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USER'S GUIDE TO BIODYN-801 AN INTERACTIVE SOFTWARE PACKAGE FOR --ETC(U)

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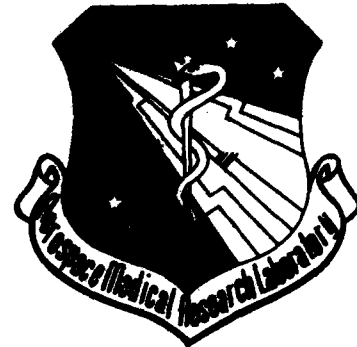
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**USER'S GUIDE TO BIODYN-80;  
AN INTERACTIVE SOFTWARE PACKAGE FOR  
MODELING BIODYNAMIC FEEDTHROUGH TO  
A PILOT'S HANDS, HEAD, AND EYES**

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**AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY  
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## TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



HENNING E. VON GIERKE  
Director  
Biodynamics and Bioengineering Division  
Air Force Aerospace Medical Research Laboratory

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><p>This is the User's Manual for BIODYN-80, an interactive computer program for solving the dynamic motion response of seated aircrew (pilots or equipment operators) working in a biodynamic environment (such as vibration or changing levels of acceleration in aircraft, surface vehicles, or motion simulators). The multi-degree-of-freedom, lumped-parameter model includes elements for: pelvis, torso, neck, head, eyes, upper and lower arms, hand-grip and control stick (center-stick with arm rest). An active 21-parameter neuromuscular system is operable with either the limb or head control. The eye's image</p> |                                                                                     |                                               |

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## 20. ABSTRACT (continued)

motion dynamics include a 13-parameter model for the fixation and vestibulo-ocular reflexes. The nonlinear equations of motion of the body's main elements are linearized about a general set of body-limb-head postures, ranging from prone, to erect, to supine. Inputs are vertical or fore-aft accelerations of the seat, while a wide variety of outputs are available, including motions of the shoulder, head, eyes, arm, hand, or control stick. Typical parameter ranges and sources are given, along with two "typical" sets: a seated-pilot with center-stick, and a seated crewman with hands in lap.

The program can be run in a mode interactive with the user, or in a batch mode. The program helps the user load the necessary parameters, and offers a "quick-look" printer plot of the resulting frequency responses, in standard Bode-plot forms. The program also can produce biomechanical transmissability files needed for use in the Air Force's PIVIB program for tracking performance estimation.

Procedures and examples are given for both a Cyber 175 version available on "INTERCOM" for Wright-Patterson Air Force Base users, and a PDP-10 version, available on the Tymshare national computer network for other users.

# PREFACE

This report was prepared by Systems Technology, Inc., Hawthorne, California, under Contract F33615-79-C-0519, for the Air Force Aerospace Medical Research Laboratory (AFAMRL). Mr. Charles Harmon, Biodynamic Effects Branch of the Biodynamics and Bioengineering Division, served as the technical monitor for AFAMRL in support of Project 2312-V3-20, "Man-Machine Interface Model."

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## **INTRODUCTION**

### **A. SCOPE**

BIODYN-80 is a versatile computational tool used to determine transmissibilities (transfer functions) between vertical and/or fore-aft vibrational inputs and important biodynamic outputs, such as motions of the torso, head, eyes, arms or hands. The program scenario assumes a seated pilot, gripping an arbitrary-angle stick and viewing a display, possibly engaged in a tracking task. The physical model uses an "isomorphic," (lumped parameter,) approach to represent the relevant portions of the whole-body torso, limbs and head, as well as postural compliances among the joints. The implementation of this model includes a chain of interacting parallel and serial second-order elements, with neuromuscular and other force feedbacks at the arm or head. The resulting equations are in "second-order element" matrix form and apply to a wide range of seated postures. A separate input file, which describes the particular set of parameters to be used, is created by the user (usually by modifying one of a cataloged set). This file is incorporated in the matrix to produce linearized coefficients for perturbations about the selected equilibrium posture. A variety of outputs and inputs can be specified to evaluate the desired transmissibility transfer functions, and these are written to a file in formatted form for plotting or use in other programs. On-line, printer-drawn frequency response plots (Bode format) are available to aid in interactive user-computer operations, or to screen significant results from batch runs.

### **B. BACKGROUND**

BIODYN-80 is one result of a several year small-scale development effort, reported in detail in References 1-6. It is based on vibration

measurements made at the Aerospace Medical Research Lab/Biodynamics Division (AMRL/BB) and elsewhere. Most of the torso, limb and stick model elements are based on independent vibration measurements (e.g., Reference 5), and the neck, head and eye effects show promising correlations with the few available measurements on image motion effects (Reference 6). However, many aspects remain to be explored, validated or upgraded as more experiments are run and interpreted via BIODYN-80.

### C. APPLICATIONS

The possible applications of this program are many. It should be used in the early stages of experimental design for determining the optimal locations for vibration measurements and/or selection of frequencies. It can also be used by development engineers for solving practical pilot-vehicle interface design problems such as pilot-induced oscillations and for optimizing design alternatives such as seat location, orientation and suspension parameters. Flight control system designers can make use of BIODYN-80 output in optimizing vehicle/ aircrew ride qualities and visual performance effects, possibly incorporating anti-vibration devices to improve the design.

One further application of BIODYN-80 deserves special mention. Its vibration-input to biodynamic parameter-output transfer functions are ideally suited as input to PIVIB, another software package which relates pilot tracking performance to the vibration environment (Reference 7). PIVIB accepts biomechanical transfer functions in the format created by BIODYN-80. The details of the BIODYN-80/PIVIB interface will be found in a later section.

The remainder of this report details the use of BIODYN-80, and describes the model and the equations comprising it. Detailed instructions for the creation of the required input files, and a complete example problem are also included.

## SOFTWARE OVERVIEW

Figure 1 is a functional block diagram description of the elements in BIODYN and its interface with PIVIB. The BIODYN-80 package is composed of three programs. The first, called CREATE,\* interactively sets up the two input files used by BIODYN. The second program called BIODYN, is the actual "number cruncher," which structures and solves the biomechanical equations and computes the desired transfer functions. The third program called PLOT, accepts the file of BIODYN transfer functions, prints selected ones in a form readily comprehended by the user, and prepares "quick plot" Bode plots on the line printer, to facilitate a visual interpretation of the transfer function information. Both BIODYN and PLOT are designed primarily as batch programs while, CREATE permits conversational user interaction in structuring input data.

A subsequent link in this series of programs is PIVIB. It is a large batch program with three modules. The first, BDMOD, computes the response behavior of the various biomechanical subsystems. The second, PVMOD, uses the results of BDMOD and the BBN optimal control model to estimate pilot tracking performance within the vibration environment. The final module, VEXEC, provides the top level communication interface between BDMOD and PVMOD, and performs no actual computation. The BDMOD module expects biodynamic transfer functions in a format generated by BIODYN. Only the relationships of BIODYN-80 to PIVIB are described herein, because PIVIB is run separately and has its own User's Manual (Reference 7).

Figure 2 presents a flow chart covering the use of BIODYN and PIVIB in a given session. The detailed description of the various steps for BIODYN is found in Section D. Note that the flow of execution can be

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\*The CREATE program should not be confused with INTERCOM's EDITOR subcommand CREATE; it has been given the permanent file name EXECRT to distinguish it from the latter.

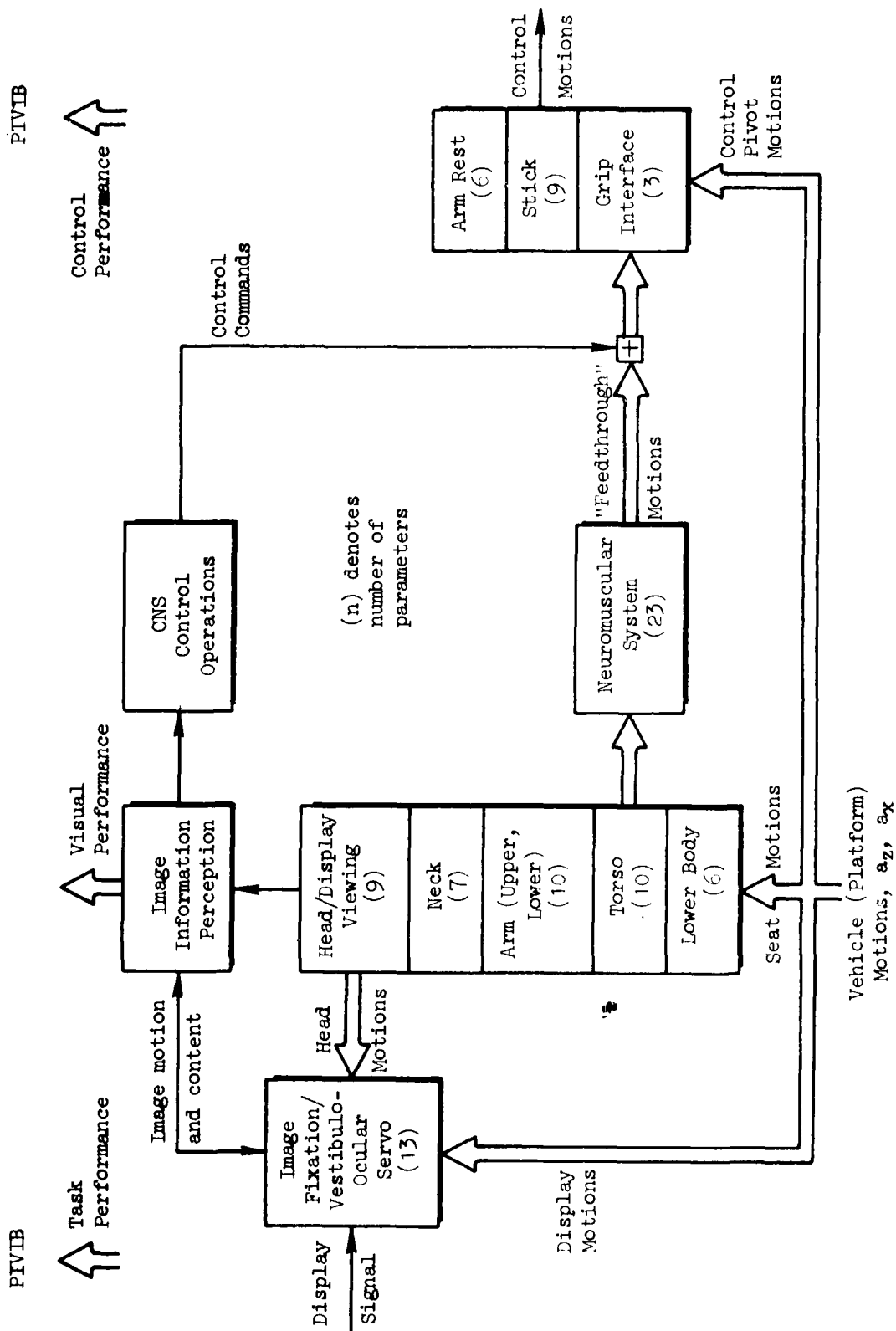


Figure 1 Overview of BIODYN-80

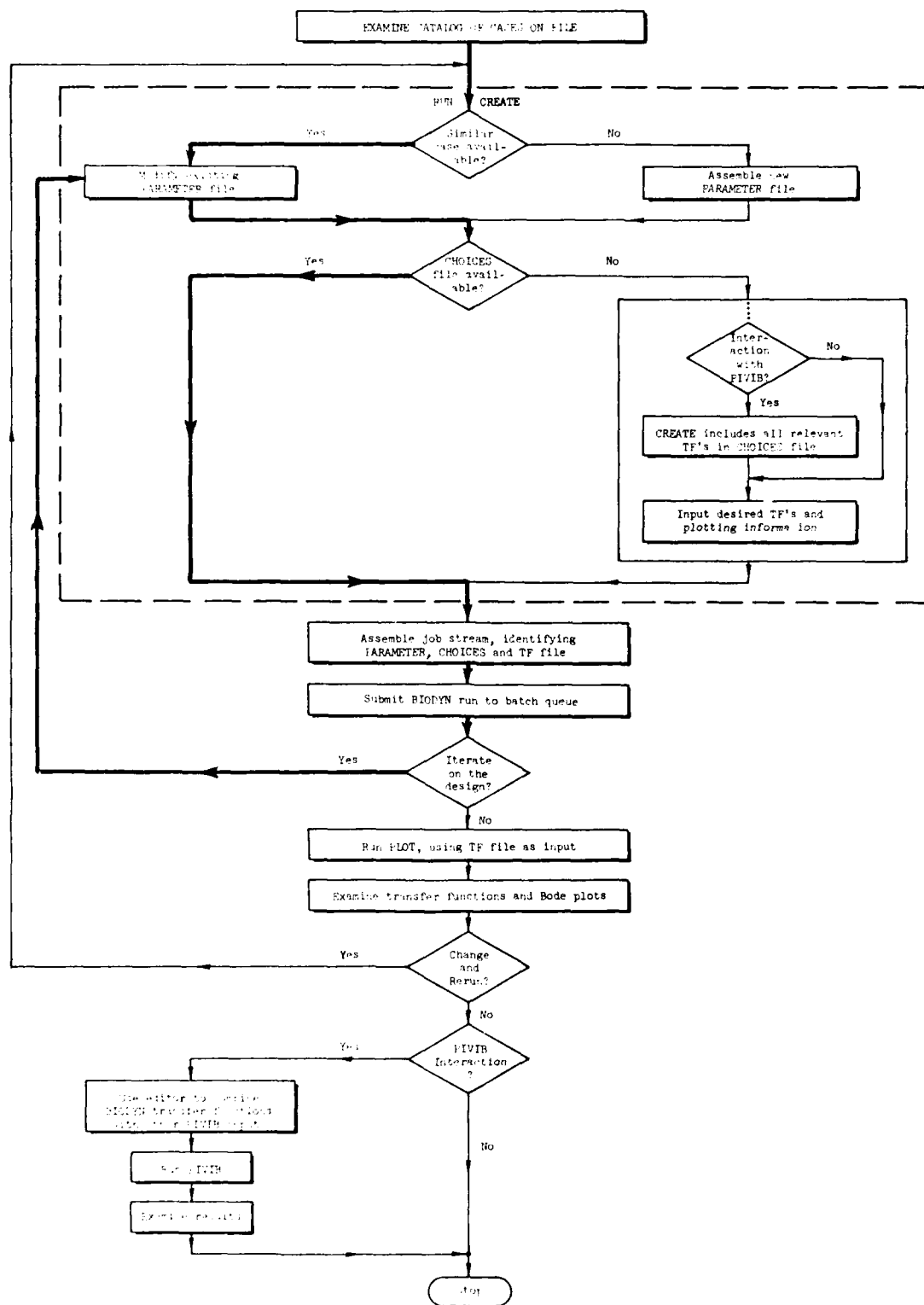


Figure 2 BIODYN-80 Flow Chart

used to solve a single problem, by submitting a single batch request, or to iterate on a design by submitting a number of batch requests using the same CHOICES file and slightly altered PARAMETER files (heavy lines in Figure 2).

BIODYN-80 uses three separate files in performing its computations. The PARAMETER file contains the set of 96 parameters used to define the specific pilot/posture/display/vibration characteristics. Appendix A contains a complete description of each parameter, including definition, mnemonic, nominal value, recommended range of values and reference (where available). CREATE is used to assemble this file and can modify an existing file or produce an entirely new file. The CHOICES file contains the list of desired transfer functions to be computed and output by BIODYN, as well as directives for producing the line printer Bode plots. Again, this CHOICES file is assembled by CREATE. Finally, the TF file is used to store the resulting transfer functions output by BIODYN, and is read by the PLOT routine for generating Bode plots.

PIVIB employs a single large file to direct its flow of execution. This file defines the vibration environment, biomechanical transfer functions, tracking dynamics, tracking performance requirements, and pilot limitations (bandwidths, time delays, etc.). Currently, this file is assembled in the editor, using output from BIODYN-80 if desired.

BIODYN-80 and each of its predecessors were developed on the Tymshare, Inc., PDP-10 computers. BIODYN-80 has been adapted to the CDC "Intercom" System on the CDC 6600 or CYBER 175 at WPAFB in order to increase its availability to Air Force users, and to interact with PIVIB, which is also operable on the WPAFB CDC computer. The details of this manual will address its use on the CDC machine; an example of a Tymshare session is given in Appendix D. Throughout the manual, however, it is assumed that the user is familiar with the WPAFB CYBER 175, and in particular has experience with the INTERCOM operating system. If not, the user should read References 8 and 9 first.

## MODEL DESCRIPTION

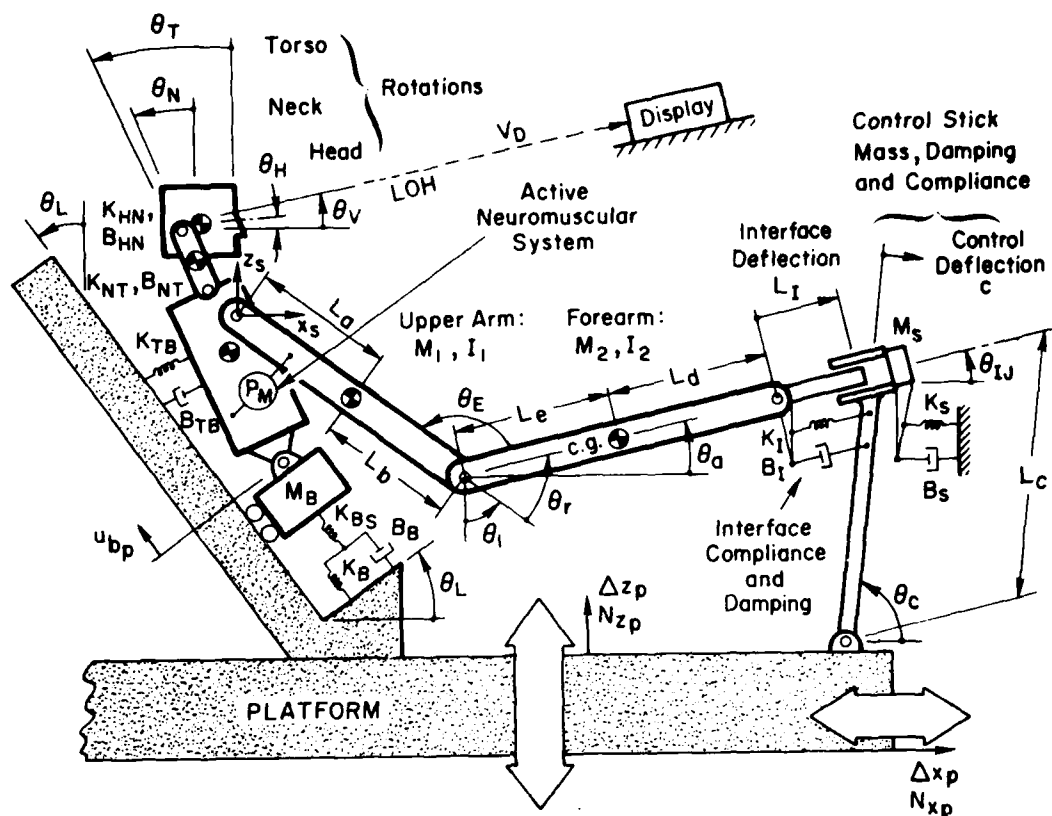
Three distinct subsystem models are included in BIODYN-80. They are described individually below.

### A. BIOMECHANICAL MODEL

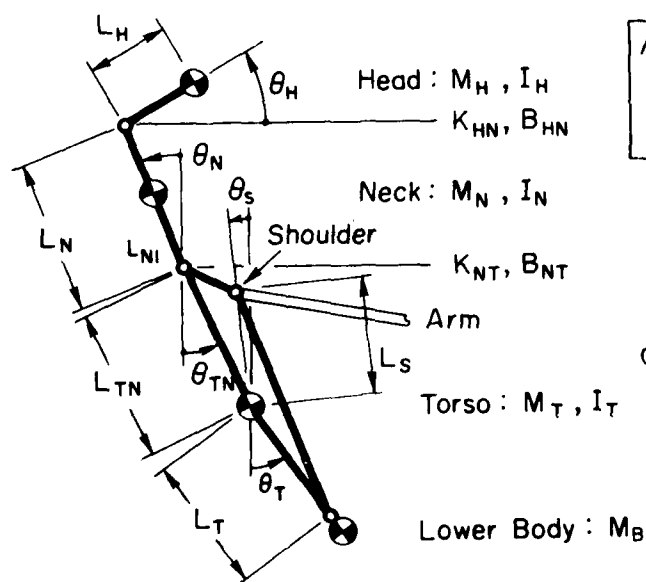
Figure 3 (updated from Figure 2 of Reference 3) presents the biomechanical model and defines many of the necessary parameters that describe the nominal (or trim) situation. It utilizes an "isomorphic," or body-mimicking representation, of the major body segments in their orientations, simplified to a minimum number of lumped parameter equivalents. The biomechanical features include:

- Semisupine torso; sliding hip plus rocking chest supported on a compliant buttocks/seat.
- Head bobbing on an articulated neck with passive compliance, or active neuromuscular system.
- Upper arm and forearm links plus grip-interface compliance, driven by an active neuromuscular system.
- Arm-rest restraints (optional).
- Stick "feel system" dynamics from zero to infinite stiffness, and any angle of stick or grip.

The simplified torso model was derived to describe the dominant motions of the head and arm elements; the "pin joint" node between upper and lower torso segments is not meant to represent any physical feature. In practice, the masses and inertias are obtained from tabulated biomechanical and anthropometric data for the appropriate sized person (e.g., Reference 11), the postural angles are based on the actual situation (preferably via a side-view photo), and the spring forces and damping coefficients are fitted to data or taken from other sources (e.g., References 3 and 12).



a) Basic Elements

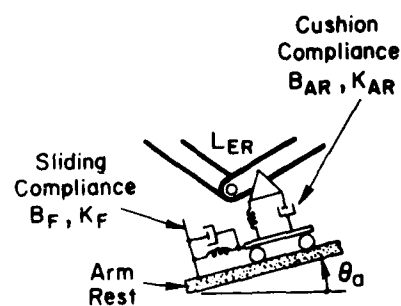


b) Body Parameters

Note:

$$L_1 = L_a + L_b \quad \theta_r = 180^\circ - \theta_E$$

$$L_2 = L_d + L_e \quad \theta_a = 90^\circ - \theta_E + \theta_i$$



c) Arm Rest Detail

Figure 3 Main Biomechanical Elements

## **B. LIMB NEUROMUSCULAR MODEL**

The active neuromuscular system noted on Figure 3 is a schematic representation of the net effect of complex agonist/antagonist muscle pairs controlling the upper arm or head based on the work summarized in Reference 10. An "NM switch" is defined in the PARAMETER file which causes this neuromuscular model to control the limb ( $NM = 0$ ) or the head ( $NM = 1$ ). A linearized representation of the limb neuromuscular model is shown in Figure 4, while the head neuromuscular model is depicted in Figure 5. This model relates the action of the muscle pairs to the effective (spindle) sensors of muscle length and force as well as proprioception from the stick grip interface (in the case of the limb neuromuscular model) or the head-neck interface (in the case of the head neuromuscular model), thus closing the receptor-CNS-effector loop.

Unless neuromuscular properties are being investigated, it is recommended that the typical values of the parameters shown in Table A-1 be used. These are representative of a normal person's arm-hand or head-neck system, and generally yield reasonably damped neuromuscular servo properties. The neuromuscular parameters listed in Appendix A are characteristic of the largest muscles in the body (e.g., the legs), but experience has shown that the dynamic properties (torque/inertia ratios, damping ratios, natural frequencies, etc.) are about the same for all postural muscle pairs. Here, an empirical scale factor  $S$  ( $> 1.0$ ) is used to scale the normalized muscle to a particular configuration, as though the muscle acted normal to the upper arm c.g. A more detailed description of the neuromuscular model is found in Reference 10.

## **C. NECK/HEAD/EYE MODELS**

Figure 6 illustrates the basic elements involved in the neck/head/eye model. Details involving validation and example use of this subsystem model are found in Reference 6. The task is to keep the eye fixated on the target, i.e., null the relative eye (point of regard) deviation (RED) at the display. The moving base can produce image error disturbances, both from induced head rotation and translation as well as

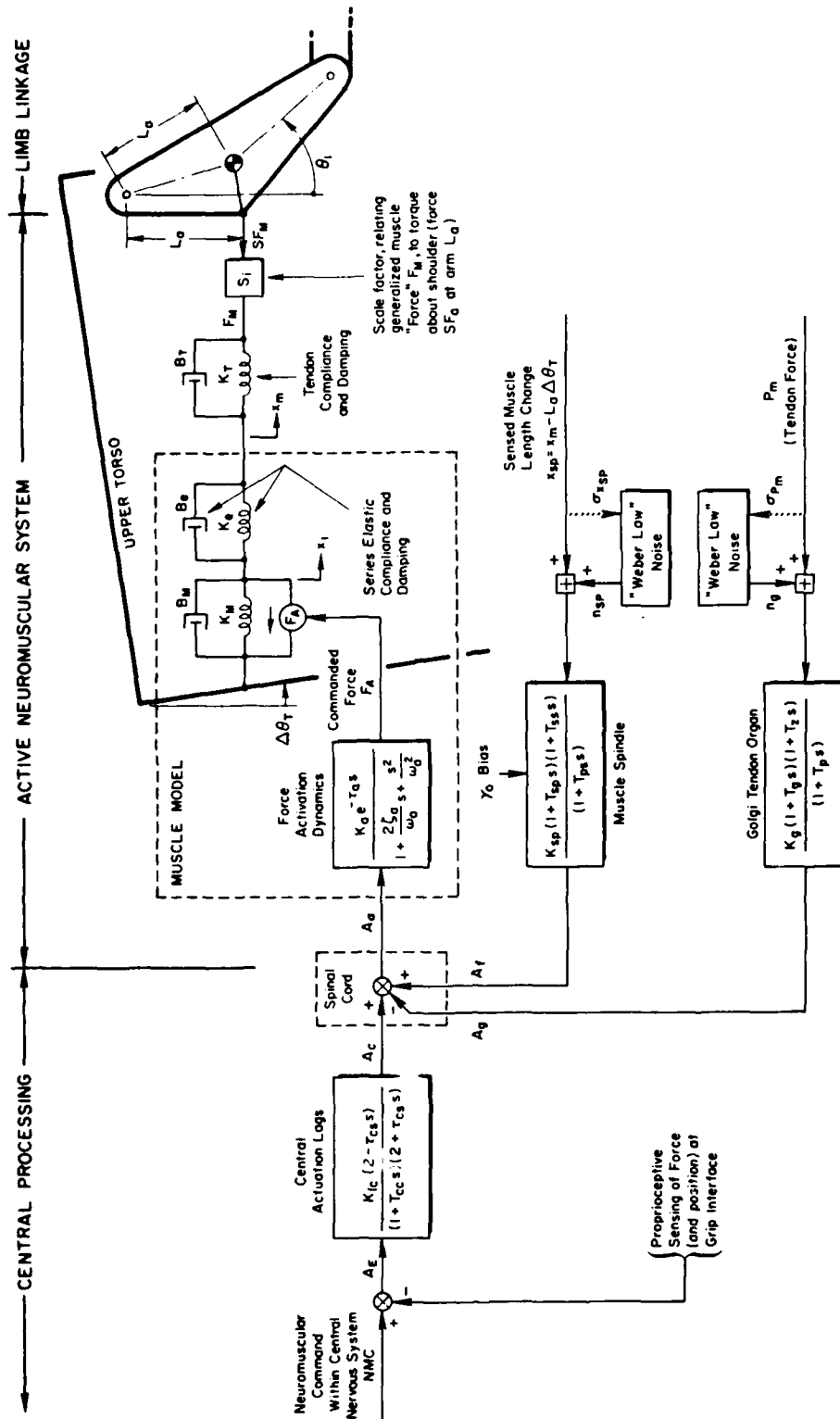
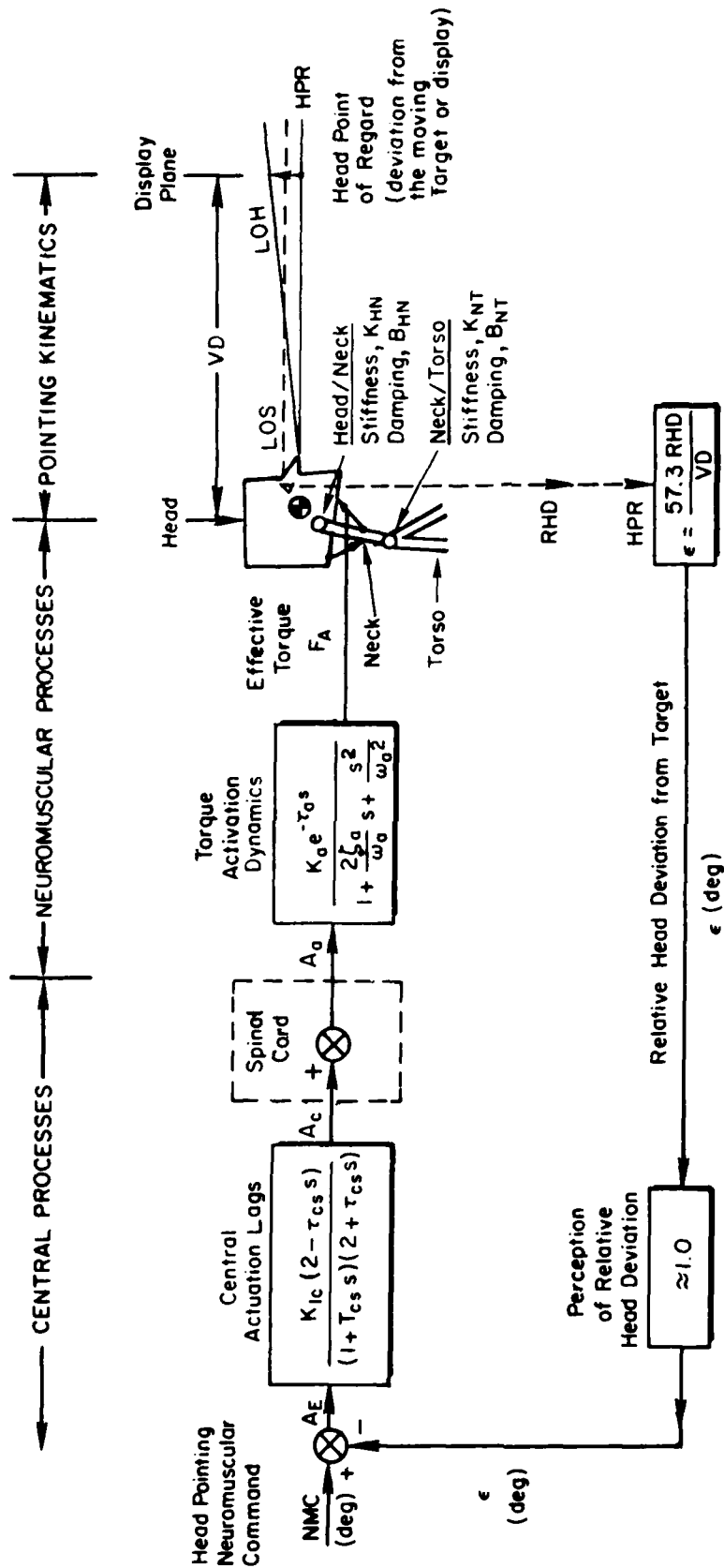


Figure 4 Linearized Limb Neuromuscular System (When the Option NM = 0)



**Notes:**

When  $NM=1$ , this simplified NM system is connected to the head to maintain head pointing at the vibrating target. The values of the parameters  $F_A$ ,  $K_{1c}$ ,  $K_a$ , etc. are different between the limb case ( $NM=0$ ) and head case ( $NM=1$ )

Figure 5 Simplified Head Pointing Neuromuscular System  
(When Option NM = 1)

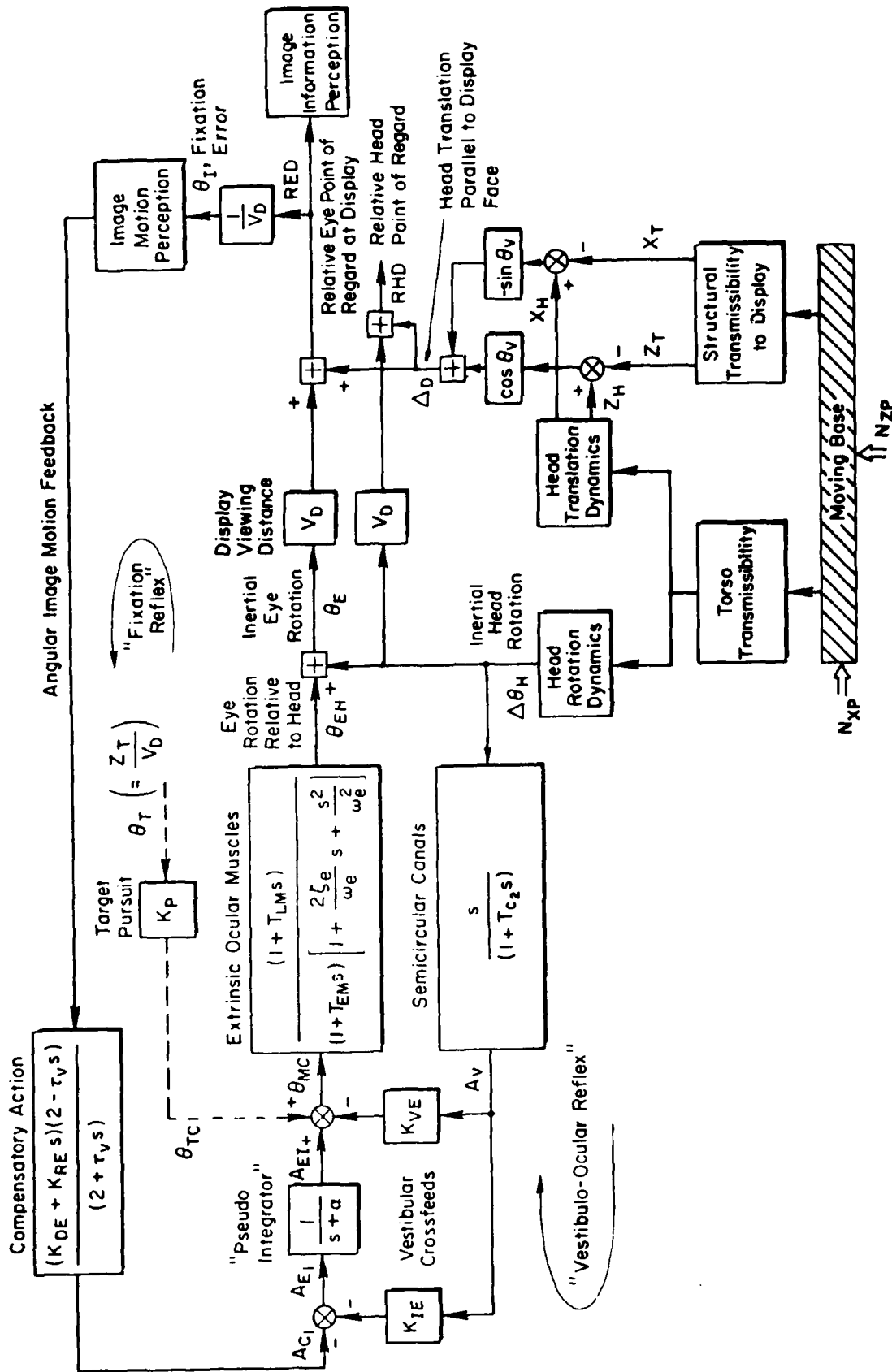


Figure 6 Block Diagram for Head, Eye, Vestibular Models and Display Kinematics

target motions. The "vestibulo-ocular reflex" is a "crossfeed" (or "feedforward") that rotates the eye oppositely to the head to compensate for head rotation, i.e., to maintain approximate inertial eye fixation.

The "Fixation Reflex" or feedback tracking loop involves the subject's efforts to null the image error  $\theta_I$  by compensatory eye movements. The "Target Pursuit" path (shown dashed) models the subject's "feedforward" operations on the perceived absolute target motions in inertial space (as distinct from the image error motions). For highly predictable and perceivable target motions the Target Pursuit path is capable of greatly reducing the image errors, but it is not involved in most vibration cases because of insufficient bandwidth.

The linearized model formulation assumes that the target remains within the foveal area (3-4 deg field), and that angular velocities are small (i.e., less than 20 deg/sec) such that saccades are rare and can be ignored. Additionally, the vibration-induced motions will always be small enough to permit linearization of all angular functions and allow a quasi-linear representation of the dynamic elements about each "operating point" (posture, view geometry, frequency). The operating point angles can have any values within human limits for a seated pilot or crewman.

The three subsystem models described above contain parameters which must be assigned values via the PARAMETER file, in order to describe the desired problem to BIODYN. These parameters are defined in Appendix A. The available input (forcing function) variables and output (response) variables are given in Appendix B. Two different input deflection variables are available for the x and z axes. BZP and BXP should be used when absolute outputs (referenced to inertial space) are desired; DZP and DXP are used when outputs relative to the moving platform are desired. The equations of motion are in Appendix C. Background on their derivation and development are given in a series of prior reports (References 1-3, 6, 10).

## USING BIODYN-80

Three job steps are required for a complete run of BIODYN-80. The CREATE program is used interactively via a remote terminal, to assemble the PARAMETER and CHOICES files. These files are then read by BIODYN and the transfer functions computed, stored on the TF file, and listed at a line printer. The TF file is in turn read by the PLOT program to produce any Bode plots desired. Each of these steps is described in detail. Note that all user interaction with the computer assumes the user is logged in to CDC's INTERCOM. It is assumed that the user has access to Intercom set "AFML" where the program and its files reside. For other setname groups, please consult your Computer Center Representative to get on the AFML list, or for instructions on how to use a "modified job stream listing" (Reference 8).

### A. CREATE

Because of the large number of parameters required by BIODYN-80, it was decided that a dedicated interactive "editor" for creating parameter files was needed to produce rational, error-free input files, and thereby avoid aborting during the subsequent, and expensive, batch run of BIODYN (for example, due to a missing decimal point). Furthermore, this approach allows the maintenance of a "catalog" of PARAMETER files for various postures and situations, from which the most appropriate one can be easily selected and modified for a particular situation. The CREATE program serves in this regard by allowing a user to interactively assemble new parameter files or modify existing ones. CREATE also performs various data checks and identifies common parameter entry errors. This section details the use of the CREATE program.

#### 1. Entering CREATE

CREATE makes use of five files, as defined by the PROGRAM card:

TAPE4 = INPUT file (the user's terminal)

TAPE5 = OUTPUT file (the user's terminal)  
 TAPE7 = CHOICES file (if new one is created)  
 TAPE8 = PARAMETER file (new or modified)  
 TAPE20 = PARAMETER file (existing)

The PROGRAM card automatically assigns the INPUT and OUTPUT files to the appropriate tape units. If an existing PARAMETER file is to be accessed, it must be assigned prior to executing CREATE. The job stream to be input by the user looks like this (detailed examples are given later, in Appendices D and E):

|                                |                                              |
|--------------------------------|----------------------------------------------|
| REQUEST,TAPE7,*PF              | (pfn <sub>1</sub> is the PARAMETER file name |
| REQUEST,TAPE8,*PF              | selected by the user from the                |
| ATTACH,TAPE20,pfn <sub>1</sub> | permanent file catalog within                |
| ATTACH,EXECRT                  | the setname AFML group)                      |
| EXECRT                         |                                              |

Now the user is at the entry level of CREATE. The first issue addressed is creating the PARAMETER file, or modifying an existing PARAMETER file. The computer's first prompt

NEW FILE?

asks the user to identify which option is desired. Answers are YES or NO; any other response will cause the query to be repeated.

## 2. Modifying a PARAMETER File

If the answer is NO, the values stored on the file assigned to TAPE20 are read. The user may list those values by responding to the next prompt

LISTING DESIRED?

with YES. A NO response will skip over the listing option. Any other response will cause repeat of the question. The listing produced can either be long or short. The long listing provides parameter definition, mnemonic, units and current value, while the short listing prints only values, grouped according to each element (see Table A-2, Appendix A). Examples of each are given in Figures 7 and 8, respectively.

Response to the prompt:

(LONG OR (SHORT LISTING?

determines which listing to generate. A response other than LO or SH will cause repeat of the question.

Values are now ready for change, as indicated by the message:

INPUT MNEMONIC (5 CHARS) AND VALUE FOR EACH CHANGE,  
TO EXIT, TYPE XXX.

To change any desired parameter value, its mnemonic from the second column of the definitions in Appendix A is input. Mnemonic must be left justified within a 5 character field followed by a comma, followed by the new value. The mnemonic is then checked against the internal list of permissible mnemonics; e.g., if ABDCE is not found, the message:

MNEMONIC ABCDE NOT PERMISSIBLE. PLEASE REINPUT.

appears and the user should try again. Likely errors include typos, and forgetting to pad the 5 character field with trailing blanks.

Once a correct mnemonic is identified, its new value is compared with the recommended range of values for that parameter. If the value is not within that range, a warning message appears:

WARNING - RECOMMENDED RANGE FOR THIS PARAMETER IS  
0.5 TO 3.5 GS  
DO YOU WANT TO CHANGE THE VALUE?

# STD CREWMAN, HANDS ON KNEES

| PARAMETER DEFINITION           | MNEMONIC | UNITS  | VALUE       |
|--------------------------------|----------|--------|-------------|
| LOWER BODY MASS                | XMB      | KG     | 14.0000     |
| L. BODY SEAT CUSHION DAMPER    | BB       | N/M/S  | 315.000     |
| L. BODY SEAT CUSHION STIFFNESS | XKB      | N/M    | 49360.0     |
| SERIES SPRING GRAD.-LOWER BODY | GK1      | N/M    | 119320.     |
| SEAT TILT ANGLE                | THL      | DEG    | 13.0000     |
| TRIM VERTICAL ACCEL.           | G        | M/S2   | 9.80000     |
| TORSO MASS                     | XMT      | KG     | 18.0000     |
| TORSO INERTIA                  | ZIT      | KGM2   | .800000     |
| TORSO DAMPING                  | BTB      | NM/R/S | 40.0000     |
| TORSO STIFFNESS                | XKTB     | NM/R   | 500.000     |
| ANGLE OF XLT FROM VERTICAL     | THT      | DEG    | -15.0000    |
| TORSO CG TO HIPS PIVOT LENGTH  | XLT      | M      | .150000     |
| ANGLE OF XLTN                  | THTN     | DEG    | -5.00000    |
| TORSO CG TO NECK/TORSO PIVOT   | XLTN     | M      | .300000     |
| ANGLE OF XLS                   | THS      | DEG    | -5.00000    |
| TORSO CG TO SHOULDER LENGTH    | XLS      | M      | .300000     |
| NECK MASS                      | XMN      | KG     | 1.24000     |
| NECK INERTIA                   | ZIN      | KGM2   | .240000E-02 |
| NECK/TORSO DAMPER              | BNT      | NM/R/S | .100000     |
| NECK/TORSO STIFFNESS           | XKNT     | NM/R   | 50.0000     |
| ANGLE OF XIN                   | THN      | DEG    | -30.0000    |
| NECK LENGTH                    | XLN      | M      | .124440     |
| NECK CG TO NECK/TORSO PIVOT    | XLN1     | M      | .622200E-01 |
| HEAD MASS                      | XMH      | KG     | 3.10000     |
| HEAD INERTIA                   | ZIH      | KGM2   | .303000E-01 |
| HEAD/NECK DAMPER               | BHN      | NM/R/S | .126000     |
| HEAD/NECK STIFFNESS            | XKHN     | NM/R   | 15.0000     |
| HEAD/NECK COMPLIANCE           | CH       | -      | 1.00000     |
| ANGLE OF XLH                   | TH       | DEG    | 60.0000     |
| HEAD CG TO HEAD/NECK PIVOT LEN | XLH      | M      | .250000E-01 |
| LINE OF SIGHT ANGLE            | THV      | DEG    | -30.0000    |
| VIEWING DISTANCE               | VD       | M      | .685300     |
| UPPER ARM MASS                 | XM1      | KG     | 1.37200     |
| UPPER ARM INERTIA              | Z1       | KGM2   | .120000E-01 |
| UPPER ARM ANGLE                | T1       | DEG    | 15.0000     |
| UPPER ARM LENGTH               | D1       | M      | .290000     |
| UPPER ARM CG                   | R1       | M/M    | .440000     |
| LOWER ARM MASS                 | XM2      | KG     | 1.01700     |
| LOWER ARM INERTIA              | Z2       | KGM2   | .152000E-01 |
| ELBOW ANGLE                    | TE       | DEG    | 115.000     |
| LOWER ARM LENGTH               | D2       | M      | .305000     |
| LOWER ARM CG                   | R2       | M/M    | .500000     |
| GRIP INTERFACE ANGLE           | TIJ      | DEG    | 0.          |
| GRIP INTERFACE TIME CONSTANT   | TIF      | S      | .100000     |
| GRIP INTERFACE COMPLIANCE      | CI       | M/N    | 1.00000     |

(continued)

Figure 7 Example Long Format File Listing

|                          |       |       |             |
|--------------------------|-------|-------|-------------|
| ARM REST DAMPER          | XMS   | KG    | 4.00000     |
| ARM REST DAMPER (NORMAL) | BS    | N/M/S | 240.000     |
| ARM REST DAMPER (TANG)   | XKS   | N/M   | 10000.0     |
| ARM REST DAMPER (TANG)   | CKS   | -     | 1.00000     |
| ARM REST DAMPER (TANG)   | SX    | N/G   | 0.          |
| ARM REST DAMPER (TANG)   | SZ    | N/G   | 0.          |
| ARM REST DAMPER (TANG)   | THC   | DEG   | 90.0000     |
| ARM REST DAMPER (TANG)   | XLC   | M     | .550000     |
| ARM REST DAMPER (TANG)   | XKSC  | /M    | .100000E-01 |
| ARM REST DAMPER (TANG)   | BAR   | N/M/S | 0.          |
| ARM REST DAMPER (TANG)   | XKAR  | N/M   | 0.          |
| ARM REST DAMPER (TANG)   | BAT   | N/M/S | 0.          |
| ARM REST DAMPER (TANG)   | XKAT  | N/M   | 0.          |
| ARM REST DAMPER (TANG)   | XLER  | M     | 0.          |
| ARM REST DAMPER (TANG)   | ARMR  | -     | 0.          |
| ARM REST DAMPER (TANG)   | NM    | -     | 0.          |
| ARM REST DAMPER (TANG)   | SI    | -     | 50.0000     |
| ARM REST DAMPER (TANG)   | ICC   | S     | .909000E-01 |
| ARM REST DAMPER (TANG)   | ICS   | S     | .890000E-01 |
| ARM REST DAMPER (TANG)   | XKAA  | N/N   | 1.00000     |
| ARM REST DAMPER (TANG)   | ZA    | -     | .800000     |
| ARM REST DAMPER (TANG)   | WA    | R/S   | 16.0000     |
| ARM REST DAMPER (TANG)   | TAA   | S     | 0.          |
| ARM REST DAMPER (TANG)   | BM    | N/N/S | 1.00000     |
| ARM REST DAMPER (TANG)   | XKM   | N/M   | 2.00000     |
| ARM REST DAMPER (TANG)   | BE    | N/M/S | 2.43000     |
| ARM REST DAMPER (TANG)   | XKE   | N/M   | 40.0000     |
| ARM REST DAMPER (TANG)   | BT    | N/M/S | 0.          |
| ARM REST DAMPER (TANG)   | XKT   | N/M   | 80.0000     |
| ARM REST DAMPER (TANG)   | XKSP  | N/M   | 5.00000     |
| ARM REST DAMPER (TANG)   | TSP   | S     | .909000E-01 |
| ARM REST DAMPER (TANG)   | TPS   | S     | 0.          |
| ARM REST DAMPER (TANG)   | TSS   | S     | 0.          |
| ARM REST DAMPER (TANG)   | XKG   | N/N   | .500000     |
| ARM REST DAMPER (TANG)   | TG    | S     | .550000E-01 |
| ARM REST DAMPER (TANG)   | TZ    | S     | 0.          |
| ARM REST DAMPER (TANG)   | TP    | S     | 0.          |
| ARM REST DAMPER (TANG)   | XKDE  | R/R   | 7.07750     |
| ARM REST DAMPER (TANG)   | XKRE  | R/R/S | 0.          |
| ARM REST DAMPER (TANG)   | TV    | S     | .450000E-01 |
| ARM REST DAMPER (TANG)   | ALPHA | R/S   | .300000     |
| ARM REST DAMPER (TANG)   | XKP   | R/S   | 0.          |
| ARM REST DAMPER (TANG)   | XKIE  | -     | .670000     |
| ARM REST DAMPER (TANG)   | XKVS  | -     | .100000     |
| ARM REST DAMPER (TANG)   | TC2   | S     | .100000E-01 |
| ARM REST DAMPER (TANG)   | TEM   | S     | .100000     |
| ARM REST DAMPER (TANG)   | FLM   | S     | .125000E-01 |
| ARM REST DAMPER (TANG)   | QE    | -     | 1.00000     |
| ARM REST DAMPER (TANG)   | ZE    | -     | .650000     |
| ARM REST DAMPER (TANG)   | WE    | R/S   | 316.230     |

Figure 7 (Concluded)

PARAMETERS FOR:

SEATED CREWMAN - VIEWING DISTANCE = 9 CM

LOWER BODY

|        |        |        |            |        |        |
|--------|--------|--------|------------|--------|--------|
| 14.000 | 315.00 | 49360. | .11932E+06 | 13.000 | 9.8000 |
|--------|--------|--------|------------|--------|--------|

TORSO

|         |        |         |        |         |        |
|---------|--------|---------|--------|---------|--------|
| 18.000  | .80000 | 40.000  | 500.00 |         |        |
| -15.000 | .15000 | -5.0000 | .30000 | -5.0000 | .30000 |

NECK

|         |            |            |        |  |  |
|---------|------------|------------|--------|--|--|
| 1.2400  | .24000E-02 | .10000     | 50.000 |  |  |
| -30.000 | .12444     | .62220E-01 |        |  |  |

HEAD/DISPLAY VIEWING

|        |            |         |            |        |  |
|--------|------------|---------|------------|--------|--|
| 3.1000 | .30300E-01 | .12600  | 15.000     | 1.0000 |  |
| 60.000 | .25000E-01 | -30.000 | .90000E-01 |        |  |

ARM (UPPER, LOWER)

|        |            |        |        |        |  |
|--------|------------|--------|--------|--------|--|
| 1.3720 | .12000E-01 | 15.000 | .29000 | .44000 |  |
| 1.0170 | .15200E-01 | 115.00 | .30500 | .50000 |  |

GRIP INTERFACE

|    |        |        |  |  |  |
|----|--------|--------|--|--|--|
| 0. | .10000 | 1.0000 |  |  |  |
|----|--------|--------|--|--|--|

STICK

|        |        |            |        |    |    |
|--------|--------|------------|--------|----|----|
| 4.0000 | 240.00 | 10000.     | 1.0000 | 0. | 0. |
| 90.000 | .55000 | .10000E-01 |        |    |    |

ARM REST

|    |    |    |    |    |    |
|----|----|----|----|----|----|
| 0. | 0. | 0. | 0. | 0. | 0. |
|----|----|----|----|----|----|

NEUROMUSCULAR SYSTEM

|            |            |            |        |    |        |
|------------|------------|------------|--------|----|--------|
| 0          | 50.000     |            |        |    |        |
| .20000E-01 | .90900E-01 | .89000E-01 |        |    |        |
| 1.0000     | .80000     | 16.000     | 0.     |    |        |
| 1.0000     | 2.0000     | 2.4300     | 40.000 | 0. | 80.000 |
| 5.0000     | .90900E-01 | 0.         | 0.     |    |        |
| .50000     | .55000E-01 | 0.         | 0.     |    |        |

IMAGE FIXATION/VESTIBULO-OCULAR SERVO

|        |            |            |        |        |  |
|--------|------------|------------|--------|--------|--|
| 7.0795 | 0.         | .45000E-01 | .30000 | 0.     |  |
| .67000 | .10000     | .10000E-01 |        |        |  |
| .10000 | .12500E-01 | 1.0000     | .65000 | 316.23 |  |

Figure 8 Example Short Format PARAMETER File Listing

If a mistake has been made in typing the new value, a YES answer will allow retyping of both the mnemonic and its corrected value. If, however, the value is correct, even if out of range, a NO answer will cause the value to be stored as it stands. Any response other than YES or NO will cause the warning message to be repeated.

The range of parameters given in Appendix A is as wide as can be allowed for typical applications of BIODYN-80 (e.g., arm joint limits). Values outside this range are used at the user's risk, and precise postural angles for the given case should be carefully checked at this point. (It is good practice to check your lengths and angles by drawing a stick figure to scale, using the desired values.)

When all the desired changes have been made, an input of XXX causes control to leave the modify mode. An opportunity to change the case title is then presented as

TITLE IS STD CREWMAN, HANDS ON KNEES  
CHANGE DESIRED?

A YES answer causes the message

NEW TITLE:

to appear and a new title (60 characters maximum) can be typed. A NO response skips this section; other responses cause the prompt to repeat.

After all desired changes have been made, the user is once again given the opportunity to list the file, using either the LONG or SHORT format, as described above. At this point the computer writes the new values to the PARAMETER output file, TAPE8.

### 3. Assembling a New PARAMETER File

If most of the parameters are new, then instead of modifying an existing file the initial prompt

NEW FILE?

is answered YES. Every parameter value must then be input. The message

INPUT VALUE FOR EACH MNEMONIC. FOR FURTHER EXPLANATION, TYPE?

initiates this process. For each parameter, the mnemonic is printed as, for example, Viewing Distance, VD:

VD =

and the value is accepted in floating point format. If the user is uncertain as to the range of appropriate values, an expanded prompt may be requested by typing "?". The expanded prompt for VD is, for example:

VD = ?

VD VIEWING DISTANCE  
RECOMMENDED RANGE = 0.5 TO 3.0 M  
VD =

the user can then enter the desired value.

As each value is read, it is checked against the recommended range of values, in order to weed out input errors due to wrong sign or incorrect decimal placement. If the value is not within range, the warning message given previously appears. The user always has the option of modifying or saving any value typed.

This process continues until all 26 parameters have been entered. The case title is then added as a response to

INPUT TITLE FOR THIS CASE:

At this point, a Long or Short format listing may be generated as discussed above. The file is then written by the computer to the PARAMETER file designated TAPE8.

#### 4. Assembling the CHOICES File

The next section of CREATE is used to assemble a new CHOICES file which specifies the transfer functions to be output. Note that there is no provision for modifying an existing CHOICES file; any changes to an existing CHOICES file must be made by creating an entirely new file. The prompt

NEW CHOICES FILE?

has two responses: a NO allows the user to skip this entire section if an existing CHOICES file will be used as input to BIODYN; a YES response will cause prompting for the CHOICES file components as described below. Any other response will cause the prompt to be repeated.

A YES response to the next prompt

BIODYN TFS DESIRED FOR PIVIB?

will automatically generate the ten transfer functions to be included in the PIVIB input file. This is mandatory if interaction with PIVIB is anticipated. The response and forcing function variables involved are shown later, in Figure 12. A NO answer skips this section; other answers cause repeat of the question.

All other desired transfer functions are entered by the user in response to the following computer-specified format:

TRANSFER FUNCTION INPUT:  
FIRST LINE - RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC  
(AAA, AAA); ENTER XXX TO STOP  
SECOND LINE - PLOTTING INFORMATION, 5 ITEMS:  
BODE LOWER FREQ. LIMIT  
BODE UPPER FREQ. LIMIT  
BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)  
BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)  
LIST (1. TO LIST TABLE, 0. FOR NO LIST)  
IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS

Note that the parameters for each transfer function are entered on two consecutive lines, each item separated by a comma, each line followed by CR.

The mnemonics requested are three-character codes as defined in Appendix B. The program checks each mnemonic against the list of acceptable codes. If a match is not made, the error message

XYZ NOT PERMISSIBLE, PLEASE REINPUT.

is given and the entire first line must be retyped.

If Bode plots are desired, the frequency and phase limits must be entered; if not, zeros are assumed. The frequency limits must bound a frequency range of no more than 3 decades. If frequencies with an unacceptable range are entered, the message

MAX FREQUENCY RANGE IS 3 DECADES  
PLEASE REINPUT ENTIRE LINE

appears and, all five items for that transfer function must be re-typed. The phase limits are unbounded, but entering zeros will cause default to +200.0 deg and -400.0 deg for the upper and lower limits, respectively. If a tabular listing, including frequency, amplitude, and phase at 20 increments/decade intervals is desired, a 1.0 should be entered as the fifth item; otherwise enter 0.0.

The CREATE program stops when an XXX is read in the CHOICES file section. The two files created must be saved as permanent files by giving the following INTERCOM commands:

CATALOG,TAPE7,pfn<sub>2</sub>,RP=10  
CATALOG,TAPE8,pfn<sub>3</sub>,RP=10

where pfn<sub>2</sub> is a new (seven character) permanent file name assigned to the CHOICES file and pfn<sub>3</sub> is a new (seven character) permanent file name assigned to the PARAMETER file. The user is now ready to exercise BIODYN.

The user can interactively create a number of PARAMETER and CHOICES files, each uniquely named for subsequent use in the BIODYN program. In

most cases one same set of transfer function choices will be adequate for a variety of different parameter sets.

## B. BIODYN

Because of memory size limitations presently imposed by the INTERCOM operating system, BIODYN must be run in the batch mode. A batch job can be submitted through INTERCOM using the following command sequence

```
EDITOR
CREATE,S
ABC,CM150000,STCSA.
ATTACH,TAPE7,pfn2.      User supplies desired
ATTACH,TAPE8,pfn3.      file name for each pfn
REQUEST,TAPE19,*FF.
ATTACH,EXEBIO.
EXEBIO(TAPE4,OUTPUT,TAPE7,TAPE8,TAPE19,TAPE21).
CATALOG,TAPE19,pfn4,RP=999.
*EOR
SAVE,GOBIO,NOSEQ
END
COMMAND = BATCH,GOBIO,INPUT,HERE
```

The first section of this batch request assigns the PARAMETER and CHOICES files produced by CREATE to the tape units which BIODYN reads. The BIODYN program is then retrieved and executed.

BIODYN first reads the PARAMETER file and uses it to set up the equations in the form

$$Ax = Bu$$

where  $x$  is a vector of response variables (currently dimensioned 48) and  $u$  is a vector of forcing function variables (dimensioned 9). The desired transfer functions (as listed in the CHOICES file) are then evaluated, using Cramer's rule and several advanced factorization algorithms in order to obtain the first- and second-order poles and zeros. These are all written to a file called TAPE19 (the TF file), as well as to the line printer (via the OUTPUT file). The format used by the program for

printing the transfer functions is shown in Figure 9, while the format for storing these transfer functions on TAPE19 is given in Figure 10.

The TF file (TAPE19) is used by the PLOT program for generating the quick-look Bode plots on the line printer. Thus, the last lines supplied by the user in the batch job stream "rewind" this file and assign it a permanent file name pfn<sub>4</sub>.

### C. PLOT

The Bode plots, if desired, may be generated at the user's terminal or written to a local file for later examination, as the user wishes. The user's job stream looks like the following:

|                                  |                                      |
|----------------------------------|--------------------------------------|
| ATTACH,TAPE19,pfn <sub>4</sub> . | pfn <sub>4</sub> is the file name of |
| ATTACH,EXEPLT.                   | the plot instructions                |
| EXEPLT(OUTPUT,TAPE19)            |                                      |

The output from this routine consists of four items. First, the input file mnemonics are printed, so the user can identify which plots are forthcoming. Then, for each transfer function, three items are printed. The transfer function dipoles (first and second order) which have been cancelled are first, followed by the numerator and denominator of the transfer function. Then, the Bode plot is "drawn." Finally, if a listing was requested in the CHOICES file, it follows the Bode plot. An annotated example is given in Figures 11a, b, and c.

### D. INTERFACE WITH PIVIB

Ten of the possible BIODYN-80 transfer functions can be used as input to PIVIB. These are listed in Figure 12. The input file structure for PIVIB is quite lengthy and complex, involving over 200 parameters. An explanation of it is beyond the scope of this user's manual, and the interested reader is referred to Reference 7, the PIVIB User's Manual. A brief outline of the steps used to generate the PIVIB input file is given below.

Each transfer function is to be interpreted as

$$\text{Transfer Function} \equiv \frac{N_{\text{input}}}{\Delta}(s) = \frac{\kappa \left\{ \pi \left( s + \frac{1}{T_z} \right) \right\} \cdot \left\{ \pi \left( s^2 + 2\zeta_z \omega_z s + \omega_z^2 \right) \right\}}{\left\{ \pi \left( s + \frac{1}{T_p} \right) \right\} \cdot \left\{ \pi \left( s^2 + 2\zeta_p \omega_p s + \omega_p^2 \right) \right\}}$$

where  $\pi$  denotes a product of first- or second-order roots, and  $\kappa$  is the so-called "root locus gain" (of the high-frequency asymptote):

$$\kappa = \frac{\text{High Frequency Gain of Numerator}}{\text{High Frequency Gain of Denominator}}$$

and the various first- and second-order poles and zeros are indicated below. The transfer function can also be interpreted in Bode format, as:

$$\text{Transfer Function} \equiv \frac{\kappa \left\{ \pi (T_z s + 1) \right\} \cdot \left\{ \pi \left( \frac{s^2}{\omega_z^2} + \frac{2\zeta_z s}{\omega_z} + 1 \right) \right\}}{\left\{ \pi (T_p s + 1) \right\} \cdot \left\{ \pi \left( \frac{s^2}{\omega_p^2} + \frac{2\zeta_p s}{\omega_p} + 1 \right) \right\}}$$

where  $K_{OL}$  is the gain of the low-frequency asymptote ("Bode gain"):

$$K_{OL} = \frac{\text{Low Frequency Gain of Numerator}}{\text{Low Frequency Gain of Denominator}}$$

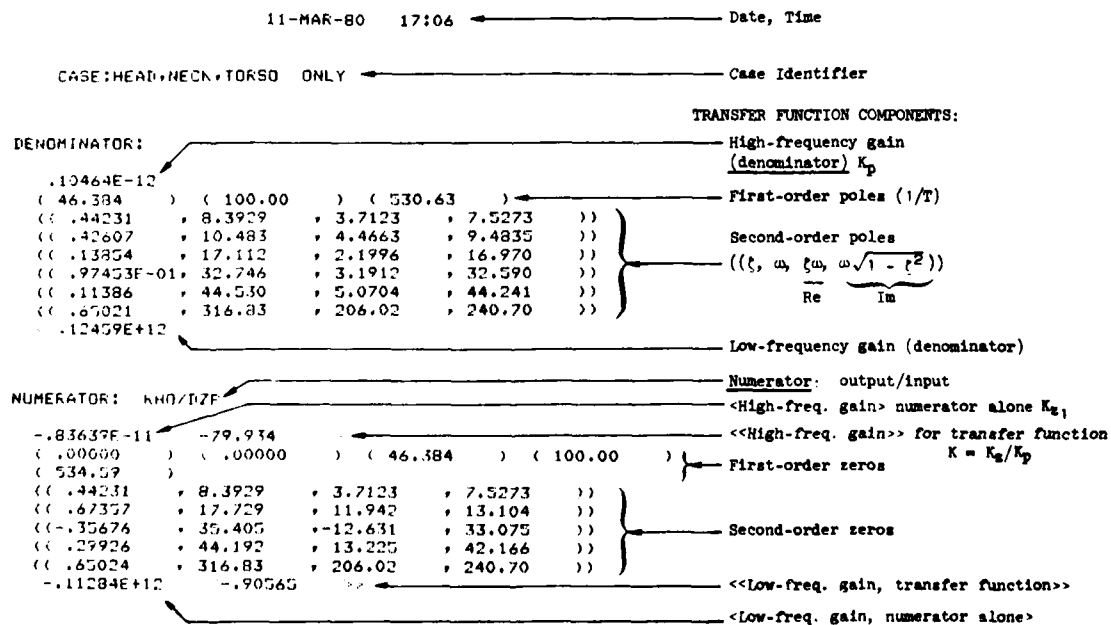


Figure 9 Format for BIODYN-80 Transfer Function Printouts

| Format                                        | Comment                                               |
|-----------------------------------------------|-------------------------------------------------------|
| Case title (15A4)                             |                                                       |
| D\$\$                                         | (Specifies denominator)                               |
| NP1, NP2, K <sub>p</sub> , 0., 0., 0., 0., 0. | (2I4, G14.6, 5F7.1)                                   |
| 1/T <sub>p1</sub>                             |                                                       |
| 1/T <sub>p2</sub>                             | First-order poles (5X, G14.6)                         |
| .                                             |                                                       |
| .                                             |                                                       |
| .                                             |                                                       |
| ζ <sub>p1</sub> , ω <sub>p1</sub>             | Second-order poles (ζ <sub>1</sub> , ω <sub>1</sub> ) |
| ζ <sub>p2</sub> , ω <sub>p2</sub>             | (5X, 2F14.6)                                          |
| .                                             |                                                       |
| .                                             |                                                       |
| .                                             |                                                       |
| XXX/XXX                                       | First transfer function<br>numerator                  |
| NZ1, NZ2, K <sub>z</sub> , W1, WF, XU, XL, XP | (2I4, G14.6, 5F7.1)                                   |
| 1/T <sub>z1</sub>                             |                                                       |
| 1/T <sub>z2</sub>                             | First-order zeros (5X, G14.6)                         |
| .                                             |                                                       |
| .                                             |                                                       |
| .                                             |                                                       |
| ζ <sub>z1</sub> , ω <sub>z1</sub>             |                                                       |
| ζ <sub>z2</sub> , ω <sub>z2</sub>             | Second-order zeros (ζ <sub>2</sub> , ω <sub>2</sub> ) |
| .                                             | (5X, 2G14.6)                                          |
| .                                             |                                                       |
| .                                             |                                                       |
| XXX/XXX                                       | Second transfer function<br>numerator                 |
|                                               | .                                                     |
|                                               | .                                                     |
|                                               | .                                                     |

where

|                                                  |                                                |
|--------------------------------------------------|------------------------------------------------|
| NP1 = No. first-order poles                      | K <sub>z</sub> = High-frequency numerator gain |
| NP2 = No. second-order poles                     | W1 = Bode plot lower frequency limit           |
| K <sub>p</sub> = High-frequency denominator gain | WF = Bode plot upper frequency limit           |
| NZ1 = No. first-order zeros                      | XU = Bode plot upper phase limit               |
| NZ2 = No. second-order zeros                     | XL = Bode plot lower phase limit               |
|                                                  | XP = Listing switch                            |

Figure 10. Format Used for BIODYN-80 TAPE19 File of Transfer Functions

BIODYN T.F. 05/20/80 15.13.57.  
SEATED CREWMAN - VIEWING DISTANCE = 9 CM

Title

D\*\*  
RHD/DZF

Dump of file

BIODYN T.F.

BIODYN T.F. 05/20/80 15.13.57.  
SEATED CREWMAN - VIEWING DISTANCE = 9 CM

Title

RHD/DZF  
D\*\*

FIRST-ORDER DIPOLES CANCELLED :  
46.384000  
100.00000

SECOND-ORDER DIPOLES CANCELLED :  
.44230900 , 8.3929300  
.60022000 , 50.002500  
.65024400 , 316.83100

NUMERATOR:

-.81361

(0. ) (0. ) ( 10.955 ) ( 11.950 ) } First-order zeros  
( 22.500 ) ( 107.75 ) ( 535.79 )

(( .22639 , 8.4561 , 1.9144 , 8.2365 )) } Second-order zeros  
(( .78552 , 13.624 , 10.702 , 8.4311 ))  
(( .82761 , 20.272 , 16.777 , 11.379 ))  
(( -.16669 , 21.651 , -3.6090 , 21.348 ))  
(( .22759 , 47.017 , 10.700 , 45.783 ))

DENOMINATOR:

( 10.957 ) ( 11.983 ) ( 22.499 ) ( 107.81 ) } First-order poles  
( 531.02 )

(( .22869 , 8.4682 , 1.9366 , 8.2437 )) } Second-order poles  
(( .40550 , 13.701 , 5.5558 , 12.524 ))  
(( .24026 , 16.682 , 4.0081 , 16.193 ))  
(( .82362 , 20.305 , 16.723 , 11.516 ))  
(( .94299E-01 , 31.293 , 2.9509 , 31.153 ))  
(( .19289 , 46.973 , 9.0608 , 46.091 ))

-.13857E-02

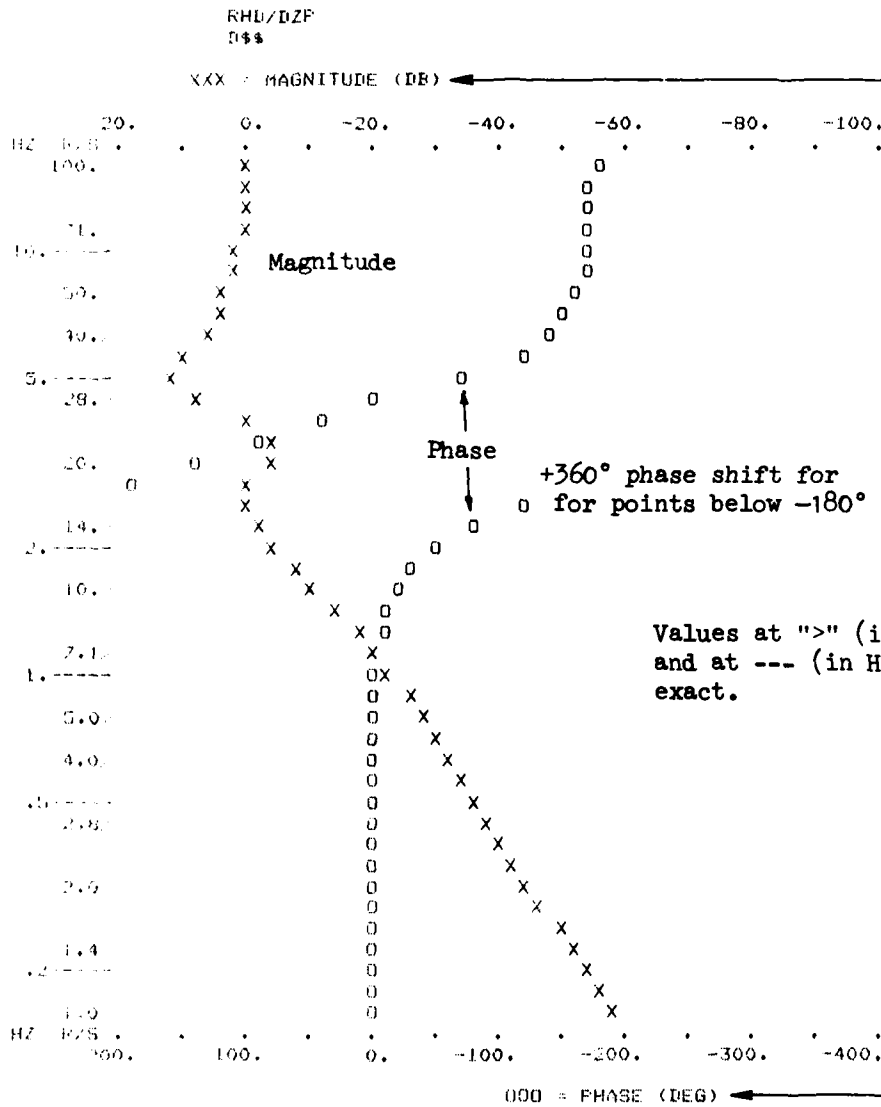
BIODYN T.F.

BIODYN T.F. 05/20/80 15.13.57.  
SEALED CREWMAN - VIEWING DISTANCE = 9 CM

Title

Top scale

XXX is  
magnitude



b) Printer-Generated Frequency Response (Bode Plot)

Figure 11 (Continued)

SIIDYN T.F.

SIIDYN T.F.

05/20/80

15.15.37

Title

SEATED CRUISEMAN - VIEWING DISTANCE - 9 CM

RMS/HPZP

364

| FREQ  | DB      | PHS   |
|-------|---------|-------|
| 1.00  | -17.11  | 360.0 |
| 1.12  | -18.07  | 360.0 |
| 1.26  | -18.97  | 360.0 |
| 1.41  | -19.91  | 360.0 |
| 1.58  | -20.91  | 360.0 |
| 1.75  | -21.97  | 360.0 |
| 1.95  | -23.01  | 360.0 |
| 2.14  | -24.01  | 360.0 |
| 2.35  | -25.07  | 360.0 |
| 2.57  | -26.11  | 360.0 |
| 2.80  | -27.11  | 360.0 |
| 3.04  | -28.15  | 360.0 |
| 3.29  | -29.15  | 360.0 |
| 3.54  | -30.15  | 360.0 |
| 3.80  | -31.15  | 360.0 |
| 4.07  | -32.15  | 360.0 |
| 4.34  | -33.15  | 360.0 |
| 4.62  | -34.15  | 360.0 |
| 4.91  | -35.15  | 360.0 |
| 5.20  | -36.15  | 360.0 |
| 5.50  | -37.15  | 360.0 |
| 5.80  | -38.15  | 360.0 |
| 6.11  | -39.15  | 360.0 |
| 6.42  | -40.15  | 360.0 |
| 6.74  | -41.15  | 360.0 |
| 7.06  | -42.15  | 360.0 |
| 7.39  | -43.15  | 360.0 |
| 7.72  | -44.15  | 360.0 |
| 8.06  | -45.15  | 360.0 |
| 8.40  | -46.15  | 360.0 |
| 8.74  | -47.15  | 360.0 |
| 9.09  | -48.15  | 360.0 |
| 9.44  | -49.15  | 360.0 |
| 9.79  | -50.15  | 360.0 |
| 10.14 | -51.15  | 360.0 |
| 10.50 | -52.15  | 360.0 |
| 10.85 | -53.15  | 360.0 |
| 11.21 | -54.15  | 360.0 |
| 11.57 | -55.15  | 360.0 |
| 11.93 | -56.15  | 360.0 |
| 12.30 | -57.15  | 360.0 |
| 12.67 | -58.15  | 360.0 |
| 13.04 | -59.15  | 360.0 |
| 13.41 | -60.15  | 360.0 |
| 13.79 | -61.15  | 360.0 |
| 14.17 | -62.15  | 360.0 |
| 14.55 | -63.15  | 360.0 |
| 14.93 | -64.15  | 360.0 |
| 15.32 | -65.15  | 360.0 |
| 15.70 | -66.15  | 360.0 |
| 16.09 | -67.15  | 360.0 |
| 16.48 | -68.15  | 360.0 |
| 16.87 | -69.15  | 360.0 |
| 17.26 | -70.15  | 360.0 |
| 17.65 | -71.15  | 360.0 |
| 18.04 | -72.15  | 360.0 |
| 18.43 | -73.15  | 360.0 |
| 18.83 | -74.15  | 360.0 |
| 19.22 | -75.15  | 360.0 |
| 19.61 | -76.15  | 360.0 |
| 20.01 | -77.15  | 360.0 |
| 20.40 | -78.15  | 360.0 |
| 20.80 | -79.15  | 360.0 |
| 21.19 | -80.15  | 360.0 |
| 21.59 | -81.15  | 360.0 |
| 21.98 | -82.15  | 360.0 |
| 22.38 | -83.15  | 360.0 |
| 22.77 | -84.15  | 360.0 |
| 23.17 | -85.15  | 360.0 |
| 23.56 | -86.15  | 360.0 |
| 23.96 | -87.15  | 360.0 |
| 24.35 | -88.15  | 360.0 |
| 24.75 | -89.15  | 360.0 |
| 25.14 | -90.15  | 360.0 |
| 25.54 | -91.15  | 360.0 |
| 25.93 | -92.15  | 360.0 |
| 26.33 | -93.15  | 360.0 |
| 26.72 | -94.15  | 360.0 |
| 27.12 | -95.15  | 360.0 |
| 27.51 | -96.15  | 360.0 |
| 27.91 | -97.15  | 360.0 |
| 28.30 | -98.15  | 360.0 |
| 28.70 | -99.15  | 360.0 |
| 29.09 | -100.15 | 360.0 |

Listing of frequency  
(rad/sec), amplitude (dB)  
and phase (deg) at 20  
evenly-spaced increments/  
decade. (This listing is  
only generated if XL = 1.0  
in the CHOICES file for this  
transfer function)

### c) Listing of Frequency Response Values

Figure 11 (Concluded)

Note:  $\emptyset$  denotes a typed blank space.

| <u>Output</u>    | <u>BIODYN TF</u>                   |   | <u>PIVIB TF</u>     |                                                                                                  |
|------------------|------------------------------------|---|---------------------|--------------------------------------------------------------------------------------------------|
| Shoulder:<br>(S) | $\frac{\emptyset XS}{BXP}$         | - | $\frac{Ch1}{Ch1}_S$ | - $\frac{\text{Inertial horizontal shoulder deflection}}{\text{Horizontal platform deflection}}$ |
|                  | $\frac{\emptyset XS}{BZP}$         | - | $\frac{Ch1}{Ch2}_S$ | - $\frac{\text{Inertial horizontal shoulder deflection}}{\text{Vertical platform deflection}}$   |
|                  | $\frac{\emptyset Z1}{BXP}$         | - | $\frac{Ch3}{Ch1}_S$ | - $\frac{\text{Inertial vertical shoulder deflection}}{\text{Horizontal platform deflection}}$   |
|                  | $\frac{\emptyset Z1}{BZP}$         | - | $\frac{Ch3}{CH2}_S$ | - $\frac{\text{Inertial vertical shoulder deflection}}{\text{Vertical platform deflection}}$     |
| Head:<br>(H)     | $\frac{DTH}{BXP}$                  | - | $\frac{Ch3}{Ch1}_H$ | - $\frac{\text{Inertial head pitch}}{\text{Horizontal platform deflection}}$                     |
|                  | $\frac{DTH}{BZP}$                  | - | $\frac{Ch3}{Ch2}_H$ | - $\frac{\text{Inertial head pitch}}{\text{Vertical platform deflection}}$                       |
|                  | $\frac{DZH}{BXP}$                  | - | $\frac{Ch2}{Ch1}_H$ | - $\frac{\text{Inertial vertical head deflection}}{\text{Horizontal platform deflection}}$       |
|                  | $\frac{DZH}{BZP}$                  | - | $\frac{Ch2}{Ch2}_H$ | - $\frac{\text{Inertial vertical head deflection}}{\text{Vertical platform deflection}}$         |
| Stick<br>(C)     | $\frac{\emptyset C\emptyset}{DXP}$ | - | $\frac{Ch1}{Ch1}_C$ | - $\frac{\text{Longitudinal stick deflection}}{\text{Horizontal platform deflection}}$           |
|                  | $\frac{\emptyset C\emptyset}{DZP}$ | - | $\frac{Ch1}{Ch2}_C$ | - $\frac{\text{Longitudinal stick deflection}}{\text{Vertical platform deflection}}$             |

Assumptions: Of the 3 vibration inputs possible, 2 are X and Z. Assume X is Channel 1, Z is Channel 2 for the above table.

Figure 12 BIODYN-80 Transfer Functions Which May Be Used as PIVIB Input

1. Specify title for run
2. BDMOD - enter the biodynamic response module
  - a. FREQS - specify all frequencies required for biodynamic analysis
  - b. VIBR - specify vibration input/source transfer functions
  - c. BIOTR - specify biodynamic transfer functions. This is the interface between BIODYN-80 and PIVIB.
  - d. BDOUT - specify biodynamic outputs for printing
  - e. BCOMP - given all information specified above, compute and print biodynamic quantities
3. PVMOD - enter the pilot/vehicle module
  - a. Specify various P/V parameters in state vector form
  - b. VBINT - controls communication between BDMOD and PVMOD
  - c. PCOMP - perform pilot/vehicle computations and print results
  - d. FDREP - compute and print frequency domain measures, e.g., describing functions, remnants, signal spectra
4. Repeat 2 and 3 for each case
5. END

#### **E. FOR ASSISTANCE**

New and inexperienced users should have an experienced INTERCOM or batch user assist them through the first application. For technical questions concerning this program or models, please call or write: Henry R. Jex at Systems Technology, Inc., 13766 S. Hawthorne Blvd., Hawthorne, CA 90250. Telephone Number (213) 679-2281.

APPENDIX A  
DEFINITION OF PARAMETERS, SYMBOLS, RANGES AND TYPICAL VALUES

TABLE 1 PARAMETER AND SYMBOL DEFINITIONS, RANGES, AND TYPICAL VALUES

| PARAMETER       | FORTRAN NAME | UNITS             | LOCATION DEFINITION                  | SOURCE* (Refs.) | REASONABLE RANGE |          | TYPICAL VALUES (STD CASES) |         |
|-----------------|--------------|-------------------|--------------------------------------|-----------------|------------------|----------|----------------------------|---------|
|                 |              |                   |                                      |                 | MINIMUM          | MAXIMUM  | STDPLT†                    | STDTCRW |
| LOWER BODY      |              |                   |                                      |                 |                  |          |                            |         |
| M <sub>B</sub>  | XMB          | kg                | Lower body mass (Hips)               | T(1,2,3)        | 10.              | 25.      | 14.                        | 14.     |
| B <sub>B</sub>  | BB           | n/m/s             | Lower body/seat cushion damper       | F(1,4,5)        | 100.             | 2,000.   | 1290.1                     | 315.    |
| K <sub>B</sub>  | XKB          | N/m               | Lower body/seat cushion stiffness    | F(1,4,5)        | 20,000.          | 100,000. | 29585.                     | 49360.  |
| K <sub>GS</sub> | GK1          | N/m               | Series spring gradient in lower body | F(1,4,5)        | 50,000.          | 200,000. | 71519.                     | 119322. |
| θ <sub>L</sub>  | THL          | deg               | Seat (hips) tilt angle               | M(1)            | -20.             | +80.     | 13.                        | 13.     |
| G               | G            | m/s <sup>2</sup>  | Trim vertical acceleration           |                 | 0.1              | 100.     | 9.8                        | 9.8     |
| TORSO           |              |                   |                                      |                 |                  |          |                            |         |
| M <sub>T</sub>  | XMT          | kg                | Torso mass                           | T(1,2,3)        | 10.              | 30.      | 18.                        | 18.     |
| I <sub>T</sub>  | ZIT          | kg.m <sup>2</sup> | Torso inertia                        | T(1,2,3)        | 0.5              | 2.       | 0.8                        | 0.8     |
| B <sub>TB</sub> | BTB          | N.m<br>rad/s      | Torso damping                        | F(1,4)          | 10.              | 100.     | 16.75                      | 40.     |
| K <sub>TB</sub> | XKTB         | N.m<br>rad        | Torso stiffness                      | G,F(1,4)        | 100.             | 2,000.   | 500.                       | 500.    |
| θ <sub>T</sub>  | THT          | deg               | Angle of XLT from vertical           | M(1,3,4)        | -30.             | +90.     | 10.                        | -15.    |
| L <sub>T</sub>  | XLT          | m                 | Torso c.g. to hips pivot length      | T,M(1,2,3)      | 0.12             | 0.40     | 0.15                       | 0.15    |
| θ <sub>TN</sub> | HTN          | deg               | Angle of XLTN                        | M,T(1,2,3)      | -30.             | +90.     | 5.                         | -5.     |
| L <sub>TN</sub> | XLTN         | m                 | Torso c.g. to neck/pivot             | T,M(1,2,3)      | 0.15             | 0.30     | 0.3                        | 0.3     |
| θ <sub>S</sub>  | THS          | deg               | Angle of XLS                         | M,T(1,3)        | -30.             | +90.     | 5.                         | -5.     |
| L <sub>S</sub>  | XLS          | m                 | Torso c.g. to shoulder length        |                 | 0.10             | 0.30     | 0.3                        | 0.3     |

†"STDPLT" = STD pilot, stiff centerstick

†"STDTCRW" = STD crewman, hand on knees

\*Sources Legend: Measured (e.g., photo) or specified by situation  
Tabulated, cadaver or anthropometric tables  
Fitted, to transfer function data  
Guesstimate (on basis of physical properties)

(continued)

TABLE 1. (Continued)

| PARAMETER                   | FORTRAN NAME | UNITS             | LOCATION DEFINITION                                               | SOURCE* (Refs.) | REASONABLE RANGE |                   | TYPICAL VALUES (STD CASES) |        |
|-----------------------------|--------------|-------------------|-------------------------------------------------------------------|-----------------|------------------|-------------------|----------------------------|--------|
|                             |              |                   |                                                                   |                 | MINIMUM          | MAXIMUM,          | STDPLT                     | STDCRW |
| <u>NECK</u>                 |              |                   |                                                                   |                 |                  |                   |                            |        |
| M <sub>N</sub>              | XMN          | kg                | Neck mass                                                         | T(1,3,6)        | 0.               | 3.0               | 0.0**                      | 1.24   |
| I <sub>N</sub>              | ZIN          | kg.m <sup>2</sup> | Neck inertia                                                      | T(1,2,3,6)      | 0.               | 0.010             | 0.0**                      | 0.0024 |
| B <sub>N</sub>              | BNT          | N.m<br>rad/s      | Neck/torso damper                                                 | G,F(1,5)        | 0.               | 0.40              | 0.25                       | 0.1    |
| K <sub>NT</sub>             | XXNT         | N.m<br>rad        | Neck/torso stiffness                                              | G(1,5)          | 10.              | 80.               | 50.0                       | 50.0   |
| θ <sub>N</sub>              | THN          | deg               | Angle of XLN                                                      | M(1,3)          | -90.             | +90.              | -20.                       | -30.   |
| L <sub>N</sub>              | XLN          | m                 | Neck length                                                       | M,T(1,2,3,6)    | 0.05             | 0.25              | 0.1                        | .12444 |
| L <sub>NL</sub>             | XLNL         | m                 | Neck c.g to neck/<br>torso pivot                                  | T,G(1,3)        | 0.02             | 0.15              | 0.05                       | .06222 |
| <u>HEAD/DISPLAY VIEWING</u> |              |                   |                                                                   |                 |                  |                   |                            |        |
| M <sub>H</sub>              | XMH          | kg                | Head mass                                                         | T,G(1,2,3,5)    | 2.0              | 10.0              | 4.34                       | 3.1    |
| I <sub>H</sub>              | ZIH          | kg.m <sup>2</sup> | Head inertia                                                      | T,G(1,2,3,6)    | 0.010            | helmeted<br>0.100 | 0.039                      | 0.0303 |
| B <sub>HN</sub>             | BHN          | N.m<br>rad/s      | Head/neck damper                                                  | G,F(1,8)        | 0.               | helmeted<br>0.40  | 0.0**                      | 0.126  |
| K <sub>HN</sub>             | XXHN         | N.m<br>rad        | Head/neck stiffness                                               | G,F(1,4,8)      | 10.              | 30.               | 10.**                      | 15.    |
| G <sub>H</sub>              | CH           | -                 | Head/neck compliance<br>parameter (CH = 0.<br>locks head on neck) | M(1,8)          | 0.0<br>locked    | 1.<br>unlocked    | 0.0**                      | 1.     |
| θ <sub>H</sub>              | TH           | deg               | Angle of XLG(pivot-CG)                                            | M,T(1,2,3,6)    | -30.             | +150.             | 70.                        | 60.    |
| L <sub>T</sub>              | XLH          | m                 | Head c.g. to head/<br>neck pivot length                           | T,M(1,2,3,6)    | 0.0              | 0.100             | 0.0*                       | 0.025  |
| θ <sub>V</sub>              | THV          | deg               | Angle of line of<br>sight                                         | M,T(1,3)        | -90.             | +90.              | -30.                       | -30.   |
| V <sub>D</sub>              | VD           | m                 | Viewing distance<br>from head/neck<br>pivot                       | M(1)            | 0.               | 1000.             | 0.75                       | 0.6853 |

\*Sources Legend:

Measured (e.g., photo) or specified by situation

Tabulated, cadaver or anthropometric tables

Fitted, to transfer function data

Guesstimate (on basis of physical properties)

\*\*Head/Neck Locked

TABLE 1. (Continued)

| PARAMETER                      | FORTRAN NAME | UNITS             | LOCATION DEFINITION                                       | SOURCE* (Refs.) | REASONABLE RANGE |                  | TYPICAL VALUES (STD CASES) |        |
|--------------------------------|--------------|-------------------|-----------------------------------------------------------|-----------------|------------------|------------------|----------------------------|--------|
|                                |              |                   |                                                           |                 | MINIMUM          | MAXIMUM          | STDPLY                     | STDGRW |
| <u>ARMS (Upper, Lower)</u>     |              |                   |                                                           |                 |                  |                  |                            |        |
| M <sub>1</sub>                 | XM1          | kg                | Upper arm mass                                            | T,M(1,2,3)      | 1.0              | 4.0              | 1.372                      | 1.372  |
| I <sub>1</sub>                 | Z1           | kg.m <sup>2</sup> | Upper arm inertia                                         | T(1,2,3)        | 0.01             | 0.05             | 0.012                      | 0.012  |
| θ <sub>1</sub>                 | TI           | deg               | Upper arm angle                                           | M,T(1,3,8)      | -30.0            | +90.0            | 40.                        | 15.    |
| L <sub>1</sub>                 | D1           | m                 | Upper arm length<br>( = L <sub>a</sub> + L <sub>b</sub> ) | M,T(1,3,8)      | 0.2              | 0.5              | 0.29                       | 0.29   |
| L <sub>a</sub> /L <sub>1</sub> | R1           | m/m               | Upper arm c.g.<br>(fractional distance)                   | T,G(1,2,3)      | 0.2              | 0.6              | 0.44                       | 0.44   |
| <u>LOWER ARM</u>               |              |                   |                                                           |                 |                  |                  |                            |        |
| M <sub>2</sub>                 | XM2          | kg                | Lower arm mass                                            | T,M(1,2,3)      | 0.5              | 3.0              | 1.017                      | 1.017  |
| I <sub>2</sub>                 | Z2           | kg.m <sup>2</sup> | Lower arm inertia                                         | T,(1,2,3)       | 0.01             | 0.10             | 0.0152                     | 0.0152 |
| θ <sub>E</sub>                 | TE           | deg               | Elbow angle                                               | M,T(1,3,8)      | 60.0             | 170.0            | 145.                       | 115.   |
| L <sub>2</sub>                 | D2           | m                 | Lower arm length<br>( = L <sub>e</sub> + L <sub>d</sub> ) | M,T(1,3,8)      | 0.2              | 0.5              | 0.305                      | 0.305  |
| L <sub>d</sub> /L <sub>2</sub> | R2           | m/m               | Lower arm c.g.<br>(fractional distance)                   | T,G(1,2,3)      | 0.2              | 0.6              | 0.5                        | 0.5    |
| <u>GRIP INTERFACE</u>          |              |                   |                                                           |                 |                  |                  |                            |        |
| θ <sub>IJ</sub>                | TIJ          | deg               | Grip interface angle                                      | M,G(3)          | -45.0            | +45.0            | 0.0                        | 0.0    |
| B <sub>I</sub> /K <sub>I</sub> | TIF          | s                 | Grip interface time constant                              | G,F(1,8)        | 0.0              | 0.5              | 0.01                       | 0.1    |
| C <sub>I</sub>                 | CI           | m/N               | Grip interface compliance K <sub>I</sub> -1               | M,G,F(1,8)      | 0.0<br>fixed     | 1000.0<br>"free" | .0000558                   | 1.0    |

\*Sources Legend: Measured (e.g., photo) or specified by situation  
 Tabulated, cadaver or anthropometric tables  
 Fitted, to transfer function data  
 Guesstimate (on basis of physical properties)

TABLE 1. (Continued)

| PARAMETER       | FORTRAN NAME | UNITS      | LOCATION DEFINITION                                                                                | SOURCE* (Refs.) | REASONABLE RANGE |                | TYPICAL VALUES (STD CASES) |         |
|-----------------|--------------|------------|----------------------------------------------------------------------------------------------------|-----------------|------------------|----------------|----------------------------|---------|
|                 |              |            |                                                                                                    |                 | MINIMUM          | MAXIMUM        | STDPLT                     | STDORW  |
| STICK           |              |            |                                                                                                    |                 |                  |                |                            |         |
| M <sub>S</sub>  | XMS          | kg         | Stick/hand mass (referred to grip)                                                                 | M,F(1,8)        | 0.0              | 1.0            | 1.31                       | 4.0     |
| B <sub>S</sub>  | BS           | N/m/s      | Stick damper                                                                                       | M,F(1,8)        | 0.0              | 5.0            | 2.                         | 240.0   |
| K <sub>S</sub>  | XKS          | N/m        | Stick gradient                                                                                     | M(1,8)          | 0.01             | 20,000.0       | 1300.                      | 10000.0 |
| Q <sub>KS</sub> | QKS          | -          | Stick compliance parameter (QKS=0 means that XKS=0)                                                | M(1)            | 0.0<br>"fixed"   | 1.0<br>"fixed" | 1.0                        | 1.0     |
| S <sub>X</sub>  | SX           | N/g        | Bobweight sensitivity to N <sub>X</sub>                                                            | F,M,G(1,8)      | -5.0             | +10.0          | 0.0                        | 0.0     |
| S <sub>Z</sub>  | SZ           | N/g        | Bobweight sensitivity to N <sub>Z</sub>                                                            | F,M,G(1,8)      | -10.0            | +10.0          | 0.0                        | 0.0     |
| STICK ANGLE     |              |            |                                                                                                    |                 |                  |                |                            |         |
| θ <sub>c</sub>  | THC          | deg        | Stick angle                                                                                        | M(1)            | -20.0            | +120.0         | 90.                        | 90.     |
| L <sub>c</sub>  | XLC          | m          | Stick length (pivot to center of grip)                                                             | M(1)            | 0.0              | 2.0            | 0.61                       | 0.55    |
| K <sub>SC</sub> | XKSC         | Units<br>m | Stick output scale factor (rescales stick displacement to "specified" units (e.g., deg, cm, etc.)) | F,G(1,8)        | 0.01             | 20,000.0       | 1300. (N/m)                | 0.01    |
| ARM REST        |              |            |                                                                                                    |                 |                  |                |                            |         |
| B <sub>AR</sub> | BAR          | N/m/s      | Arm rest damper (normal)                                                                           | M,G(1)          | 0.0              | 1.0            | 0.0†                       | 0.0†    |
| K <sub>AR</sub> | XKAR         | N/m        | Arm rest stiffness (normal)                                                                        | M,G(1)          | 0.0              | 10,000.0       | 0.0†                       | 0.0†    |
| B <sub>F</sub>  | BAT          | N/m/s      | Arm rest damper (tangential)                                                                       | G,M(1)          | 0.0              | 150.0          | 0.0†                       | 0.0†    |
| K <sub>F</sub>  | XKAT         | N/m        | Arm rest stiffness (tangential)                                                                    | G,M(1)          | 0.0              | 10,000.0       | 0.0†                       | 0.0†    |
| L <sub>ER</sub> | XLER         | m          | Elbow to arm rest distance                                                                         | M(1)            | 0.0              | 0.5            | 0.0†                       | 0.0†    |
| A <sub>MR</sub> | ARMR         | -          | Fraction of arm weight on arm rest                                                                 | G(1)            | 0.0              | 1.0            | 0.0†                       | 0.0†    |

\*Sources Legend: Measured (e.g., photo) or specified by situation  
 Tabulated, cadaver or anthropometric tables  
 Fitted, to transfer function data  
 Guesstimate (on basis of physical properties)

†Armrest disabled.

TABLE 1. (Continued)

| PARAMETER | FORTRAN NAME | UNITS | LOCATION DEFINITION                                                                       | SOURCE* (Refs.) | REASONABLE RANGE |             | TYPICAL VALUES (STD CASES) |        |
|-----------|--------------|-------|-------------------------------------------------------------------------------------------|-----------------|------------------|-------------|----------------------------|--------|
|           |              |       |                                                                                           |                 | MINIMUM          | MAXIMUM     | STDPLY                     | STDCRW |
|           |              |       | <u>NEUROMUSCULAR SYSTEM:</u><br><u>Actuation Elements:</u>                                |                 |                  |             |                            |        |
| NM        | NM           | -     | Switch for central or force activation dynamics 0 for arm control 1 for head/neck control | M               | 0.0<br>arm       | 1.0<br>head | 0.0                        | 0.0    |
| Si        | SI           | -     | Overall scale factor                                                                      | F,G(1,8)        | 0.0              | 200.0       | 104.4                      | 50.0   |
| Klc       | XKLC         | N/N   | Neuromuscular actuation gain                                                              | F,G(1,8)        | 0.0              | 1.0         | .02044                     | .02    |
| Toc       | TCC          | s     | Neuromuscular actuation time                                                              | F,G(1,8)        | 0.0              | 0.2         | .0909                      | .0909  |
| cs        | TCS          | s     | Neuromuscular actuation lag                                                               | F,G(1,8)        | 0.0              | 0.3         | 0.089                      | .089   |
| Ka        | XKAA         | N/N   | Gain of force activation dynamics                                                         | F,G(1,8)        | 0.0              | 10.0        | 1.                         | 1.     |
| ζa        | ZA           | -     | Damping in force activation dynamics                                                      | F,G(1,8)        | 0.0              | 1.0         | 0.8                        | 0.8    |
| ωa        | WA           | rad/s | Natural frequency in force activation dynamics                                            | F,G(1,8)        | 10.0             | 20.0        | 16.                        | 16.    |
| Ta        | TAA          | s     | Time delay in force activation dynamics                                                   | F,G(1,8)        | 0.0              | 0.10        | 0.0                        | 0.0    |

\*Sources Legend: Measured (e.g., photo) or specified by situation  
 Tabulated, cadaver or anthropometric tables  
 Fitted, to transfer function data  
 Guesstimate (on basis of physical properties)

TABLE 1. (Continued)

| PARAMETER       | FORTRAN NAME | UNITS | LOCATION DEFINITION                                              | SOURCE* (Refs.) | REASONABLE RANGE |         | TYPICAL VALUES (STD CASES) |        |
|-----------------|--------------|-------|------------------------------------------------------------------|-----------------|------------------|---------|----------------------------|--------|
|                 |              |       |                                                                  |                 | MINIMUM          | MAXIMUM | STDPLY                     | STDGRW |
|                 |              |       | NEUROMUSCULAR SYSTEM:<br><u>Actuation Elements:</u><br>continued |                 |                  |         |                            |        |
| B <sub>M</sub>  | BM           | N/m/s | "Hills law" damper                                               | G,F(1,7,8)      | 0.0              | 20.0    | 1.                         | 1.0    |
| K <sub>M</sub>  | XKM          | N.m   | Spring in neuromuscular system                                   | G,F(1,7,8)      | 0.1              | 20.0    | 2.                         | 2.     |
| B <sub>e</sub>  | BE           | N/m/s | Series elastic element damper                                    | F(1,7,8)        | 0.0              | 10.0    | 2.431                      | 2.43   |
| K <sub>e</sub>  | XKE          | N/m   | Series elastic element gradient                                  | G,F(1,7,8)      | 0.1              | 100.0   | 40.                        | 40.    |
| B <sub>T</sub>  | BT           | N/m/s | Tendon damper                                                    | G,F(1,7,8)      | 0.0              | 10.0    | 0.                         | 0.     |
| K <sub>T</sub>  | XKT          | N/m   | Tendon gradient                                                  | G,F(1,7,8)      | 0.1              | 300.0   | 80.                        | 80.    |
| K <sub>sp</sub> | XKSP         | N/m   | Muscle spindle model gain                                        | G(1,7,8)        | 1.0              | 10.0    | 5.                         | 5.     |
| T <sub>sp</sub> | TSP          | s     | Muscle spindle lead time constant                                | G(1,7,8)        | 0.02             | 0.15    | 1/11.                      | 1/11.  |
| T <sub>ps</sub> | TPS          | s     | Muscle spindle lag time constant                                 | G(1,7,8)        | 0.0              | 0.1     | 0.0                        | 0.0    |
| T <sub>ss</sub> | TSS          | s     | Muscle spindle high frequency lead time constantly               | G(1,7,8)        | 0.0              | 0.1     | 0.0                        | 0.0    |
| K <sub>g</sub>  | XKG          | N/N   | Golgi tendon organ model gain                                    | G(1,7,8)        | 0.1              | 1.0     | 0.5                        | 0.5    |
| T <sub>g</sub>  | TG           | s     | Golgi tendon organ time constant                                 | G(1,7,8)        | 0.02             | 0.1     | 1/18.                      | 1/18.  |
| T <sub>z</sub>  | TZ           | s     | Golgi tendon organ time constant                                 | G(1,7,8)        | 0.0              | 0.1     | 0.0                        | 0.0    |
| T <sub>p</sub>  | TP           | s     | Golgi tendon organ lag time constant                             | G(1,7,8)        | 0.0              | 0.1     | 0.0                        | 0.0    |

\*Sources Legend: Measured (e.g., photo) or specified by situation  
 Tabulated, cadaver or anthropometric tables  
 Fitted, to transfer function data  
 Guesstimate (on basis of physical properties)

TABLE 1. (Concluded)

| PARAMETER                                    | FORTRAN NAME | UNITS        | LOCATION<br>Definition                                                                                         | SOURCE*<br>(Refs.) | REASONABLE<br>RANGE         |         | TYPICAL VALUES<br>(STANDARD CASES) |        |
|----------------------------------------------|--------------|--------------|----------------------------------------------------------------------------------------------------------------|--------------------|-----------------------------|---------|------------------------------------|--------|
|                                              |              |              |                                                                                                                |                    | MINIMUM                     | MAXIMUM | STDPLT                             | STDORW |
| <u>IMAGE FIXATION/VESTIBULO-OCULAR SERVO</u> |              |              |                                                                                                                |                    |                             |         |                                    |        |
| K <sub>DE</sub>                              | XKDE         | rad<br>rad   | Fixation error gain                                                                                            | F (9)              | 1.0                         | 10.0    | 7.08                               | 7.08   |
| K <sub>RE</sub>                              | XKRE         | rad<br>rad/s | Fixation rate gain                                                                                             | F (9)              | 0.0                         | 10.0    | 0.0                                | 0.0    |
| τ <sub>v</sub>                               | TV           | s            | Time delay in fixation loop                                                                                    | F (9)              | 0.0                         | 0.10    | 0.045                              | 0.045  |
| α                                            | ALPHA        | rad/s        | "Pseudo Integrator" break frequency                                                                            | G, F(9)            | 0.0                         | 0.5     | 0.3                                | 0.3    |
| K <sub>p</sub>                               | XKP          | rad<br>rad   | Target pursuit gain (Optional)                                                                                 | G (9)              | 0.0                         | 1.0     | 0.0                                | 0.0    |
| K <sub>IE</sub>                              | XKIE         |              | Position gain from "Vestibular" sensor                                                                         | F (9)              | 0.1                         | 1.0     | 0.67                               | 0.67   |
| K <sub>VE</sub>                              | XKVE         |              | Velocity gain from "Vestibular" sensor                                                                         | F (9)              | 0.0                         | 0.1     | 0.1                                | 0.1    |
| T <sub>c2</sub>                              | TC2          |              | "Vestibular" lag                                                                                               | F, T(9)            | 0.005                       | 0.015   | 0.01                               | 0.01   |
| T <sub>EM</sub>                              | TEM          | s            | Ocular Servo Lag time constant                                                                                 | F (9)              | 0.05                        | 0.10    | 0.1                                | 0.1    |
| T <sub>LM</sub>                              | TLM          | s            | Ocular Servo Lead time constant                                                                                | F (9)              | 0.010                       | 0.020   | 0.0125                             | 0.0125 |
| Q <sub>E</sub>                               | QE           |              | Switch for fast mode in Ocular Servo<br>1. use Z <sub>E</sub> , W <sub>E</sub><br>0. W <sub>E</sub> = infinity | M                  | 0.0<br>(ω <sub>E</sub> = ∞) | 1.0     | 1.0                                | 1.0    |
| ζ <sub>e</sub>                               | ZE           | -            | Ocular Servo Damping Ratio                                                                                     | F (9)              | 0.2                         | 1.0     | 0.65                               | 0.65   |
| ω <sub>e</sub>                               | WE           | rad/s        | Ocular Servo Natural frequency                                                                                 | F (9)              | 200.0                       | 400.0   | 316.23                             | 316.23 |

\*Sources Legend: Measured (e.g., photo) or specified by situation  
 Tabulated, cadaver or anthropometric tables  
 Fitted, to transfer function data  
 Guesstimate (on basis of physical properties)

TABLE 2. PARAMETER FILE STRUCTURE (SHORT FORMAT)

A. Lower Body

$M_B$        $B_B$        $K_B$        $K_{BS}$        $\theta_L$        $G$

B. Torso

$M_T$        $I_T$        $B_{TB}$        $K_{TB}$

$\theta_T$        $L_T$        $\theta_{TN}$        $L_{TN}$        $\theta_S$        $L_S$

C. Neck

$M_N$        $I_N$        $B_{NT}$        $K_{NT}$

$\theta_N$        $L_N$        $L_{N1}$

D. Head/Display Viewing

$M_H$        $I_H$        $B_{HN}$        $K_{HN}$        $C_H$

$\theta_H$        $L_H$        $\theta_V$        $V_D$

E. Arms (Upper then lower)

$M_1$        $I_1$        $\theta_1$        $L_1$        $L_a/L_1$

$M_2$        $I_2$        $\theta_E$        $L_2$        $L_d/L_2$

F. Grip Interface

$\theta_{IJ}$        $B_I/K_I$        $C_I$

G. Stick

$M_S$        $B_S$        $K_S$        $C_{KS}$        $S_x$        $S_z$

$\theta_C$        $L_C$        $K_{SC}$

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H. Arm Rest

$B_{AR}$      $K_{AR}$      $B_F$      $K_F$      $L_{ER}$      $Arm_R$

I. Neuromuscular System

$NM$      $S_i$

$K_{1c}$      $T_{cc}$      $\tau_{cs}$

$K_a$      $\zeta_a$      $\omega_a$      $\tau_a$

$B_M$      $K_M$      $B_e$      $K_e$      $B_T$      $K_T$

$K_{sp}$      $T_{sp}$      $T_{ps}$      $T_{ss}$

$K_g$      $T_g$      $T_z$      $T_p$

J. Image Fixation/Vestibulo-Ocular Servo

$K_{DE}$      $K_{RE}$      $\tau_v$      $\alpha$      $K_p$

$K_{IE}$      $K_{VE}$      $T_{c2}$

$T_{EM}$      $T_{LM}$      $Q_E$      $\zeta_e$      $\omega_e$

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APPENDIX B  
DEFINITION OF FORCING FUNCTION AND  
RESPONSE VARIABLES

TABLE 3 INPUT (FORCING FUNCTION) VARIABLES

| MATRIX<br>COLUMN<br>NUMBER | INPUT<br>VARIABLE<br>NAME | COLUMN<br>CODE* | UNITS | POSITIVE<br>DIRECTION | DEFINITION AND USAGE                |
|----------------------------|---------------------------|-----------------|-------|-----------------------|-------------------------------------|
| 1                          | N <sub>zp</sub>           | NZP             | g     | Upward                | Platform acceleration               |
| 2                          | $\Delta_{zp}$             | DZP             | m     | Upward                | Platform deflection                 |
| 3                          | N <sub>xp</sub>           | NXP             | g     | Forward               | Platform acceleration               |
| 4                          | $\Delta_{xp}$             | DXP             | m     | Forward               | Platform deflection                 |
| 5                          | F <sub>D</sub>            | $\emptyset$ FD  | N     | Forward               | Force input to stick                |
| 6                          | B <sub>zp</sub>           | BZP             | m     | Upward                | Special Platform deflection+        |
| 7                          | B <sub>xp</sub>           | BXP             | m     | Forward               | Special Platform deflection+        |
| 8                          | NMC                       | NMC             | N     |                       | Neuromuscular command within<br>CNS |
| 9                          | $\theta_{TI}$             | TTI             | rad   |                       | Test input into fixation error      |

\*Small "b" represents a typed-blank space.

+These are used to get transfer functions of  $\frac{\text{Inertial shoulder (or head) motion}}{\text{Platform motion}}$

TABLE 4 OUTPUT (RESPONSE) VARIABLES

| MATRIX COLUMN NUMBER | RESPONSE VARIABLE NAME | MATRIX COLUMN CODE* | UNITS  | POSITION DIRECTION   | DEFINITION AND USAGE                                                |
|----------------------|------------------------|---------------------|--------|----------------------|---------------------------------------------------------------------|
| 1                    | c                      | $\beta C \beta$     | m or N | Forward              | Stick output ( $K_{CS}$ used to scale as force)                     |
| 2                    | $f_{ca}$               | FCA                 | N      | Forward on stick     | Interface force at stick grip                                       |
| 3                    | $\Delta z_l$           | $\beta Z_l$         | m      | Upward               | Vertical shoulder deflection relative to platform ( $z_s - z_p$ )   |
| 4                    | $\Delta \theta_l^+$    | DTL                 | rad    | Pitch up             | Lower arm angle                                                     |
| 5                    | $\Delta \theta_a$      | DTA                 | rad    | Pitch up             | Lower arm angle                                                     |
| 6                    | $f_{ly}$               | FLY                 | rad    | Up on upper arm      | Vertical interface force at elbow                                   |
| 7                    | $F_M$                  | $\beta FM$          | N      |                      | Muscle model force referred to upper arm c.g.                       |
| 8                    | $L_I$                  | $\beta LI$          | N      | Forward              | Grip interface deflection (stick to lower arm)                      |
| 9                    | $f_{lx}$               | FLX                 | N      | Forward on upper arm | Horizontal interface force at elbow                                 |
| 10                   | $x_m$                  | $\beta XM$          | m      |                      | Internal state in muscle model                                      |
| 11                   | $f_{rs}$               | FNS                 | N      | Forward on upper arm | Horizontal interface force at shoulder/upper arm                    |
| 12                   | $f_{vs}$               | FVS                 | N      | Up on upper arm      | Vertical interface force at shoulder/upper arm                      |
| 13                   | $x_s$                  | $\beta XS$          | m      | Forward              | Horizontal shoulder deflection relative to platform ( $x_s - x_p$ ) |
| 14                   | $\Delta \theta_T$      | DTT                 | rad    | Pitch up             | Torso rotation                                                      |
| 15                   | $f_{nh}$               | FNH                 | N      | Forward on           | Head/neck interface force                                           |
| 16                   | $\Delta \theta_H$      | DTH                 | rad    | Pitch up             | Head rotation                                                       |
| 17                   | $f_{vh}$               | FVH                 | N      | Up on head           | Head/neck interface force                                           |
| 18                   | $f_{by}$               | FBY                 | N      | Up on Torso          | Vertical hips/torso interface force                                 |
| 19                   | $F_{bx}$               | FBX                 | N      | Forward on hips      | Hips/torso interface force                                          |

\*Note: Small "b" represents a typed-blank space.

#Note:  $\Delta \theta_l$  (Column 4) means small signal perturbation of  $\theta_l$  given in fig. 3

TABLE 4 (Continued)

| MATRIX COLUMN NUMBER | RESPONSE VARIABLE NAME | MATRIX COLUMN CODE* | UNITS | POSITIVE DIRECTION     | DEFINITION AND USAGE                                               |
|----------------------|------------------------|---------------------|-------|------------------------|--------------------------------------------------------------------|
| 20                   | $u_{sp}$               | USP                 | m     | Up the seat back       | Internal state in hip model                                        |
| 21                   | $u_{bp}$               | UBP                 | m     | Up the seat back       | Hip deflection relative to platform (parallel to seat-back)        |
| 22                   | $x_1$                  | $\beta x_1$         | m     |                        | Internal state in muscle model                                     |
| 23                   | $\Delta \theta_N$      | DTN                 | rad   | Pitch up               | Neck rotation                                                      |
| 24                   | $f_{nN}$               | FNN                 | N     | Forward on neck        | Neck/torso horizontal interface force                              |
| 25                   | $f_{vN}$               | FVN                 | N     | Up on neck             | Neck/torso vertical interface force                                |
| 26                   | RHD                    | RHD                 | deg   | Up relative to display | Head point of Regard relative to a display on the platform         |
| 27                   | $A_a$                  | $\beta A_a$         | N     |                        | Muscle model command out of spinal cord                            |
| 28                   | $F_A$                  | $\beta F_A$         | N     |                        | Commanded force out of force activation dynamics                   |
| 29                   | $f_{aa}$               | FAA                 | N     |                        | Internal state in force activation                                 |
| 30                   | $A_g$                  | $\beta A_g$         | N     |                        | Output of golgi tendon organ sensors                               |
| 31                   | $A_c$                  | $\beta A_c$         | N     |                        | Spinal cord command                                                |
| 32                   | $A_e$                  | $\beta A_e$         | N     |                        | Error between neuromuscular command and proprioceptive stick force |
| 33                   | $x_{sp}$               | $x_{sp}$            | m     |                        | Muscle length change sensed by spindle model                       |
| 34                   | $\Delta r_n$           | DRN                 | m     |                        | Relative normal deflection of arm and rest                         |
| 35                   | $\Delta r_t$           | DRT                 | m     |                        | Relative tangential deflection of arm and rest                     |
| 36                   | $\Delta z_h$           | DZH                 | m     |                        | Vertical component of head motion relative to platform             |

\*Note: Small "b" represents a typed-blank space.

TABLE 4 (Concluded)

| MATRIX COLUMN NUMBER | RESPONSE VARIABLE NAME | MATRIX COLUMN CODE* | UNITS | POSITIVE DIRECTION     | DEFINITION AND USAGE                                     |
|----------------------|------------------------|---------------------|-------|------------------------|----------------------------------------------------------|
| 37                   | $A_{c1}$               | AC1                 | rad   |                        | Output of compensatory action in eye fixation loop       |
| 38                   | $A_{E1}$               | AEI                 | rad   |                        | Output of "Pseudo Integrator"                            |
| 39                   | $\theta_{MC}$          | TMC                 | rad   |                        | Command to Ocular Servo                                  |
| 40                   | $A_v$                  | bAV                 | r/s   | Head up                | Output of "Vestibular" Sensor                            |
| 41                   | $\theta_{EH}$          | TEH                 | rad   | Up                     | Eye rotation relative to head                            |
| 42                   | $\theta_{M1}$          | TMI                 | rad   |                        | Internal node in Ocular Servo                            |
| 43                   | $\theta_I$             | THI                 | rad   | Up                     | Fixation error                                           |
| 44                   | RED                    | RED                 | m     | Eye up rel. to display | Relative eye point of regard at display                  |
| 45                   | $\theta_{TC}$          | TTC                 | rad   |                        | Output of "Image Pursuit" operation                      |
| 46                   | $Z_T$                  | $\emptyset ZT$      | m     | Up                     | Display inertial displacement (vertical)                 |
| 47                   | $\theta_E$             | THE                 | rad   | Up                     | Inertial eye rotation                                    |
| 48                   | $\Delta x_h$           | DXH                 | m     | Forward                | Horizontal component of head motion relative to platform |

\*Note: Small " $\emptyset$ " represents a typed-blank space.

APPENDIX C  
EQUATIONS OF MOTION

$$1 \quad \text{if } C_{K_S} \neq 0$$

$$(\sin \theta_c) c - x_s - L_1(\cos \theta_1) \Delta \theta_1 + L_2(\sin \theta_a) \Delta \theta_a - L_I(\cos \theta_{IJ}) = -B_{x_p}$$

$$2 \quad \begin{array}{cc} \text{if } C_{K_S} \neq 0 & \text{if } C_{K_S} = 0 \\ \hline \left\{ -(M_s s^2 + B_s s + K_s) - \frac{S_x}{L_c} - M_2(\cos \theta_c)^2 s^2 \right\} c / K_{sc} - c \\ + (\sin \theta_c) L_{ca} + (\cos \theta_c) L_{1y} - M_2(\cos \theta_c)(\sin \theta_{IJ}) s^2 L_I \\ - M_2 L_d(\cos \theta_c)(\cos \theta_a) s^2 \Delta \theta_a + (\cos \theta_c)(B_{AR} s + K_{AR})(\Delta x_n) \\ + (\cos \theta_c)(B_{FS} + K_F)(\Delta x_t) \\ = - (z/g + M_2 \cos \theta_c) a_{z_p} - S_x/g a_{x_p} - F_d \end{array}$$

$$3 \quad \text{if } C_{K_S} \neq 0$$

$$\Delta z_1 + L_1(\sin \theta_1) \Delta \theta_1 + L_2(\cos \theta_a) \Delta \theta_a + L_I(\sin \theta_{IJ}) + \frac{(\cos \theta_c)}{K_{sc}} c = 0$$

$$4 \quad \left\{ I_1 s^2 + (L_d M_1 g + L_1 M_2 g - L_1 F_{av0}) \cos \theta_1 \right\} \Delta \theta_1 - L_b(\sin \theta_1) f_{1y}$$

$$+ L_b(\cos \theta_1) f_{1x} + L_a(\cos \theta_1) f_{ns} + L_a(\sin \theta_1) f_{vs} - S_1 L_a F_M = 0$$

NOTE:  $F_{av0} = \text{Arm}_R (M_1 + M_2)g$  ;  $\theta_a = 90 + \theta_1 - \theta_E$ ;

$$a_{z_p} = g N z_p + s^2(\Delta z_p + B z_p) ; a_{x_p} = g N x_p t + s^2(\Delta x_p + B x_p)$$

$$\begin{aligned}
5 \quad & \left\{ (I_2 + M_2 L_d^2 \cos^2 \theta_a) s^2 + (F_{av0} - M_2 g) L_e \sin \theta_a \right\} \Delta \theta_a - L_e (\sin \theta_a) f_{1x} \\
& - L_2 (\cos \theta_a) f_{1y} - L_d (\sin \theta_a) f_{ca} \\
& - (L_e - L_{ER} + L_d \cos^2 \theta_a) (B_{AR} s + K_{AR}) \Delta r_n \\
& - (L_d \sin \theta_a \cos \theta_a) (B_F s + K_F) \Delta r_t \\
& + \frac{\text{if } C_{K_s} \neq 0}{K_{sc}} \left\{ L_d M_2 (\cos \theta_a) (\cos \theta_c) s^2 c + L_d (\cos \theta_a) M_2 (\sin \theta_{IJ}) s^2 L_I \right\} = L_d (\cos \theta_a) M_2 a_{zp}
\end{aligned}$$

$$6 \quad f_{1y} + f_{vs} - M_1 s^2 \Delta z_1 - M_1 L_a (\sin \theta_1) s^2 \Delta \theta_1 = M_1 a_{zp}$$

$$\begin{aligned}
8 \quad & C_I (\cos \theta_{IJ}) f_{ca} + \left\{ C_I (\sin \theta_{IJ})^2 M_2 s^2 + B_I / K_I + 1 \right\} L_I \\
& + C_I (\sin \theta_{IJ}) (\cos \theta_a) M_2 L_d s^2 \Delta \theta_a \\
& + \frac{\text{if } C_{K_s} \neq 0}{K_{sc}} \left\{ C_I (\sin \theta_{IJ}) (\cos \theta_c) M_2 s^2 c - C_I (\sin \theta_{IJ}) f_{1y} \right\} \\
& + C_I (\sin \theta_{IJ}) [ - (B_F s + K_F) (\sin \theta_a) \Delta r_t ] \\
& = C_I (\sin \theta_{IJ}) M_2 a_{zp} \\
& + C_I (\sin \theta_{IJ}) [ - (B_{AR} s + K_{AR}) (\cos \theta_a) \Delta r_n ]
\end{aligned}$$

$$\begin{aligned}
9 \quad & \frac{\text{if } C_{K_s} \neq 0}{K_{sc}} \left\{ -M_2 (\sin \theta_c) s^2 c + M_2 (\cos \theta_{IJ}) s^2 L_I - \left\{ (M_2 L_d \sin \theta_a) s^2 + F_{av0} \right\} \Delta \theta_a \right\} \\
& + f_{1x} - f_{ca} - (B_F s + K_F) (\cos \theta_a) \Delta r_t + (B_{AR} s + K_{AR}) (\sin \theta_a) \Delta r_n = M_2 a_{xp}
\end{aligned}$$

$$11 \quad f_{ns} - f_{1x} - M_1 s^2 x_s - M_1 L_a (\cos \theta_1) s^2 \Delta \theta_1 = M_1 a_{xp}$$

$$12 \quad f_{vs} + f_{VN} - f_{by} + M_T (\cos \theta_L) s^2 u_{bp} - M_T L_T (\sin \theta_T) s^2 \Delta \theta_T = -M_T a_{zp}$$

$$13 \quad x_s + (\sin \theta_L) u_{bp} + (L_T \cos \theta_T + L_s \cos \theta_s) \Delta \theta_T = B_{xp}$$

$$14 \quad [L_T s^2 + (B_{TB} + B_{NT})s + K_{TB} + K_{NT} - W_E] \Delta \theta_T - (B_{NTS} + K_{NT}) \Delta \theta_N \\ - (L_s \cos \theta_s) f_{ns} - L_{TN} (\cos \theta_{TN}) f_{nN} - L_s (\sin \theta_s) f_{vs} \\ - L_{TN} (\sin \theta_{TN}) f_{VN} + L_T (\cos \theta_T) f_{bx} \\ - L_T (\sin \theta_T) f_{by} + S_1 L_a F_M = 0$$

$$W_E = L_T \cos \theta_T [(M_H + M_N + M_T + M_1 + M_2)g - F_{avO}] \\ + L_s \cos \theta_s [(M_1 + M_2)g - F_{avO}] + L_{TN} \cos \theta_{TN} (M_H + M_N)g$$

$$15 \quad f_{nh} + M_H (\sin \theta_L) s^2 u_{bp} + M_H (L_T \cos \theta_T + L_{TN} \cos \theta_{TN}) s^2 \Delta \theta_T \\ + M_H L_N (\cos \theta_N) s^2 \Delta \theta_N + M_H L_H (\cos \theta_H) s^2 \Delta \theta_H = M_H a_{xp}$$

$$16 \quad [ (I_H s^2 + B_{HNS} - M_H g L_H \cos \theta_H) C_H + K_{HN} ] \Delta \theta_H + F_A \quad \text{if } NM \neq 0 \\ - (B_{HN} C_H s + K_{HN}) \Delta \theta_N - C_H L_H (\sin \theta_H) f_{vh} - C_H L_H (\cos \theta_H) f_{nh} = 0$$

$$17 \quad f_{vh} - M_H (\cos \theta_L) s^2 u_{bp} + M_H (L_T \sin \theta_T + L_{TN} \sin \theta_{TN}) s^2 \Delta \theta_T \\ + M_H L_N (\sin \theta_N) s^2 \Delta \theta_N + M_H L_H (\sin \theta_H) s^2 \Delta \theta_H = M_H a_{zp}$$

$$18 \quad (\cos\theta_L)f_{by} + (B_Bs + K_B)u_{bp} + (\sin\theta_L)f_{bx} + M_Bs^2u_{bp} = M_B(\sin\theta_L)a_{xp} \\ - M_B(\cos\theta_L)a_{zp}$$

$$19 \quad f_{bx} + f_{nN} + f_{ns} - M_T L_T (\cos\theta_T) s^2 \Delta\theta_T - M_T (\sin\theta_L) s^2 u_{bp} = -M_T a_{xp}$$

$$20 \quad \left( \frac{B_Bs + K_B}{K_{BS}} + 1 \right) u_{bp} - u_{bp} = 0$$

$$21 \quad (\cos\theta_L)u_{bp} - (L_T \sin\theta_T + L_S \sin\theta_S) \Delta\theta_T - \Delta z_1 = 0 - B_{zp}$$

$$23 \quad [I_N s^2 + B_{NT} s + K_{NT} - (M_H g L_N + M_N g L_{N1}) \cos\theta_N] \Delta\theta_N \\ - L_{N1} (\sin\theta_N) f_{VN} - L_{N1} (\cos\theta_N) f_{nN} - [(L_N - L_{N1}) \sin\theta_N + L_H \sin\theta_H] f_{vh} \\ - [L_H \cos\theta_H + (L_N - L_{N1}) \cos\theta_N] f_{nh} + [I_H s^2 - M_H g L_H \cos\theta_H] \Delta\theta_H \\ - (B_{NT} s + K_{NT}) \Delta\theta_T = 0$$

$$24 \quad f_{nN} - f_{nh} + M_N (\sin\theta_L) s^2 u_{bp} + M_N (L_T \cos\theta_T + L_{TN} \cos\theta_{TN}) s^2 \Delta\theta_T \\ + M_N (L_{N1} \cos\theta_N) s^2 \Delta\theta_N = M_N a_{xp}$$

$$25 \quad f_{VN} - f_{vh} - M_N (\cos\theta_L) s^2 u_{bp} + M_N (L_T \sin\theta_T + L_{TN} \sin\theta_{TN}) s^2 \Delta\theta_T \\ + M_N (L_{N1} \sin\theta_N) s^2 \Delta\theta_N = M_N a_{zp}$$

# NEUROMUSCULAR MODEL EQUATIONS

$$7 \quad F_M + (B_T s + K_T) L_a(\Delta \theta_1) - (B_T s + K_T) x_m = 0$$

$$10 \quad F_M + (B_e s + K_e) x_m - (B_e s + K_e) x_1 = 0$$

$$22 \quad F_M - (B_M s + K_M) L_a(\Delta \theta_T) + (B_M s + K_M) x_1 + \underbrace{F_A}_{\text{if NM} = 0} = 0$$

$$27 \quad (T_{pss} + 1)(A_a + A_g - A_c) - \underbrace{K_{sp}(T_{sp} s + 1)(T_{ss} s + 1) x_{sp}}_{\text{if NM} = 0} = 0$$

$$28 \quad (\tau_a s + 2) F_A + K_a (\tau_a s - 2) F_{aa} = 0$$

$$29 \quad \underbrace{\left[ 1 + \frac{2\zeta_a}{\omega_a} s + \frac{s^2}{\omega_a^2} \right]}_{\substack{\text{This set to 1.0} \\ \text{if } \omega_a = 0}} F_{aa} - F_{aa} = 0$$

$$30 \quad (T_p s + 1) A_g + \underbrace{K_g (T_g s + 1)(T_z s + 1) F_M}_{\text{if NM} = 0} = 0$$

$$31 \quad (\tau_{cs} s + 2)(T_{cc} s + 1) A_c + K_{1c} (\tau_{cs} s - 2) A_E = 0$$

32

$$NM = 0$$

$$\begin{aligned} & \left( \frac{M_c}{K_{sc}} \cos^2 \theta_c s^2 \right) c - \sin \theta_c f_{ca} + (M_2 L_d \cos \theta_a \cos \theta_c s^2) \Delta \theta_a - \cos \theta_c f_{ly} \\ & + (M_2 \sin \theta_{IJ} \cos \theta_c s^2) L_I - (B_{AR} \cos \theta_a \cos \theta_c s + K_{AR} \cos \theta_a \cos \theta_c) \Delta r_n \\ & - (B_F \sin \theta_a \cos \theta_c s + K_F \sin \theta_a \cos \theta_c) \Delta r_t + A_E \\ & = M_2 \cos \theta_c a_{zp} + NMC \end{aligned}$$

$$NM = 1$$

$$A_E + RHD/VD = NMC$$

33

$$x_{sp} + L_a \Delta \theta_T - x_m = 0$$

26

$$\begin{aligned} & [L_T \sin(\theta_T - \theta_V) + L_{TN} \sin(\theta_{TN} - \theta_V)] \Delta \theta_T - V_D \Delta \theta_H - \cos(\theta_L - \theta_V) u_{bp} \\ & + L_N \sin(\theta_N - \theta_V) \Delta \theta_N + RHD = B_{zp} \cos \theta_V - B_{xp} \sin \theta_V \end{aligned}$$

34

$$\Delta r_n + \frac{\overbrace{c \cos(\theta_c - \theta_a)}^{\text{if } C_{K_S} \neq 0}}{K_{sc}} + (L_2 - L_{ER}) \Delta \theta_a + L_I \sin(\theta_a - \theta_{IJ}) = 0$$

35

$$\Delta r_t - c \frac{\overbrace{\sin(\theta_c - \theta_a)}^{\text{if } C_{K_S} \neq 0}}{K_{sc}} + L_I \cos(\theta_a - \theta_{IJ}) = 0$$

$$36 \quad \Delta z_H + (L_T \sin \theta_T + L_{TN} \sin \theta_{TN}) \Delta \theta_T$$

$$- (\cos \theta_L) u_{bp} + (L_N \sin \theta_N) \Delta \theta_N = B_{ZP}$$

$$37 \quad (2 + \tau_V s) A_{C1} + (\tau_V s - 2)(K_{RE} s + K_{DE}) \theta_I = 0$$

$$38 \quad (s + \alpha) A_{EI} + A_{C1} + K_{IE} A_V = 0$$

$$39 \quad \theta_{MC} - \theta_{TC} - A_{EI} + K_{VE} A_V = 0$$

$$40 \quad (T_{C2} s + 1) A_V - s \Delta \theta_H = 0$$

$$41 \quad Q_E = 0 \quad \{ \theta_{EH} - \theta_{M1} = 0$$

$$Q_E = 1 \quad \left\{ \left( 1 + \frac{2\zeta_e}{\omega_e} s + \frac{s^2}{\omega_e^2} \right) \theta_{EH} - \theta_{M1} = 0 \right.$$

$$42 \quad (1 + T_{EM} s) \theta_{M1} - (1 + T_{LM} s) \theta_{MC} = 0$$

$$43 \quad \theta_I - \frac{RED}{V_D} = \theta_{TI}$$

$$44 \quad [L_T \sin(\theta_T - \theta_V) + L_{TN} \sin(\theta_{TN} - \theta_V)] \Delta \theta_T - V_D \Delta \theta_H$$

$$- u_{bp} \cos(\theta_L - \theta_V) + \Delta \theta_N L_N \sin(\theta_N - \theta_V) - V_D \theta_{EH} + RED$$

$$= B_{ZP} \cos \theta_V - B_{XP} \sin \theta_V$$

$$45 \quad \theta_{TC} - \frac{K_p}{V_D} z_D = 0$$

$$46 \quad z_D = \Delta z_p$$

$$47 \quad \theta_E - \Delta\theta_H - \theta_{EH} = 0$$

$$48 \quad \Delta x_h + (\sin\theta_L)u_{bp} + (L_T \cos\theta_T + L_{TN} \cos\theta_{TN})\Delta\theta_T + L_N(\cos\theta_N)\Delta\theta_N = B_{xp}$$

## APPENDIX D

### TYMSHARE EXAMPLE PROBLEM

This appendix documents the use of CREATE, BIODYN and PLOT on the Tymshare System 31 PDP 10.\* The computer dialog appears on the next several pages for a typical session. An existing PARAMETER file is modified, a CHOICES file is created, BIODYN generates the requested transfer functions (only one of which is illustrated), and PLOT produces a quick-look Bode plot. Throughout the dialog, all user inputs/ responses are underlined. The following 6 character filenames are accessed in the course of this example (these are not the Standard Pilot and Standard Crewman which are available on Tymshare):

|                          | <u>File Name</u> | <u>Title</u>  |
|--------------------------|------------------|---------------|
| Existing PARAMETER file: | BB19             | "Stiff Stick" |
| Modified PARAMETER file: | SEMI             | "Semi-Supine" |
| CHOICES file:            | CHOSAR           |               |
| TF file:                 | TAPE19           |               |

There are several differences between the CDC version of the BIODYN-80 package and its Tymshare counterpart. These are listed below:

- All three programs run interactively on Tymshare; all files are specified by the user during execution.
- CHOICES filename can be an existing file, whose name is to be modified. (In CDC, the CHOICES filename must be a new name.)

---

\*A user planning to use BIODYN-80 on Tymshare should be familiar with the Tymshare manual, XEXEC, especially Section 3. At present, BIODYN-80 is not a current Tymshare Library Program, and a potential user should contact the second author for the required procedures.

- Because of the above differences, there are slight changes in the dialog for the Tymshare version (e.g., the NEW PARAMETER FILE? query is not used, since the PDP-10 software can determine internally whether or not a new filename has been input).

## D.1 Running CREATE

EXEC CREATE

LOADING  
EXECUTION

Execute CREATE

INPUT PARAMETER FILENAME :

PR19

LISTING DESIRED?

IF

(LONG OR (SHORT) LISTING?

SH

PARAMETERS FOR:

STIFF STICK

LOWER BODY

11.000 1290.1 29585. 71519. 13.000 9.8000

TORSO

18.000 0.80000 15.750 500.00 0.00000 0.30000

10.000 0.15000 5.0000 0.30000 0.00000 0.30000

NECK

0.00000 0.00000 0.25000 50.000 0.00000 0.00000

-20.000 0.10000 0.50000E 01

HEAD/DISPLAY VIEWING

4.3400 0.39000E-01 0.00000 1.0000 0.00000 0.00000

70.000 0.00000 -20.000 0.75000 0.00000 0.00000

ARM (UPPER, LOWER)

1.3720 0.12000E-01 40.000 0.29000 0.11000 0.00000

1.0170 0.15000E-01 145.00 0.30500 0.50000 0.00000

GRIFF INTERFACE

0.0000 0.10000E-01 0.55781E-04

STICK

0.31000 2.0000 13900. 1.0000 0.00000 0.00000

90.000 0.81000 13900. 0.00000 0.00000 0.00000

ARM REST

0.00000 0.00000 0.00000 0.00000 0.00000 0.00000

NEUROMUSCULAR SYSTEM

0 01.40

0.00417E-01 0.90709E-01 0.89888E-01

1.0000 0.00000 16.000 0.00000 0.00000 0.00000

1.0000 0.00000 2.4312 40.000 0.00000 80.000

5.0000 0.00000E-01 0.00000 0.00000 0.00000 0.00000

0.50000 0.55556E-01 0.00000 0.00000 0.00000 0.00000

IMAGE FIXATION/VESTIBULO-OCCULAR SERV

7.0775 0.00000 0.10000E-01 0.30000 0.00000 0.00000

0.67000 0.10000 0.10000E 01 0.30000 0.00000 0.00000

0.10000 0.10000E-01 1.0000 0.65000 416.23 0.00000

CHANGES DESIRED?

YE

INPUT NUMERICAL CHANGES AND VALUE FOR EACH CHANGE,

TO EXIT, TYPE XXX.

THE 0.0000

IN 0.110.

END

Interactive input of  
PARAMETER file to be  
modified

Generate short listing  
of file to modify

Make changes to file

(continued on next page)

[illegible]

Interactive input  
of filename on which  
to store modified  
PARAMETER file

60

# D.1 (Concluded)

|                                                                                                                                                                                                                                                                                                                                                                                                                    |   |  |                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|--|---------------------------------------------------|
| INPUT CHOICES FILENAME :                                                                                                                                                                                                                                                                                                                                                                                           | } |  | Interactive input of<br>CHOICES filename          |
| <u>CHOSAR</u>                                                                                                                                                                                                                                                                                                                                                                                                      |   |  |                                                   |
| BIODYN IFS DESIRED FOR PIVIB ?                                                                                                                                                                                                                                                                                                                                                                                     | } |  | No PIVIB TF's desired                             |
| <u>NO</u>                                                                                                                                                                                                                                                                                                                                                                                                          |   |  |                                                   |
| TRANSFER FUNCTION INPUT :<br>FIRST LINE-RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC<br>(AAA,AAA) ; ENTER XXX TO STOP<br>SECOND LINE-PLOTTING INFORMATION, 5 ITEMS :<br>BODE LOWER FREQ. LIMIT<br>BODE UPPER FREQ. LIMIT<br>BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)<br>BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)<br>LIST (1. TO LIST TABLE, 0. FOR NO LIST)<br>IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS |   |  | }<br>Format for CHOICES file<br>information input |
| <u>C,NZF</u>                                                                                                                                                                                                                                                                                                                                                                                                       | } |  | Input CHOICES file<br>information                 |
| <u>1.,100.,0.,0.,0.</u>                                                                                                                                                                                                                                                                                                                                                                                            |   |  |                                                   |
| <u>21,BZF</u>                                                                                                                                                                                                                                                                                                                                                                                                      |   |  |                                                   |
| <u>1.,100.,0.,0.,0.</u>                                                                                                                                                                                                                                                                                                                                                                                            |   |  |                                                   |
| <u>PTH,BZF</u>                                                                                                                                                                                                                                                                                                                                                                                                     |   |  |                                                   |
| <u>1.,100.,0.,0.,1.</u>                                                                                                                                                                                                                                                                                                                                                                                            |   |  |                                                   |
| <u>XXX</u>                                                                                                                                                                                                                                                                                                                                                                                                         |   |  |                                                   |
| EXIT                                                                                                                                                                                                                                                                                                                                                                                                               | ← |  | Exit CREATE                                       |

## D.2 Running BIODYN

EXEC BDNBO,NIRFN  
LOADING  
EXECUTION

Execute BIODYN

ENTER INPUT FILE NAME: SEMI  
ENTER CHOICES FILE NAME: CHOSAR

Interactive input of  
PARAMETER and CHOICES  
files

11-Mar-80 11:53

BIODYN execution

CASE: SEMI-SUPINE

Case title

ENTER SYSTEM OUTPUTS FILE NAME: TAPE20  
NEW FILE

Interactive input of  
TF file

FLOATING UNDERFLOW FC=111246  
FLOATING UNDERFLOW FC=111246

### DENOMINATOR:

```
.10444E-26
( 16.591 ) ( 46.384 ) ( 56.079 ) ( 97.512
( 100.00 ) ( 285.86 ) ( 353.22 )
( .44231 , 8.3929 , 3.7123 , 7.5273 )
( .25697 , 11.509 , 2.9060 , 10.929 )
( .20726 , 13.642 , 2.8274 , 13.346 )
( .19865 , 24.860 , 4.9386 , 24.365 )
( .32015 , 32.898 , 10.532 , 31.167 )
( .85789 , 32.931 , 28.251 , 16.921 )
( .19448 , 57.685 , 11.219 , 56.583 )
( .65024 , 316.83 , 206.02 , 240.70 )
.18027E+11
```

Printout of DTH/DZP  
transfer function

### NUMERATOR: DTH/DZP

```
.29296E-27 << .28049 >>
( .20000 ) ( .00000 ) ( -10.621 ) ( 16.590 )
( 46.384 ) ( 97.067 ) ( 100.00 ) ( -138.57 )
( 209.05 )
( .44231 , 8.3929 , 3.7123 , 7.5273 )
( .21687 , 11.488 , 2.4913 , 11.214 )
( .98984 , 16.317 , 16.646 , 2.3916 )
( .95130 , 33.163 , 28.232 , 17.400 )
( .70646 , 55.410 , 11.440 , 54.216 )
( .65024 , 316.83 , 206.02 , 240.70 )
( .26657 , 336.66 , 325.41 , 86.321 )
.67996E+08 .37719E+02
```

(See Figure 9 for  
explanation of  
format)

TRU =123.31 11-Mar-80 11:58

EXIT

Exit BIODYN

### D.3 Running PLOT

EXEC GCPLOT,CCUR,CRODTP  
LOADING  
EXECUTION

ENTER TRFN SYSTEM FILE NAME: TAPE20

M.TMP 11-Mar-80 11:53  
SCMT-SUPINE

\$\$\$  
C/NZP  
Z1/DZF  
DTH/DZF

Execute PLOT

Interactive entry  
of TF file

Case title

Dump of TF file  
contents

TAPE20

M.TMP 11-Mar-80 11:53  
SCMT-SUPINE

DTH/DZF  
\$\$\$

FIRST ORDER DIPOLES CANCELLED :  
16.381000  
100.000000

SECOND-ORDER DIPOLES CANCELLED :  
11.110000 8.3929400  
1.5024400 316.83100

NUMERATOR:

|             |             |             |             |   |
|-------------|-------------|-------------|-------------|---|
| 1.28049     |             |             |             |   |
| ( 1.00000 ) | ( 1.00000 ) | ( -10.621 ) | ( 16.590 )  |   |
| ( 97.057 )  | ( -138.57 ) | ( 109.05 )  |             |   |
| ( 1.21687 ) | ( 11.488 )  | ( 2.4215 )  | ( 11.214 )  | ) |
| ( 1.93984 ) | ( 14.817 )  | ( 16.646 )  | ( 24.3917 ) | ) |
| ( 1.85130 ) | ( 33.163 )  | ( 28.230 )  | ( 17.400 )  | ) |
| ( 1.29646 ) | ( 55.410 )  | ( 11.140 )  | ( 54.216 )  | ) |
| ( 1.96807 ) | ( 335.66 )  | ( 325.41 )  | ( 84.321 )  | ) |

DENOMINATOR:

|             |            |            |            |   |
|-------------|------------|------------|------------|---|
| ( 14.091 )  | ( 55.079 ) | ( 97.512 ) | ( 285.86 ) |   |
| ( 353.1 )   |            |            |            |   |
| ( 1.20427 ) | ( 11.309 ) | ( 2.9060 ) | ( 10.929 ) | ) |
| ( 1.10026 ) | ( 13.642 ) | ( 2.8274 ) | ( 13.346 ) | ) |
| ( 1.12865 ) | ( 21.860 ) | ( 4.9586 ) | ( 24.365 ) | ) |
| ( 1.32915 ) | ( 12.398 ) | ( 10.532 ) | ( 31.167 ) | ) |
| ( 1.85289 ) | ( 52.931 ) | ( 28.251 ) | ( 16.921 ) | ) |
| ( 1.12448 ) | ( 57.685 ) | ( 11.219 ) | ( 56.583 ) | ) |

PLOT execution

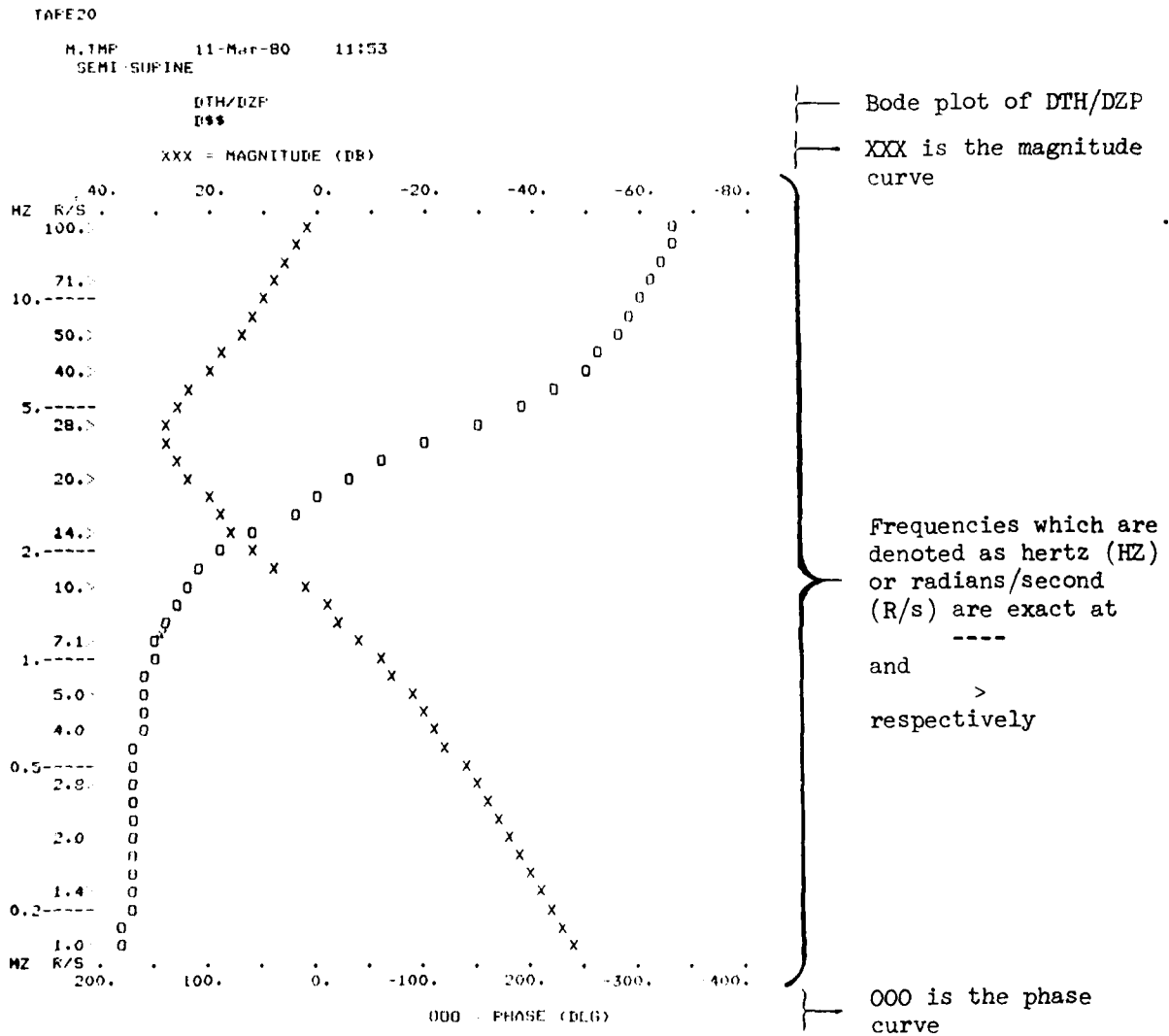
Transfer function DTH/DZF

Identical roots in numera-  
tor and denominator are  
cancelled; close pairs are  
retained

Transfer function to  
be plotted (see  
Figure 11 for explana-  
tion of format)

(Continued on next page)

### D.3 (Continued)



(Continued on next page)

### D.3 (Concluded)

TAPE TO  
M. THE 11-MAR-80 11:53  
SERIAL-SUPINE

| R/S    | DB     | DTH/DZF<br>DEG |
|--------|--------|----------------|
| 1.00   | -48.34 | 175.9          |
| 1.12   | -46.31 | 175.4          |
| 1.26   | -44.27 | 174.9          |
| 1.41   | -42.21 | 174.3          |
| 1.58   | -40.15 | 173.5          |
| 1.78   | -38.07 | 172.8          |
| 2.00   | -35.96 | 171.9          |
| 2.24   | -33.83 | 170.8          |
| 2.51   | -31.67 | 169.7          |
| 2.82   | -29.46 | 168.4          |
| 3.16   | -27.20 | 167.0          |
| 3.55   | -24.88 | 165.3          |
| 3.98   | -22.48 | 163.4          |
| 4.47   | -19.97 | 161.2          |
| 5.01   | -17.34 | 158.6          |
| 5.62   | -14.56 | 155.5          |
| 6.31   | -11.58 | 151.7          |
| 7.08   | -8.38  | 147.1          |
| 7.94   | -4.91  | 141.1          |
| 8.91   | -1.17  | 133.2          |
| 10.00  | 2.85   | 122.9          |
| 11.22  | 7.30   | 110.0          |
| 12.59  | 12.34  | 89.2           |
| 14.13  | 16.45  | 56.6           |
| 15.85  | 18.74  | 24.4           |
| 17.78  | 20.72  | -1.7           |
| 19.95  | 23.31  | -27.3          |
| 22.39  | 26.34  | -60.1          |
| 25.12  | 28.34  | -104.6         |
| 28.18  | 27.92  | -150.8         |
| 31.62  | 26.04  | -189.7         |
| 35.48  | 23.40  | -221.9         |
| 39.81  | 20.29  | -246.8         |
| 44.67  | 17.12  | -264.3         |
| 50.12  | 14.43  | -275.8         |
| 56.23  | 12.60  | -285.8         |
| 63.10  | 10.82  | -299.4         |
| 70.79  | 9.59   | -311.4         |
| 79.43  | 8.37   | -320.3         |
| 89.13  | 7.35   | -327.3         |
| 100.00 | 6.61   | -333.2         |

EXIT

4

Listing of frequency (rad/sec),  
amplitude (dB) and phase (deg)  
at 20 evenly-spaced increments  
per decade for DTH/MZP

(This listing is only generated  
if XL = 1.0 in the CHOICES file  
for this transfer function)

Exit PLOT

## APPENDIX E

### INTERCOM EXAMPLE PROBLEM

This appendix presents a typical terminal session in the Intercom 4.7 operating system, accessing the CSA mainframe at Wright-Patterson AFB's ASD Computer Center. The dialog is annotated so that a typical user will easily understand the basic sequences of parameter entry and job steps. All user responses are underlined; each is terminated by a carriage return.

This particular session was an exercise using a 9 cm viewing distance and the standard crewman (STDCRW) parameter set. It was one of a series of runs which attempted to determine optimal display distance for minimizing image motion of a vertically vibrating crewman. The example is carried far enough for the potential user to see how the programs interface with INTERCOM job control and file management commands.

The steps followed in the investigation are listed below:

- 1) Log in to Intercom.
- 2) Attach the PARAMETER file to be modified and name it TAPE20.
- 3) Attach the CREATE program, called EXECRT.
- 4) Run EXECRT, make changes to existing file, assemble new CHOICES file.
- 5) Assemble batch job to run BIODYN and PLOT, using the two PARAMETER file (old and modified) and the new CHOICES file.
- 6) Submit batch job to input queue.
- 7) When job completed, list the output file.

The user is advised to retain in his permanent files only those which he wishes to use in the future, and to frequently purge his directory of unneeded parameter and output files in order to forestall job failures resulting from file space overload.

# Typical INTERCOM Terminal Session

user responses underlined

```

ASD COMPUTER CENTER INTERCOM 5.0
SYSTEM CSA
DATE 05/20/80      TIME 14.46.39.
PLEASE LOGIN
ENTER 3-DIGIT TERMINAL ID-
05/20/80  LOGGED IN AT 14.46.52.
          WITH USER-ID CA
          EQUIP/PORT 12/001

COMMAND- REQUEST,TAPE7,*PF
COMMAND- REQUEST,TAPE8,*PF
COMMAND- ATTACH,TAPE20,STDCRW

PF CYCLE NO. = 001

COMMAND- ATTACH,EXECRT
PFN IS
EXECRT
PF CYCLE NO. = 001
COMMAND- EXECRT
NEW FILE ?
NO LISTING DESIRED?
YE (LONG OR (SHORT LISTING?
LI (LONG OR (SHORT LISTING?
LO NEW CHOICES FILE ?
YE BIDDYN YES DESIRED FOR PIVIB ?
NO
TRANSFER FUNCTION INPUT :
FIRST LINE-RESPONSE MNEMONIC, FORCING FUNCTION MNEMONIC
(AAA,AAA) ; ENTER XXX TO STOP
SECOND LINE-PLOTTING INFORMATION, 5 ITEMS :
BODE LOWER FREQ. LIMIT
BODE UPPER FREQ. LIMIT
BODE UPPER PHASE LIMIT (0. DEFAULTS TO 200.)
BODE LOWER PHASE LIMIT (0. DEFAULTS TO -400.)
LIST (1. TO LIST TABLE, 0. FOR NO LIST)
IF NO PLOT DESIRED, ENTER 0. FOR ALL ITEMS
RHF,DZF
RHF NOT PERMISSIBLE, PLEASE REINPUT
RHD,DZF
1,200,0,0,1.
MAX FREQUENCY RANGE IS 3 DECADES
PLEASE REINPUT ENTIRE LINE
1,100,0,0,1.
XXX
STOP
.222 OF SECONDS EXECUTION TIME

```

1. Log in to INTERCOM

2. Attach files to I/O units

3. Attach EXECRT(CREATE) program file

4. Execute EXECRT program module

5. Select existing data file (STDCRW)

6. List data file

7. Program rejects unrecognizable input

8. Long listing option selected

9. Affirmative on CHOICES option

10. Negative on PIVIB option

11. Illegal parameter selected

12. Program screens for out-of-limit values

13. Finally, valid input

14. Exit from CREATE

Session continues with batch run

# Sample INTERCOM Batch run

|                                                         |                                    |
|---------------------------------------------------------|------------------------------------|
| COMMAND- <u>EDITOR</u>                                  | 1. Invoke INTERCOM editor          |
| <u>..CREATE,S</u>                                       |                                    |
| ENTER LINES                                             |                                    |
| <u>SAR,CH100000,STCSA, L800015,RIEDEL,(213)679-2281</u> |                                    |
| <u>ATTACH,TAPE7,CHOICE1.</u>                            |                                    |
| <u>ATTACH,TAPE8,VIEW9.</u>                              |                                    |
| <u>ATTACH,EXEBIO.</u>                                   |                                    |
| <u>ATTACH,EXEPLT.</u>                                   |                                    |
| <u>EXEBIO(TAPE4,OUTPUT,TAPE7,TAPE8,TAPE19,TAPE21).</u>  |                                    |
| <u>REWIND,TAPE19.</u>                                   |                                    |
| <u>EXEPLT(OUTPUT,TAPE19).</u>                           |                                    |
| <u>#FOR</u>                                             |                                    |
| <u>=</u>                                                |                                    |
| <u>..SAVE,GOFIL,NOSEQ</u>                               |                                    |
| <u>..STORE,GOFIL,L800015</u>                            |                                    |
| CT ID= L800015 PFN=GOFIL                                |                                    |
| CT CY= 001 00000128 WORDS.:                             |                                    |
| <u>..END</u>                                            |                                    |
| COMMAND- <u>BATCH,GOFIL,INPUT,HERE</u>                  | 4. Batch job stream to input queue |
| COMMAND- FILES                                          |                                    |
| --LOCAL FILES--                                         |                                    |
| *EXECRT *GOFIL \$INPUT \$OUTPUT *TAPE7                  |                                    |
| *TAPE8 *TAPE20                                          |                                    |
| --REMOTE EXECUTING JOBS--                               |                                    |
| SARCK02                                                 |                                    |
| COMMAND-                                                |                                    |
| TASK "N..TEL" TERMINATED                                |                                    |
| TASK EXIT WITH OUTSTANDING IO                           |                                    |
| PC=106646                                               |                                    |
| PS=170000                                               |                                    |
| RO=003770                                               | 5. Job terminated by system crash  |

Note: Output files generated by BIODYN, when listed, are identical in format to printouts shown in Appendix D.

## REFERENCES

1. Jex, H. R., and R. E. Magdaleno, Modeling Biodynamic Effects of Vibration, Fifth Year; Final Scientific Report, Systems Technology, Inc., SR-1037-1, Aug. 1979.
2. Jex, H. R., and R. E. Magdaleno, "Progress in Measuring and Modeling the Effects of Low Frequency Vibration on Performance," Models and Analogues for the Evaluation of Human Biodynamic Response, Performance and Protection, AGARD CP-253, June 1979, pp. A29-1 through A29-11.
3. Jex, H. R., and R. E. Magdaleno, "Biomechanical Models for Vibration Feedthrough to Hands and Head for a Semisupine Pilot," Aviation, Space and Environmental Med., Vol. 49, No. 1, Jan. 1978, pp. 304-316.
4. Magdaleno, R. E., and H. R. Jex, User's Guide to BIODYN-78, An Interactive Computer Program for Modeling Biodynamic Feedthrough to a Pilot's Hands and Head, Systems Technology, Inc., TR-1037-2, July 1979.
5. Jex, H. R., and R. W. Allen, "Evaluating Biodynamic Interference with Operational Crews," Vibration and Combined Stresses in Advanced Systems, AGARD CP-145, Mar. 1975, pp. B24-1 through B24-18.
6. Jex, H. R., and R. E. Magdaleno, Modeling Biodynamic Effects of Vibration; Fourth Year Interim Scientific Report, Systems Technology, Inc., ISR-1037-4, Sept. 1978.
7. Berliner, Jeffrey E., and William H. Levison, PIVIB: A Computer Program for Analysis of Pilot Biodynamic and Tracking Response to Vibration, Bolt, Beranek and Newman, Rept. 3457, Dec. 1976.
8. ASD Computer Center CDC NOS/BE User's Guide, Rev. E, Jan. 1978.
9. ASD Computer Center INTERCOM Guide, Rev. A, Sept. 1976.
10. Magdaleno, R. E., D. T. McRuer, and G. P. Moore, Small Perturbation Dynamics of the Neuromuscular System in Tracking Tasks, NASA CR-1212, Dec. 1968.
11. Braune, W., O. Fischer, J. Amar, and W. T. Dempster, Human Mechanics; Four Monographs Abridged, AMRL-TDR-63-123, Dec. 1963. (AD 600618)
12. "Symposium on Biodynamic Models and Their Applications," Dayton, Ohio, 15-17 Feb. 1977, published in Av., Space and Environ. Med., Vol. 49, No. 1, Jan. 1978.

END

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