to the influence of the comprehender's representation of the discourse. Previous investigations into the role of working memory in language comprehension found that resource consuming processes require more working memory. With this information in hand, we speculated that working memory capacity should be related to the second of the two processes in context effects. In order to examine this relationship we took two measures of working memory capacity (the reading span task and an alphabet recoding task) and used some materials from an earlier study to measure the effect of context on word recognition.

In our first study we collected data from 220 Air Force recruits at Lackland AFB. These data were sent to us two weeks ago and we are currently in the process of analyzing them.

Our second study is closely related to the first in that it also examines the relationship between working memory capacity and context effects in word recognition. The second study, in contrast to the first, imposes a memory load on subjects while they are performing the word recognition task. The logic behind this experiment is as follows: if working memory capacity is the only thing that is mediating the influence of context on word recognition, then imposing a memory load on subjects with relatively large working memories should force them to perform like subjects with relatively small working memories who are not given a memory load. One could imagine an alternative where large working memory capacity subjects not only differ from small working memory capacity subjects in their working memory size but also in their comprehension skill. If this were the case then subjects with large vs. small working memory capacities may still perform qualitatively differently even when the former have a memory load imposed on them.

Data collection for the second study is nearing completion and the programmers at Lackland AFB are currently processing it. Once all data collection and analyses have been completed, the final project report will be written.

DESIGN OF A JET FUEL/HALON REPLACEMENT COMBUSTION TOXICOLOGY APPARATUS

Charles J. Kibert
Associate Professor
Fire Testing and Research Center

University of Florida
FAC 101
Gainesville, Florida 32611

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Research Initiation Program
Armstrong Laboratory

Sponsored by:
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and

University of Florida

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Design of a Jet Fuel/Halon Replacement Combustion Toxicology Apparatus

Charles J. Kibert, Ph.D., P.E.
University of Florida

Abstract

The fielding of a replacement for Halon 1211 caused attention to be focused on the affects of the products of interaction of the candidate replacements and the various jet fuels in use by the Air Force: JP4 and JP8. The exposure of unprotected U.S. Air Force flight line personnel, especially mechanics who are normally the personnel to apply "band-aid" fire control measures to fuel fires in and around aircraft, led to the proposal of a standard experiment that could scale the nominal flight line fire to a laboratory setting, with the ability to utilize various end-points such as incapacitation and lethality as measures of the relative toxicity of the combustion products. The apparatus developed for this purpose is described in this report together with the large scale experiments from which it was scaled and against it would ultimately be benchmarked. The toxic constituents that are target compounds having the greatest potential are described for the purpose of comparison. A series of procedures that might be considered for use in carrying out the experiments are outlined as starting points for a detailed analysis.

INTRODUCTION

The Air Force has been heavily dependent on Halon 1211 as a fire suppression agent for the protection of its worldwide airbase assets. As a consequence of the 1987 Montreal Protocol, the Clean Air Act of 1990, and various Department of Defense Directives and Air Force Regulations, the Air Force embarked on a rigorous program to find the best agent to replace Halon 1211 from among substances that were in production or nearing production. Time constraints prevented a wider program that would look at all candidate replacement compounds regardless of their near term availability. The quantity of Halon 1211 used in 1987 by the Air Force was 785,000 pounds and even with recycling, reduced training, and other measures to reduce emissions, it was expected that consumption would remain at significant levels, approximately 250,000 pounds per year.

Throughout the entire development program one of the criteria for selection of the Halon 1211 replacement was that it must not produce unusual deadly substances that might endanger the lives of the flightline personnel who wield the 150 lb. fire extinguishers to suppress the fire at its initiation stage, before it would burn out of control, causing damage to aircraft and affecting the mission of the unit. Historically there are a total of about 40-45 incidents per year at Air Force bases involving aircraft that fall into this category. Each flightline mechanic receives extensive fire suppression training at the start of their career and annual refresher training thereafter to maintain their competence. The mechanic receives not only training in the extinguisher system but also in the tactics of fighting various types of fires: pool fire, engine nacelle fire, and various combinations of nacelle, pool, and running fuel fires. The successful suppression of these potentially devastating fires depends upon the knowledge and skill of the mechanic. The Air Force Fire Department provides back-up to the flight line mechanic, but its arrival usually means that the fire has gone out of control and that comparatively massive damage has occurred. The result is that the Halon 1211 replacement program had to provide the flightline mechanics with a potent substitute, one that was fully capable of dealing with these threat scenarios.

The Halon 1211 replacement program began in 1986 with the screening of 588 compounds as potential new agents. Initial screening was on the basis of Ozone Depletion Potential (ODP), acute toxicity, fire suppression effectiveness, and availability. These were reduced to 12 agents for laboratory scale testing to examine their relative effectiveness using cup burner tests, gathering additional toxicity information, performing initial materials compatibility testing, and examining physical characteristics such as electrical conductivity, boiling point, and viscosity to determine their suitability. The final testing involved large scale testing of the candidates with the overall greatest potential: perfluorohexane and Halotron, a proprietary blend consisting largely of HCFC-123. This large scale testing is the experiment utilized to scale the laboratory experiment described in this report.

PURPOSE

The end-product of this research is the design of a standard experiment that can be used to determine the compounds that are the products of interaction of fuels and fire suppressants in flightline firefighting incidents. The large scale experiments described as a starting point for benchmarking consisted of JP4 as the fuel and Halon 1211, perfluorohexane, and HCFC-123 as the fire suppressants. The interaction products of these fire suppressants with JP8 has not been determined. When newer fuels or newer fire suppressants are introduced a standard experiment of the sort described herein will help assess the products of interaction without having to resort to large scale tests. A database of information that contains the products of interaction can be used to determine if unusual concentrations of toxics are being generated. This standard experiment can be used in either a combustion products collection and analysis mode, an animal testing mode, or a combination of the two.

Appendix A is a description of the feasibility study that initially proposed the design of this experiment. It includes much of the background regarding combustion toxicity required to make use of the system of analysis described in this report.

LARGE SCALE TESTING AND BENCHMARK ESTABLISHMENT

Midwest Research Institute (MRI) and New Mexico Engineering Research Institute (NMERI) conducted the large scale testing for the Air Force during August-October 1991. The objectives of this study were to:

(1) determine the species of airborne chemical compounds emitted from a test burn of JP4 in a 75 ft^2 flowing fuel fire;

(2) determine the species of airborne compounds emitted during firefighting training exercises when using Halon 1211 to extinguish a JP4 fire in a 75 ft^2 flowing fuel fire;

(3) determine the species of airborne compounds emitted during firefighter training exercises when using the candidate replacement agents for Halon 1211: perfluorohexane and HCFC-123;

(4) assess the level of exposure based on firefighter position relative to the fire;

(5) assess firefighter health hazards associated with the replacement extinguishment agent relative to the exposure associated with Halon 1211 and the fuel only fire;

(6) determine steps that might be used to reduce firefighter exposure to hazards;

(7) evaluate the fate and effects of combustion products emitted to the atmosphere during training exercises, including the potential for chemical transformation and long-range atmospheric transport and the potential for human exposure (via ingestion and dermal contact) and adverse environmental effects resulting from dry deposition onto soils, crops, surface waters, and dermal surfaces, and any subsequent groundwater contamination.

The testing consisted of a series of 10 firefighting tests carried out at NMERI's fire test area at Kirtland Air Force Base, New Mexico. The test fire consisted of a running fuel fire using JP4 as the fuel. A 55-gallon drum hanging 2 m. above a 3 m. diameter pit was the simulation configuration for these experiments. Jet fuel was poured into the drum and exited through perforations into the test pit. Ignition of the fire in the drum and the pit created the running fuel fire. The fire was allowed to burn for 30 s. prior to fire suppression after which a firefighter used one of the agents to extinguish the fire. A series of concentric wind screens were utilized to attempt to isolate the fire from the vagaries of local wind conditions.

Data from the fire plumes were gathered at several locations to provide a complete database for assessing the comparative combustion chemistry of the replacement agents. In this series of tests, Halon 1211 was used as the basis of comparison and its combustion interaction products were compared to perfluorohexane and Halotron. Three trace organic stations were located within the plume, beside the firefighter, and downwind from the plume. Measurements were also taken to obtain a vertical profile of combustion product concentrations at the firefighter location.

A wide variety of devices were utilized to collect data from the large scale experiments. A Fourier Transform Infrared (FTIR) spectrometer was employed to measure volatile inorganics and organics, especially acid gases (HF, HBr, HCl, and phosgene), CO, other inorganic gases, and as a backup measurement of halocarbon agents and unburned JP4. Polyurethane Foam (PUF) cartridges were used to collect semivolatile organics, dioxins, and furans. SUMMA canisters and adsorbent traps were used to collect volatile organics.

Table 1 is a summary of the test sampling and analysis methods for the main series of tests. Table 2 is a list of the target compounds and sampling methods that were utilized to collect the data. Table 3 is a list of the Volatile Organic Compound (VOC) target analytes used in a screening study prior to the conduct of the main test showing the various sampling methods used to examine the data. Table 4 is a list of the tests that were conducted in the large scale sequence. Note that the first test included JP4 fuel only to produce a baseline of information without fire suppressant interference. This provides data on firefighter toxic exposure that in essence cannot be prevented and it therefore makes an excellent basis for assessing firefighter hazards. The tests provide a good measurement of the incremental hazards posed by the addition of fire suppressants.

An important issue is the limitation on target compound data that can be collected as a consequence of the method utilize to detect the presence of a particular compound. Table 5 lists Method Detection Limits (MDL) for a set of the VOCs that were included in the study.

Figures 1 and 2 indicate the geometry of the large scale tests. A 55-gallon from with a concentric interior simulates a single engined fighter aircraft such as an F-15. Fuel is fed into the drum, accumulates to a level of about 5 gallons, then overflows, pouring into a pool defined by a ring on the ground. The rings can be arranged to produce a variety of pool fires on the ground. Wind screens surrounding the site eliminate to a great degree the effects of wind on the testing.

Figures 3 and 4 indicate the layout of the sampling devices during the large scale experiments. Table 6 is a summary of the results of the main sequence consisting of 10 tests. Tables 7 through 12 contain the resulting concentrations of target compounds measured in the plume and downwind from the fire during the tests. Specific data on semivolatile organic (SVO) analysis from the testing is shown in Table 13 for the firefighter breathing area. Similar information is shown for plume locations in Tables 14 and 15. Tables 16 and 17 indicate downwind locations from which data was collected. FTIR data collected during the tests is shown in Tables 18 and 19 for acid gases, carbonyl fluoride, JP4, and acetone.

SCALED-FIRE APPARATUS (SFA) DESIGN

The scaled-fire apparatus (SFA) designed to assess the toxics resulting from the interaction of fuels and fire suppressants was based on the large scale experiments conducted by MRI and NMERI. Various sized pool fires were examined to determine the suitability for laboratory use, keeping safety in mind as an objective. A 15 cm x 15 cm pan fire was selected as the basis for the experiment because it maintained some of the turbulent character of the large scale fire. Smaller pan fires had a laminar behavior that did not provide the level of mixing that would occur in the large scale fire, thereby affecting the products of combustion. The test apparatus also had to be functional in two modes. First, it had to provide the ability to collect information from the plume and from regions near the plume for comparison to the field data. Second, it had to be usable for animal testing. This latter capability was produced by use of an animal chamber near the exhaust of the apparatus.

Clearly it is very difficult to produce an exact representation of the large scale effects in a laboratory experiment. But the consistent application of the methods described in this report would give an excellent case-by-case comparison of the interaction products of fuels and fire suppressants to determine if unusual toxics are created. A case in point was an issue affecting the possible selection of perfluorohexane as the Halon 1211 replacement. The manufacturer, 3M, reported the presence of perfluoroisobutene (PFIB), a deadly toxic gas, in controlled laboratory experiments. Consequently in the large scale tests a specific effort was made to determine if PFIB was present in the plume when perfluorohexane was utilized as the fire suppressant. In the large scale tests that were conducted, PFIB was not detected, largely because the MDLs of the collection techniques did not have the ppb capability to find PFIB. In the laboratory experiments using the SFA, PFIB will become a target analyte, with appropriate methods to detect PFIB among other compounds.

Froude modeling was used as the basis for design of the SFA. The background for selecting this method is described in Appendix A. The system of equations used to perform the modeling are listed below together with the resulting SFA dimensions, air flows, and fire characteristics.

$$\dot{m}'' = \dot{m}''_{\infty}\,(1 - e^{-k\beta D}) \tag{1}$$

$$\dot{Q}_c = \dot{m}''\Delta H_c\, A_f \tag{2}$$

$$l = 0.23\,\dot{Q}_c^{\frac{2}{5}} - 1.02\,D \tag{3}$$

$$u_o = \dot{Q}_c^{\frac{1}{5}}\,k\left(z / \dot{Q}_c^{\frac{2}{5}}\right)^{\eta} \tag{4}$$

$$T_c = \frac{T_o}{2g}\left(\frac{k}{c}\right)^2\left(z / \dot{Q}_c^{\frac{2}{5}}\right)^{2\eta-1} + T_o \tag{5}$$

$$Fr = \frac{u_\infty^2\,\rho}{l\,g\,\Delta p} \tag{6}$$

where:

$\dot{m}''$ = mass burn rate, Kg/s
$\dot{m}''_{\infty}$ = mass burn rate, infinite pool, Kg/s
D = pool diameter, m
$k\beta$ = extinction-absorption coefficient of the flame
$\dot{Q}_c$ = heat release rate, MJ/s
ΔH_c = combustion energy, MJ/Kg
A_f = pool area, m^2
l = flame height, m
T_c = centerline temperature, ^{o}K
u_o = flame velocity, m/s
ρ = density, Kg/m^3
Fr = Froude Number

The parameter values for the full scale fire and model fires are as follows:

	Full Scale	Model
A_f, m^2	13.94	0.0225
D, m	4.21	0.1693
$\dot{m}''$, Kg/s	0.051	0.0174
$\dot{Q}_c$, KJ/s	30,925	16,900
l, m	10.1	0.54
u_o, m/s	21.51	5.0
T_c, $°C$	873.5	893.4
Fr	4.72	4.72

The sequence of events for collection of gases is a function of the desires of the experimenter. The fuel is placed in the pan in the center of the combustion chamber, ignited, allowed to burn for a period of time, and the fire suppressant is injected. It is up to the experimenter to decide the gas collection timing and other procedures that may be utilized to assess the interaction products.

Drawings of the apparatus developed to analyze the Halon/jet fuel interactions are shown in Appendix B. The dimensions shown on these drawings was based on the Froude scaling of the full scale fire described above.

The diameters of the duct in the SFA are based on trying to keep air velocities as low as practicable to both simulate the natural convection of the pool fire and provide for the movement of the gases through the device. The following are the combustion parameters that were utilized in the design, based again on the scaling of the full scale fire:

Parameter	Description	Unit	Value
$\dot{m}_{JP8}$	JP8 burn rate	Kg/s	0.003915
$\dot{m}_{air}$	Combustion air	Kg/s	0.0059
$\dot{V}_{air}$	Combustion air	m^3/s	0.005
v_{air}	Air velocity	m/s	0.02
$\dot{V}_{prod}$	Combustion products	m^3/s	0.020
T_{prod}	Combustion products	°C	873.4

The SFA is also designed to allow various levels of dilution to occur. Using a dilution factor, n, the air flows can be modulated to dilute the combustion products from n=0 to n=100, depending on the scenario that is desired.

CONCLUSION

The SFA is designed to assess the combustion products and interaction products of fuels and Halon replacements. The object is to insure that the firefighter is not exposed to unusual, deadly toxics that could compromise their health as well as the mission readiness of the Air Force. The use of the SFA will allow the comparison of fuel/suppression agent combinations without the need to rely on expensive large scale fires that present tremendous problems in data collection and analysis. Clearly a key step will be the comparison of the results of using the SFA with the large scale fire results presented in this report. The SFA should be fine-tuned using these large scale results to insure that future experiments are providing an accurate scaling of real world fire scenarios.

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Kibert, Charles J. "A Proposed Methodology for Flaming Combustion Toxicology Testing of Halon Replacement Agents," included as Appendix A

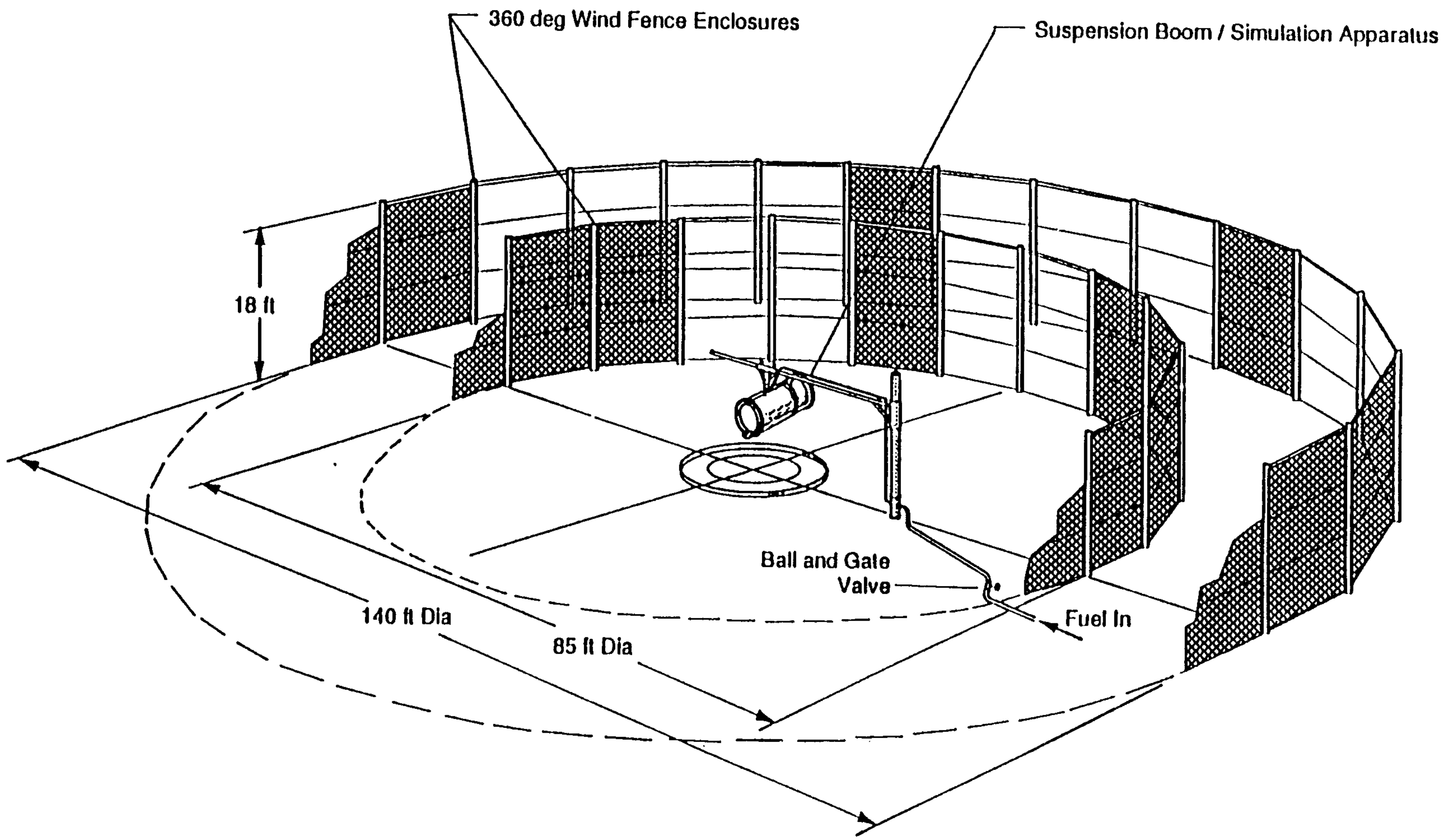

Figure 1. Wind Fence Enclosed Test Site.

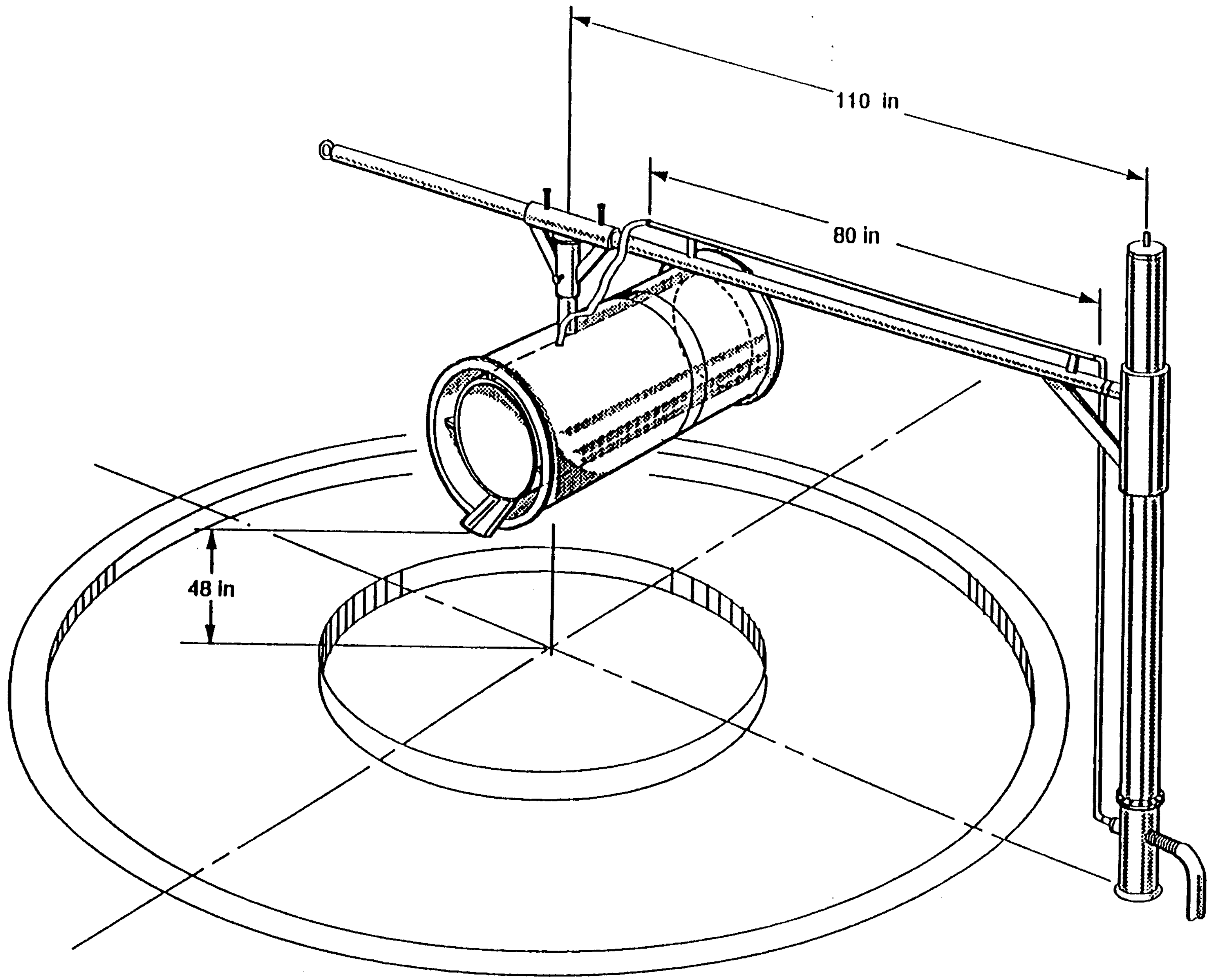

Figure 2. Three-Dimensional Running Fuel Apparatus.

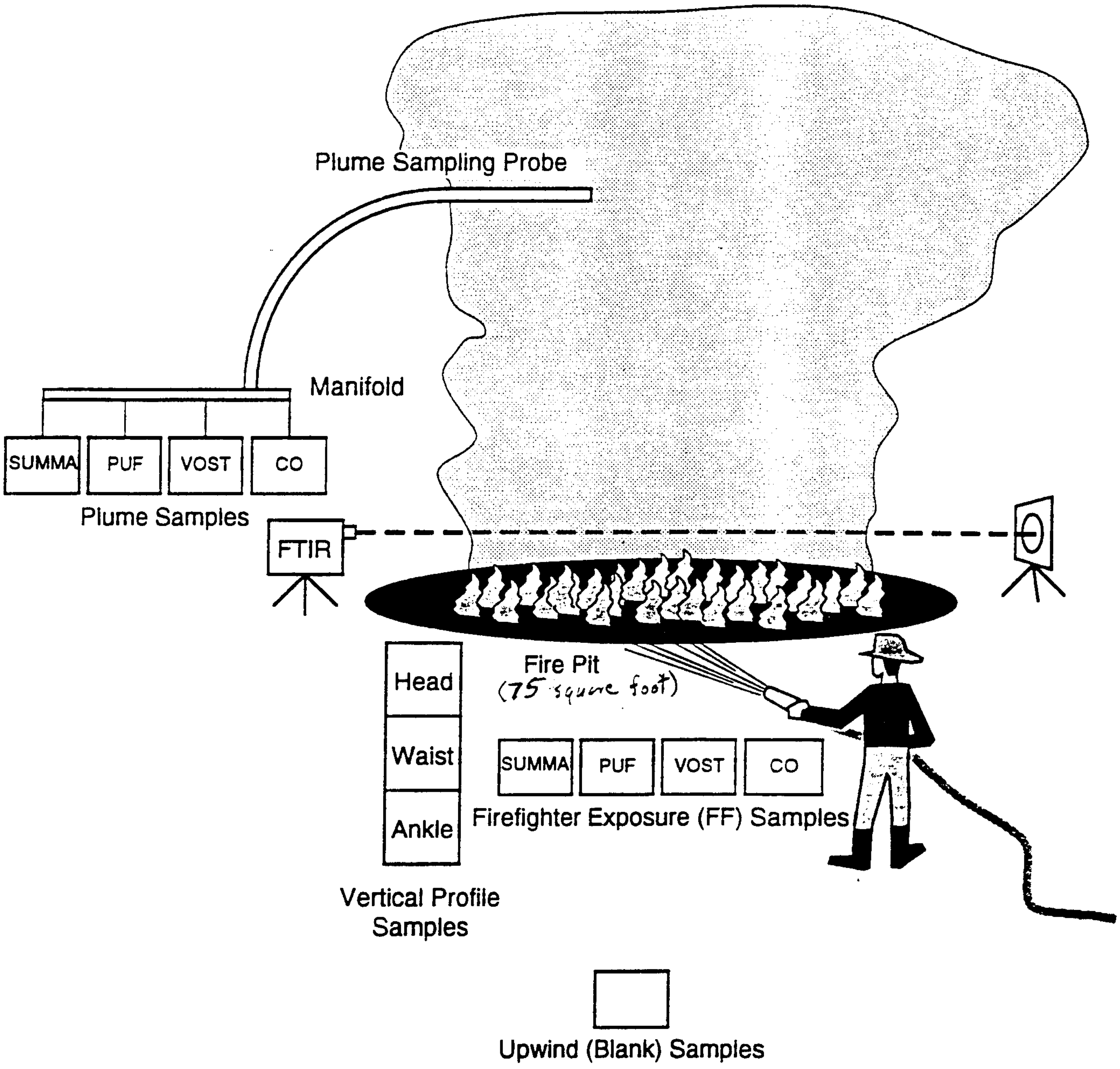

Figure 3. Schematic of Screening Study Sampler Array.

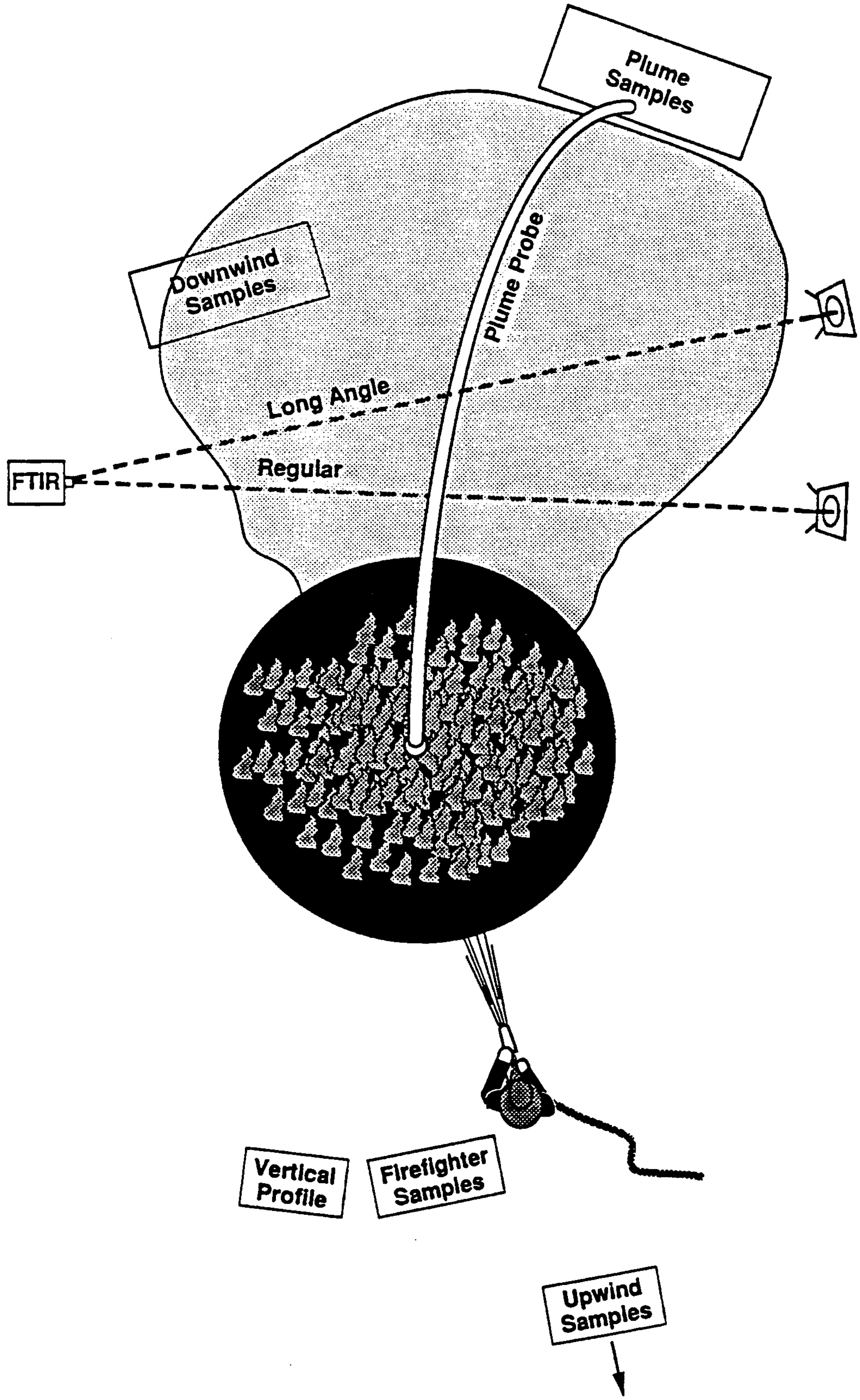

Figure 4. Vertical View of Sampler Array.

TABLE 1. SAMPLING AND ANALYSIS METHODS FOR FIREFIGHTER STUDY.

Analyte(s)	Sampling method	Analysis method
Volatile organic compounds	Tenax/charcoal adsorption	Gas chromatography/ mass spectrometry (Modified EPA Method T02 and 8260)
	SUMMA passivated canister	Gas chromatography/ mass spectrometry (Modified EPA Method T014 and 8260)
Semivolatile organics compounds	Polyurethane foam (PUF) absorption	Gas chromatography/mass spectrometry (Modified EPA Method T04 and 8270)
Polychlorinated dioxins and furans	PUF	MRI Modified EPA Method GC/MS 8290
Total particulate mass and bound organic carbon	Filtration	Gravimetric and GC/MS
Volatile toxic gases	Continuous monitor	Portable Fourier-transform infrared analyzer
	Draeger tube w/personnel sampler pump	Length-of-stain tube
Agent	Canister, vertical profile	Gas chromatography

TABLE 2. REVISED LIST OF TARGET COMPOUNDS AND SAMPLING METHODS.

Category	Compound	Method
Fire extinguishing agents	Halon-1211	a,c,e
	HCFC 123	a,c,e
	Perfluorohexane	a,c,e
Fuel	JP-4	a,c,d,e
Acute toxic hazards	Hydrogen chloride (HCl)	a,b
	Hydrogen fluoride (HF)	a,b
	Hydrogen bromide (HBr)	a,b
	Carbon monoxide (CO)	a
	Carbonyl fluoride (COF_2)	a,b
Carcinogens/teratogens	Polynuclear aromatic hydrocarbons (PAHs)	d
	Benzene	a,c,e
	Dioxins/furans	d
	Benzo[*a*]pyrene (BaP)	d
	Ethylene dibromide (EDB)	a,c,e
	Ethylene dichloride (ECB)	a,c,e
	1,3-Butadiene	a,c,e
	Carbon tetrachloride	a,c,e
	Trichloroethylene (TCE)	a,c,e
	Perchloroethylene (PCE)	a,c,e
Other contaminants	Phenols	d
	Toluene	a,c,e
	Xylene	a,c,e
	Nitrogen oxides (NO_x)	a
	Sulfur oxides (SO_x)	a
	1,1,1-Trichloroethane (TCA)	a,c,e

[a] FTIR
[b] Draeger tube
[c] SUMMA canister
[d] PUF
[e] Tenax/charcoal

TABLE 3. VOC TARGET ANALYTES FOR THE SCREENING STUDY.

Summa Analysis
Target analytes
Chloromethane
1,3-Butadiene
Halon 1211
Benzene
Toluene
Surrogates
Spiked at 50 ng/adsorbent trap
d_8-Toluene
Bromofluorobenzene
Internal standards
Spiked at 50 ng/adsorbent trap
1,4-Difluorobenzene
d_5-Chlorobenzene
Tenax Analysis
Target analytes
1,3-Butadiene
Halon 1211
1,1,1-Trichloroethane
Carbon tetrachloride
Benzene
Trichloroethene
Toluene
Tetrachloroethene
Ethylene dibromide
p-Xylene
JP-4
Surrogates and internal standards
Sample as Summa analysis
Carbosieve III Analysis
Target analytes
1,3-Butadiene
Halon 1211
Internal standard
Spiked at 50 ng/adsorbent trap
Chloromethane

TABLE 4. FINAL MAIN TEST MATRIX.

Run No.	Test type	Sampling methods	Fire out	Sample locations	Notes
1	Fuel only (baseline)	All	N/A	Plume, FF, downwind	–
2	H-1211	All	No	Plume, FF, downwind	–
3	H-1211	FTIR, D.T.	Yes	Downwind	FTIR off-angle
4	HCFC 123	All	No	Plume, FF, downwind	–
5	HCFC 123	All	Yes	Plume, FF, downwind	–
6	Perfluorohexane	All but FTIR	No	Plume, FF, downwind	
7	Perfluorohexane	All	Yes	Plume, FF, downwind	–
8	Perfluorohexane	FTIR, D.T.	Yes	Downwind	Repeat of Run 6, FTIR
9	Perfluorohexane	FTIR, D.T.	Yes	Downwind	FTIR off-angle
10	HCFC 123	FTIR, D.T.	Yes	Downwind	FTIR off-angle

ALL = PUF
Tenax/charcoal
SUMMA
Vertical canisters
FTIR
Draeger tubes (D.T.)

FF = Firefighter location

TABLE 5. METHOD DETECTION LIMITS AND CONCENTRATION RANGES FOR MAIN TEST VOCs.

Analyte	Absorbent trap (ppb)		Summa cannister 1 L analysis volume (ppb)		Summa cannister 5 µl analysis volume (ppb)
	Min	Max	Min	Max	Max
Halon 1211	0.26	32	6.0	730	150,000
HCFC 123	0.21	26	4.8	600	123,000
Perfluorohexane	0.10	12	2.2	270	55,000
Dichlorodifluoromethane	0.27	33	6.0	760	155,000
Chloromethane	0.64	80	14.7	1,830	370,000
1,3-Butadiene	0.60	74	13.6	1,700	350,000
Dichlorofluoromethane	0.32	39	7.2	900	183,000
1,2-Dichloro-1,1,2-trifluoroethane	0.21	26	4.8	600	123,000
Dibromofluoromethane	0.17	21	3.8	480	97,000
Benzene	0.41	51	9.4	1,170	240,000
Dibromomethane	0.18	23	4.2	530	108,000
Toluene	0.35	44	8.0	1,000	203,000
m-and *p*-xylene	0.30	38	6.9	860	177,000
Ethynylbenzene	0.32	39	7.2	900	183,000
o-Xylene	0.30	38	6.9	860	177,000
Styrene	0.31	39	7.0	880	180,000
1-Phenyl-1-propyne	0.28	35	6.3	790	161,000
4-Ethynyltoluene	0.28	35	6.3	790	161,000

TABLE 6. MAIN TEST SUMMARY

	Test No.									
	1	2	3	4	5	6	7	8	9	10
Date	15 Oct 91	15 Oct 91	15 Oct 91	16 Oct 91	17 Oct 91	17 Oct 91	18 Oct 91	18 Oct 91	18 Oct 91	18 Oct 91
Time of day	10:20 a.m.	12:30 p.m.	1 p.m.	9:10 a.m.	8:40 a.m.	11:30 a.m.	8:30 a.m.	11:15 a.m.	11:45 a.m.	12:05 p.m.
Ambient temp (°F)	70	80	82	70	68	75	65	78	79	80
Wind direction, speed (mph)	Calm	SSW, Gusts 1 to 5	SSW, 1 to 5	Calm	Calm	SSE, 1 to 2	Calm	Calm	Calm	Calm
Fuel amount (gal)	20	8.6	7.3	14	4.4	5.9	4.8	3.4	4.3	4.0
Fuel flow rate (gpm)	4.5	3.6	4.1	6.5	4.2	4.2	3.7	3.3	3.2	3.0
Agent type (lb)	None	H1211	H1211	HCFC123	HCFC123	C_6F_{14}	C_6F_{14}	C_6F_{14}	C_6F_{14}	HCFC123
Agent amount (lb)	N/A	150	65	130	99	124	67	88	100	88
Agent flow rate (lb/s)	N/A	3.2	2.0	2.5	4.7	3.2	4.9	5.1	4.5	4.6
Nozzle type	N/A	TFT	STD	TFT	TFT	TFT	TFT	TFT	TFT	TFT
Extinguisher pressure (lb/in.^{2})	N/A	200	200	200	230	230	230	230	230	230
Preburn duration (s)	N/A	40	38	28	13	12	13	14	16	14
Fire duration (min)	4:30	2:00	1:17	3:46	0:35	2:28	0:27	0:31	0:39	0:33
Types of samples	All	All	FTIR, D.T.	All	All	All	All	FTIR, D.T.	FTIR, D.T.	FTIR, D.T.
Fire extinguished	N/A	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes

D.T. = Draeger tube sampling.

TABLE 7. SUMMARY OF TARGET ANALYTE CONCENTRATIONS FOR ALL SAMPLES COLLECTED IN FIREFIGHTER'S BREATHING ZONE FOR MAIN TEST.
(Concentration, ppb)

Analyte	JP-4[e]	HALON 1211	HCFC 123	PFH
Halon 1211	0-.13	>209-4000	24.7-44	0-96
HCFC 123	0	0-0.216	>199->5400	21.4-88**
Perfluorohexane	0	0	0	69-26100
Dichlorodifluoromethane	0-1.06	0-1.62	0.97-7.3	0-17.6
Chloromethane	0-0.22	0-0.41	0-0.63	0
1,3-Butadiene	0	b	0	0
Dichlorofluoromethane	0	2.69-5.6	0	0
1,2-Dichloro-1,1,2-trifluoroethane	0	0	121-2520[d]	0-9.2
Dibromofluoromethane	0	0	0	0
Benzene	1.24-59	27.2-27.7	3.7-63	3.5-62
Dibromomethane	0	0-0.022	0	0
Toluene	2.58-94	38-50	12.7-150[a]	6.9-154*
m- and *p*-xylene	0.51-19.1	10.5-13.2	1.55-36	2.27**-33*
Ethynylbenzene	0.19-5.8	0-1.16	0-6.6	2.2**-2.4*
o-Xylene	0.35-12.8	7.5-9	0.89-33	1.56**-22.5*
Styrene	0.057-5.2	0-1.17	0.137**-6.5	0-0.74*
1-Phenyl-1-propyne	21.1[c]	0-5[c]	0-14.3	0-3.5[c]
4-Ethynyltoluene	0.088-22.1	0-0.57	0-21	0

[a] Excedes upper limit of T/C calibration curve.
[b] Interference from high amounts of Halon 1211 makes quantitation suspect.
[c] Interference from 1,2,3-trimethylbenzene makes quantitation suspect.
[d] Interference from high amounts of HCFC 123 makes quantitation suspect.

* Ignored the higher level detected from 5 ml sample.
** Ignored ND results from summas.

TABLE 8. SUMMARY OF TICs (TENTATIVELY IDENTIFIED COMPOUNDS) IN THE FIREFIGHTER'S BREATHING ZONE FOR MAIN TEST.
(Concentration ppb)

Sample No.	1013	2013	3013	5013
Agent used	none	Halon 1211	HCFC 123	PFH
Compound				
Methylcyclopentane	24	–	–	–
Dimethylcyclopentane	10	–	–	–
Methylcyclohexane	74	–	–	–
Ethylbenzene	–	4	–	0.3
Dimethylbenzene	–	–	10	–
Ethylmethylbenzene	–	8	–	–
Trimethylbenzene	–	2	–	–
Methylpropylbenzene	–	1	–	–
Methylphenylethane	–	1	–	–
Carbon dioxide	34	–	–	–
2-Methylfuran	–	1	–	1
Bromochlorodifluoromethane	–	–	10	14
Dichlorotrifluoroethane	–	–	1000	40
Trimethylmethoxysilane	–	–	–	3

TABLE 9. SUMMARY OF PLUME SAMPLE TARGET ANALYTE CONCENTRATIONS FOR THE MAIN TEST.
(Concentration, ppb)

Analyte	JP-4[e]	HALON 1211	HCFC 123	PFH
Halon 1211	—	>1000-90000	30-1800	1.5-5
HCFC 123	—	0-3	>180-180000	2-80*
Perfluorohexane	—	0	0	>100-24000
Dichlorodifluoromethane	3.4	50-85	12-260*	0-12
Chloromethane	—	130->2700[a]	0->360[a]	>320-540
1,3-Butadiene	25.5	100[b]	0	3-15
Dichlorofluoromethane	—	6-82	0-40	0
1,2-Dichloro-1,1,2-trifluoroethane	—	-	>100-16000[d]	0-5
Dibromofluoromethane	—	0-0.4	0	0
Benzene	1020	180-440	40-700*	13-100
Dibromomethane	—	45-70	0	0
Toluene	76	340-450	100-460*	70->175[a]
m- and *p*-xylene	11.8	70-115	20-100*	12-18
Ethynylbenzene	65	20-190[a]	14-160*	7**-25
o-Xylene	8.9	60-70	13-60	7-14
Styrene	35	15-25	0-33*	2**-5
1-Phenyl-1-propyne	21.4	0[c]	0-1800[c]	0[c]
4-Ethynyltoluene	56	0-3	0-8	0-2

[a] Excedes upper limit of T/C calibration curve range.
[b] Interference from Halon 1211 makes quantitation suspect.
[c] Interference from 1,2,3-trimethylbenzene makes quantitation suspect.
[d] Interference from HCFC 123 makes quantitation suspect.
[e] Summa results only; vol. sampled data not available for T/C sample.

* Ignored the higher level detected from 5 ml summa sample.
** Ignored ND results from summas.

TABLE 10. SUMMARY OF PLUME SAMPLE TICs FOR THE MAIN TEST.

	Concentration (ppb)			
Agent:	None	Halon 1211	HCFC 123	
Sample No.:	1012	2012	3012	5012
Compound				
Methylcyclopentane	1	15	17	2
Dimethylcyclopentane		8	6	
Methylcyclohexane		50	50	5
Dimethylcyclohexane		5		
Ethylcyclohexane		16	17	2
Trimethylcyclohexane			5	0.6
Trimethylcyclopentane			3	1
Dimethylhexane			5	
Ethylbenzene	0.5	12	3	0.6
Ethylmethylbenzene		2	2	
Methylethylbenzene		3	2	
2-Hexane	3			
Chlorotrifluoromethane			65	
Trifluorochloroethane			16	
Difluorodichloroethane			4	
Hydroxypropanone			21	
Trifluorodichloropropene			1	
Trichlorofluoroethene			3	
Chloromethyl methoxybenzene			2	
Methylheptane			3	
Methylethylcyclohexane		4	6	0.8
Methylpropylbenzene			1	
Hexafluoroethane				21
Tetradecafluorohexane				4
Dimethyltricyclohexane				0.2
Pentylcyclohexane				0.7
Dimethylcyclopropane	0.8			
Methylbutanone	14			
Trichloroeicosysilane	1			
Butanoic acid	1			
Octamethylcyclotetrasilane	3			
Epoxyehtylbutanone	4			
Phenylethanone	1			
Nonanone	6			
Chlorodifluoromethane		5		
Bromopropene		2		
Bromochloromethane		2		

TABLE 11. SUMMARY OF DOWNWIND LOCATION TARGET ANALYTE CONCENTRATION FOR MAIN TEST. (Concentration, ppb)

Analyte	JP-4[e]	HALON 1211	HCFC 123	PFH
Halon 1211	-	112,000	100 to 1,800	0 to 25
HCFC 123	-	-	>170 to 129,000	35 to 280
Perfluorohexane	-	-	0	> 96 to 380,000[a]
Dichlorodifluoromethane	-	31	20 to 135	0
Chloromethane	-	30	50** to 100	0 to 7
1,3-Butadiene	-	103[b]	0 to 55[b]	0 to 17
Dichlorofluoromethane	-	120	3 to 20	0
1,2-Dichloro-1,1,2-trifluoroethane	-	-	? to 25,000[d]	1 to 23
Dibromofluoromethane	-	-	0	0
Benzene	-	69	40 to 350	50 to 270
Dibromomethane	-	-	0	0
Toluene	4.9	250	140 to 1,200	190 to 1,220
m- and *p*-xylene	-	77	50 to 250	45 to 280
Ethynylbenzene	-	-	2 to 40	7** to 9*
o-Xylene	-	46	30 to 150	9 to 170
Styrene	-	-	4.** to 20	3 to 12*
1-Phenyl-1-propyne	4.5	-	0 to 10[c]	0 to 27 (3)
4-Ethynyltoluene	3.6	-	0	0 to 20

[a] Excedes upper limit of T/C calibration curve.
[b] Interference from Halon 1211 makes quantitation suspect.
[c] Interference from 1,2,3-trimethylbenzene makes quantitation suspect.
[d] Interference from HCFC 123 makes quantitation suspect.
[e] Summa results only; T/C sample lost during analysis.

* Ignored the higher level detected from 5 ml summa sample.
** Ignored ND results from summas.

TABLE 12. SUMMARY OF DOWNWIND LOCATION TICs FOR THE MAIN TEST.

	Concentration (ppb)			
Agent:	None	Halon 1211	HCFC 123	Perfluorohexyl
Sample No.:	1027	2027	3027	5027
Compound				
Methylcyclopentane		20	20	2
Dimethylcyclopentane				2
Methylcyclohexane		78	75	9
Dimethylcyclohexane		26		0.4
Ethylbenzene			7	0.7
Ethylmethylbenzene			6	0.3
Methylethylbenzene			1	
Butanone				
Methylfuran	2			
Hexane		23		
Carbon dioxide		15		
Methylheptanone	16			
Hexanone	4			
Trichlorotrifluoroethane	12			
Dibromochlorofluorocyclopropane	58			
Dichlorotrifluoroethane		2		
Methylpentane		19		
Trimethylpentane		9		
Dimethylhexane		14		
Tetradecafluorohexane				8
S-Methyloctane				1
Dimethoxymethane				0.2
Ethyldimethylbenzene			2	
Methylpropylbenzene			3	
Trimethylbenzene			2	
Butylcyclohexane			8	
Ethylcyclohexane			20	
Trimethylcyclopentane			6	
Butanone			3	
Dichloromethane			35	
Dichloropentafluorobutane			5	
Dichlorotetrafluoroethane			7	
Dimethyltricyclopentane			10	
Dimethyltricyclohexane			6	
Dimethyl-*cis*-cyclohexane			3	

TABLE 13. SEMIVOLATILE ANALYSIS RESULTS FOR THE FIRE FIGHTER'S BREATHING AREA—MAIN TEST.
(Runs 1 to 7; results reported in total $\mu g/m^3$[a])

No.	Target compound	Run 1 Jet fuel C + F 1006-1007	Run 2 Halon 1211 C + F 2006-2007	Run 4 HCFC 123 C + F 3006-3007	Run 5 HCFC 123 C + F 4006-4007	Run 6 PFH C + F 5006-5007	Run 7 PFH C + F 6006-6007
9	Phenol	9.51	< 0.8	–	< 0.9	< 1	< 0.9
10	Acenaphthene	–	< 0.8	–	–	< 1	–
11	Acenaphthylene	–	–	–	< 0.9	< 1	–
12	Anthracene	–	–	–	–	–	–
13	Benzo[a]anthracene	–	–	–	–	–	–
14	Benzo[a]pryene	–	–	–	–	–	–
15	Benzo[b]fluoranthene	–	–	–	–	–	–
16	Benzo[k]fluoranthene	–	–	–	–	–	–
17	Benzo[g,h,i]perylene	–	–	–	–	–	–
18	Chrysene	–	–	–	–	–	–
19	Dibenzo[a,h]anthracene	–	–	–	–	–	–
20	Fluoranthene	–	< 0.8	–	< 0.9	–	–
21	Fluorene	–	< 0.8	–	–	–	–
22	Indeno[1,2,3-cd]pyrene	–		–	–	–	–
23	Naphthalene	< 1.9	1.1	< 0.8	1.79	< 1	1.09
24	Phenanthrene	–	0.82	–	< 0.9	–	–
25	Pyrene	–	< 0.8	–	–	–	–
27	1-Methylnaphthalene	< 1.9	2.55	–	2.57	< 1	2.56
29	Biphenyl	–	< 0.8	–	< 0.9	< 1	< 0.9
30	1-Phenylnaphthalene	–	–	–	–	–	–
33	1,3-Dimethylnaphthalene	–	< 0.8	–	< 0.9	< 1	0.93
34	1,2-Dimethylnaphthalene	–	–	–	–	–	–
35	2-Vinynaphthalene	–	–	–	–	–	–
	Surrogates (% recovery)						
1	d_5-Nitrobenzene	42.2	58.0	28.0	28.0	27.0	22
2	d_4-1,2-Dichlorobenzene	15.1	22.0	6.4	7.7	9.2	5.38
3	d_{14}-Terphenyl	96.0	104	82.5	79.7	63.8	71.5
	Lab code	27951	27953	27955	27957	27959	27961
	GC/MS file (6207...)	K21W2	K21W4	K21W6	K21W7	K21W8	K22W4
	Date sampled						
	Date analyzed	21 Nov 91	21 Nov 91	21 Nov 91	21 Nov 91	21 Nov 91	22 Nov 91

[a] Sample split factor = 2, final sample extract volume = 100 µl.

C = cartridge, F = filter, R = probe rinse
(–) = not detected
< = detected but less than X $\mu g/m^3$

TABLE 14. SEMIVOLATILE ANALYSIS RESULTS FOR THE PLUME.
(Results reported in total µg/m[3a])

No.	Target compound	Run 1 Jet fuel C + F + R 1003-1005	Run 2 Halon 1211 C + F + R 2003-2005	Run 4 HCFC 123 C + F + R 3003-3005	Run 5 HCFC 123 C + F + R 4003-4005	Run 6 PFH C + F + R 5003-5005	Run 7 PFH C + F + R 6003-6005
9	Phenol	2.84	4.00	15.7	11.6	3.03	2.67
10	Acenaphthene	1.72	–	< 1.2	–	–	< 0.8
11	Acenaphthylene	120[b]	9.54	21.1	< 1.3	7.20	2.15
12	Anthracene	9.32	–	< 1.2	–	< 1.4	–
13	Benzo[a]anthracene	10.8	1.76	8.51	–	–	–
14	Benzo[a]pryene	10.6	–	4.16	–	–	–
15	Benzo[b]fluoranthene	–	5.68	12.2	–	–	–
16	Benzo[k]fluoranthene	15.2	5.13	< 1.2	–	–	–
17	Benzo[g,h,i]perylene	5.58	–	3.64	–	–	–
18	Chrysene	9.93	–	3.18	–	–	–
19	Dibenzo[a,h]anthracene	–	–	< 1.2	–	–	–
20	Fluoranthene	64.0[b]	24.8	51.6[b]	1.3	3.40	0.92
21	Fluorene	16.7	4.12	7.34	1.3	–	0.84
22	Indeno[1,2,3-cd]pyrene	6.70	–	< 1.2	1.3	< 1.4	–
23	Naphthalene	110[b]	120	172[b]	4.78	20.3	7.84
24	Phenanthrene	60.2[b]	16.0	63.6[b]	1.56	4.63	4.70
25	Pyrene	35.4	5.54	17.6	< 1.3	2.11	< 0.8
27	1-Methylnaphthalene	6.60	21.9	14.2	–	10.8	6.89
29	Biphenyl	14.3	17.3	20.7	< 1.3	2.92	1.43
30	1-Phenylnaphthalene	1.88	–	1.32	–	–	–
33	1,3-Dimethylnaphthalene	2.19	6.24	4.02	< 1.3	3.98	2.29
34	1,2-Dimethylnaphthalene	–	–	–	–	–	–
35	2-Vinynaphthalene	7.90	< 1.7	1.56	–	< 1.4	–
	Surrogates (% recovery)						
1	d_5-Nitrobenzene	30.8	–	7.53	46.2	35.2	97.2
2	d_4-1,2-Dichlorobenzene	7.83	23.6	20.0	20.0	9.20	27.8
3	d_{14}-Terphenyl	59.5	64.5	65.2	71.5	57.2	150
	Lab code	27963	27964	27965	27966	27967	27968
	GC/MS File (6207...)	K22W12	K22W11	K22W10	K22W5	K22W7	K22W2
	Date sampled						
	Date analyzed	22 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91

[a] Sample split factor = 2, final sample extract volume = 100 µl.
[b] Results are from an analysis of a dilution of the original analyzed sample.

C = Cartridge, F = filter, R = probe rinse.
(–) = Not detected.
< = Detected but less than X µg/m³.

TABLE 15. SUMMARY OF TICs FOR SMVs ANALYSIS OF PLUME SAMPLES FOR MAIN TEST. (Runs 1 to 7; results reported in total $\mu g/m^3$)[a]

Compound	Run 1 Jet Fuel C + F + R 1003-1005	Run 2 Halon 1211 C + F + R 2003-2005	Run 4 HCFC 123 C + F + R 3003-3005	Run 5 HCFC 123 C + F + R 4003-4005	Run 6 PFH C + F + R 5003-5005	Run 7 PFH C + F + R 6003-6005
Chlorotoluene		280	940			27
Methylphenol		570	5400		100	74
Bromotoluene		980			11	
Unknown C10-C15 hydrocarbon	12	79	85		53	
Benzoic acid			210			
Benzothiozole					5.3	
Biphenylene	12					
Ethylhexyl propenoic acid	8					
Unknown substituted benzene			3000		22	
Unknown substituted cyclohexane					7.2	
Unknown carboxylic acid			170		27	
Unknown substituted chlorotoluene				46		
Unknown phthalate						51
Unknown		1500	78	58	16	30
Lab code	27963	27964	27965	27966	27967	27968
GC/MS file (6207...)	K22W12	K22W11	K22W10	K22W5	K22W7	K22W2
Date sampled						
Date analyzed	Nov-22-91	Nov-22-91	Nov-22-91	Nov-22-91	Nov-22-91	Nov-22-91

[a] Sample split factor = 2; final sample extract volume = 100 µl.
C = cartridge, F = filter, R = probe rinse.

TABLE 16. SEMIVOLATILE ANALYSIS RESULTS FOR DOWNWIND—MAIN TEST.
(Results reported in total µg/m³[a])

No.	Target compound	Run 1 Jet fuel C + F + R 1024-1025	Run 2 Halon 1211 C + F + R 2024-2025	Run 4 HCFC 123 C + F + R 3024-3025	Run 5 HCFC 123 C + F + R 4024-4025	Run 6 PFH C + F + R 5024-5025	Run 7 PFH C + F + R 6024-6025
9	Phenol	109	< 1.3	–	41.0	2.99	5.21
10	Acenaphthene	–	< 1.3	–	< 1.3	< 1.7	–
11	Acenaphthylene	–	< 1.3	< 1.3	< 1.3	< 1.7	< 1.3
12	Anthracene	–	–	–	–	< 1.7	–
13	Benzo[a]anthracene	–	–	–	–	–	–
14	Benzo[a]pryene	–	–	–	–	–	–
15	Benzo[b]fluoranthene	–	–	–	–	–	–
16	Benzo[k]fluoranthene	–	–	–	–	–	–
17	Benzo[g,h,i]perylene	–	–	–	–	–	–
18	Chrysene	–	–	–	–	–	–
19	Dibenzo[a,h]anthracene	–	–	–	–	–	–
20	Fluoranthene	–	< 1.3	< 1.3	< 1.3	–	< 1.3
21	Fluorene	–	< 1.3	–	–	–	< 1.3
22	Indeno[1,2,3-cd]pyrene	–	–	–	–	–	–
23	Naphthalene	< 5.8	4.03	6.74	13.0	3.2	12.6
24	Phenanthrene	–	< 1.3	2.08	1.87	< 1.7	< 1.3
25	Pyrene	–	–	–	–	–	< 1.3
27	1-Methylnaphthalene	< 5.8	19.4	19.3	1.47	14.9	90.0[b]
29	Biphenyl	–	2.85	4.96	3.57	2.39	7.20
30	1-Phenylnaphthalene	–	–	–	–	–	–
33	1,3-Dimethylnaphthalene	–	10.4	9.27	6.17	7.85	38.6[b]
34	1,2-Dimethylnaphthalene	–	< 1.3	< 1.3	< 1.3	–	2.16
35	2-Vinynaphthalene	–	< 1.3	–	–	–	1.41
	Surrogates (% recovery)						
1	d_5-Nitrobenzene	50.8	28.5	37.2	54.5	42.5	39.0
2	d_4-1,2-Dichlorobenzene	20.8	6.30	20.7	25.4	15.3	7.25
3	d_{14}-Terphenyl	95.0	104	81.8	72.0	77.5	70.2
	Lab code	27952	27954	27956	27958	27960	27962
	GC/MS File (6207...)	K21W3	K21W5	K22W6	K22W8	K22W3	K22W9
	Date sampled						
	Date analyzed	21 Nov 91	21 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91

[a] Sample split factor = 2, final sample extract volume = 100 µl.
[b] Results are from an analysis of a dilution of the original analyzed sample.

C = Cartridge, F = filter, R = probe rinse.
(–) = Not detected.
< = Detected but less than X µg/m³.

TABLE 17. SEMIVOLATILE TENTATIVELY IDENTIFIED COMPOUNDS (TICs) OBSERVED FOR THE DOWNWIND.
(Runs 1 to 7; results reported in total $\mu g/m^3$)[a]

Compound	RUN 1 JET FUEL C + F + R 1024-1025	RUN 2 HALON 1211 C + F + R 2024-2025	RUN 4 HCFC 123 C + F + R 3024-3025	RUN 5 HCFC 123 C + F + R 4024-4025	RUN 6 PFH C + F + R 5024-5025	RUN 7 PFH C + F + R 6024-6025
Benzoyl chloride			1900			
Methyl phenol	140		13			450
Substituted chlorobenzene			21			
Unknown C6-C15 hydrocarbon		86	840	57	51	170
Benzoic Acid			32			
Unknown substituted benzene		32	420			19
Unknown phthalate	100				49	
BHT (butylated hydroxytoluene)		36				
Unknown C8H16 subcyclohexane						49
Dimethylnaphthalene						23
Unknown	39					
Lab code	27952	27954	27956	27958	27960	27962
GC/MS file (6207...)	K21W3	K21W5	K22W6	K22W8	K22W3	K22W9
Date sampled						
Date analyzed	21 Nov 91	21 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91	22 Nov 91

[a] Sample split factor = 2, final sample extract volume = 100 µl.
C = cartridge, F = filter, R = probe rinse.

TABLE 18. FTIR DATA BY FIRE PHASE

Test Number		1	2	3	4	5	7	8	9	10
	AGENT	NONE	H1211	H1211	H123	H123	PFH	PFH	PFH	H123
	Fuel		0.0	0.0	b	0.0	0.0	0.0	0.0	0.0
	Fire		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Agent		4300	3400	1200	8200	940	1400	870	5400
	Out[a]		570	220	62	1700	940	730	600	1800
HCl	Fuel		0.0	0.0	b	0.0				0.0
	Fire		0.0	0.0	0.0	0.0				0.0
	Agent		80	30	120	240				110
	Out[a]		0.05	0.79	1.1	17				16
HF	Fuel		0.0	0.0	b	0.0	0.0	0.0	0.0	0.11
	Fire		0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	Agent		44	24	60	120	65	120	43	69
	Out[a]		2.5	1.6	1.0	15	11	7.9	10	16
HBr	Fuel		0.0	0.0						
	Fire		0.0	0.0						
	Agent		140	42						
	Out[a]		0.0	0.62						
COF2	Fuel		0.0	0.0	b	0.0	0.0	0.0	0.0	0.0
	Fire		0.0	0.0	0.0	0.58	0.0	0.0	0.0	0.0
	Agent		35	19	26	72	87	95	35	33
	Out[a]		0.76	0.55	0.0	2.2	9.6	5.6	5.4	4.5
CO	Fuel	0.0	24	2.1	b	0.0	0.0	0.0	1.4	0.0
	Fire	6.5	33	1.6	0.0	0.0	0.0	6.2	3.8	0.0
	Agent		140	52	52	180	79	110	44	69
	Out[a]	0.0	22	7.2	16	20	9.7	5.2	11	14
JP-4	Fuel	3.7	140	0.23	b	2.1	50	6.9	3.6	0.0
	Fire	2.9	23	4.5	50	15	56	37	3.6	0.66
	Agent		220	220	38	200	110	72	45	120
	Out[a]	7.1	29	27	0.83	38	40	20	11	54
ACET	Fuel	0.0	1.1	0.07	b	0.0	0.14	0.06	0.0	0.0
	Fire	0.26	0.7	0.07	0.11	0.0	0.23	0.28	0.0	0.0
	Agent		6.4	3.10	1.4	11	0.0	0.29	0.86	2.9
	Out[a]	0.0	0.85	0.25	0.49	0.96	1.10	0.0	2	0.37

[a] Fire was not extinguished in Runs 1, 2 and 4.
[b] FTIR began recording when the fire started.

TABLE 19. FTIR SUMMARY DATA.

Test Number		1	2	3	4	5	7	8	9	10
	AGENT	NONE	H1211	H1211	H123	H123	PFH	PFH	PFH	H123
	1 min maximum		4,300	3,000	1,100	5,600	1,900	1,000	900	3,400
	Avg. conc. worst case		2,900	2,500	350	23,000	11,000	1,900	1,700	6,200
	Mass (g)/kg agent		1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Total mass (g)		68,000	29,000	59,000	45,000	30,000	40,000	45,000	40,000
HCl	1 min maximum		72	25	120	150				56
	Avg. conc. worst case		36	20	32	370				97
	Mass (g)/kg agent		2.7	1.8	22	3.8				3.7
	Total mass (g)		180	52	1,300	170				150
HF	1 min maximum		41	21	59	77	47	66	29	40
	Avg. conc. worst case		24	18	17	240	170	120	52	71
	Mass (g)/kg agent		0.99	0.86	6.2	1.4	0.9	3.7	1.8	1.5
	Total mass (g)		68	25	370	62	27	150	80	60
HBr	1 min maximum		130	34						
	Avg. conc. worst case		64	27						
	Mass (g)/kg agent		11	5.2						
	Total mass (g)		720	150						
COF_2	1 min maximum		32	16	26	40	52	50	22	17
	Avg. conc. worst case		17	12	7.1	83	160	93	36	29
	Mass (g)/kg agent		2.3	2	8.7	1.5	2.9	9.4	4.1	2
	Total mass (g)		160	59	510	69	87	370	190	81
CO	1 min maximum	30	130	45	51	110	49	61	30	38
	Avg. conc. worst case	9.4	120	49	23	350	160	110	55	67
	Mass (g)/kg agent		7.1	3.3	12	2.8	1.2	4.8	2.6	2
	Total mass (g)		480	97	720	120	36	190	120	79
JP-4	1 min maximum	5.9	210	190	79	130	100	55	30	84
	Avg. conc. worst case	5.3	190	190	26	550	630	110	58	160
	Mass (g)/kg agent		62	70	75	24	9.4	26	15	26
	Total mass (g)		4200	2,100	4,400	1,100	290	1,000	700	1,000
ACET	1 min maximum	58	5.9	2.6	1.4	7	3.5	0.25	2.9	1.5
	Avg. conc. worst case	0.38	5.1	2.5	0.69	19	12	0.47	4.3	2.6
	Mass (g)/kg agent		0.27	0.16	0.33	0.14	0.08	0.02	0.19	0.07
	Total mass (g)		18	4.6	20	6.2	2.6	0.74	8.7	2.8

APPENDIX A

A Proposed Methodolgy for Flaming Combustion Toxicology Testing
of Halon Replacement Agents

WHITE-NOISE ANALYSIS
OF
CAROTID BARORECEPTOR FUNCTION IN BABOONS

Arthur J. Koblasz, Ph.D.
Associate Professor
School of Civil Engineering

Georgia Institute of Technology
CE 0355
Atlanta, GA 30332

Final Report for:
Research Inititation Program
Armstrong Laboratory

Sponsored by:
Air Force Office of Scientific Research
Bolling Air Force Base, Washington, D.C.

January 1993

WHITE-NOISE ANALYSIS OF CAROTID BARORECEPTOR FUNCTION IN BABOONS

FINAL REPORT

by
Brian R. Carter
Greg S. Zinkel
and
Arthur J. Koblasz
School of Civil Engineering
Georgia Institute of Technology

Abstract

A white-noise protocol was evaluated for characterizing carotid baroreceptor function in baboons. The white-noise (random) stimulus was created by varying the pressure in the right carotid sinus. The baroreceptor response was indicated by continuously measuring the pressure in the right femoral artery. A first-order Wiener kernel was then calculated, which characterized the baroreceptor response to the random stimulus. Next, the first-order Wiener kernel was used to predict the response to a pulse stimulus. This predicted pulse response was then compared with the measured pulse response.

The accuracy of the predicted pulse response demonstrates the accuracy of the first-order Wiener kernel for characterizing the baroreceptor responses to non-random stimuli. Hence, it is possible to perform one white-noise experiment and then use the Wiener kernels to predict the responses to a variety of G-induced pressure changes.

Figure 1. Photographs of animal surgery

Figure 1. Cont.

<u>Background</u>

The white-noise method for characterizing nonlinear biological systems has been successfully demonstrated in catfish retina studies (Marmarelis and Naka, 1973), in human ERG studies (Koblasz, et al, 1980) and in a variety of other vertebrate studies (Marmarelis, 1976). Similar nonlinear characterization schemes have been demonstrated using random square wave stimuli (Yasui and Koblasz, 1984) and random pulse sequences (Fricker and Sanders, 1975).

Recently, a white-noise protocol has been demonstrated in a study of aortic baroreceptor function using in vivo rabbit preparations (Masaru, et. al., 1990). The aortic pressure was modulated by electrically stimulating the right ventricle using pacing electrodes triggered at a constant frequency of 400 beats per minute. The pacing was sustained for variable durations of greater than 1 second per burst, and the interval between bursts was varied to produce aortic pressure fluctuations with a <u>fairly</u> flat power spectrum over the frequency range of DC to 1/2 Hz. (In our protocol, we will block the normal pulsatile flow into the left carotid artery and will then modulate the left carotid pressure to produce a stimulus power spectrum which is <u>very</u> flat over the frequency range of DC to 5 Hz.)

In Masaru's protocol, the aortic pressure was measured using a high-fidelity micromanometer (Millar MPC-500), and the baroreceptor response was measured using Ag/AgCl bipolar electrodes positioned at the distal end of the (desheathed) left aortic depressor nerve. Linear transfer functions were calculated using these stimulus/response data. The resulting math model characterized the combination of aortic wall mechanics followed by neural transduction and encoding mechanisms.

EXPERIMENTAL PROTOCOL

Three adult male baboons were anesthetized with Ketamine (30mg IM) followed by periodic doses of a-Chloralose (50mg/kg for the first dose and 20 mg/hr thereafter). Pancuronium Bromide (.1mg/kg IV) was also given to each animal to reduce muscle activity. A 3-French Millar pressure transducer (single-tipped) was inserted into the right femoral artery to record systemic pressure changes resulting from the pressure stimuli applied to the right carotid sinus. EKG was also recorded to indicate changes in heartrate. Figure 1 presents a collection of photographs which were taken during the animal surgery.

In the first set of experiments, the variations in carotid pressure were produced by randomly varying the flow rate of IV fluid injected into the common carotid artery. The flow rate was modulated using a stepping motor connected to a linear hydraulic valve, as depicted in Figure 2. At periodic intervals, equivalent volumes of blood were removed from the right femoral vein. Unfortunately, the relationship between the volume of blood injected into the carotid artery and the carotid sinus pressure is much more complicated than we had expected. Futhermore, it is difficult to maintain a constant total blood volume during a prolonged experiment.

In the second set of experiments, the right carotid sinus was isolated by ligating all incoming and outgoing vessels approximately 1 cm above and below the carotid sinus. A small catheter was then inserted into the carotid sinus, along with a 2-French Millar (single-tipped) pressure transducer. The catheter was connected to a Skinner three-way hydraulic valve (Type B14), which allowed the catheter to be switched between two reservoirs of warmed physiological saline solution. The reservoirs were positioned at different heights above the carotid sinus; hence, switching between the two reservoirs produced step changes in pressure inside the carotid sinus. Since the carotid sinus was completely isolated, the pressure shifts occurred nearly instantaneously with no significant flow of saline into or out of the sinus.

The circuit shown in Figure 3 was used to create a pseudo-random binary (two-level) signal and was also used to generate periodic step and pulse signals-- the latter being more conventional stimuli. The pseudo-random binary signal was used as a control input to the three-way hydraulic valve, thus producing pseudo-random binary pressure changes inside the carotid sinus. The more conventional step and pulse stimuli were also generated to validate the pseudo-random data (see report for Summer 1992).

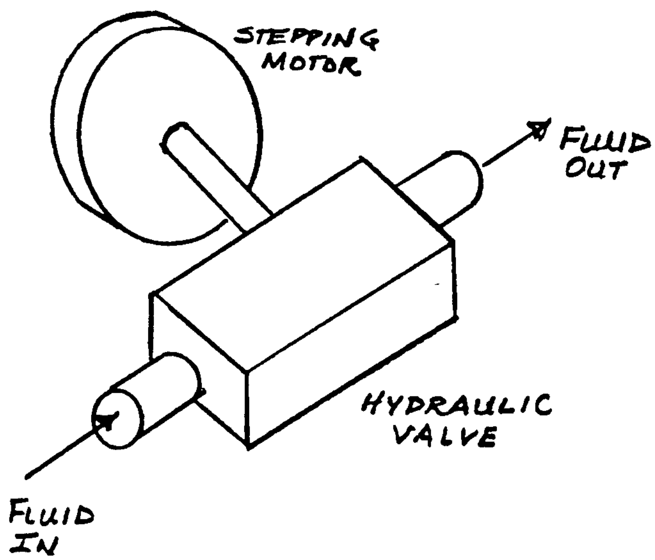

FIGURE 2
Linear hydraulic valve

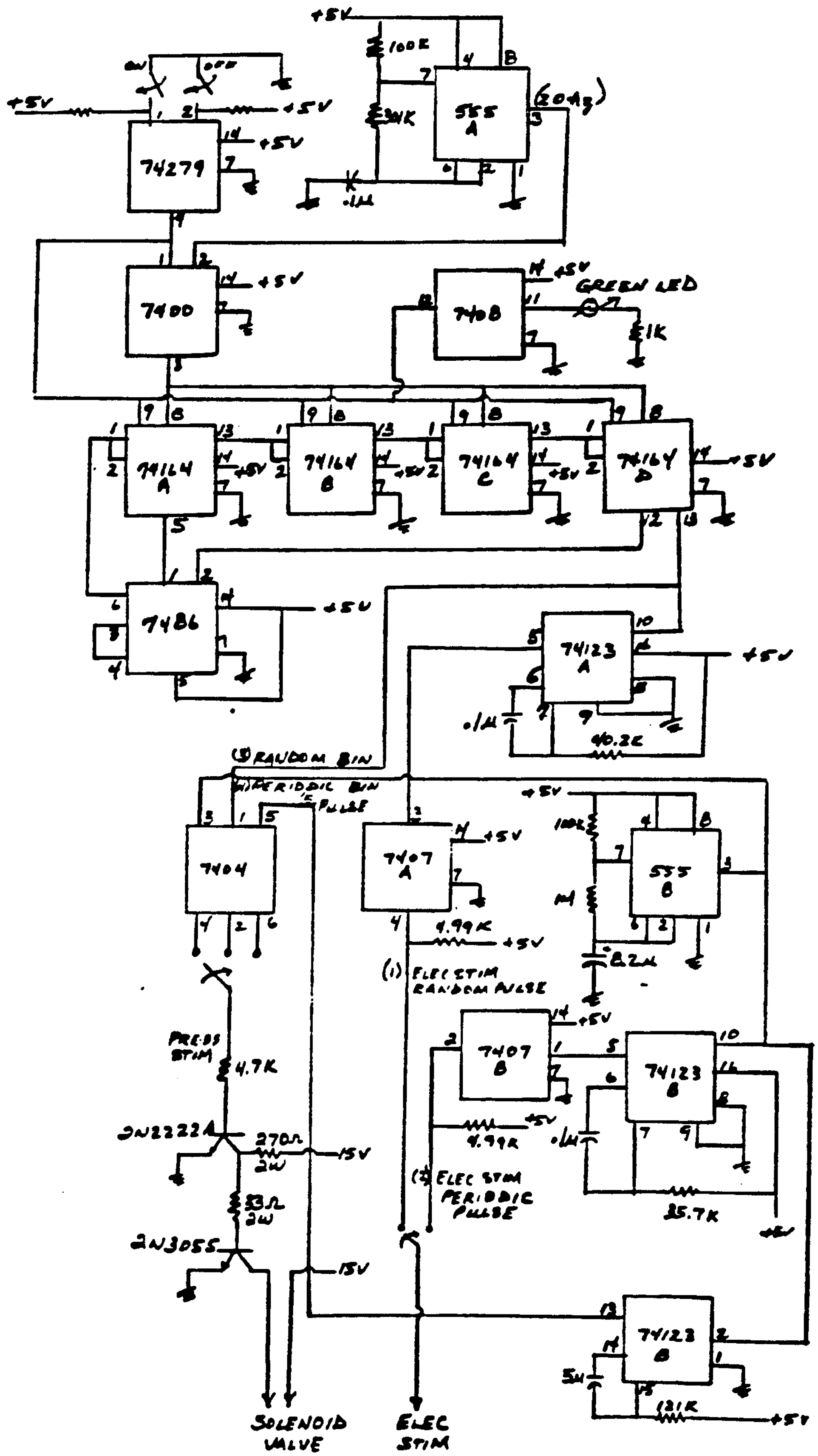

Figure 3
Electrical Circuit

During each period of data acquisition, the pseudo-random binary stimulus was sustained for three minutes . In the first run, the two reservoirs were positioned to provide a mean carotid pressure of 40mm Hg, and the random binary stimulus fluctuated about the mean by ± 20mm Hg. In the second run, the mean was raised to 70mm Hg, and the binary fluctuations were first set at ± 20mm Hg and then increased to ± 50mm Hg. In the last run, the mean was set at 100mm Hg and the binary fluctuations were ± 20mm Hg.

RESULTS

Two Georgia Tech students (B. Carter and G. Zinkel) are currently analyzing the data collected in the above experiments, and they are also analyzing the pulse/step data collected in other experiments (see report for Summer 1992). Thus far, several files of data have been low-pass filtered (100 Hz corner frequency) and played into a 12 Bit A/D converter (Data Translation, DT2801A) at a sampling rate of 200 Hz. These files have been copied onto 3 1/2" microdisks and mailed to Georgia Tech.

The students are calculating first-order Wiener kernels for the pseudo-random binary data (Koblasz, 1978-- see Appendix), and they are also computing average pulse and step responses from the data obtained last summer. The first-order Wiener kernels are used to predict the reponses to impulse stimuli. These predicted responses are then compared with the measured pulse responses for the same stimulus conditions (i.e. the same average pressure in the carotid sinus). The differences between the predicted impulse responses (via Wiener kernels) and the measured pulse responses (via pulse stimuli) demonstrate the accuracy of the Wiener kernels in characterizing the baroreceptor control system. Figure 4 shows the BASIC program which was written to perform these analyses.

Figure 5 shows a plot of the carotid pressure during the second run when the mean was set at 70mm Hg and the random binary fluctuations were ± 50mm Hg. Figure 6 presents a plot of the pressure measured in the right femoral artery-- during the same period of time as presented in Figure 5. The low frequency periodic component of the femoral pressure is related to respiration and the higher frequency component is the typical systolic/diastolic waveform. Figure 7 displays the first-order Wiener kernel calculated for 160 seconds of data during this period when the pseudo-random stimulus was set at 70mm Hg ± 50mm Hg. For this calculation, the stimulus was the measured carotid pressure (Figure 5) and the response was the pressure in the femoral artery (Figure 6).

```
'....................sub: rdata............
CONST arraysiz = 32000
m% = arraysiz
'$DYNAMIC
CLS
DIM VIN1(arraysiz) AS INTEGER
DIM VOUT1(arraysiz) AS INTEGER
DIM VIN2(arraysiz) AS INTEGER
DIM VOUT2(arraysiz) AS INTEGER
DIM H!(1000)

OPEN "c:\91wn70" FOR BINARY AS #1
OPEN "c:\91wn70RV.dat" FOR OUTPUT AS #11 LEN = 16000
OPEN "c:\91wn70L.dat" FOR OUTPUT AS #12 LEN = 16000
OPEN "c:\91wn70H.dat" FOR OUTPUT AS #13 LEN = 32000

i% = 0
WHILE NOT EOF(1)
    i% = i% + 1
    IF i% > arraysiz THEN
        PRINT "maximum storage space filled."
        GOTO QuitMe
    END IF
    GET #1, 3! + (i% - 1!) * 10!, VIN1(i%)
    GET #1, 9! + (i% - 1!) * 10!, VOUT1(i%)
    ' .....set according to +- values
    VIN1(i%) = VIN1(i%) - 2048
    VOUT1(i%) = VOUT1(i%) - 2048
    IF i% MOD 150 = 0 THEN PRINT i%
'     .....Write the data in human readable format.
    WRITE #11, i%, VIN1(i%), VOUT1(i%)
WEND
PRINT i%
QuitMe:

CLOSE #1
CLOSE #11
PRINT
PRINT
PRINT "32,000 records have successfully been stored in data file"

'         ....................AVERAGING.........................
FOR AV% = 1 TO m%
    TOT& = TOT& + VIN1(AV%)
NEXT AV%
XBAR% = TOT& \ m%
PRINT
PRINT "The average of the input voltages is", XBAR% / 819.2

'         ...................AC COUPLING.......................
FOR XSUM% = 1 TO m%
    DUM% = VIN1(XSUM%) - XBAR%
    VIN1(XSUM%) = DUM%
NEXT XSUM%
'         ...................LOW PASS FILTER...................
N% = m% - 5
FOR i% = 6 TO N%
'         .....low pass vin
    SUML% = VIN1(i% - 5) + VIN1(i% - 4) + VIN1(i% - 3) + VIN1(i% - 2)
    SUMID% = VIN1(i% - 1) + VIN1(i%) + VIN1(i% + 1)
```

Figure 4. BASIC Program

```
    SUMH% = VIN1(i% + 2) + VIN1(i% + 3) + VIN1(i% + 4) + VIN1(i% + 5)
    VIN2(i%) = (SUML% + SUMID% + SUMH%) / 11
         .....low pass vout
    SUML% = VOUT1(i% - 5) + VOUT1(i% - 4) + VOUT1(i% - 3) + VOUT2(i% - 2)
    SUMID% = VOUT1(i% - 1) + VOUT1(i%) + VOUT1(i% + 1)
    SUMH% = VOUT1(i% + 2) + VOUT1(i% + 3) + VOUT1(i% + 4) + VOUT1(i% + 5)
    VOUT2(i%) = (SUML% + SUMID% + SUMH%) / 11
    SUML% = SUMID% = SUMH% = 0
    'IF i% MOD 150 = 0 THEN PRINT i%, VIN1(i%), VIN2(i%), , VOUT1(i%), VOUT2(i%)
NEXT i%
FOR i% = 6 TO N%
    VIN1(i%) = VIN2(i%)
NEXT i%
FOR i% = 11 TO N% - 5
'        ..... 2nd low pass vin
    SUML% = VIN1(i% - 5) + VIN1(i% - 4) + VIN1(i% - 3) + VIN1(i% - 2)
    SUMID% = VIN1(i% - 1) + VIN1(i%) + VIN1(i% + 1)
    SUMH% = VIN1(i% + 2) + VIN1(i% + 3) + VIN1(i% + 4) + VIN1(i% + 5)
    VIN2(i%) = (SUML% + SUMID% + SUMH%) / 11
    WRITE #12, i%, VIN2(i%), VOUT2(i%)
NEXT i%
'        ....................CROSS CORRELATION.................
FOR i% = 1 TO 1000
    O% = m% - 1000
    SUM! = 0
    FOR j% = 6 TO O%
        SUM! = SUM! + VIN2(j%) / 819.2 * VOUT2(j% + i%) / 819.2
    NEXT j%
    H!(i%) = SUM! / O%
    PRINT i%, H!(i%)
    WRITE #13, i%, H!(i%)
NEXT i%
CLOSE #1, #11, #12, #13
END
```

```
'....................sub: rdata1............
CONST arraysiz = 32000
'$DYNAMIC
CLS
DIM VIN1(arraysiz) AS INTEGER
DIM VOUT1(arraysiz) AS INTEGER
DIM VOUT2(arraysiz) AS INTEGER

OPEN "c:\91pp70" FOR BINARY AS #1 LEN = 30000
OPEN "c:\91pp70RV.dat" FOR OUTPUT AS #11 LEN = 30000

i% = 0
WHILE NOT EOF(1)
    i% = i% + 1
    IF i% > arraysiz THEN
        PRINT "maximum storage space filled."
        GOTO quitme
    END IF
    GET #1, 3! + (i% - 1!) * 10!, VIN1(i%)
    GET #1, 9! + (i% - 1!) * 10!, VOUT1(i%)
'   .....set according to +- values
    VIN1(i%) = VIN1(i%) - 2048
    VOUT1(i%) = VOUT1(i%) - 2048
    IF i% MOD 250 = 0 THEN PRINT i%
    .....Write the data in human readable format.
    WRITE #11, i%, VIN1(i%), VOUT1(i%)
WEND
PRINT i%
quitme:
CLOSE #1
CLOSE #11
PRINT
PRINT
PRINT "32,000 records have successfully been stored in data file"
'         ..................ENSEMBLE VALUES......................
OPEN "c:\91pp70E.dat" FOR OUTPUT AS #12 LEN = 16000
FOR j% = 1 TO 1500
    SUM& = VOUT1(433 + j%) + VOUT1(2714 + j%) + VOUT1(4992 + j%)
    SUM& = SUM& + VOUT1(7268 + j%) + VOUT1(9543 + j%) + VOUT1(11814 + j%)
    SUM& = SUM& + VOUT1(14091 + j%) + VOUT1(16365 + j%) + VOUT1(18640 + j%)
    SUM& = SUM& + VOUT1(20911 + j%) + VOUT1(23185 + j%) + VOUT1(25461 + j%)
    SUM& = SUM& + VOUT1(27731 + j%) + VOUT1(30019 + j%)
    VOUT2(j%) = SUM& \ 14
    SUM& = 0
'    PRINT VOUT1(j% + 14161), VOUT2(j%), VOUT1(j% + 16435), VOUT1(18710 + j%), V
    WRITE #12, j%, VOUT2(j%)
NEXT j%

'        ....................AVERAGING........................
FOR XSUM% = 1 TO m%
    DUM% = VIN1(XSUM%) - XBAR%
    VIN1(XSUM%) = DUM%
NEXT XSUM%
CLOSE 12
END
```

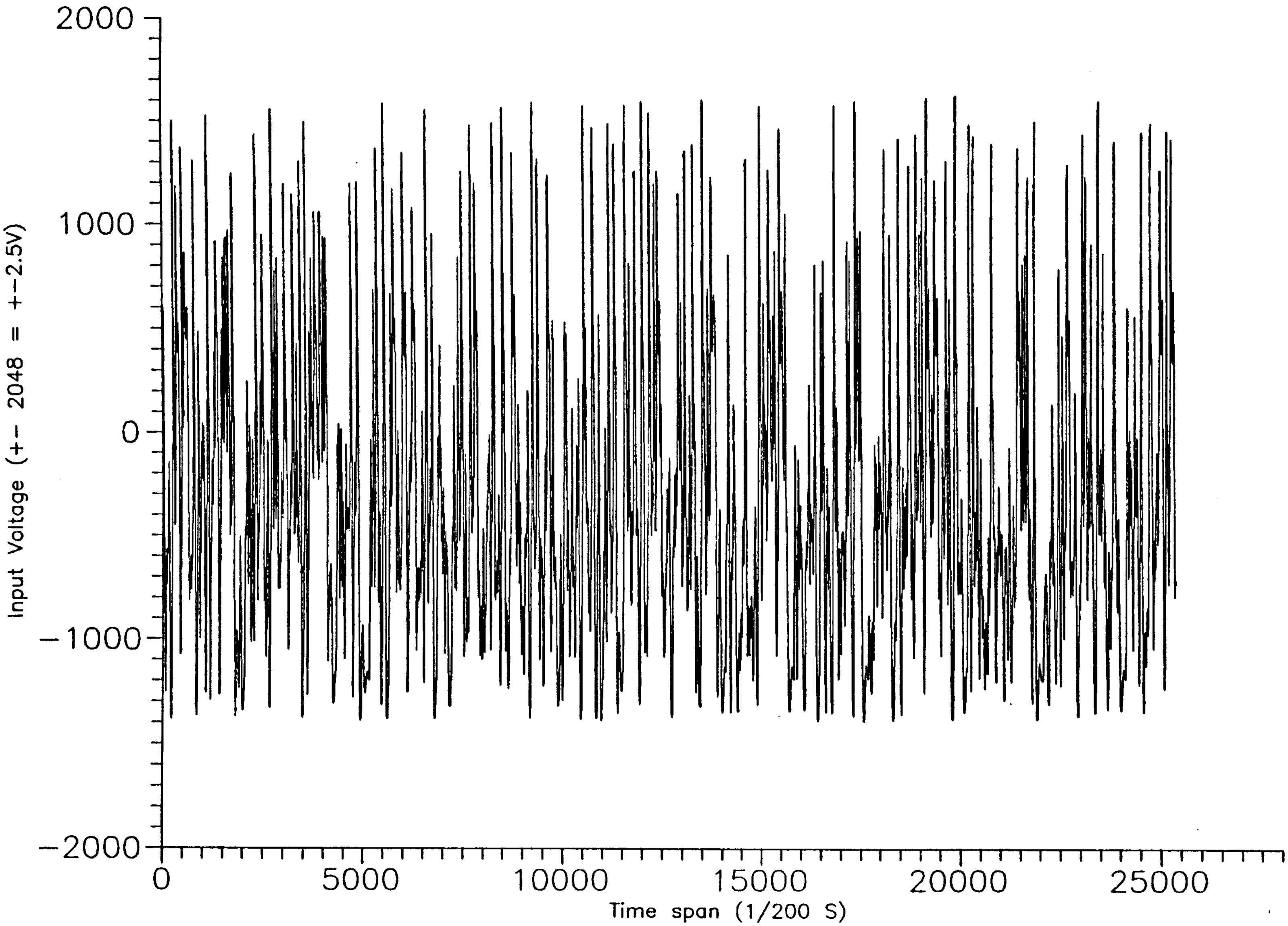

Figure 5. Right Carotid pressure during pseudo-random experiment

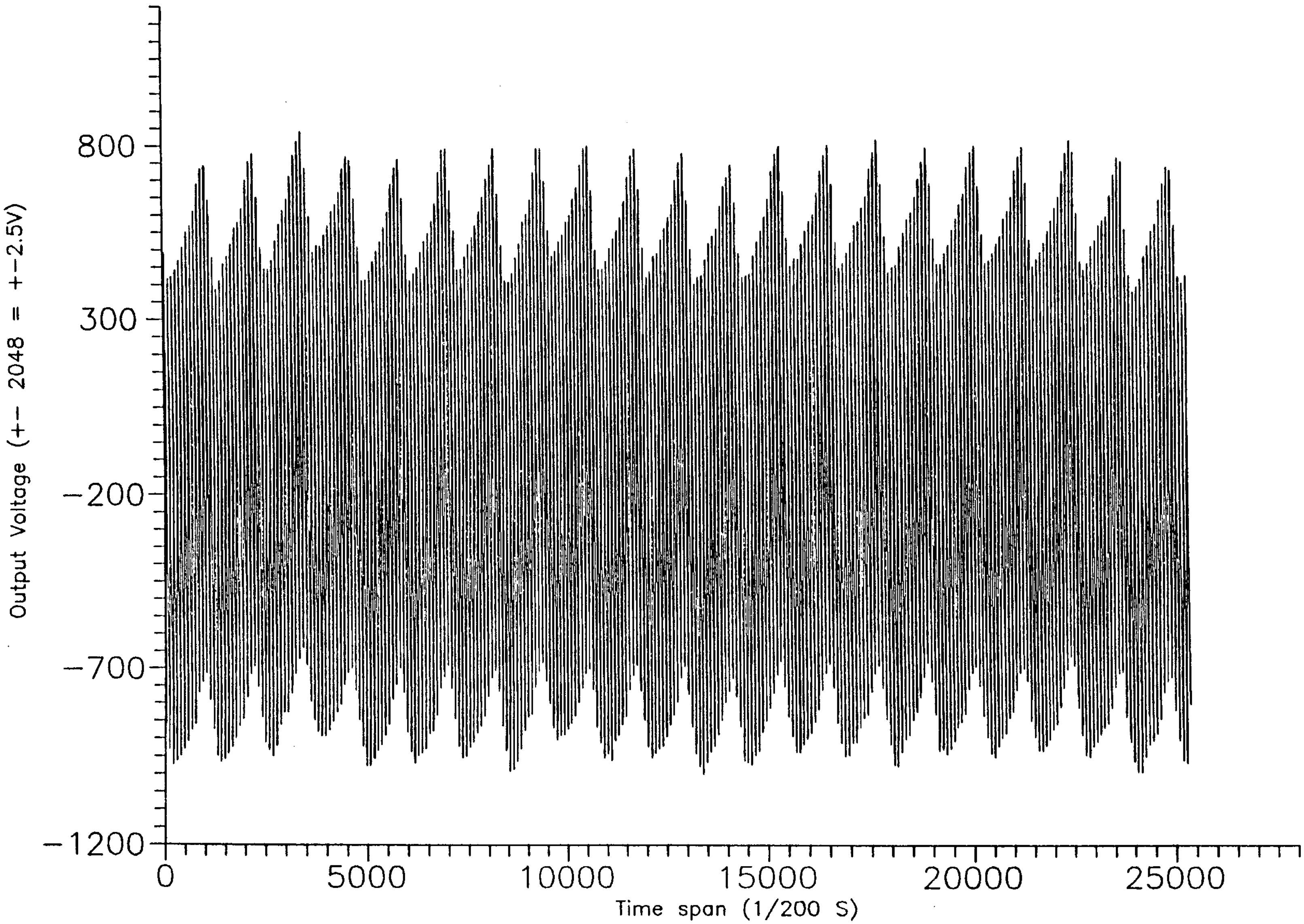

Figure 6. Right Femoral Artery pressure during pseudo-random experiment

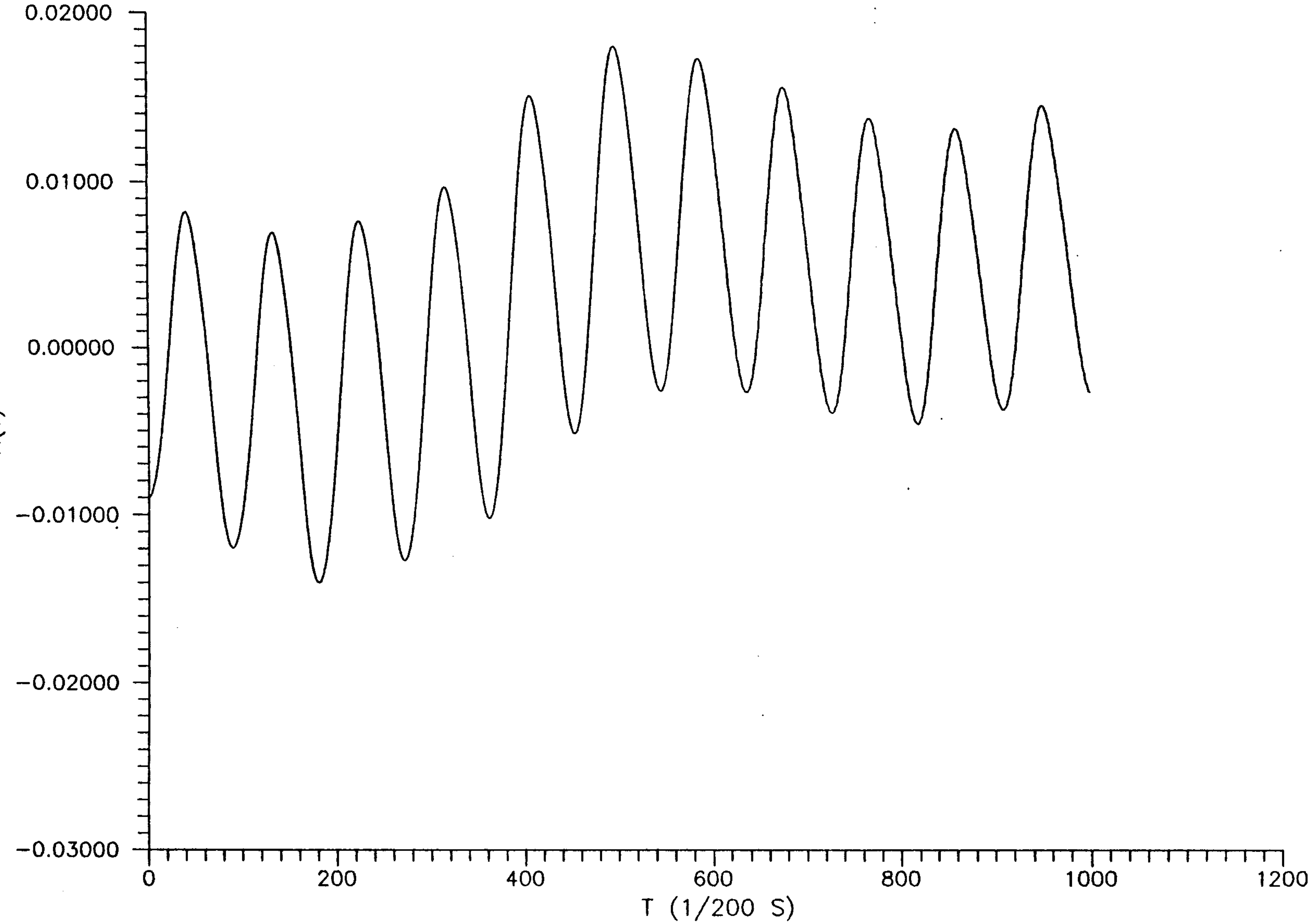

Figure 7. First-order Wiener kernel

The first-order Wiener kernel is the best linear prediction (i.e. least mean square error) of the impulse response; therefore, the first-order kernel in Figure 7 displays the predicted reponse (at the femoral artery) to a hypothetical impulse stimulus (at the carotid sinus). The predicted impulse response contains systolic/diastolic fluctuations with a gradual increase and subsequent decrease in systolic/diastolic pressure. Figure 8 is a plot of the predicted systolic pressure versus time following the hypothetical impulse stimulus. The peak value of the systolic pressure occurs at 2.5 seconds following the impulse stimulus.

Figure 9 shows a plot of the average femoral pressure response to 11 pulse stimuli presented at the carotid sinus. Each pulse stimulus had a duration of .2 seconds, an amplitude of 50mm Hg and was superimposed onto a steady pressure level of 70mm Hg (see final report for Summer 1992). Figure 10 shows how the average systolic pressure varies following the pulse stimulus. At this time, we are not certain why the measured pulse response has a peak value at approximately 3.5 seconds, when the Wiener prediction is 2.5 seconds. One possible explanation for this difference is that the actual pulse stimulus had a duration of more than .2 seconds and ringing which continued for about .5 seconds; hence, it was not a very good approximation of an impulse stimulus. On the other hand, we have not yet examined the power spectrum or the probability density of the pseudo-random stimulus.

During the next 12 months, Georgia Tech students will transfer the remaining files via Ethernet to our 386 Microcomputer at Georgia Tech. We will analyze the remaining data and will hopefully reveal the following details:

1) how much the second-order Wiener kernel improves the predicted impulse response,

2) how accurately the first- and second-order Wiener kernels predict the step response, and

3) how much the first- and second-order Wiener kernels are dependent upon mean carotid pressure.

We will also begin considering the feasibility of stimulating two baroreceptors at the same time, using independent pseudo-random modulations of pressure at each location. This two-input protocol will characterize the nonlinear interactions (e.g. inhibition or facilitation) between the two baroreceptors.

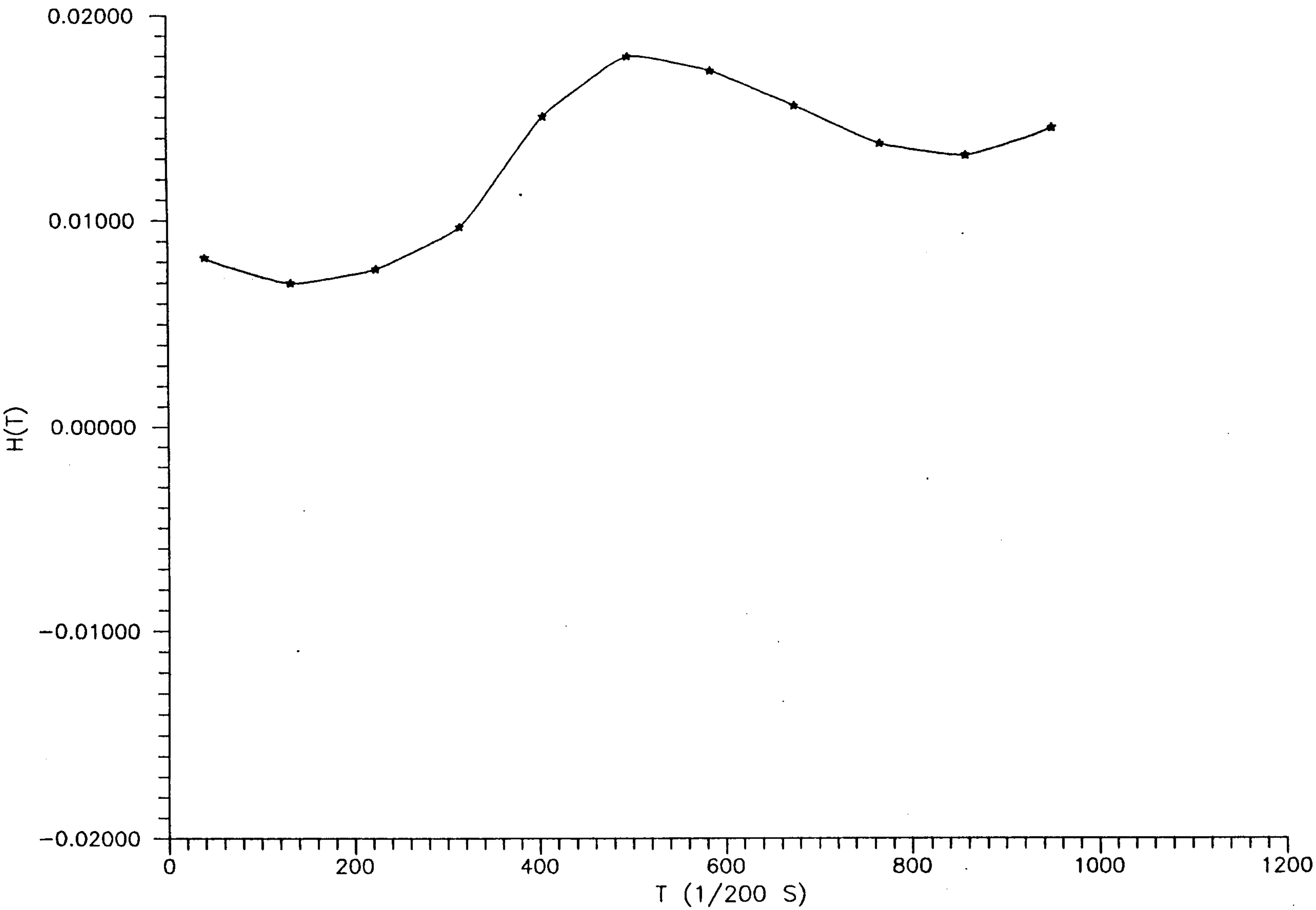

Figure 8. Predicted peak systolic pressure in Right Femoral Artery following impulse stimulus at Right Carotid Sinus

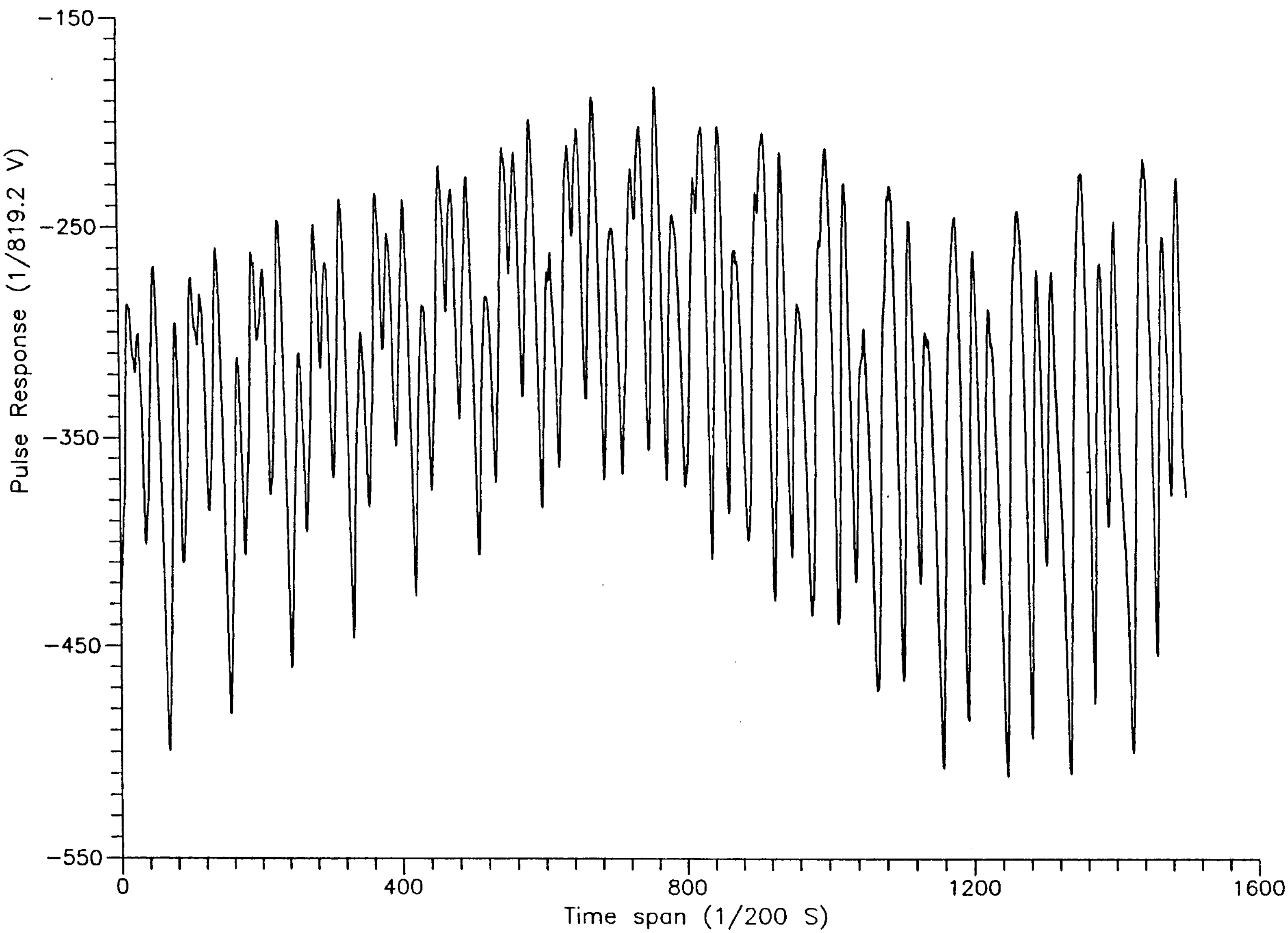

Figure 9. Measured pulse response at Right Femoral Artery-- averaged over 11 pulse stimuli presented at Right Carotid Sinus

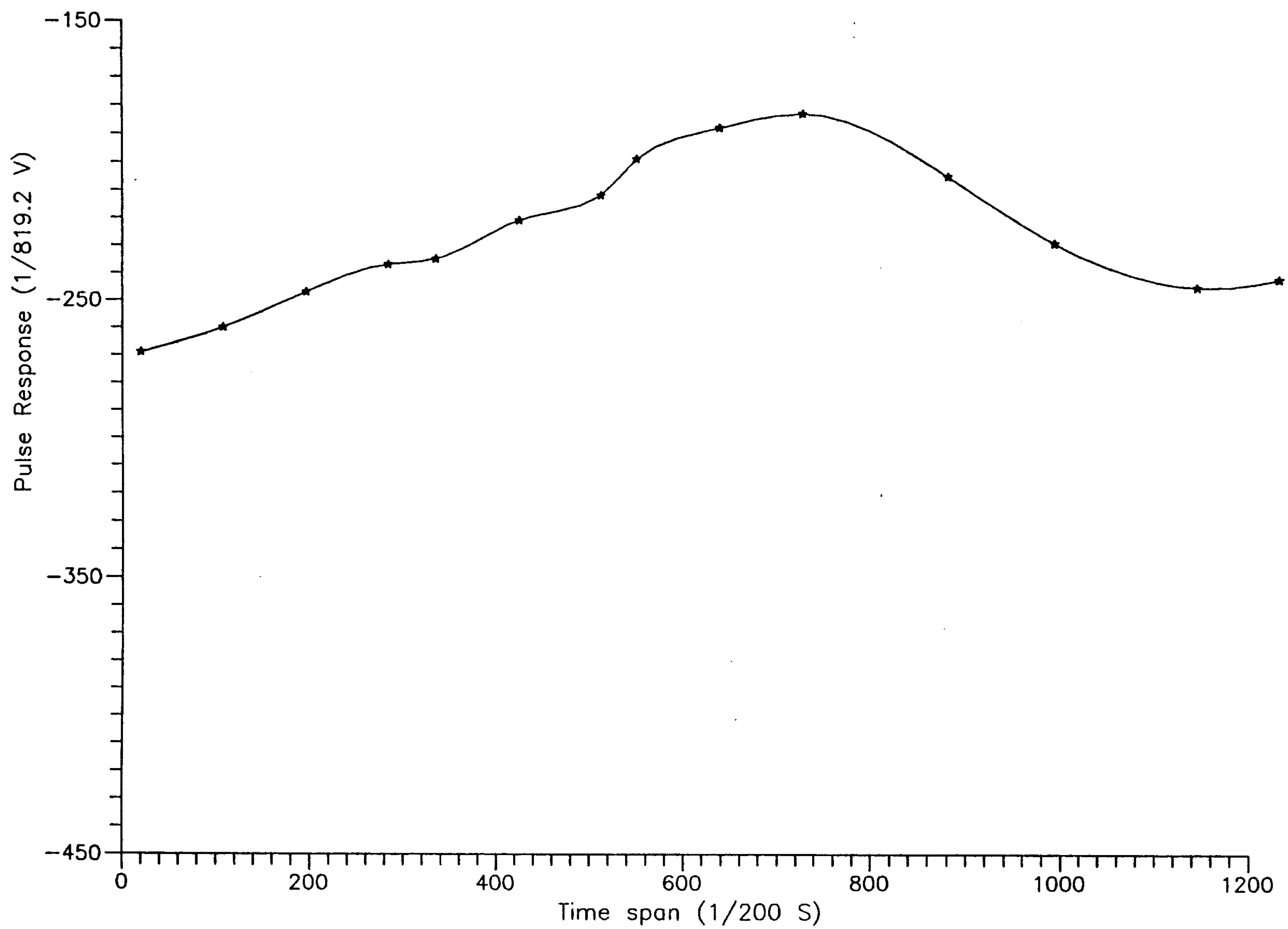

Figure 10. Average systolic response at Right Femoral
for 11 pulse stimuli presented at Right Carotid Sinus

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APPENDIX

White-noise analysis of biological systems

Arthur Koblasz, Ph.D.

Departments of Ophthalmology & Otolaryngology, The University of Texas Medical Branch, Galveston, Texas 77550

The linear and nonlinear operations of a biological system can be represented by a set of functions called Wiener kernels. This type of analysis is becoming increasingly important in the field of biological systems analysis. This paper reviews the theoretical and practical aspects of testing a biological system with white-noise and provides a guide for interpreting Wiener kernels which result from such studies. A study of the human electroretinogram is presented as an example.

Introduction

Researchers have been studying biological systems for centuries. Usually the unknown system is analysed by controlling an input to the system and observing the response. Both linear and nonlinear analyses are possible using test inputs of pulses, square waves, or sinewaves. A linear system can be entirely characterized by its unit-impulse response. Furthermore, once the unit-impulse response of a linear system is known, the response to any input can be predicted using the convolution integral. A nonlinear system can also be studied using a stimulus which is a sequence of impulses. However, the impulse response is likely to be a nonlinear function of the impulse amplitude. Furthermore, the response to one input stimulus may change the characteristics of the system such that the next impulse stimulus elicits a different response.

Recently, a new testing procedure which utilises band limited white-noise inputs [1, 2, 3] has become popular. For time-invariant nonlinear systems, Wiener [1] proposed the following functional expansion to define the response y(t) for a zero-mean, Gaussian, white-noise input x(t):

$$y(t) = \sum_{n=0}^{\infty} G_n(h_n;x)$$

where the first three terms of the expansion are

$$G_0 = h_0$$

$$G_1 = \int_0^{\infty} h_1(\tau)x(t-\tau)d\tau$$

$$G_2 = \int_0^{\infty}\int h_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 - P\int_0^{\infty} h_2(\tau_1,\tau_1)d\tau_1$$

The term $G_1(h_1; x)$ is like the convolution integral of linear system theory. The functions $h_n(\tau_1,\ldots,\tau_n)$ called Wiener kernels and P refers to the constant power spectral density of the white-noise stimulus. Once the Wiener kernels are known, the response y(t) to any input x(t) can be predicted. Hence, the characterization problem becomes one of estimating the Wiener kernels for the unknown system.

Lee and Schetzen [2] derived the following equation to estimate the Wiener kernels in time of multiple-order cross-correlations between the white-noise stimulus and the measured response:

$$h_n(\tau_1,\tau_2,\ldots,\tau_n) = \frac{1}{n!P^n} E\{[y(t) - \sum_{k=1}^{N} G_{n-2k}(h_{n-2k};x)]x(t-\tau_1)\cdots x(t-\tau_n)\} \quad (3)$$

where E denotes expected value and N is the largest integer not exceeding n/2.

That is,

$$h_0 = E\{x(t)\}$$

$$h_1(\tau) = \frac{1}{P}E\{y(t)x(t-\tau)\}$$

$$h_2(\tau_1,\tau_2) = \frac{1}{2P^2}E\{[y(t)-h_0]x(t-\tau_1)x(t-\tau_2)\} \quad (4)$$

For example, the double cross-correlation which defines $h_2(\tau_1,\tau_2)$ is obtained by simply multiplying the response y at each time t by the preceding stimulus amplitude at time $t-T_1$, and then again multiplying this product by the stimulus amplitude at time $t-T_2$. The average value of this double product for all t indicates the value of the second-order kernel $h_2(\tau_1,\tau_2)$ at $\tau_1 = T_1$ and $\tau_2 = T_2$.

Defining the response in terms of the Wiener expansion becomes theoretical very simple. However, the characterization is computationally practical only when the higher-order kernels are relatively small, in other words, when the Wiener expansion can be truncated after some low-order term. Although the expansion is mean-square convergent for white-noise inputs, it may not converge for deterministic inputs. Hence, it is best to interpret the Wiener kernels in the context of a white-noise stimulus.

The general interpretation of the Wiener kernels is discussed in reference [4]. If the Wiener expansion can be truncated after the second-order term, then the kernels can be more simply interpreted in terms of impulse responses as described in reference [3]. That is, suppose an impulse of amplitude m_1 occurs at time T_1, as an input $x(t) = m_1\delta(t-T_1)$, where $\delta(t-T_1)$ is a dirac delta function.

Then from equations (1) and (2), the predicted response is

$$y_1(t) = C_1 + m_1h_1(t-T_1) + m_1^2h_2(t-T_1,t-T_1) \quad (5)$$

where the constant

$$C_1 = h_0 - m_1^2\int_0^{\infty} h_2(\tau,\tau)d\tau \quad (6)$$

Notice if the system were linear, the second- and higher-order kernels would be zero. Then changes in the magnitude of the impulse stimulus would only produce changes in the amplitude of the predicted response, i.e., $y_1(t) = C + m_1h_1(t-T_1)$. However, for a nonlinear system, because of the different scale factors for the first- and second-order kernels, the shape of the impulse response can be a function of the amplitude of the input impulse.

If we next let the input be an impulse at time T_2 of amplitude m_2, then

$$y_2(t) = C_2 + m_2h_1(t-T_2) + m_2^2h_2(t-T_2,t-T_2) \quad (7)$$

Finally, if the input is a combination of the pulse at T_1 and the pulse at T_2, then the double-impulse predicted response is

$$y_3(t) = y_1(t) + y_2(t) + 2m_1m_2h_2(t-T_1,t-T_2) \quad (8)$$

The term $2m_1m_2h_2(t-T_1,t-T_2)$ is a measure of the error in assuming the superposition of the single-impulse responses $y_1(t)$ and $y_2(t)$ referred to above. This error is usually dependent on the spacing between the two pulses (T_2-T_1).

Hence, we could determine the second-order Wiener kernel for this special case by simply measuring the single-impulse responses for different amplitude impulses and the double-impulse responses for different spacing between impulses. The second-order kernel could be then tabulated as in Figure 1a or drawn as a contour map by connecting points of equal value as in Figure 1b. Finally, the axes of the contour map could be changed as in Figure 1c, which is the format used in subsequent figures. On the other hand, it is much simpler to estimate the Wiener kernels using the cross-correlation formula of equation (3).

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Pitfalls in the practical application

There are several subtle assumptions associated with the Wiener expansion which at times make the practical application of the theory very difficult. First, it is impossible to generate a perfectly Gaussian and white stimulus. The bandwidth of the white-noise signal must be finite and is frequently not exactly flat for any range of frequencies. Furthermore, the stimulus characteristics may change significantly between experiments; therefore, the same random stimulus should be repeated for all experiments in order to insure that differences in the kernels are not related to differences in stimulus characteristics. Then it is appropriate to consider the characterization problem as depicted in Figure 2. If the bandwidth of the white-noise stimulus encloses the characteristic bandwidth [3] of the unknown system and if the bandpass characteristics are known, then the exact transfer characteristics of the unknown system can be deconvolved from the kernels defining the total system, which is obvious from references [5] and [6]. Fortunately, the deconvolution is not necessary for empirical studies, in other words, when it is sufficient to identify structural changes in the kernels for the total system in Figure 2 resulting from functional changes of the unknown biological system.

Another pitfall in the practical application of the theory involves the assumption of time-invariance. Many biological systems undergo systematic changes in characteristics with respect to time (for example, retinal adaptation), which are actually deterministic and time-invariant. Yet for testing periods comparable in time to the time constant of the biological changes, the system will be seen to be time-variant. In such cases the kernels estimated by equation (3) will reflect the time average of the system characteristics during the testing period, which can be useful information. However, the Wiener expansion will be invalid.

Another mistake possible in implementing the theory is related to the common assumption that third- and higher-order kernels are insignificant. The functional interpretation of the kernels is highly dependent upon the amplitudes of the higher-order terms in the Wiener expansion [4]. A simple test for the significance of higher-order terms in the Wiener expansion is to use the lower-order terms to predict the response to the same white-noise stimulus originally used for testing the system [3]. If the predicted response is nearly the same as the measured response, then it is safe to assume higher-order terms are insignificant for white-noise inputs.

This test for nonlinearities is not possible when the signal-to-noise ratio is very small, which is frequently the case for biological measurements. Another (partial) test more appropriate for noisy systems is to measure the response to discrete sinewave stimuli with a range of frequencies covering the bandwidth of the white-noise stimulus. The amplitude of the n_{th}- harmonic of the sinewave response indicates the magnitude of the main diagonal of the n-dimensional Fourier Transform of the n_{th}-order kernel, but does not assess the amplitudes of off-diagonal components (deduced from equation (6) of reference [5]).

Finally, the signal-to-noise ratio itself can be a major problem in implementing the theory. The white-noise stimulus tests the system with relatively small modulations about the mean of the stimulus. This permits testing at physiological levels, but since the stimulus is small, the response is also small; consequently, the signal-to-noise ratio of the measured response can become very small. However, if the noise is uncorrelated with the stimulus, very long experiments can be performed to effectively average out the uncorrelated noise [4]. Alternatively, a different type of random stimulus which has a

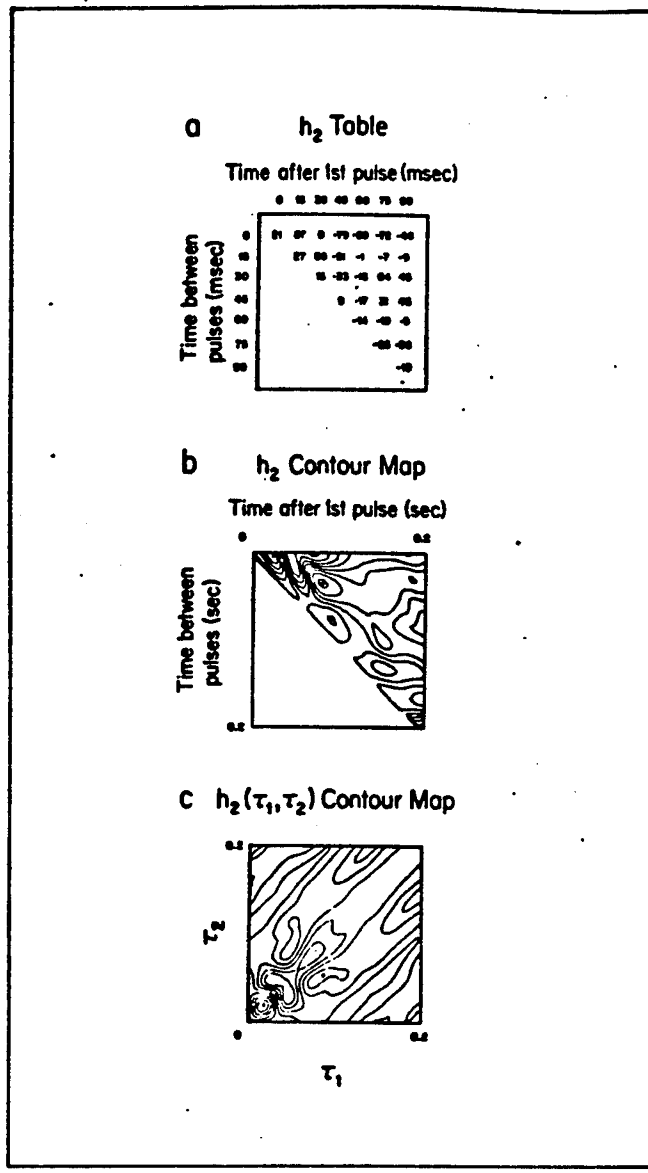

Figure 1. (a) table representing second-order Wiener kernel derived from two inpulse experiments, i.e., the measured response is the superposition of single pulse responses plus values shown in the table along a horizontal line specified by the spacing between the pulses; (b) contour map obtained by connected points of equal value in matrix similar to that presented in Figure 1(a); (c) contour map resulting when axes of Figure 1(b) are changed.

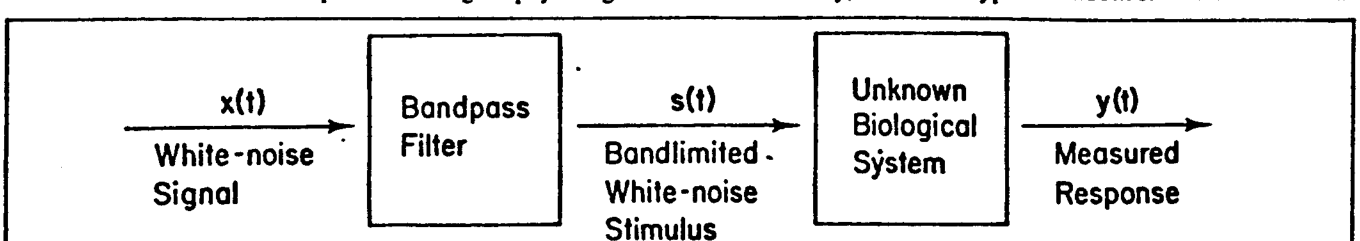

Figure 2. Equivalent system which accounts for the finite bandwidth of the stimulus.

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non-Gaussian amplitude distribution, such as a pseudo-random binary sequence (PRBS), can be used. In general, such alternative stimuli produce larger response signals, but the resulting kernels are more difficult to interpret.

Example application

We have analyzed the human electroretinogram (ERG) response to white-noise modulations in light intensity [7]. The retinal response to a light stimulus causes local changes in ion concentrations which are propagated to the front corneal surface of the eye via the electrolytic media inside the eye. An electrode positioned near the front corneal surface detects a spatial average of this retinal response and is called the ERG. The characteristics of the ERG are known to change systematically for certain retinal diseases. For example, the scotopic components of the ERG flash response are significantly attenuated by retinitis pigmentosa [7]. It is possible that the Wiener kernels will empirically reflect these functional changes more precisely. The following experiment produced first- and second-order Wiener kernels for assumed normal subjects with the same retinal adaptation states.

Equipment

There are several ways to generate a Gaussian, bandlimited, white-noise voltage signal. We used a design which applied the random noise signal generated by a reverse-biased zener diode to a digital circuit designed to produce a random-period binary signal [7]. When this is appropriately high- and low-pass filtered, it produces the desired continuous random signal [8, 9].

Figure 3 shows the optical bench used to provide white-noise stimuli of different mean levels. The pen motor rotated a 3M louver filter. The transmission through this filter was proportional to the sine of the angle between the plane of the filter and the incident light. We used maximum louver excursions of only six degrees, and within this range the transmission can be assumed proportional to the angle with an error less than .2%; therefore, white-noise current signals driving the pen motor produced the desired modulations in light intensity. The modulated light was next passed through neutral density filters to permit step changes in the mean level of the random modulations. The light was then optically condensed onto one end of a coherent fibre-optic bundle and transmitted to the Maxwellian optical assembly also shown in Figure 3. This assembly of lenses created a 45-degree Maxwellian view [7] of the light stimulus with a superimposed cross-hair target located virtually at infinity.

The ERG response was measured by the cup electrode [10] mounted at the top of the Maxwellian optical assembly. The cup was first filled with an artificial tear solution, then each subject submerged his eye into the solution with an orientation similar to that required when looking into a conventional microscope. An annular-shaped Ag/AgCl electrode suspended in the solution detected the ERG signal, and a second cup electrode measured the ERG of the unstimulated eye for use as a reference signal.

During an experiment, the stimulus and response signals were sampled at 5 ms intervals (in other words, 100 Hz Nyquist folding frequency) by a 12-bit A/D converter, and multiplexed onto a digital tape. Later the data sets were digitally filtered and analyzed using a PDP-11/45 computer system.

Experimental protocol

A normal adult male subject was used for the white-noise ERG test. The subject was initially exposed to ambient room illumination of approximately 3 cd/m² for a period of 15 minutes. After this preliminary adaptation period, the subject submerged each eye into the solution contained in the cup electrodes and adjusted himself to attain a 45-degree Maxwellian view of the white-noise stimulus. As discussed above, the stimulus was super-imposed onto a cross-hair target located virtually at infinity and projected to the right eye; the ERG response was measured from the stimulated right eye with respect to a reference signal obtained from the unstimulated left eye. The mean of the random stimulus was set at 85 trolands (td.) for the first three minutes, then immediately changed to 850 td. for a second three-minute period, and finally changed to 8500 td. for the last three minutes.

Results and Discussion

Figure 4 presents the mean first-order Wiener kernal ± one standard deviation of the mean, for an ensemble of four 30-

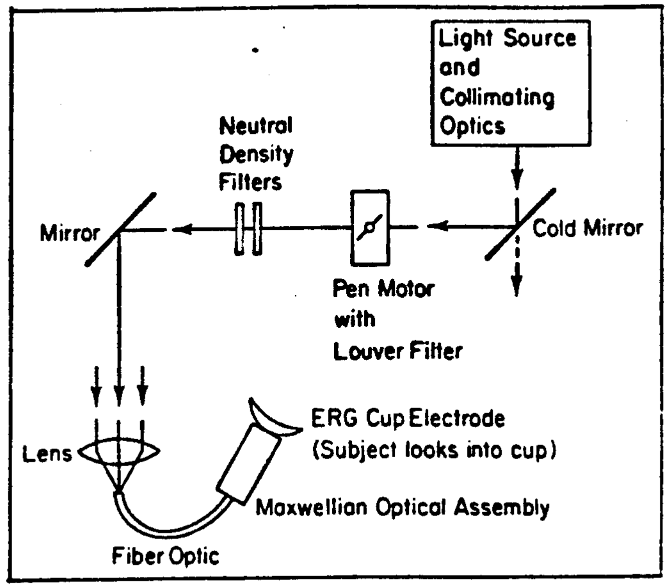

Figure 3. Electro-optical bench and ERG cup electrode.

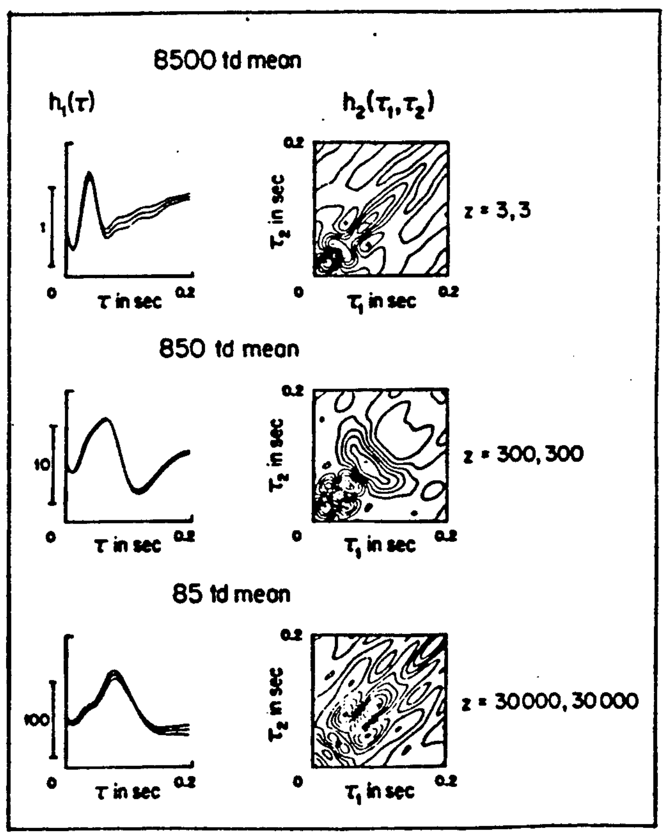

Figure 4. Mean $h_1(T)$ and mean ± standard deviation of the mean along with mean $h_2(T_1, T_2)$ for different average levels of white-noise light stimuli; the numbers alongside the kernel estimates indicate the relative amplitudes of the kernels.

second segments of data at each intensity level. A contour plot of the mean second-order kernel for each level is also shown for this subject.

The standard deviation of the mean of each first-order kernel estimate is relatively small, signifying that only small variations occur between kernels estimated for the same stimulus conditions. Yet both the first- and second-order kernels change drastically for step changes in the stimulus mean. Hence, we can infer that the kernels are reliable and in some way reflect actual ERG characteristics. However, the exact transfer characteristics of the ERG are undoubtedly distorted as discussed in the context of Figure 2.

It is possible to relate some of the *observed* changes in the kernels with *changes* in retinal function. For example, the maximum amplitudes of the kernels decrease with increasing stimulus mean, reflecting a general decrease in retinal sensitivity. The latencies of the distinct components also seem to decrease with increasing stimulus mean. Hopefully, such changes in the kernels can be empirically linked with retinal disease processes.

Hence, the first- and second-order Wiener kernels can accurately characterize both linear and nonlinear aspects of the ERG system. Furthermore, the representation is in a concise and meaningful form. Presumably many biological systems can be studied using the analytical procedures described for the ERG, and the results may offer better resolution of the mechanisms which control the system.

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The experimental work presented in this manuscript was performed in the laboratories of Dr. Derek H. Fender at the California Institute of Technology. I am very grateful for the guidance and help availed there by Dr. Fender and his laboratory assistants. I am also very grateful for the many theoretical insights generously rendered by Dr. Syozo Yasui of the University of Texas Medical Branch.

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Digital ultrasonic imaging with microprocessor manipulation

P. T. Ostro, B.Sc.
Dept. of Medical Physics, Queen's Medical Centre, University Hospital, Nottingham.

L. Harrison, B.Eng., Ph.D.
Dept. of Electrical and Electronic Engineering, University of Nottingham, Nottingham NG7 2RD

The author describes the development of a digital scan converter system which accepts ultrasonic B-scans in "oscilloscope" format and displays them in video format. The system involves the use of a microprocesor, the funciton of which is outlined in the paper. A brief comparison with a system employing a scan converter tube is given.

Introduction

The use of ultrasound in medical imaging is now wide-spread. The technique depends on a pulse-echo principle, whereby a pulse of high frequency sound is emitted into the body and any echoes that are produced are detected and displayed. The simplest method of viewing the echoes consists of an amplitude versus time display, and is called an A-scan. The familiar, two-dimensional B-scan is obtained by combining the A-scan with information about the position and orientation of the emitting transducer at the time the pulse was generated. The necessary spatial information is collected and processed to draw a line on an oscilloscope which mimics the path travelled by the ultrasound within the body. The intensity of this line is controlled by the amplitude of the A-scan.

Most B-mode scanners rely on an operator to manually scan the transducer over the patient. Since this is a process which takes a long time when compared to the persistance of a normal cathode ray tube (C.R.T.), resort must be made to a storage type tube in order to build up the image. The earliest versions of these were capable only of displaying two tones — black and white. The A-scan was therefore electronically thresholded and the images produced were called 'bi-stable'.

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INTEGRATING MOTIVATION IN THE INSTRUCTIONAL DESIGN MODEL

Robert Main, Ph.D.
Department of Communication Design

Kate Robinson
Department of Communication Design

Joyce Scott
Department of Communication Design

California State University, Chico
Chico, CA 95929-0504

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INTEGRATING MOTIVATION IN THE INSTRUCTIONAL DESIGN MODEL

This paper is an extension of an Integrated Motivation Instructional Design (IMID) Model originally proposed by Main (1992) for including the affective domain as an integrated component of the instructional process. The model essentially merges the five phased instructional systems design (ISD) model used by the military services (NAVEDTRA 110A, 1981). with the motivational components of instruction described by Keller (1983) as ARCS (Attention, Relevance, Confidence and Satisfaction).

The ISD model is based on the foundations of learning principles and standard system theory (Tennyson, 1989). It is divided into five categories of activities or phases. The name of each phase is descriptive of the activities involved: ANALYSIS, DESIGN, DEVELOPMENT, and CONTROL (labelled EVALUATION for the IMID model).

The Integrated Motivation Instructional Design (IMID) Model.

A conception of how Keller's ARCS Model can be integrated with a modified version of the military ISD model to create an integrated affective domain/ISD Model of the design process is shown in Figure 1.

INSTRUCTIONAL DESIGN PHASES

AFFECTIVE DOMAIN	Analysis	Design	Development	Implementation	Evaluation
Attention					
Relevance					
Confidence					
Satisfaction					
	Validation/Feedback				

Figure 1. ISD Model Integrating Affective Domain

Across the top of the model are the five phases of the military ISD model: *Analysis, Design, Development, Implementation*, and *Evaluation* (this is the control phase in the military ISD model).[1] Down the left side of the figure are the four categories defined by Keller as components of motivation: *Attention, Relevance, Confidence*, and *Satisfaction*. Along the bottom of the model is a rectangular cell labelled *Validation/Feedback* to depict the formative evaluation which occurs throughout the instructional design process and serves to validate that the tasks in each phase have been completed and reviewed. The arrows indicate the two-way flow of information between the phases that provide feedback for improvement and maintenance of the system. It also shows the process is on-going and not necessarily linear. Kemp (1985), for example, has developed an instructional design model that is circular to illustrate that instructional development is a dynamic process where evaluation data provides input for improving the instruction for the next class.

The following is a list of the tasks that are to be performed in each phase, including questions and examples These tasks apply for *cognitive, psychomotor* and *affective* domains.

ANALYSIS Phase

1. **Determine why the instruction is needed** (establish the purpose and goals of the instruction).
Is performance deficiency due to:

- Lack of knowledge?
- Lack of skills?

---

[1] A detailed listing of tasks performed in designing military training is provided in MIL-STD-1379D.

• Lack of practice?
• Lack of feedback?

Could the employee perform the task if his/her life depended on it? If the answer is yes and there is still a performance discrepancy, then it is affective based. Regardless of whether it is affective based, the following factors or questions should be considered during the analysis because motivated students learn both cognitive and psychomotor skills more rapidly. To analyze the affective components of the instruction, the designer should pose the following questions.
What is the value of the knowledge and skills for the learner in terms of:

• Immediate application?
• Improving learner's well-being?
• Improving learner's health and safety?
• Learner's motivation for attending?
• Enhanced career opportunities?
• Improving learner's confidence?
• Personal satisfaction (intrinsic motivation)?
• Recognition of achievement (extrinsic motivation)?
• Changing the learner's attitude, values and beliefs.

The importance of immediate application, from the learner's perspective, is relevance. Will the knowledge and skills be used in 'real world' situations in the near future? If not, you could be faced with a motivation problem or one where a lack of practice may cause a future problem. The more immediately such skills are applied the more interested and motivated the learner will be. Just-in-time learning (Hudspeth, 1992) is a concept whereby knowledge and skills are presented in timely proximity to the student's need for application. Knowledge decay and skill degradation may be severe when practical application is in the distant (and worse, indeterminate) future.

Learner well-being must also be looked at from the learner's perspective. Will the learner gain self-confidence, leading to a greater sense of personal ability to achieve, thus improving motivation and creating a positive attitude toward learning? Or are anxieties created? A secretary, given a new computer and user training to replace the old electric typewriter, may view this with great anxiety, not the excitement the trainer had anticipated. Installing a new tool may be perceived by the learner as unnecessary and burdensome unless an appropriate benefit to the learner can be demonstrated. It is important to look at such things as frustration, humiliation, and boredom, when considering learner well-being. The learner's health and safety should be enhanced. Will the acquired knowledge and skills place the learner in a higher risk position? Will the training reduce risk in his/her present occupation?

The motivation for attending takes into consideration whether the learner is attending voluntarily, or whether the training is required. Required attendance does not guarantee a motivated learner. In fact, it may create a less motivated learner spurring the need to focus on affective issues in order to combat the bad attitude the learner may bring with him/her. By the same token, voluntary attendance may also impose demands for affective domain needs. After all, voluntary implies a choice was made by the learner that placed presumptive value on the instruction. If these expectations of value are not reinforced, the learner may suffer extreme disaffection, particularly if the choice involved payment of money or hardship to take the class.

How will the knowledge and skills relate to personal goals of the learner? Intrinsic motivation is attained through matching goals of instruction to personal goals of the learner; they must not compete, but should complement one another (Ames & Ames, 1989). A challenge should be presented that has meaning to the learner. The learner should be in control, feel himself/herself as the originator of the learning process, not feel pushed or tricked into doing something (deCharms, 1976).

Will there be recognition for achievement? Though intrinsic motivation creates a higher level of learning (Ames & Ames, 1989) and a stronger positive effect on learning, many people are conditioned to expect some type of reward or recognition for their achievement (extrinsic motivator).

2. **Describe *who* needs the instruction** (determine learner characteristics, attributes).
   • Will the learner like performing the task?
   • What is the learner's prerequisite knowledge?
   • What are the demographics of the learner?

In analyzing for learner affective domain, the following should be considered:

- Learner's perception of the association between effort, ability and success.
- Personality traits.
- Learner preferences for learning.
- Psychographics.
- Learner aptitudes.
- Learner experience.

Through years of research advertisers have discovered and made successful use of such tools as psychographics, personality traits and demographics to target their audience successfully. These tools can also be used effectively by the lesson developer. By knowing such things as whether the learner is a leader or a follower we can better design our instruction to suit the learner.

With regard to effort, ability and success, will the learner believe the success is worth the effort? Many people who lack the strategic knowledge simply don't put forth the effort so they can claim that they just didn't try, rather than having tried and failed.

Personality traits should be considered to determine if the learner is suited to the proposed instructional situation. Someone who likes teamwork may view a training session where he/she will be working on their own, with dread. Likewise, knowing something of the learner's preferences for learning, i.e. more inclined towards visual or auditory presentation of material, will aid in assuring proper mode and method of presentation.

The greater the ability to individualize the instruction, the greater the need to consider individual learner attributes and characteristics. The more the lesson developer knows about the learner, the greater the precision in selecting appropriate instructional strategies, learning activities and media.

3. **Establish the content of the instruction.** The *what* determines the attitude, knowledge domain, intellectual skills, or psychomotor skills desired.
In making this determination consider the following:

- Does the learning involve discrimination?
- Does the learning involve concrete concepts?
- Does the learning involve defined concepts?
- Does the learning involve rules?
- Does the learning involve higher-order rules?
- Does the learning involve imitation?
- Does the learning involve precision psychomotor skills?
- Does the learning involve automation of psychomotor skills?

Attitudes are usually given short shrift in analyzing instructional content. Affective considerations in determining the content of the course should include consideration of:

- From the <u>learner's</u> perspective, is the subject matter attractive, glitzy, glamorous?
- Will levels of attention be affected by subject matter prejudice?
- Is the subject matter relevant to the learner?
- Is the performance discrepancy due to lack of knowledge or skills or is it primarily a result of attitude?

There are some things that learners find inherently more interesting than others, such as: physical activity, things that are manipulative, familiar, or have immediate application, as well as things that provide immediate gratification (Dweck, 1989). A key to establishing internal motivation in the learner is the presentation of a challenge which, from the learner's perspective, is relevant (Ames & Ames, 1989). Some factors which produce a challenging environment are goals, uncertain outcomes, variable levels of difficulty, novelty, or complexity, uncertainty, perceived control and self-determination (Newby & Alter, 1989). Analysis of the learner characteristics will enable the designer to establish those ideas which are relevant to the learner, as well as determining if a subject matter prejudice exists. Further examination of these possible problems will be discussed within the DESIGN and DEVELOPMENT phases.

Establishing the instructional content, of course, is directly related to the performance analysis. A desired level of performance is determined and the difference between the learner's current performance and the desired performance becomes the basis for determining the instructional content. The performance deficiency must be carefully analyzed, however, to determine what part of the deficiency is due to lack of the ability of the learner and what part is due to lack of willingness to perform to standard.

4. Determine *where* and *when* the instruction will take place (establish the location and schedule for the instruction).
Affective considerations are equally important in considering time and place of instruction. To assure their inclusion the following should be reviewed:

- How many will be involved in the instruction?
- Is instruction taking place on company time or learner's time?
- When will the knowledge and skills be needed by the learner?
- Is the instruction taking place in a convenient location?
- Is the instruction taking place individually or in teams?
- If instruction takes place in teams, are they normal working teams?
- Is one of the goals of instruction to establish a network of qualified people who will need to keep in touch after the instruction is completed?
- Will follow-up/follow-on instruction take place?

If instruction takes place on the company's time, the learner is more likely to view such instruction as being meaningful to the employer, thus establishing a vision of a shared goal. Instruction which takes place on the learner's time could lead to a motivation problem and every effort should be made to establish the training as an important goal which the learner and the company share. If the learning is to be team-based, it is important to consider whether they are the usual working teams with which the learner is familiar.

Just-in-time education (Hudspeth, 1992) is a powerful concept for affective domain instruction. Whether the overall instructional goals are learner attitudes, knowledge or skills, the proximity between the delivery of the instruction and it's application to a learner problem (or task of immediate consequence to the learner) is important to the learner's motivation toward the instruction.

DESIGN Phase

1. Specify performance objectives (behavior desired, standard and conditions of performance described).

- Are the learning objectives specified in terms of measurable student behavioral outcomes?
- Is activity to meet learning objectives actually possible to set up?
- Do the learning objectives clearly identify what the student is expected to do?
- Are the conditions specified under which the desired performance is to occur?
- Do the learning objectives describe a specific performance standard?
- Can the desired performance by the learner be observed?
- Are cues for behavior performance provided (context in which performance is necessary or appropriate)?

Affective considerations of performance objectives are crucial in assuring their effect as a positive, not a negative motivating force. To include the affective domain in the design of performance objectives, the lesson developer should pose the following questions:

- Are the performance objectives seen as having value (being relevant) from the learner's perspective?
- Is there an opportunity for the learner to be included in developing the performance objectives?
- Are the performance objectives stated in clear and concise language?
- Do learning objectives pose a sufficient challenge to the learner to create personal satisfaction in accomplishment?
- Are learning objectives developed for desired learner attitudes?

Performance objectives, or goals, should be seen by the learner as being relevant, having value or meaning. The learner will quickly recognize time consuming, menial tasks, and his/her motivation level will drop. Learning objectives can be shown to be relevant to the learner by relating how they cross disciplines, their importance in career progression, and to everyday life (Meece, 1990). They can also be given relevance by relating them to past experiences and knowledge, how they will be needed for future goals, and that they have immediate value and worth (Gagne, Briggs, & Wager, 1988).

Communicating clear and definite learning objectives builds confidence in the learner that the task can be done successfully (Gagne & Driscoll, 1988). Either too high or too low a level of difficulty in attaining the learning objective will adversely affect the learner's motivation. Goals must be challenging for them to hold meaning for the learner (Ames & Ames, 1989). On the other hand, children will sometimes set unrealistic goals for themselves knowing they will fail, thus being able to blame the whole experience on fate (deCharms, 1976). The learner must understand that it is the effort put forth to attain each goal that is linked to success. The connection of effort to success should be a prime goal of the instructional design.

Development of learning objectives requires careful attention to insure they not only encompass the knowledge and skills determined in the ANALYSIS phase, but that they also serve to stimulate the learner in their achievement. Use a small group of representative learners to pilot test learning objectives to make sure they are clear, unambiguous and inspirational.

Learning objectives should be developed from the perspective of the learner. What is it the learner must do in order to close the "gap" between existing performance and desired performance? Is the performance deficiency due to lack of knowledge, a lack of skill, or to an improper attitude? Most likely it is a combination of all three, but most certainly the instructional designer will want the learner to be motivated to master the instructional objectives.

2. **Establish how performance will be measured** (evaluation criteria).
   - Is the evaluation an authentic assessment of the desired behavior?
   - Will something besides the performance standard set for the learning objective be used?
   - Will a test be administered?
   - Will assessment be based on competitive performance?
   - Will a point system be used?
   - Does the instrument of measurement yield valid, reliable test scores to judge the learner's mastery of the objectives or instructional quality?

In designing measurements of learner performance in the affective domain, the following should be considered:
- Is self-evaluation by the learner of his/her performance included?
- Does the performance measurement provide feedback and reinforcement to the learner?
- Does the evaluation process instill confidence in the transfer of skills beyond the classroom?
- Does the evaluation generate intrinsic and extrinsic rewards for effort expended and performance achieved?

Authentic assessment involves the evaluation of performance based on task accomplishment (Cradler, Bakker, Lathrop, Finkel, & Main, 1991). It involves the measurement of attitudes, knowledge and skills by means other than traditional paper-pencil tests. It may include projects, simulations, problem solving, creative writing, portfolio review, role playing, and on-the-job performance assessments. Feedback which focuses on incidental activities or ideas may be perceived by the learner as a sign that the instructor believes he/she lacks the ability to accomplish the task (Ames & Ames, 1989). Ideally, evaluation criteria for learning is indistinguishable from criteria for success outside the learning environment, i.e., in "real" life.

Because long term residual or persistent affective objectives are difficult to measure does not mean they should be excluded from the instructional design. What is needed are innovative and creative methods for tracking behavior and measuring performance over time. This feedback will lead to improvements in instructional design.

3. **Determine instructional strategies to be used.**
   - Are we teaching information learning?
   - Are we teaching intellectual skills?
   - Are we teaching cognitive strategies?
   - Are we teaching attitudes?
   - How much time do we have?
   - Will discovery learning strategies be most appropriate?
   - Will directed learning strategies be most appropriate?

In the affective domain, how will instructional strategies effect the learner in terms of:
- Developing intrinsic motivation?
- Keeping the learner's attention?
- Improving the learner's confidence?
- Developing a positive attitude towards the subject matter?
- Relating the instructional environment to the real world?

Instructional strategies are perhaps most impacted by situational constraints. Shall the instruction be delivered in a conventional classroom setting or will it be presented individually via computer based instructional stations?

Answers to these questions are often not determined by the instructional designer, but rather by the facilities or project manager on the basis of program budget.

The lesson developer needs to identify with the learner, see ourselves in their place, to be able to recognize desired goals, and qualities, and know what is familiar to him/her (Smith, 1954). To generalize about the learner personality type from the *WHOM* analysis without considering the role in which the training places the learner, or the relevance of the information to his/her life would be irrelevant and possibly even misleading (King, 1971).

To increase intrinsic motivation we must first establish in the learner an expectancy that he/she will gain satisfaction through the attainment of the stated learning objectives (goals) (Gagne', et al., 1988). The instructor should, for example, place an emphasis on, and recognize or reward, the learner who understands and can use the strategies for attaining the learning objectives, not merely the learner who gets the correct answer. Show learners that problems have more than one way to arrive at the answer, and that many times, more than one right answer is possible (Hecht & Tittle, 1990).

4. Sequence the learning activities.

- Are learning objectives linked to learner's needs for application (just-in-time education)?
- Are learning objectives dependent, independent or supportive?
- Consider content and learning.

  Are the learning objectives hierarchic or sequential?

In sequencing learning activities, the following questions in the affective domain should be considered:

- Will the learners confidence be increased as he/she moves through the activities?
- Will the learning activities appear relevant in relation to the learning objectives?
- Do the learning activities vary throughout the program to maintain interest?
- Are the learning activities sequenced to insure relevance of the class is perceived at the beginning of instruction?

Successful learning is more likely when learning activities are carefully sequenced in relation to the learning objectives (Kemp, 1977). Content should be organized sequentially from simple to complex. That is, starting with factual learning, then moving on to concept formation, principles, and eventually to higher intellectual levels, such as problem-solving, prediction and inference.

Two factors mentioned earlier come into play in the sequencing of learning activities. The first is learner participation and the second is just-in-time education. Practical exercises, hands-on and group activities should be scheduled throughout the instruction rather than waiting until the end of the program. Learning activities may be clumped around particular task training.

Sequencing learning activities is facilitated by classifying all learning objectives as independent, dependent or supportive. Independent objectives are those that require no prerequisites in the lesson. The knowledge and skills are not hierarchical and the motivational components are not based on prior attitude formation. The independence of the objectives means they can be inserted in the curriculum at any time without regard to a particular order or sequence. Many affective domain objectives are independent especially those for attention and relevance. Confidence and satisfaction components are more closely linked to appropriate cognitive or psychomotor objectives for scheduling. Achievement of a confidence objective, for example, will almost certainly require satisfactory completion of some task with a high level of perceived difficulty.

Any objective relating to satisfaction might likely be associated with a milestone event in the instruction. In many cases confidence and satisfaction may be inter-related and associated with the same instructional event. The same is true for attention and relevance. It would seem virtually impossible to achieve a high degree of relevance without generating the attention of the student. Attention gained at the beginning of instruction must be rejuvenated throughout the process. The same is true for relevance, confidence and satisfaction.

5. Design the delivery system.

- Is the mode of instruction appropriate?
- Is the method of instruction appropriate?
- What is being learned in terms of verbal information, intellectual skills, cognitive strategies, attitudes, motor skills, or a combination?
- What kinds of support for the learning process must be provided by instructional events?
- What is the class size?
- Will the delivery of instruction be group, tutoring, self-guided, or a combination?

In designing the delivery system, the following questions in the affective domain should be considered:

- Does the delivery system incorporate some level of individual instruction (exploration, invention and inquiry)?
- Does the system allow for individual differences of learners?
- Does the system allow some locus of control for the learner?
- Does the delivery system promote learner interaction with the instructional process and with other students?

The best way to deal with affective objectives is through cooperative group activities. Through the give and take of discussion, the learner can develop new ways of making judgements and discriminations, can establish strategies for dealing with novel situations, and increasing their own motivation to learn (Kemp, 1977).

The learner's ability and level of motivation will vary greatly. Pitsch (1991) reminds us that to teach math, for example, activities must adjust to different levels of student ability. To maintain motivation, use methods which actively involve the learner. This leads to a sense of achievement, maintains a high level of arousal, and provides satisfaction through acceptance by and recognition from a group (Beard & Senior, 1980).

One of the most effective methods for motivating learners is the use of team training. Team training promotes cooperative behaviors, allows advanced learners to tutor others less adept, and permits the sharing of group successes that might not be easily attainable for some students competing as individuals. Team selection should be handled in such a manner as not to be perceived as an indication of talent or accomplishment. Realistic team training can provide a virtually transparent and seamless transition from training to production.

6. Select presentation media.

- Have needs assessment and learner objectives been considered in selecting appropriate presentation media?
- Are cost considerations realistic and reasonable?
- What are the audience characteristics?
- What is the instructional setting?
- Will media support instruction, or carry the instruction?
- What are the capabilities to produce media?
- How much time is available to produce media?
- How much time is available for media use?
- What is the desired learner outcome?
- What level of fidelity is required of the presentation media to insure optimal transfer of skills?
- Is it appropriate to use 'realia', i.e., the real thing?

In selecting the presentation media, the following questions in the affective domain should be considered:

- Does the media selected promote active participation by the learner?
- Will the learner perceive the media selected as integral to the curriculum?
- Does the media selected enhance the subject matter?
- Does the media selected fit the individual learning aptitudes of the learner?
- Does the media selected arouse and maintain attention?
- Will the media enhance the relevance of the instruction?
- Will the media promote greater learner confidence in the ability to transfer skills to practical applications?

Today's learners relate as much or more directly to picture images and sound as they do to the printed word (Kemp, 1977). Viewing television, for example, appears to be an activity that is inherently motivational. The brevity of scenes, use of sound, and the frequency of abrupt changes are video techniques that are highly effective in capturing and holding the attention of learners. One of the most striking ways video contributes to instruction is in the establishment and modification of attitudes. Video can present human models, such as heroes and heroines of fiction, personages of history, and political or sports figures, in a realistic form that appeals to, and can be modeled by, the learner (Gagne' & Driscoll, 1988).

From past experiences and social cues, we learn that little mental effort is required for viewing video. A video cassette gives the instructor the option of starting and stopping a program in order to highlight key points and concepts. This causes the learner to become active and focus attention on the learning objectives. Because the instructor took the time to preview the program, the learner may perceive this effort as an indication of importance, and place a higher value on the learning process.

Audio cassettes are of particular usefulness in providing individualized instruction. Audio is valuable in directing the learner's attention by emphasizing features of the message. Audio tapes are particularly useful in learners who are too young to read or who are not good readers. Audio has one distinct advantage over competing media - it can be used during other activities. One only need to observe the frequency of headsets on joggers, commuters and workers with their portable casettes and CD-ROM, players

The visual and audio versatility of computers offers many possibilities for gaining and holding the learner's attention. Computers can also provide immediate feedback as to the correctness of the learner's response (Gagne' & Driscoll, 1988). Computer graphics can also assist in establihing attitudes. For example, a figure, such as an owl, can represent the attitude of careful reading and appear when added attention is requred of newly introduced text. The reappearance of the figure serves as reinforcement for the attitude.

It is essential that instructors are provided with quality equipment, trained in the use of the equipment, and supported in the maintenance of the equipment. Researchers have discovered that learners expect a high level of technical quality and become distracted when technical quality is poor (Gagne' & Driscoll, 1988).

In order to motivate the learner to expect success in the learning process, care must be taken to choose a form of media that is familiar to all learners, or allow adequate time for learners to become familiar with the media selected. Media can be one of the most powerful tools for the instructional designer in manipulating the affective domain. The media not only attract our attention, they are compelling when used artfully to dramatize events, illustrate difficult concepts and transport the learner through time and space. Media can be used very effectively in demonstrating the relevance of the learning objectives to situations directly benefitting the learner. It can generate confidence in accomplishment by modeling performances of others perceived as peers and the media can project rewards and recognition that inspire satisfaction in accomplishment. Most importantly, media are very effective in attitude formation and change. The ability to involve the learner emotionally through identification with characters and situations is very powerful and persuasive when it is well done.

DEVELOPMENT Phase

1. **Produce or select learning materials** (text, work books, graphics, visuals, training aids).
   - Are costs of various materials within budget?
   - Can existing media be adopted or adapted?
   - Are commercial media available and appropriate?
   - Is in-house production feasible and necessary?

In analyzing the materials to consider affective domain, the following should be considered:

- Are advertising techniques which gain and maintain attention appropriate?
- Is the appropriate reading level too high or too low to maintain attention?
- From the learner's perspective is the material attractive, glitzy, glamorous?
- Does the material aim to teach the learner and not a subject?
- Is there room for learner input?
- Does the material appear fresh, current and relevant to the performance objective and real world application?
- Can the learner identify with characters, situations and events presented?

For years advertisers have been studying the most effective means of gaining and maintaining audience attention and what constitutes an effective message in terms of audience response. These techniques are valuable tools that should be used by the lesson developer. Many of them are purely affective based such as the catchy tune that the listener finds pleasing, the use of humor, fear of social disapproval, and visual placement keys. The lesson developer who uses materials which are visually pleasing, easy to read, and interesting is going to have more success in capturing the interest and maintaining the motivation of the learner.

The analysis of the learner attributes will help in determining appropriate reading level and what he/she will find attractive, glitzy and glamorous. Though advertising layout techniques can help they are only part of the puzzle. Knowing that the learner is particularly interested in fishing, for example, would allow incorporation into the lesson development examples and projects that involve fishing, thus increasing the chance of the learner finding the lesson attractive. This technique will also help in making sure the lesson is teaching the learner and not the subject.

From the learner's perspective, material that has immediate real world application is going to be of the most interest because it will generate the most positive reinforcement. For eighth grade math students, a year of setting up and running their own bookstore put their newly learned skills to work and gave them "relevance and excitement" (Fuchs, & More, 1990). The learner's level of satisfaction and confidence will rise in direct relation to his/her ability to apply the newly learned knowledge or skills. Where a real-world application is difficult to visualize, the use of fantasy can help. The learner can identify with a character and through that character experience relevance or meaning that in the "real world" would elude him/her, or that might otherwise be mundane (Ames & Ames, 1989).

It is important that the media present the information within a context to which the learner can readily relate. Hair and clothing styles, locations, situations and events portrayed, music, etc., must seem realistic and credible to the learner. Failure to establish source credibility is fatal to the achievement of objectives involving attitude change or formation (Travers, 1972). Music is a powerful medium for the affective domain used along or with video and film, but it is especially sensitive to age, ethnicity, and social identification of the learner. Sound effects can create a "theater of the mind" to great effect. Ken Burn's Civil War video series is an excellent example of the skillful blending of music, sound effects, first person narrative and archival photographs to create a powerful and gripping history lesson.

2. Develop delivery system hardware.

- Delivery instructor based (traditional classroom)?
- Will lessons be distributed in part or wholly by computer, video, or print means?
- What equipment will be needed?

To assure the consideration of the affective domain, the following should be considered when developing the delivery system hardware:

- Is the system engaging (interactive)?
- Is the system designed for multi-media use?
- Is there an element of hands-on engagement in the system?
- Is the learning realistic in terms of presenting practical exercises or simulations?
- Is the system reliable?
- How much control does the learner have?

The lesson developer must be careful not to fall into the trap of merely producing an electronic page turner, or a video which talks at the learner. A passive learner does not experience the level of arousal, involvement or emotion that the active participant experiences (Fleming & Levie, 1978). A learner run bookstore, for example, could involve the learner in ordering, buying, selling, etc. All are mathematical calculations, and he/she learns by doing

Having an engaging, or interactive system also allows for the activities that adjust to different levels of challenge. As noted earlier, it is the challenge that requires not too high or too low a level of effort, and which leads to a goal (short-term) which is meaningful to the learner, that will help develop intrinsic motivation in the learner. The system should focus on developing strategies in the learner to attain these short-term goals.

The multi-media applications of any system being used should be fully considered and used to advantage. Through a change of presentation, print to picture, non-motion to motion, etc., the designer will increase his/her chances of gaining and maintaining the attention of the learner. Variety is important to keep in mind (Beard & Senior, 1980).

As described by researchers such as Cotton and Savard (1982), lessons which feature activities that involve touch, movement and interaction with learning materials generate motivation in the learner. Such activities as having the learner do something to help them recognize their environment, restructuring the room, noticing something new in the room, etc., helps to focus attention (Hawley & Hawley, 1979).

Above all, the delivery system must be reliable. Technology is wonderful, but if it doesn't work, it not only doesn't teach the desired lesson, it may impart a very different message that is injurious to the learning process. It may be especially negative for the affective domain. Learner attention is quickly focused on the message delivery problem--not the message. Confidence in the instructor may be eroded as equipment malfunctions are easily interpreted as instructor and school administration incompetence. Frustration and irritation replace satisfaction. At best the interruptions annoy and frustrate the desire to learn, at worst they see the system's unreliability as a negative indicator of the lesson's importance.

Realism in the delivery system is a function of the content of the instruction (i.e. perceived relevance of activities to practical application) and the equipment used in the presentation. The most realistic situation is obviously the actual environment in which the knowledge and skills are to be used. Varying degrees of realism fidelity are possible through simulations from the use of realia to physical mock-ups to scenarios that present symbolic representations of realistic situations. In general, the more realistic the learning situation, the easier the transfer of knowledge and skills and the greater the learner motivation.

3. Generate software for system operation.

- Are the learning activities properly sequenced?
- Are lesson plans complete?
- Are exams prepared?

Considerations of the Affective domain for system operation software should include:

- Does the sequence allow for individual differences and pacing?
- Do lesson plans follow short-term goals?
- Do the exams focus on the same goals as the lessons?
- Do the exams allow room for the learner to check his/her own work?
- Is the system software easy to use?
- Is the software easily maintained, i.e., updated, modified, tailored?

It should be kept in mind that if the lesson goals are to encourage learner choice, and intrinsic motivation, it is contradictory to then turn around and evaluate the learner on a normative scale making public comparisons. If this happens, the learner will avoid making the choice to pursue a challenging yet interesting task, in favor of the one he/she knows he/she will do well completing (Ames, 1990) .

We should remember that short-term goals are the focus. The learner needs practice in setting and developing strategies to attain short-term goals as a means for making progress toward the long term goal. This will allow the learner to focus on the strategies and not the outcomes (Ames, 1990).

The delivery system software must be as transparent to the user as possible. This is true for both instructor and learner. Training time is always limited and costly. Time required to learn to use the instructional delivery system reduces the time available for presentation of the instructional materials. More importantly it may damage learner motivation by distracting attention from the learning objectives. Effort expended in learning to operate the presentation system may be perceived as irrelevant to the course learning objectives. Difficulty in mastering the system may reduce learner confidence and satisfaction with the lesson itself.

Software that requires extensive training to develop course materials or to set up for delivery may result in poor instructional design and use of the easiest courseware rather than the most appropriate. Outdated or inappropriate sections in the instructional presentation will certainly degrade learner motivation.

4. Create courseware.

- Design the lesson.
- Develop overheads.
- Develop courseware materials.
- Develop lecture notes.

Affective considerations include:

- Is there a good use of manipulatives?
- Is there a good use of multi-media?
- From the learner's perspective is the material attractive, glitzy and glamorous?
- Is there appropriate use of media techniques to draw the learner's attention to the relevant points and not clutter the presentation with irrelevant information?
- Is the content appropriate for the learner? For the learning situation?

Role playing (a manipulative) is an excellent example of active participation which is far more effective in bringing about attitude change than passive receptions of information (Fleming & Levie, 1978). Stodolsky and Glaessner (1991) found, for example, that the times when learners enjoyed math, was when they were actively participating. Media used for a purpose, rather than simply for the sake of using the media, will aid in motivating the learner. Irrelevant improper use of various media will clutter the message and aid only in confusing the learner.

5. **Test and validate instructor/student/system interaction** (interface).
   - Are there appropriate levels of knowledge?
   - Are the learning goals clear?
   - Is the instructor available for help?
   - Is the learning process cohesive?
   - Do the learning objectives seem realistic for the time allotted?
   - Is the learning process cohesive (i.e. do the instructional strategies and learning activities seem integrated with the sequencing of instruction and media used?
   - Do learners have difficulty in understanding the process or the presentation?

Affective considerations:
- Does the instructor/system appear enthusiastic?
- Does the instructor/system facilitate positive reaction toward the subject?
- Does the instructor/system allow room for individual learner differences?
- Does the lesson attract and maintain the attention of the learner?
- Does the learner perceive the relevance of the presentation?
- Does the lesson generate confidence in the learner that the learning objectives will be mastered?
- Is the learner satisfied with the learning environment?

The purpose of pilot testing the lesson is to insure the instructional system performs as planned. Observation of representative students allows adjustments and fine tuning of the instruction to determine that the instructional components integrate seamlessly and the learner perceives the presentation as logical and cohesive. The lesson timing for each learning objective should be checked to make sure the time on task is adequate for mastery but not so excessive it generates boredom. Most importantly, the pilot test permits assessment of learner attentiveness and enthusiasm for the subject and its manner of presentation.

IMPLEMENTATION Phase

1. **Enroll students.**
   - Are students representative of the target audience identified in the needs assessment?
   - Do students meet the selection criteria (i.e. pre-requisite skills)?

Affective considerations for the enrollment phase include:
- Is selectness of the group emphasized through tough criteria already met?
- Have pre-enrollment brochures about the course been provided?
- Are introductory remarks by student recognized authority scheduled?

By emphasizing the selection process and congratulating the learners on their selection for the training, you give them confidence that they can accomplish the forthcoming learning objectives based on their past learning experiences. Pre-requisite deficiencies may require rejection of the learner or some form of remediation for the student before instruction can begin. Pre-enrollment brochures and advanced study materials generate anticipation for the program and enthusiasm in participation. Advanced distribution of a student roster will also heighten interest.

Having a recognized authority address the opening session will emphasize the importance of the learning task and spur motivation. An example of such activities are those used by a corporate resident artificial intelligence training course. The program was extremely rigorous and required participants to work each night and many weekend hours over a six month period. To encourage voluntary enrollment and generate a positive attitude toward the instruction a number of steps were taken within the affective domain. Student applicants were required to have an endorsement from their manager and at least one letter of reference from a professional colleague. Such letters by nature are laudatory and boosted the applicant's confidence in mastering the course and satisfaction in applying as well as relevance for future career opportunities within their department. Applicants selected for attendance were notified by a congratulatory letter signed by the Vice President for Research of the Company. An accompanying packet of materials included a copy of an article about the course that had appeared in the corporate in-house magazine, a brochure of the program that showed the facilities, described the curriculum and profiled the faculty. A welcoming speech by the Company President kicked off the introductory class and a reception was held the first evening of the course attended by corporate executives and the manager of each student's division as well as the staff and faculty of the program. All of these activities contributed to a highly motivated student body willing to use their own time in mastering the program's learning goals.

2. **Schedule instruction** (assign classroom and structure activities)?
   - Are facilities prepared and classrooms adequate for class size and activities?
   - Is there enough time for all learners to use equipment?

In considering the affective domain, the following should be considered:
   - Is time and place appropriate (from the needs assessment)?
   - Is support for student administrative needs available?
   - What are the provisions for making up missed training periods?
   - How are failures handled (remediation, setback)?

As important as designing the lessons to be exciting and rewarding is the attention to the environment in which the instruction takes place. Instructors who are well qualified, motivated and dynamic overcome most deficiencies of design and generate enthusiasm in the learner. As technology is used more and more for instructional delivery, the traditional role of the instructor in motivating the learner must be incorporated into the lesson design.

Kemp (1985) notes that learner involvement in the instructional process is key. This can be accomplished in many ways. The message can be presented in dramatic form and engage the learner emotionally. Problems, puzzles, and embedded questions can involve the learner intellectually. Physical participation is perhaps the most certain method for insuring learner involvement. Role playing, team projects, work shops and practical exercises are all learner participant activities. The more the instructional strategy involves learner participation, the less the instructor control and the greater the requirement for attention to the instructional management.

3. **Deliver instruction to the student.**
   - Is there adequate time for interaction?
   - Is stimulation for recall of previously learned information or skills provided?

Affective considerations:
   - Are as many personal references as possible used?
   - Are discussion and inquiry promoted?
   - Does the method of instructional delivery motivate the student to learn?

Traditionally, it is in the classroom where affective domain needs are addressed. The distinction between a good teacher and a great teacher is how proficient they are in motivating their students to learn. In a recent study by the Main (1992), 154 students were asked to name the one teacher they remembered as being most effective and to write a paragraph explaining their selection. Every student named an affective variable in their rationale. Comments included: The teacher made me want to learn. . ., I never liked this subject until . . ., The teacher made the class interesting . . ., and the teacher made me realize how important it is to know . . .Only one in ten mentioned the teacher's knowledge or how much was learned from the teacher. The data clearly indicated the teachers remembered as most effective, are those that caused the learner to care about learning (in general) and to value the subject in particular.

The learner may react differently to the presentation than expected. Attention levels must be monitored to make sure strategies are working, and if not, re-work and re-implement. Hecht and Tittle (1990) suggest that a good amount of "wait time" be given before an answer is expected. Even as simple a strategy as placement of the question addressed may affect learner involvement in the instructional process. If a student is selected to answer a question before it is asked, other students may lose incentive to answer the question for themselves. On the other hand, if the question is presented first and the instructor pauses before selecting the student to answer, every student is likely to mentally prepare a response because they may be called upon to provide the answer. It would be wise to encourage the learner to take time to think, to work in pairs and groups to solve problems.

4. Maintain the learning environment.

- Are the facilities clean?
- Are the learning materials neat and well maintained?
- Is the instructional equipment working and available?
- Is decorum in the classroom maintained?
- Are reference and research facilities adequate?

Affective considerations:

- Does the instruction appear to have priority for available resources?
- Is administrative support adequate and responsive?
- Does the appearance of the learning environment promote the feeling that the instruction is valuable and the learner's comfort important?

Poorly maintained facilities and materials can undermine design efforts in motivating the learner. Neglect of the learning environment sends a powerful message that affects the perceived importance of the learner's achievements and/or the value of the learning objectives. Research projects will not be seen as valuable by the students if the library is not open after class. Efforts expended by students in processing administrative requirements take time, energy and attention from academic pursuits.

5. Monitor instructional progress.

- Are learning problems diagnosed early?
- Is alternative presentation or remediation scheduled?

Affective considerations:

- Are the attention strategies working?
- Are there group dynamics which are inhibiting the learner's confidence or satisfaction?

As noted throughout, a constant process of evaluation must be on-going. One specific for maintaining the learning environment is the consideration of group dynamics. Though group work can be motivating, a group that has too many leaders, or too many followers will be counterproductive. Initial placing of individuals in groups may not always work, be prepared to make changes.

Just as progress in cognitive and motor skill achievements are monitored and problems diagnosed, so too must learner motivation be checked. A study of failures in a military course of instruction indicated three out of four were attributable to attitude problems. Flagging attention and other affective domain failures need early diagnosis and alternative strategies available for remediation.

EVALUATION Phase

1. Measure achievement in performance of learning objectives.

- How many targeted learners reached an acceptable level of performance?
- What were the reasons for failure?

Evaluation is not a trivial task. It is critical for improving the instructional system and determining training value. The investment of time in the development and execution of a valid performance measurement will pay dividends in insuring the competency of the learner, improving the quality of instruction and the instructional design process.

The Affective Domain is the most difficult aspect of instructional evaluation. However, it should not be ignored because it is very important to the learning process. There are two aspects of the Affective Domain involved in the EVALUATION phase. The first consideration is the effect the testing method has on the learner's motivation. Testing procedures can have profound implications on all four areas of the Affective components of the Integrated Design Model. Simply informing the learner that achievement of the learning objectives will be measured will normally have a salutary effect on gaining and holding attention. It also helps establishing relevance for the instruction at least in the short term. However, reliance on testing alone as the incentive for attending to the instruction may not contribute to knowledge transfer to long term memory or motivation for continued effort in expanding knowledge, improving skills or reinforcing attitudes. Quite the contrary effects occur if the testing procedure is perceived as being unfair or inequitable (not properly covered by the instruction or not adequately discriminating between levels of effort or achievement by learners) or irrelevant either to the course objectives or utility of the knowledge skills and attitudes measured for applications beyond the classroom.

The perception of relevancy can also affect the learner's confidence. If the learner feels the test does not accurately measure his/her achievement, he/she may be unsure of how to apply the knowledge or skills (i.e. transfer) to real world problems or uncertain of their ability to perform tasks dependent on the instruction. Confidence may also be affected by the difficulty of the exam. A test that is too hard and results in a low score may create a perception of substandard ability or feelings of inferiority or inadequacy.

Poor testing performance obviously affects learner satisfaction as well. This is especially true for learners who rely primarily on extrinsic rewards for their feelings of satisfaction. On the other hand, tests perceived as too easy may also undermine the learner's satisfaction with the instruction and the value of his/her achievement. The effort-justification theory that the greater the effort expended in achieving a goal, the more valuable the goal is perceived applies to training and education. The concept of elite organizations is based on the concept that membership is limited to those with some extraordinary abilities. The more difficult (and consequently extraordinary) the achievement, the more valued the membership.

Analysis of learners failing to satisfactorily meet the terminal performance objectives can provide valuable information for improving the instructional process. Failed students and their instructors should be interviewed to determine <u>why</u> the student failed. More attention needs to be given to assessing the effectiveness of motivation strategies and means for strengthening them.

2. Evaluate instructor performance.

- Is the instructor qualified in the subject content?
- Is the instructor trained in presentation techniques?

Affective considerations should include questions such as:

- Did the instructor appear enthusiastic?
- Was the instructor approachable?
- Did the instructor appear comfortable in the role?
- Were affective objectives achieved?
- Were students motivated to learn?
- Do students value the knowledge and skills achieved?
- Do students want to continue learning about the subject matter and/or refine the skills presented?

The second aspect of evaluation that involves the Affective Domain is the measurement of achievement of affective learning objectives. According to Martin and Briggs (1986), one of the reasons the Affective Domain is so neglected in instructional design is that it is difficult to develop an accurate and valid evaluation. Feelings, emotions and attitudes are internal states that can only be observed through indicator behaviors, but so are cognitive and psychomotor abilities. Techniques are available for ascertaining the accuracy and validity of such tests in objective terms that can be easily quantified. Areas considered highly subjective in performance, such as musical proficiency and athletic prowess, are routinely evaluated in quantifiable terms. For example panels of experts observe ice skaters, divers and gymnasts perform specified routines and award numerical scores as to achievement that are generally accepted without argument as accurate and valid measurements.

Krathwohl (1964) advances the argument that there is a reluctance to include affective objectives in education because measuring the achievement of the objectives may be invalidated by the learner masking his/her true feelings and espousing those attitudes known to be desired by the instructor. While deception is certainly possible, it seems no less true for cognitive abilities. For example, applicants for jobs may mislead prospective employers as easily about their intellectual ability as about their motivation for the position.

Affective achievements are arguably no less concrete or observable than cognitive intellectual skills such as critical thinking, synthesis, analysis or evaluation. There are widely accepted measurements of intelligence which seems much more abstract a concept than affective variables of attention, relevance, confidence and satisfaction. In our daily encounters, we are generally as comfortable about judging people's attitudes as we are in assessing their knowledge or intellect. If there is a dearth of measurement tools to assess the achievement of Affective Domain objectives, the reasons are more probably due to historical neglect than inherent difficulty. Although, not a trivial task, behaviors can be identified that measure learner attitudes, beliefs, and values.

3. **Assess the instructional system performance** (course materials, mode and methods of instruction, and hardware/software operation).
   - Was the equipment time well used?
   - Was added explanation often needed?
   - Did the learners find any portion of the instruction overly confusing?
   - Was there a comfortable melding of source materials, mode and methods of instruction and hardware/software operations?

4. **Validate performance measures through external criteria and follow-up evaluations of related job performance.**
   - Has the performance deficiency been corrected?
   - Are knowledge and skills being used?
   - Is there a reasonable return on investment?
   - Have graduates expanded knowledge and intellectual skills, improved psychomotor skills and reinforced attitudes?
   - Is refresher training needed?
   - Is the instruction still needed?

Affective considerations: (Realize that many affective outcomes take time to become observable.)
   - Is the learner's attitude toward the subject equal to or better than when the training started.
   - Is the learner interested in further training?
   - Is the learner confident in his/her ability to apply the learned knowledge and skills in a new situation?
   - Does the learner feel his/her time in the course was well spent?

Attention needs to be paid to the development of evaluation techniques for the Affective Domain both as measurement of learner motivation about the subject content and attitude toward the manner of presentation and also the achievement of affective learning objectives directed to behavior modifications, such as reduced substance abuse or employee thefts. For example, since affective learning objectives are generally directed to attitude formation or change that will last over time, consideration needs to be given to follow-up evaluation methods. Assessments may be made six months or a year after instruction to determine long-term effects.

VALIDATION/FEEDBACK Phase

1. **Conduct formative evaluation of the instructional design process.**
   - Is existing courseware available for adoption?
   - Are related instructional design processes available for review and evaluation?
   - Are all the tasks accomplished?
   - Are constraints identified?
   - Are the methods and techniques used appropriate?
   - Are the conclusions adequately supported?
   - Are assumptions reasonable?
   - Are decisions rational?

2. **At the end of each phase test, validate, and re-work (if necessary) before moving on.**

Affective considerations:
   - Have Attention, Relevance, Confidence and Satisfaction been adequately considered in each phase?

3. **Provide feedback for system maintenance and improvement.**
   - Is documentation of process maintained?
   - Are knowledge, skills and attitudes current?
   - Is scheduling convenient?
   - Are system and facilities properly maintained?
   - Has the performance deficiency been corrected?
   - Are knowledge and skills being used?
   - Is there a reasonable return on investment?

- Have graduates expanded knowledge and intellectual skills, improved psychomotor skills and reinforced attitudes?
- Is refresher training needed?
- Is the instruction still needed?

Validation and Feedback are provided throughout the instructional design process by formative evaluation. The Integrated Model indicates formative evaluations are conducted for each phase. The process of validation and feedback is continuous, as shown by the lack of vertical divisions in the model. The information from the formative evaluations flows freely across the instructional design phases indicating its use in improving the process and the output of each task as well as providing input for tasks that follow. Tasks in each phase, although listed linearly as a progressive process, may not necessarily be performed in a linear fashion depending on particular situations. Rarely are instructional designers tasked to build an entirely new curriculum. Even with new weapon systems, crew training courses contain large areas of knowledge and skills that are being taught in other courses. For example, the Pershing Missile curriculum developed for the U.S. Army in 1963 and '64, although an entirely new weapon system, contained large components of instruction on operation and maintenance of the tracked vehicles, diesel generator and electronics that were being taught with other missile systems.

Formative evaluation is also conducted for inclusion of the Affective Domain in each design phase. Validation insures attention, relevance, confidence and satisfaction have been considered in each phase and embedded within the curriculum development. The validation process provides feedback for the designer as a quality check of tasks performed that permits corrections and revisions before time and resources are invested in production and installation where change may be very costly. Validation and feedback serves the function of program quality management for curriculum development.

SUMMARY AND CONCLUSION

Instructional design has traditionally focused on acquisition of knowledge, cognitive strategies and motor skills -- the ability of the learner to perform some prescribed task. But human behavior is determined as much by what an individual wants to do as by what he/she is able to do. This study presents a taxonomy of motivation considerations embedded within an Integrated Motivation Instructional Design (IMID) Model . The concept of integrating the affective domain into the instructional design process was developed from an Air Force research effort (Main, 1992). The IMID model incorporates the ARCS model of motivation (Attention, Relevance, Confidence, and Satisfaction) developed by John Keller (1983) with the military's traditional five phases of instructional design (Analysis, Design, Development, Implementation and Evaluation) and adds a Validation and Feedback component for continuous formative evaluation and quality control.

This study examines the IMID model and further systematizes the integration of learner motivation by developing a taxonomy of affective considerations for each instructional design task in the five phases. This effort is by no means comprehensive or complete. Since the affective domain has been historically neglected in curriculum development and instructional strategies, there are relatively few sources of documented practices and procedures for including motivation considerations in the instructional design process.

The need for including the affective domain in the curriculum is beginning to receive a great deal of attention from the public as well as professional educators. The need for motivation of students to simply stay in school is becoming self-evident as the dropout rate of students entering junior high school and failing to graduate approaches one in three in some California school districts. It is hoped this recognition of the need to create a positive attitude toward learning and the value of education will lead to an emphasis on research and the identification of successful strategies in integrating motivation in the design of instruction.

It is widely accepted that a major difference between a good teacher and a great teacher is the ability of the great teacher to motivate his/her students to <u>want</u> to learn. "If the students want to know bad enough, you can't keep them from learning" is the way one high school teacher expressed the importance of motivation in his class.

This paper presents the proposition that the difference between a good lesson and a great lesson is the consideration of learner motivation in its design. Operationalizing motivation in the instructional design process is the thrust of this effort. It is a modest start but perhaps it will inspire the search for more definitive and appropriate strategies for each phase of curriculum design and development. Toward this effort, it may be useful to examine the principles and practices of persuasive communication practitioners in the entertainment, advertising and public relations professions.

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Toward Development of an Acoustic Index of Primate Emotionality

B. E. Mulligan
Professor

Department of Psychology
University of Georgia
Athens, GA 30602

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B. E. Mulligan
Professor
Department of Psychology
University of Georgia
Athens, GA 30602

Abstract

Acoustical recordings and analyses of vocalizations and associated behavior of naturally ranging groups of *Macaca mulatta* were carried out in order to establish a natural basis for understanding how the vocal behavior of rhesus macaques living under captive, research laboratory conditions can be used as an empirical indicator of their emotional and psychological wellbeing. Determination of the acoustical and behavioral characteristics of naturally occurring rhesus vocalizations was thus an essential first step in the development of an acoustical index for the assessment of vocal emotionality in captive members of this important group of non-human primates. It was found that adult rhesus utilize seven or eight acoustical categories of calls in communicating vocally under natural conditions. Acoustical differences in calls correlate with behavioral context and functional significance of calls. Types of information contained in rhesus calls include individual location and identity, distress, solicitations of aid, predator alarm, threat of aggression, defense, or submission. Emotional condition, i.e., arousal intensity and valence ("fear" vs "anger"), is thus represented acoustically in the calls of these animals.

Toward Development of an Acoustic Index of Primate Emotionality

B. E. Mulligan

INTRODUCTION

Vocal communication among animals has been for many years a subject of considerable scientific interest, especially vocal behavior of non-human primates (e.g., Cheney and Seyfarth, 1992; Snowdon, Brown, and Petersen, 1982). Our interest in rhesus monkeys, *Macaca mulatta*, is both scientific and pragmatic. We want to establish the vocal repertoire of *M. mulatta*, as it occurs under natural conditions, to serve as a foundation for the evaluation of their "normal" vocal behavior under captive, laboratory conditions. This would provide an objective and non-invasive approach to the assessment of emotionality and, by extension, the psychological health of rhesus macaques employed as laboratory research subjects.

The first acoustical studies of rhesus vocalizations were conducted by Rowell (1962) and Rowell and Hinde (1962) on a captive colony of 22 animals. They distinguished between two general vocal classes , agonistic "noises" and mostly non-agonistic "clear calls". Thirteen years later, Erwin (1975) cited this work as "...the best description available..." of a highly variable vocal system that is extremely difficult to classify on either acoustical or functional grounds. In fact, Rowell and Hinde (1962) took the position that their acoustical analyses did not separate rhesus vocalizations into exclusive call categories and they presented some evidence of sounds they said to be "transitional" between call categories. Erwin (1975) likewise noted that vocalizations of rhesus may contain mixtures of tonal clear calls with atonal noises. Indeed, he suggested that rhesus vocalizations function primarily to signal the caller's emotive condition.

Rhesus agonistic "screams" were extensively studied by Gouzoules, Gouzoules, and Marler (1984) in a large, free-ranging colony on Cayo Santiago. Contrary to previous findings, Gouzoules *et al.* found that sounds emitted during agonistic encounters were acoustically divisible into five discrete call categories each of which functions as a representational signal. Calls were found to be associated with status of the opponent (dominance rank or matrilineal relatedness) and level of aggression. Because they did not observe that either scream type or probability of subsequent behavior of the receiver varies with the caller's level of arousal level, they concluded that arousal information is not a primary informational component of rhesus screams.

Most recently, Hauser (1992) reported a study on the rhesus "coo" vocalization, a tonal, or clear call that is said to function as a "social contact" signal that contributes to group cohesiveness. Recordings were made from the colony on Cayo Santiago. The call acoustic structure of the call was reported to consist of closely spaced (about 400 Hz) harmonically related narrow bands below about 10 kHz. Call duration was found to vary between 100 and 650 msec. Remarkably, the members of one matriline were found to produce coos that were consistently more "nasal" than coos emitted by other animals. Nasality was defined acoustically as the level of noise between bands in the call. While it is interesting that nasality appeared to be limited to a single matrilineal line, it was not determined whether monkeys respond differentially to this condition.

It is implicit in the above discussion that the vocal repertoire of *M.mulatta* is not yet established. Our own preliminary observations in 1991 of vocalizations of laboratory-housed rhesus suggested the existence of some differences between their calls and those reported in the literature. However, it was not possible for us to assess whether these differences were an effect of laboratory housing, or perhaps a result of the improved analytical capabilities of the instrumentation that we were using, or due to some other factors.

It was apparent that the natural vocal repertoire of the rhesus macaque would have to be re-examined before meaningful conclusions could be reached concerning the "emotionality" of vocal behavior in laboratory-housed animals.

BACKGROUND RATIONALE

Our goal was to lay the foundation for development of a method that could be used to convert acoustical records of rhesus vocalizations into measures of emotionality. While this technique would be designed for application in laboratory colonies of research primates, it would need to be based on the behavior of free-ranging animals living under "natural" conditions. The first step, then, would be to determine the "normal" acoustical characteristics of rhesus vocalizations and associated behavior. Once this was accomplished, acoustical correlates of emotional valence (i.e., fear to calm to anger) and and emotional arousal (i.e., intensity) would be established for the normative group of free-ranging animals and provide a basis for measuring, or indexing, the vocally-expressed emotionality of captive groups.

Such a technique would be non-invasive and would permit real-time conversion of acoustical records into continuous tracks of vocally-expressed emotional variation. It would thus provide an objective means to document the dependence of emotional state on such major parameters affecting animal welfare as housing conditions, composition of social groups, environmental enrichments, and research procedures requiring handling, training, isolation, surgery, recovery, etc. This technique also would offer new opportunities for reducing and regulating stress in the behavior and health of laboratory-housed research subjects and it could prove to be useful to future programs of health management. For example, potential contributions of this technology to the wellbeing of primates used in critical Air Force research would include:

1. Lowered stress levels, more emotionally stable research subjects, and decreased animal health costs for the care and maintenance of non-human primates;

2. An objective and non-invasive method for demonstrating compliance with federal standards and requirements (Federal Register, 15 August 1990, pp. 33512-33526) to assure the "psychological well-being" of laboratory-housed primates;

3. An inexpensive approach to the "environmental enrichment" of laboratory housing facilities in keeping with the intent of Congress "...to provide adequate space equipped with devices...consistent with the primate's natural instincts" (Congressional Record, 17 December 1991, pp. H12335-H12336).

METHODOLOGY

All recordings of *M. mulatta* vocalizations were made on Morgan Island (operated by LABS, Inc.) off the coast of South Carolina. The area of the island is about 500 acres and contains abundant natural vegetation (large live oaks, pines, cabbage palmetto, etc.). The colony of free-ranging rhesus on the island is relatively large, approximately 4000 animals in about 32 social groups, although animal density appears to be relatively low. Stations are located around the island where animals are fed daily and provided continuous access to fresh water.

Vocalizations were recorded with a Sennheiser MKH 416 P48 supercardioid/lobe condenser microphone (frequency response 40-20000 Hz) feeding a Sony TCD-D10 Pro II digital audio recorder sampling at 48 kHz. The microphone was held in a shock mount and, for most recordings, it was enclosed in a Sennheiser MZW 60 blimp windscreen. Acoustical analyses were performed using a Sony PCM-2700 recorder to read the prerecorded digital tapes into a Kay CSL model 4300 unit operating at a rate of 51,200 samples per second within a 80486 33 MHz computer with SVGA display. Data was spooled directly from the PCM-2700 via CSL to 90 Mbyte Bernoulli disks and stored as files for analysis. This system permitted temporal, spectral, and three dimensional graphic and numeric analyses of very large vocal data sets.

Data collection was begun in the Spring of 1992 and continued through early Fall. Acoustical recordings were supplemented by video-sound recordings for behavioral analyses and by recorded commentaries of primatologists experienced in field studies of rhesus behavior. Categories of rhesus calls were established entirely on the basis of distinctive acoustical characteristics that were found to be common to groups of vocalizations. Behavioral interpretations of each call category were derived from field observations made both at the time of recording and later after acoustical segmentation of vocalizations into categories of calls.

Acoustical and behavioral data were then evaluated for each call category to determine emotional valence and arousal. Calls were sorted into one of three valence groups; *aggression* (threatening movements and facial expressions with or without attack), *evadance* (avoidance movements, facial grimmaces, escape), or *neutral* (social calm, relief from threat, anticipatory excitement, e.g., for food). Calls within each these categories were then ranked according to intensity of associated actions. The resulting groupings were then analyzed to determine acoustical correlates of aggression, evadance and neutral categories and to identify systematic intensive variations among calls within each grouping.

RESULTS

Vocal Repertoire of Adult *Macaca mulatta*

1. ***Low Bark***. These relatively quiet, low-pitched vocalizations are emitted by females and males when group behavior appears to be relatively stable, but with some small potential for danger, or conflict. In this context, *low barks* often are produced by only one individual at a time in a group, without apparent focus, possibly serving as acoustic markers of the caller's location and condition of mild arousal. Slightly more intense *low barks* that are focused toward a specific source of arousal, e.g., an intruder or an aggressor against a coalition member, may be emitted by one or more individuals.

The low pitch and flutter-like quality of this call results from both its spectral and pulsatile structure. *Low barks* are composed of 2-5 pulses (mean 3.2) each and the pulses are generated at audible rates between 16 and 24 pps (mean 19.4 pps). Individual pulse durations vary between 31 and 54 msec (mean 45 msec). The effect is a low guttural flutter. Low pitch is reinforced by pulse spectral composition; energy is primarily concentrated in two bands, one very low band below about 890 Hz on average and one intermediate band that averages between about 2.5 and 5.9 kHz. Excited callers may expand this band to frequencies as high as 10 kHz. Conversely, the call may be emitted with energy no higher than about 4 kHz. Call durations also appear to covary with intensity, ranging between brief low level calls of about 84 msec and more intense calls of about 265 msec (mean 166.6 msec).

Rate and intensity of vocalization appear to reflect the caller's arousal level and whether the call is specifically directed or not. *Low Barks* may be directed as mild threats toward a particular recipient, or generally broadcast without specific focus. Under apparently mild arousal conditions (e.g., group foraging on ground), *low barks* may be emitted non-directionally in clusters of several calls each with variable silent periods intervening between clusters. In this context, the non-directed *low bark* may signal proximity or spacing and may contribute to maintenance of group cohesion.

In the case of *low barks* directed toward a specific recipient, these calls may be produced at sustained rates of 2 or 3 per second over periods of several minutes by an individual responding focally to the presence of a non-aggressing intruder. Effectively, the calls mark the continued presence of the intruder and may act as group alerting, or warning, signals.. If the caller is suddenly further aroused by aggressive action of the intruder, *low barks* are likely to be replaced by either *threat barks* or *alarm barks*, depending on characteristics of the intruder (e.g., size, sex, rank, group membership, etc.) and the caller's resulting emotional valence (anger-defense *vs* fear-flight). If the caller is attacked, its vocalizations are likely to become *screams*.

2. ***Gruff Bark***: More intense and temporally compact than *low barks*, these low-pitched, harsh vocalizations are emitted while facing toward the focus of aggression. At their lowest levels *gruff barks* exceed *low barks* in intensity by 10 to 15 dB and the intensities at which *gruff barks* are produced may be varied by as much as 30 dB, a relatively large dynamic range for one type of call. At lowest levels, *gruff barks* may be emitted singly, or at irregular intervals, and may serve as a prelude to imminent physical aggression, especially when head-bobbing, piloerection, and tail elevation are evident in the threatening animal. The more intense *gruff barks* tend to be emitted at rates averaging between about 3 and 5 calls per second and are nearly always associated with physical attack by the caller. Conflicts between

adults frequently involve simultaneous production of aggressive *gruff barks* and defensive (or, possibly submissive) *screams* alternating with aid-soliciting *shrill cries*.

The *gruff bark* is a simple, but acoustically distinctive, variation of the *low bark*. The slow pulses of the *low bark* are temporally fused into continuous bands of energy, one band below about 700 Hz on average, and a second broad band which averages between about 2.5 and 13 kHz. This spectral structure differs from that of the *low bark* primarily in the greater average width of the mid-frequency band, a result simply of the greater average intensity of threat calls; spectra of *gruff barks* emitted at low intensities match pulse spectra of the more intense *low barks*.

Durations of *gruff barks* average about 157 msec. This is about the same as the average of the distribution of *low bark* durations, but there is significantly less variability in the durations of *gruff barks* than *low barks* (standard deviations of 32 and 59 msec, respectively). The amplitude pattern of *gruff barks*, though variable, tends toward sharp rise times followed by slower decays; rise times average about 38 msec (range 21-75 msec), less than a third of the call duration. This asymmetrical onset/offset pattern of relatively stable duration probably reflects vocal limits in the production of high intensity calls.

3. ***Echoic Bark***: Most acoustically intricate of rhesus atonal calls, the structure of *echoic barks* appears to mimic reflected sounds. These intense calls seem to reverberate through the

canopy as if reflected by distant and scattered surfaces, perhaps creating an illusion of calls originating from multiple locations and distances greater than actually exist. The effect might be acoustic camouflage, i.e., disguise of acoustic cues to the caller's spatial location, a particularly advantageous feature for a call that signals alarm.

The echoic semblance of this call is probably due to amplitude differences and time intervals between sharply-onset pulses. The call contains several pulses emitted in close succession at increasing amplitudes. The first pulses (usually two) are brief (mean 36 msec; range 12-42 msec) and precede a more intense pulse of longer duration (mean 71 msec; range 33-101 msec). In many calls, this main pulse offsets directly into a less intense band of noise of about the same duration (mean 88 msec; range 58-143 msec) which effectively extends the main pulse of the bark, but at a lower energetic level. Durations of *echoic barks* (mean 199 msec; range 138-321 msec) exceed on average durations of *low* and *gruff barks*.

Intervals between successive pulses of *echoic barks* are approximately the same, averaging about 28 msec. If these intervals actually were reverberation times, they would correspond to increases in propagation distances of about 32 ft between first and second pulses, and twice this distance between first and third (main) pulses. Unlike the slow and audible pulse rates in *low barks*, pulse rates in *echoic barks* (mean 37 pps; range 34-43 pps) are auditorially fused, but not temporally fused as in *gruff barks*. Fusion of temporally delayed segments in *echoic barks* would contribute to the perception of spatial displacement of these calls. The illusion of reverberation might be reinforced by the substantial increments in pulse amplitudes (10 dB mean increment between first and second pulses; 14 dB mean increment between second and main pulses) and by the associated increments in upper limit of pulse bandwidths (first pulse 0.09-4.84 kHz; second pulse 0.16-13.62 kHz; main pulse 0.09-22.00 kHz; offset noise 1.3-16.3 kHz) which may be heard as an increasingly loud, rising pitch.

Echoic barks function as alarm signals. They are emitted by males and females preparatory to, and during, escape from frightening and dangerous situations, e.g., approach of a potential predator. They seem to be emitted when the source of danger (rarely a conspecific) is within sight of the caller and they nearly always appear to be associated with escape movements. *Echoic barks* from one animal may excite other group members to orient toward the source of danger and to begin emitting the same call, especially if the group is arboreal. Animals on ground may take to the trees in response to *echoic barks* from the canopy and those in trees may move to higher branches, or the group may flee, Emission of these barks during flights on ground through vegetation appear to be infrequent.

Aroused individuals facing a moderately threatening potential predator may equivocate between aggressive displays and escape movements while alternately emitting *gruff* and *echoic* *barks*. If distance between the source of danger and the caller is abruptly shortened, equivocation gives way to escape and alarm signals. If the predator does not pursue and if escape succeeds in re-establishing a safe distance, the caller may again resume equivocating between aggression and escape.

4. ***Scream***: As its name may suggest, the scream is an atonal, noisy expulsion of acoustic energy over a broad band of frequencies. Elicited by threat of aggression or actual attack, both the energy content and the spectral structure of *screams* appear to depend on the severity of the aggression. A threatening gesture received from a higher ranking individual may elicit low level *screams* from the recipient. If the gesture is followed by further aggression (lunging toward or chasing), the energy levels and spectral distributions of the ensuing *screams* expand. The defensive individual may emit a series of *screams* interspersed with *shrill cries* (and "looks" for coalitionary support), the number and intensity of its calls apparently depending on the effectiveness of its attempts to escape. If the aggression involves actual physical contact (e.g., slapping, biting), the defensive *scream* usually becomes a super intense acoustic *blast* directed toward the aggressor's face.

Screams may consist of single vocalizations, but usually they are composed of several successive bursts of broadband energy. Occasionally, *screams* may be preceded by *clicks*, perhaps warning of very high stress levels. Tonal *shrill cries* soliciting coalitionary support also are often associated with *screams*, either preceding or interspersed among them in series of calls. *Screams* usually are broadcast directly toward the antagonist while *shrill cries* appear to be emitted with the caller's head turned away, probably in the direction of animals who might provide aid. Alternatively, rather than serving as a counter-aggression, defensive expressions, screams might also signal some degree of submission.

The spectral structure of *screams* is built around a wide band (2 to 8 kHz bandwidth) of intense energy often displaying irregular frequency modulation within its more intense regions. The lower edge of the high energy band is in the region 2.4-3.2 kHz with little energy below about 1.7 kHz in moderate level *screams*. As *scream* intensity increases, the width of the high energy band expands to higher frequencies (an increase in call intensity by 25 dB corresponds to an expansion in upper frequency of the band from about 5.4 kHz to about 10.6 kHz). Although the upper region of this band usually does not exceed about 12 kHz, lower level noise extends to beyond 22 kHz. In the most intense forms of this call, *blasts*, it appears that the high energy band expands to encompass the entire spectrum which is nearly flat to beyond 22 kHz.

Although the abruptness of *scream* onsets appears to increase as intensity increases (from about 93 to 26 msec), call duration is not correlated with intensity. Calls range in duration between 150 msec to 1.2 sec (mean 436 msec), the length of the *scream* seeming to depend on the severity and persistence of aggression. The nature of the attack also is evident in irregular patterns of amplitude modulation that may be present in calls from an animal experiencing sustained aggression from which it cannot immediately escape. In this case, individual *screams* may consist of 2-5 contiguous ragged pulses of energy. Times between successive *screams*, or *screams* and *shrill cries*, of animals under attack range between about 20-48 msec, a nearly continuous cacophony of intense sound. Such rapid sequences of calls may be difficult for human listeners to resolve without practice, especially if these calls are mixed with intense *gruff barks* from an aggressing animal.

5. ***Shrill Cry***. This piercing tonal call may be emitted as brief chirps or intensely warbling whistles by males or females soliciting coalitionary support while receiving threats or responding directly to physical aggression. In addition to the apparent recruitment-of-aid function of the *shrill cry*, its intense and acoustically complex nature probably makes it an ideal signal for the transmission of location information, as well as the caller's individual identity and condition of distress. The tonal nature of *shrill cries* is due to the banded structure of their energy spectra which we usually hear as having pitch. Though adult *shrill cries* may occur independently of other calls, often they are emitted in conjunction with atonal *screams*. In these defensive (and/or submissive) sequences, it appears that

the caller faces its aggressor as it *screams*, but looks away, probably toward supporters, as it *shrill cries*.

One of the more acoustically variable of the rhesus calls, the *shrill cry* exhibits complex modulation in both amplitude and frequency domains. Tight distributions of energy in narrow bands (range 0.2-3.0 kHz; mean 900 Hz) are spaced roughly at harmonic intervals that co-vary in center frequency and amplitude over the variable durations of the *shrill cry* giving this type vocal expression a sound quality that may range from brief, intense chirps to more protracted and sharply pitch-modulated whistle sounds.

Patterns of frequency modulation may involve combinations of such pitch-varying effects as abrupt up or down sweeps in bands, harmonic warbling, and variations in sharpness of tuning (width) of bands. The extent of frequency modulation in *shrill cries* exceeds that of other rhesus calls, ranging between 0.7 and 5.5 kHz (mean modulation range 3.1 kHz). Amplitude also may undergo appreciable modulation (e.g., 7-19 dB) during *shrill cry* emission depending apparently on momentary events to which the caller is reacting, as well as its arousal level. Irregular amplitude patterns composed of multiple pulses of different shapes and durations appear to be associated with high levels of distress.

Shrill cries usually contain at least three detectable energy bands separated by intervals of 1.4-5.2 kHz (mean 3.9 kHz). The lowest and most intense band tends to be in the range 1.6-7.7 kHz (mean 5.1 kHz) and averages 17 dB greater SPL than its first harmonic (it is probably this lowest band that determines the pitch heard by humans). The average difference in SPL between the first and second harmonic is only 4 dB, which appears to represent the rate at which the intensity of the higher harmonics declines. However, even if *shrill cries* contain more than the first three bands, some of the higher bands may be missing, or buried in noise. In the case of relatively intense calls, the upper range of the highest band may extend beyond 20 kHz.

6. ***Coo***: A clear, tonal call that is emitted at low-to-moderate intensities usually by several individuals in a group under conditions that appear to be behaviorally reinforcing, e.g., conditions involving either receipt of food or removal of threat. For example, sight of food and events anticipatory of food presentation elicit from a group in trees near a familiar feeding place a chorus of excited *coos*. Similarly, if withdrawal of a fear-inducing situation (aggressing intruder on the ground; monkeys in trees) results in cessation of alarm barking, group *coo*-calling tends to follow the apparent reduction of group anxiety. It is not inconsistent with this association between group *coo*-calling and reinforcing conditions to hear occasional isolated *coos* from single individuals in low states of arousal, e.g., while reclining on a shady limb in mid-afternoon heat.

General features of *coo* spectral and temporal structures are relative stable. Energy is distributed throughout the spectrum in very narrow bands (bandwidth: 100-200 Hz) at approximately regularly spaced intervals that range between 400 and 900 Hz, depending on the frequency of the fundamental. However, one or more energy bands may be absent, or at undetectably low amplitudes, in the spectra of some calls. Bands usually are not found a frequencies above about 11 kHz.

The pattern of pitch variation in most *coos* is visible in the patterns of frequency modulation that spectral bands undergo. Pitch gradually climbs to about the midpoint of the call and then declines, the direction and range of modulation increasing towards the middle of the call. The range of frequency modulation of energy bands increases with frequency, though not with harmonic regularity. Modulation may be negligible in low frequency bands near the fundamental, as much as 700 Hz in mid spectrum bands, and approach 1.6 kHz in upper spectral bands. However, the pattern of frequency modulation in upper bands often is not present in lower bands, and upper band structure may vary in calls successively emitted by the same animal. These differential vocal effects may constitute recognizable individual differences or possibly contextually significant information. In any case, we have firm evidence that individuals may alter the upper spectral structure of successively emitted *coos*. Spectral structure is not fixed.

Call durations, relative amplitudes, and amplitude patterns appear to covary and may be related to differences in general features of social contexts. Although the range of relative amplitudes of *coos* appears narrow (4-6 dB) in comparison to other calls, amplitudes of calls produced by excited animals in anticipation of food tend to be greater than those produced by animals relieved of tension. Likewise, while amplitude patterns of low level *coos* tend to be flat with gradual, symmetrical rise/decay times of about 64 msec and moderate durations (mean 192 msec), more intense *coos* exhibit sharper rise times (about 45 msec) and longer durations (mean 328 msec). The apparent contextual dependency of these acoustic differences may not be valid if, indeed, the differences turn out to be reliable.

7. ***Click***: The briefest of rhesus vocalizations, this sound is a single, intense pulse ranging in duration from 12 to 40 msec (mean 26 msec). *Clicks* may be emitted singly or in irregularly distributed pulse trains at average rates of about 44 pps for several seconds at a time. Although most energy is concentrated in a band between about 2.6 and 12 kHz, the spectra of more intense *clicks* are relatively flat with energy extending to beyond 22 kHz. *Clicks* may occur independently of any other calls, or in conjunction with *screams* and *shrill cries*. The short durations and broad spectra of *clicks* would appear to make these sounds readily localizable, especially when emitted as pulse trains. It is possible that *clicks* signal a high level of arousal, perhaps predictive of likely aggressive or defensive reactions if arousal-inducing conditions persist. However, *click* pulse structure offers little room for individual variation and

probably would not be a strong signal of caller identity.

8. ***Shrill Scream***: A mixture of *shrill cry* and *scream*. Acoustical characteristics of this call a those of intense *screams* overlaid by tight, irregularly modulated bands of energy typical of the *shrill cry*. The relatively greater intensity of the latter makes the this call appear as a more intense and noisy (less tonal) *shrill cry*. It appears to be emitted by highly aroused animals under attack with little opportunity for immediate escape. The *shrill scream* seems to simultaneously combine components of defense (acoustic blasts) with piercing solicitations of aid.

While the acoustical properties of this call appear to be completely described by *screams* plus *shrill crys*, the *shrill scream* is not simply two calls produced independently then summed. Remarkably, it is a call produced as an integral output of a single vocal system.

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Categorical classification of rhesus calls as either aggression, escape, or neutral was not possible in all cases. *Low barks* emitted at relatively low levels tend to be more associated with neutral behavior than aggression. The same call emitted at higher intensities appears to be an expression of aggression. Relatively low level *echoic barks* appear to be associated with equivocating threat aggression and escape movements, while *echoic barks* of greater intensity appear to be mostly associated with "fear grimmaces" and escape movements of more highly aroused animals. With these exceptions, rhesus calls were reliably placed into one of the three mutually exclusive categories of emotional valence. *Gruff barks* are always aggression calls. *Screams, shrill crys, clicks and shrill screams* are each evadance calls. Coos are always neutral.

While the neutral condition assigned *coos* actually represents a third affective valence (perhaps ranging between relief and gratification), for present purposes it appears adequate to scale rhesus emotional behavior on bivalent dimensions of emotion representing the opposed polarities of "anger" (aggression) and fear (evadence) divided by a "calm" or "happy" neutral point. Also, due to the apparent high correlation between acoustic intensity of rhesus vocalizations and arousal or behavioral intensity, for present purposes it appears adequate to scale emotional intensity in terms of acoustic intensity.

Automatic measurement of vocal emotionality in the rhesus monkey therefore may be accomplished in two steps, *viz.*, (1) call identification and (2) call intensity. Several approaches are under consideration for accomplishment of step one (e.g., detection of differences in spectral distributions of energy, correlation of energy patterns with template, etc.). Step two requires determination of some measure of energy levels within calls that can be meaningfully compared across calls. These two pieces of information will specify both emotional valence and intensity of rhesus vocal expressions.

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DEVELOPMENT OF A ONE-DEGREE-OF-FREEDOM MASTER-SLAVE DEVICE TO STUDY BILATERAL TELEOPERATION

Edgar G. Munday
Assistant Professor
Mechanical Engineering and Engineering
Engineering Science Department

University of North Carolina
at Charlotte
Charlotte, NC 28223

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Edgar G. Munday
Assistant Professor
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Abstract

A One-degree-of-freedom master-slave device was built to study bilateral teleoperation. The test apparatus allowed the slave to be driven by a DC servomotor for some of the experiments, and by a stepping motor for other tests. The master was driven only by a DC servomotor.

The basis for control of the slave was position error between master and slave, whereas, the control of the force in the master was based on the error in force between slave and master. To achieve stability, "damping" was introduced in the force loop by negative feedback of the derivative of the force in the master. Graphical overlays of slave force and master force show reasonable force reflection fidelity and a highly stable operation for the DC servomotor-driven slave.

The stepping motor provided reasonable tracking of the slave under simple position control. However, with a force applied to the slave, the stepping motor behaved unstably, inducing such severe vibration as to prevent further meaningful tests.

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INTRODUCTION

Wartime scenarios involving chemical, biological, or radiological contamination present hazards to personnel who must maintain aircraft and perform a variety of other tasks. Developing greater capability to perform highly dextrous tasks without putting humans at risk is of interest to the U.S. Air Force. Remote control of sophisticated mechanical manipulators has been recognized as a means to achieve the desired goal.

The objective of this work was to develop a one-degree-of-freedom master-slave device to provide preliminary insight into system performance and stability. The device also provides a means to assess control strategy modifications before full-scale implementation is undertaken.

TECHNICAL BACKGROUND

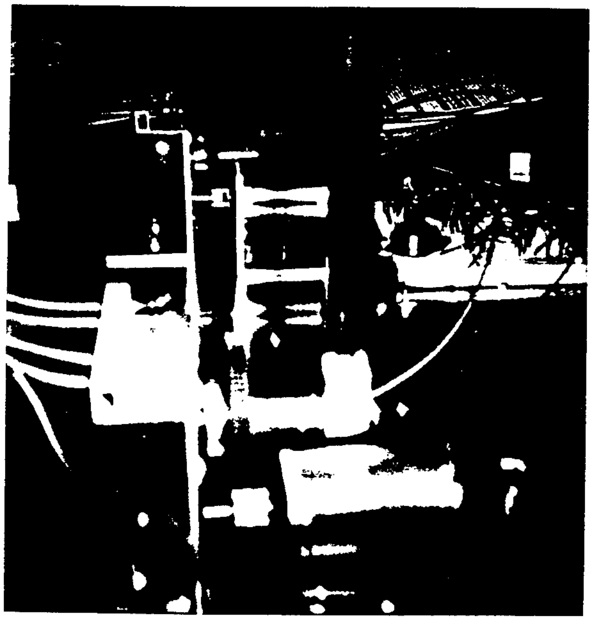
A considerable amount of work has been performed to deal with the problem of a manipulator in contact with its environment.[1,2,3,4,5,6]. Previous work has included one-degree-of-freedom prototypes and detailed models.[7,8,9,10,11]. Although most investigations have been specific to autonomous manipulators, the insights gained have some relevancy to force-reflecting teleoperation. Most work to date has been performed using DC servo-based manipulators rather those with stepping motor drives.

APPARATUS

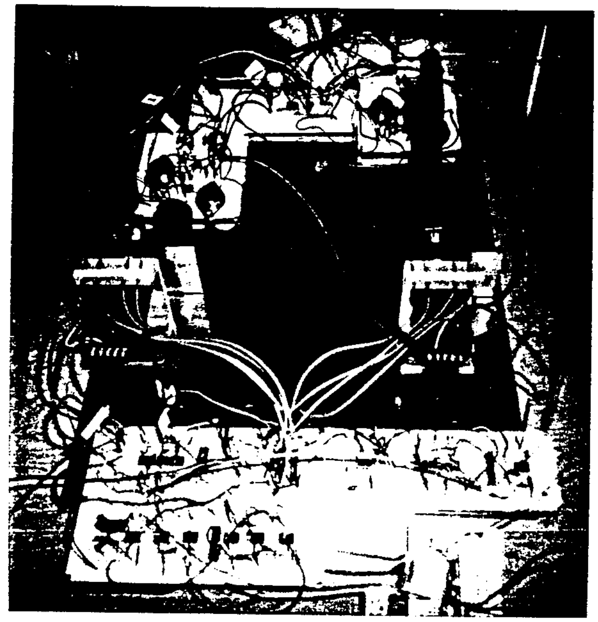
Figures 1(a),(b) and (c) are photographs of the master-slave device from several different angles. Figure 1(d) shows the stepping motor installed at the slave. Two personal computers (PC's), not shown in Fig. 1, were used to control the system and for data acquisition. Also, not shown in Fig. 1 are the four 12 volt dry cell batteries that were used to power the master-slave device.

Figure 2 shows a block diagram of the control system based on the servomotor-driven slave. The position control loop for the stepping motor driven slave consists only of a one-step correction issued to the step motor each time the error between master and slave is sampled. Proportional-integral-derivative (PID) controllers are shown in both the master and slave block diagrams.

The angular positions of the master and slave devices were monitored by angular displacement transducers (ADT's). The ADT's produced an analog signal which was made available to the computer by means of a 12-bit analog to digital (A/D) multi-function carrier board installed in one of the computer card slots. Analog voltage output was made possible by a 12-bit digital to analog (D/A) module which was an accessory to the carrier board. The computer control was implemented by means of a "C" program. A 386-based PC with math co-processor and 33 MHz clock was used for position control, and a 50 MHz, 486 PC was used for the force loop. The sampling rate for the servomotor-



(a)



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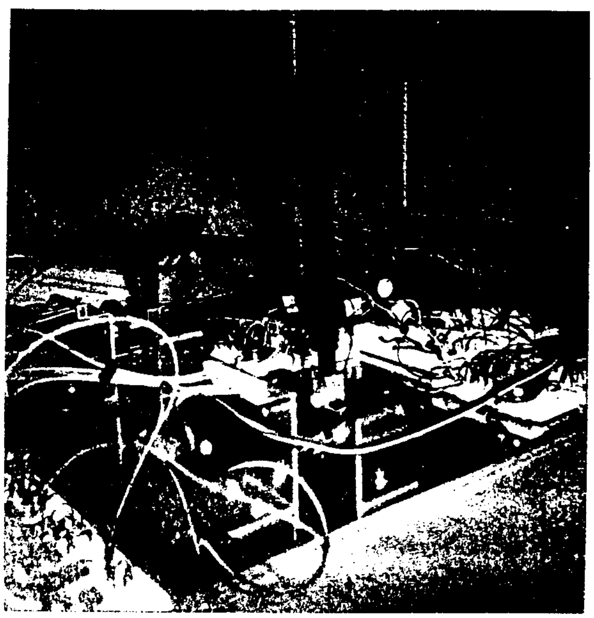
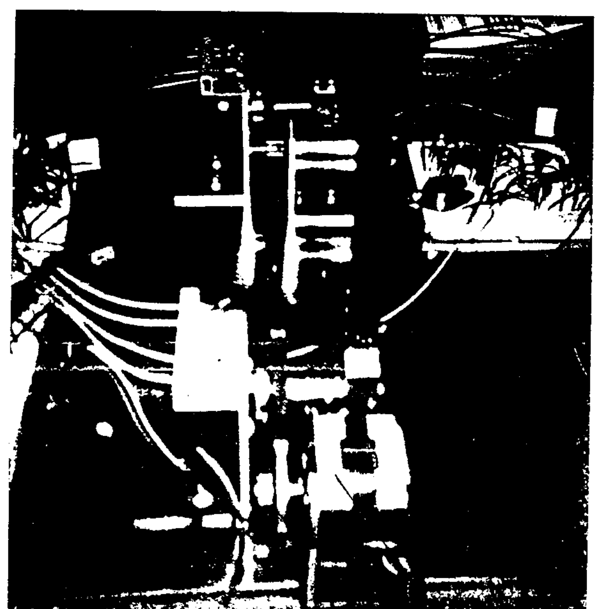


(c)



(d) stepping motor

Fig. 1. (a),(b), and (c) Show the Master-Slave Device From Several Different Angles. Fig. 1(d) Shows Stepper Motor Installed on Slave

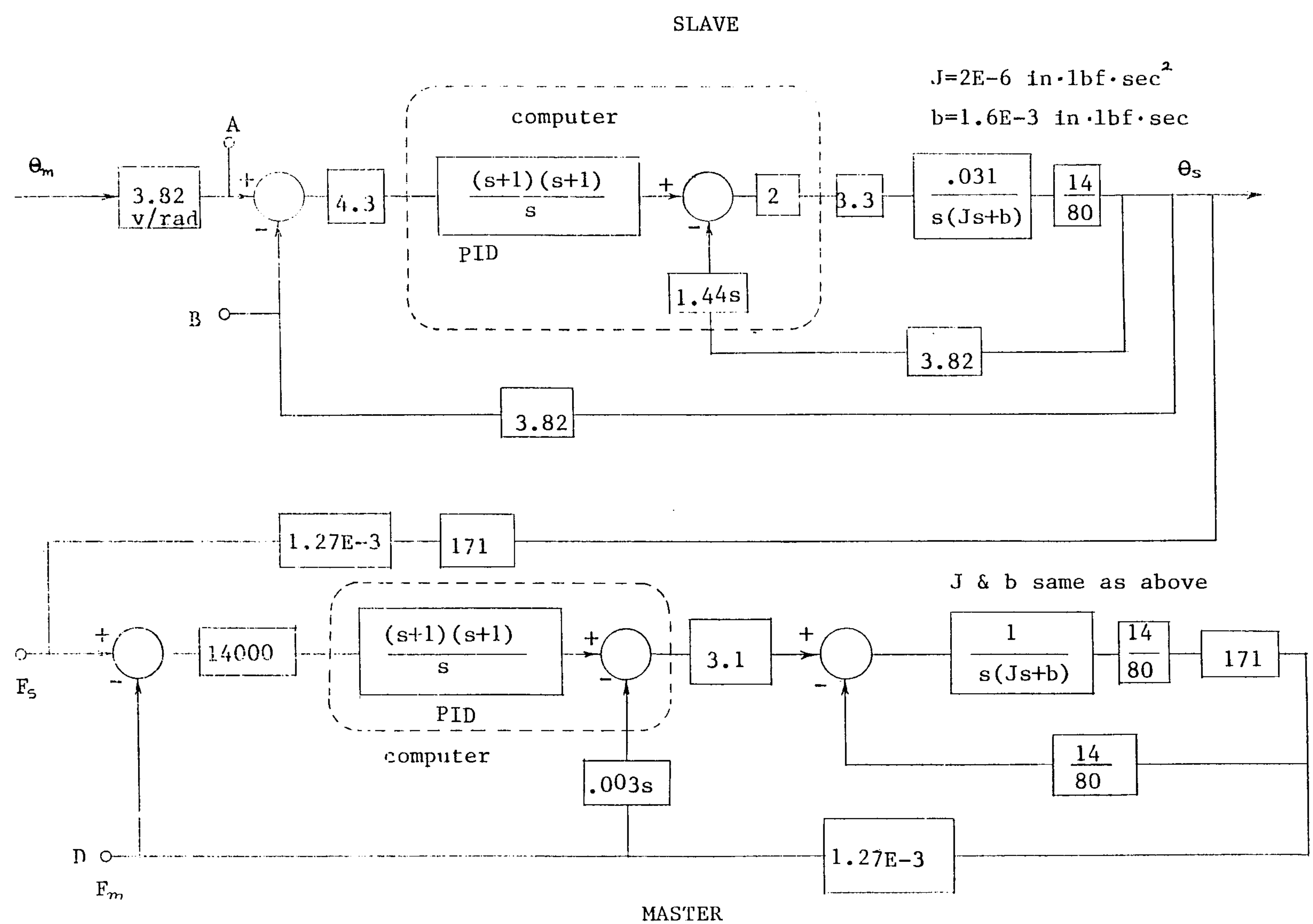


Fig. 2. Block Diagram of Control System

driven slave was around 15,000 Hz and for the stepping motor-driven slave, it was around 40,000 Hz. The sampling rate for the force loop was around 20,000 Hz. The "C" program for the position control of the DC servomotor-driven slave, which is somewhat similar to the force control routine, is listed in the appendix as a sample of the programming.

The forces on the master and slave levers were detected by strain gages. The gages were mounted so as to be self-compensating for temperature. The output of the bridge was amplified 14,000 times before entering the computer.

TEST RESULTS

To show the tracking of the slave position relative to the master, data were obtained from the outputs of the angular displacement transducers. The position of the master was read at the point labeled "A" in Fig. 2 and the position of the slave at point "B." Figure 3 shows an overlay of the displacements from master and slave during oscillatory motion. The frequency of the motion is around 7.3 Hz in the first region, which was as rapidly as it could be moved by hand. The overlay shows the master and slave displacements to nearly coincide. Figure 3 was produced using the servomotor driven slave.

Figure 4 shows an overlay of displacements of master and slave with a rapid change in position applied to the master. The change in position was produced by vigorously striking the master and stopping it abruptly by driving it into a brick. The slave shows roughly a 20 % overshoot.

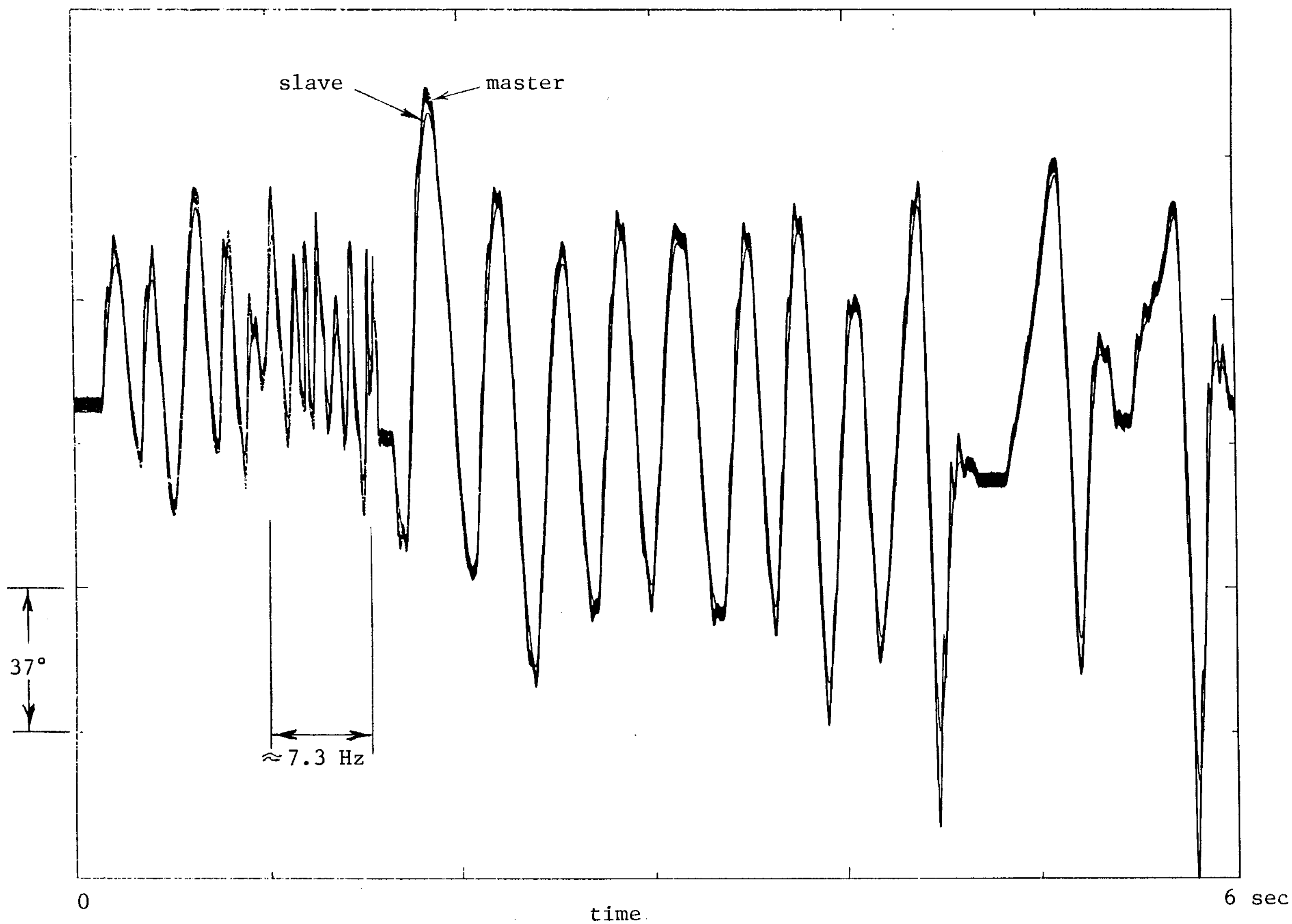


Fig. 3. Overlay of Displacements from Master and Slave During Oscillatory Motion

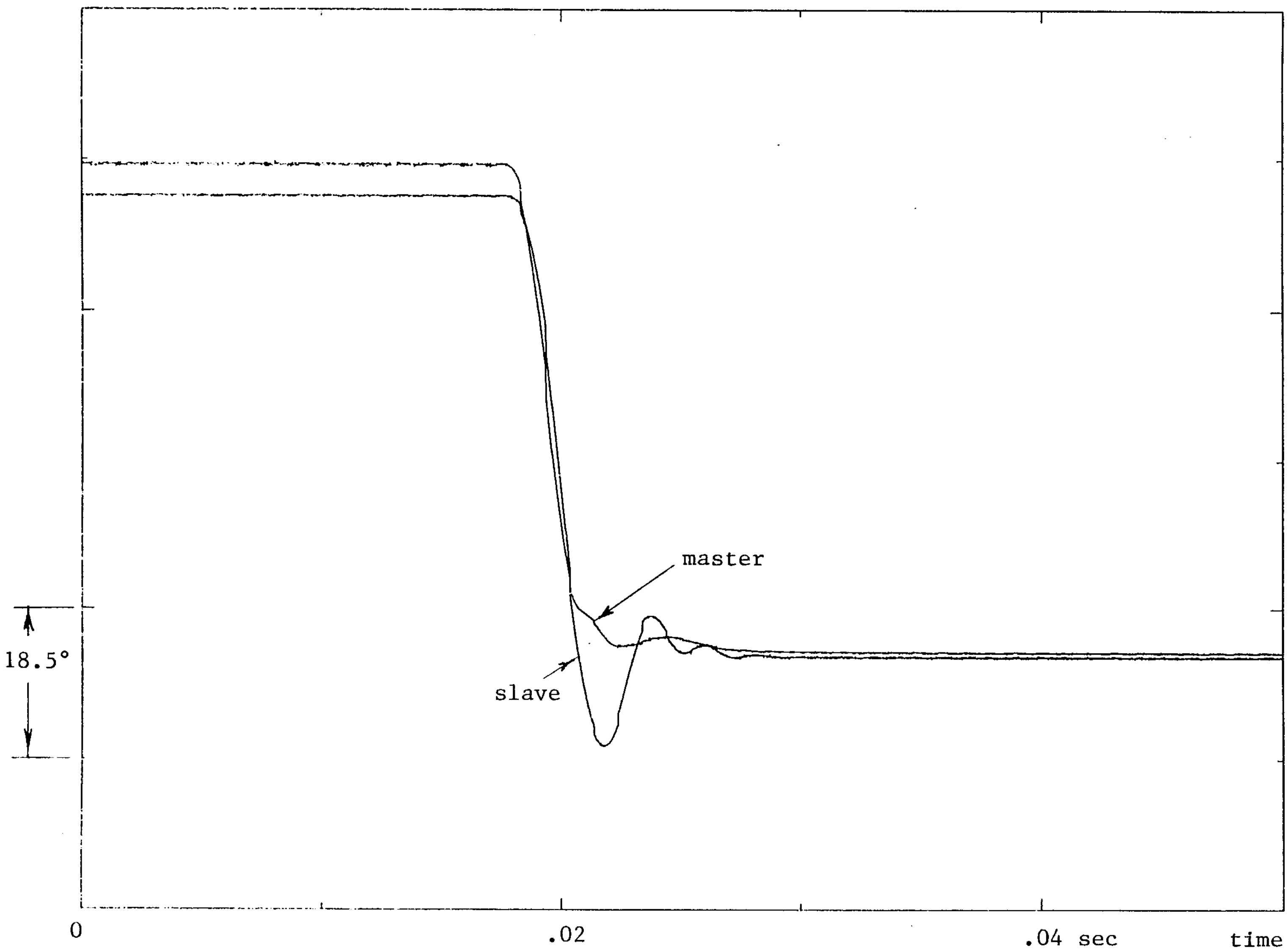


Fig. 4. Overlay of Displacements of Master and Slave with Step Change in Position Imparted to the Master.

Despite the good performance of the position control, there needs to be more work on the numerical differentiation and integration required for the PID controller as well as for the negative velocity feedback used to increase damping. Differentiation was based on the difference between the new value and the old value, while integration was based on the sum of the last 100 values. An indication of numerical problems is shown by the following: The velocity was obtained by differentiating position as suggested above. Perhaps due to noise, the damping based on this computed velocity was far less than expected. The 1.44s shown in the velocity feedback loop in Fig. 2 should have made the system many times overdamped, which was not the case. Figure 5 shows similar results from a Matlab simulation of the slave response due to a step input at the master. In the simulation, the only damping was the estimated damping due to friction and windage. The results are not appreciably different from that seen in Fig. 4.

Figure 6 shows the results of overlaying the master and slave displacements during oscillatory motion with the stepping motor driving the slave. The frequency of motion is around 5.5 Hz.

To monitor the forces in the master and slave, voltages were calibrated and read from the master leg and slave leg of the strain gage bridge. The slave force was measured at point "C" in Fig. 2 and the master force was measured at point "D." The force loop was made stable by introducing a damping effect based upon

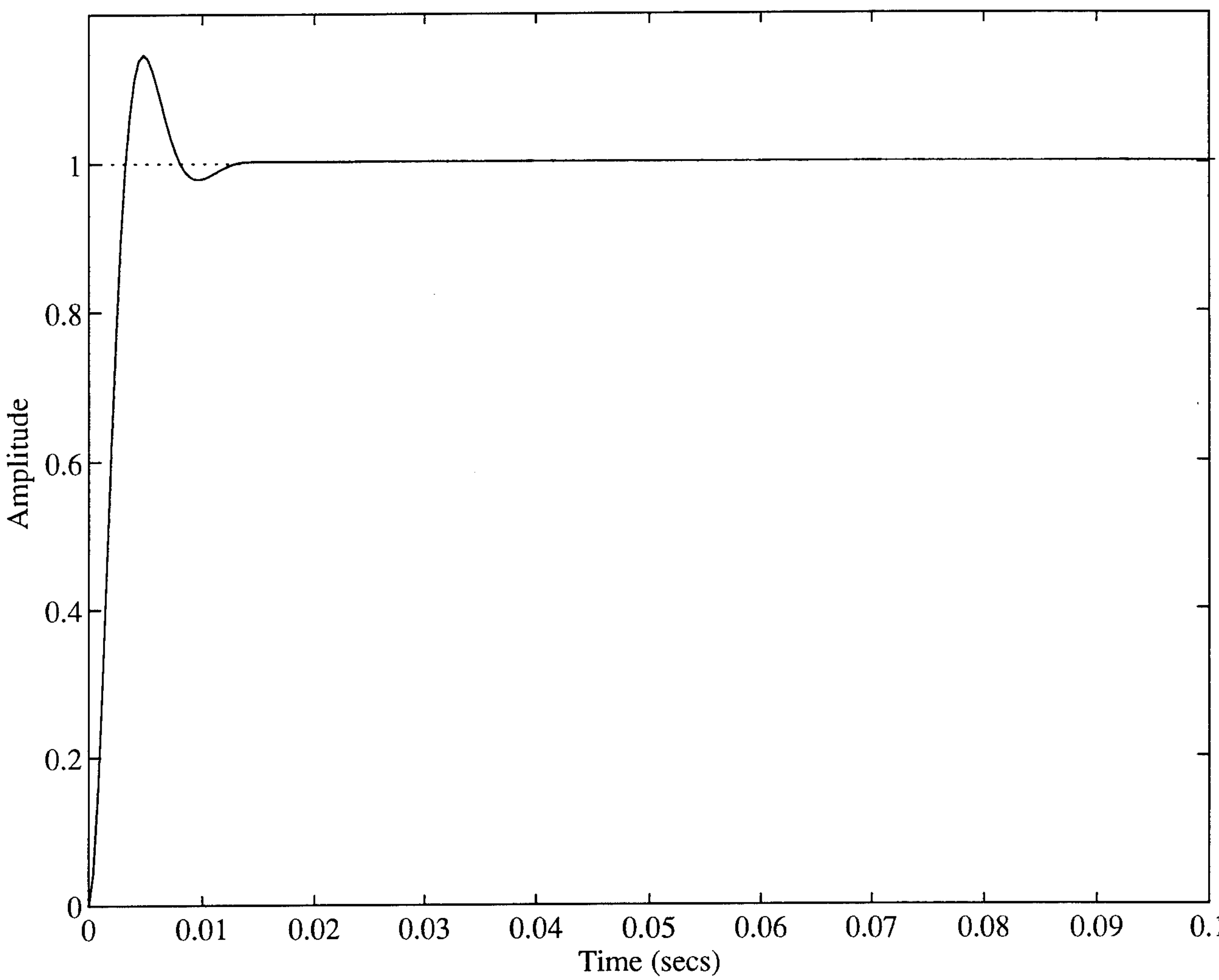


Fig. 5. Matlab Simulation of Slave Response Due to Step Input to Master.

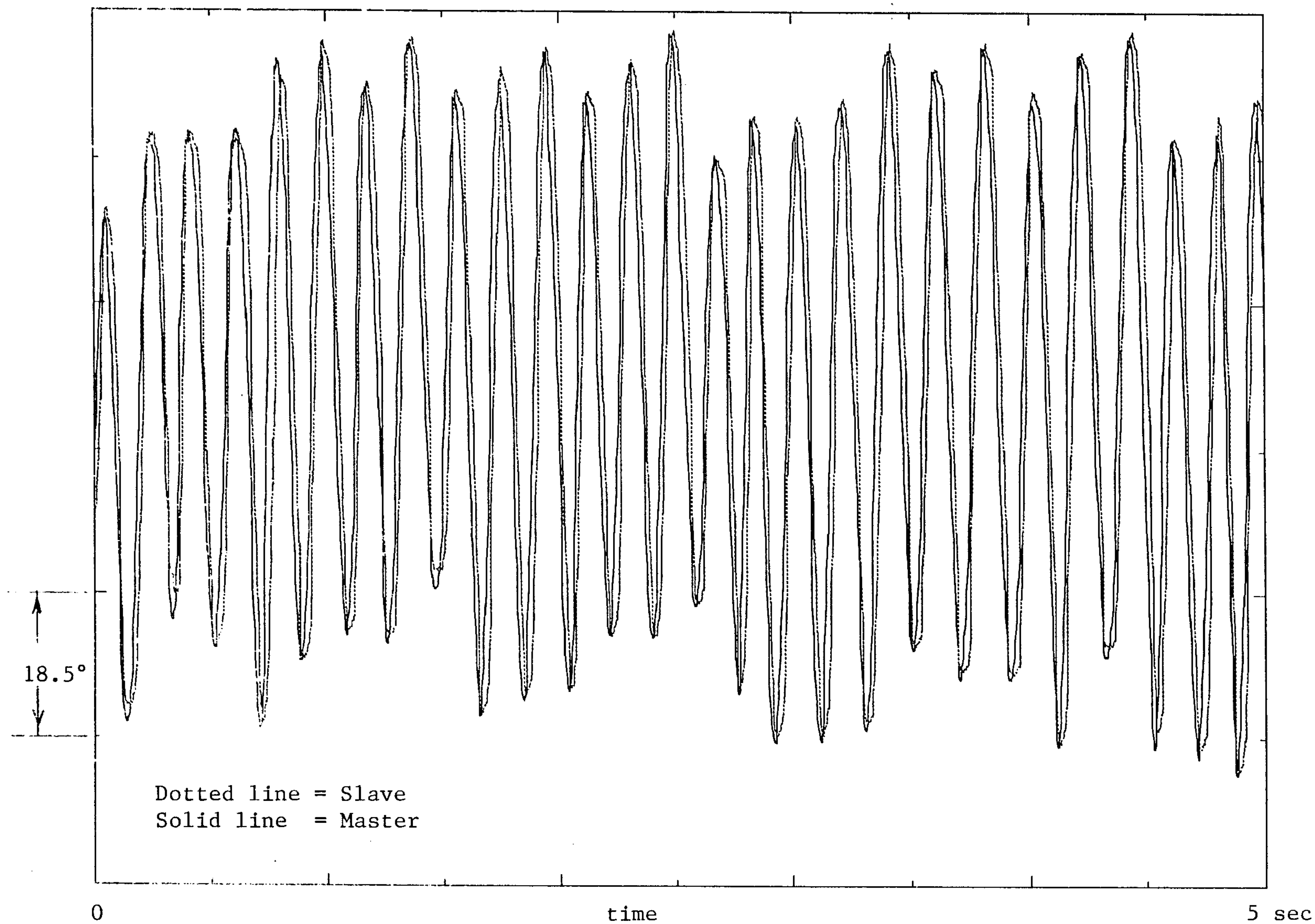


Fig. 6. Overlay of Displacements From Master and Slave During Oscillatory Motion with Stepping Motor-Driven Slave

the negative feedback of the derivative of force in the master. This means of introducing damping appears to be novel, as the author is unaware of it being suggested is in previous literature. For example, Hannaford [12] uses the derivative of position to stabilize the force loop.

The numerical differentiation appeared to be totally ineffective for producing the damping in the force loop. To achieve the needed damping, it was necessary to build an op amp-based, differentiating circuit. Thus, the .003s in the negative feedback loop is outside the computer in Fig. 2. Due to the extremely noisy force signal, it is unclear how effective the PID controller in the force loop actually was.

Figure 7 shows an overlay of master force and slave force. The first two spikes represent sharp collisions of the slave into a brick. The remaining regions of elevated force are due to a more gradual loading and unloading of force on the slave. The data was obtained by proportional control only, and with the hardware differentiator for damping, mentioned above. The master force was stable and followed the slave quite well, although at reduced amplitude. One way to make the amplitudes more nearly equal would have been to increase the open loop gain. Unfortunately, to do so without inducing instability, required more damping than could be achieved. Effective integration in the PID controller would also result in better force amplitude correspondence between master and slave.

No force data could be obtained for the stepper motor-

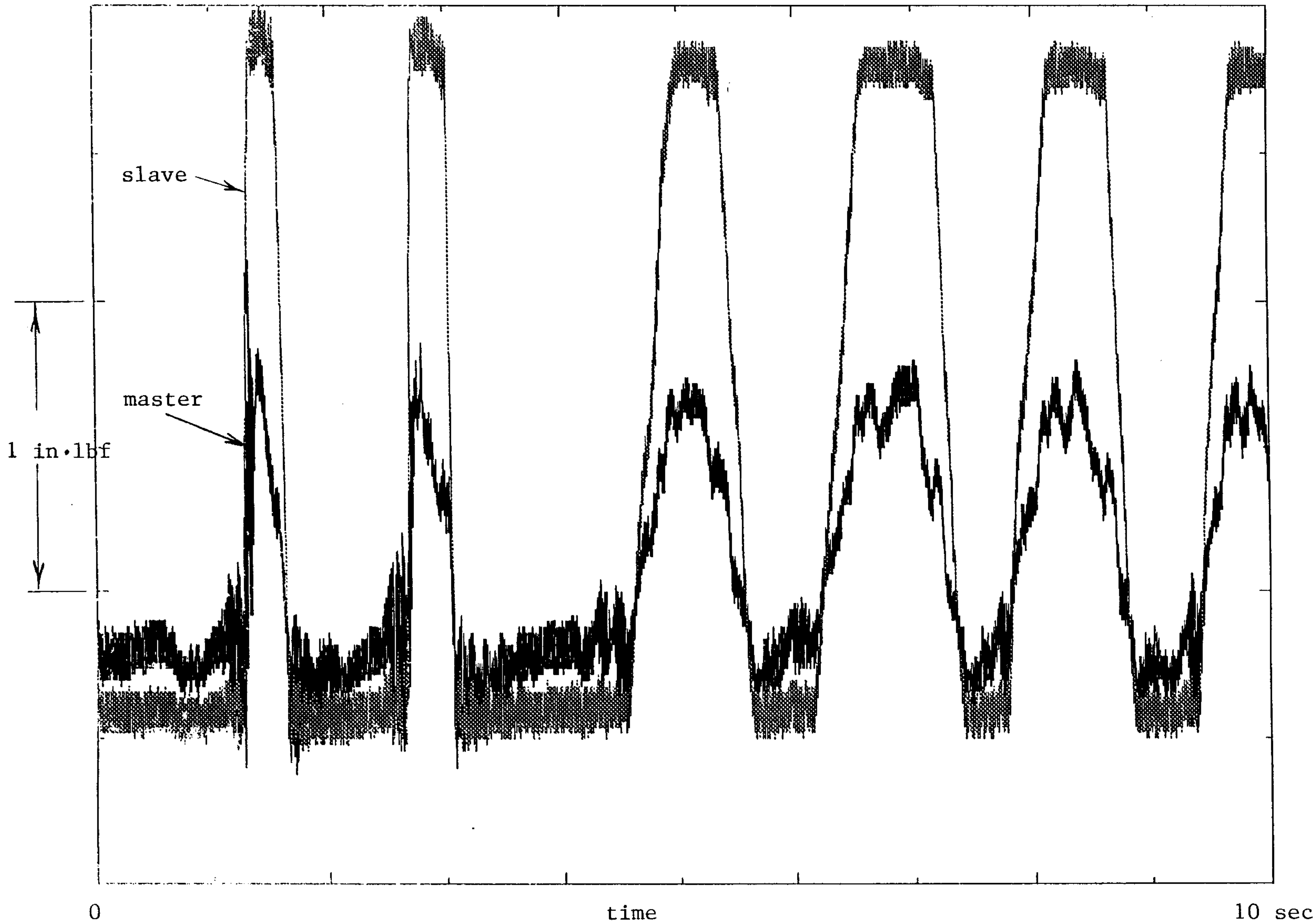


Fig. 7. Overlay of Master Force and Slave Force.

driven slave. With the stepper motor driving it, the slave behaved unstably when under load. The resulting vibration was too severe for meaningful tests.

Conclusion

A master-slave device was built with loop modifications made possible by software. The position control provided accurate tracking of the slave with the master. The force reflection from slave to master was reasonably good, but could be further improved. Especially in need of further work is the numerical differentiation and integration of noisy signals.

The force control was made stable by negative feedback of the derivative of the force in the master. This means of damping may be a novel concept.

The stepping motor driven slave showed an unexpected instability under load, thus requiring further work.

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9. S. Eppinger and W. Seering, "Understanding Bandwidth Limitations in Robot Force Control, Proceedings of IEEE Conference on Robotics and Automation, pp. 904-909, 1987.

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11. A.K. Bejczy and M. Handlykken, "Experimental Results with a Six-Degree-of-Freedom Force Reflecting Hand Controller," Proceedings of the 17th annual conference on Manual control, Los Angeles, CA, June 1981.

12. B. Hannaford and R. Anderson, "Experimental and Simulation Studies of Hard Contact in Force Reflecting Teleoperation," Proceedings of IEEE Conference on Robotics and Automation, pp. 584-589, 1988.

APPENDIX

C program listing for position control

```
/* This program is used for position control */
/* A multifuntional carrier board is used for interfacing */

#include <dos.h>
#include <stdio.h>

int sum[30000];

main()
{
     unsigned char far *p;
     unsigned int i,lsb,lsb1,msb,msb1,c,d;
     int a,s,ap,g,h,q,j = 0,jp = 0;
     long int k;
     unsigned int seg_val;
     unsigned int off_val;


     struct dostime_t start;
     struct dostime_t end;

     _dos_gettime(&start);

   for ( i = 0; i < 100; i++)
   {
      sum[i] = 0;
   }

   for (k = 100; k < 10000000; k++)
   {
        /* Read the first channel of the analog to digital
           interface to obtain the position error */

        /* The channels are configured as differential
           to obtain the difference in the position between
           master & slave */

           unsigned int seg_val = 0xce00;
           unsigned int off_val = 0x5;

          FP_SEG(p) = seg_val;
          FP_OFF(p) = off_val;
          *p = 5;

          off_val = 0x11:
          FP_OFF(p) = off_val;
          c = *p;

          try:

          off_val = 0x5;
          FP_OFF(p) = off_val;
          d = *p;
          d = d & 8;

          if (d == 8)
          {
                  off_val = 0x12;
                  FP_OFF(p) = off_val;
                  lsb = *p;
```

```
        off_val = 0x13;
        FP_OFF(p) = off_val;
        msb = *p;

}

else

{
        goto try;
}

a = ((msb & 15) * 256 + lsb) - 2048;

/* Read second channel to obtain the position of
   slave to be used as negative velocity feedback
   to introduce extra damping */

seg_val = 0xce00;
off_val = 0x5;

FP_SEG(p) = seg_val;
FP_OFF(p) = off_val;
*p = 5;

off_val = 0x11;
FP_OFF(p) = off_val;
c = *p;

trial:

off_val = 0x5;
FP_OFF(p) = off_val;
d = *p;
d = d & 8;

if ( d == 8)
{

        off_val = 0x12;
        FP_OFF(p) = off_val;
        lsb1 = *p;

        off_val = 0x13;
        FP_OFF(p) = off_val;
        msb1 = *p;
}

else
{
        goto trial;
}

g = ((msb1 & 15) * 256 + lsb1) - 2048;
h = (g - j) * 50;
j = g;

/* PID control */

q = a * 2;

ap = 35  * (q - jp);
jp = a;


sum[i] = sum[i-1] - sum[i-100] + a;
```

```
            s = sum[i] / 100 * (17*1/1000000) ;

            if (i % 30000 == 0)
            {
             for ( i = 0; i < 100; i++)
             {
              sum[i] = sum[i + 29900];
              }
             i = 100;
            }
             i = i + 1;

            q = (q + ap + s);


            /* Sum the damping after PID */

            q = (q - h) + 2048;



            /* Send the output through a digital to analog Interface*/

            if ( q < 0 )
            {
                 msb  = 0,lsb = 0;
            }

            else if (q > 4096)
            {
                 msb = 15,lsb = 255;
            }

            else
            {
                 lsb = q & 255,msb = q / 256;
            }

            seg_val = 0xce20;
            off_val = 0x1;
            FP_SEG(p) = seg_val;
            FP_OFF(p) = off_val;
            *p = lsb;

            off_val = 0x2;
            FP_OFF(p) = off_val;
            *p = msb;

            off_val = 0x3;
            FP_OFF(p) = off_val;
            *p = 0x5;

    }

    /* print the time of execution of the program */

  _dos_gettime(&end);
  printf("start %d:%d:%d\n",start.minute,start.second,start.hsecond);
  printf("end time %d:%d:%d\n",end.minute,end.second,end.hsecond);

} /* main */
```

SIMULATION OF HYBRID-III MANIKIN HEAD/NECK DYNAMICS DUE TO -Gx IMPACT ACCELERATION

Amit L. Patra
Associate Professor
General Engineering Department

University of Puerto Rico at Mayaguez
P.O.Box 5635, RUM
Mayagüez, PR 00681

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Amit L. Patra
Associate Professor
General Engineering Department
University of Puerto Rico

ABSTRACT

This effort extended research initiated at the Armstrong Laboratory (AL) to investigate the dynamics of the neck and head of a Hybrid-III manikin during impact. The original effort was conducted to provide an analytical modeling foundation for a better understanding of the dynamic response of the head/neck system using human volunteers. The summer effort succeeded in developing and validating a modeling methodology for +Gz impact response. The primary emphasis was on modeling experimental data obtained from tests on human volunteers at the Armstrong Laboratory (AL) for head acceleration and neck flexion. It was proposed that the work be extended to validate -Gx impact responses, examine the predicted loading at the occipital condyle interface, and perform extensive model parametric studies to explore the changes in acceleration, flexion and neck loading due to various impact conditions on the head of a Hybrid-III dummy. These surrogate data, presented here, validated with human data, is expected to be highly valuable for providing guidance in the development of specifications and standards for aircrew members subject to crash and ejection impact exposures.

Simulation of Hybrid-III Manikin Head/Neck Dynamics due to -Gx Impact Acceleration

Amit L. Patra

I. OBJECTIVES & SIGNIFICANCE:

Realistic simulation of the neck response in a dummy is of vital importance to obtain a humanlike dynamical behavior of the head. Trajectories of the head and the nature of head contact with vehicle interior or exterior are critically dependent on the neck structure. A through literature search has been conducted to understand neck performance criteria in forward flexion and extension. Mathematical modelling has attained wider acceptance in recent years, mainly because of difficulties involved in human volunteer testing. The use of computer programs to simulate the dynamic response of a human in a crash situation has became an attractive alternative to full scale experiment. For some time now, AAMRL/BBM have been describing the mathematical framework, underling an empirical model, that predicts human head response using only the motion present at vertebra T1.

Based on this framework, a model for -Gx impact acceleration was developed from data obtained on volunteer subjects participating in the NBDL impact acceleration experiments. Model performance was evaluated by comparing the errors in the predicted head responses of different subjects under identical impact acceleration. Independent sets of data were used for building the model. The results of the simulation indicate that the model could be useful in human response to impact acceleration.

In a series of tests the model predicted the time-varying inertial response of the unrestrained human head to -Gx impact acceleration. Using the linear acceleration time profile of neck (T1 vertebra) motion as input information, the model produces time profiles for the accelerations at the head center of gravity. The similarities between the predictive simulation values (ATB model) and the human data (NBDL) are sufficient to ensure humanlike head and neck motion. It was planned to limit the study for -Gx neck (T1) acceleration as the input and to confine to analyzing trends and correlating specific segment (head, neck and upper torso) response characteristics to anatomically feasible interactions.

A variety of mathematical models have been developed to predict human biodynamic responses in impact environments. But validation of a computer model which accurately predicts the mechanical behavior of the dummy head/neck structure under impact conditions has not yet been satisfactorily performed.

Ideally, with the experimental data obtained from human volunteer studies, the computer simulation and test dummy with acceptable biofidality would help us to better understand the human head/neck response under impact conditions. Unfortunately, although Hybrid-III dummy surrogate data suggests better biomechanics, it needs to be correlatable to existing and future volunteer data. During the last few years a number of investigators contributed to the development of the present Hybrid-III dummy. Paver and co-workers (1,2) developed data sets for computer models for Hybrid II-manikin. Foster et al. (3) presented similar information for a Hybrid-III dummy. Frisch and Frisch (4) successfully employed a modified Hybrid-III dummy for high speed ejection tests. At the Armstrong Laboratories Kaleps et al. (15) measured relevant properties and developed analytical data base for the Hybrid-III dummy. The body of information is slowly increasing in the literature that identifies usefulness of mechanical human surrogates. But very little, if any, data is available relating validation of data correlating dummy tests with human tests and computer simulations of head/neck response due to impact acceleration.

The Armstrong Laboratory (AL) at Wright-Patterson Air Force Base has developed a computer program, the Articulated Total Body (ATB), model which predicts human dynamic responses under impact conditions. Recently the ATB model has been applied to predictively model the head/neck response to impact using experimental data obtained from tests done on human volunteers at the Naval Biodynamics Laboratory (NBDL) and at AL for head acceleration and neck flexion (5). Similar modeling of neck response has been done by Wismans and Spenny (6), Bosio and Bowman (7), and Seeman et al. (8). Muzzy and his co-workers conducted impact tests with human volunteers with attached extra masses to their heads (9,10). Using the pool of human experimental test data of NBDL, Bowman and Schneider (11) investigated relationships between dynamic head/neck response and biomechanical properties of the neck.

Kallieries et al. (12) compared human volunteer and cadaver head/neck response in frontal flexion. This study showed larger dynamic values for post mortem human impact motions when compared with NBDL data. King et al. (13) considered the effect of muscle forces on head/neck motions due to sudden impacts. The body of published literature suggests that the human head/neck motion simulations using rigid body dynamics is approximate at best. The AL is seeking to develop some guidelines, specifications, and standards, both qualitative and quantitative, for head/neck load limitations for aircrew members subject to crash, and ejection impact parameters.

The present research investigated the use of an analytical simulation model to describe the effects on the neck of a dummy under -Gx acceleration conditions. The simulation model used the Articulated Total Body (ATB) model for prediction of head and neck responses and comparison was made with the NBDL and AL corresponding dummy test data. The basic assumptions was that a two joint system (one at the occiput and the other at the T1 vertebra) is adequate to assess the effects on neck loading levels, and that the head and neck inertial properties and joint locations did not change during the impact.

The specific issues that this research addressed are the variations in the loads, torques, angular accelerations and angular rotations at the head/neck joint. The NBDL/AL dummy head/neck test data was used for the ATB simulation validation.

The technical objectives were to address in this investigation were:

1. Establishment of a representative human head and neck ATB data set based on head/neck properties. The simulation would be based upon -Gx impact acceleration with T1 X-direction acceleration as the input.

2. Validation of the above data set in (1) using -Gx NBDL impact test results.

3. Develop head/neck model for -Gx as is done in (1) for modeling of the head/neck system for a dummy under a -Gx acceleration pulse.

II. EXPERIMENTAL DESIGN:

To achieve the above objectives we planned to follow this experimental design:

a. Facilities and Equipment.

All simulations were made using the ATB computer model. The time histories of interest were plotted. The Hybrid-III data set was generated from data derived from program GEBOD. The DYNAMAN program (a Personal Computer implementation of the ATB model) was used for the simulations using a 386 based personal computer dedicated to the research effort. A 386 Personal Computer with math co-processor (Intel 80387 chip), 2 Megabyte RAM, 3.3 DOS, and with EGA or VGA monitor was available to the project.

b. Test Conditions.

The primary effort during this re arch was to develop and validate a modelling methodology for volunteer -Gx impact responses. This effort was conducted to validate by comparison simulation tests with human volunteer (NBDL and AL) and Hybrid- test data for a better understanding of the dynamic response of the head/neck system.

Following the simulation validation procedure established elsewhere (14) -Gx impact response simulations were performed for a dummy. Then simulations were conducted to predict dynamic head/neck response variations in head acceleration, head rotation, and torque and force on the head/neck joints.

c. Experimental Procedures.

The primary simulations consisted of validation studies to ensure that the head/neck systems were properly represented. The methodology used to validate the data set are explained in detail elsewhere (14). The T1 linear acceleration was used for the input time profile to drive the system, for all simulations. The simulation results from the ATB model were compared and validated with similar NBDL and AL data for the different G forces. The linear head accelerations, and head angular rotations were used for validation. The head/neck torque and joint forces were output with T1 accelerations as inputs. Quantitative data were provided in terms of time history plots of the parameters that could be correlated to injury.

III. RESULTS:

T1 acceleration due to impact is difficult to simulate because it is affected by the torso motion, the restraint system, and head and neck feedback. Therefore, as suggested by Frisch and Cooper (17), the measured T1 deceleration profile was chosen to drive the head and neck system. The data used was from human volunteers participating in the Naval Biodynamics Laboratory (NBDL) impact acceleration experiments (5).

Simulations were produced using the ATB model with T1 acceleration data from ten subjects chosen at random from NBDL sled test data. General body descriptions for each simulation were produced by program GEBOD from the subject's height and weight. The force characteristics for contact of the head and upper torso used in the model were obtained from Bosio and Bowman (7).

This report will describe the development of a preliminary simulation of the head/neck response to -Gx acceleration (Figure 1) using three segment, two joint model with a viscoelastic slip joint applied to the neck/torso articulation (Figure 2).

To determine the general behavior of this analog, a preliminary simulation was developed for use with the ATB computer model. The test consisted of short duration 10 G acceleration with volunteer subject accelerated. The DYNAMAN program (a Personal Computer implementation of the ATB model) would be used for the simulations using a 386 based personal computer dedicated to the research effort. A 386 Personal Computer with math co-processor (Intel 80387 chip), 2 Megabyte RAM, 3.3 DOS, and with EGA or VGA monitor were made available to the investigation.

The anatomical measurements of the subject included the head mass, head moment of inertia, and the anatomical joint locations.

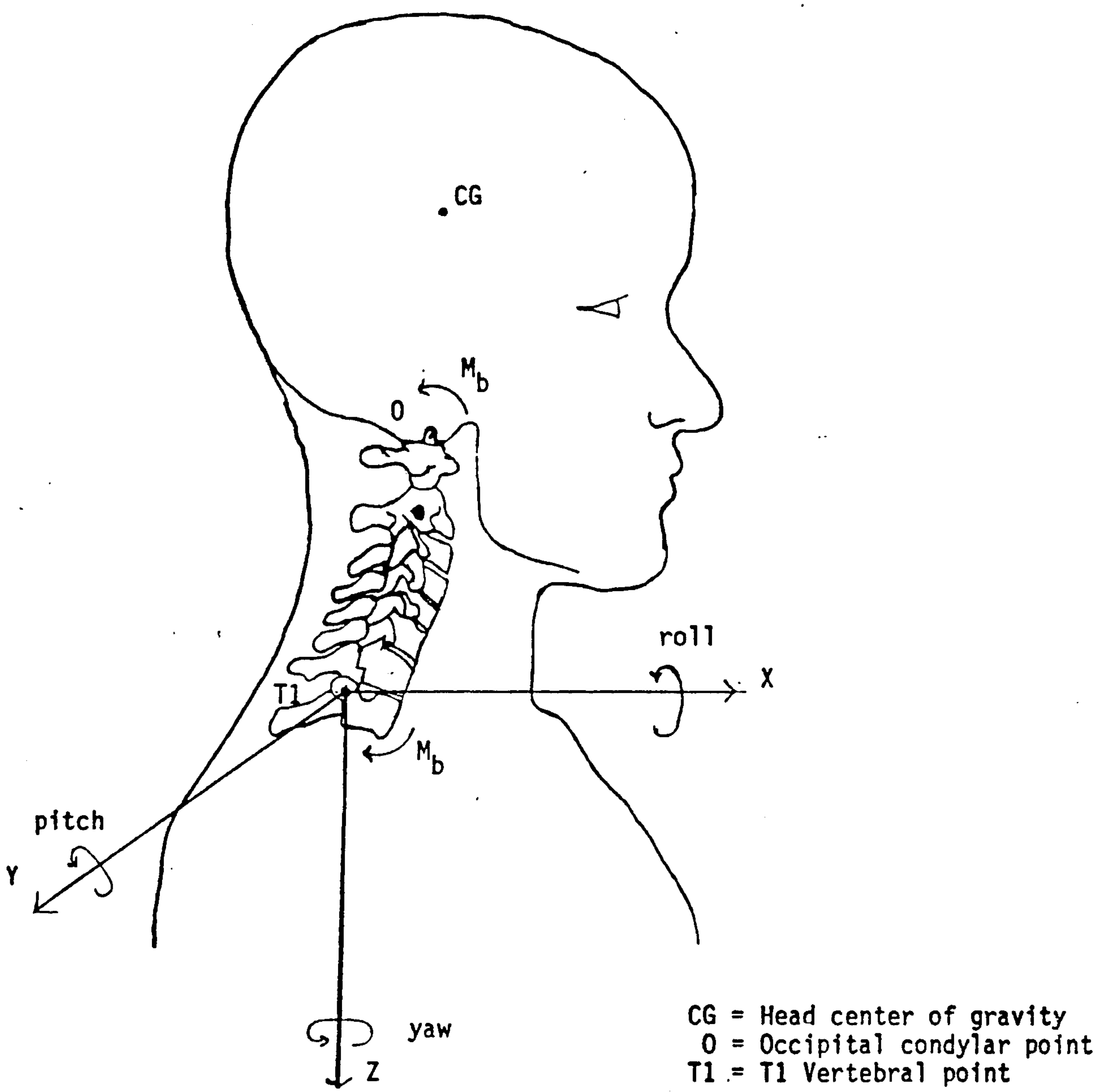


Figure 1. Selected coordinate system and germain head and neck locations.

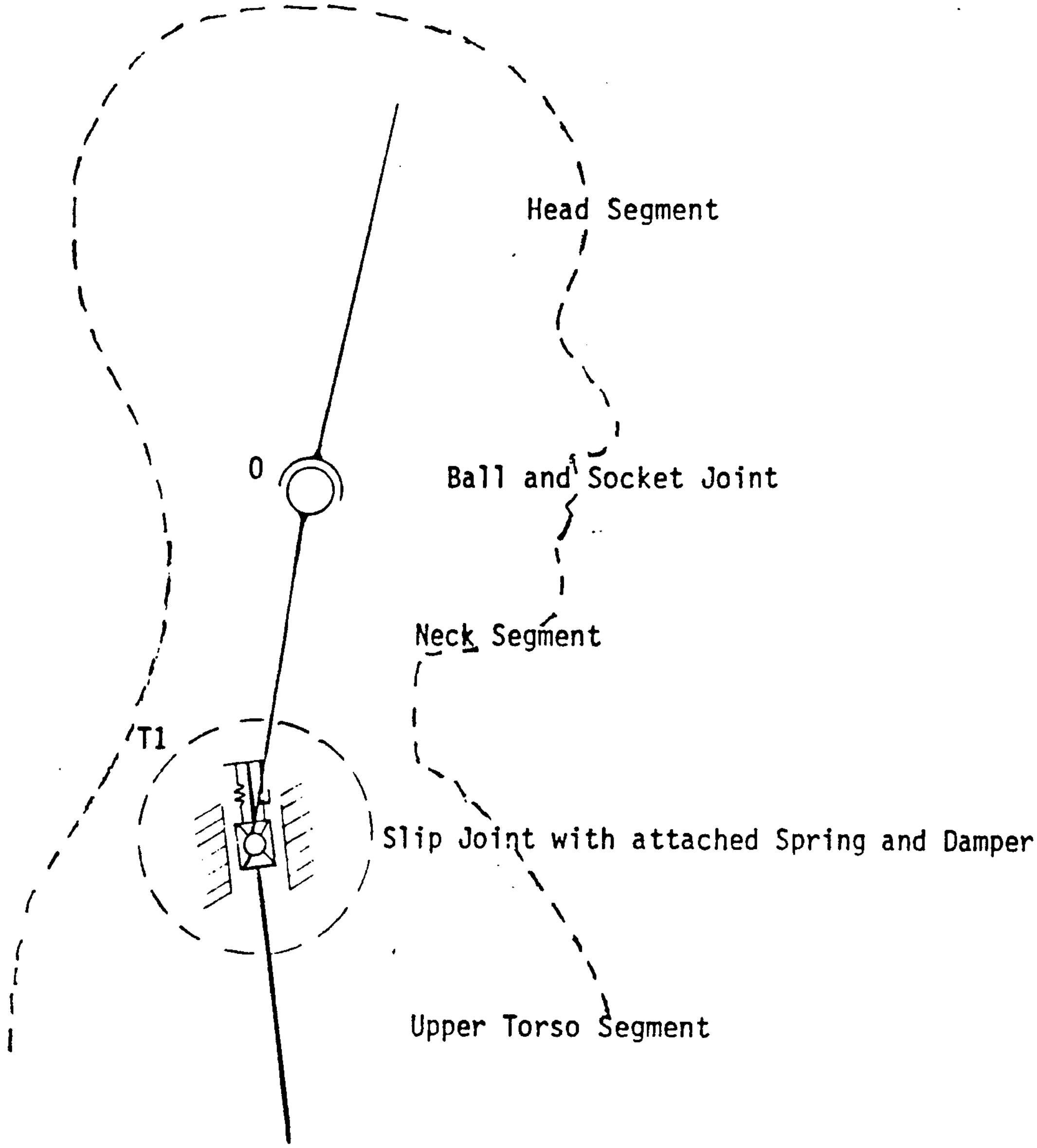


Figure 2. Three segment, two joint model of the head/neck system

Measurements of the helmet/mask system included mass and moment of inertia. These measurements were collected at Armstrong Laboratory and used in describing model joint locations. The measurements of the neck and torso segments were obtained using the program GEBOD (Generator of Body data). The time history of subject-L7 measured chest +Gz acceleration was filtered using a Fast Fourier Transform and used as the driving input force to the model at T1. The assumption that the linear acceleration of the chest and T1 are equivalent was based on the small rotation of torso (theta max. = 0.005 degrees).

The head/neck system was assumed to be a two joint model with a slip joint for the lower neck joint at the anatomical T1 position. The motion of the slip joint was restricted to be a parallel spring-damper system (Figure 3). The spring has an initial length of zero, with one end attached to the neck segment and one end attached to the upper torso segment, both points located at the T1 location. The spring and damping coefficients were randomly varied with an initially linear spring coefficient calculated from a measured head/neck natural frequency of 17 Hz. Because little data is available for viscous behavior of the neck the damping coefficient was estimated to be 1. This was the damping necessary to control the initial oscillatory motion of the neck. Simulations were performed with various coefficients. Figures 4(a,b,c,d) shows the typical joint characteristics, torque relations, head and neck torque characteristics used as inputs to the simulation resulting head segment linear Z-acceleration profile compared with the head

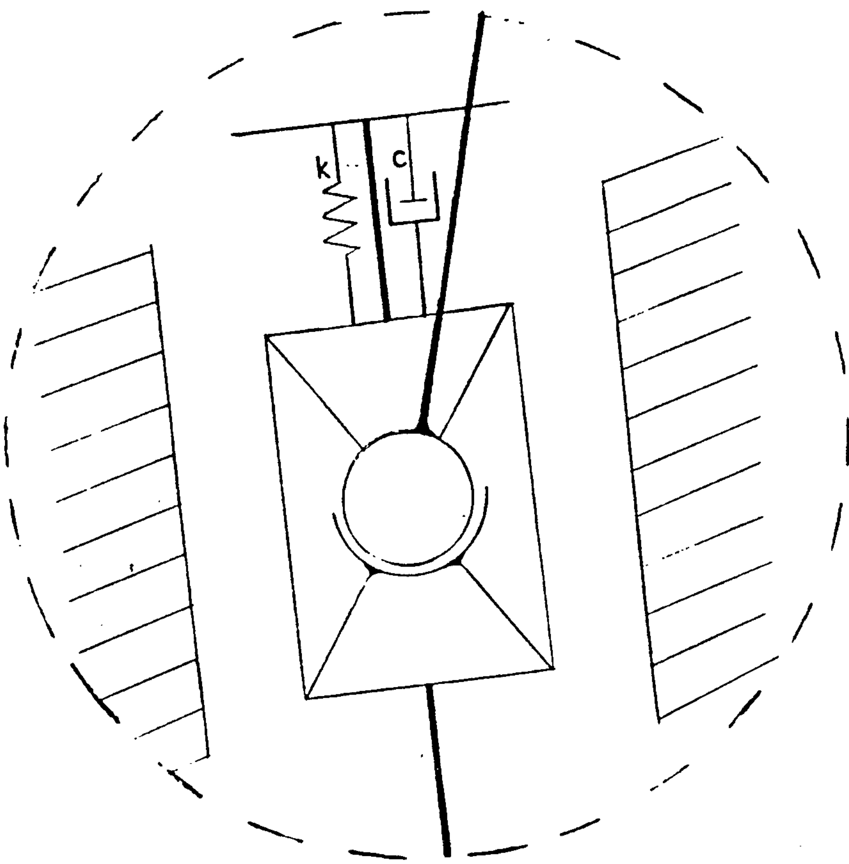
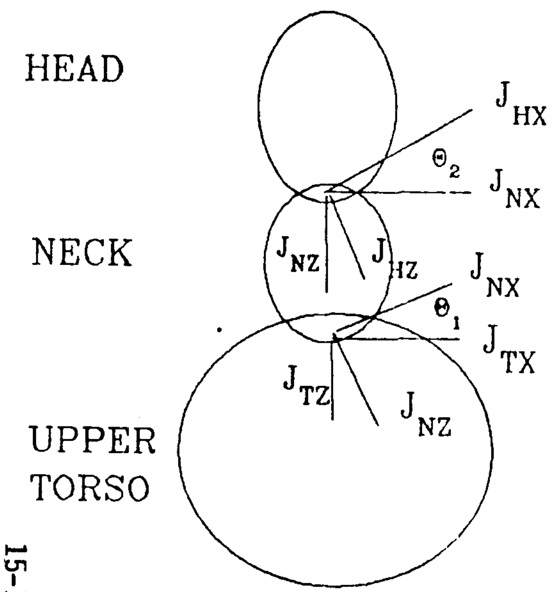


Figure 3 . Slip Joint with attached Spring and Damper

Figure 4. HUMAN HEAD/NECK JOINT CHARACTERISTICS FOR ATB MODEL Gx IMPACT SIIMULATION



JOINT 2
INITIAL AXIS ORIENTATION
$\theta_2 = 0$

JOINT 1
INITIAL AXIS ORIENTATION
$\theta_1 = 0$

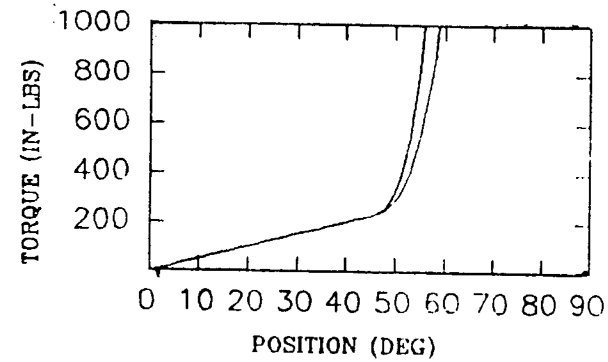
TOTAL TORQUE FOR EACH JOINT = T + TS

$T = S_1 \, |\Theta|$

WHEN $\Theta \geq S_5$ AND $d\Theta/DT > 0$
THEN $TS = S_2(|\Theta| - S_5)^2 + S_3(|\Theta| - S_5)^3$

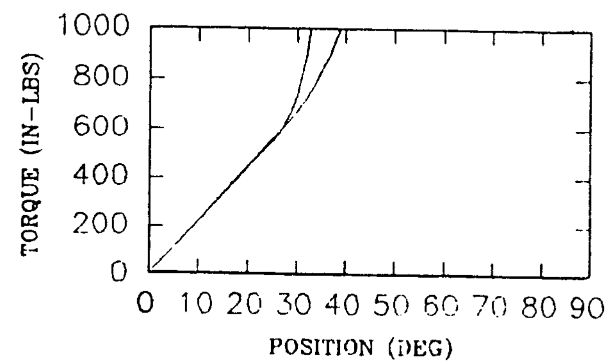
WHEN $\Theta \geq S_5$ AND $d\Theta/dt < 0$
THEN $TS = S_4 TS$

TORQUE CHARACTERISTICS FOR HEAD JOINT (JOINT 2)



LINEAR COEFFICIENT $S_1 = 5.0$
QUADRATIC COEFFICIENT $S_2 = 0.5$
CUBIC COEFFICIENT $S_3 = 0.5$
ENERGY DISSIPATION COEFFICIENT $S_4 = 0.5$
JOINT STOP LOCATION $S_5 = 45$
VISCOUS COEFFICIENT = 0.7

TORQUE CHARACTERISTICS FOR NECK JOINT (JOINT 1)



LINEAR COEFFICIENT $S_1 = 22$
QUADRATIC COEFFICIENT $S_2 = 0.5$
CUBIC COEFFICIENT $S_3 = 0.5$
ENERGY DISSIPATION COEFFICIENT $S_4 = 0.1$
JOINT STOP LOCATION $S_5 = 25$
VISCOUS COEFFICIENT = 0.7

acceleration z-profile. Figure 5 shows this simulation for +Gz acceleration. The best effort simulation involved a spring with elastic response function given by

$$F = 30x + 100x^2$$

and a damper with a viscous response function given by

$$F = \dot{x}$$

where x is the change in neck length.

The model head segment and the subject head z acceleration responses are shown in Figures 6 & 7. Table 1 lists the input description data for human test subject and Hybrid-III manikin used for DYNAMAN impact simulation. The response profiles are very similar to the subjects, with the subjects head peak z axis acceleration of 15.66 Gs occurring at 81 ms (Figure 6) and the simulation head segment peak axis acceleration of 13.8 Gs occurring at 75 ms. The secondary acceleration pulse was also simulated well with the maximum z axis response for the subject head of 4 Gs at 205 ms and the segment head acceleration of 2.5 Gs at 210 ms. It is noted that the simulation response is shifted up 1 G relative to the measured human response. Figures 1-7 were adopted from reference 16.

Using Dynaman program an impact simulation was run with input data from human volunteer and Hybrid-III dummy. Following ATB Fortran input format data were supplied to the program for subject L-7 test 1715 and Hybrid-III respectively (Table 1).

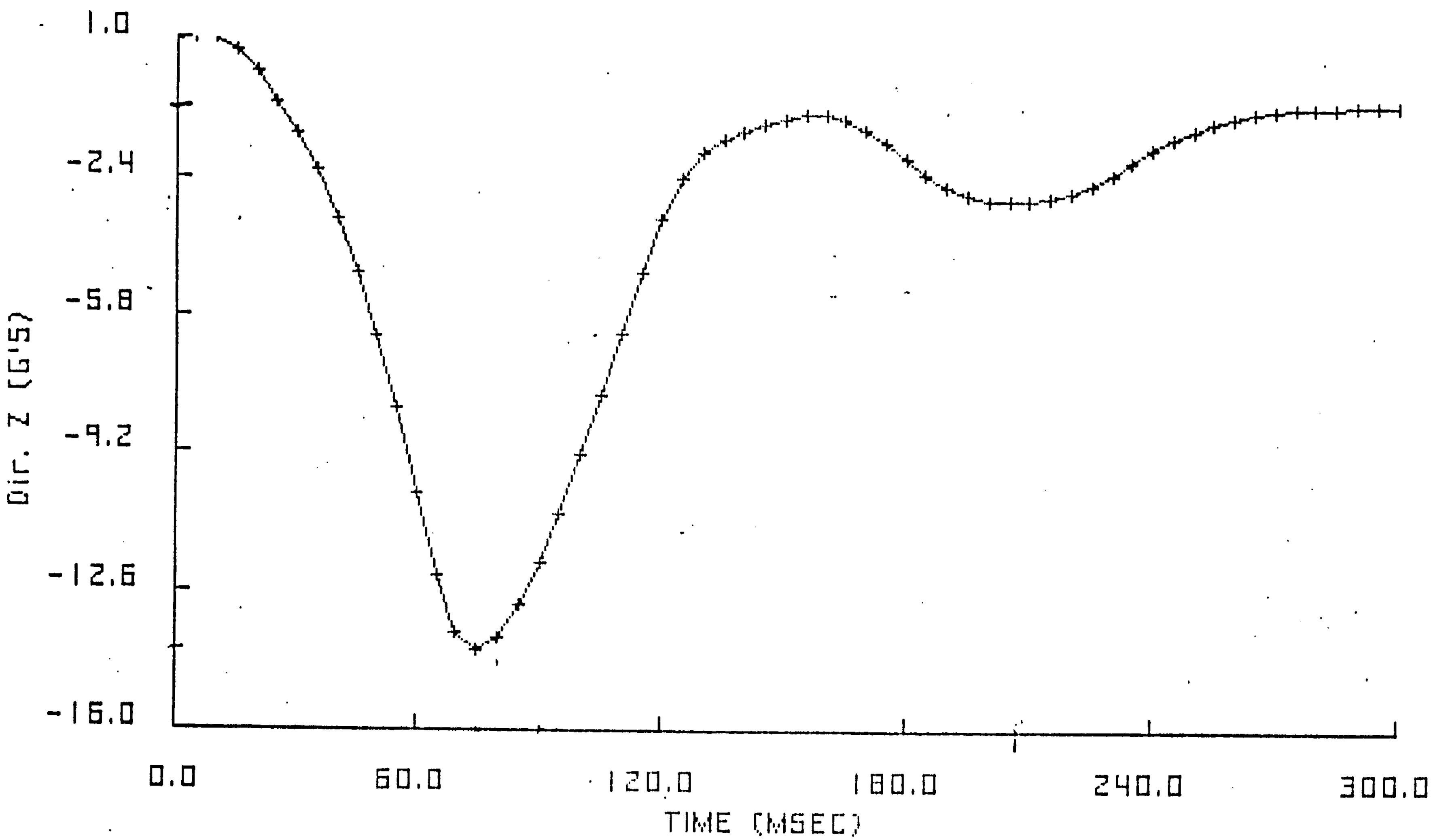


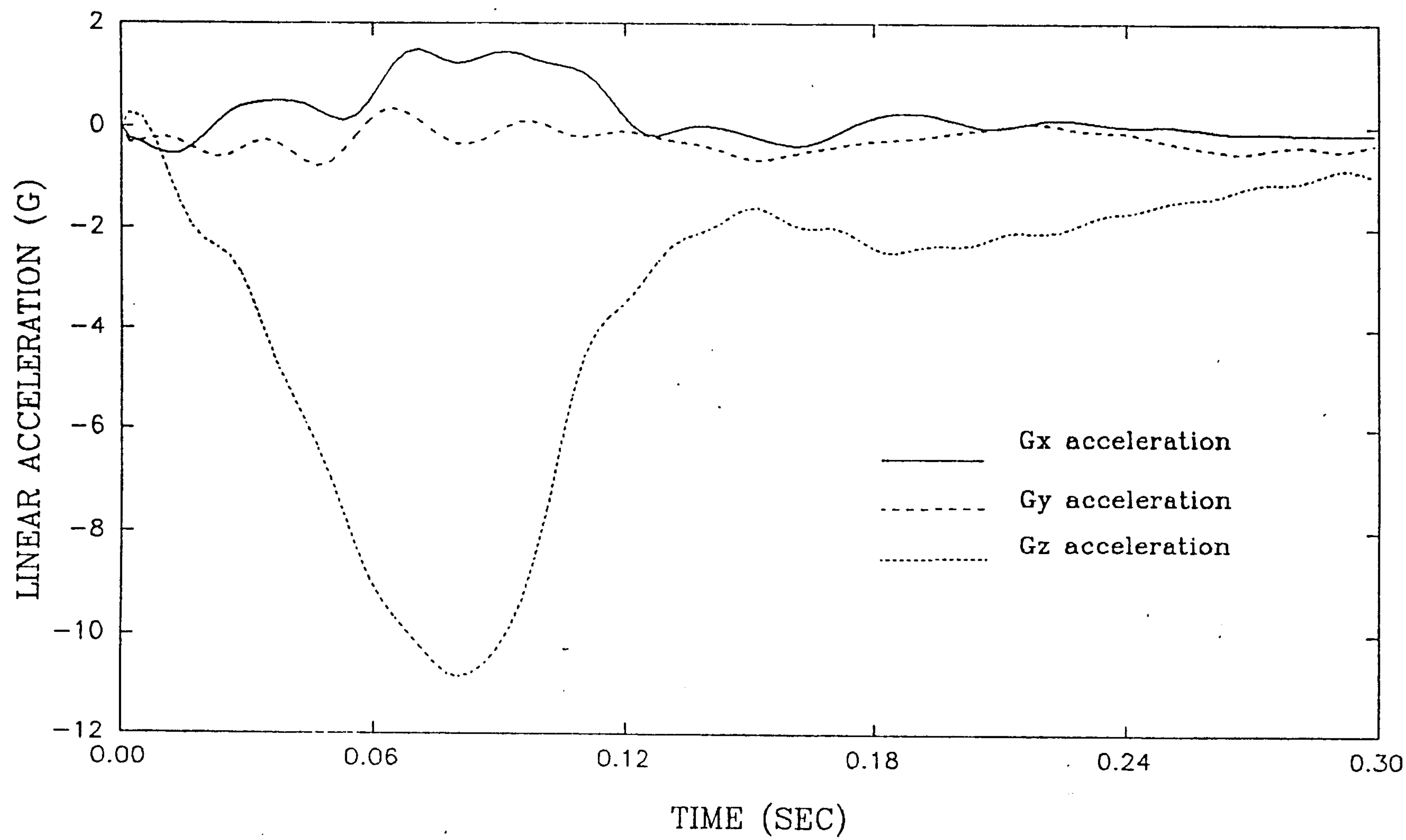
Figure 5. Dynaman simulation of head/neck system to Z axis acceleration
Head Segment Z acceleration.

Table 1. Input description data for human test subject and Hybrid-III manikin in Fortran format used for DYNAMAN impact simulation.

```
MAY 1991        0    0.0000000                                          A.1
Head/Neck Simulation
SUBJECT L7 TEST 1715
 IN. LB.SEC.  0.00000000  0.00000000  386.088043  0.00000000
   4 150.0020000.0005000.0010000.0000625
10 050 2 0 0 0 0 0 0 0 0 0 0 0 0 0 7 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1
     3      2         NECK & HEAD                                       B.1
 UT  U44.7403.33562.43252.02624.52806.12106.6040.00000.00000.00000    1  B.2
           .0000014.400.00000
NECK N1.9900.01240.01500.018302.31502.31503.0110-.4630.000001.6240    1
           .00000.00000.00000
HEAD H13.060.35499.35750.300603.87003.03505.5970.00000.00000.00000    1
           .0000025.000.00000
  NP      1   5-.1200.00000-7.290-.8000.000001.6100    1.00000.00000       B.3
            .00000.00000.00000.00000.00000.00000.00000.00000.00000 3 2 1 3 2 1
  HP      2   21.0100.00000-2.540.30000.000002.4600    0.00000.00000
            .00000.00000.00000.00000.00000.00000.00000.00000.00000 3 2 1 3 2 1


MAY 1991        0    0.0000000                                          A.1
Head/Neck Simulation
HYBRID III DUMMY
 IN. LB.SEC.  0.00000000  0.00000000  386.088043  0.00000000
   4 150.0020000.0005000.0010000.0000625
10 050 2 0 0 0 0 0 0 0 0 0 0 0 0 0 7 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1
     3      2         NECK & HEAD                                       B.1
 UT  U44.7403.33562.43252.02624.52806.12106.6040.00000.00000.00000    1  B.2
           .0000014.400.00000
NECK N2.6680.02540.02570.0084 1.675 1.675 3.000 0.000 0.000 0.000     1  B.2
           0.00 0.00 180.0
HEAD H9.9210.14080.21280.1956 4.250 2.875 4.000 0.000 0.000 0.000     1  B.2
           0.00-26.58 180.0
  NP O    1    0  0.00  0.00 -5.96  0.00  0.00  2.76                    B.3
                  0.00  0.00  0.00  0.00  0.00  0.00
  HP P    2    0  0.00  0.00 -2.84 -0.55  0.00  2.00                    B.3
                  0.00  0.00  0.00  0.00  0.00  0.00
```

Figure 6. SUBJECT L-7 TEST 1770
CHEST ACCELERATION IN THE Gx, Gy, AND Gz DIRECTIONS (IN ATB COORDINATES)
FILTERED AT 50 Hz



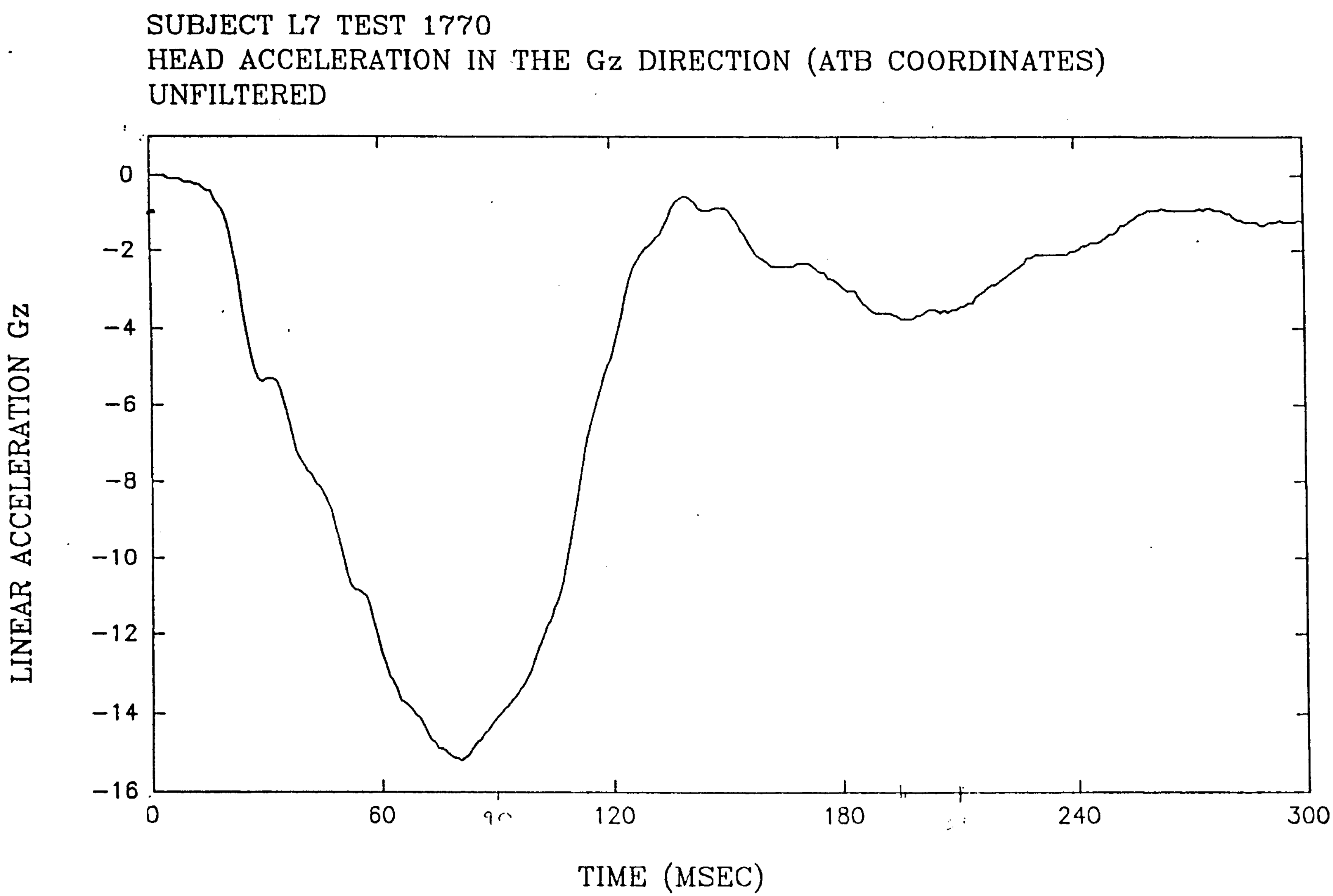


Figure 7 . NVG Test Data Head Acceleration in the z direction.

Figure 8 shows the input T1 X-directional acceleration used for the simulation at 10 G for comparison between human volunteer subject and the Hybrid-III dummy impact. Figure 9 shows the corresponding Z-directional acceleration subject to maximum value of 10G at about 80 msec. of impact.

Using the input shown in Figures 8 & 9 a series of simulations were drawn for the human test subject and correspondent Hybrid-III dummy. Figures 10 and 11 show the similarities in the profiles except towards the end of the simulation. For the dummy after 80 msec the X-directional G-values does not come down as in the case of a human. This can be attributed to the elastic nature of human neck and mechanical stiffness of a Hybrid-III neck. Figure 11 shows the Z-directional acceleration time history. As expected they are very similar in nature for both the simulations. In an actual test the human neck tend to move significantly smooth in the X-direction. Figures 12 & 13 show respectively the similar X-directional and Z-directional acceleration profiles for head pin. Again the simulations for the Z-direction shows remarkable similarities, while there are marked differences in the actual G-values. The dummy head has a tendency of vibrational decay type motion, while human head has a smoother absorptional characteristics. The major difference in these series of simulations can be attributed to this physical property.

Figures 14-17 show the neck angular displacement for the human and Hybrid-III for roll, pitch, yaw and resultant respectively.

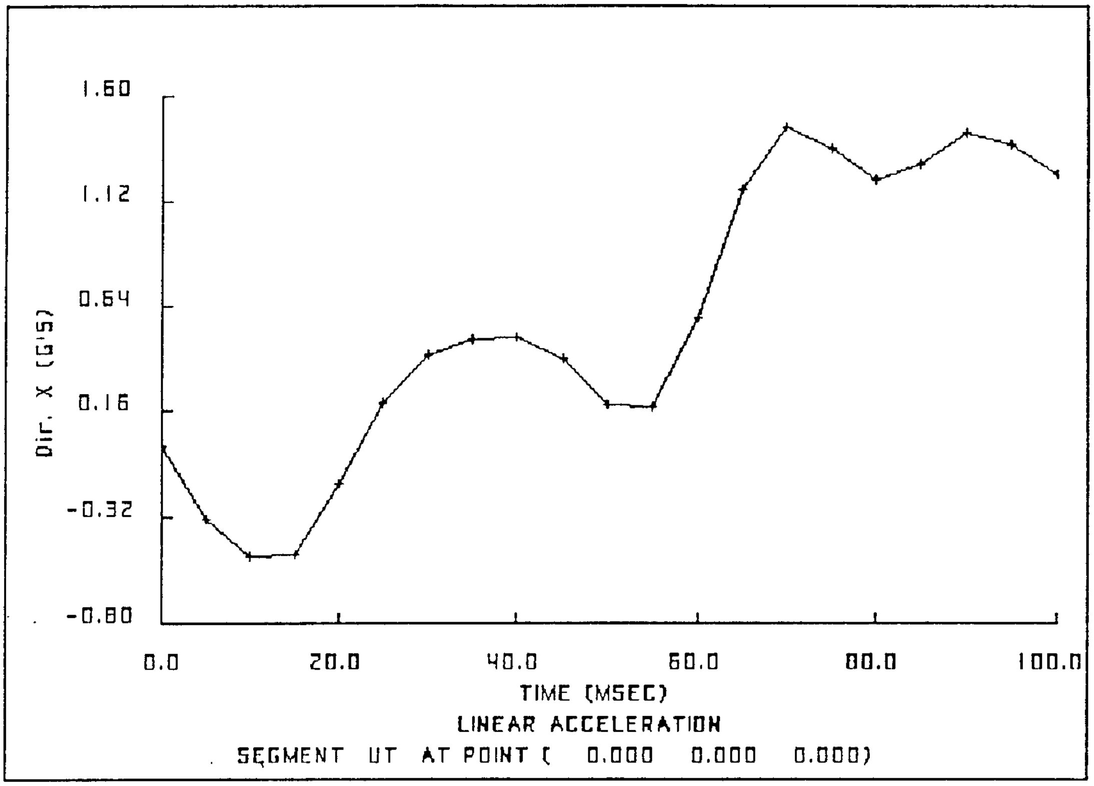


Figure 8. Input T1 x-directional acceleration used for simulation for both human and Hybrid-III impact studies.

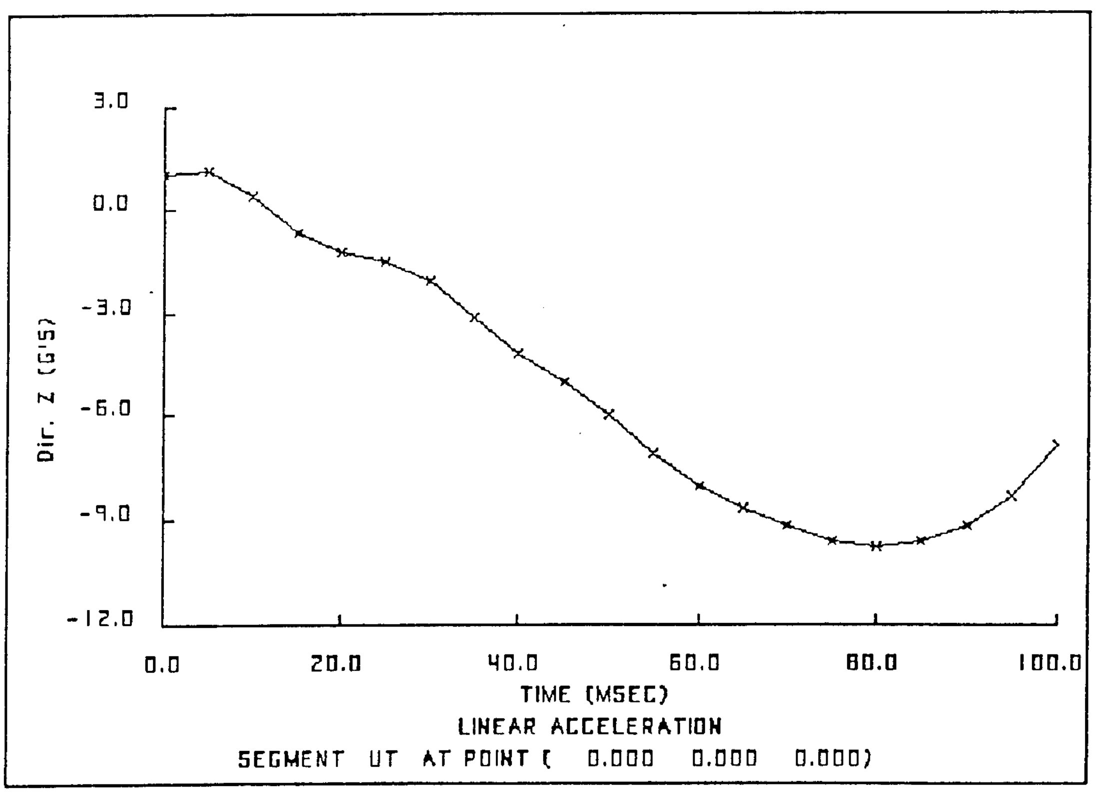
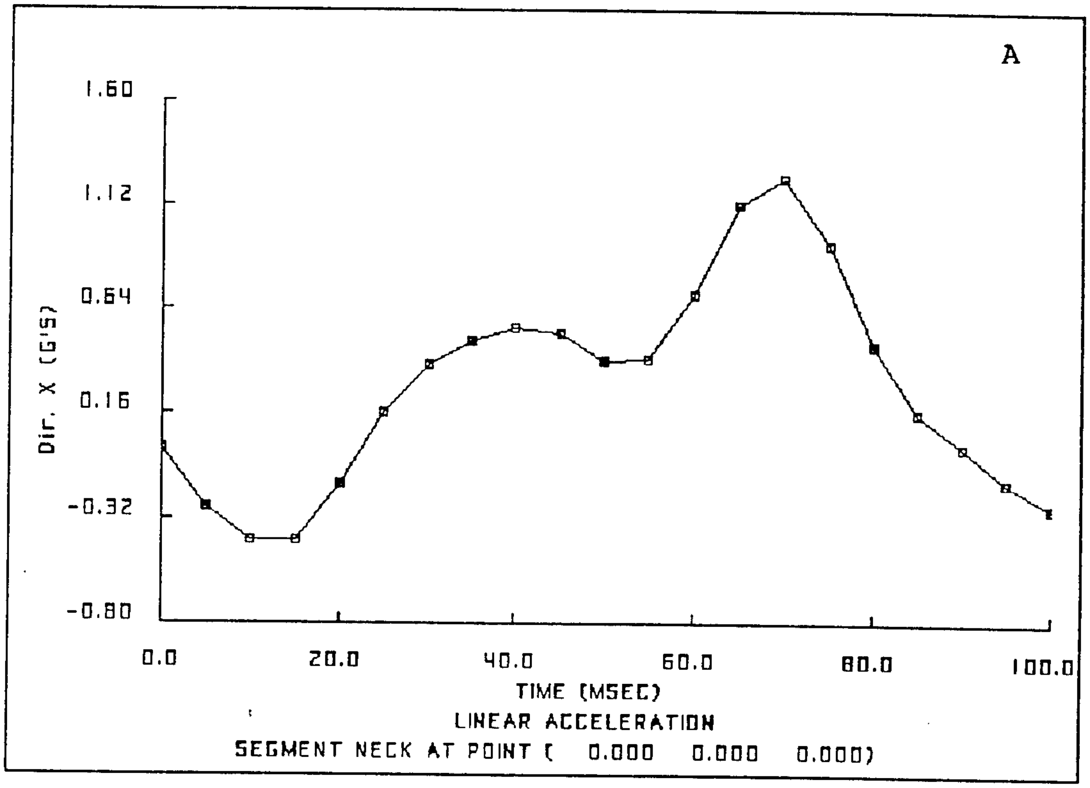


Figure 9. Z-directional input acceleration time profile used for simulation. Maximum value 10G at 80 msec.



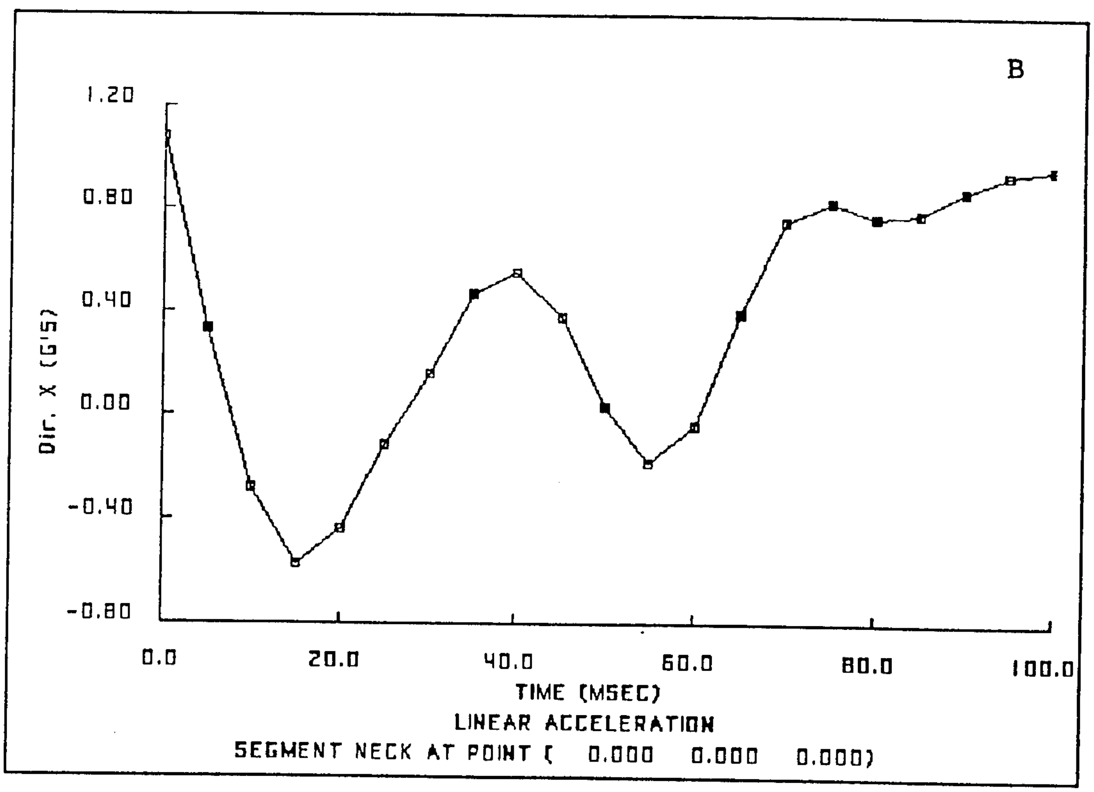


Figure 10. X-directional linear acceleration profile simulated for human (A) and Hybrid-III (B) at neck.

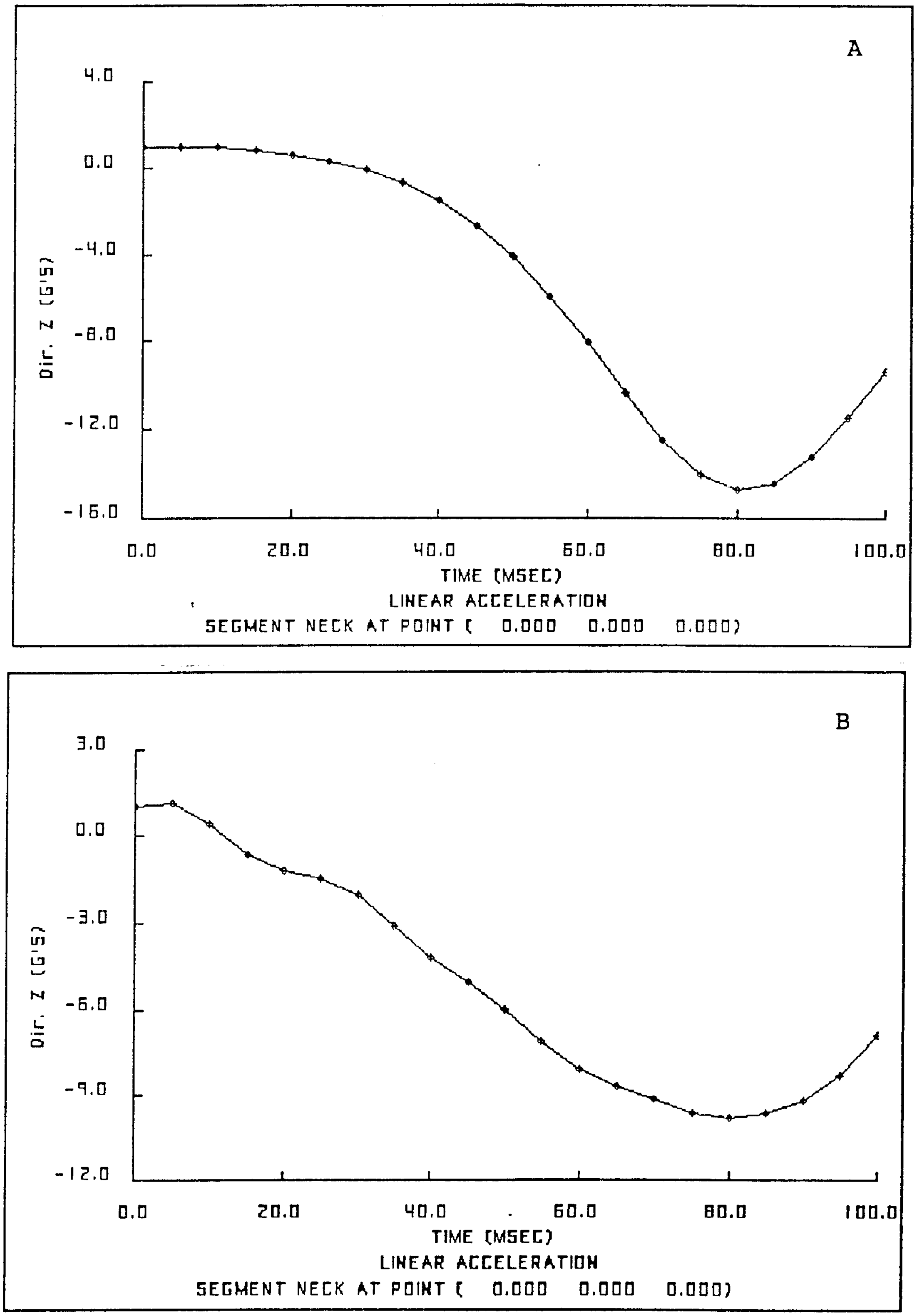
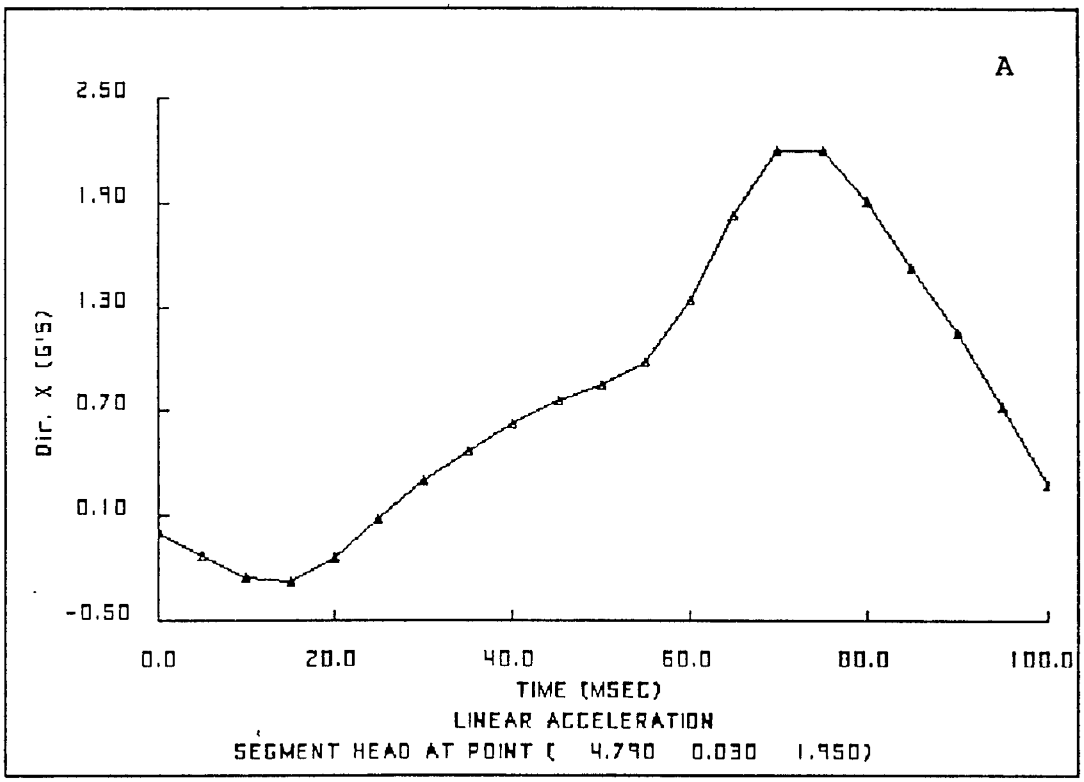


Figure 11. Linear z-directional neck joint acceleration profile, human (A) and Hybrid-III (B).



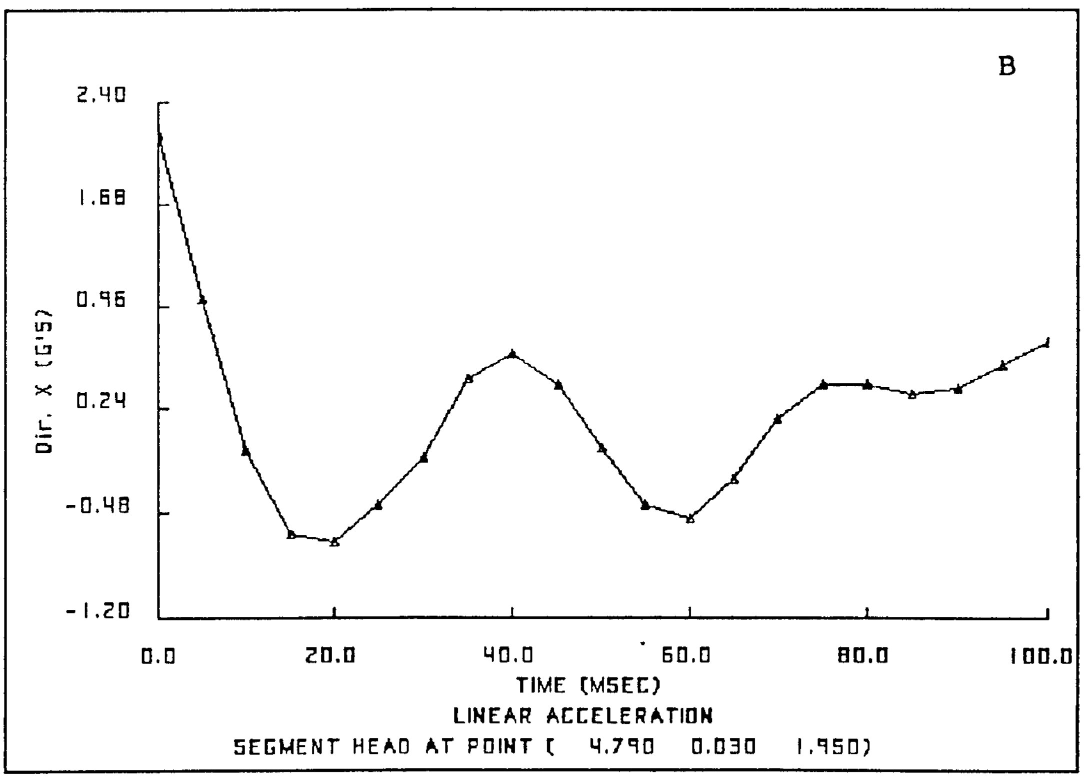


Figure 12. X-directional simulated accelerations for head pin in human (A) and Hybrid-III (B).

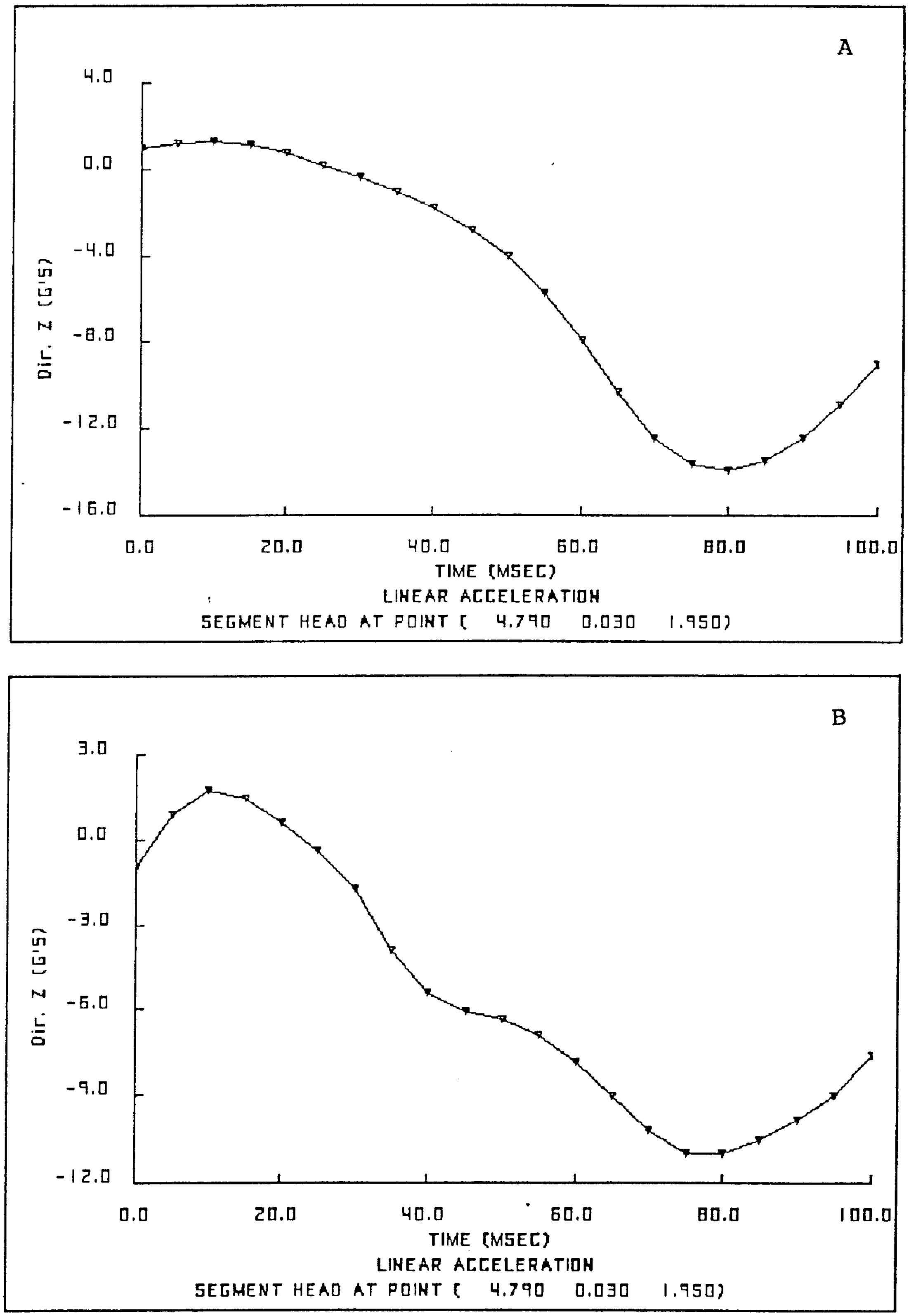


Figure 13. Z-directional acceleration for human (A) and Hybrid III (B) studies.

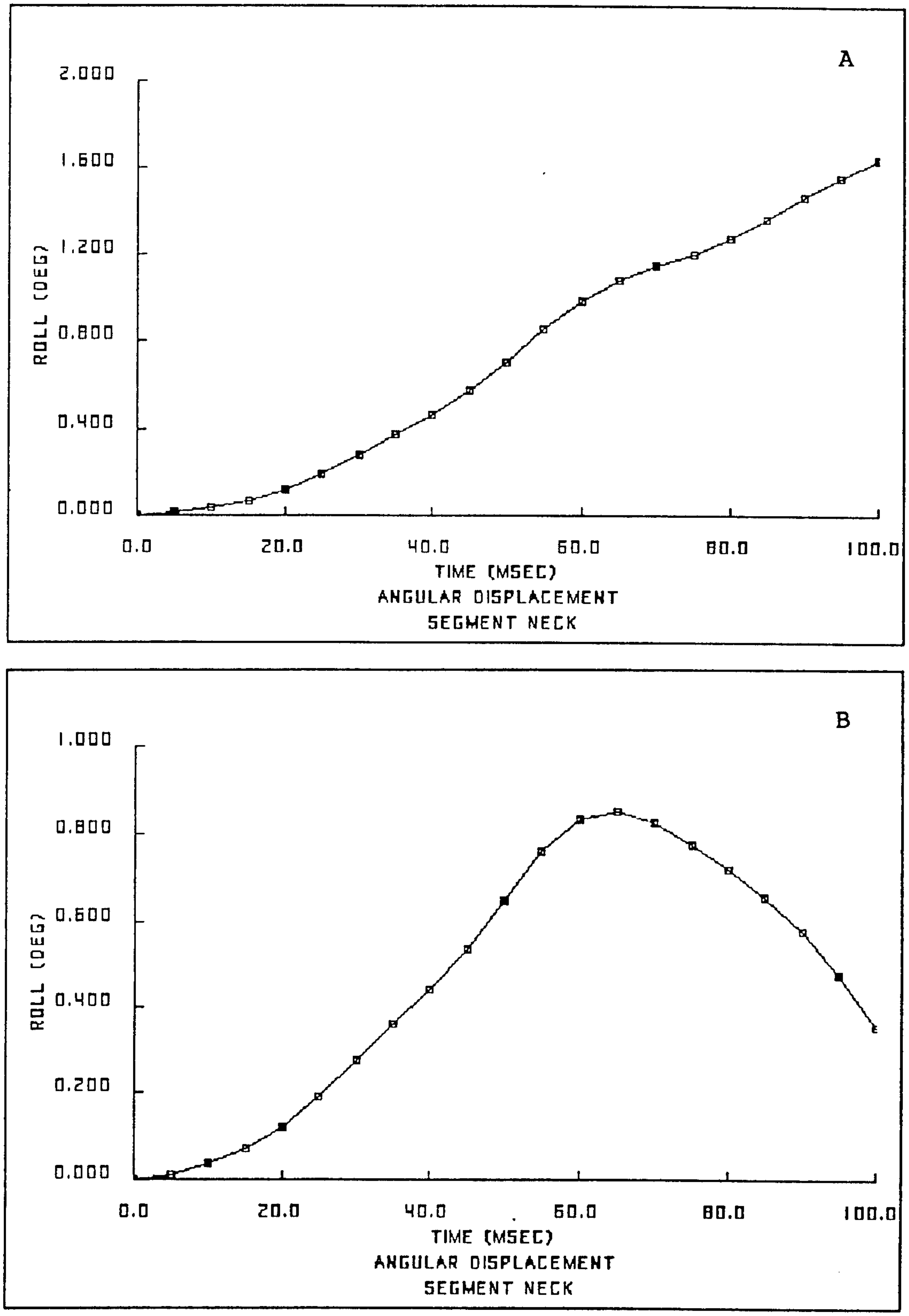
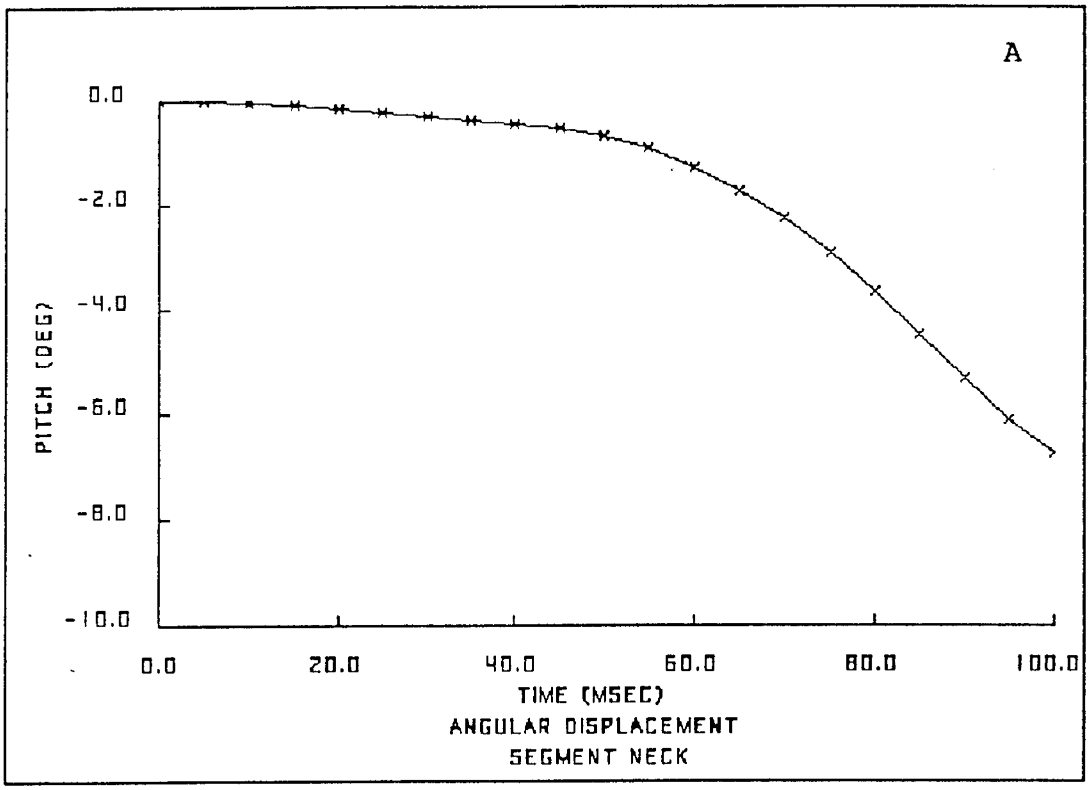


Figure 14. Angular displacement in Roll for human (A) and Hybrid-III (B).



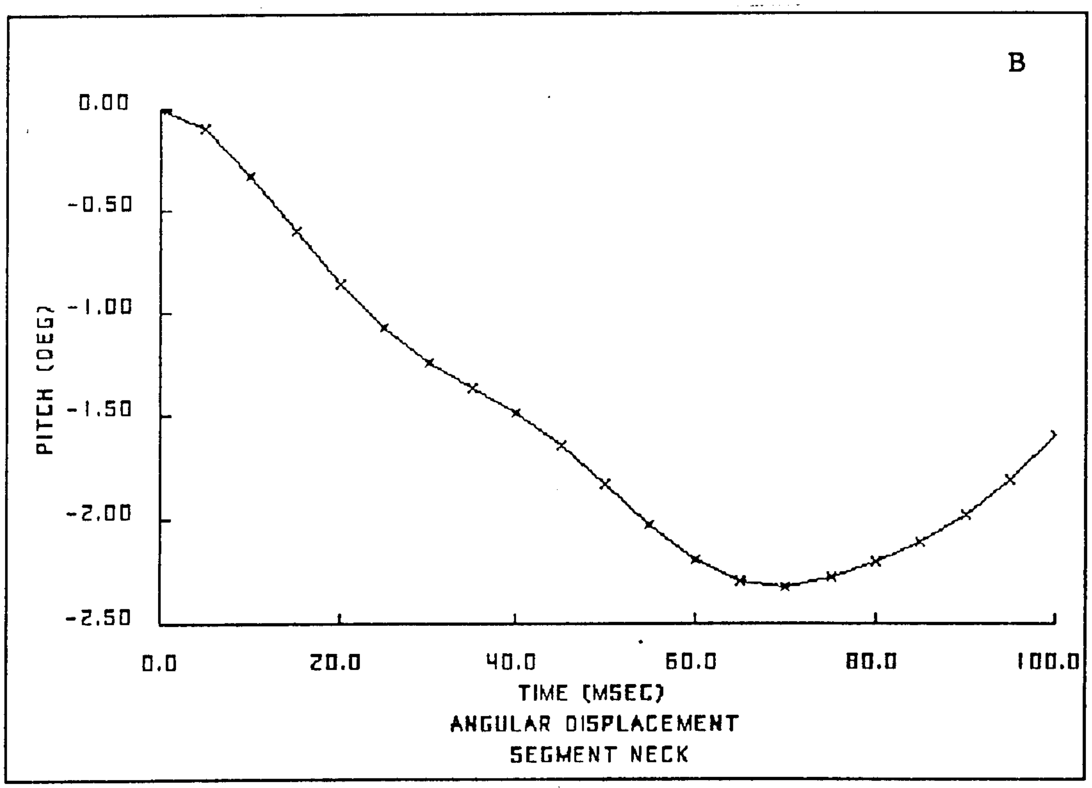


Figure 15. Angular displacement of neck in pitch for human (A) and Hybrid-III (B).

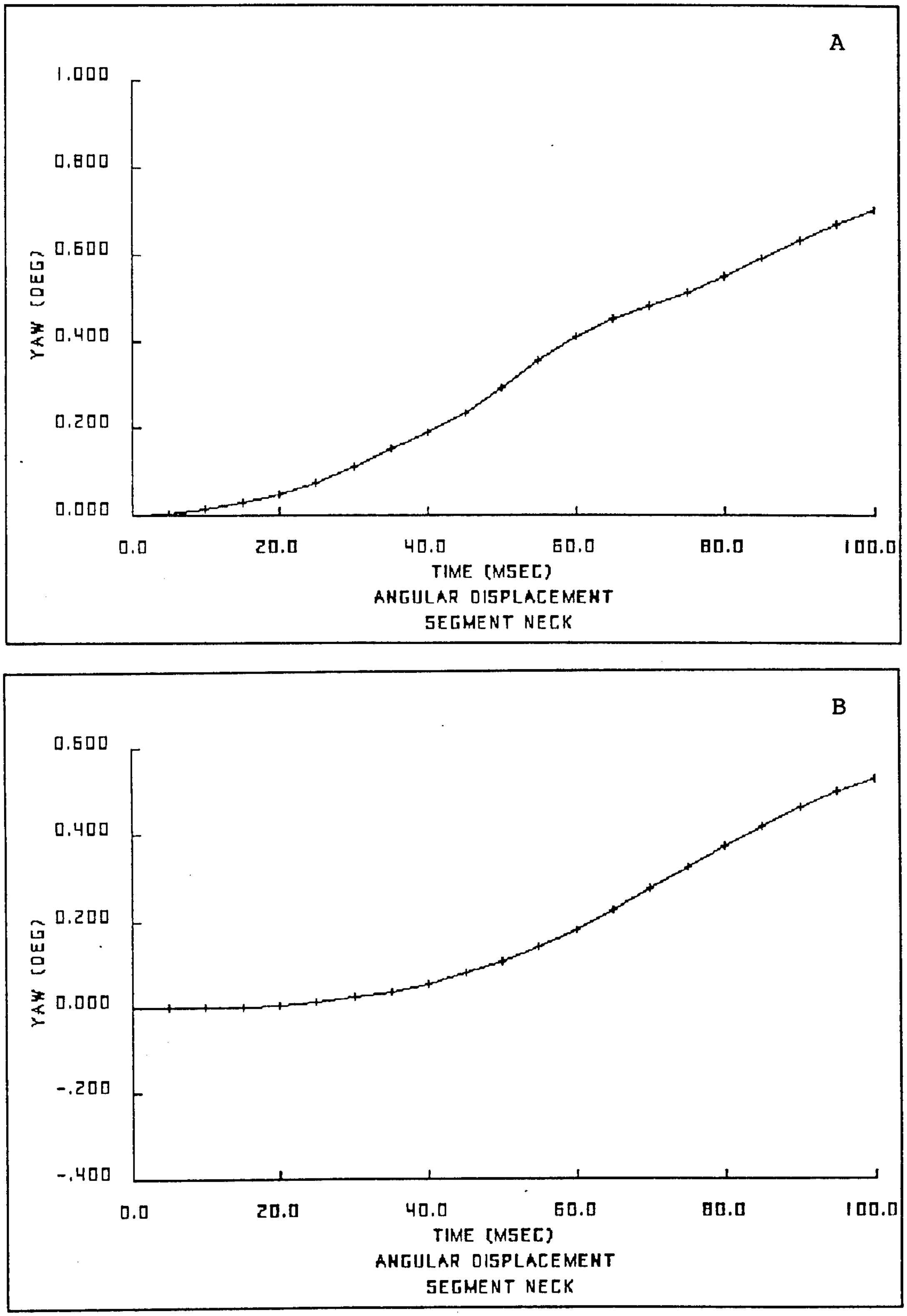
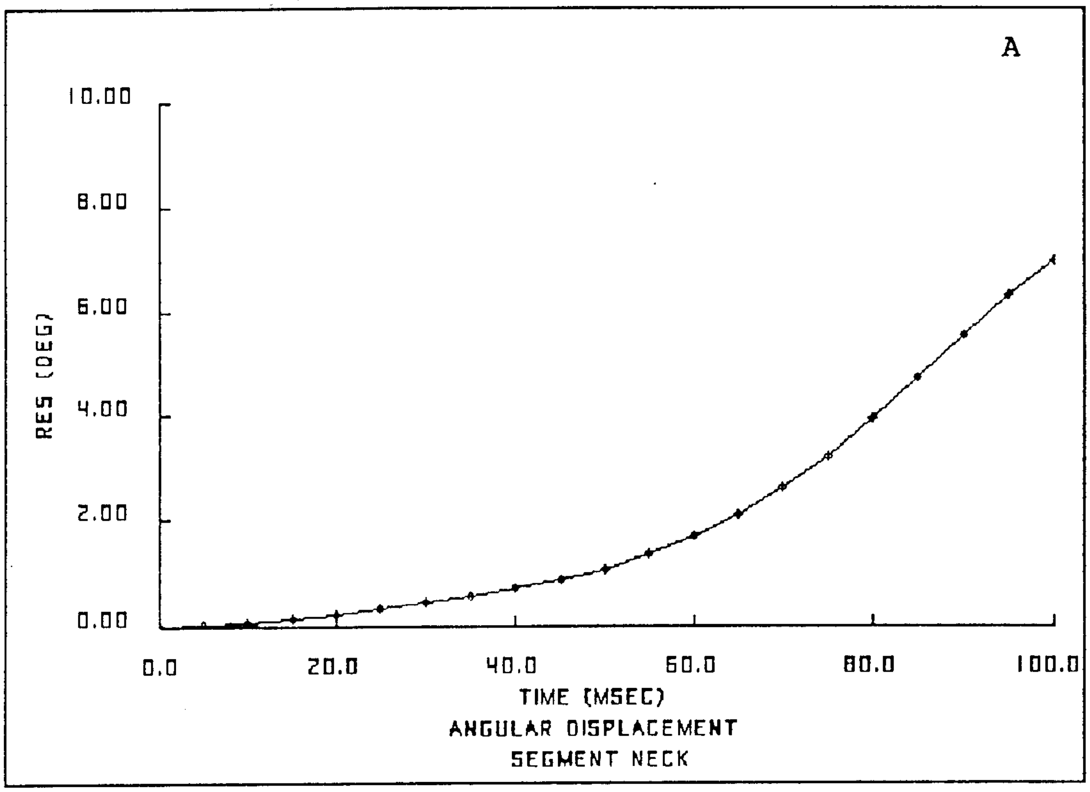


Figure 16. Angular displacement for neck in yaw for human (A) and Hybrid-III (B).



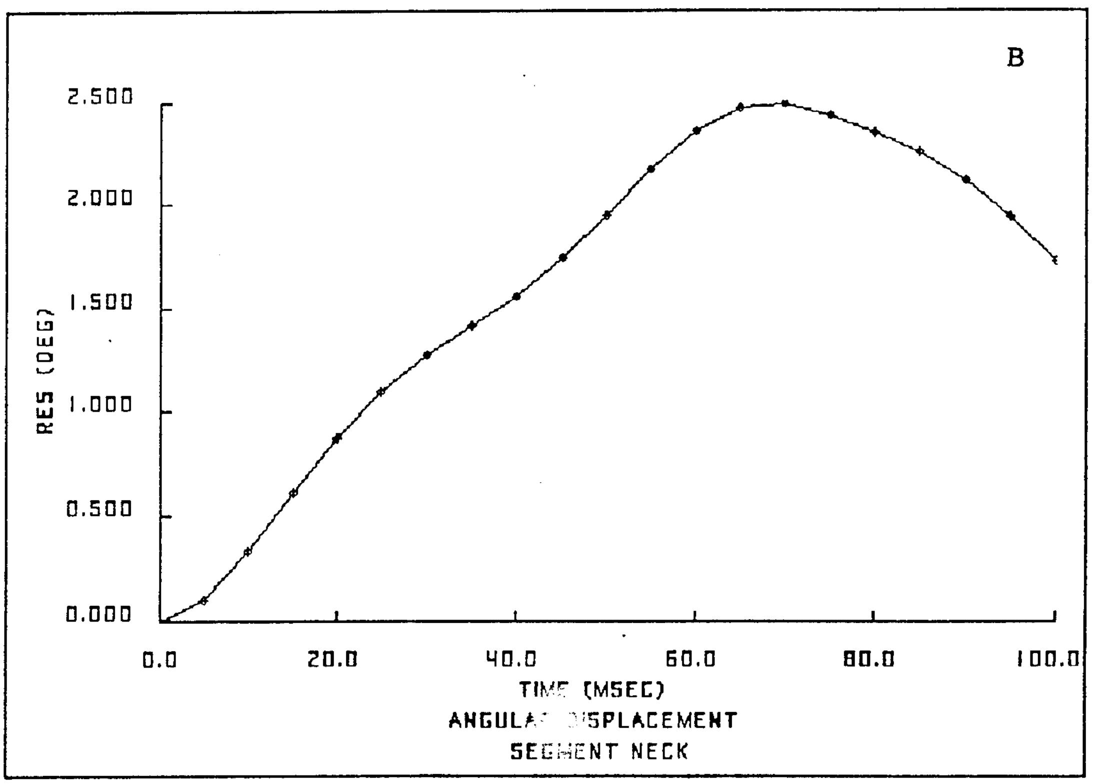
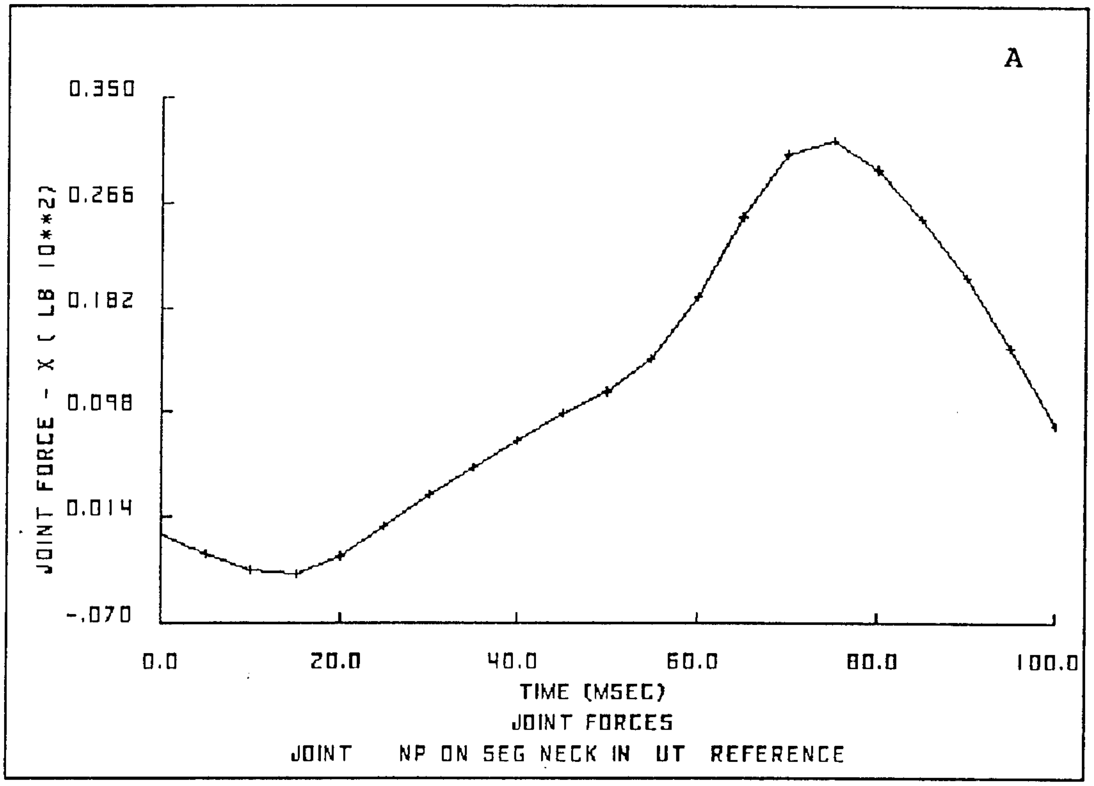


Figure 17. Resultant angular displacement of neck for human (A) and Hybrid-III (B).

For all the simulations up to 60 msec the values are comparable. The yaw, roll and resultant are comparable for a larger time profile, while pitch angular displacements are vastly different between the two tests. Again this could be suggested as due to the neck-head joint characteristics of a Hybrid-III dummy which is quite different from the human head-neck joints.

Figures 18 and 19 show joint forces in the X and Y directions respectively for a NP joint using upper torso as the reference point. The two types of test simulation results are quite different in the X-direction but has remarkable similarities in the Y-directional joint force. Suggesting a poor model representation by the Hybrid-III when compared with actual human neck characteristics. Figures 20-22 show the simulation results of the joint torque profile for neck pin joint in the X, Y, and Z direction respectively using upper torso as reference. The torque characteristics in the X-direction for human after about 80 msec dissipates, while the manikin torque value bounces back. The numerical values of the torque in Y and Z direction shows very good to excellent correlation between the two sets of data. Again not so good correlation in the X-direction can be attributed to the difference between the physical characteristics of human and dummy neck.

Figure 23 shows the typical spring damper profile as spring force applied in the UT-neck joints for human and manikin. In human the force is smooth and increases and decreases in a



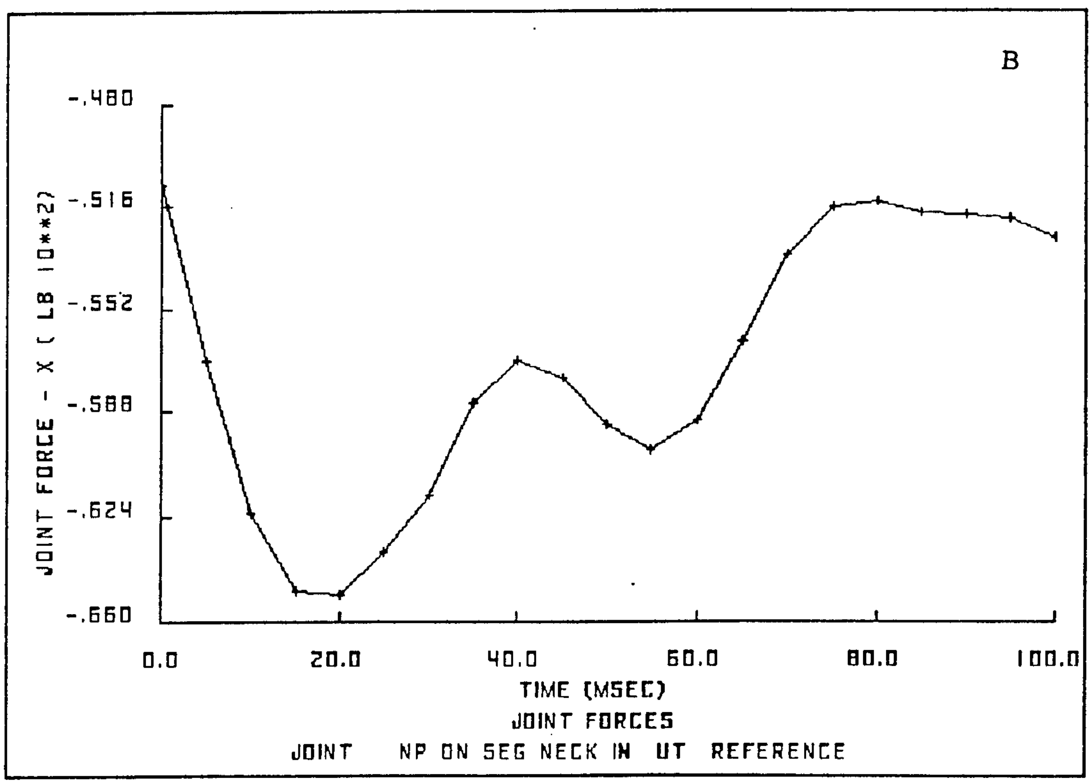
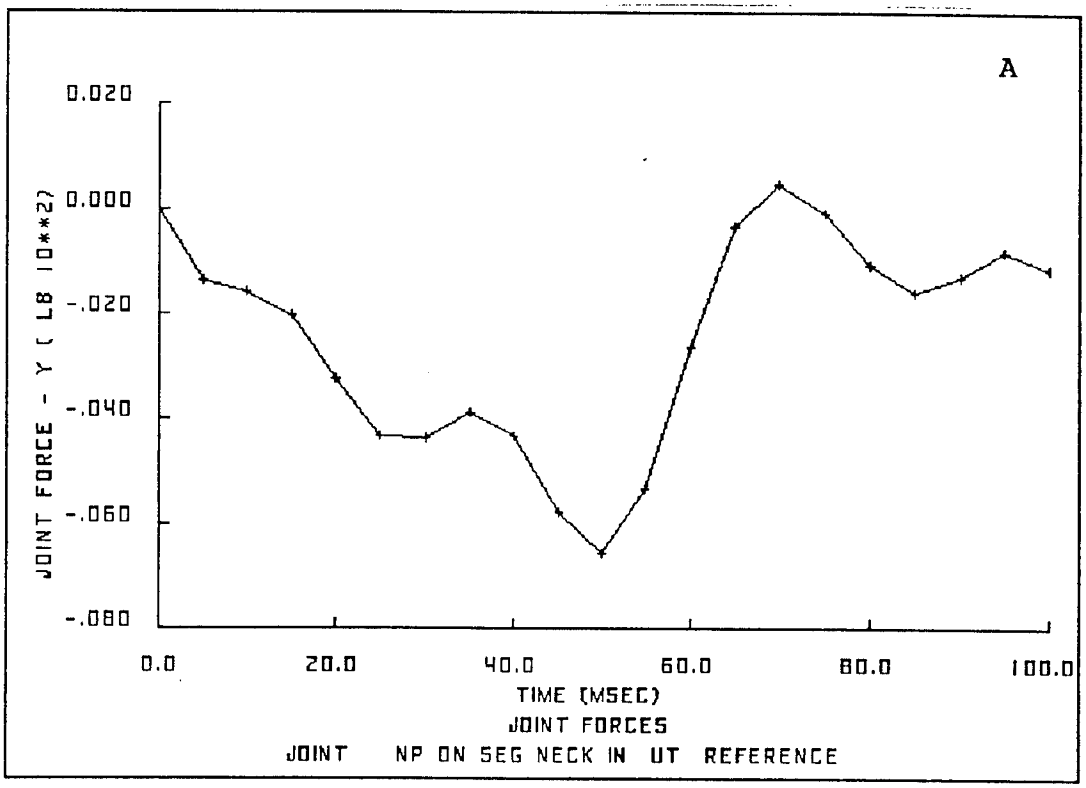


Figure 18. NP joint forces in x-direction with upper torso as reference. (A) human and (B) Hybrid-III.



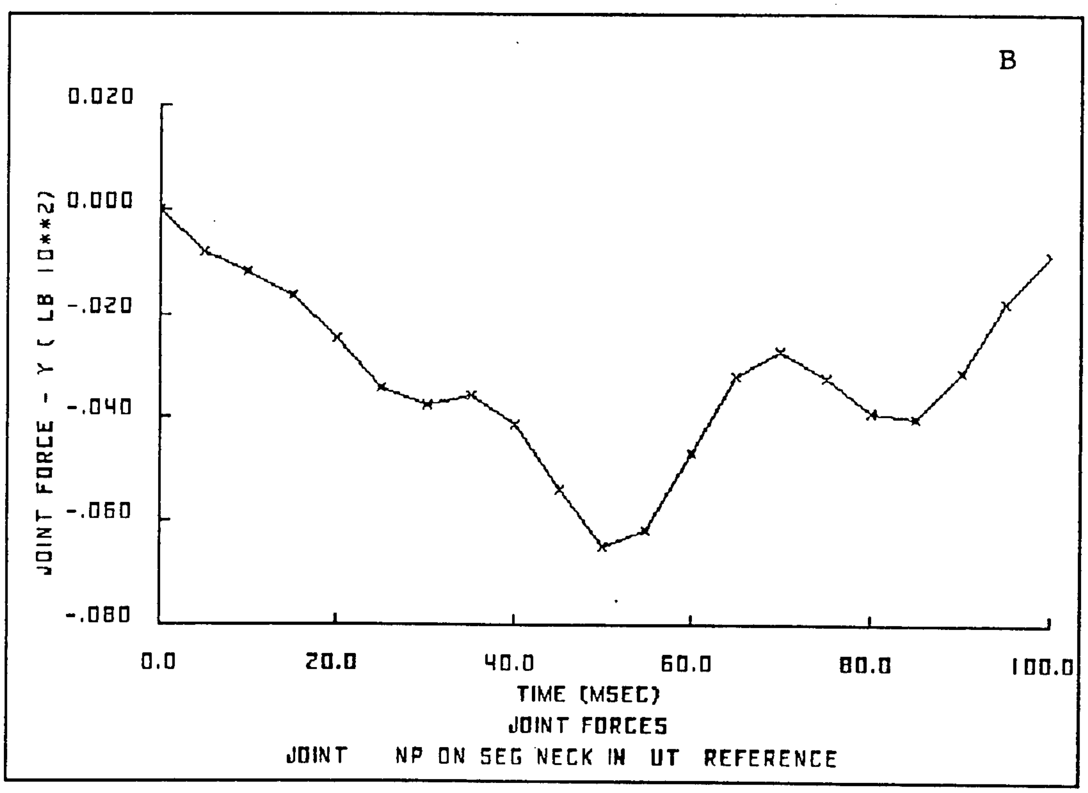
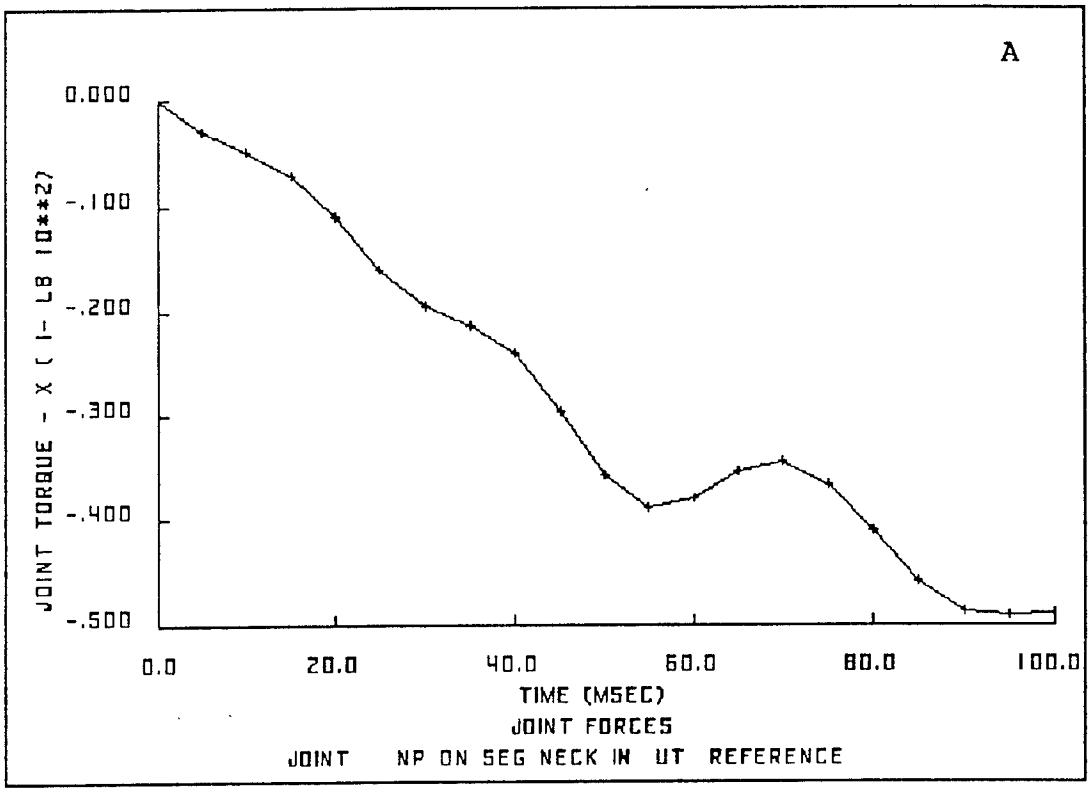


Figure 19. NP joint forces in y-direction with upper torso as reference, human (A) and Hybrid-III (B).



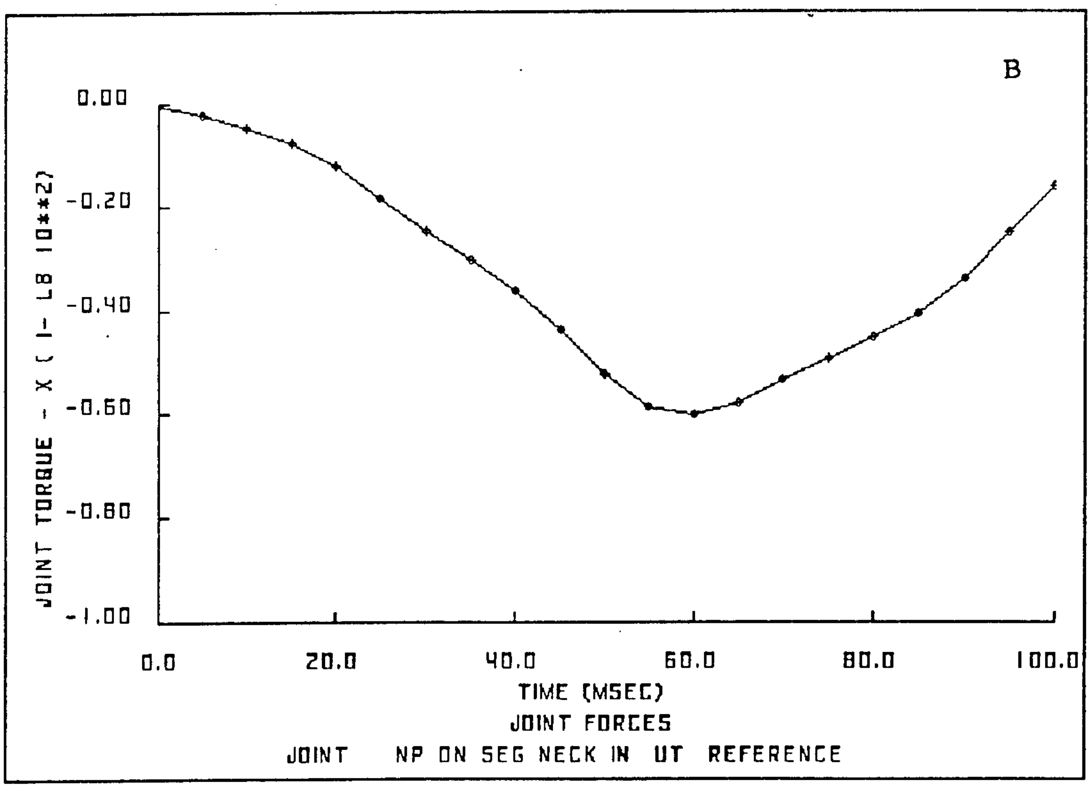
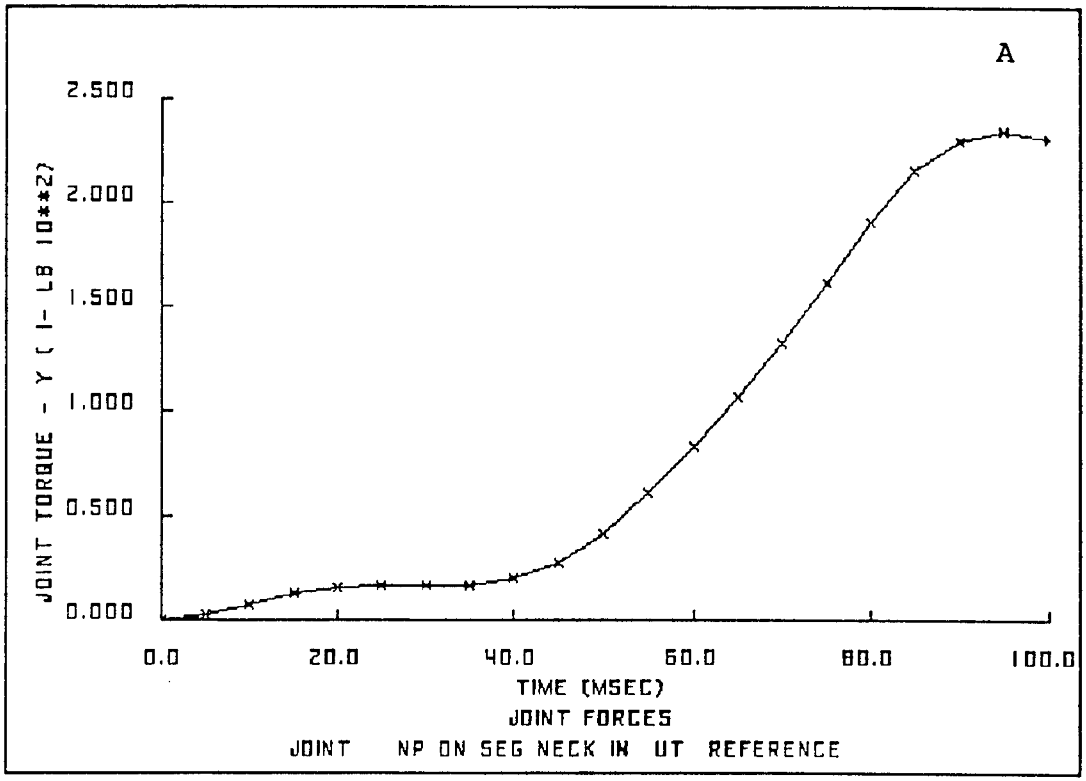


Figure 20. Joint torque profile for NP joint in the x-direction using UT as reference, (A) human, (B) Hybrid-III.



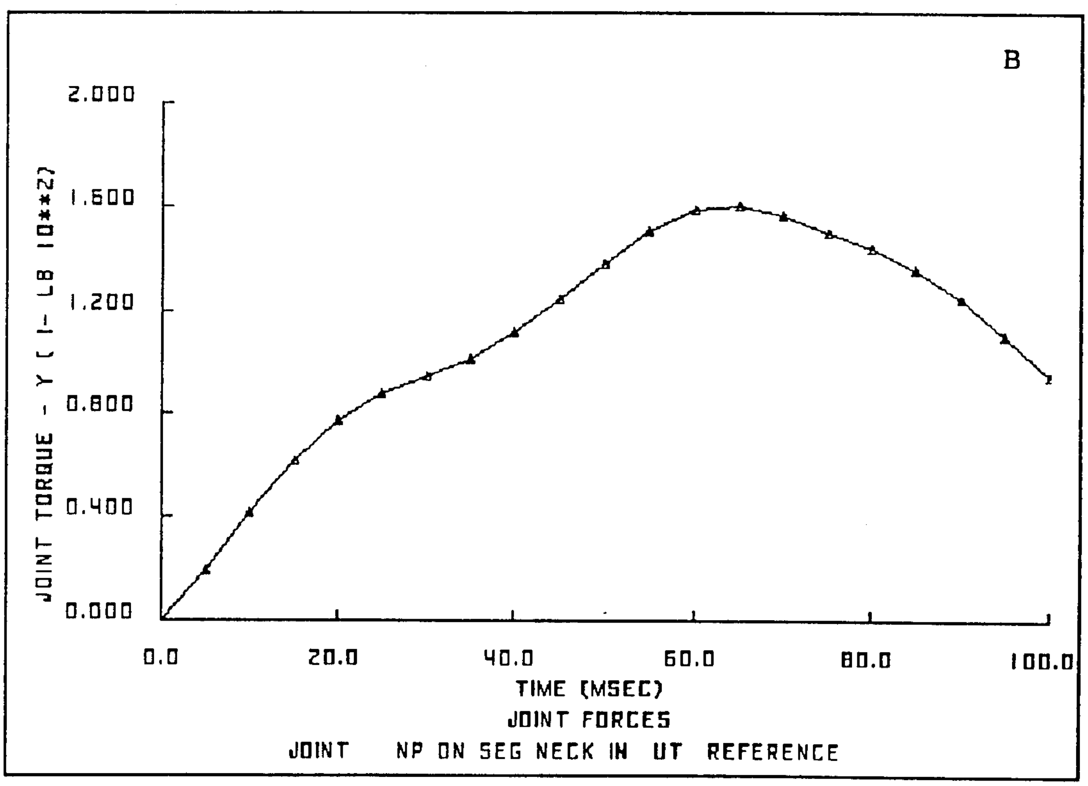


Figure 21. Joint torque profile for NP joint in the y-direction using UT as reference, (A) human, (B) Hybrid-III.

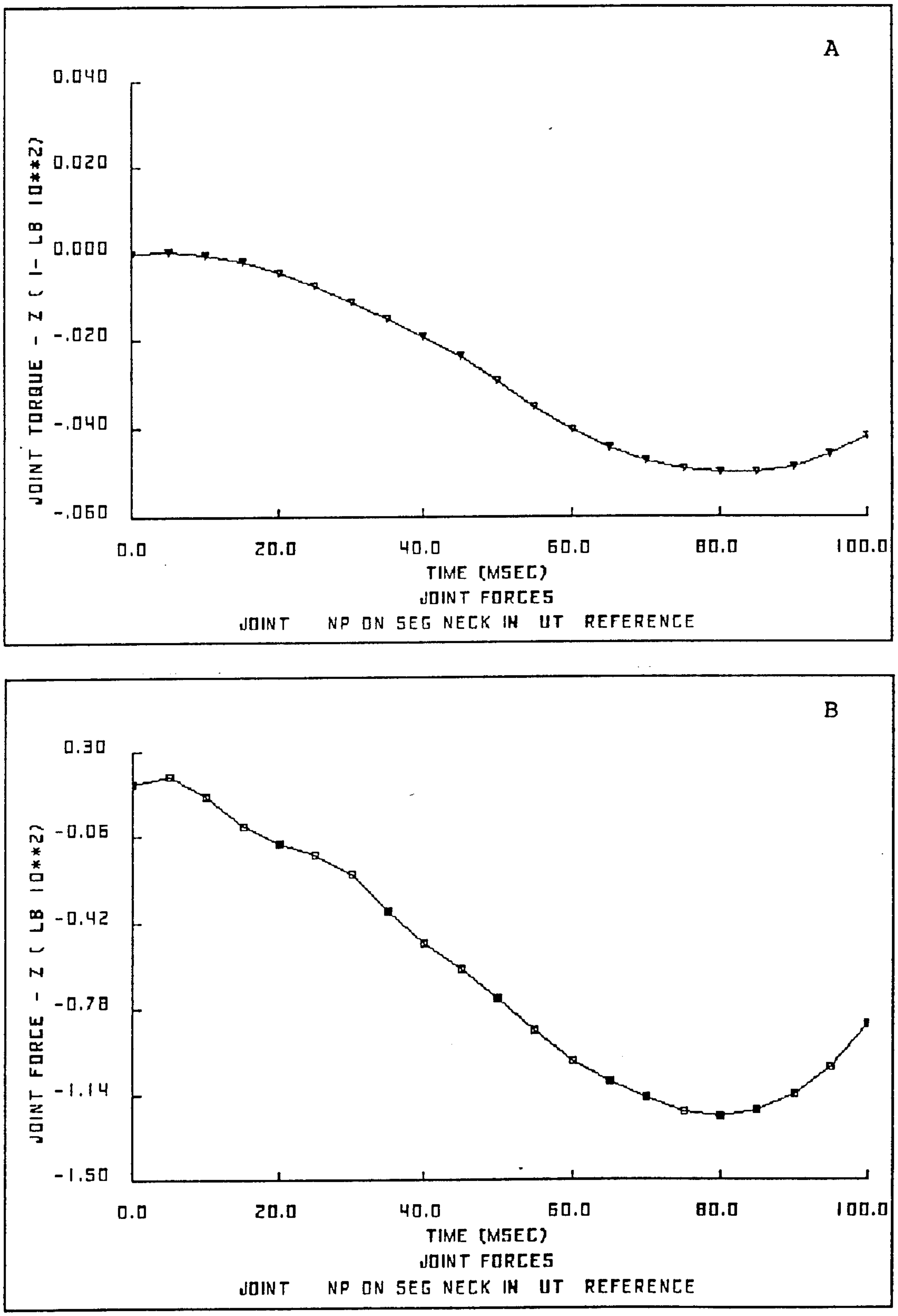


Figure 22. Joint torque profile for NP joint in the z-direction using UT as reference, (A) [illegible]man and (B) Hybrid-III.

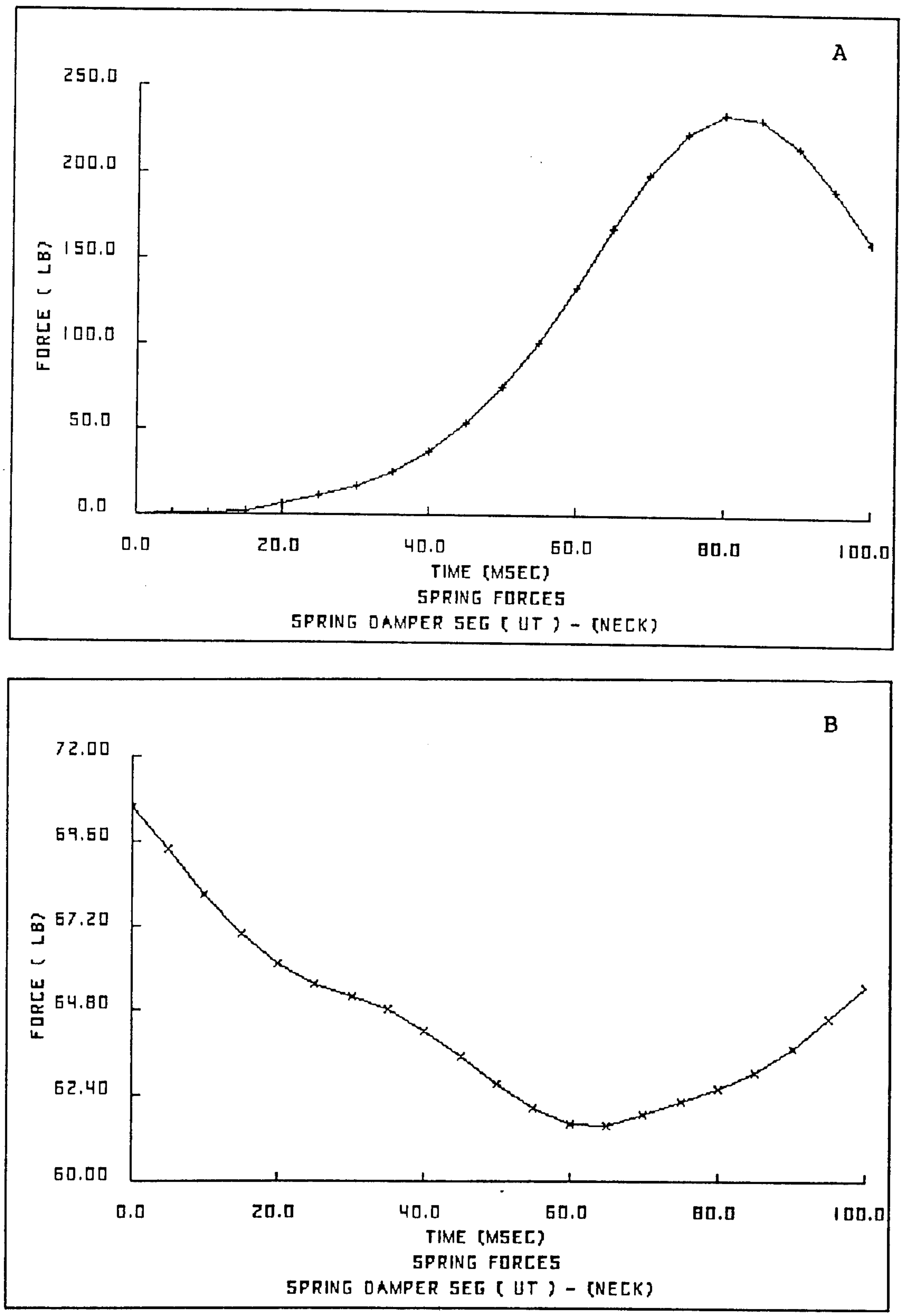


Figure 23. Typical spring damper profile for UT-neck joints for (A) human and (B) Hybrid-III.

predictable manner. In case of manikin the values are lower than human and changes are different from human profiles.

VI. DISCUSSION:

Most of the information available for impact acceleration are for human volunteers (5). There exists little data for dummy impact conditions. At the lower G values (e.g., 0-5 G) human volunteers are capable of contributing force, torque, accelerations etc. which are of significant importance to Air Force. Unfortunately humans can not be subjected to higher G loadings due to human volunteer protocol, although higher values are often seen by the pilots. Loading as high as 10G or more has only been reported by Mertz and Patrick (17). Beyond a tolerance limit they have used cadavers to support the tolerance envelope developed by them. Literature search show a marked gap in data for a high G impact.

Hybrid-III manikin are used as a surrogate to human in number of studies where exposure to human subjects can not or will not be permitted. Amstrong Laboratory at Wright Patterson Air Force Base collected and conducted number of impacts using Hybrid-III dummy. Most of these information are on the higher range of G that can not be validated using human volunteers. Among the data recorded are head and chest accelerations. The photographic records are also documented to determine the kinematics of the head, shoulder, and neck. The Articulated Total Body (ATB) model has been used to simulate the head and neck response for impact using the experimentally obtained chest acceleration as input.

The simulation uses certain specific parameters, i.e., neck stiffness, dumping forces etc. as inputs for validation with the experimental results. Reference (16) detailed the values used and their justifications. The series of simulations ran in this study show usefulness and lack of it when dummy data and human data were compared. In almost all instances the Y and Z directional time history profiles of acceleration, joint force, joint torque, angular displacement, etc., show remarkable similarities between the human and the manikin studies under similar inputs. When the X directional profiles were compared the correlations are not that good any more. This difference in the profiles can be explained if one considers the physical limitations of a Hybrid-III manikin. The head/neck assembly of the Hybrid-III is a hollow aluminum casting representing head and a right circular cylinder of butyl rubber. In the simulation the spring and dashboard concept has been used to mimic the human head/neck structure. The human neck under impact would extend in the X direction much more than in the Y or Z directions. In case of dummy the neck would not extend in any of the three directions significantly. For the Y and Z directions hence the simulation would show good to excellent correlations while the X directional data would not.

Given the limitations implied in the use of dummy as a surrogate for impact studies the computer simulation of the impacts are highly desirable. Once validated at a lower G loading with available human volunteer data a computer simulation can predict the necessary parameters with minimal cost and time required. In case of dummy the higher values of G that cannot be experimentally achieved can be easily tested. The computer models that can successfully predict kinematics and kinetics of the human head/neck opens the door to further developments of other body parts motion in a similar manner.

V. CONCLUSION:

The present research, in a limited capacity due to time constraint, investigated the use of an analytical simulation model to describe the usefulness of a manikin under impact acceleration conditions. The simulation model used the Articulated Total Body (ATB) model for prediction of head responses and comparison were made with the AL corresponding human test data. The basic assumption, a two joint system (one at the occiput and the other at the T1 vertebra), seems adequate to assess the effects on neck loading levels, and the head and neck inertial properties and joint locations do not change during the impact. The effects of impacts on a dummy Hybrid-III were assessed by comparing changes in maximal neck flexion and force transmission across the occipital condyle joint with human volunteer.

VI. ACKNOWLEDGEMENTS:

The author would like to thank the Air Force Systems Command, the Air Force Office of Scientific Research and the Armstrong Laboratory (AL) for sponsorship and support of this research. Research and Development Laboratory must be mentioned for their concern and help to me in all administrative and directional aspects of this program. Dr. Ints Kaleps (Amstrong Laboratories) provided me with support, encouragement, and a truly enjoyable working relationship. The help of Ms. D. Dodd, Ms. A. Rizer and Ms. M. Gross at Wright Patterson was invaluable in overcoming many administrative and technical roadblocks. Ms. Christina Estep and Ms. Tandrian Romero were two students from Virginia Polytechnic Institute and University of Puerto Rico respectively. Their help in all phases of this study was invaluable. The computer related help of Lt K.L.Kline (AL) was greatly appreciated. The encouragement and help of Dr. L. A. Obergefell (AL) clearly added to every aspect of this research project.

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The Determinants of Retention of Military Medical Personnel in Wilford Hall Medical Center

Professor James L. Price, Principal Investigator
Department of Sociology
University of Iowa
Iowa City, Iowa 52242

Final Report for
Research Initiation Program (Proposal 92-48)
Armstrong Laboratory

Sponsored by
Air Force Office of Scientific Research
Bolling Air Force Base, Washington, D.C.
and
University of Iowa

February 1993

Abstract

This final report on the determinants of retention of military medical personnel in Wilford Hall Medical Center (RIP Proposal 92-48) describes four different types of activities performed in connection with the grant. First, data were collected regarding retention in the Air Force of employees studied in the Summer of 1990. Second, the questionnaire used in the Summer of 1990 was redesigned and administered to the employees from the 1990 cohort who remained in the Air Force in the Spring of 1992. Third, the data collected in the Summer of 1990 has been used for two dissertations. Fourth, three papers will come from the 1990 data; one of these papers has already been accepted for publication.

The Determinants of Retention of Military Medical Personnel in Wilford Hall Medical Center

Four different types of activities were performed with this research grant: collection of data about retention, questionnaire redesign-administration, dissertation research, and preparation of papers. Each of these activities will be now described.

Collection of Data About Retention. The first phase of this research began in the Summer of 1990 when Price, the principal investigator, was an Air Force Fellow at Armstrong Laboratory. During this summer Price designed and administered a questionnaire to 3,146 military medical personnel at Wilford Hall Medical Center (WHMC). This questionnaire assessed the variables, which based on past research, are likely to produce variations in retention in the Air Force. The plan was to follow these employees for five years to give most of them time to complete the obligations they owed to the Air Force. 1,521 questionnaires were returned, for a response rate of forty-eight percent.

In May of 1992 Price went to Armstrong Laboratory to collect data about this cohort of 1,521 military medical personnel. He found that 198 of these individuals had left the Air Force (112 voluntary exits, 81 involuntary exits, and five with insufficient data to classify). This left

1,323 individuals to whom a second questionnaire was to be sent. Armstrong Laboratory supplied the current address for these individuals.

Questionnaire Redesign and Administration. The 1990 questionnaire was revised slightly and mailed to the 1,323 individuals of the 1990 cohort. By September 30, 1992, the shut-off date, we received 734 responses to these questionnaires, for a response rate of fifty-five percent. To respond the individual had only to return an answer sheet included with the questionnaire. The remaining individuals either chose not to return the questionnaire or could not be located. The answer sheets were mailed to Armstrong Laboratory in the Fall of 1992 and we are scheduled to receive the computer tapes with the data in February 1993.

Dissertation Research. The data collected in the Summer of 1990 has been used for two dissertations. Dr. Tanya Uden-Holman, a sociologist, finished a dissertation on enlisted personnel at WHMC and a copy of a paper from this dissertation is enclosed in Appendix A ("Commitment and Intentions to Stay Among U.S. Air Force Enlisted Medical Personnel"). This paper has been accepted for reading at the American Sociological Association Meetings in Miami Beach in August 1993. A copy of Dr. Uden-Holman's paper has also been sent to Armstrong Laboratory and WHMC. Sue Morhead, a Ph.D. student from the College of Nursing, is analyzing intent to stay among nurses at the WHMC; her dissertation should be finished in the Spring of 1993. Papers will be prepared from the completed dissertation and circulated to Armstrong Laboratory and WHMC. Professors Price and C. W. Mueller (Sociology) directed both of these dissertations.

Preparation of Papers. Professors Price, working with a Ph.D. student in Sociology (Sang-Wook Kim), has had accepted for publication by *Armed Forces and Society* one paper from the 1990 data ("The Relationships between Demographic Variables and Intent to Stay Among Military Medical Personnel in a U.S. Air Force Hospital"). This paper by Price and Kim is found in Appendix B.

Professors Price and Mueller are working on two additional papers from the 1990 data. One paper examines what it means to be a professional in a military hospital and examines four types of personnel in WHMC: physicians, nurses, technicians, and managers. The sample size for this paper is 1,336. Sang-Wook Kim is also working on this paper with Price and Mueller. The second paper seeks to explain intent to stay in the Air Force by physicians. Dr. Thomas Walson of Armstrong Laboratory, is working with Price, Mueller, and Kim on the second paper. The sample size for this paper is 249. Most of this analysis is done on these two papers and they should be ready to submit for reading and publication in the Summer of 1993. When finished, as is our custom, these papers will be sent to Armstrong Laboratory and WHMC.

Appendix C contains the final financial report from the University of Iowa regarding the grant; the signed copy of this statement was sent by the University of Iowa to Research and Development Laboratories.

Appendix A

COMMITMENT AND INTENTIONS TO STAY AMONG U. S. AIR FORCE ENLISTED MEDICAL PERSONNEL

BY

Tanya Uden-Holman
517 Westlawn South
Center for Health Services Research
University of Iowa
Iowa City, IA 52242
319-335-8708

Charles W. Mueller
W140 Seashore Hall
Department of Sociology
University of Iowa
Iowa City, IA 52242
319-335-2491

James L. Price
W140 Seashore Hall
Department of Sociology
University of Iowa
Iowa City, IA 52242
319-335-2497

December 1992

COMMITMENT AND INTENTIONS TO STAY AMONG U.S. AIR FORCE ENLISTED MEDICAL PERSONNEL

ABSTRACT

The purpose of this study is to develop an integrated model of commitment based on economic, psychological, and structural variables and then apply this model to a population that has not received much attention in the literature--the military. The specific military population studied in this paper is enlisted medical personnel and represents a bridge between civilian models of commitment and more "pure" military models. Several variables specific to the military are added to the model to take into account the unique nature of this organization. These variables are sense of belonging to the military community, and rate of skill advancement. LISREL is used to analyze the causal model of commitment and intentions to stay based on a sample of 782 enlisted medical personnel stationed at Wilford Hall Medical Center. Met expectations has the largest total causal effect on intentions to stay in the Air Force followed by a sense of belonging to the military community, alternative job opportunities, commitment to the Air Force, search behavior, rate of skill advancement, promotional opportunity, kinship responsibility, family support, legitimacy, and fringe benefits. Three of the control variables also have significant total causal effect on intentions to stay--owed service, rank, and race. Job satisfaction has a surprisingly small net effect on commitment and does not play a mediating role. The causal model explains 85 percent of the variance in commitment to the Air Force and 75 percent of the variance in intentions to stay among these personnel.

COMMITMENT AND INTENTIONS TO STAY AMONG U.S. AIR FORCE ENLISTED MEDICAL PERSONNEL

Introduction

Over the past decade there has been a growing interest in the commitment of workers to their employing organization. Research in this area can be found in the economic, psychological, and sociological literature. It should be noted that although economists (e.g., Parsons 1973, 1977; Jovanovic 1979, 1984, Black, 1981) and industrial/organizational psychologists (e.g., Mobley, 1982; Mowday, Porter and Steers, 1982) have been interested in the concept of commitment, their main concern has been in specifying the determinants of employee turnover. Recent explanations within the sociological tradition have focused primarily on how the characteristics and organization of work (i.e., structure) within a firm affect the commitment level of workers. This paper furthers the study of commitment by developing an integrated model based on economic, psychological, and structural variables and then applying this model to a population that has not received much attention in the literature--the military.

The specific military population that is studied in this paper--enlisted medical personnel--represents a bridge between civilian models of commitment and more "pure" military models. For this particular population the employment relationship is structured by a specified and contractual length of service. Because of this, some of the hypotheses developed for civilian models of commitment may need to be modified when applied to this military sample.

Definition of Commitment

There are two major uses of the term "organizational commitment" in the sociological literature. Although both have the organization as the referent and refer to the level of attachment the worker has to the organization, they differ as to whether this attachment is affective (emotional) or affectively neutral (Mueller, Wallace, and Price, 1992). The former may be labeled "affective organizational commitment" and be defined as "the relative strength of an individual's identification with and involvement in a particular organization" (Mowday et al., 1979, p. 226; see also Lincoln and Kalleberg, 1990).

The other use of the term views the commitment of workers to the firm as being affectively neutral and focuses on an employee's intention to stay or leave the organization. "Intent to stay" involves calculative or instrumental assessments of the perceived utility of remaining with the organization, relative to leaving (Mueller, et al, 1992). This is the conceptualization of commitment used by Halaby (1986) and Halaby and Weakliem (1989), who refer to it as attachment.

Recent research on the concept of commitment acknowledges that "intent to stay" is a separate construct that is distinct from "affective organizational commitment" (Mueller, et al., 1992). In addition, intent to stay is viewed as a consequence of affective organizational commitment (Mueller and Price, 1990; Price and Mueller, 1986), and a precursor to employee turnover (Bluedorn, 1982; Halaby, 1986; Halaby and Weakliem, 1989; Mobley, 1982; Mowday et al, 1982; Price and Mueller, 1986). To simplify the discussion, from this point on affective organizational commitment will be referred to as "commitment."

Causal Model

This study draws from three models of commitment: (1) Lincoln and Kalleberg (1985, 1990), (2) Halaby (1986) and Halaby and Weakliem (1989), and (3) Price and Mueller, (1986) and Mueller and Price (1990). After a brief discussion, key variables are drawn from these models to develop the model examined in this study.

The models developed by Lincoln and Kalleberg (1985, 1990) and Halaby (1986) and Halaby and Weakliem (1989) focus on structural characteristics of the workplace. Lincoln and Kalleberg (1985, 1990) are concerned with explaining commitment in modern corporatist organizations. They label as "corporatist" any organizational structures and practices aimed at fostering worker loyalty, commitment, and dependence on the organization. According to Lincoln and Kalleberg, the following structures are found in corporatist work organizations: (1) structures facilitating worker participation in the organization, (2) structures facilitating integration, (3) structures facilitating individual mobility and careers, and (4) structures fostering legitimacy.

Halaby (1986) and Halaby and Weakliem (1998) focus on several specific structural features of the workplace and explore them in detail. Like Lincoln and Kalleberg (1990), Halaby (1986) also stresses the importance of legitimacy in the creation of worker commitment. He argues that workers assess the costs of subordination by appraising the legitimacy of employer governance practices. The lack of legitimacy is viewed as an authority cost. Therefore, when employer governance is viewed as arbitrary, authority costs are increased and commitment is lowered. The other structural model developed by Halaby and Weakliem (1989) stresses the importance of autonomy in the creation of commitment. It argues that workers must have a sense of control over the production process and of partnership in running the firm if they are to be committed.

The third model of commitment was proposed by Price and Mueller (1986) and Mueller and Price (1990). The Price and Mueller model differs from the models proposed above because in addition to including numerous structural variables in their model, they include economic variables, such as alternative job opportunities, and psychological variables such as distributive justice and work motivation. In this sense the model they develop is an "integrative" model.

The determinants of commitment drawn from these models are listed and defined in Table 1.[1] The model is integrative; it includes economic, psychological, and structural variables. In addition, although the concept of met expectations is not included in the models discussed above, this paper will include it because of its importance in the commitment literature associated with industrial/organizational psychologists (Mowday et al., 1982).

Figure 1 presents the model to be tested. It shows the exogenous variables leading to job satisfaction which in turn leads to search behavior and finally, intentions to stay. Although there is some debate as to the causal ordering of job satisfaction and commitment, Porter Steers, Mowday, and Boulian (1974) argue that satisfaction represents an unstable and immediate affective reaction to the work environment compared with commitment which is viewed as a long-term, slower developing attitude. On this basis they argue that satisfaction should causally precede commitment. Search behavior has been included in several integrated models that examine satisfaction and commitment as endogenous variables (e.g., Mobley, 1982; Iverson, 1992; Wallace, 1992). Search is included as an intervening variable between commitment and intentions to stay.

1. This table also contains definitions for variables drawn from the military literature and the control variables.

Causal Model Applied to the Military

The model of commitment developed above is based on theories and empirical work from the civilian literature. It is difficult to find empirical work and theories on commitment that are specifically concerned with the military, but there is literature on the subject of turnover in the military that can be drawn on. First, however, it is useful to briefly describe the military work setting.

Military versus Civilian Occupations

There are four features of the military that, when taken in combination, distinguish it from civilian organizations.[2] First, the military has characteristics of a community. Military personnel often interact for extended periods of time. There is also a definite "in-group" feeling, with an explicit line between members and civilians. Frequency of interaction and clear distinctions between military personnel and civilians give the military more of a "community" feeling. A military "community" appeals to the ideas of patriotism, honor, and altruistic service. These concepts are not usually emphasized in the civilian sector (Holman, 1989).

Second, there is often an element of danger in military occupations. The basic mission of the military is to defend the country and enforce government policy through force. Although most military occupations are not classified as combat positions, all military personnel are expected to sacrifice their lives should the need arise (Holman, 1989).

Third, leaving the military often involves leaving an occupation. Sometimes skills learned in the military are directly transferable to civilian occupations, sometimes they are not. For example, occupational specialties such as infantryman, sniper, and artilleryman do not have civilian equivalents. For personnel in areas such as these, leaving the military means leaving an occupation (Holman, 1989).

Finally, military personnel are contracted to an explicit term of duty. Stolzenberg and Winkler (1983) argue the foremost difference between military jobs and civilian jobs is that civilians can terminate their employment at any time, whereas military personnel sign up for an explicit term of duty and are bound by law to see this term through. The fact that military personnel sign up for an explicit term of employment may influence their perceptions of their job and their affective orientations toward their job (e.g., job satisfaction

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2. A fifth difference is mentioned, career support from significant others. However due to data limitations the model does not include this concept.

and commitment). The amount of time a person still owes the service may also influence his/her perceptions. Therefore, in the analysis it is important to control for the amount of time an individual still owes the service. It should be noted that none of these four features is unique to the military, but it is the combination of all four aspects that sets military occupations apart.

The Air Force Enlisted System

The following section focuses specifically on the Air Force. However, before beginning several comments are in order. First, it should be noted that the Air Force is probably the most "civilianized" branch of the Armed Services (Wood, 1982). Second, Air Force personnel actually have two jobs. Their primary job is being a member of the Air Force. Their secondary job is referred to as their Air Force Specialty (AFS). This AFS is equivalent to an occupation (e.g., medical technician). The focus of this study is on commitment to being a member of the Air Force (primary job). However, it is possible that commitment to the Air Force is influenced by one's commitment to his/her AFS (secondary job).

One must pass basic training before actually becoming an enlisted person in the Air Force. After passing basic training, most new Air Force enlisted personnel go on to technical school where they receive specialized skill training for their AFS. Upon graduation from technical school, personnel are usually reassigned to a permanent duty station (Valey, 1988). After being reassigned to a permanent duty station, most airmen have a long period of on-the-job training (OJT) in their AFS.

It should be noted that enlisted members each have a skill level associated with their AFS that designates their level of proficiency. These skill levels start at "1" and move to "3," "5," "7," and "9." Airmen must take proficiency exams and display a thorough knowledge of their AFS before they are moved up to higher skill levels. In some regards, this "skill ladder" represents another way, besides being promoted in rank, in which enlisted member can "move up" in the Air Force.

The last feature of the Air Force to be discussed is the promotion system. Although promotions are important in any organization, they may take on added importance in the Air Force since Air Force personnel wear their rank "on their sleeve" for everyone to see.

Air Force members who begin as an airman basic are promoted to airman and airman first class on a noncompetitive basis. However, an airman must be selected to be appointed to noncommissioned officer

(NCO) status and the grade of sergeant. Promotion to the upper enlisted ranks is on a competitive basis. Enlisted personnel must take exams covering their knowledge of their AFS and an exam covering general Air Force knowledge. Their scores on these exams along with scores on their performance reports, time-in-service, time-in-grade, and decorations awarded determine who is promoted.

Air Force Medical Personnel

The above sections point out how the military differs from civilian organizations. However, before concluding that a commitment model developed for civilian organizations cannot be applied to Air Force personnel, it is important to examine the specific AFSs included in this study--namely medical AFSs. As mentioned earlier, the sample used in this study represents a bridge between civilian and military models of commitment.

This sample differs from many other Air Force enlisted occupations because personnel in the medical AFSs have general training. Examples of these medical AFSs include: dental technician, physical therapy specialist, medical laboratory technician, and pharmacy technician. An examination of the description of the medical AFSs shows that few, if any, require skills that are specific to the Air Force. The skills and knowledge acquired for these medical AFSs are easily transferable to the civilian sector and are often in high demand. Therefore, due to the nature of their training, military medical personnel may be even more "civilianized" than the Air Force as a whole.

Changes to the Causal Model

As mentioned, little research has been done on commitment in the military. Therefore, in examining how a model for the military differs from civilian models, it was necessary to draw on literature dealing with turnover in the military. Based on an extensive literature review of turnover in the military (Holman, 1989) and the above discussion, four main differences were found between civilian and military models of turnover. The differences involve kinship responsibility, hazardous work conditions, the sense of belonging to the military community, and the impact of the rate an individual advances in skill level.

Kinship responsibility is hypothesized to have a positive effect on turnover in the military, whereas in civilian models of turnover it is hypothesized to have a negative relationship. Holman (1989) suggests this can be thought of as married military personnel wanting to leave the military and "get on with their lives."

Being a member of the military can mean being separated from family and frequent transfers, all of which can be disruptive to family members' lives. However, it should be noted that some scholars argue that even in the military kinship responsibility has a negative effect on turnover. Since the Air Force is the most "civilianized" branch of the military and we are dealing with a sample of medical personnel that is similar to the civilian sector, the hypothesis is that kinship responsibility has a positive effect on commitment and intentions to stay (presented in Figure 1).

The second difference involves hazardous work conditions. There is some evidence that hazardous work conditions have a positive effect on commitment in the military. This may be explained by the fact that the most dangerous military jobs are often the most prestigious, and this leads to a special esprit de corps in these elite units. However, since this is a sample of medical personnel who face similar dangers to their civilian counterparts (e.g., hepatitis and AIDS), hazardous work conditions is hypothesized to lead to lower commitment and intentions to stay.

Third, military models often include the idea of one's sense of belonging to the military community. In this dissertation, "military community" is defined as the "the extent to which the military embraces an individual's total social life." Individuals who feel a part of the military community and who immerse themselves in the military as a way of life will be more committed and less likely to leave the military.

Finally, the discussion of skill advancement in the Air Force enlisted system suggests there may be more than one type of internal labor market (ILM) operating. The first ILM is concerned with promotion in rank. However, enlisted members also have the opportunity to advance in skill level. In this case movement up the ladder is just based on progressive development of knowledge and skills (not seniority). White and Althauser (1984) refer to this as a skill ILM.

Although the linking of skills with promotions is usually thought to increase employee commitment, this assertion is based on the assumption that these skills are idiosyncratic (firm-specific). If these skills are general, then the worker is actually in a better position to leave the firm. In fact rapid skill development and promotion may actually be a signal to the worker of his/her potential value to other firms. This is the case for the enlisted medical personnel in this sample. In this study skill advancement is defined as "the rate of advancement in an individual's skill level" and is hypothesized to have a negative effect on commitment and intentions to stay.

Data and Methods

Data

Wilford Hall Medical Center (WHMC), Lackland Air Force Base, Texas is the site for this study. WHMC is the USAF's largest medical center with 806 beds. Since WHMC is such a major medical center, it may not be representative of other USAF medical centers. The sample consists of all military medical personnel stationed at WHMC at the time of the survey. Although data were collected on both officers and enlisted, the focus of this study is on enlisted personnel. This decision was made for two interconnected reasons. First, a preliminary report to the USAF using this data set showed significant differences between officers and enlisted on several key variables, including intentions to stay. This in and of itself makes the analysis difficult, but not impossible. However, when one also considers the fact that little research has been done on the determinants of commitment and intentions to stay in the military, it is extremely difficult to hypothesize which determinants should affect the commitment and intentions to stay of officers and enlisted differently and why.

Data were collected by survey and from records as part of a larger study of turnover from the USAF. In July and August of 1990, all military medical personnel at WHMC were sent surveys through the base mail distribution system. Of 1,695 surveys mailed to enlisted personnel, 782 were returned for a response rate of 46 percent. The survey included questions designed to capture all of the explanatory variables in the model presented in Figure 1, along with several demographic variables. Other demographic variables were obtained from personnel records at Armstrong Laboratory, Brooks AFB, Texas.

Measurement and Analysis

The conditions of the workplace are measured by using the perceptions of the employees. This strategy is consistent with research done in this area (e.g., Halaby, 1986; Halaby and Weakliem, 1989; Lincoln and Kalleberg, 1985, 1990; Mueller and Price, 1990; Price and Mueller, 1986). Except for pay, family support, kinship responsibility, and rate of advancement, the constructs are measured using multiple

Likert-type items, thus allowing us to use LISREL maximum likelihood estimation procedures. To increase confidence that the observed relationships between the independent and dependent variables really exist, it is necessary to control for the effects of potentially confounding factors. Positive affectivity, race. sex, rank, education, and the amount of time the respondent still owes the Air Force are used as control variables in the present study.[3] These variables are defined in Table 1.

LISREL takes advantage of information that is provided by multiple indicators and is a more powerful statistical procedure than multiple regression because it corrects for unreliability and also allows one to compare different models to see which fits the data best. LISREL produces both a statistical measure of goodness-of-fit of the model and the explained variance of the endogenous variables in the model.

Results

LISREL Estimates of Causal Model

Initially, we estimated the model presented in Figure 1 which is a semi-chain model. However, we felt that our original semi-chain model was perhaps too restrictive. Although there are several ways of fitting LISREL models to the data (Bollen, 1989; Marsh, Bolla, and McDonald, 1988; Mueller, Price, and Iverson, 1990; Wheaton, 1987), this study follows the strategy employed by Mueller et al. (1990), which involves the use of two basic steps: (1) all paths from the original causal model are retained and are not "trimmed," even if they are not significant, and (2) the original causal model is expanded and modified by "freeing up" additional paths between variables (as indicated by LISREL modification indices) that are theoretically relevant.[4] Only the results of the final LISREL model estimated are presented below. Table 2 contains the LISREL standardized coefficients for this model.

The results indicate that nine of the theoretically based exogenous variables have statistically significant net effects on job satisfaction--routinization (-), autonomy (+), work overload (-), fringe benefits (+), role conflict (-), legitimacy (-), work motivation (+), general training (+), and met expectations (+). In

3. Of these controls only positive affectivity need be justified. Since recent research has found that dispositional variables, such as positive affectivity, are predictors of job satisfaction, it is important to control for their effects (Agho, 1989; Griffin, 1982; Levin and Stokes, 1989). Positive affectivity is a relatively stable personality trait that is formed outside of the place of employment.
4. Control variables are also included in this version of the revised model.

addition, the results indicate the control variable "positive affectivity" has a significant net effect on job satisfaction. In fact, positive affectivity has the greatest impact of all the variables hypothesized to affect job satisfaction. It should be noted that the effect of legitimacy on job satisfaction is not in the predicted direction. The variables in this model explain 88 percent of the variance in satisfaction.

For the endogenous variable of Air Force commitment, the results suggest that six of the determinants have statistically significant net effects. These variables are (in order of importance): met expectations (+), sense of belonging to the military community (+), legitimacy (+), general training (-), job satisfaction (+), and kinship responsibility (+). All relationships are in the predicted direction. None of the control variables had a significant effect on commitment to the Air Force.

These results suggest that enlisted medical personnel who have their expectations concerning the Air Force met, have a sense of belonging to the military community, view their superiors as exercising legitimate authority, do not have skills and knowledge that are easily transferable to the civilian sector, are satisfied with their job, and have family obligations are more committed to the Air Force. The variables included in this model explain 85 percent of the variance in commitment to the Air Force.

Four of the determinants of search behavior have statistically significant net effects–alternative job opportunities (+), met expectations (-), promotional opportunity (-), and fringe benefits (-). In addition, the control variable "race" has a significant negative net effect on search behavior, indicating that nonwhites are more likely to engage in search behavior. It is worth noting that neither of the endogenous variables, job satisfaction nor commitment to the Air Force, has a significant net effect on search behavior. The variables included in the revised model explain 52 percent of the variance in search behavior.

For the endogenous variable of intentions to stay in the Air Force, all but one of the substantive determinants have significant net effects. These variables are (in order of importance): met expectations (+), Air Force commitment (+), search behavior (-), military community (+), alternative job opportunities (-), rate of skill advancement (-), promotional opportunity (+), and family support (-), and kinship responsibility (+). The effect of family support on intentions to stay is not in the predicted direction. In addition, two of the control variables had a significant net effect on intentions to stay--the amount of time the respondent still owes the Air Force (+) and rank (-). These findings suggest that enlisted personnel who owe the Air Force more time and personnel who are lower in rank are more likely to intend to stay in the Air Force. The variables included in the revised model explain 75 percent of the variance in intentions to stay in the Air Force.

Total and Indirect Effects

Table 3 presents the decomposed direct, indirect, and total causal effects of the variables, including the endogenous variables of satisfaction, commitment, and search behavior, on intentions to stay in the Air Force. Although the focus of this study is on both commitment and intentions to stay, only the decomposition of the effects on intentions to stay is examined here because it is the "final" variable in the causal process.

The results indicate that 11 substantive variables have a significant total causal effect on intentions to stay. Met expectations has the greatest total causal effect followed by sense of belonging to the military community, alternative job opportunities, commitment to the Air Force, search behavior, rate of skill advancement, promotional opportunity, kinship responsibility, family support, legitimacy, and fringe benefits. In addition, three of the control variables have significant total causal effects on intentions to stay--owed service, rank, and race.

In addition, six variables had a significant total indirect effect on intentions to stay. Met expectations had the greatest total indirect effect followed by military community, alternative job opportunities, legitimacy, promotional opportunities, and fringe benefits. It should be noted that job satisfaction did not have a significant total causal effect or total indirect effect on intentions on intentions to stay.

Conclusions and Discussion

Two variables included in the model had unexpectedly strong effects--met expectations and military community. The strong effect of met expectations suggests that it may be especially important in the military for personnel to have an idea of what is expected of them before they join. This ties in with the idea of realistic job previews. If personnel have a realistic idea of what the Air Force will be like before they join, those who do not like what they hear will not join, and those who do join will be more likely to have met expectations which may lead to higher levels of satisfaction, commitment, and intentions to stay.

The variable of military community also had a strong impact. This variable may actually be tapping Air Force personnel who are more "gung-ho." In other words, people who participate in base-activities and have close friends in the Air Force may have more of a "gung-ho" attitude. This attitude may spill over and affect how they perceive their job in the military and their responses to their work environment.

A variable that was specific to the military, rate of advancement, also had a significant effect on intentions to stay. This concept also does not have a clear-cut counterpart in the civilian sector. It seems to contradict internal labor market theory by suggesting that even though there may be opportunity to move up the ladder in terms of skill level, this does not automatically function to tie employees to the firm. Enlisted personnel with skills are more likely to intend to leave the Air Force. A possible explanation is that since the skills and knowledge these enlisted medical personnel have are easily transferred to the civilian sector, it may be that moving up quickly in skill level may actually signal to them that they are acquiring valuable skills faster than other personnel. Since their specific skills are transferable to the civilian sector, this would lead to lower intentions to stay. In addition, two of the control variables that are specific to the military, rank and owed service, also had significant net effects on intentions to stay in the Air Force.

One unexpected finding was the small net effect of job satisfaction on commitment to the Air Force. This was unexpected because most research has found satisfaction to be an extremely important determinant of commitment. A possible explanation for this finding is that job satisfaction and Air Force commitment are really formed on two different levels. Job satisfaction has to do with the actual job the person is performing--their AFS. However, the questions concerning commitment assess commitment to the Air Force, not the hospital in which they are performing their job. In other words, even though a person may hate his/her job at the hospital, he/she may still be very committed to the ideas and values of the Air Force.

Overall, the findings for this military population were similar to the previous findings for the civilian sector. However, the importance of a sense of belonging to the military community, the idea of realistic job previews prior to entry, the negative effect of the rate of skill advancement on intentions to stay in the Air Force, the small effect of job satisfaction on commitment to the Air Force, and the effect of rank and owed service on intentions to stay point out that in some ways Air Force enlisted medical personnel do differ from civilian workers. These differences are important to keep in mind when trying to develop a model that explains commitment and intentions to stay as completely as possible in a military population. These differences lead to several suggestions for future research on military personnel.

First, it would be interesting to study a more "pure" military sample–specifically, military occupations with skills that are specific to the military and that cannot be easily transferred to the civilian sector. Second, research incorporating enlisted personnel and officers would be useful. However, it may be wise to first study a sample of only officers to see how commitment and intentions to stay operate in this segment.

It is important for future research on the military to examine more closely the variable "rate of advancement," and perhaps develop other measures to capture it. The effect of this variable on intentions to stay may differ depending on the specific sample that is being studied. It is expected to have the opposite effect for a more "pure" military sample. In addition, future research will want to examine more closely the role of fringe benefits and retirement benefits in retaining Air Force personnel. When interviewed, some of the Air Force personnel at Lackland AFB mentioned the importance of fringe benefits in keeping them in the Air Force. Although the pay may be lower in the Air Force than the civilian sector, the benefits and the promise of a good retirement plan may serve as an incentive to keep people in the service.

The fact that the results of the model for this military population differ in some ways from models developed for the civilian sector reemphasizes the importance of keeping the specific population in mind when developing a causal model. However, the fact that the results were similar to civilian models of commitment and intentions to stay suggests it is possible to think of this population of enlisted medical personnel as a bridge between a "pure" military sample and the civilian samples that have been studied in the past.

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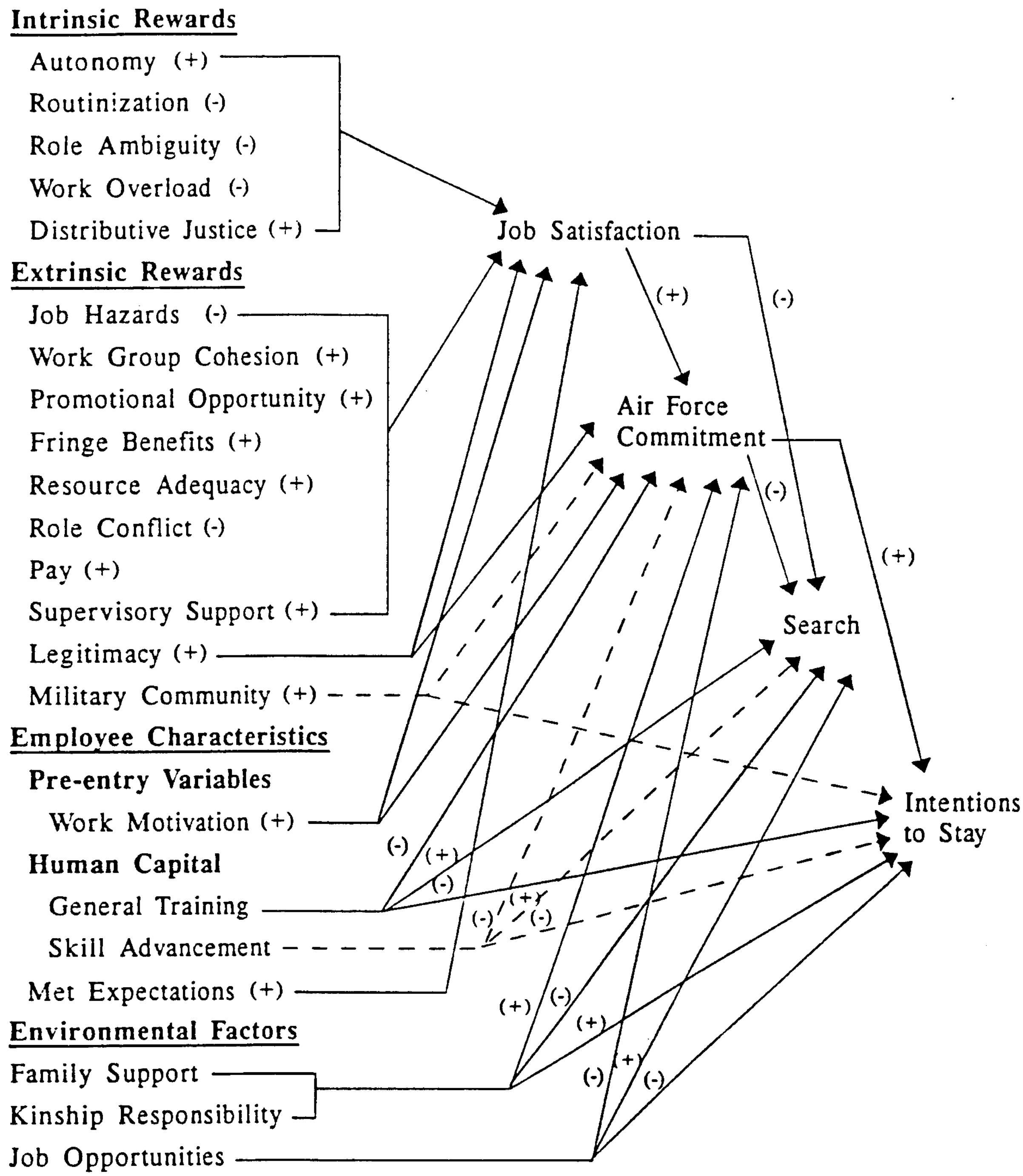

Figure 1. The Causal Model[a]

[a]Dashed lines represent variables added to the model based on the military literature.

Table 1 Variable Definitions

Variable	Definition
Autonomy	The degree of free: :m an individual has over his/her work environment.
Routinization	The degree to which a job is repetitive.
Role Ambiguity	The degree to which an individual's role expectations are not clear.
Work Overload	The degree to which an individual's workload is excessive.
Distributive Justice	The degree to which rewards and punishments are related to performance inputs.
Job Hazards	The degree to which employees are exposed to harmful physical working conditions.
Work Group Cohesion	The extent to which employees have close friends at work.
Promotional Opportunities	The degree of potential vertical occupational mobility within an organization.
Fringe Benefits	Nonwage payments the organization provides the employee.
Resource Adequacy	The extent to which resources are available to fulfill the responsibilities of assigned jobs.
Role Conflict	The degree to which an individual's role expectations are incompatible
Pay	Wages that organizations give to employees in return for their service.
Supervisory Support	The degree of consideration expressed by the supervisory for the subordinates.
Legitimacy	The degree of acceptance by employees of the authority structure of the organization.
Military Community	The extent to which the military embraces one's total social life.
Work Motivation	The degree to which work is an individual's central life interest.
General Training	The degree to which the skills and knowledge of an employee can increase the productivity of different organizations.
Skill Advancement	The rate of advancement in an individual's skill level.
Met Expectations	The degree to which preconceived ideas held by employees concerning organizational life are met.
Family Support	The consideration expressed by immediate relatives.

Table 1 (cont.)

Kinship Responsibility	The degree of an individual's obligation to immediate relatives.
Job Opportunities	The extent of available unoccupied roles in an organization's environment.
Job Satisfaction	The degree of an employee's affective orientation toward the overall job situation.
Organizational Commitment	The relative strength of an individual's identification with and involvement in a particular organization.
Search Behavior	The extent to which an individual is actively seeking another job.
Intentions to Stay	An individual's expected likelihood of remaining employed in the same organization.
Positive Affectivity	The degree to which an individual feels enthusiastic over time and across situations.
Owed Service	Date of separation from the military minus date of survey.
Rank	1 - Airman Basic (E-1) 2 - Airman (E-2) 3 - Airman First Class (E-3) 4 - Senior Airman/Sergeant (E-4) 5 - Staff Sergeant (E-5) 6 - Technical Sergeant (E-6) 7 - Master Sergeant (E-7) 8 - Senior Master Sergeant (E-8)
Sex	0 - Males 1 - Females
Race	0 - Nonwhite 1 - White
Education	1 - High School Graduate 2 - One Year of College 3 - Between one and Two Years of College 4 - Between Two and Four Years of College 5 - College Degree 6 - Master's Degree

Table 2

LISREL Results (Standardized Coefficients) for Revised Causal Model with Control Variables

	Job Satisfaction	Air Force Commitment	Search Behavior	Intentions to Stay
Intrinsic Rewards				
Autonomy	.109*			
Routinization	-.326*			
Role Ambiguity	-.012			
Work Overload	-.084*			
Distributive Justice	-.067			
Extrinsic Rewards				
Job Hazards	.016			
Work Group Cohesion	-.034			
Promotional Opportunity	-.046		-.194*	.071*
Fringe Benefits	.080*		-.150*	
Resource Adequacy	-.028*			
Role Conflict	-.092*			
Pay	-.002			
Supervisory Support	.002			
Legitimacy	-.125*	.186*		
Military Community		.410*		.179*
Employee Characteristics				
Pre-entry Variables				
Work Motivation	.189*	-.059		
Human Capital				
General Training	.061*	-.114*	-.106	.030
Skill Advancement		.010	-.045	-.127*
Met Expectations	.198*	.480*	-.269*	.246*
Environmental Factors				
Family Support		-.045	-.007	-.071*
Kinship Responsibility		.085*	-.001	.063*
Opportunity		.022	.463*	-.077*
Control Variables				
Owed Service	.015	.026	-.051	.082*
Sex	.021	.032	-.053	.007
Race	.038	.027	-.076*	.027
Rank	.020	-.024	-.049	-.101*
Education	-.035	.015	.031	.004
Positive Affectivity	.444*			
Endogenous Variables				
Job Satisfaction		.086*	.064	
Air Force Commitment			.107	.228*
Search Behavior				-.185*
R^2	.880	.850	.520	.750
χ^2 (3216)=6301.26, p<.0001				

*p<.05, one-tailed test.

Table 3

Decomposed Direct, Indirect, and Total Causal Effects of Determinants on Intent to Stay, with Control Variables[a]

		Indirect Effects Via							
Determinants	Direct Effect	Comm Only	Search Only	Sat and Comm	Sat and Search	Comm and Search	Sat, Comm and Search	Total Indirect Effects	Total Causal Effects
Intrinsic Rewards									
Autonomy	----	----	----	.002	-.001	----	-.000	.001	.001
Routinization	----	----	----	-.006	.004	----	.001	-.002	-.002
Role Ambiguity	----	----	----	-.000	-.000	----	.000	-.000	-.000
Work Overload	----	----	----	-.002	.001	----	.000	-.001	-.001
Distributive Justice	----	----	----	-.001	.001	----	.000	-.000	-.000
Extrinsic Rewards									
Job Hazards	----	----	----	-.000	-.000	----	-.000	.000	.000
Work Group Cohesion	----	----	----	-.001	.000	----	.000	-.000	-.000
Promotional Opportunity	.071	----	.036	-.001	.001	----	.000	.036*	.107*
Fringe Benefits	----	----	.028	.002	-.001	----	-.000	.028*	.028*
Resource Adequacy	----	----	----	-.001	.000	----	.000	-.000	-.000
Role Conflict	----	----	----	-.002	.001	----	.000	-.001	-.001
Pay	----	----	----	-.000	.000	----	.000	-.000	-.000
Supervisory Support	----	----	----	.000	-.000	----	-.000	.000	.000
Legitimacy	----	.042	----	-.002	.001	-.004	.000	.038*	.038*
Military Community	.179	.093	----	----	----	-.008	----	.085*	.264*
Employee Characteristics									
Work Motivation	----	-.013	----	.004	-.002	.001	-.000	-.011	-.011
General Training	.030	-026	.020	.001	-.001	.002	-.000	-.004	.026
Skill Advancement	-.127	.002	.008	----	----	-.000	----	.010	-.117*
Met Expectations	.246	.109	.050	.004	-.002	-.010	-.000	.151*	.397*
Environmental Factors									
Family Support	-.071	-.010	.001	----	----	.001	----	-.008	-.079*
Kinship Responsibility	.063	.019	.000	----	----	-.002	----	.018	.081*
Opportunity	-.077	.005	-.086	----	----	-.000	----	-.081*	-.258*
Control Variables									
Owed Service	.082	.006	.009	.000	-.000	-.001	-.000	.015	.097*
Sex	.007	.007	.010	.000	-.000	-.001	-.000	.017	.024
Race	.027	.006	.014	.001	-.000	-.001	-.000	.020*	.047*
Rank	-.101	-.005	.009	.000	-.000	.000	-.000	.004	-.097*
Education	.004	.003	-.006	-.001	.000	-.000	.000	-.003	.001
Positive Affectivity	----	----	----	.009	-.005	----	-.001	.003	.003
Endogenous Variables									
Job Satisfaction	----	.020	-.012	----	----	-.002	----	.006	.006
Air Force Commitment	.228	----	-.020	----	----	----	----	-.020	.208*
Search Behavior	-.185	----	----	----	----	----	----	----	-.185*

[a]All effects are based on standardized coefficients; significance tests are based on unstandardized coefficients.

*p < .05, one-tailed test.

Appendix B

The Relationships between Demographic Variables and Intent to Stay among Military Medical Personnel in a U.S. Air Force Hospital*

by

James L. Price
Sang-wook Kim
Department of Sociology
University of Iowa
Iowa City, Iowa 52242
(319-338-2740)

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Abstract

This paper tested empirically the relationships between eleven demographic variables and intent to stay, used as a proxy for turnover. The research reported in this paper was conducted among military medical personnel at Wilford Hall Medical Center, Lackland Air Force Base, Texas. Data were collected by questionnaire and from records. Ordinary Least Squares regression analysis was used to estimate the effects of the eleven demographic variables upon intent to stay in the U.S. Air Force. The results support three of Price's empirical generalizations regarding the relationships between demographic variables (occupation, education, and age) and turnover; added two new generalizations (rank and gender); and do not support one relationship (length of service). The research had no data to support or not support Price's two generalizations pertaining to blue-collar employees. Suggestions were made for future research.

The Relationships between Demographic Variables and Intent to Stay among Military Medical Personnel in a U.S. Air Force Hospital

The purpose of this paper is to test empirically the relationships between selected demographic variables and intent to stay in a military organization. Eleven demographic variables will be examined: occupation, education, rank, length of service, race, gender, religion, age, place of birth, marital status, and ethnicity. Intent to stay is examined because its relationship with turnover is moderately strong (Pearson correlation coefficient of about .50).[1] Ever since the work of Mobley[2] intent to stay has been recognized as the closest variable to turnover in the causal chain of explanation. Because of this relationship, scholars who wish to study turnover will commonly focus on intent to stay. Greeley's study of priests[3] is one such example.

This paper seeks to make the following type of statement for each demographic variable: "With the other ten demographic variables controlled, women intend to stay in the organization studied more often than men." It is not possible to make statements like this with the current state of knowledge. Price's codification of the turnover literature[4] makes no such statements; the closest he could come is to note that the relationships between length of service and age, on the one hand, and turnover, on the other hand, are supported by a large amount of evidence. Henceforth, the statements which this paper seeks to make will be termed *empirical generalizations*. Merton defines empirical generalizations as "... observed uniformities of relationships between two or more variables."[5]

Empirical generalizations have at least four uses, three for causal model construction and one for practice. First, they serve as crude checks on proposed models. Anyone, for example, who proposes an explanation of turnover must take into account the nine generalizations that Price advances in his codification.[6] The proposed explanation becomes more plausible if it is consistent with these nine generalizations. Second, generalizations help to narrow the search for determinants. A well-established relationship between cigarette smoking and lung cancer, for instance, suggests that there is something about smoking cigarettes that produces lung cancer. The nature of this "something" is not indicated, but the search for determinants is narrowed by focusing on cigarette smoking rather than a large number of other possible determinants. This benefit of generalizations is repeatedly illustrated in epidemiological research.[7] Third, sets of generalizations may suggest specific determinants. Durkheim's famous study of suicide[8] is an illustration. His idea of integration as a determinant of suicide may have been suggested by the extensive set of generalizations that he compiled regarding this type of behavior. The work of Berelson and his colleagues[9] on voting behavior is a contemporary attempt to suggest determinants by compiling generalizations. Fourth, because they are a form of knowledge, generalizations can be useful for managers. The U.S. military, for instance, has data indicating that high school graduates are more often likely to remain in the service than nonhigh school graduates. If this is true, and it is supported by an extensive amount of data, then recruiters can focus on high school graduates to decrease turnover from the military. The recruiters need not know why turnover occurs to implement this strategy. These four uses of empirical generalizations make them valuable. Although they do not explain anything--they are not causal models--they provide a solid factual base on which explanations can be based, and until the explanation is constructed, they can help in the management of organizations.

Methodology

Site. The site of this research is Wilford Hall Medical Center, Lackland Air Force Base, Texas. Wilford Hall has 806 beds, offers treatment in 136 medical specialties-subspecialties, operates two dental clinics, provides advanced medical education for more than half of the Air Force's physicians, and conducts an extensive program of clinical research. Expenditures for fiscal 1988 were slightly over $82,000,000. Wilford Hall is, in short, a major medical center; no claim is made that the center is representative of hospitals in the Air Force.

Sample. The research focuses on military medical personnel in Wilford Hall. As would be expected from a major medical center, most of those in the sample are highly educated professional and technical employees. Physicians, nurses, and dentists constitute the core of this professional and technical staff. Nearly half of the sample are officers, length of service is brief, most of the employees are white, male, Protestants, who are young, born outside the South, married, and are U.S. citizens. Details regarding the sample are contained in Table 1.

Table 1 About Here.

The sample of 1,504 appears to be quite representative of the universe of 3,146. Two universe characteristics are available, rank (whether officer or enlisted) and gender. In the universe of 3,146, there are 46% officers (N=1,451) and 54% enlisted (N=1,695); the gender distribution is 65% male (N=2,058) and 35% female (N=1,088). The corresponding percentages in the sample are as follows: 48% officers (N=725), 52% enlisted (N=782), 65% male (N=990), and 34% female (N=517). A chi-square test indicates no significant differences between the universe and sample in the distribution of rank ($X^2_{(1)}$=2.4, $P > .05$) and gender ($X^2_{(1)}$=.047, $P > .05$). The rank and gender distributions of the universe and sample are thus quite similar.

The military site and sample was selected for two reasons. First, Wilford Hall employs salaried physicians and dentists. When physicians and dentists are studied outside the military they are typically self-employed businesspersons. Since salaried physicians and dentists are becoming more important in the delivery of health care in the United States, Wilford Hall offered the chance to study this type of employee.

Second, the nursing staff at Wilford Hall is composed of male <u>and</u> female nurses all of whom have baccalaureate training. Nursing staffs outside the military are almost totally composed of females and mostly consist of nurses trained in hospitals schools, that is, "diploma" nurses. A substantial number of civilian nurses are also trained in community colleges ("associate" nurses). Since more males are entering nursing and since baccalaureate training is the preferred pattern, Wilford Hall provided the opportunity to focus on this type of employee. In short, Wilford Hall was selected because its military medical employees represent, in important ways, how future health care will be delivered to the American people.

<u>Data Collection</u>. Data were collected by questionnaire and from records. The intent to stay data were collected from questionnaires mailed to all military medical personnel in the summer of 1990. The demographic data were obtained from personnel records at Armstrong Laboratory, Brooks Air Force Base, Texas. Each respondent who returned a questionnaire-answer sheet provided his/her social security number which was used to obtain demographic data maintained on Air Force personnel at Armstrong Laboratory. The senior author was an Air Force Fellow at Armstrong Laboratory during the summer of 1990.

Questionnaires were mailed to all 3,146 military medical personnel at Wilford Hall in the summer of 1990. Two mailings were done, one in July and the other in August. Answer sheets from the questionnaires were returned to Armstrong Laboratory and accepted until the last day of September. A total of 1,521 answer sheets were returned, for a response rate of 48%. This response rate is comparable to prior work on civilian hospitals in which the senior author has been involved.[10] Intensive field work was done in Wilford Hall in June and July by the senior author.

<u>Measurement</u>. Data to measure intent to stay were collected by four questionnaire items: I plan to leave the Air Force as soon as possible (negative), under no circumstances will I voluntarily leave the Air Force (positive), I would be reluctant

to leave the Air Force (positive), and I plan to stay in the Air Force as long as possible (positive). Each of the four items has five possible responses: strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree. The scores run from five to one, with strongly agree scored as five for positive items. For negative items, the scores were reversed. The four items were summed to create an index which has good psychometric properties. A factor analysis using varimax rotation reveals a single factor and the coefficient alpha is .90. The facto analysis provides data regarding the validity of the index, whereas the alpha constitutes an assessment of reliability. Additional data about the psychometric properties of the intent to stay index are contained in the work of Iverson[11] and Krishnaswamy.[12] The mean and standard deviation of the index are 11.97 and 4.44, respectively. Intent to stay, it may be recalled, is used as a proxy for turnover.

The data in Table 1 basically indicates how the eleven demographic variables were measured. The categories in Table 1 are mostly the categories used by Armstrong Laboratory to refer to the demographic variables. More detail about these measures does not seem to be necessary, since a substantial amount of space would be required to present customary measures.

Analysis. Ordinary Least Squares (OLS) regression analysis was used to estimate the effects of each of the eleven demographic variables upon intent to stay. What is especially important is that OLS provides estimates of net effects of a variable with statistical controls for the effects of other variables. The measure of explanatory power (the variance accounted for by the demographic variables) is not of major significance, since the analysis does not estimate a causal model of intent to stay. Causal model terminology--such as stating that one variable has an *impact* on another variable--is used only to take advantage of the statistical controls provided by OLS. Though the analysis looks as if a causal model is being estimated, this is not the case. Given that regression analysis basically requires continuous independent variables, each of the seven nominal-level, demographic variables was introduced into the multiple regression equation by coding as a dummy variable.

To assess the validity of the basic assumptions required for multiple regression, two sets of tests were performed, one for nonlinearity and one for multicollinearity. First, an analysis of variance was conducted to see whether linear relationships existed between each demographic variable and intent to stay. The nonlinearity test turned out to be significant for education, rank, and length of service, but nonsignificant for the rest of the variables. A further examination of mean values for intent to stay for the various levels of these three variables clearly indicated that the nonlinearity pattern was essentially a curvilinear quadratic function--a concave form. The three variables of education, rank, and length of service were transformed by introducing the squared value of each variable into the multiple regression equation.[13] Second, the result of checking multicollinearity among the demographic variables by using the eigenvalue decomposition method showed a strong multicollinearity among the three transformed variables of education, rank, and length of service.[14] This means that the 3 variables are highly interrelated and cannot be used as a predictor variable by themselves. Thus, to resolve the problem of multicollinearity in regression estimation, three different regression equations were separately estimated by dropping any two variables among the three from the original equation.

Results

Before examining the effects of demographic variables on intent to stay, it is necessary to discuss briefly some descriptive statistics for each variable and its zero-order correlations with intent to stay. Table 2 shows the means and standard deviations for the four continuous variables of education, rank, length of service, and age. Means and standard deviations would, of course, be meaningless for the nominal-level variables.

Table 2 About Here.

Pearson correlation coefficients indicating the relationships between demographic variables and intent to stay are contained in Table 3. Consider first the variables which have a linear relationship with intent to stay. The results indicate that intent to stay is associated with occupation, race, and gender: professional/technical staff, whites, and males generally have a significantly weaker intent to stay in the Air Force than managers, nonwhites, and females.

Table 3 About Here.

Education, rank, and length of service, which are significantly associated with intent to stay in Table 3, must be interpreted differently from the other variables due to their nonlinear relationships with intent to stay. As indicated in the previous description of the analysis, these three variables are associated with intent to stay in the manner of a quadratic function. The statistically significant correlations for the three transformed as well as untransformed variables in Table 3 indicate that there are some relationships which require an interpretation. (What is pertinent at this point are correlation coefficients for the untransformed variables rather than those for the transformed ones, given that the latter are introduced only for the purpose of analyzing the problem of nonlinearity in the OLS regression analysis. Note also that information on the average intent to stay for the various levels of the three variables is not provided in Table 3 since it was felt to be redundant.) First, an examination of mean intent to stay for the various levels of education indicates that intent to stay is strongest (13.06) for those military medical personnel who have had one or two years of college; intent to stay, however, is weaker when education is both below and above this level. Second, in evaluating rank, intent to stay is strongest (13.46) for the noncommissioned officers, and becomes weaker for both airmen and commissioned officers. Third, for length of service, intent to stay is strongest (13.91) for those who served in the Air Force for ten to fourteen years, while it is generally weaker for personnel who have fewer than ten years or more than fourteen. In sum, at the zero-order level, strong intent to stay is concentrated among the managers, nonwhites, females, noncommissioned officers, those personnel who have had one or two years of college, and those who have been in the Air Force for ten to fourteen years.

These zero-order correlations need to be examined with statistical controls for the influences of the other demographic variables. The regression results which follow make use of such controls and present the net effects of these variables for the entire sample. As mentioned above, due to the multicollinearity among education, rank, and length of service, three different regression estimations are presented with each dropping two of the three variables from the original equation. Table 3 also contains the results of regressing intent to stay on each demographic variable. (The focus here is on the unstandardized, rather than standardized, regression coefficients. Interpreting the relative importance among the variables in terms of standardized coefficients is meaningless since they are coded as dummy variables.)

<u>Regression Results for the Demographic Variables Excluding Education and Rank</u>. When education and rank are dropped from the analysis, out of the nine remaining demographic variables, four--occupation, length of service, gender, and age--have significant effects on intent to stay. First, for occupation, while there is no difference in intent to stay between technicians and managers, there exists a significant difference between professionals and managers. In short, controlling for the effects of the other demographic variables, the professionals intend to stay in

the Air Force less often than the managers. This tendency was also evident without controls.

Second, in order to interpret the relationship between length of service--the nonlinear variable--and intent to stay, predicted values of intent to stay which control for the effects of the rest of the variables were estimated and graphically presented in Figure 1.[15] An examination of average intent to stay for the various levels of length of service clearly indicates that intent to stay is strongest (12.71) for those who served for eleven years in the Air Force, decreasing continuously for those who served below and above this period. To compare the latter two groups, intent to stay decreases faster for those who served longer than for those who served for a shorter period. This tendency, too, remained generally the same without controls for such variables.

Figure 1 About Here.

Third, the role of male has a negative effect on intent to stay, which indicates that, controlling for the influences of the other variables, men intend to stay in the Air Force less often than women. This tendency was the same without controls.

Finally, age has a positive effect on intent to stay. In other words, when the effects of other variables are held constant, the older personnel intend to stay in the Air Force more often than the younger personnel. Before controls, on the other hand, age had virtually no influence on intent to stay.

In sum, when predicting the intent to stay in terms of nine demographic variables, exclusive of education and rank, it may be said that managers, those who served for eleven years, women, and older personnel reveal a stronger intent to stay in the Air Force than professionals, those who served for fewer or more than eleven years, men, and younger personnel.

Regression Results for the Demographic Variables Excluding Education and Length of Service. When education and length of service are dropped from the analysis, four variables--occupation, rank, gender, and age--have significant effects on intent to stay. These findings are exactly the same as those when education and rank were excluded from the analysis, except for the case of rank. Again, in order to interpret the relationship between rank and intent to stay, the predicted values of int nt to stay, controlling for the effects of the rest of the variables, are estimated and graphically presented in Figure 2.[16] An examination of average intent to stay for the various levels of rank clearly indicates that intent to stay is highest for the officers below colonel (12.39), and decreases for airmen, noncommissioned officers, and colonels. To compare the strength of intent to stay among the latter three groups, airmen (11.44) intend to stay in the Air Force less often than noncommissioned officers (12.20) and colonels (12.01). These findings are slightly different from the ones without controls: whereas the strongest intent to stay is found among the noncommissioned officers before controls, it is found among the officers below colonel after controls.

Figure 2 About Here.

In short, when education and length of service are excluded to predict intent to stay, strong intent to stay is observed among managers, officers below colonel, women, and the older personnel.

Regression Results for the Demographic Variables Excluding Rank and Length of Service. When rank and length of service are dropped from the analysis, education, gender, and age have significant effects on intent to stay, whereas occupation is not significant. An examination of the predicted values of intent to stay for the levels of education (Figure 3), controlling for the effects of the rest of the variables,[17] indicates that intent to stay decreases continuously with higher levels of education, although high school graduates have slightly weaker intent to stay (13.06) than those who have had one year of college education (13.30). In particular, those who have finished graduate school (M.A. or Ph.D) reveal the weakest tendency to stay in the Air Force (M.A.=11.19; Ph.D.=9.89). This tendency was also generally true without controls. It may be generally said, therefore, that the higher the educational attainment, the le·s the intent to stay in the Air Force.

Figure 3 About Here.

In short, when rank and length of service are excluded, a strong intent to stay in the Air Force is concentrated among those who have not finished college, women, and older personnel.

Without controls, the variables which had significant effects (at .01 level) on intent to stay were occupation, education, rank, length of service, race, and gender. When controls were introduced, occupation, education, rank, length of service, and gender continued to be significant, but race was no longer significant. The effect of race on intent to stay, in brief, was removed by the effects of the other controlled variables. What is particularly surprising is that while age had significant and positive effects on intent to stay when the influences of the other variables were removed, it had virtually no effects at the zero-order level.

To summarize, data analysis suggests the following conclusions:

1. When the effects of the other demographic variables are held constant, professionals intend to stay in the Air Force less often than managers.[18]
2. In general, the higher the educational attainment, the less the intent to stay in the Air Force.
3. Officers below colonel intend to stay in the Air Force more often than airmen, noncommissioned officers, and colonels.

4. Intent to stay increases slowly to a certain point until the length of service becomes eleven years, but it tends to decrease faster after that point.
5. Men intend to stay in the Air Force less often than women.
6. Older personnel intend to stay in the Air Force more often than younger personnel.

Discussion

The results of this study will be discussed in the context of Price's codification of empirical generalizations. Two comments about his codification are pertinent. First, he has published the only review of *empirical generalizations* in the literature. There are many summaries of *theoretical propositions* regarding turnover, but he is the only scholar who has drawn together "observed uniformities of relationships"--to refer to Merton's previously cited definition of empirical generalizations--between demographic variables and turnover. Second, his codification examines literature regarding military turnover. However, the literature about military turnover was not extensive when he did his review in the mid 1970s so he cites only a few studies of military turnover.

Price has three empirical generalizations regarding occupation in his codification of the turnover literature: unskilled blue-collar, blue-collar, and nonmanagerial employees usually have higher rates of turnover than skilled blue-collar, white-collar, and managerial employees.[19] The first two generalizations have a medium amount of support in the literature, whereas the third has a small amount of support. Finding that professionals have weaker intent to stay in the Air Force than managers is relevant to the third generalization, since professionals are one type of nonmanagerial employee. Since the results from this study used extensive controls, this considerably strengthens the generalization. Price is dealing, of course, with turnover rather than intent to stay. To evaluate the first two generalizations requires a sample with blue-collar employees, and this Wilford Hall sample has no such employees.

The codification has only one generalization regarding education, namely, that better educated employees usually have higher rates of turnover than less well educated employees.[20] Finding that the higher the educational attainment, the weaker the intent to stay in the Air Force supports this generalization. Since the finding from this research uses extensive controls, this considerably strengthens the generalization which is only based on a small amount of data. As just indicated, he is examining turnover and not intent to stay.

The codification has no generalizations pertaining to rank, so finding that officers below colonel have stronger intent to stay in the Air Force than airmen, noncommissioned officers, and colonels adds a new generalization to the literature. The use of extensive controls means that the new generalization is well supported.

Length of service is one of Price's best supported generalizations; he notes that employees with low lengths of service usually have higher rates of turnover than employees with high lengths of service.[21] The findings of this research do not fit this negative relationship, since intent to stay increases until eleven years, which is what one would expect, but then begins to decrease, which is not what one would expect. In this study, the long-service employees generally intend to stay less often than the short-service employees! This finding, however, may be the result of the Air Force's unusual career structure. Employees enter the Air Force with the expectation of retiring considerably before comparable civilian employees retire. Thus, long-service employees may generally intend to stay less often than short-service employees, because the careers of the long-service employees are drawing to a close. The Navy and the Army also have career structures like that of the Air Force and it would be useful to see if this finding can be replicated in the other two services.

The codification included no generalization about gender because the data examined were inconsistent.[22] Finding that men intend to stay in the Air Force less often than women thus adds a second generalization to the literature. And with the extensive controls used in the analysis, the generalization is solidly supported.

Age is another one of well supported generalizations: younger employees usually have higher rates of turnover than older employees.[23] Finding that the older personnel have stronger intent to stay in the Air Force than young.r personnel confirms this generalization. Unlike the findings for length of service, those for age are consistent with the long tradition of research on turnover.

In summary, three of Price's generalizations--those pertaining to occupation, education, and age--are supported by the findings of this research. The generalization regarding length of service is not supported, but this may be the result of the Air Force's unusual career structure. Two new generalizations are added, namely, those for rank and gender. The findings about gender are especially interesting and should be explored further, since there is much contemporary concern about equal opportunity for women in the work place. Since this research contains no blue-collar employees, the two generalizations pertaining to occupation could be neither supported nor not supported.

This research found no support for the relationship between intent to stay and five demographic variables: race, religion, place of birth, marital status, and ethnicity. Nor does Price's codification refer to any of these variables. Race might have been significant with three categories: White, African-American, and Asian. However, this could not be attempted because the official records contained only two distinct racial cat..gories, White and Non-White. Religion might have been significant with more respondents who were Jewish (N=17) and Orthodox (N=6). This would have made four religious categories rather than two. Place of birth was included in the analysis because there are data which indicate that Southerners more often make a career of the military than non-Southerners.[24] In this research, those born in foreign countries (N=149) were classified as non-South. It is possible that some of the individuals born in a foreign country were the children of Southerners and this might have made a difference could such a classification have been made. The results for marital status are puzzling. Price and Mueller[25] have found that marital status, when used as a measure of kinship responsibility, contributes to reduced turnover. One might, therefore, have expected that marital status would be positively related to intent to stay. Conversely, it might even be argued that married life in the Air Force is difficult, and that it might, therefore, be negatively related to intent to stay. A negative relationship would at least be a relationship, so it is puzzling that no relationship was found. Ethnicity might have been significant had it been possible to have four or five categories rather than the two used in the analysis. To settle these questions, further research will have to be conducted regarding race, religion, place of birth, marital status, and ethnicity.

Summary and Conclusion

This research tested empirically the relationships between eleven demographic variables and intent to stay among military medical personnel in a U.S. Air Force hospital. Intent to stay was used as a proxy for turnover. Multiple regression analysis indicated that intent to stay was weakest for professionals, the better educated, airmen-noncommissioned officers-colonels, those with low and high lengths of service, men, and the younger personnel. With controls for the other variables, race, religion, place of birth, marital status, and ethnicity were not significantly related to intent to stay.

These results supported three of Price's empirical generalizations regarding the relationships between demographic variables (cccupation, education, and age) and turnover; added two new generalizations (rank and gender); and did not support one relationship (length of service). The study had no results relevant to the two generalizations pertaining to blue-collar employees, because the sample contained only white-collar employees.

Six suggestions are made for future research. (1) Although intent to stay is commonly used as a proxy for turnover, the results of this research must remain tentative until the demographic variables are related to turnover, as in Price's codification. (2) A the discussion section indicated, future research should obtain more precise measures for race, religion, place of birth, and ethnicity. These variables might be significant with more precise measurement. (3) Additional demographic variables should be examined: political identification, size of community in which the respondent mostly lived until he/she was seventeen, shift work (day, night, evening), and source of referral to the organization (personal or impersonal). The literature on turnover discusses all of these variables but political identification. (4) This paper uses demographic variables to refer to individuals. Price's codification, however, also uses these variables to refer to social systems; he has three such generalizations. He first notes, for example, that periods with high levels of employment usually have higher rates of turnover than periods with low levels of employment.[26] Secondly, he states that the United States has higher rates of turnover than other industrialized countries.[27] Finally, he states--the third generalization--that nongovernment organizations usually have higher rates of turnover than government organizations.[28] Levels of employment--the first social system generalization--implicitly uses communities and societies as the units of analysis, whereas the second and third generalizations explicitly use societies and organizations as units. Further research should seek to obtain demographic variables which use social systems rather than individuals as the unit of analysis. Comparative data for the military medical systems of different countries would be an illustration of such data. (5) A larger sample should be examined. Wilford Hall is an atypical hospital in the Air Force and a more representative sample of military medical personnel should be studied. In the long run, it would be desirable to explore the relationships between demographic variables and turnover in the three military services among all military personnel, not just the medical. (6) Finally, the findings need to be explained. Explanation is a major topic and anything that could be offered at the end of this paper would be superficial. Elsewhere the senior author has developed an explanation of turnover.[29] The explanation developed by the senior author is basically supported by a review of the literature on *military* turnover by Holman,[30] who is a student of Price.

Attached Note

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4. James L. Price, *The Study of Turnover* (Ames, IA.: Iowa State University Press, 1977), 24-43.

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12. Sujatha Krishnaswamy, "A Causal Model of Employee Absenteeism: An Empirical Test" (Ph.D. diss., University of Iowa, 1992).

13. See Alan Agresti and Barbara F. Agresti, *Statistical Methods for the Social Sciences* (San Francisco, Calif.: Dellen, 1979), 365-371.

14. See Richard F. Gunst, "Regression Analysis with Multicollinear Predictor Variables: Definition, Detection, and Effects," *Communications in Statistics--Theory and Methods* 12(1983): 2217-2260.

15. The predicted values of intent to stay for various levels of length of service were estimated by taking the mean values for each of the other ten demographic variables from the following equation: Intent = 10.665 + .361*(L of S) - .016*(L of S)^2.

16. As was the case with the length of service, the predicted values of intent to stay for various levels of rank were estimated from the following equation: Intent = 10.107 + 1.619*(Rank) - .286*(Rank)^2.

17. The predicted values of intent to stay for various levels of education were estimated from the following equation: Intent = -14.088 + 4.122*(Ed) - .155*(Ed)^2.

18. This finding, however, does not hold for the analysis which drops rank and length of service.

19. James L. Price, *The Study of Turnover*, 31-34 and 37-38.

20. James L. Price, *The Study of Turnover*, 35-37.

21. James L. Price, *The Study of Turnover*, 26-28.

22. James L. Price, *The Study of Turnover*, 39-41.

23. James L. Price, *The Study of Turnover*, 28-29.

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25. James L. Price and Charles W. Mueller, *Absenteeism and Turnover of Hospital Employees*, 15-16.

26. James L. Price, *The Study of Turnover*, 29-31.

27. James L. Price, *The Study of Turnover*, 34-35.

28. James L. Price, *The Study of Turnover*, 38-39.

29. Price and Mueller, *Professional Turnover*.
-----------------, *Absenteeism and Turnover of Hospital Employees*.

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Table 1. Data for the Demographic Variables

Demographic Variables	Frequency[a]	Percent
Occupation		
Professional	687	45.7
Technician	549	36.5
Manager	268	17.8
	1,504	100.0
Education		
High School Graduate	169	11.2
One Year College	192	12.8
One-Two Years College	281	18.7
Two-Four Years College	101	6.7
College Graduate	251	16.7
Masters Degree	139	9.2
Post-Masters Degree	371	24.7
	1,504	99.9
Rank		
Airmen	442	29.4
Noncommissioned Officers	337	22.4
Officers Below Colonel	376	25.0
Colonels	349	23.2
	1,504	100.0
Length of Service		
Less than Five Years	628	41.8
Five to Nine Years	409	27.2
Ten to Fourteen Years	228	15.2
Fifteen Years and Longer	239	15.9
	1,504	100.1
Race		
White	1259	83.7
Non-White	245	16.3
	1,504	100.0
Gender		
Male	988	65.7
Female	516	34.3
	1,504	100.0
Religion		
Protestant	836	57.5
Catholic	475	32.6
No Religion	144	9.9
	1,455[b]	100.0
Age		
Less than 25 Years	286	19.0
25-29 Years	394	26.2
30-34 Years	324	21.5
35-39 Years	291	19.3
40 Years and Older	209	13.9
	1,504	99.9

Place of Birth		
South	409[c]	27.2
Non-South	1095[d]	72.8
	1,504	100.0
Marital Status		
Married	1019	67.8
Nonmarried	485	32.2
	1,504	100.0
Ethnicity		
American	1293	86.0
Non-American	211	14.0
	1,504	100.0

a The frequencies do not add to 1,507 because 3 cases are missing from constructing the index of intent to stay.

b The frequencies do not add to 1,504 because there are 49 missing cases. These 49 respondents were not Christians and were treated as missing data due to their small number.

c South refers to the states in the Confederacy.

d Respondents born in foreign countries are categorized as non-South.

Table 2. Means and Standard Deviations for Continuous Demographic Variables

Demographic Variables	Mean	Standard Deviation
Education	15.31	2.09
(Education)[a]	238.84	63.74
Rank	2.42	1.14
(Rank)[a]	7.15	5.69
Length of Service	8.54	6.18
(Length of Service)[a]	111.12	146.62
Age	31.24	7.35
N = 1,504		

a Transformed scores.

Table 3. Zero-Order Correlations and Multiple Regression Results for the Demographic Variables

Demographic Variables	Zero-Order Correlations	Regression Coefficients[a] Education & Rank Excluded	Education & Length of Service Excluded	Rank & Length of Service Excluded
Occupation[b]	.1693**			
Professional		-2.3238**	-2.5564**	- .2540
Technician		- .2461	- .1577	- .2827
Manager		-----	-----	-----
Education	-.2058**	-----	-----	4.1215**
(Education)[c]	-.2137**	-----	-----	- .1551**
Rank	-.1243**	-----	1.6186*	-----
(Rank)[c]	-.1343**	-----	- .2858*	-----
Length of Service	.0714**	.3613**	-----	-----
(Length of Service)[c]	.0272**	- .0159**	-----	-----
Race[b]	.0663**			
White		- .1603	- .2886	- .1389
Non-White		-----	-----	-----
Gender[b]	.1127**			
Male		-1.2660**	-1.2559**	- .8085**
Female		-----	-----	-----
Religion[b]	.0236			
Protestant		.0714	.0011	- .0792
Catholic		.2302	.1752	.0908
No Religion		-----	-----	-----
Age	-.0048	.0713*	.0504*	.0910**
Place of Birth[b]	-.0259			
South		.1148	.0234	.0061
Non-South		-----	-----	-----
Marital Status[b]	.0214			
Married		.0019	.2300	.3003
Nonmarried		-----	-----	-----
Ethnicity[b]	.0270			
American		.0312	.0870	.0535
Non-American		-----	-----	-----
Constants		10.3792	10.5287	-16.2996
R^2		.0837	.0657	.0871
Adjusted R^2		.0763	.0581	.0798
N = 1,504[d]				

* Significant at .05 level.

** Significant at .01 level.

a Unstandardized.

b Coded as dummy variables. The blank categories for each dummy variable were coded as zero.

c Transformed scores.

d N = 1455 for religion.

Figure 1. Predicted Value of Intent to Stay for Various Levels of Length of Service, Controlling for the Effects of Other Demographic Variables

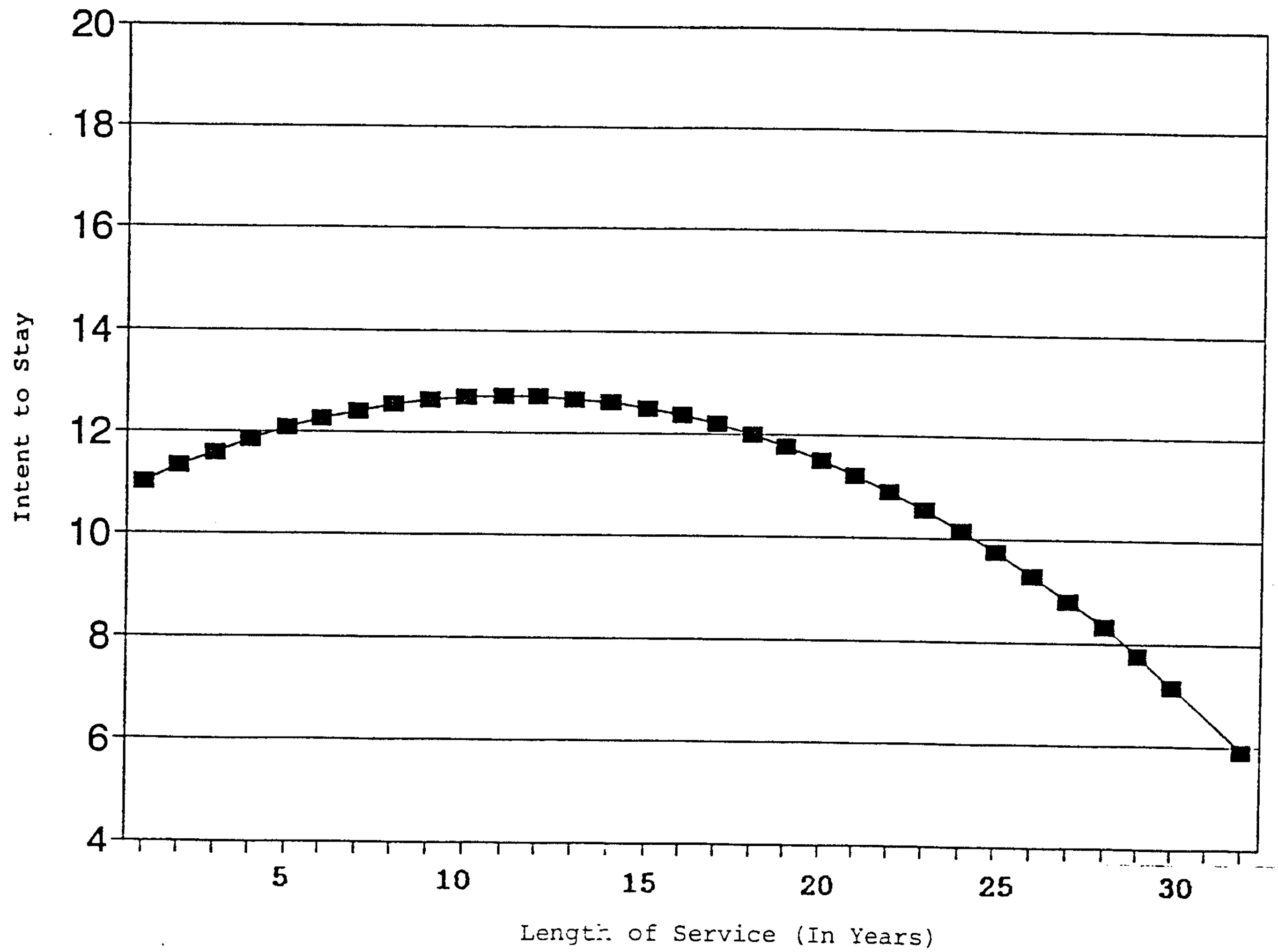
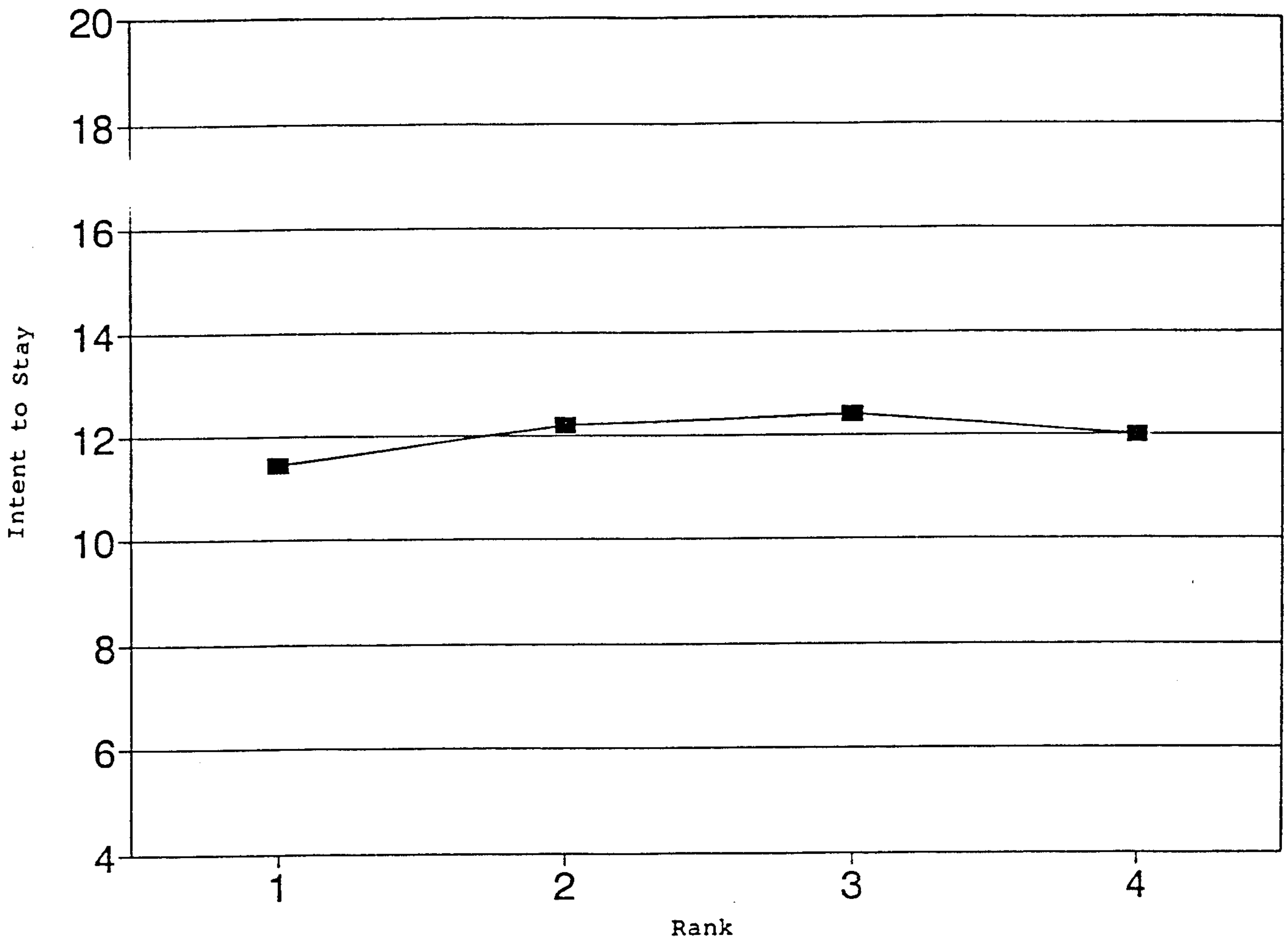
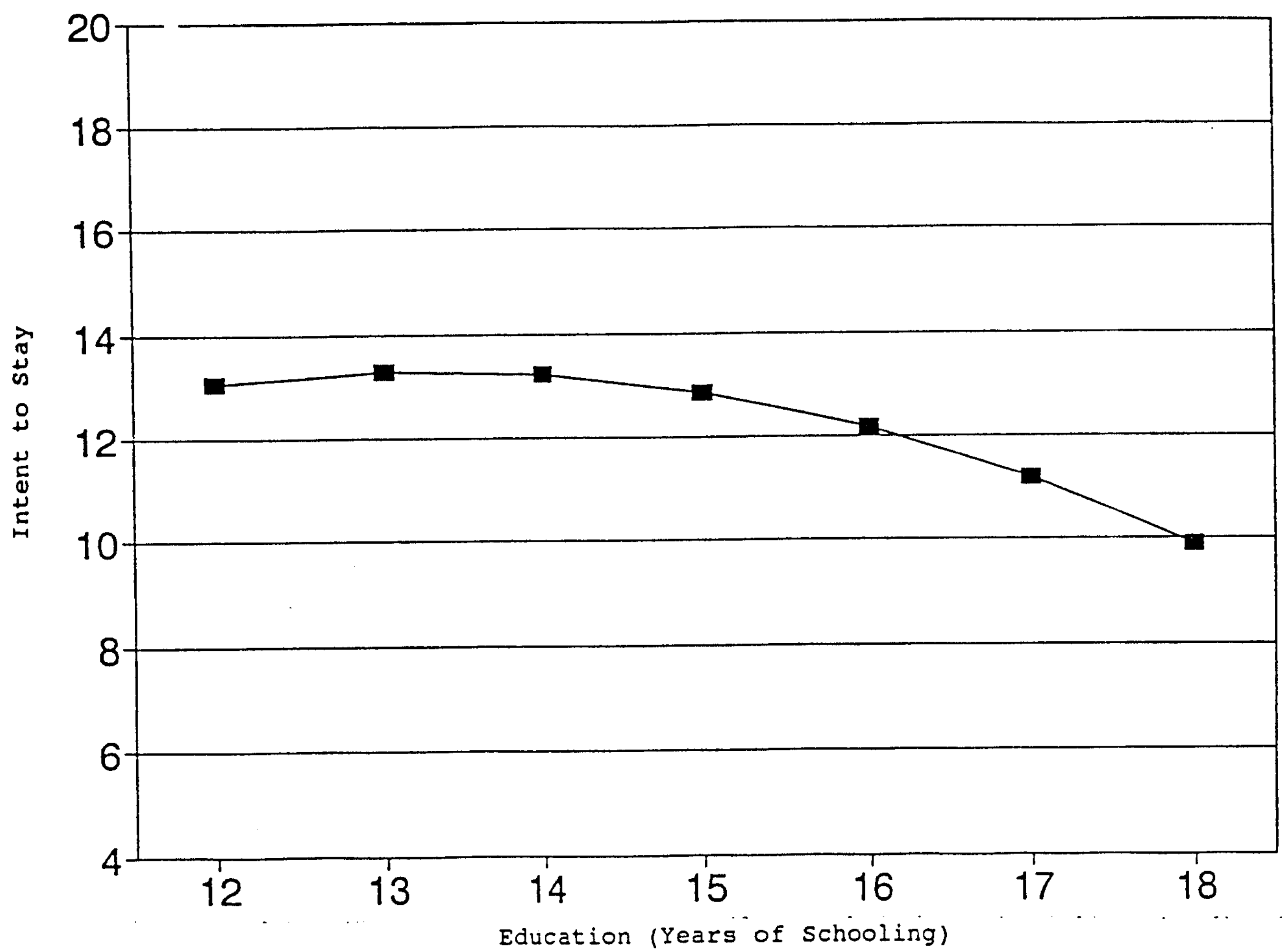


Figure 2. Predicted Value of Intent to Stay for Various Levels of Rank, Controlling for the Effects of Other Demographic Variables



1 Airmen.
2 Noncommissioned Officers.
3 Officers Below Colonel.
4 Colonels.

Figure 3. Predicted Value of Intent to Stay for Various Levels of Education, Controlling for the Effects of Other Demographic Variables



12 High School Graduate.
13 One Year College.
14 One-Two Years College.
15 Two-Four Years College.
16 College Graduate.
17 Masters Degree.
18 Post-Masters Degree.

COORDINATION OF POSTURAL CONTROL AND VEHICULAR CONTROL: IMPLICATIONS FOR MULTIMODAL PERCEPTION OF SELF MOTION

Gary E. Riccio
Assistant Professor
Department of Kinesiology
Bioengineering Program
Beckman Institute for Advanced Science and Technology

University of Illinois at Urbana-Champaign
405 North Matthews Avenue
Urbana, Il 61801

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Gary E. Riccio
Assistant Professor
Beckman Institute for Advanced Science and Technology
University of Illinois at Urbana-Champaign

Abstract

The purpose of this research is to reveal the aspects of perception and action that are essential for simulating <u>self</u> motion in a virtual environment. It is assumed that a goal of the associated technology is to provide for compelling experiences of presence in virtual environments. The potential manifestations and applications of this emerging technology are sufficiently diverse that general treatments are difficult. Consequently, the present work focuses on flight simulation. While the analysis is couched in the particulars of flight simulation, it is emphasized that the design principles and strategies are not limited to flight simulation. To promote generality, self motion in real and virtual environments are analyzed from the perspectives of ecological psychology and control theory. The centrality of these complementary perspectives is due to the fact that they have generated a significant body of theoretical and empirical research in which the interaction between a human and an environment and the linkage between perception and action are fundamental. These perspectives emphasize that theories and experiments on the perception of self motion must consider the multiplicity of perceptual systems that are sensitive to forces and motions. For example, the extent to which a visually displayed event can be perceived as self motion is determined by the sensitivity of the nonvisual perceptual systems to the presence or absence of variations in constraints on postural control. The introduction of novel dependent and independent variables in an otherwise familiar flight-simulation paradigm is recommended in order to reveal the role of postural control in the multimodal perception of self motion. Exploratory observations in such a paradigm and the attendant analysis of human-vehicle interactions lead to recommendations about alternative cuing modules for flight simulation and other virtual envrionments.

COORDINATION OF POSTURAL CONTROL AND VEHICULAR CONTROL: IMPLICATIONS FOR MULTIMODAL PERCEPTION OF SELF MOTION

Gary E. Riccio

Exploratory Observations and Conceptual Analysis

Systems that include a human in the loop are common in vehicle simulation, telerobotics, teleoperation, and various applications of "virtual reality." The perception and control of self motion is often an important consideration in the design, development, and use of such systems. An extensive program of collaborative research on the simulation of self motion has been conducted in the Armstrong Laboratory over the past decade. The substantial and diverse body of experimental data from this program of research provided the basis for a conceptual reformulation of the problem of simulating self motion in flight simulators and other virtual environments. The reformulation motivated exploratory observations of a new range of phenomena involving postural control in virtual environments during the simulation of self motion. The result of this review of prior experiments, conceptual reformulation, and exploratory observation is a monograph that presents a comprehesive overview of self motion in real and virtual environments (Riccio, in press-a). Ongoing work includes the incorporation of special devices into a flight simulation laboratory that provide for the measurement of postural control during the simulation of self motion and after exposure to such altered environments.

The monograph on self motion (Riccio, in press-a) is organized into four major sections. The first section reviews general themes from ecological psychology and control theory that are relevant to the perception and control of self motion. Since the correspondence between ecological psychology and control theory is somewhat controversial, care is taken in this section to emphasize the deep conceptual connections between these two approaches to perception and action. The second section applies the general concepts to the problem of perception and control of aircraft motion. This is a familiar problem in control theory and ecological psychology; however, ecological research on self motion in general has been limited by an unnecessary preoccupation with visual perception. Consequently, the necessity of multimodal perception is emphasized in this section. The third section examines an essential but generally neglected aspect of vehicular control: coordination of postural control and vehicular control. To facilitate presentation of this new idea, postural control and its coordination with vehicular control are analyzed in terms of conceptual categories that are familiar in the analysis of vehicular control. Thus, the third section is an elaboration of section two. The fourth section reveals the implications of sections two and three for the simulation of self motion. To facilitate comparison, there is a correspondence between section four and the preceding two sections with respect to the topics and their order of presentation in each section. The juxtaposition of these sections makes explicit the conceptual foundations for any simulation of self motion.

Preliminary Conclusions

Implications for Perception Science

Multimodal perception. The issues raised in this research have some important implications for the study of perception. One implication is that it is dangerous to overemphasize isolated perceptual systems and sensory organs. The study of isolated perceptual systems is necessary but not sufficient to understand the perception and control of human-environment interactions. Moreover, the study of isolated perceptual systems can be misleading if the functional context for these systems is neglected. Perceptual systems must be studied in the context of the meaningful environment (J. Gibson, 1979). Information required for the achievement of goals must be considered at the outset, and this information may or may not be available to individual perceptual systems. The putative dominance of visual perception does not follow from any of the first principles -- direct perception, the perception of affordances, the temporally unbounded and developmentally nested process of perception, the obtaining of stimulation by active perceivers, attunement to invariant structure in stimulation, the nesting of perception and action systems, and the nested structure of the meaningful environment -- upon which this research is based (E. Gibson, 1991; J. Gibson, 1966, 1979; Reed & Jones, 1982). The necessity of vision for the control of locomotion in most situations does not imply that vision is sufficient for the robust and adaptive control of the nested dynamical systems involved in locomotion. The issues presented in this research emphasizes that vision is rarely sufficient for the control of locomotion. Visual perception of self motion must be considered in the context of multimodal perception because information for the affordances of self motion is generally available only in multimodal stimulation.

Information in stimulation. Another implication for perception is that the perception and control of interactions with the environment unfold over time scales that are long relative to the time scales defined by the attendant structure in stimulation. One can perceive and control variations in posture, orientation, and self motion up to rates of several cycles per second, but the sensory organs associated with proprioception and kinesthesis can attune to variations as high as several hundred cycles per second (see e.g., Young, 1984). This bandwidth of sensitivity could be useful if the high-frequency activity is modulated or structured by controllable and task-relevant variations at lower frequencies (Riccio, in press-b). There is information in low-frequency variation of high-frequency stimulation, and the phenomenology of perception presumably corresponds to the pick up of this low-frequency information. This suggests some epistemologically important analogies between nonvisual systems, such as the vestibular system, and the visual system. High-frequency motion may be to the vestibular system what light is to the eye. They are each a medium of stimulation that is structured by the environment at the scale of human interactions with the environment. There is information in the stimulation of a variety of perceptual systems about the human-environment interaction. Such an approach to nonvisual perception, which is commensurate with the ecological approach to visual perception, facilitates the analysis of multimodal perception. The various perceptual systems are unified by considering the information in multimodal stimulation about the meaningful environment (cf., J. Gibson, 1966; Ryan, 1938, 1940). The study of perception should begin with, and be grounded in, the environment to be perceived. Perceivables for the kinesthetic and proprioceptive systems include aspects of the dynamical layout that have affordances for the nested perception and action systems. These qualitative dynamical properties of the human-environment interaction are critical regions in the relation between moveability of the body and the orientation and motion of the body (Riccio, in press-b). The direction of balance is such a perceivable (Riccio et al., 1992). Many other potential perceivables emerge from the dynamical interaction among the nested components of the human body. This meaningful landscape is largely unexplored in perception science. Progress in understanding proprioception and kinesthesis is fundamentally dependent on the identification of these perceivables and the ability to simulate and experimentally manipulate them.

Implications for Movement Science

Nested systems. The theoretical perspective presented in this paper also has implications for the study of human movement. A central theme in this paper is the nesting of control systems. A superordinate system is formed when an action system is coupled with its surroundings, and this superordinate system may be capable of achieving goals that cannot be achieved with any of the component subsystems. These superordinate goals do not necessarily replace the goals or functions of the subsystems. The goals and coupled subsystems become nested in the sense that the goal-directed behavior of the superordinate systems constrains the way the goals of component subsystem can be achieved, and vice versa. While the goal-directed behavior of a system imposes such task-specific constraints on the behavior of component subsystems, the associated coupling affords opportunities that may not be possible without the coupling. Intentional systems presumably perceive and act upon these affordances by adaptively coupling with their surroundings in ways that are consistent with the attendant constraints. The surroundings of a human action system can be the surfaces, media, and objects in the natural environment; human artifacts in the modified environment; or other systems and components of the human body. This paper focuses on the coupling of the postural control system with various types of real and simulated vehicles. The coupling between the postural control system and the eye-head system is also discussed, albeit briefly. Similar functional interactions among components of the human body are discussed more extensively elsewhere (Riccio, in press-b). Such couplings reveal that the various components of the human body are generally controlled and coordinated with respect to multiple criteria. Research on the multi-criterion control of posture and self motion is important because it emphasizes that different modalities or patterns of stimulation do not necessarily provide information about the same system states. They generally provide information about the multiplicity of states that are relevant to nested goals (e.g., maintenance of balance and visibility of the surroundings). Consideration of multi-criterion control in human movement reduces the potential for an erroneous assumption that multiple sources of information are either redundant or conflicting (Riccio & Stoffregen, 1988, 1991; Stoffregen & Riccio, 1988, 1991).

Dual control. Informative dynamical components are presented as a source of coupling in nested systems. Balancing the head or other body segments in the cockpit, for example, can provide information about the inertial environment that is relevant to vehicular control. Postural control in the cockpit and control of the vehicle can become coupled if the informativeness of postural control depends on the way the body segments are balanced or moved. One may tolerate the consequences of a moderate amount of imbalance in the head, for example, to enhance sensitivity to the inertial environment (cf. Riccio et al., 1992). That is, the exigencies of vehicular control could induce exploratory postural adjustments that otherwise would be avoided. This may be a general organizing principle in human movement. A moderate amount of instability may be tolerated in component subsystems so that information in the obtained stimulation can enhance stability in the superordinate system. A moderate amount of instability in one aspect of an activity may enhance the stability of the activity as a whole (cf., Beek et al., in press). Informative dynamical components reveal the importance of considering exploratory behavior in models of concurrent performatory behavior. This dual-control problem, and the related problem of multi-criterion control, present significant challenges to extant models of human movement. However, understanding these aspects of control in nested systems may be necessary to understand the adaptability that is an essential property of human movement (Riccio, in press-b).

Implications for Modeling the Perception and Control of Self Motion

Rigid-body assumption. A great deal has been learned about the characteristics of human controllers by applying formal models from control-systems engineering to data from experiments on closed-loop manual control (see e.g., McRuer, 1980). In general, these analytical approaches focus on tasks for which the degrees of freedom in control behavior are relatively small and the performance criteria are relatively simple. The precision of the associated mathematical models is impressive as is their accuracy within this limited domain. The disadvantage of such models is that there is a tendency to loose sight of the characteristics of human controllers that are beyond the scope of the models. In the study of vehicular control, for example, the success of analytical models has fostered the assumption that the human operator is rigid and rigidly attached to the vehicle. There is nothing wrong with this assumption when it is explicitly stated. It is problematic, however, when the models that are built on such assumptions are applied to situations where the assumptions are not valid. This paper reveals that the rigid-body assumption is not valid for the control of self motion, in general, and specifically for vehicular control. In some situations, analytical models based on a rigid-body assumption could accurately describe vehicular control. The rigid-body assumption would be either be valid, irrelevant, or unnecessary in such situations. It is valid, for example, when variation in the velocity vector of self motion is minimal; and it is irrelevant to aspects of vehicular control that are robust to disturbances of perception and action in the cockpit. The rigidity assumption is relevant to vehicular control, but unnecessary for an isolated description, if posture can be stabilized and coordinated with vehicular control. In situations where the pilot is nonrigid, for example, coordination of postural control and vehicular control could lead to vehicular control behavior comparable to that obtained when the pilot is rigid. The assumption is relevant in such situations because the way the pilot copes with nonrigidity is part of the flight control skill. Vehicular control behavior might appear to be quantitatively similar, but the skills that underlie the vehicular control behavior could be qualitatively different. Conversely, vehicular control behavior could be quantitatively different (e.g., because of fatigue or motivation) while the skill of coordinated postural and vehicular control could be qualitatively similar. It follows that transfer of training between vehicles cannot be predicted on the basis of the quantitative similarity in vehicular control behavior (Flach et al., 1986; E. A. Martin et al., 1986).

Qualitative dynamics. Nested control systems and multi-criterion control should be central in formal models for the perception and control of self motion. The mathematical basis for such models is likely to be quite different from the models that are commonly adapted from classical or modern control theory. Promising directions for modeling self motion are suggested by models developed for other human-environment interactions (e.g., Beek, 1989; Beek et al, in press; Shaw et al., 1992). Such models reflect both the exploratory and performatory aspect of human movement. They are necessarily nonlinear, and they are generally heterogeneous with respect to both components (subsystems) and performance criteria (cf. Beek & Bingham, 1991). It is best to begin the analysis of these systems by emphasizing the critical regions in the controllability and observability of system states, that is, the qualitative characteristics of the system dynamics that emerge through the nonlinear interactions among the components. These characteristics include the classical optimal control regions for systems with invariant dynamics, but they also include regions where control breaks down, and regions that maximize observability of a system's dynamics (Riccio, in press-b; Riccio & Stoffregen, 1988, 1991). The latter are important when the dynamics or the performance criteria of a system vary and exploratory action is necessary. Exploration of the state space or the performance envelope of a system is robust if the stability limits of the system are not exceeded. Exploration promotes adaptation of control behavior and improvement in performance. It is virtually impossible to differentiate between exploratory behavior and adaptive modifications in performatory behavior without some understanding of the underlying dynamics. The functional dynamical layout is likely to be quite complex for the nested systems considered in this research and, perhaps, for human-environment interactions in general. Models for self motion must shift their focus from the quantitative details of control behavior to the qualitative characteristics that bound this behavior. Accuracy and breadth of analysis must not be sacrificed for precision and depth of analysis.

Implications for Flight Simulation and Virtual Environments

Felt presence. Perception science, movement science, and mathematical modeling all have contributed to developments in flight simulation. Technological developments have been limited, however, by the dominant scientific assumptions and paradigms. Ecological psychology provides an alternative approach to the phenomenon of self motion and to any technology that attempts to simulate movement of an observer-actor in a virtual environment. Ecologically essential issues for such technology are presented in this paper, and special emphasis is given to those issues that have been previously neglected. In particular, the broad analysis of self motion emphasizes the nonrigidity of a pilot (or human operator in any vehicle) and the multicriterion task structure that is necessitated by the fact of nonrigidity. From this perspective, the task of vehicular control cannot be considered alone or independently of the task of postural control in the vehicle. The nesting of tasks, and the associated nesting of control systems, is partially due to the mechanical coupling between vehicular control and postural control. Vehicular control normally influences the dynamics of balance in the cockpit, and the absence of such influences in a simulator seriously limits felt presence in the virtual environment. The absence of mechanical coupling between vehicular control and postural control is information that the human operator is not present in the simulated environment. This information is fundamentally multimodal because information is available to the visual system about variation in the vehicular velocity vector and information is available to the nonvisual systems about the presence or absence of variation in the dynamics of balance in the cockpit. Information about the dynamics of balance is always available in subtle patterns of nonvisual stimulation obtained through ubiquitous postural control activity. The absence of covariation (i.e., coupling) between vehicular velocity and the dynamics of balance, for example, is revealed in multimodal patterns of stimulation even in a simulator that contains only a visual display. Technological improvements that promote felt presence and movement in a virtual environment require explicit consideration and control of these multimodal patterns.

Dynamics of balance. The issues considered in this research constitutes a strong set of arguments for multimodal approaches to virtual environments and, in particular, for nonvisual devices in flight simulators. The arguments do not imply that existing motion-base systems are superior to existing fixed-base simulators with respect to experiential or action fidelity. The relative efficacy of these devices depend on how well they simulate or recreate constraints on postural control in real vehicles. The constraints on postural control in a motion-base simulator depend heavily on the algorithms that are used to link states of the simulated vehicle to motions of the platform and on the implementation of the algorithms. A motion-base simulator could have poor fidelity because of inappropriate algorithms, inappropriate implementation, or insufficient calibration of the moving platform. If properly designed and maintained, motion platforms can recreate many of the forces that real aircraft impose on the pilot's body. The conspicuous exception is the magnitude of the gravitoinertial force vector. An ecological approach indicates that this is important because of the effect that gravitoinertial magnitude has on the consequences of imbalance. While variation in gravitoinertial magnitude can be achieved in centrifuges, coriolis forces create consequences for imbalance that are different from those encountered during common trajectories of aircraft motion. A different type of device is needed for this essential category of information. One possibility is suggested by the experiment of Riccio et al. (1992). In this experiment, the perception of upright (or vertical) was determined primarily by the experimentally controlled dynamics of balance for the body as a whole (cf,. Riccio & Stoffregen, 1990; Stoffregen & Riccio, 1988). A similar concept could be adapted to a fixed or moving cockpit by connecting torque motors to the pilot's helmet (cf., Brown et al., 1991; Kron et al., 1980). Both the direction of balance and the consequences of imbalance could be manipulated through the orientation dependence of torque on the head. Such a helmet-loading system could simulate the perceivable effects of variation in the direction and magnitude of the gravitoinertial vector. The results of Riccio et al. (1992) suggest that the helmet loader would promote experiential fidelity with respect to this important category of information. Furthermore, it could promote action fidelity by improving postural control in the cockpit, minimizing simulator sickness, and reducing postural aftereffects.

Nonrigidity of human operator. Variation in the gravitoinertial force vector is caused by variation in the velocity vector of self motion. Variation due to controlled changes in heading or altitude generally occurs over long time scales while variation due to vibration and transients can occur over relatively short time scales. It is unnecessary, and perhaps unwise, to use a helmet loader to recreate the effects that gravitoinertial variations have on the direction of balance and the consequences of imbalance when these variations are faster than the corresponding postural control activities. These high-frequency variations in force tend to move the various body segments, and it is best to consider them as sources of postural perturbations. Driving a helmet loader at high frequencies could lead to injury. Such high-frequency forcing also would tend to create patterns of head-torso motion that would be different than in an aircraft where forcing is applied through the seat. Such high-frequency effects could be attenuated, while low-frequency variation in balance constraints could be preserved, with a low-pass filter in the helmet loading system. An undesirable effect of a low-pass filter on a helmet loader would be the removal of information about high-frequency vehicular motion that would otherwise be available in patterns of head-torso disturbance. This information would be preserved in the high-frequency fidelity of a motion platform. Helmet loaders and motion platforms would be complementary; together they could provide for high-fidelity simulation of transient and sustained changes in the inertial environment.

High-frequency motion of a nonrigid pilot could be included in a fixed-base simulator by visually simulating and manipulating the inside-cockpit surroundings. Instruments and edges of the windscreen, for example, could be included in the visual display and could be moved independently of the visually displayed scene outside the cockpit. The relative motion of inside-cockpit structure and outside-cockpit structure, and the accretion and deletion of the latter by the former, would correspond to a changing point of observation in the cockpit; that is, it could simulate the movement of the pilot in the cockpit due to transients and vibration. In this way, simulated inside-cockpit structure would be analogous to a dynamic seat. Motion of these simulator components should be based on the fact that the pilot is not rigidly attached to the cockpit. Motion of these two components would be different to the extent that the head and the upper part of the torso move differently than the lower part of torso. Together, inside-cockpit structure and a dynamic seat could simulate the nonrigidity of the pilot. This may not require a quantitatively precise biomechanical model to determine the relative motion of the two displays. Qualitative accuracy could be achieved simply by driving the inside-cockpit structure (i.e., simulated head motion) so that it lags the dynamic seat (i.e., simulated motion of lower torso). Visual simulation of nonrigidity would provide an alternative to motion-platform systems that actually move the pilot in the cockpit. Nevertheless, some nonvisual devices such as dynamic seats and helmet loaders are necessary for simulation of self motion.

A different approach. This research presents a unique conceptual analysis of real and simulated self motion. As such, it is an alternative to the more traditional mathematical and engineering analyses. It may be complementary to some of the more traditional treatments; however, irrespective of such complementarity, the present analysis should lead to a more accurate "picture" of self motion. The conceptual analysis emphasizes the most important issues in the perception and control of self motion. These issues have considerable generality. The various sections in the paper, and many of the details presented in the context of real and simulated flight, can be applied to all forms of real and simulated locomotion. In any case, it should be clear that the present perspective motivates and emphasizes different types of displays than do traditional approaches to flight simulation and virtual environments. Helmet loaders and near-field optical structure, in particular, may be useful for simulating movement of an observer-actor in any virtual environment. The difference in emphasis is important because it indicates that the present perspective is not tantamount to an argument for increased complexity or physical (or pictorial) fidelity in flight simulation and virtual environments. To the contrary, it suggests that displays need only be approximately correct if the essential categories of information are represented in the simulation. Indeed, if such categories of information can be preserved, it may be desirable to reduce the complexity of displays to increase temporal fidelity (E. A. Martin, et al., 1986; McMillan et al. in preparation) or to facilitate perceptual learning (R. Warren & Riccio, 1985).

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VISUALIZATION OF EVOKED ELECTRICAL ACTIVITY IN THE HAMSTER SUPRACHIASMATIC NUCLEUS

David M. Senseman
Associate Professor
Center for Information Visualization
Division of Life Sciences

The University of Texas at San Antonio
6900 N. Loop 1604 W.
San Antonio, TX 78249

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Abstract

Multiple-site optical recording was used to study the effects of retino-hypothalamic tract (RHT) stimulation on neurons in the hamster suprachiasmatic nucleus (SCN). A new imaging system allowed electrical activity to be monitored simultaneously in 464 contiguous regions (42 x 42 um^2) of a 400 um thick hypothalamic slice preparation containing the SCN, optic nerves and optic chiasm with millisecond temporal resolution. Relatively large, voltage-dependent optical signals could be recorded at 7300 nm ($\pm$ 400 nm) from the SCN's after staining the tissue with the potentiometric probe RH155. Each SCN was found to receive similar levels of input from both optic nerves. Clear regional differences were found, however, in the distribution of RHT afferents within the SCN's as well as the spatiotemporal patterns of post-synaptic activity evoked by RHT stimulation. RHT terminals and their primary synaptic targets were largely restricted to the caudal half of the SCN. Caudal SCN neurons excited by RHT inputs relayed excitation to neurons in the rostral half of the SCN. RHT-evoked activity in the caudal SCN was abolished by bath application of serotonin (50 um) suggesting the possibility of pre-synaptic inhibition of the RHT afferents.

VISUALIZATION OF EVOKED ELECTRICAL ACTIVITY IN THE HAMSTER SUPRACHIASMATIC NUCLEUS

David M. Senseman

INTRODUCTION

Most life forms, including man, exhibit cyclical changes in behavior and physiological processes that have a period of about 24 hrs. In higher multicellular organisms, such diurnal rhythms are driven by neuronal circuit(s) that function as circadian pacemakers. There is now strong evidence for rodents, at least, that the circadian pacemaker is located within the suprachiasmatic nucleus (SCN) of the anterior hypothalamus (e.g. Shibata, et al.,[1]; Groos & Hendrick [2]; Moore [3]; Moore & Eichler [4]; Gillette & Reppert [5]; Shibata & Moore [6]).

An important attribute of circadian pacemakers is their ability to be "entrained" by environmental cues, primarily by diurnal fluctuations in light and temperature (Aschoff, [7]). In nocturnal rodents the sensitivity of the circadian pacemaker to light entrainment is particularly acute (e.g. Pittendrigh & Daan [8]) and is mediated by the retino-hypothalamic tract (RHT) (Pickard, [9]).

The efficacy and "sign" of light entrainment is critically dependent on the circadian time of the stimulation. In "free-running" hamsters under conditions of constant darkness, light stimulation during the early part of the subjective night causes a phase delay in the circadian cycle while later light pulses induce a phase advance (e.g. Boulos & Rusak [10]). In contrast, light stimulation during the animal's subjective day, even when the animal is awakened, has no effect on the phase of the circadian rhythmicity.

How light information carried by RHT afferent input affects phase shifts is still largely unknown although there is some reason to believe that regional differences neuronal organization may play a role in the entrainment process. In hypothalamic slice preparations, spatial differences in SCN field potentials have been observed following optic nerve stimulation by Shibata, et al.,[1] while Gillette and her group have found functional differences in endogenous rhythmicity between ventral and dorsal SCN neuronal populations (M. Gillette, personal communication). The present study was designed to further characterize these regional differences in RHT-evoked activity using the technique of multiple-site optical recording and determine their sensitivity to the neurotransmitter 5-HT.

METHODS

PREPARATION

All experiments were performed on male Syrian golden hamsters (160-180 gm) obtained from a commercial supplier (Charles River Inc). Animals were maintained on a strictly enforced 14:10 LD cycle for at least 2 weeks prior to use.

Hypothalamic brain slices were prepared following the procedure of Hatton et al. [11]. Prior to decapitation, a deep level of anesthesia was induced with Metofane. The brain was then rapidly removed from the cranium and placed in chilled (4^{o} C) mammalian Ringer's solution (NaCl 125 mM, KCl 5 mM, $MgSO_4$ 2 mM, $CaCl_2$ 3 mM, NaH_2PO_4 25.5 mM, D-glucose 10 mM) for 30 s to reduce metabolic activity. A block of anterior hypothalamic tissue containing the SCN's, optic nerves and chiasm was prepared and mounted on the stage of an oscillating tissue slicer (Fredrick Haer model OTS-3000) using cyanoacrylate adhesive. A single 400 um thick slice was cut in the horizontal plane from the ventral surface and placed in an moist incubation chamber supplied with continuously flowing 95% O_2 / 5% CO_2. Following a 30 min recovery period, the SCN was stained for 60 min with the voltage-sensitive dye RH155 (Nippon Kankoh-Shikiso Kenykyusho Co., Okayama, Japan). After removing excess dye with fresh mammalian Ringer's, the slice was allow to recover an additional 30 min in the incubation chamber.

Optical Recording

For optical recording, the stained slice was removed from the incubation chamber and secured to the Sylgard-coated glass bottom of a recording chamber by means of miniature tungsten staples. Each optic nerve was drawn into a plastic suction electrode also fastened to the Sylgard layer. The electrodes were connected to a four channel stimulation system (WPI model 800) that delivered electrical pulses (1.0 - 1.5 mA, 0.5 ms duration) to the electrodes under computer control.

The chamber was mounted on the stage of a large binocular microscope (Zeiss UEM) and the preparation perfused with 10 ml/min oxygenated mammalian Ringer's. Perfusion was maintained throughout the duration of the experiment except for brief periods (20-30 sec) during the actual acquisition of the optical signals. This interruption of flow was necessary to minimize contamination of the optical signals by vibrational noise.

[Fig. 1 about here]

Fig. 1 shows a semi-diagrammatic representation of the experimental setup. The preparation was trans-illuminated with light from a 100-watt tungsten-halogen lamp driven by a stable DC power supply. The collimated light was passed through a narrow bandpass interference filter (7300 ±400 nm) before being focused on the preparation by means of the microscope's substage condenser. A 16X (0.5 NA) water immersion objective (Zeiss) collected the transmitted light and formed a real image of the preparation on the surface of a 464-element silicon photodiode array (Centronic Inc., model MD-464). The photocurrent output from each diode element was passed in parallel to a 2-stage amplifier system that amplified and low- and high-pass filtered the signals before being digitized (16-bit resolution) and stored on a MC68030-based computer system (Motorola MVME-147). Details about the amplification and digitization subsystems have been published elsewhere [12]. At the end of the experiment, the photodiode array was replaced with a conventional video camera (Hammamatsu model C2400) and a high-resolution (512 x 512 pixels) grey-scale (8-bit) image of the preparation acquired using a low power (4X) microscope objective. The image was stored on a optical disc memory recorder (Panasonic model TQ-2025F) and later digitized with a image processor system (Imaging

Technologies Inc. series 151). Digitized video and photodiode array information was transferred to a 64-bit MIPS R4000-based UNIX workstation (Silicon Graphics Inc. model 4D/RPC "Indigo") for data display and analysis as previously described [13].

[Fig. 2 about here]

RESULTS

Two types of responses were optically recorded in the slice following electrical stimulation of a single optic nerve (Fig. 2). The first type was a small, fast-rise signal that resembled a nerve action potential. These signals were recorded primarily from regions anterior and lateral of the SCN's. Because these signals were largely restricted to areas transversed by the stimulated optic nerve, we believe they reflect synchronous activity of RHT and/or geniculohypothalamic tract (GHT) nerve afferents.

[Fig. 3 about here]

Substantially larger optical signals were recorded by diode elements positioned directly over the SCN's. These signals generally exhibited a bi-phasic waveform with an initial fast-rise depolarizing response followed by a second and much slower and prolonged depolarizing response (Fig. 3). Since the initial fast transient is similar in waveform and time course of the fast. We believe that the initial fast transient corresponds to Shibata et al.'s [1] Signals with the largest amplitude were typically recorded from the caudal half of the nucleus (Figs 3 & 4).

[Fig. 4 about here]

In order to directly map the location of the pre-synaptic terminals of the RHT within the SCN, we exploited an advantage of the optical recording technique to monitor DC shifts in intracellular membrane potential. Relatively large, hyperpolarizing DC current pulses (100 ms) were injected into an optic nerve and the passive spread down the axons into the terminal fields optically monitored. The results of a such an experiment is shown in Fig. 5. Large downward deflections were observed in the caudal half of the SCN's while,

[Fig. 5 about here]

upward excitatory responses were observed in the rostral half. We believe the large downward deflects represent hyperpolarization of the RHT pre-synaptic fibers and indicate the location and extent of their SCN terminal fields. This finding is in close agreement with the histological studies of Johnson *et al.* [14] who also found the RHT projected to the caudal half of the hamster SCN.

[Fig. 6 about here]

Since the SCN's receive a serotonergic projection from the raphe nuclei, we wanted to determine the effects of bath applied serotonin (5-HT) on RHT-evoked activity. The results of a typical experiment are shown in Fig.s 6-8. Fig. 6 is a control record showing the effects of dual optic nerve stimulation on the SCN with an interpulse interval of 100 ms. Large amplitude signals can

[Fig. 7 about here]

be clearly seen in both SCN's. Fig. 7 shows the pronounced inhibitory effects of bath application of 50 uM 5-HT for 10 min. on the same preparation while Fig. 8 shows partial recovery of the signal after washing for 30 min with fresh mammalian Ringers.

[Fig. 8 about here]

DISCUSSION

A major objective of the current series of experiments was to achieve high-resolution imaging of RHT-evoked SCN activity using a new 464-element photodiode light detector subsystem. While a number of technical problems needed to be resolved, successful high-resolution imaging of the SCN was finally achieved near the end of the project period. The new imaging system provides a more detailed looked at RHT-evoked activity in the SCN than previously possible.

One aspect of the new system that is difficult to appreciate because of the limitations on this report format, is the dynamic quality of the response. This is particularly true of the caudo-rostral movement of RHT activity with the SCN's. While this effect is clearly visible in PAM display of the data show in Fig. 3, it can not be seen from the waveform data of the static "Page" display. Because of the close proximity of the Armstrong Labs to my lab at UTSA, it has been possible for members of Dr. Michael Rea's team to directly observe and analyze the dynamic aspects of the response using my lab's computer workstations.

One area that was not addressed the current series of experiments is the degree to which functional differences can be visualized between dorsal and ventral SCN populations with this technique. Attempts to develop a coronal SCN slice preparation suitable for optical recording is currently under development.

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FIGURE LEGENDS

Fig. 1. Schematic drawing of the experimental apparatus. A 24 x 24 silicon *photodiode array* was used for high-speed optical recording (1ms/frame) of voltage-sensitive signals from the experimental preparation (*brain*). Photocurrents from the 464 central array elements were passed in parallel to an amplifier bank (*not shown*) and then to a 512 channel digital-to-analog converter system (*not shown*) before processing on a 32-bit Motorola MC68030-based microcomputer system (*data acquisition system*). A Hammamatsu C2400 *video camera* system was used at the end of an experiment to record a high-resolution video image of the experimental preparation. The video image was stored on a Panasonic *video disc recorder* prior to digitization and processing on a Imaging Technology Series 151 *image processor* system. A Silicon Graphics Inc. 4D/RPC color *graphics workstation* produced the animated PAM displays from the combined optical recording data and the enhanced image data.

Fig. 2. Page display of optical signals recorded from the ventral surface of the hamster hypothalamic slice prepation. Optical signals recorded in response to brief electrical stimulation of the transected optic nerve (0.5 msec, 1.5 mA). The slice had been stained 60 min with the voltage-sensitive dye RH155 (0.5 mg/ml). Signals were recorded under brightfield illumination using a 7300± 400nm bandpass intereferncе filter. Thin lines indicate approximate location of the SCN's. Examples of signal waveforms corrsponding to Shibata et al.'s [1] early peak (*P2*), and slow wave (*N*) are indicated.

Fig. 3. Two selected traces from this display (detectors 43 & 99) are shown in Fig. 2. at higher magnification. Detector 43 was located over the stimulated

(right) optic nerve while detector 99 was located over the contralateral (left) SCN. Note that while detector 43 shows only a single fast response, the signal recorded by detector 42 shows a multiphasic response with an initial fast transient recorded coincident with the 'spike' in detector 13 followed by a much larger depolarizing transient and later broad depolarization. Based on neuroanatomical and neurophysiological considerations, we believe the initial transient in both records represents evoked afferent of the retino-hypothalamic tract (pre-synaptic response). The large transient that occurs 10-20 ms later in detector 99 would therefore represent the synaptic activation of the SCN neurons by these incoming visual fibers. The later, broad depolarization seen in detector 99 is presumably due to recurrent excitation within the SCN itself.

Fig. 4. Page display of optical signals recorded from the ventral surface of the horozontal hypothalamic slice. Optical signals recorded in response to brief electrical stimulation of the transected olfactory nerve (0.5 ms, 1.5 mA). Tissue had been stained 60 min with the voltage-sensitive dye RH155 (0.5 mg/ml). Signals were recorded under brightfield illumination using a 7300 $\pm$ 400 nm bandpass intereference filter. Thin lines indicate approximate location of the SCN's. Note that largest signals are found in the caudal half of the nuclei.

Fig. 5. Page display of optical signals recorded from the ventral surface of the hamster hypothalamic slice prepation. Optical signals recorded in response to 100 ms hyperpolaring pulse to the transected optic nerve (1.5 mA). The slice had been stained 60 min with the voltage-sensitive dye RH155 (0.5 mg/ml). Signals were recorded under brightfield illumination using a 7300$\pm$

400nm bandpass interefernce filter. Thin lines indicate approximate location of the SCN's. Note that the areas showing the largest downward deflections (hyperpolarizations) were located in the caudal half of the SCN's.

Fig. 6. Page display of optical signals recorded from the ventral surface of the hamster hypothalamic slice prepation prior to adminstration of 5-HT (control record).

Fig. 7. Page display of optical signals recorded from the ventral surface of the hamster hypothalamic slice prepation after bath application of 5-HT (50 um) for 10 min.

Fig. 8. Page display showing partial recovery of optical signals recorded from the ventral surface of the hamster hypothalamic slice prepation after 30 min of washing with fresh mammalian Ringer's.

Fig. 1

Experimental Apparatus

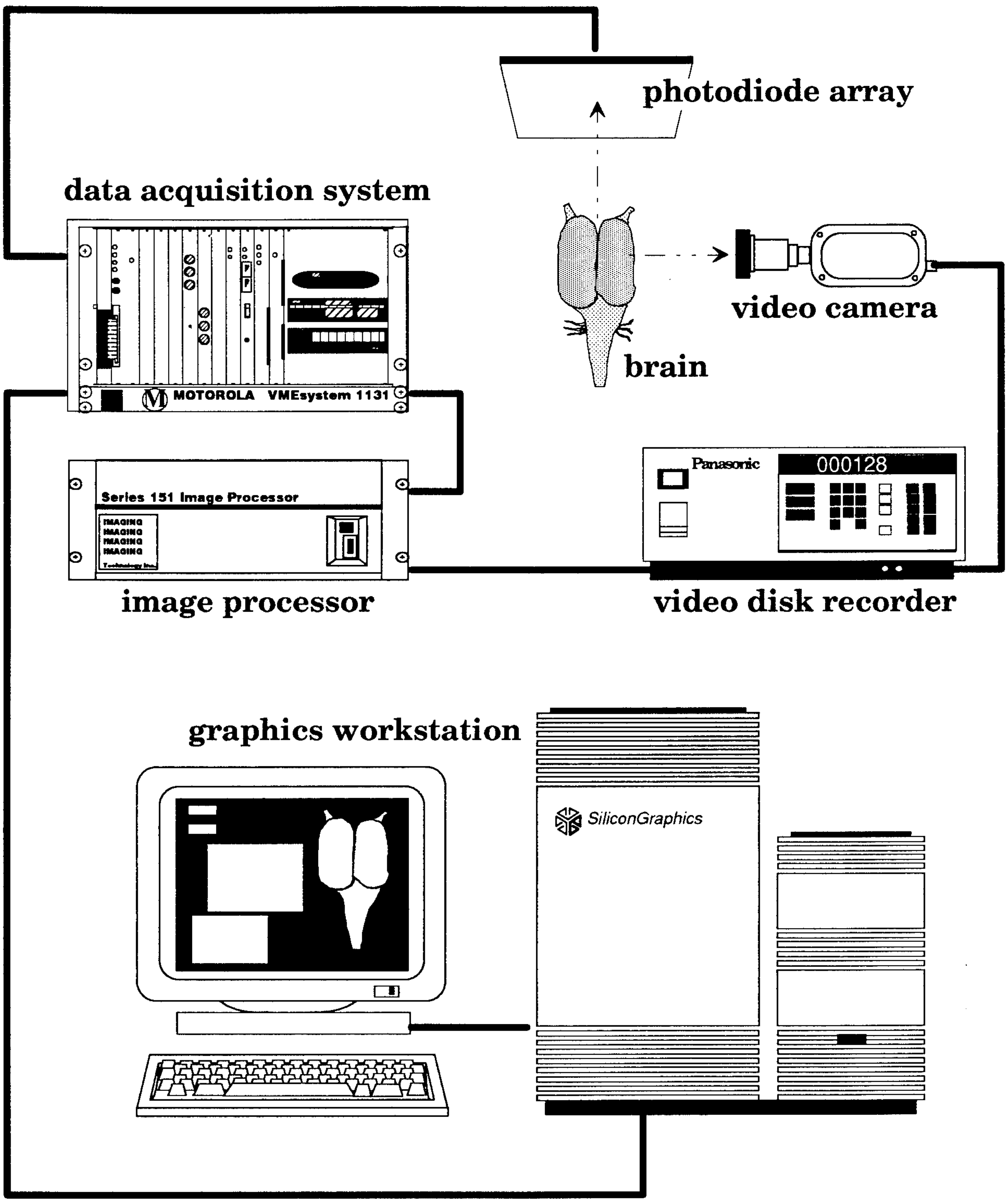


Fig. 2

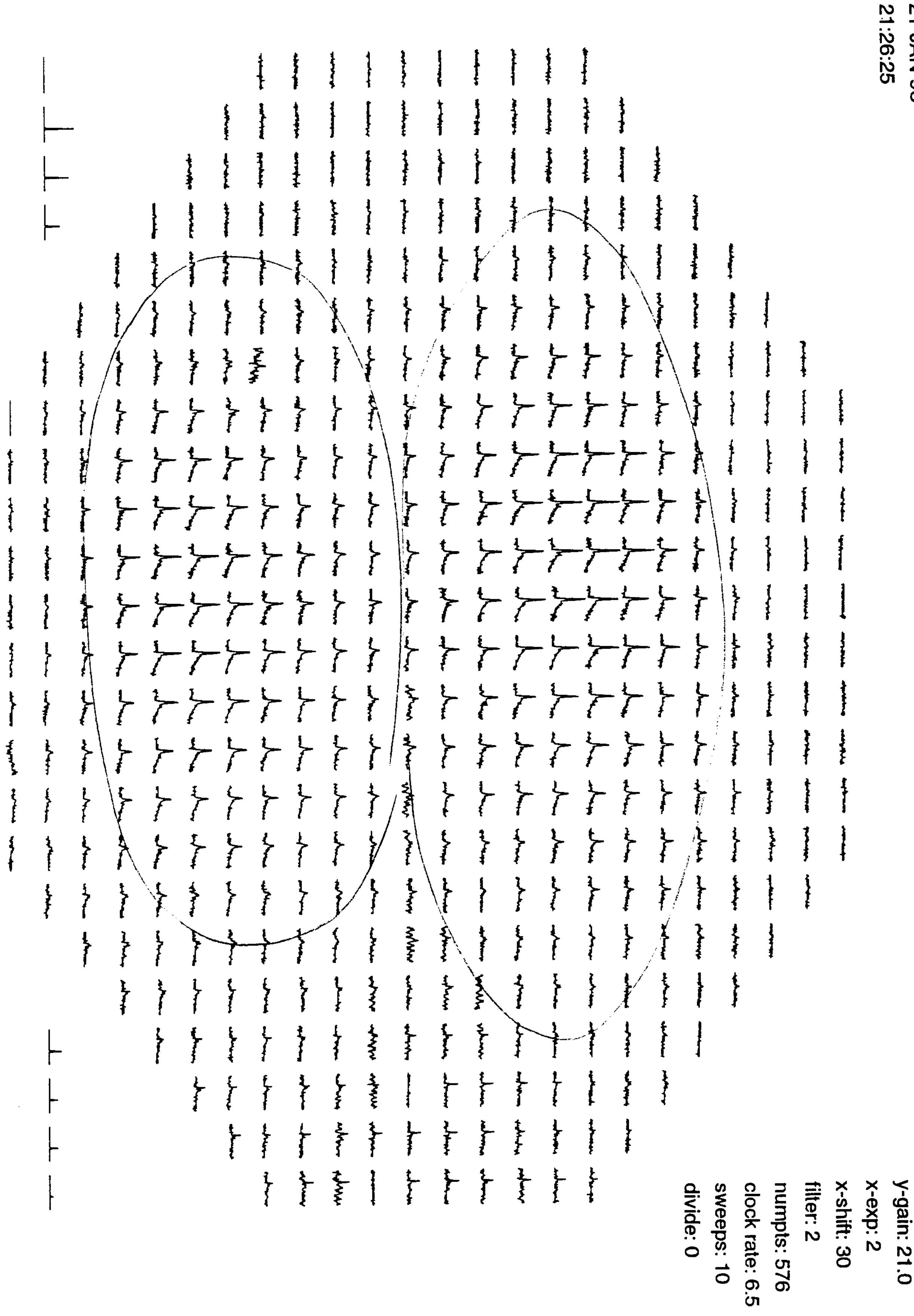
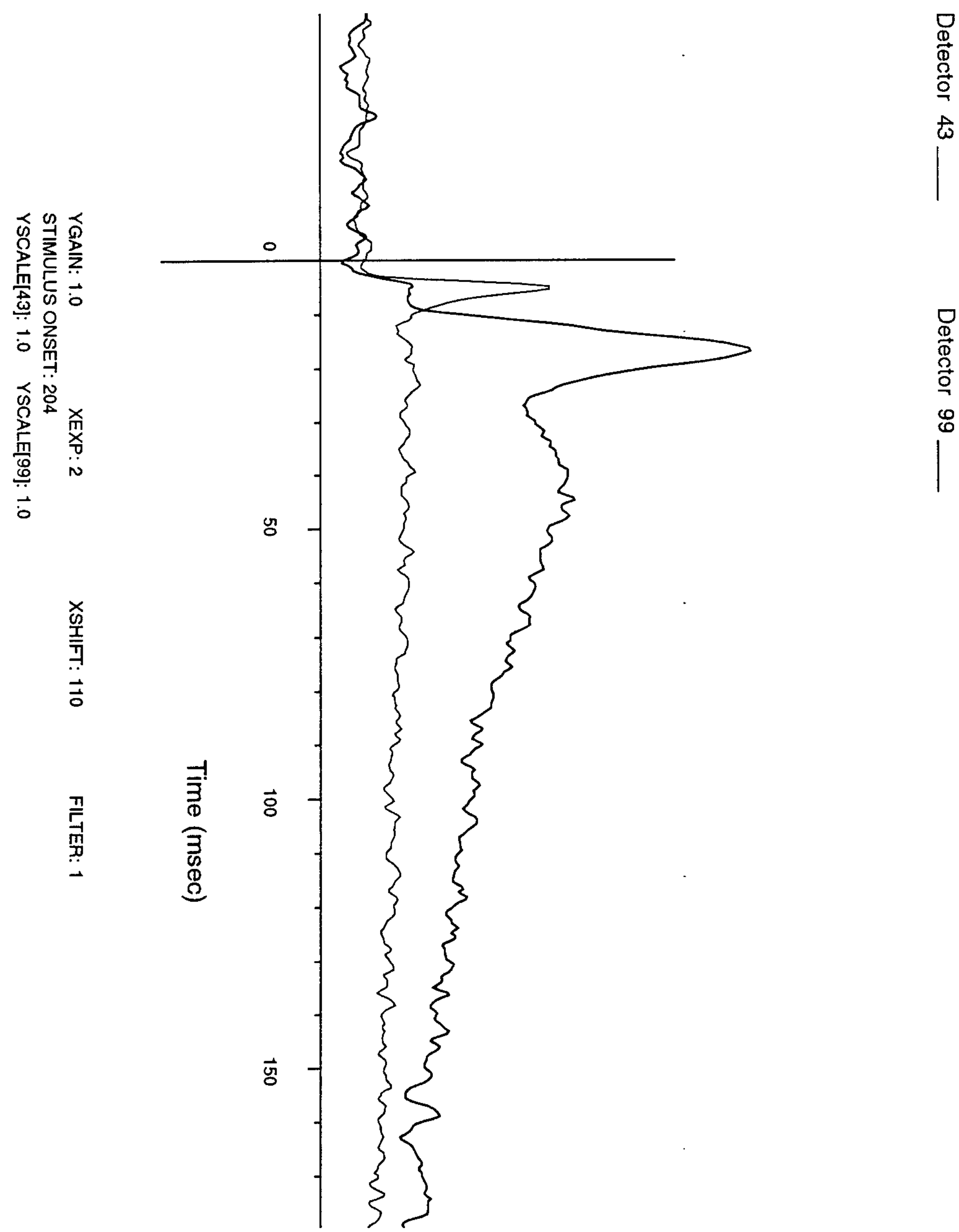
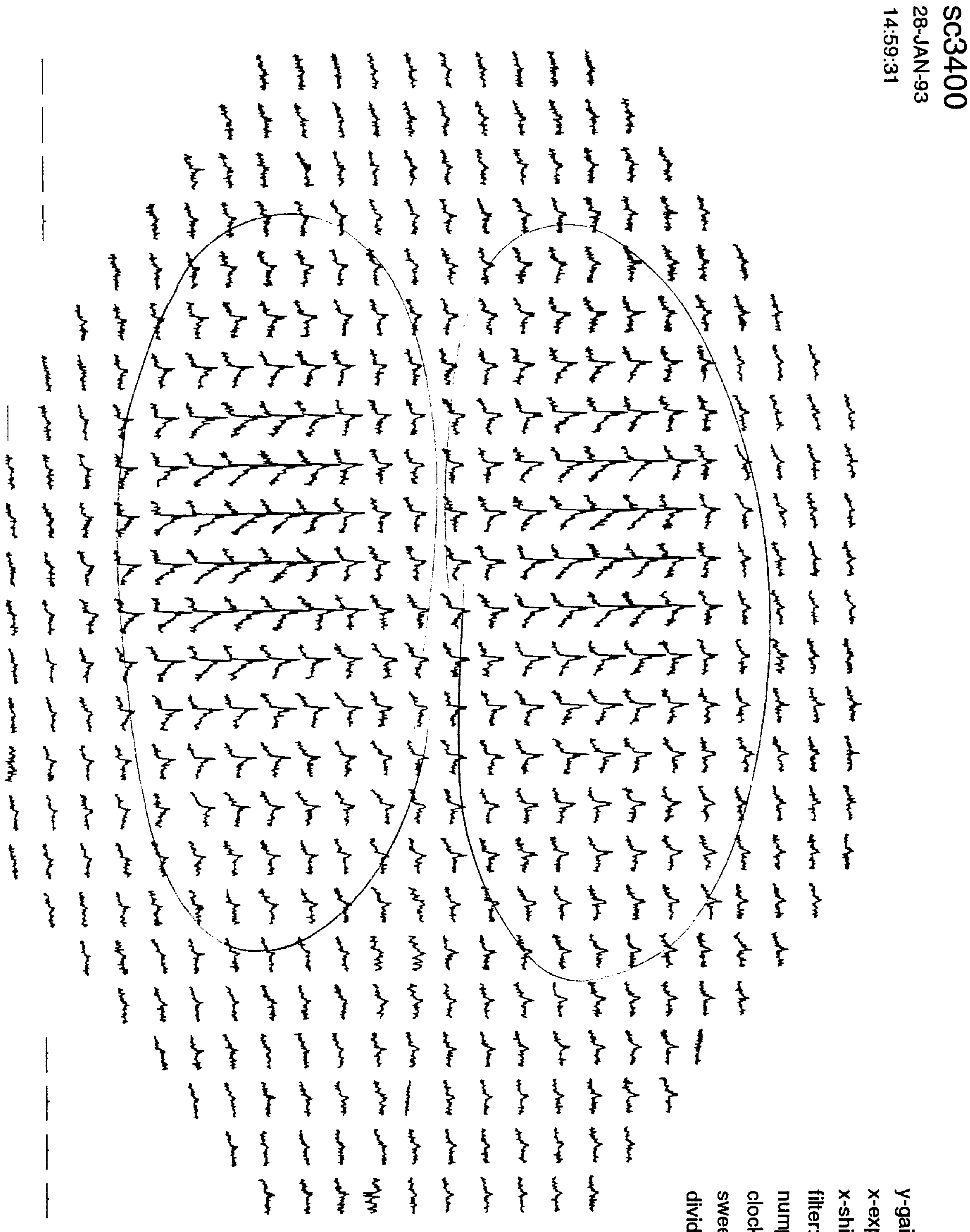

sc3103
21-JAN-93
21:26:25
y-gain: 21.0
x-exp: 2
x-shift: 30
filter: 2
numpts: 576
clock rate: 6.5
sweeps: 10
divide: 0

Fig. 3



Detector 43
Detector 99
0
50
100
150
Time (msec)
YGAIN: 1.0
XEXP: 2
XSHIFT: 110
FILTER: 1
STIMULUS ONSET: 204
YSCALE[43]: 1.0
YSCALE[99]: 1.0

Fig. 4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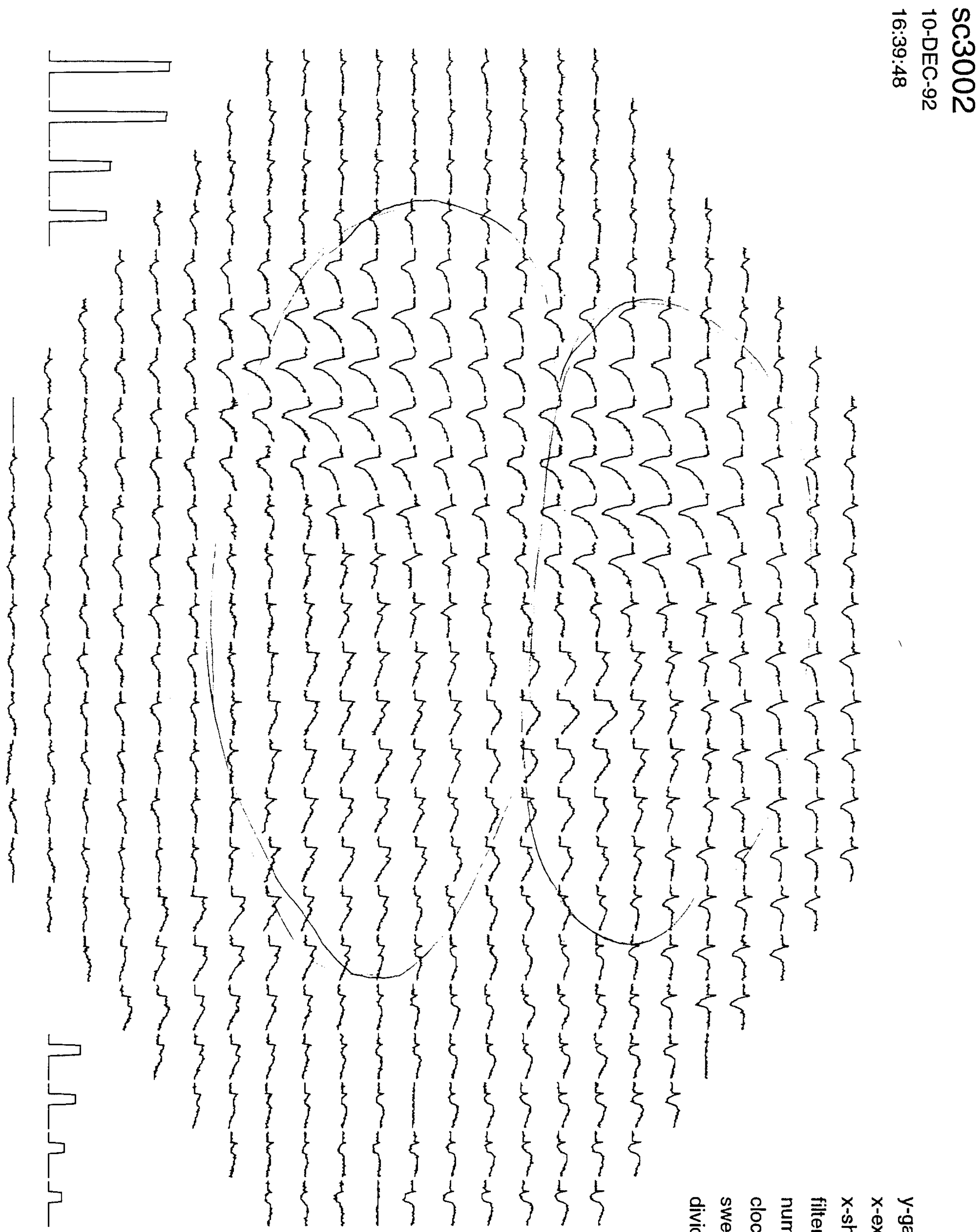
28-JAN-93
14:59:31
y-gain: 40.0
x-exp: 2
x-shift: 15
filter: 3
numpts: 576
clock rate: 6.5
sweeps: 10
divide: 0

Fig. 5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10-DEC-92
16:39:48
y-gain: 18.0
x-exp: 1
x-shift: 0
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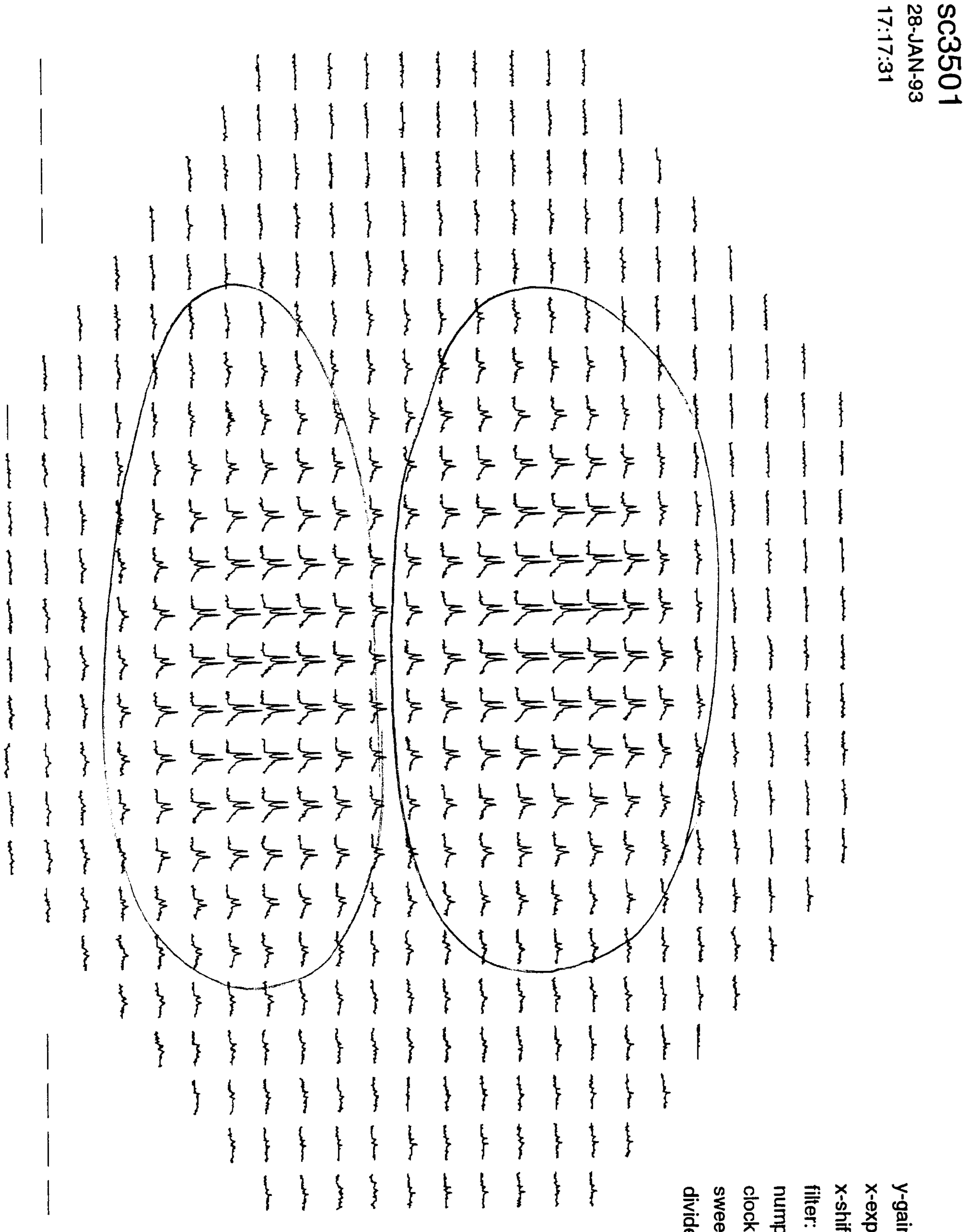
clock rate: 6.5
sweeps: 10
divide: 0

Fig. 6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28-JAN-93
17:17:31
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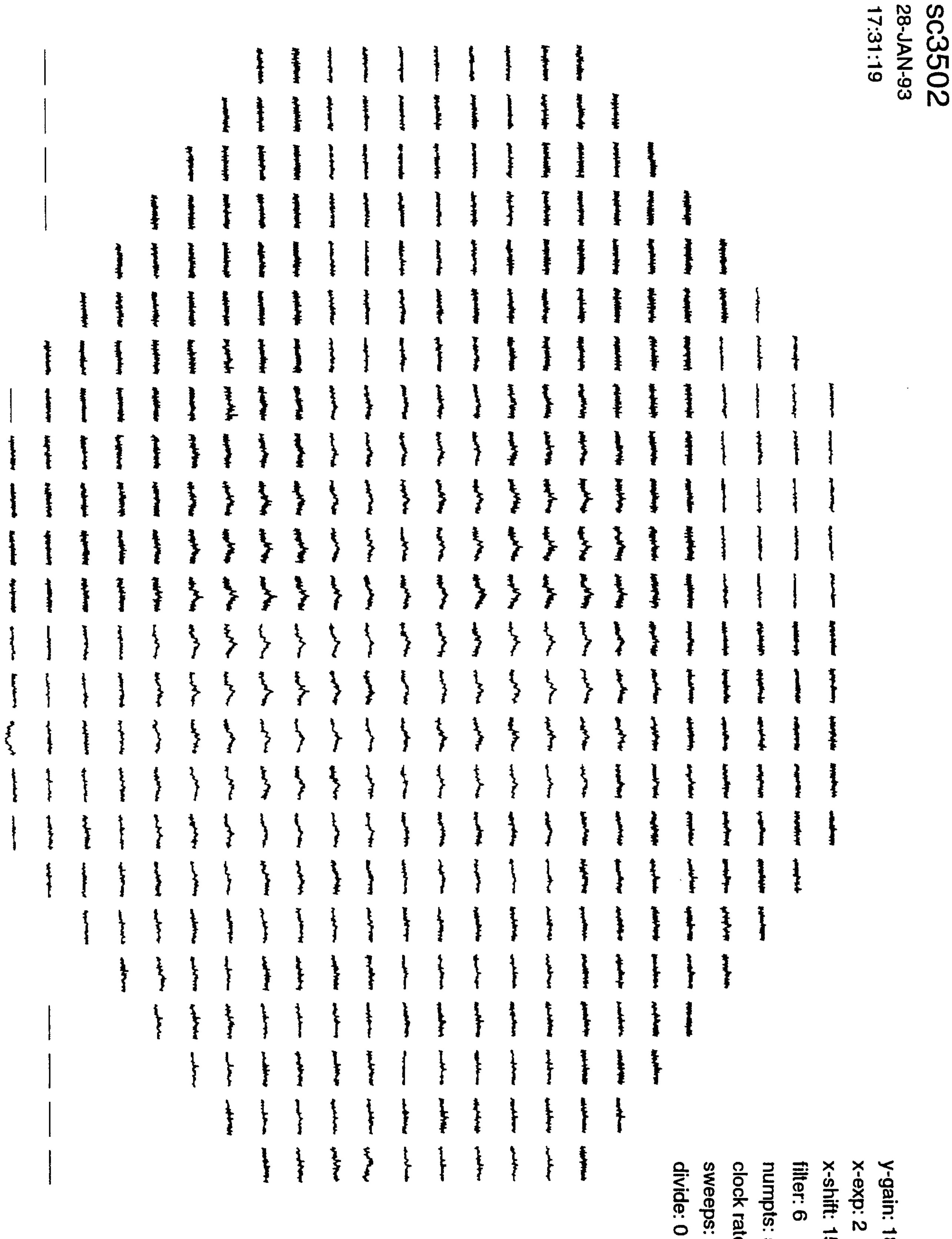
x-exp: 2
x-shift: 15
filter: 6
numpts: 576
clock rate: 6.5
sweeps: 6
divide: 0

Fig. 7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28-JAN-93
17:31:19
y-gain: 18.0
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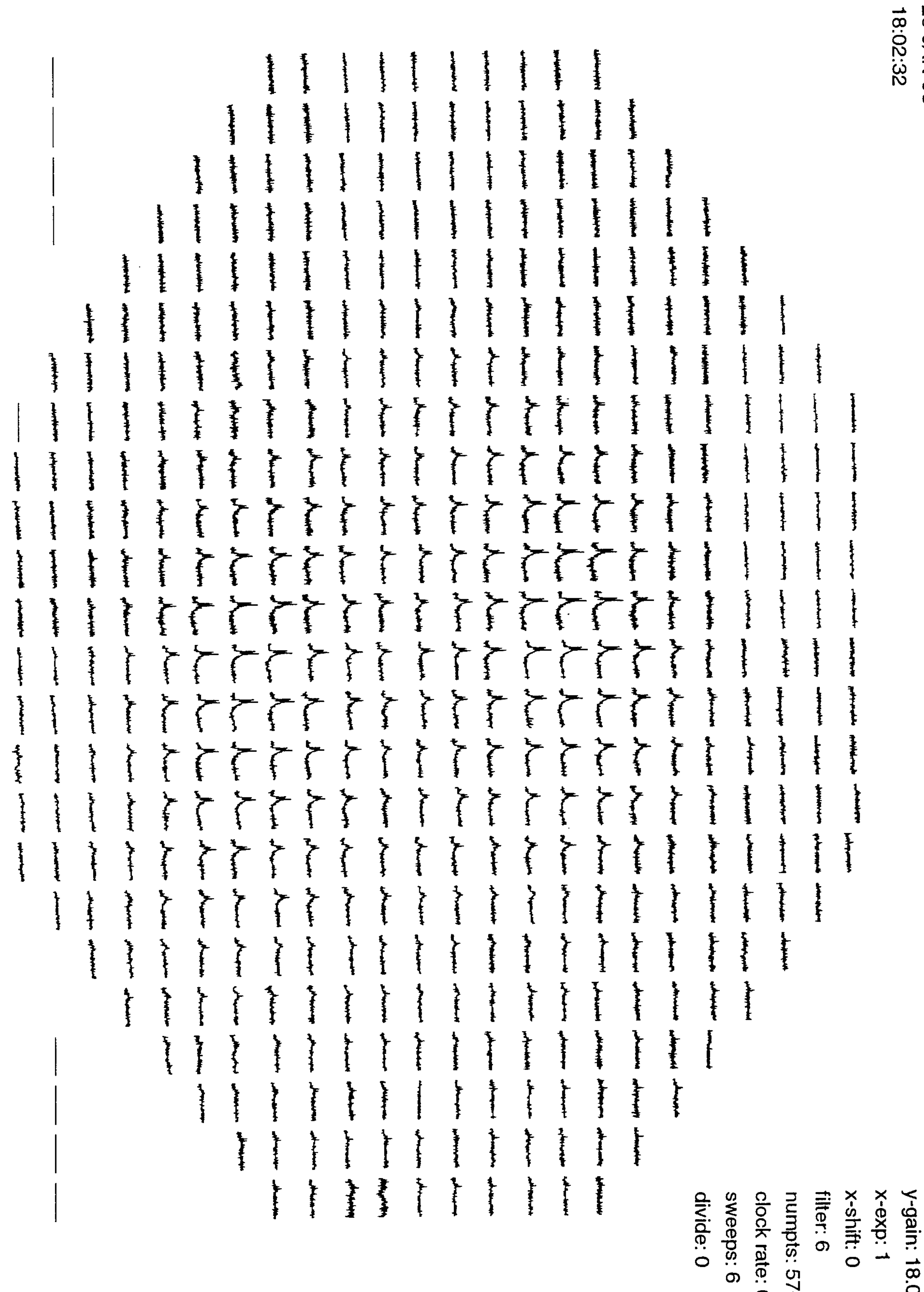
sweeps: 6
divide: 0

Fig. 8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18:02:32
y-gain: 18.0
x-exp: 1
x-shift: 0
filter: 6
numpts: 576
clock rate: 6.5
sweeps: 6
divide: 0

MODELS OF SPATIAL VISION APPLIED TO LOW FREQUENCIES

Benjamin R. Stephens
Associate Professor
Department of Psychology

Clemson University
Brackett Hall
Clemson, SC 29634

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Abstract

Three related experiments were conducted. The experiments continued the summer project that investigated the visual system's response to threshold and suprathreshold pattern information in the low spatial frequency range. Low frequency _pattern discrimination_ for three similar compound waveforms was assessed in 3 trained observers. The results indicate that the fundamental of compound waveforms can influence discrimination. In the second experiment, the effect of direct manipulation of _spatial frequency information in compound gratings_ was identified in a discrimination task. These results indicate that the phase of the harmonics does not strongly influence detection of the fundamental. Finally, the perceived _image quality_ of low frequency gratings was measured. The results suggest that perceived image quality for simple features is consistent with models proposed by Cannon and Fullenkamp (1992).

Introduction

Current models of spatial vision attempt to account for both threshold and suprathreshold performance. Typical data to be described by these models include contrast sensitivity, contrast discrimination and/or apparent contrast functions (e.g. Cannon & Fullenkamp, 1991; Wilson, 1980). These models are important as initial descriptions of the pattern information available to human observers in complex scenes, and may have important applications in areas such as pilot object identification and assessment of image quality (Cannon and Fullenkamp, 1992). Most models are similar in that they describe spatial vision in terms of arrays of pattern sensitive units that are tuned to respond to a specific location, spatial frequency and orientation. The models also posit characteristics of the system that lead to non-linear responses as contrast level of the input increases from threshold to suprathreshold levels. Although these models provide useful descriptions of basic pattern processing, little quantitative evidence exists to allow application of these models to more complex perceptual judgments, such as pattern recognition and discrimination for real-world stimuli. Most attempts to account for these judgments rely on heuristics concerning the perceptual effects of the presence or absence of bands of spatial frequency information (e.g. Ginsburg, 1984; Campbell et al, 1978). For example, Campbell et al have demonstrated that the ability to detect the third harmonic of a high frequency square wave grating predicts the contrast at which the square and sine grating (of the same fundamental frequency) can be discriminated. Campbell et al (1978) applied a similar style of reasoning to account for the missing fundamental illusion. Figure 1 presents the intensity profile and amplitude spectra for a sine, square, and missing fundamental gratings. The missing fundamental grating is simply a square-wave grating with the fundamental (F) removed. Note that the removal of F creates a "scallop" in the intensity profile. The missing fundamental grating is nonetheless perceived as a square-wave grating under low-contrast, low spatial-frequency conditions. Campbell et al's explanation of this missing fundamental illusion is that F is not normally detectable under these conditions, so its removal does not alter the appearance or detectability of the square wave.

This account of the illusion seems to be inconsistent with Ginsburg et al's (1980) explanation of apparent contrast in square-wave gratings. Their contrast matching data show that adults require roughly 27% more contrast in a sine-wave grating to be equal in apparent contrast to a square-wave grating of the same fundamental frequency. Since the fundamental of a square wave is 27% higher in contrast than the physical contrast of the grating, they interpreted their results as indicating that the fundamental mediates apparent contrast, even under low-contrast, low frequency conditions.

This inconsistency could be due to the higher harmonics of the square-wave, which might mediate both detection and apparent contrast under low-frequency conditions. Alternatively, judgments concerning the quality of a pattern (e.g. apparent contrast) may not involve identical mechanisms as those involving detection or discrimination.

Working in collaboration with Mark Cannon, three preliminary experiments were conducted to resolve the apparent discrepancy between these two reports (Stephens, Cannon, and Fullenkamp, 1992). Contrast sensitivity, contrast matching, and pattern recognition experiments were conducted using sine, square (SQ), and missing fundamental (MF) gratings. We also employed a stimulus that is a square wave with the fundamental component shifted 180 degrees in phase. The profile of this stimulus resembles a missing fundamental grating, however the amplitude of the scallop is twice that of the scallop in the missing fundamental grating. Hence we will refer to this stimulus as the double missing fundamental grating (MF2).

The contrast sensitivity and apparent contrast experiments were designed to replicate and extend results from other laboratories. The contrast sensitivity data were similar to previous reports. Sensitivity to SQ, MF, and MF2 gratings was similar at 0.125 and 1.0 cy/deg. Sine wave sensitivity was poor at 0.125 relative to 1.0 cy/deg.

The results of the contrast matching experiments were mixed. The bulk of the data did not replicate previous findings that suggest SQ gratings require less contrast to match the apparent contrast of the MF grating. Instead these observers required <u>roughly</u> equal contrast in the two stimuli to judge their contrasts as equal. If representative, these results suggest that the apparent contrast of low-frequency stimuli is mediated mainly by the visual system's response to the information contained in the harmonics. This result is also consistent with the notion that the MF illusion is due to the inability to detect the fundamental of the SQ grating.

However, one subject's data clearly indicate that the SQ grating was judged higher in apparent contrast than the MF grating. Further, the data of the other observers show a slight trend in the same direction, i.e. a slight tendency for the SQ contrast to be somewhat lower than the MF contrast at the equal contrast point. This pattern of results suggests that the fundamental does contribute to the apparent contrast of the SQ grating, even under low frequency, low contrast conditions. This interpretation is inconsistent with the Campbell et al explanation of the MF illusion, which relies on the observer's inability to detect the fundamental component. Further research is required to identify the factors that lead to these individual differences in perception of apparent contrast.

The results of the third experiment on pattern recognition are also inconsistent with the Campbell et al explanation of the MF illusion. Subjects were asked to identify SQ, MF, and MF2 gratings as SQ or not SQ for 0.125 and 1.0 cy/deg gratings at eight contrasts from near threshold to suprathreshold levels. The contrast associated with 75% SQ labeling was taken as the "scallop threshold". The MF scallop thresholds were reliably higher than those predicted on the basis of contrast sensitivity estimates for the fundamental. On the other hand the MF2 scallop thresholds were similar to those predicted by the fundamental contrast thresholds.

The naming data suggest that observers always require much less contrast in the MF2 grating to label it as scalloped vrs the

MF grating. Since these two stimuli should be discriminable from a square at identical contrasts, these data clearly indicate that Campbell et al's explanation of the illusion is incorrect.

The results of these three experiments have implications for models of contrast processing, as well as the relationship between pattern information and the perception of pattern structure. First, there is some evidence that the apparent contrast of square-wave gratings is judged higher than the apparent contrast of missing fundamental gratings, even under low-contrast, low frequency conditions. This result, taken together with the replication of the observation that square and missing fundamental stimuli have the same contrast threshold, should be accounted for by models that attempt to describe both threshold contrast sensitivity and suprathreshold apparent contrast data. For example, the model of Cannon and Fullenkamp (1991) can be used to predict the relative contrast sensitivity and apparent contrast for these stimuli. The model predicts that contrast threshold would be similar for both wave forms. Our data, as well as previously reported data, are consistent with this prediction. Above threshold, however, the model predicts little difference in response to the two stimuli, suggesting that the apparent contrast of the two should be similar when the physical contrast of the stimuli are identical. To compare our contrast matching data with the predictions of the model, we assumed that the two gratings would be judged equal in apparent contrast when the response to the two gratings was equal. We calculated the predicted response to the square grating for the contrast match value, and plotted the contrast of the missing fund at equal apparent contrast value at the same response level. The model is a reasonable first approximation to the data for most subjects. The predicted responses to the missing fundamental stimuli are similar to the square. These observations suggest that the model gives appropriate weight to the harmonics, relative to the fundamental, for judgments of apparent contrast, and predicting contrast sensitivity.

The naming data indicate that a simple explanation of the missing fundamental illusion in terms of sensitivity to the fundamental is not correct. Most subjects indicate that the illusion persists at contrasts higher than predicted by the estimates of contrast sensitivity for the fundamental. The illusion also "breaks down" at lower contrast levels for the MF2 grating compared to the MF grating. Thus it is unlikely that the illusion exists because, at low contrasts, the fundamental of a square wave grating is not detectable. Both results suggest that the visual system has information available that indicates the presence of the fundamental in the square wave grating. Therefore the illusion can not be due to the absence of such information. This interpretation implies that the harmonics may influence the salience, if not sensitivity, for the fundamental.

One potential problem with the conclusions based on the matching and naming data described above is that both tasks are open to potential bias from observers. Both tasks ask the subject to report on the nature of an internal experience that is not easily verified. Therefore in the present project we conducted an experiment that employed a discrimination task to test the hypothesis that the fundamental of a square grating is not effective for low frequency, low contrast stimuli.

A related question concerns the possible explanation of the observation that the MF2 stimulus is less illusory than the MF stimulus. Within the Campbell et al (1978) approach, it might be argued that the harmonics of the SQ grating have an inhibitory effect on sensitivity to F, and that shifting F 180 degrees in phase (MF2) reduces this effect. The second experiment addresses this possibility by estimating contrast sensitivity for F in 0 and 180 degree phase relative to the square-wave harmonics.

In the third experiment, we extend the description of the visual system's response to low frequency stimuli to the analysis of image quality. Many features in the real world are large, and so contain predominantly low frequency information. The perception of the quality of these features can be evaluated directly using magnitude estimation techniques. The grating stimuli described above were employed to provide a test of the Cannon and Fullenkamp (1992) model of image sharpness. Their image sharpness model is based on their earlier model of spatial vision (Cannon and Fullenkamp, 1991). The model accounted for sharpness estimates of real-world scenes. The grating stimuli above provide clear manipulations of frequency content and thus provide an interesting test of the model for abstract, arbitrary stimuli.

Experiment 1. Pattern discrimination for Missing Fundamental, Double Missing Fundamental, and Square wave gratings.

The preliminary data clearly indicate that observers are willing to label the missing fundamental (MF) grating as a square wave grating (SQ) at higher contrasts than predicted on the basis of sensitivity to F. Further, reliably lower contrasts are sufficient to allow correct identification of the double missing fundamental (MF2). The difference in this "scallop threshold" for MF and MF2 stimuli suggests that a simple account of the MF illusion is unlikely to be correct. However, is may be possible that a more direct discrimination task would yield results that are more consistent with the Campbell et al hypothesis, if discrimination tasks are a more sensitive measure of the observer's ability to use F to differentiate pattern profiles.

The purpose of this experiment was to estimate the contrast level of MF and MF2 gratings for which observers are able to discriminate the waveforms from a SQ wave grating whose amplitude spectra is identical to that of the other gratings.

Methods

Three trained subjects were tested. Stimuli were generated on the face of an INFAX monochromatic monitor, using a PC Pattern Generator to create and control the waveforms. Contrast of the system was calibrated using a spot photometer (UDT#61B), and was computer corrected to achieve a linear response up to contrasts of .6.

To estimate discrimination threshold, a 2-down, 1-up staircase procedure was be employed, using the two-interval forced choice technique. In each trial, two 1 sec intervals, separated by 1 sec, were presented. One interval contained the target, and the other interval contained the comparison. The observer's task was to indicate which interval contained the target. The observer's task was to indicated which interval contained the target. At the beginning of the staircase, both target and comparison were set to equal contrasts such that discrimination was suprathreshold. After two correct responses the contrast of both gratings was reduced by .1 log units, and one incorrect response was followed by an increase of 0.1 log unit of contrast. The three discrimination conditions were SQ/MF, SQ/MF2, and MF/MF2 pairs. The first member of each was defined as the target. At the viewing distance of 32cm, 4 cycles of the stimulus corresponded to a 0.2 cy/deg grating. A 1.0 c/deg grating was created by increasing the viewing distance. Five estimates of discrimination threshold were collected for each condition at each spatial frequency. The same procedure was employed to estimate contrast threshold for sine, MF, MF2, and square stimuli at each spatial frequency.

To rule out possible stimulus artifacts from explaining the results, contrast and phase were "jittered" on each trail. That is, contrast was randomly varied within a +/- 0.1 log unit range of the specified contrast. Phase was randomly varied across 180 degrees. This jitter ensured that observers were employing only profile differences in the discrimination task.

Results and Discussion

The results were consistent with the preliminary naming data (Stephens et al, 1992). Figure 2 presents the main data, i.e. the mean contrast threshold for discrimination of SQ/MF (A), SQ/MF2 (B) and MF2/MF (C) at 0.2 and 1.0 c/deg, for BRS (the other subjects' data are qualitatively similar). As expected, the contrast at discrimination threshold was similar at 1.0 cy/deg for all pairs. At 0.2 cy/deg the contrast at discrimination threshold for the SQ/MF2 and MF2/MF pairs was roughly a factor of 2.1 lower than the MF\SQ threshold. These data suggest that the MF2 stimuli was easier to discriminate from the other stimuli, but only at low frequencies. These data also reduce the likelihood that the naming task mentioned above (Stephens et al, 1992) was biased.

<u>Experiment 2 The Effect of the Squarewave Harmonics on Contrast Sensitivity to the Fundamental</u>

The preliminary data suggest that it is easier for observers to detect the phase shift of F in the square wave grating than it is to detect its removal. Perhaps the information conveyed by the fundamental concerning the structure of the waveform is not strictly predictable from the contrast sensitivity for F. One potential explanation of this failure to predict could be that the sensitivity to F alone is different depending on the phase relationships of F and the harmonics.

To examine this possibility, contrast sensitivity for F was assessed under three stimulus conditions: alone, in the presence of the square harmonics, and in the presence of the harmonics shifted 180 out of phase.

Methods

The two interval forced-choice technique and the method of constant stimuli was used to present 3 observers with 3 to 5 contrasts of F for each viewing condition. In the alone condition, one interval contained F and the other interval was blank. In the In-phase condition, the MF was presented in one interval, and the MF + F was presented in the other interval. In the Out-of-phase condition, the MF was presented in on interval, and MF + F was presented in the other, with F 180 out-of-phase.

Three estimates per condition were used to calculate contrast threshold for 0.20 and 1.0 cy/deg. For each spatial frequency, the contrast of harmonics was set 1.5 times contrast threshold.

Results and Discussion

The results at both 0.2 and 1.0 c/deg were similar: contrast sensitivity for F was not reliably different as a function of the harmonics. Although not reliable, there was a trend for the sensitivity for F alone to be high compared to sensitivity for F in both in-phase and 180-phase conditions, but only at the 0.2 c/deg viewing condition. This result may suggest weak inhibitory effects of the harmonics at low frequencies. The absence of any effects of the phase shift of F makes an explanation of the relative salience of the illusion in the MF and MF2 gratings in terms of sensitivity to F difficult to accept. However caution is required in this case, since that conclusion is based on null results.

Experiment 3: Perceived image quality of gratings.

Cannon and Fullenkamp (1992) presented a model of image sharpness estimates that is based on their model of spatial vision (1991). The model predicted observer's judgments of image sharpness for real-world scenes that varied in contrast and were low-pass filtered by various bandwidths. Relatively small effects were associated with contrast, but larger bandwidths (higher spatial frequency content) led to higher judged sharpness. These results imply that low-frequency information is not an important aspect of image quality, to the extent the image quality is due mainly to image sharpness. We measured perceived image quality for simple gratings similar to those described above so that spatial frequency content and contrast could be easily manipulated.

Methods

Nine to 10 subjects were tested at each of two spatial frequencies (0.2 and 1.0 c/deg). Six gratings were the stimuli. Three of the gratings were simple (Sine, triangular, square). The other three represent manipulations of the fundamental (F) of the SQ grating (MF, SQ-2F = MF2, and SQ+F = SQ2). Each grating was presented at each of six contrasts ranging from near threshold to high contrast levels. Estimates of perceived image quality were obtained using a free modulus magnitude estimate technique.

Results and Discussion

Figures 3 and 4 present the results for the 0.2 and 1.0 cy/deg conditions, respectively. Image quality estimates rose gradually (0.8 log units) over the 1.5 log unit range of contrasts for all stimuli and spatial frequencies; in addition the sine and tri stimuli were judged to have lower quality than the SQ, but were similar to each other in image quality. Subtracting F from the SQ (MF grating) had little effect at 0.2 c/deg, but reduced image quality at 1.0 c/deg. Subtracting 2F (MF2) improved image quality at both 0.2 and 1.0 c/deg, relative to SQ gratings, but adding F to SQ gratings (SQ2) had less effect at 0.2 c/deg than at 1.0 c/deg. The results suggest that the effects of contrast, phase, spatial frequency, and image profile are important in judgements of image quality. Preliminary comparisons of these estimates with the Cannon and Fullenkamp (1992) models of image sharpness indicate qualitative agreement between model predictions and observed estimates. These results are particularly exciting in that they suggest the model may apply to arbitrary, abstract features.

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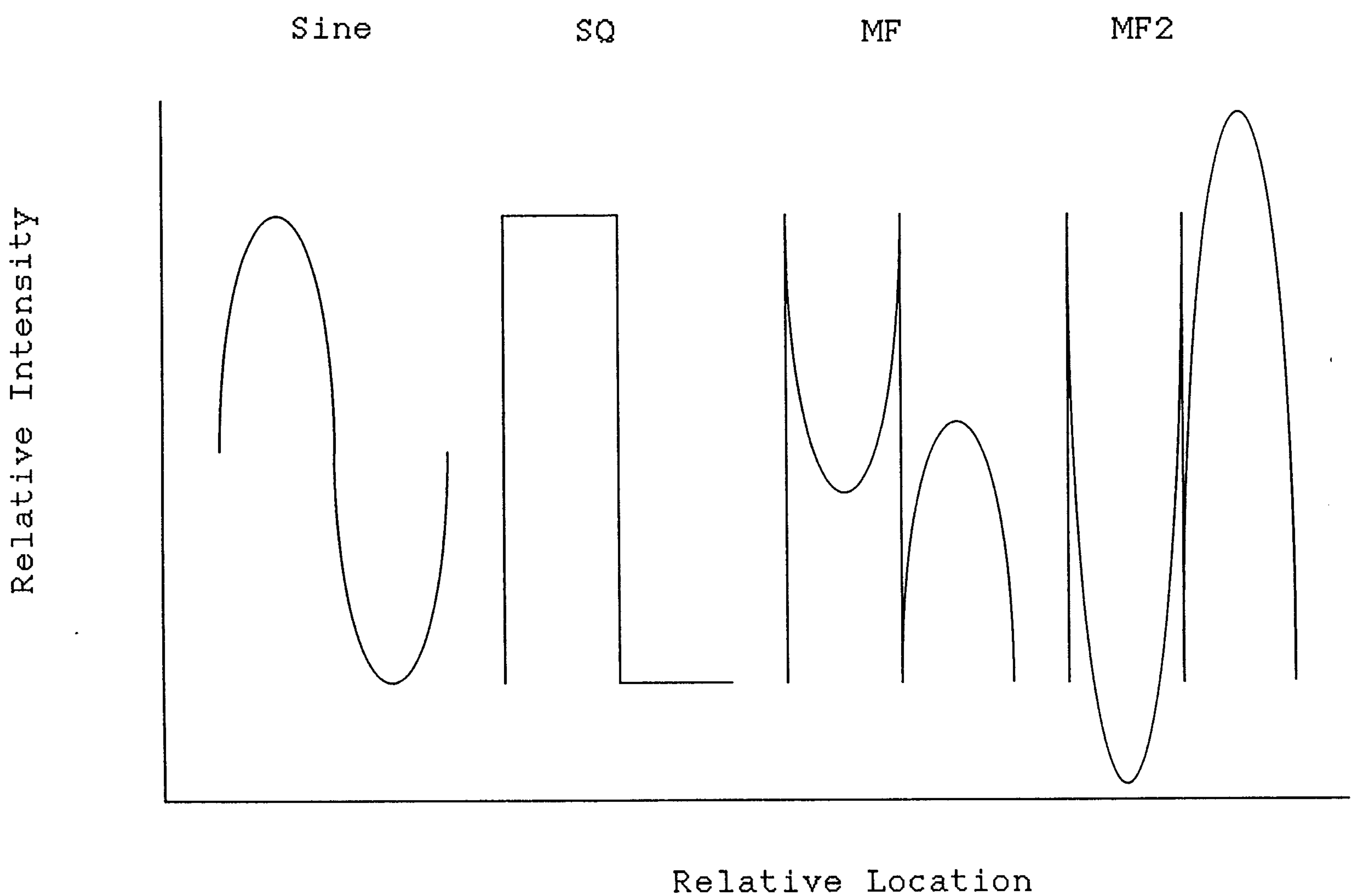


Figure 1. Intensity profiles for sine, square (SQ), missing fundamental (MF), and the phase shifted SQ (MF2). Also shown are representations of the actual stimuli.

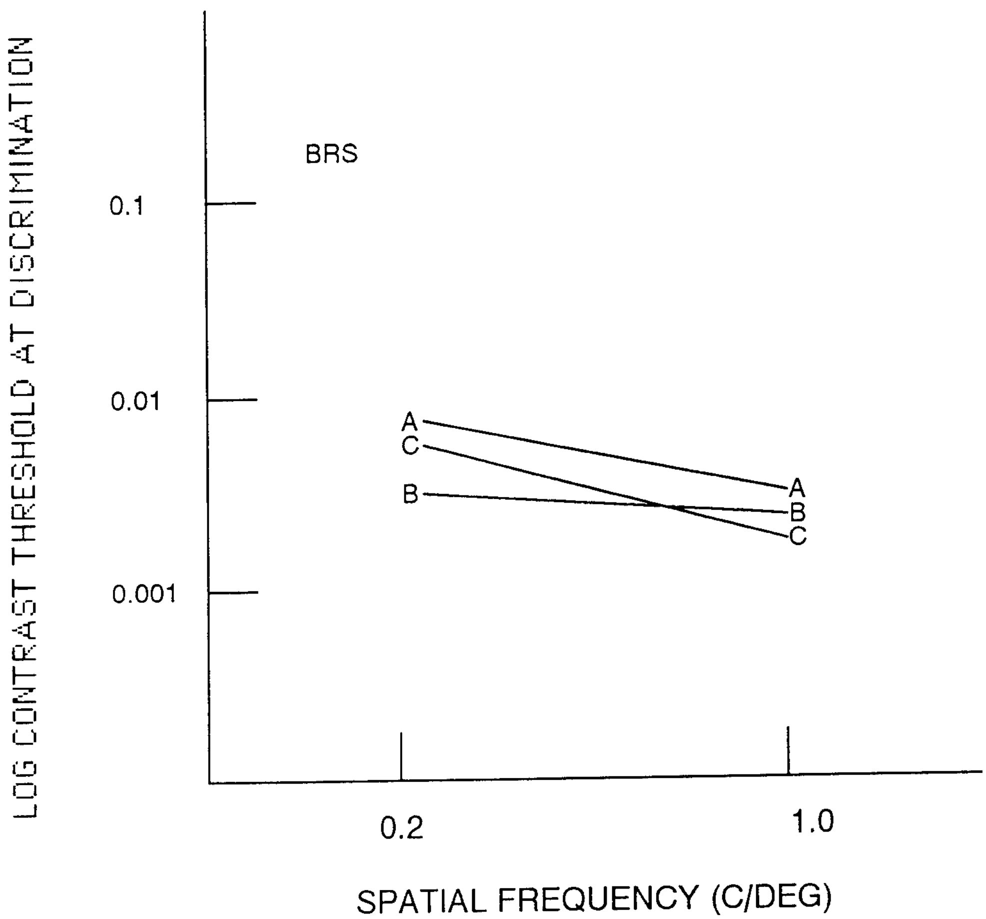
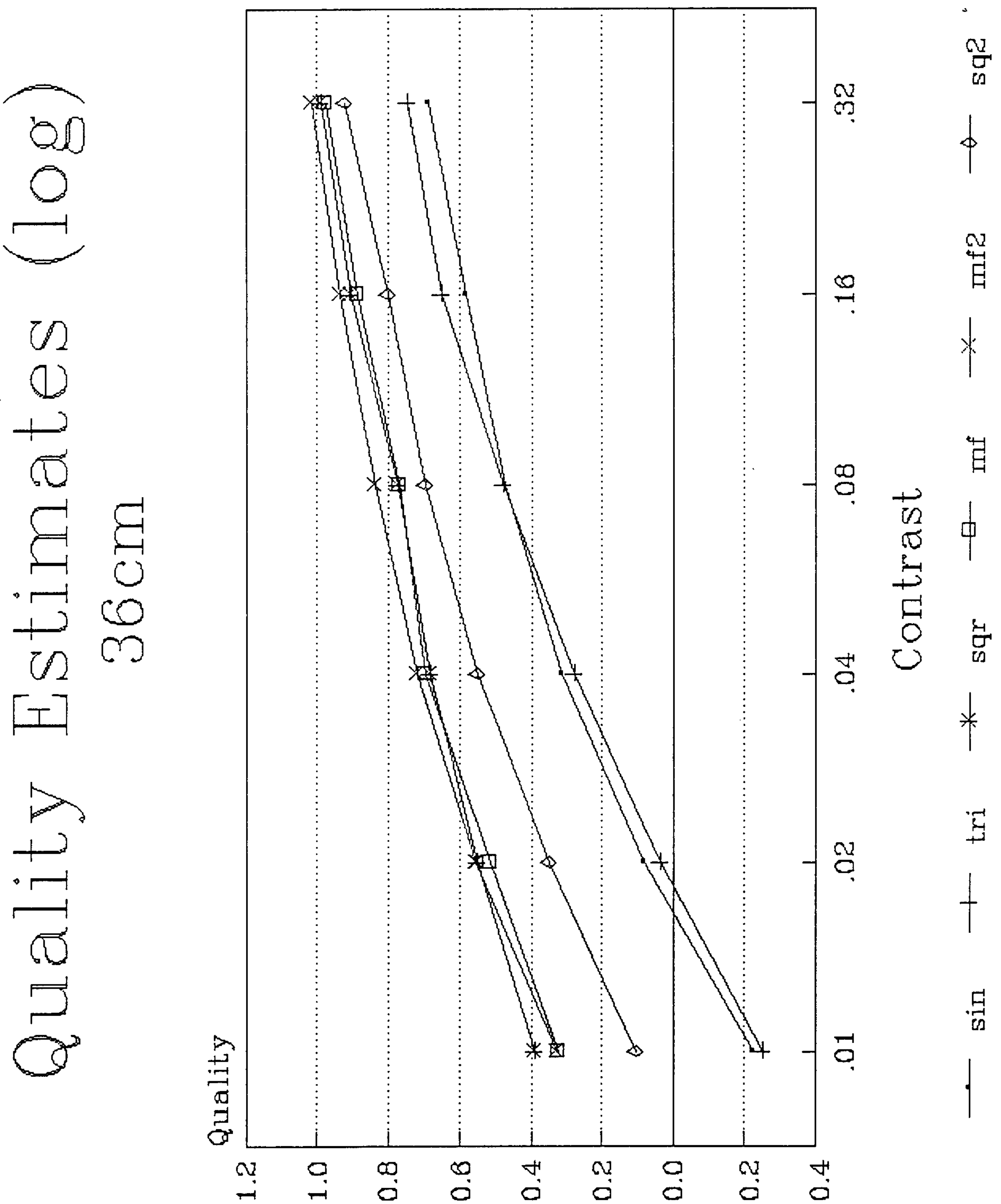
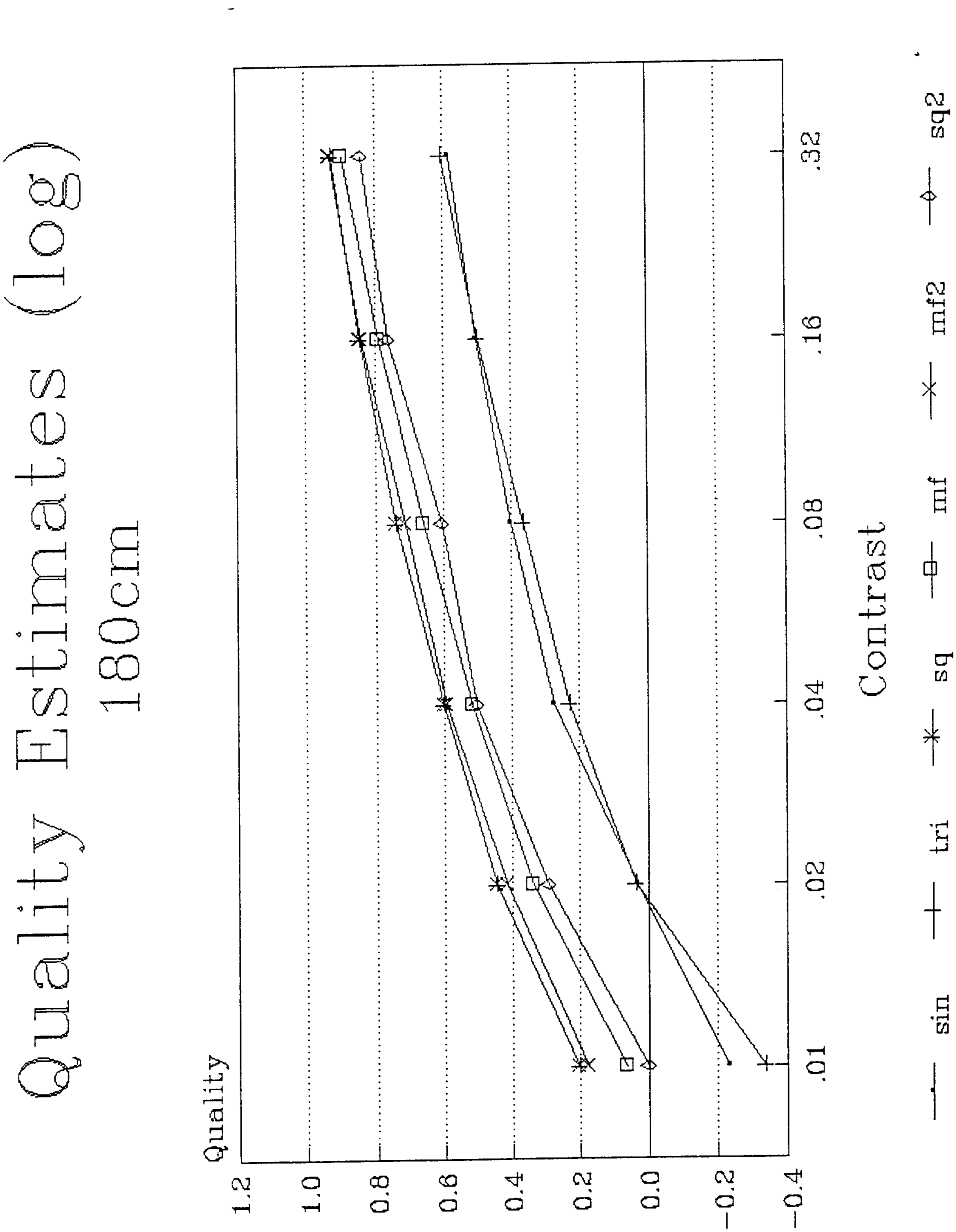


Figure 2. Contrast thresholds at for discrimination of MF/SQ (A) MF2/SQ (B) and MF/MF2 pairs (C).



Quality Estimates (log)
36cm
Quality
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
.01
.02
.04
.08
.16
.32
Contrast
sin
tri
sqr
mf
mf2
sq2


Quality Estimates (log)
180cm
Quality
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
.01
.02
.04
.08
.16
.32
Contrast
sin
tri
sq
mf
mf2
sq2

PREDICTING CHECKMARK PATTERNS IN THE AIR FORCE HEALTH STUDY

Ram C. Tripathi
Professor
Division of Mathematics, Computer Science
and Statistics

University of Texas at San Antonio
San Antonio, Texas 78249

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Ram C. Tripathi
Professor
Division of Mathematics, Computer Science, and Statistic
University of Texas at San Antonio

ABSTRACT

Problems of interpretation in the ongoing Air Force Health Study (AFHS) are discussed. This work is motivated by an assessment of health versus serum levels of 2,3,7,8-tetrachlorodibenzo-p-dioxin (dioxin) in AFHS subjects which contrasts health outcomes in three subgroups of index subjects defined by 3 intervals of dioxin levels, in parts per trillion (I_1:[0,10], I_2:(15,33.3] and I_3:(33.3,620]), with controls having dioxin levels in I:[0,10]. Letting m denote the conditional mean of the health variable in controls having dioxin levels in the interval I and m_1, m_2 and m_3 the conditional means of the health variable in the index population given that dioxin is in I_1, I_2 and I_3, necessary and sufficient conditions under which a checkmark pattern, in which the conditional means of the dependent variable are ordered as $m>m_1$, $m_1<m_2<m_3$, is expected are presented.

key words: epidemiology, dioxin.

PREDICTING CHECKMARK PATTERNS IN THE AIR FORCE HEALTH STUDY

Ram C. Tripathi

INTRODUCTION

Flanders et. al. [1] have discussed difficulties in assessing causation in cross sectional studies when the epidemiologist infers past exposure and the outcome from concurrent measurements. In particular, when a biologic marker and disease are measured concurrently, an association between the disease and the marker could arise because (a) the exposure causes the disease or (b) the disease affects the measurement of the biologic marker. The latter might occur in a study of the health consequences of exposure to a toxic chemical, for example, if the epidemiologist measures serum levels of the chemical and concurrently measured renal or hepatic impairment. An association between the level of the chemical in the serum and hepatic or renal function could reflect a detrimental effect of the chemical on hepatic or renal function or, alternatively, could reflect altered excretion, metabolism or distribution of the chemical resulting from hepatic or renal impairment.

Flanders et. al. modeled hypothesis (a) and (b), applied those models to data arising from the Air Force Health Study (AFHS) [2,3], and concluded that an observed association between concurrently measured serum levels of 2,3,7,8 tetrachlorodibenzo-p-dioxin (dioxin) and triglycerides in Air Force veterans of Operation Ranch Hand is more likely attributable to (b) rather than (a). Their conclusion was derived from the ability of model (b) and the inability of model (a) to predict a checkmark pattern of mean triglyceride values in subgroups of Ranch Hands and unexposed controls.

The purpose of this paper is to present necessary and sufficient conditions under which the checkmark pattern is expected. The pattern is expected if and only if (1) the difference of the dependent variable means (index minus control) is bounded above by a constant and if (2) there is a positive association between the marker and the health-related dependent variable in the index population and (3) the marker is appropriately categorized. A statistical model is presented which, when subjected to parametric constraints, satisfies these conditions. Several examples are given illustrating the ability of this model to predict checkmark patterns in AFHS reports.

BACKGROUND

Operation Ranch Hand was the unit responsible for aerial spraying of herbicides in Vietnam and constitutes the index group in the AFHS. The AFHS control population was selected from the population of Air Force veterans who served in Vietnam during the same period (1961 to 1972) the Ranch Hand operation was active and was matched to the Ranch Hand cohort based on age, military rank and military occupation. The controls were not occupationally exposed to dioxin in Vietnam.

There is considerable overlap between the histograms of serum dioxin concentrations of Ranch Hands and controls [2]. In fact, one half of 866 Ranch Hands have current dioxin levels at or below 12.8 parts per trillion (ppt), the 99th percentile of the control dioxin distribution. Forty percent of the Ranch Hand veterans have less than 10 ppt, the 98th percentile of the control distribution. Based on the control distribution (n=804), levels at or below 10 ppt are considered compatible with background exposure to ubiquitous sources of dioxin in the United States.

The Ranch Hand veterans had a variety of military occupations in Vietnam, some of which required no contact and some required considerable contact with herbicides and their contaminant dioxin. For example, 19 administrative officers who worked in an office have background levels (median=2.7 ppt, min=1.6 ppt, max=4.6 ppt). The enlisted ground personnel (n=399) have the highest levels (median=24 ppt, min=0 ppt, max=618 ppt) because many of them were loading bulk quantities of herbicide into aircraft tanks from holding tanks on the flightline on a daily basis. Their exposure is evident today; many have dioxin levels well in excess of background levels. For example, 45 (11.3%) of these men have current levels above 100 ppt. However, 23.3% of the enlisted ground personnel have background levels (less than or equal to 10 ppt), raising the possibility that some were not occupationally exposed to herbicides or dioxin in Vietnam. Some unexposed enlisted ground personnel are identifiable based on questionnaires administered prior to the introduction of the dioxin assay. This group contains individuals who report having no contact with herbicide because they worked in the control tower, because they had other duties that kept them far from the flight line or because they actively avoided contact with herbicide.

These data suggest that the Ranch Hand cohort is a mixture of a proportion, p, of exposed and a proportion, 1-p, of unexposed veterans. Unfortunately, because serum levels were determined in 1987, up to 25 years after their departure from Vietnam, some of the Ranch Hands with background levels may have been exposed and their dioxin body burden decayed to background levels and some were not exposed and have always had background levels of dioxin. Without additional information, current dioxin levels are not sufficient to distinguish the exposed from the unexposed Ranch Hands among those with background levels.

The proportion exposed is not estimable with available data, but based on current dioxin levels, unpublished questionnaire data and anecdotal accounts, we suspect that p is approximately 0.80. However, this figure could be as high as 0.90 and as low as 0.60. Uncertainty regarding p led Air Force investigators to exclude Ranch Hand veterans with background levels of dioxin from assessments of dose-reponse. Additional dose-response analyses were carried out excluding Ranch Hands with less than or equal to 5 ppt.

In another analysis, based on Ranch Hand and control data, three subgroups of Ranch Hands determined by dioxin level were contrasted on various health conditions and laboratory values with controls having background levels. All four categories are defined in Table 1.

Table 1

Dioxin Categories

Category Name	Definition
Background	Controls with dioxin $\leq$ 10 ppt
Unknown	Ranch Hands with dioxin $\leq$ 10 ppt
Low	Ranch Hands with 15 ppt < dioxin $\leq$ 33.3 ppt
High	Ranch Hands with dioxin > 33.3 ppt

In [2], health-related dependent variables were analyzed by testing the hypothesis of equal conditional means (or equal percent abnormal). Then the conditional means (or percent abnormal) in each of the three Ranch Hand subgroups (Unknown, Low, High) were compared with the Background mean (or percent abnormal).

In some of these analyses a checkmark pattern was observed in the conditional means defined by the strata in Table 1. An example of the pattern is given in Table 2, which gives mean percent body fat by levels of categorized dioxin.

Table 2

Checkmark Pattern of Percent Body Fat Means versus Categorized Dioxin

Dioxin Category	n	Mean Percent Body Fat
Background	786	21.91
Unknown	345	20.03
Low	196	22.15
High	187	23.55

The overall Ranch Hand and control percent body fat means are 21.58 and 21.80, a nonsignificant difference [3]. However, the four conditional means in Table 2 are significantly different ($p<0.001$) and the Unknown versus Background ($p<0.001$) and High versus Background ($p<0.001$) contrasts are significant. The Low versus Background contrast is not significant.

THE STATISTICAL MODEL

We model the relationship between the marker and a dependent variable in two cases: that the dependent variable is Gaussian and that the dependent variable is binary.

Gaussian Dependent Variables

We let X denote the marker and Y denote a dependent variable. Y and X are assumed bivariate normally distributed with density f(x,y) in the population. Hence, in the index population,

$$E(Y|X=x)=\alpha+\beta x.$$

The joint distribution of Y and X in the control population is modeled as bivariate normal with density g(x,y).

The conditional mean of Y, given that X is contained in an interval, is formulated in the Appendix in terms of the parameters of f(x,y) and g(x,y) and the marker category cutpoints. Necessary and sufficient conditions for the checkmark pattern are derived by writing $\alpha+\beta x$ in terms of bivariate normal parameters.

The checkmark pattern is the expected pattern if and only if (1) the difference of the dependent variable means (index minus control) is bounded above by a constant C_1 and if (2) the X,Y correlation in the index population is positive and (3) the marker categories are chosen so that the Background category is bounded above by a high quantile of the control marker distribution and the Unknown category is bounded above by the mean of the index marker distribution and (4) the Low and High categories are bounded below by the mean of the index marker distribution and have equal probability with respect to index marker distribution. The constant C_1 is given by the right hand side of inequality (A4) in the Appendix. If the X,Y correlation in the index population is greater than that in the control population and the variance of Y in the index population is at least as large as that in the control population, then C_1 is positive.

In the special case that the index group is unexposed and, therefore, there is no X,Y correlation, it follows from Appendix formula (A1) that the conditional and marginal means of Y coincide and there will be no checkmark pattern. Using Appendix formula (A3), one can also show that a strictly increasing trend in the conditional means is expected if the conditional mean of Y given X in the first category in the index population is greater than that in the control population and if X and Y are positively correlated in the index population.

Binary Dependent Variables

When Y is binary (abnormal: Y=1, normal: Y=0) and X is the normally distributed marker, we model $\pi(x)=P(Y=1|X=x)$ as a linear logit in X, $\text{logit}[\pi(x)]=\delta+\gamma x$, within the index population. A separate linear logit model is also assumed within the control population.

The conditional expectation of logit[$\pi(x)$], given that X is contained in an interval, is given in the Appendix in terms of the underlying parameters and the category cutpoints. Necessary and sufficient conditions for the checkmark pattern are also given.

The checkmark pattern is the expected pattern if and only if (1) the difference of mean logits (index minus control) is bounded above by a constant C_2 and if (2) the association between X and Y in the index group is positive and (3) the marker categories satisfy the same conditions as in the Gaussian case. The constant C_2 is given by the right hand side of inequality (A8) in the Appendix. If the X,Y association in the index population is greater than that in the control population and if the variance of X in the index population is greater than that in the control population, then C_2 is positive.

If the assumptions for normal discrimination hold in both populations [4], then condition (1) is equivalent to $\log(OR)<C_3$, where $OR = P_2(1-P_1)/P_1(1-P_2)$, $P_j=P(Y=1)$ in population j (Control: j=1, Index: j=2) and C_3 is given by the right hand side of inequality (A10) in the Appendix. In this case the bound will be positive if X and Y are not associated in the control population and $P_2<0.5$ [See Appendix inequality (A11)].

If the difference in means or mean logits exceed their respective upper bounds then a strictly increasing trend in conditional means or percents abnormal is predicted. If $\beta<0$ or $\gamma<0$ and the respective conditions hold then a reverse checkmark pattern is predicted.

EXAMPLE

We applied these models to databases used in the recent AFHS report of an investigation of dioxin versus health [2]. In that study, 232 health-related dependent variables were evaluated versus serum dioxin levels in 866 Ranch Hands. The controls (n=804) also had serum dioxin levels determined, of which 786 had background levels. Of the 232 dependent variables, 37 exhibited the checkmark pattern on conditional means or percent abnormal in which at least one pairwise contrast with the Background category was statistically significant. Table 3 gives the observed conditional means or percent abnormal for the 37 significant patterns. The expected means or percent abnormal were computed for each of these variables using the model and these are given. The difference (diff) of means (index minus control) or the logarithm of the odds ratio and the corresponding upper bound are also given. All but two (Percent Body Fat and Maximum PHA Response) of the 8 continuous dependent variables were log-transformed to approximate normality and these are presented in log units. Depression and the global severity index are scales derived from the Symptom Checklist-90-Revised [5]. A subject was categorized as diabetic if he was diagnosed as diabetic after return from Vietnam or if his 2 hour post prandial glucose was 200 mg/dl or more. Maximum PHA response is unadjusted for batch and day.

Table 3

Observed (OBS) and Expected (EXP) Checkmark Patterns in 37 Health-Related Dependent Variables

a) Continuous Dependent Variables

Variable (units)	Diff	Bound	Source	Conditional Mean by Dioxin Category: Bkgnd	Unkn	Low	High
Percent Body Fat (percent)	-0.42	1.46	OBS	21.9	20.0	22.2	23.6
			EXP	21.8	20.0	22.2	23.7
Log Sedimentation Rate (log mm/hr)	0.01	0.10	OBS	1.63	1.51	1.75	1.74
			EXP	1.61	1.54	1.69	1.79
Log ALT (log U/L)	0.00	0.08	OBS	3.03	2.95	3.04	3.13
			EXP	3.02	2.94	3.06	3.14

Table 3 (Continued)

Variable (units)	Diff	Bound	Source	Conditional Mean by Dioxin Category Bkgnd	Unkn	Low	High
Log GGT (log U/L)	0.02	0.09	OBS	3.47	3.36	3.56	3.61
			EXP	3.45	3.38	3.53	3.62
Log Chol/HDL	0.00	0.04	OBS	1.56	1.50	1.60	1.62
			EXP	1.55	1.51	1.57	1.62
Log Triglycerides (log mg/dl)	0.02	0.10	OBS	4.76	4.64	4.94	4.91
			EXP	4.74	4.67	4.83	4.94
Log 2 Hr PP Glucose (log mg/dl)	-0.01	0.03	OBS	4.71	4.68	4.70	4.74
			EXP	4.71	4.68	4.72	4.74
Maximum PHA Response (CPM/1000)	-0.06	0.15	OBS	109.4	106.2	107.1	113.5
			EXP	110.0	106.5	110.0	112.5
Log IgA (log mg/dl)	-0.03	0.04	OBS	5.36	5.27	5.35	5.38
			EXP	5.35	5.29	5.34	5.38
FEV1/FVC	0.00	-0.06	OBS	0.81	0.80	0.81	0.84
			EXP	0.81	0.80	0.82	0.83
FVC % Predicted (percent/100)	-0.01	-0.02	OBS	0.976	0.991	0.960	0.939
			EXP	0.976	0.984	0.960	0.944
PHA Net Response Concentration 2			OBS	1.76	1.62	1.84	1.95
(counts per minute)	-0.03	0.14	EXP	1.76	1.59	1.79	1.92
Fasting Glucose (mg/dl)	0.01	0.03	OBS	99.52	98.30	100.70	105.12
			EXP	99.18	98.08	101.95	104.70
Testosterone (ng/dl)	0.017	-0.39	OBS	525.26	554.17	525.62	515.00
			EXP	530.95	552.17	524.50	505.88
T3 % Uptake (percent)	-0.01	-0.01	OBS	30.65	30.66	30.35	30.03
			EXP	30.64	30.65	30.36	30.16
HDL (mg/dl)	0.01	-0.04	OBS	44.98	47.81	43.60	43.07
			EXP	45.31	47.18	44.75	43.15
Direct Bilirubin** (mg/dl)	0.03	0.03	OBS	0.1495	0.1480	0.1566	0.1712
			EXP	0.1493	0.1493	0.1588	0.1655

Table 3 (Continued)

Variable (units)	Diff	Bound	Source	Conditional Mean by Dioxin Category: Bkgnd	Unkn	Low	High
MCMI Psychotic Thinking Score (score)	-0.88	2.01	OBS	32.62	30.11	31.88	36.74
			EXP	32.43	29.48	32.36	34.35
MCMI Anxiety Score (score)	-0.94	1.41	OBS	47.18	44.05	46.36	49.26
			EXP	46.69	44.63	46.76	48.23
MCMI Schizotypal Score (score)	0.02	2.21	OBS	33.88	31.94	34.05	38.38
			EXP	33.22	31.41	34.73	37.01
MCMI Narcissistic Score (score)	0.06	-0.15	OBS	64.0	66.0	65.5	62.1
			EXP	64.3	66.3	64.0	62.5
MCMI Histrionic Score (score)	-1.23	-1.89	OBS	64.41	64.63	63.22	60.89
			EXP	64.81	65.08	62.86	61.30
MCMI Avoidant Score (score)	0.01	0.10	OBS	16.27	14.98	16.79	19.08
			EXP	15.76	14.61	17.02	18.89
MCMI Schizoid Score (score)	0.02	0.07	OBS	23.74	22.68	24.90	27.93
			EXP	23.39	22.37	24.96	26.92

b) Binary Dependent Variables

Variable	Diff	Bound	Source	Percent Abnormal by Dioxin Category: Bkgnd	Unkn	Low	High
Benign Systemic Neoplasm	-0.06	0.45	OBS	6.0	4.1	4.6	10.2
			EXP	5.8	3.6	6.1	8.6
Depression	0.15	0.33	OBS	7.2	6.5	7.6	13.2
			EXP	7.1	6.1	9.1	11.9
Global Severity Index	0.23	0.46	OBS	6.1	5.1	7.6	12.6
			EXP	6.4	5.0	8.5	12.0
Hyperpigmentation	-0.14	0.13	OBS	16.0	11.0	14.3	19.8
			EXP	16.4	12.6	14.7	16.3
Diabetic	0.19	0.47	OBS	8.2	5.5	8.3	16.6
			EXP	7.1	6.1	10.4	14.7

Table 3 (Continued)

Variable	Diff	Bound	Source	Percent Abnormal by Dioxin Category Bkgnd	Unkn	Low	High
Mild Obstructive Abormality			OBS	21.37	28.78	24.49	15.51
(percent)	0.22	-0.27	EXP	21.19	30.60	22.66	18.11
Verified Heart Disease	0.05	-0.21	OBS	37.98	44.37	37.29	26.45
(percent)			EXP	37.41	44.30	36.79	32.05
Abnormally High Cholesterol			OBS	11.17	16.13	12.95	12.37
(percent)	0.029	-0.11	EXP	11.24	16.10	14.15	12.93
Other Liver Disorder	0.17	0.39	OBS	7.08	5.85	9.18	11.76
(percent)			EXP	7.13	5.67	8.96	12.13
SCL-90-R Positive Symptom Total			OBS	6.09	5.10	7.02	11.38
(percent)	0.12	0.37	EXP	5.40	4.75	7.75	10.76
SCL-90-R Obsessive Compulsive			OBS	6.38	4.42	8.77	10.78
(percent)	0.09	0.35	EXP	6.37	5.08	7.88	10.55
SCL-90-R Anxiety	0.23	0.42	OBS	5.36	4.42	7.60	10.78
(percent)			EXP	5.63	4.46	7.33	10.19
Frightening Dreams	0.21	0.33	OBS	3.08	2.35	2.58	8.20
(percent)			EXP	2.88	2.73	4.26	5.74

In all cases the bound was positive and exceeded the difference in means or the logarithm of the odds ratio and the checkmark pattern was predicted. All of the remaining 23 significant patterns are also predicted by the model.

Because Flanders et. al. reverse-order model (b) depends on a mechanism under which triglycerides or percent body fat alter the measured serum dioxin levels [1], and because that model also predicts the checkmark pattern for triglycerides or percent body fat, it might also be justifiably applied to explain the checkmark pattern in variables correlated with triglycerides or percent body fat. Table 4 summarizes the correlations between triglyerides and each of the 8 other continuous variables given in Table 3. One of these 8, log IgA, is uncorrelated with log triglycerides. Maximum PHA response is correlated with triglycerides in the Ranch Hand but not in the control population.

Table 4

Correlations between Triglycerides and 8 Continuously Distributed Variables Exhibiting the Checkmark Pattern

	Correlation*		
Variable	Ranch Hands (n=866)	Comparisons (n=804)	All Subjects (n=1670)
Percent Body Fat	0.27*	0.31*	0.29*
Log Sedimentation Rate	0.26*	0.21*	0.24*
Log ALT	0.23*	0.29*	0.26*
Log GGT	0.29*	0.27*	0.28*
Log Chol/HDL	0.64*	0.66*	0.65*
Log 2 Hr PP Glucose	0.36*	0.37*	0.36*
Maximum PHA Response	0.11*	-0.06	0.03
Log IgA	0.03	0.04	0.03

* statistically significant ($p<0.05$)

The logarithm of triglycerides was unassociated with one (Hyperpigmentation) of the 5 binary variables for which the checkmark pattern was observed. These assessments of association were carried out with t-tests on log triglyceride means and are summarized in Table 5.

Table 5

Log Triglycerides versus Binary Variables
Exhibiting the Checkmark Pattern

Mean Log Triglyceride by Group and Level
of the Binary Variable

Variable	Ranch Hands (n=866) Abn	Ranch Hands (n=866) Nor	Controls (n=804) Abn	Controls (n=804) Nor	All Subjects (n=1670) Abn	All Subjects (n=1670) Nor
Benign syst neopl	4.6	4.8*	4.7	4.8	4.6	4.8*
Depression	4.9	4.8*	4.8	4.8	4.9	4.8
Global Sev Index	4.9	4.8	4.9	4.8	4.9	4.8*
Hyperpigmentation	4.7	4.8	4.8	4.8	4.8	4.8
Diabetic	5.3	4.7*	5.1	4.7*	5.2	4.7*

* statistically significant ($p<0.05$).

To summarize, the statistical model explains all checkmark patterns, regardless of their association with triglycerides, and Flanders et. al. reverse order model (b) explains the triglyceride and percent body fat pattern and, perhaps, other patterns associated with triglycerides or percent body fat.

DISCUSSION

We have posed a standard dose-response model, a linear model for normally distributed dependent variables and a linear logit model for binary dependent variables, on index (Ranch Hand) data. Using this model, we have formulated the conditional expectation of a health-related variable given that the marker is contained in an interval. This formula was applied to all 37 variables for which a significant checkmark pattern was observed in the last Air Force report [2]. In these applications, we estimated the other parameters directly from the data. The algorithm predicted all 37 patterns.

Analyses of the 37 dependent variables for which significant checkmark patterns were observed found no significant group difference (Ranch Hand versus comparisons). These negative findings might be due to some Ranch Hands not being occupationally exposed to dioxin. It was this possibility that motivated the exclusion of Ranch Hand veterans with background dioxin levels from dose-response analyses and the categorization of Ranch Hands with background levels to the Unknown category. That Ranch Hands in the Unknown category should have a lower health variable mean than controls in the Background category is predicted by the model, but may not be obvious. The checkmark pattern may, therefore, distract attention from the most important High versus Background contrast. In this regard, we view the checkmark pattern as an unfortunate statistical artifact.

The prediction of the checkmark pattern in lipid-related variables by model (b) suggests that there may be a reverse order dose-response relationship between lipid-related variables and measured dioxin. That the reverse-order and our model both predict the pattern for lipid-related variables implies that prediction is not sufficient to distinguish one over the other. However, our statistical model explains all 37 statistically significant checkmark patterns, some of which were based on variables unrelated to triglycerides. It appears possible, therefore, that the checkmark pattern might be due to a combination of some index subjects being unexposed and a correlation between health and dioxin levels in exposed index subjects.

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APPENDIX

Let X and Y be bivariate normally distributed with $EX=\mu_x$, Var $X=\sigma_x^2$, $EY=\mu_y$, Var $Y=\sigma_y^2$, with correlation coefficient ρ, $\rho>0$. Then the conditional distribution of Y given X=x is Gaussian with

$$E(Y|X=x)=\mu_y+\rho\sigma_y(x-\mu_x)/\sigma_x \tag{A1}$$

and $\mathrm{Var}(Y|X=x) = \sigma_y^2(1-\rho^2)$. Let $a<b$. Then

$$E(Y|a<X\leq b) = E[E(Y|X=x)|a<X\leq b]$$

$$= \frac{1}{\sigma_x[\Phi(B)-\Phi(A)]}\frac{1}{\sqrt{2\pi}}\int_a^b [\mu_y+\rho\sigma_y(x-\mu_x)/\sigma_x]\exp[-(x-\mu_x)^2/2\sigma_x^2]dx$$

$$=\mu_y+\rho\sigma_y[\phi(A)-\phi(B)]/[\Phi(B)-\Phi(A)], \tag{A2}$$

where $A=(a-\mu_x)/\sigma_x$, $B=(b-\mu_x)/\sigma_x$, ϕ is the standard normal density and Φ is the standard normal distribution function.

Let $b>0$. Then, using (A2), with $a=-\infty$,

$$E(Y|X\leq b) = \mu_y-\rho\sigma_y\phi(B)/\Phi(B). \tag{A3}$$

Let the control and index populations be labeled by 1 and 2.

Then, $E_1(Y|X\leq b)>E_2(Y|X\leq b)$ if and only if

$$\mu_{y2}-\mu_{y1} < \rho_2\sigma_{y2}\phi(B_2)/\Phi(B_2)-\rho_1\sigma_{y1}\phi(B_1)/\Phi(B_1) \tag{A4}$$

Assuming $\rho_2>\rho_1$ and $\sigma_{y2}\geq\sigma_{y1}$, the right hand side of (A4) is positive if

$$\rho_2\sigma_{y2}\phi(B_2)/\Phi(B_2) > \rho_1\sigma_{y1}\phi(B_1)/\Phi(B_1),$$

that is, if

$$\phi(B_2)/\Phi(B_2) > \phi(B_1)/\Phi(B_1). \tag{A5}$$

Because $\phi(x)/\Phi(x)$ is strictly decreasing, condition (A5) is satisfied if, for example, b is a high quantile of the control X distribution and a low quantile ($\Phi(B_2)<0.50$) of the index distribution. These conditions are met in the AFHS data with $\mu_{x1}=1.87$, $\sigma_{x1}=1.36$, $\mu_{x2}=3.86$, $\sigma_{x2}=1.65$, $b=\log_2(10)$, $\Phi(B_2)=0.40$ and $\Phi(B_1)=0.98$.

The monotonicity, $E_2(Y|a<X\leq b)<E_2(Y|c<X\leq d)<E_2(Y|e<X\leq f)$, with $a<b\leq c<d\leq e<f$, is satisfied when

$$\frac{\phi(A_2)-\phi(B_2)}{\Phi(B_2)-\Phi(A_2)} < \frac{\phi(C_2)-\phi(D_2)}{\Phi(D_2)-\Phi(C_2)} < \frac{\phi(E_2)-\phi(F_2)}{\Phi(F_2)-\Phi(E_2)}, \tag{A6}$$

where $A_2=(a-\mu_{X2})/\sigma_{X2}$, $B_2=(b-\mu_{X2})/\sigma_{X2}$, $C_2=(c-\mu_{X2})/\sigma_{X2}$, $D_2=(d-\mu_{X2})/\sigma_{X2}$, $E_2=(e-\mu_{X2})/\sigma_{X2}$ and $F_2=(f-\mu_{X2})/\sigma_{X2}$. There are many cutpoint patterns for which (A6) holds. In particular, (A6) holds when $a=-\infty$, $\Phi(B_2)<0.50$, $\Phi(C_2)>0.50$ and $\Phi(D_2)-\Phi(C_2)=\Phi(F_2)-\Phi(E_2)$. These conditions are met by the AFHS cutpoints ($a=-\infty$, $b=\log_2(10)$, $c=\log_2(15)$, $d=e=\log_2(33.3)$, $f=\infty$). In the AFHS study, $b<\mu_{X2}<c$ and d was the median $\log_2$(dioxin) level among subjects with $\log_2$(dioxin) greater than c.

Let $\pi(x)=P(Y=1|X=x)$ and $\text{logit}[\pi(x)]=\delta+\gamma x$. Then

$$E[\text{logit}[\pi(X)]|a<X\leq b] = E[E(\text{logit}[\pi(X)]|X=x)|a<X\leq b]$$

$$= \frac{1}{\sigma_X[\Phi(B)-\Phi(A)]}\frac{1}{\sqrt{2\pi}}\int_a^b(\delta+\gamma x)\exp[-(x-\mu_X)^2/2\sigma_X^2]dx$$

$$= \delta+\gamma\mu_X+\gamma\sigma_X[\phi(A)-\phi(B)]/[\Phi(B)-\Phi(A)], \tag{A7}$$

where $A=(a-\mu_X)/\sigma_X$, $B=(b-\mu_X)/\sigma_X$.

Let 1 label the control and 2 label the index population and let $\gamma>0$. Then, using (A7), with $a=-\infty$,

$$E_j(\text{logit}[\pi(X)]|X\leq b) = \delta_j+\gamma_j\mu_{Xj}-\gamma_j\sigma_{Xj}\phi(B_j)/\Phi(B_j),\ j = 1,2.$$

Then $E_1(\text{logit}[\pi(X)]|X\leq b)>E_2(\text{logit}[\pi(X)]|X\leq b)$ if and only if

$$\text{logit}[\pi(\mu_{X2})]-\text{logit}[\pi(\mu_{X1})] < \gamma_2\sigma_{X2}\phi(B_2)/\Phi(B_2)-\gamma_1\sigma_{X1}\phi(B_1)/\Phi(B_1). \tag{A8}$$

Assuming $\sigma_{X2} \geq \sigma_{X1}$ and $\gamma_2 \geq \gamma_1$, then the right hand side of (A8) is positive when

$$\phi(B_2)/\Phi(B_2) > \phi(B_1)/\Phi(B_1),$$

which is the same as condition (A5).

The monotonicity,

$$E_2(\text{logit}[\pi(X)] \mid a<X\leq b) < E_2(\text{logit}[\pi(X)] \mid c<X\leq d) < E_2(\text{logit}[\pi(X)] \mid e<X\leq f),$$

with $a<b\leq c<d\leq e<f$ is satisfied when

$$\frac{\phi(A_2)-\phi(B_2)}{\Phi(B_2)-\Phi(A_2)} < \frac{\phi(C_2)-\phi(D_2)}{\Phi(D_2)-\Phi(C_2)} < \frac{\phi(E_2)-\phi(F_2)}{\Phi(F_2)-\Phi(E_2)},$$

which is the same as condition (A6).

Let $P_j=P(Y=1)$ in population j and $OR=P_2(1-P_1)/[P_1(1-P_2)]$. Assume that the conditions for normal discrimination hold and let $\Delta_j=$ the square root of the Mahalanobis distance between the Y=1 and Y=0 subpopulations in population j [4]. Then condition (A8) holds if and only if

$$\log(OR)<\Delta_2\sqrt{1+\Delta_2^2 P_2(1-P_2)}\ \phi(B_2)/\Phi(B_2)-\Delta_1\sqrt{1+\Delta_1^2 P_1(1-P_1)}\ \phi(B_1)/\Phi(B_1)$$
$$-\Delta_2^2(P_2-0.5)+\Delta_1^2(P_1-0.5) \qquad \text{(A9)}$$

If $\gamma_1=0$ ($\Delta_1=0$), then (A9) reduces to

$$\log(OR)<\Delta_2\sqrt{1+\Delta_2^2 P_2(1-P_2)}\ \phi(B_2)/\Phi(B_2)-\Delta_2^2(P_2-0.5). \qquad \text{(A10)}$$

In this special case, the right hand side of (A10) is positive if and only if

$$\Delta_2\sqrt{1+\Delta_2^2 P_2(1-P_2)}\ \phi(B_2)/\Phi(B_2) > \Delta_2^2(P_2-0.5), \quad \text{(A11)}$$

and (A11) always holds if $P_2<0.5$.