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DOCUMENTATION OF GEMASS ENTRY TO TOUCHDOWN SIMULATION

ENGINEERING SYSTEMS ANALYSIS

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1.0 Summary

This design note documents the entry-to-touchdown Space Shuttle Orbiter simulation capability that has been incorporated into the GEMASS (ref. 9) Subprogram 33 (3-DOF). The simulation makes use of the guidance as outlined in the 19 Nov. 1976 SSOFT Level C FSSR (ref. 1). A digital autopilot interfaces between GEMASS and the guidance. Vehicle attitude is determined by use of the ability of GEMASS to integrate differential equations in addition to the equations of motion. Vehicle aerodynamic characteristics are obtained from an OV-102 Aerodynamic Data Tape and control surface deflections required to trim the vehicle and trimmed aerodynamic coefficients are determined internally. Several indicators to allow evaluation of subsystem performance have been included; as is the ability of the user to activate any of several error dispersion sources. The performance of the simulation compares well with more sophisticated 6-DOF simulations as will be shown later in this note in a comparison with SSFS (ref. 10). The simulation is currently available on the 1108-EXEC2 system and will soon be available on the 1110-EXEC8 system. Execution time on EXEC2 system is approximately 25% that of SSFS on the EXEC8 system which makes this a very economical simulation tool. This work was conducted under contract Number NAS 9-14960 Task Order B0705.

2.0 Introduction

The entry-to-touchdown Space Shuttle Orbiter simulation was developed to provide an economical tool for subsystem performance and evaluation studies for the Integrated Entry Task (EX43) of the Engineering Analysis Division (EAD) of NASA. Previous simulations used in this task were capable of simulating the flight of the Orbiter from entry interface (400 K ft) to M = 2.5 using the Analytic Drag Control (ADC) closed-loop guidance. An open-loop guidance routine (CLCT) was also available, but an open-loop guidance cannot achieve acceptable touchdown conditions. Since actual Shuttle flight will be controlled by closed-loop guidance techniques, extending the open-loop capability further was deemed to be of little value. Therefore, work was undertaken to extend the closed-loop capability of the GEMASS simulation.

Addition of the Terminal Area Energy Management (TAEM) guidance allowed extension of the closed-loop simulation to M = .9. At this point the TAEM guidance would initiate modulation of the speedbrake. The trimmed aerodynamic data tables being used by GEMASS were created only for the nominal speedbrake deflection schedule and adding tables of trimmed aero data for various speedbrake positions or including speedbrake as an independent variable in the tables would have been prohibitive in terms of runtime, core requirements, or program modifications. Therefore, it was necessary to add the ability to calculate trimmed aero data internally to the simulation and access the Aerodynamic Data Tape directly. To complete the simulation, the Approach and Landing (A/L) guidance was added to provide the commands necessary to deliver the vehicle to acceptable touchdown conditions.

Two existing quasi-degrees of freedom in angle of attack and bank angle were used to simulate the transient response of the vehicle to the guidance commands. The digital autopilot determines the accelerations and rates of these flight variables and the rates and accelerations are integrated by GEMASS along with the 3-DOF equations of motion.

Several additions were made to the simulation to allow evaluations of subsystem performance that would not be normally attainable in 3-DOF programs. Chief among these is a model of its the Thermal Protection Subsystem (TPS) with calculations of surface and backface temperatures and required insulation weights and thicknesses. Control surface hinge moments computations are done by the simulation; in addition, the user has the option of obtaining punched output that can be used in the sonic boom program to obtain ground overpressure levels for the entry trajectory. A payload bay venting pressure indicator was also added.

The ability to apply several off-nominal dispersion sources has been included in the simulation. Among these are increments to the aerodynamic coefficients, Guidance and Navigation errors, and atmospheric dispersions. In this latter area, two modes of dispersion value application to the neutral atmosphere are available. Winds may be applied with or without activating an alpha-wind correlation routine. Omni-direction winds or a statistical wind model with gust and shear buildup may be used.

3.0 DISCUSSION

The routines that distinguish the entry-to-touchdown simulation from the other GEMASS subprograms are those concerned with guidance, navigation, targeting, and the determination of trimmed aerodynamic data. Each of these is discussed in some detail below, and all interface with GEMASS via the digital autopilot. Obviously, this autopilot (DAPGEM) does more than the function implied by its name (this will be discussed later in some detail) as it was convenient to perform the requisite additional functions there. Enclosure 1 shows a block diagram of the information flow between GEMASS, the digital autopilot, and the other routines. The routines on the right hand side of the page are called in order from top-to-bottom of the page. The top line going into each routine shows the inputs required; the bottom line coming from each routine shows the outputs to DAPGEM. None of the routines on the right hand side of the page access each other, although some (such as targeting and navigation) furnish information which is used in routines called later. Only one guidance routine is used at a time and previously used guidance routines cannot be reentered in the same case. DAPGEM computes all input variables that are not available in GEMASS; i.e. pitch and roll angle. Others (like relative velocity) are accessed by the routines from the GEMASS A-array. No flight variables are modified by any of the routines; new variables are created (such as by coordinate transformations) which are required for the execution of the routines.

Besides serving the functions of providing and accepting information from the routines of the entry-to-touchdown simulation, DAPGEM provides GEMASS with aero coefficients in the form required, provides the rates and accelerations of angle of attack and bank angle which are integrated by GEMASS to simulate two additional degrees of freedom, provides additional useful information to the user, and assures that the guidance routines are called in the proper sequence and at the proper rate. DAPGEM is accessed by GEMASS through the DERIV routine which computes the external forces to be used in the integration of the equations of motion. For this reason DERIV is within the loop of the integration technique being used (Runge-Kutta or Adams-Moulton) and the digital autopilot is called each integration cycle. However, the guidance, navigation, and targeting routines must be cycled at specific rate, DAPGEM and the user required input discussed later in Implementation assure that this is done. Thus, DAPGEM regulates accessability to the guidance, navigation, and targeting.

The remainder of this discussion will deal with the routines mentioned on Enclosure 1 in greater detail with emphasis on user required input and useful output which may be desired during execution of the entry-to-touchdown simulation. Other routines that are available for use in Subprogram 33 such as the TPS model, sonic boom output, open-loop guidance, dispersion source modeling and other minor subroutine mods will be discussed.

DERIV

This routine computes the external forces to be used by GEMASS in the equations of motion. It requires that the user put an integer value into A(1360) to select the type of guidance to be used. A value of less than three (3) is required to access the open-loop guidance. See the discussion on CLCT for the options available. A value of greater than two (2) is required to access the closed-loop guidance for the entry-to-touchdown simulation. See the following discussion on DAPGEM for the options available.

Besides the choice of which guidance option to use, two additional sets of computations were put into DERIV for the entry-to-touchdown simulation. The viscous interaction parameter (See reference 2, Sec. 3.11) is computed here. This parameter is required during the early portion of entry as one of the independent variables in determining the aero data components. A(1351) to A(1354) are used to compute the viscous interaction parameter which is stored in A(1353).

The trajectory heating rate and load is computed by the equation in reference (3). A(1010) to A(1024) are used to store the intermediate results. The heat rate and load are stored in A(591) and A(592), respectively. These are required for use of the TPS subroutine.

DAPGEM

This routine calls the navigation, targeting, guidance and aerodynamics routines. It sends each the required computed inputs, accepts commands and interfaces with the mainstream of GEMASS (through the subroutine DERIV) to obtain body orientation, control surface deflections, and aerodynamic force coefficients. DAPGEM calls the three guidances in their normal sequence. A previous guidance cannot be re-entered unless a new case is initiated. Furthermore, the start of each guidance must be coincident with the start of a new phase. This is because a change in integration step size is required for each guidance and this can only be accomplished by starting a new phase. (Note that starting a new case also starts a new phase.) For the user to start a simulation in the entry guidance, A(1360) should be set to 3. In TAEM or A/L guidance A(1360) should be 4 or 5 respectively. The simulation will execute until a user defined stop condition is met and will then continue with the next guidance phase. This process will continue until the case or job is terminated. The section on Implimentation will innumerate what is required to make the proper phase changes and what is required at the start of each phase or case.

The entry-to-touchdown simulation does not attempt to model the baseline Flight Control System (FCS) because of the core and runtime (due to the small time steps required) required. The difficulty in employing only those parts of the FCS applicable to a 3-DOF simulation would also be prohibitive. To simulate the transient response of the vehicle to the attitude and control surface deflection commands from the guidance routines; second-order control equations are contained in DAPGEM. The equations determine the angle of attack and bank angle accelerations and rates. These quantities are integrated by GEMASS (along with the 3-DOF equation of motion) to determine the body attitude. Thus the simulation has two additional quasi-degrees of freedom. The additional equations integrated are:

angle of attack: $\dot{\alpha} = \int \ddot{\alpha}\, dt$ $\qquad \alpha = \int \dot{\alpha}\, dt$

bank angle: $\dot{\phi} = \int \ddot{\phi}\, dt$ $\qquad \phi = \int \dot{\phi}\, dt$

The second order control equations are:

$$\ddot{\alpha} = K_{\alpha}\,(\alpha_c - \alpha) - K_{\dot{\alpha}}\;\dot{\alpha}$$

$$\ddot{\phi} = K_{\phi}\,(\phi_c - \phi) - K_{\dot{\phi}}\;\dot{\phi}$$

where: K_{α}, K_{ϕ}, $K_{\dot{\alpha}}$, $K_{\dot{\phi}}$ are gains (user selected)

α_c = commanded angle of attack

ϕ_c = commanded bank angle

When TAEM and Approach and Landing guidance are being used, DAPGEM converts the normal acceleration commands into alpha commands.

Maximum rates on alpha and phi can be controlled by the user (A(1216) and A(1236), respectively), as can maximum accelerations (A(1217) and A(1237). Gains on the rate term in the control equation are controlled by A(1214) for alpha and A(1234) for phi. Gains on the angular error are input in A(1215) for the alpha error and A(1235) for the phi error. The user is required to put the initial angle of attack and bank angle into A(1211) and A(1231), respectively.

DAPGEM also produces a speedbrake rate (limited by the design opening and closing rates of 5 dps and 9 dps) from a first order control equation which is integrated by GEMASS to produce a speedbrake deflection.

The speedbrake control equation has the form:

$$\dot{\delta}_{SB} = (\delta_{SB_C} - \delta_{SB}) / \Delta t$$

where: δ_{SB_C} = commanded speebrake position

Δt = current time step (integration step size)

The integration equation used by GEMASS to determined the speebrake position is

$$\delta_{SB} = \int \dot{\delta}_{SB}\, dt$$

The user is require to input a speedbrake schedule in a table which is followed down to M = .9. After M = .9 the TAEM and A/C guidance provide the speedbrake command.

DAPGEM also retracts the body flap when this flag is set by AUTLND. The user can control the angle to which the body flap retracts by A(1226). The rate of retraction is 3 dps. When the landing gear deployment flag is set, DAPGEM produces a post-multiplier for the landing gear increments to the aerodynamics. The rate of deployment can be controlled by the user with A(1228).

EGRT

This routine computes targeting parameters required by the guidance. Inputs necessary are the target longitude and geodetic latitude which are put into A-array 106 and 107, respectively, the runway azimuth, runway ID and altitude above the Fischer ellipsoid (A(1165), A(1180), A(1192)). A redesignation capability is provided. The redesignation flag (A(1166)) is set and a velocity at which redesignation is to be done (A(1167)) is chosen. The redesignation latitude, longitude, altitude, azimuth, and runway ID (the runway number) are input (A(1161), A(1162), A(1163), A(1165), A(1185)). Only one redesignation per entry is allowed.

The approach geometry, in the form of the X coordinate of way point 2 (the nominal touchdown point), the radius of the heading alignment circle, and the distance from the WP2 to X-coordinate of the HAC (A(1169), A(1171), A(1172)) are required. EGRT provides the range to WP2 and the azimuth error to the ADC guidance (CONGID). It provides the vehicle position and velocity in runway coordinates to the TAEM and Approach and Landing guidance. Those two routines have the range and heading computations done internally.

GIDNAV

This routine provides several navigation parameters to the guidance. These are altitude above the landing site, altitude rate, drag, and total acceleration. (A(1196), A(1198), A(1199), and A(1194) respectively). No special user inputs are required. These quantities can be included in the output if desired.

CONGID

This routine contains the ADC guidance as detailed in the 19 NOV 1976 FSSR (Reference 1). Required user inputs (mission dependent or MX constants in the FSSR) are the commanded angle of attack schedule in A(1101) to A(1141) and parameters which define the drag-velocity profile to be flown in A(1142) to A(1160) and A(1177). Altitude rate feedback inputs are in A(1173) to A(1176). An option in the altitude rate feedback scheme allows for consideration of whether the FCS is the automatic or Control Stick Steering (CSS) mode. Even though the entry-to-touchdown simulation has no FCS, the capability of simulating the guidance change resulting from the FCS mode has been retained. If A(1164) is set to zero, the normal (automatic) mode calculations are used; if A(1164) is set to 1, the CSS mode calculations are used. The nominal velocity for Entry/TAEM interface is input via A(1200); when the simulation reaches a velocity less than this, A(1100) is set to 4. This "flag" may be tested as a stop condition for the ADC guidance phase. The ADC guidance returns the commanded bank angle and angle of attack to DAPGEM.

A brief description of the function of the aforementioned A-arrays is given in Enclosure 2. For a more detailed description of the ADC guidance the reader should see Section 4.6 of Reference 1 . Table 4.6.2.1-2 of this document also gives a description of the MX constants and references subsections that describe their function in more detail. Where possible the Fortran names in

CONGID correspond to the variable names in the FSSR document. Where this was not possible, the Fortran names have been made as much like the variable names as possible and the actual variable names are contained in parentheses in Enclosure 2 . This same procedure was followed in the TAEM and A/L guidances. Table A-1 of the FSSR contains the recommended OFT-1 values of the MX constants.

TAEMG

This routine contains the 19 NOV 1976 FSSR Terminal Area Energy Management guidance for OFT-1. It sends a commanded speedbrake deflection (for M < .9), a normal force command and bank angle command to DAPGEM. Transition criteria in TAEMG are tested to determine when the guidance should be exited. When an exit condition is met A(1100) is set to 5; this may be used as a stop condition for the TAEM guidance phase. Mission dependent (MX) constants that define the altitude and dynamic pressure profiles and the energy boundaries are now input by the user via A(1801) to A(1850). A brief description of these A-arrays is given in Enclosure 2. For a more detailed description of the TAEM guidance the reader should see Section 4.7 of Reference 1. Table 4.7.2.1-3 of this document also gives a description of the MX constants and references subsections that describe their function in more detail. Table B-1 of the FSSR contains the recommended OFT-1 values of the MX constants.

The quantities EMEPC1, EMEPC2, ENC1, and ENC2 are 2 x 2 matrices that should be loaded column-wise. The rows define values to be used with each steep glide slope (GAMSGS) and the column value used is determined by the range-to-go. The first steep glide slope is used for a vehicle weight of less than 250K lbs and the second is for greater than 250K lbs. All other variables (except XA) are vectors of dimension two where the value used is determined in the same manner as the steep glide slope. The quantity

XA is a vector of dimension two that defines the aim points on the runway. Initially, the first aim point is used but the user may switch aim points at any time based on one of several conditions being met. These conditions are input in A(1851) to A(1854). They are (in order): 1) time from start of phase greater than a preset value, 2) velocity less than a preselected value, 3) altitude above the runway less than a preselected value, 4) range-to-go less than a preselected value. No values are built in, so the user should input sufficiently large or small values to prevent the aim point change if not desired, i.e., values that cannot possibly be attained during the simulation. The aim point change can occur only once per simulation. The flag for the aim point change is A(1855). Zero means no change has occurred; one means the change has occurred. This flag is carried into the A/L guidance. The quantity TGGS in the NOV FSSR need not be input. It is the tangent of the steep glide slope angle and is computed internally to lessen the user input load.

Several quantities computed by the TAEM guidance have been put into the A-array (A(1242) to A(1249)) for potential output. These are defined in Table B-2 of Reference 2.

AUTLND

This routine contains the 19 Nov. 1976 FSSR Approach and Landing guidance. Mission dependent (MX) constants that define the reference trajectory to be flown are now input by the user via A(1871) to A(1892). A brief description of the function of these quantities is given in Enclosure 2. For a more detailed description of the A/L guidance the reader should see Section 4.8 of reference 1. Table 4.8.2-3 of this document also gives a description of the MX constants and references subsections that describe their function in more detail. Table C-1 of the FSSR contains the recommended OFT-1 values of the MX constants. The steep glide slope angle and the runway aim point are the same as those used in the TAEM guidance and need not be input again. The remarks about the aim point change made in the TAEMG discussion apply here as well. If an aim point change was made in TAEM, it can not and need not be done again here. The quantities DSBCTD, SIGMA, and VREF are vectors of dimension two where the first value is associated with the steep glide slope for a vehicle weight of less than 250 K lbs and the second is for greater than 250 K lbs. The quantities HK, XK, R, and XEXP are 2 X 2 matrices where the rows define the values to be used with each steep glide slope and the columns define values associated with the aim point change flag. The first column is used if no change has occured; the second is used if the change has occured. These matrices should be loaded columnwise.

Two additional user inputs are available for simulating the change in the guidance effected by operating the FCS in the automatic or the manual mode. If A(1201) and A(1202) are set to zero the guidance computations for use of the automatic pitch and roll control by the FCS are done. If they are 1, guidance computations simulating manual pitch and roll control are done.

Several quantities computed by the A/L guidance have been put into the A-array (A(1246), A(1247), and A(1278) to A(1280)) for potential output. For a brief explanation of these and other output quantities see Enclosure 2. For further explanation the FSSR should be consulted. AUTLND sends the same commands as TAEMG to DAPGEM. In addition, it sets flag commands that cause the body flap to begin to retract and the landing gear to begin deployment (A(1225) and A(1224) respectively). A touchdown flag (A(1232)) is set when the altitude of the wheels above the runway is zero.

WIND

This routine performs the alpha-wind correlation documented in ref. 4. For details of how the actual angle of attack is computed, this reference should be consulted. A(1212) is the navigated angle of attack and is used by the control equations in DAPGEM and the guidance routines. A(1310) is computed by WIND and is always the actual angle of attack outside of the guidance, with or without winds. This allows for no impact in other areas of GEMASS (i.e. sonic boom, TPS, aero tables, etc.) where actual angle of attack is required. Note that A(51) controls whether or not this subroutine is used.

The velocity at which to stop the alpha-wind correlation is input in A(1207).

TAERO

GEMASS did not have the ability to internally calculate trimmed aerodynamic data which was required to acheive the degree of fidelity desired of the simulation. Trimmed aero data tables were generated off-line as functions of angle of attack, Mach number, and body flap deflection for a scheduled speedbrake deflection. Sets of tables were prepared for several vehicle center of gravity locations and for viscous and inviscid aerodynamics. Addition of more independent variables to the tables was not possible since GEMASS is limited to three independent variables per table. To add tables to account for additional variables would have been prohibitive in terms of core storage and runtime. Therefore, it was necessary to add to GEMASS the capability of determining the contribution of each component of the aerodynamics and determining the trimmed aerodynamics internally for the flight conditions desired. This has the additional advantage of using the Aerodynamic Data Tape as the source for the tables used instead of card input tables or tapes of card image of input tables as was previously done. The files on the Aero Data Tape are set up to read by the GEMASS table reading routines. The computation of trimmed aerodynamics internally allows extension of the GEMASS simulation to touchdown. It allows use of other components of the aerodynamics such as speedbrake, landing gear and ground effects increments which would be difficult to account for with the previous aero data input method.

This routine obtains all the required aerodynamic components and determines the conditions necessary to trim the vehicle ($C_{m_{TOTAL}} = 0$). It does this through modulation of the body flap and/or elevon. An elevon schedule and an initial body flap deflection (A(1665)) are required inputs along with a dynamic pressure (A(1168)) at which to start the trim calculations. The process by which the trim elevon and body flap deflections are determined is shown in Enclosure 3. Basically, it involves finding a body flap deflection that trims the vehicle with the scheduled elevon deflection. If this cannot be done the body flap is deflected to whichever of its limits (-11.7 or 22.5 deg) is closest to $C_m = 0$ and the trim elevon deflection is determined. After the elevon deviates from its scheduled value, TAERO attempts to return it or move it nearer if possible. Once it does return, modulation of the body flap begins again. TAERO will perform the trim calculations for and X-Z center of gravity combination (A(1271) and A(1272)), respectively) where X-c.g. is measured in inches aft of the forwardmost (Body Station 1076.7 or 65% L_B) c.g. position and Z-c.g. is measured positive in inches above WL375. TAERO returns trimmed C_L and C_D and the required control surface deflections to DAPGEM.

The dynamic pressure at which the trim calculations start should be 2 psf. If an entire entry trajectory is under consideration, the switch from the viscous to the inviscid aero components should be done when the viscous interaction parameter reaches a value of .005.

The alternate table technique normally available in GEMASS may be used to transfer to the inviscid tables and A(1358) is reserved for this purpose. Similarly, a transfer from the high to low Mach number aero table should be done when Mach number reaches a value of 1.25. A(1277) is reserved for this purpose. A(1227) should be used as a post-multiplier on the landing gear components.

ROUTINES ADDED TO GEMASS

Several routines have been added to the entry-to-touchdown simulation to enhance its usability in performance and subsystem verification.

TPS - This routine contains the aerothermal, weights, and backface temperature models as defined in the RI/Houston Simplified Weight Synthesis Program (ref 3) through revision 4 of that program. A brief description of these models is contained in sec 4.8 of reference 5. Required user inputs are a flag (A(1400) equals one) to access the routine, the initial bare top temperatures (A(1434 to 1438) and A(1440 to 1444), all recommended to be set to 680), the TPS stop conditions (A(1458 to 1461)) and the number of panels (A(1651), 25 for current models). The first two stop condition inputs are A-array locations of flight variables to be tested against; i.e., stagnation heating rate (A(591)) and altitude (A(108)). The next two are the values these flight variables are to obtain before the TPS calculations are to be stopped. If the stop is desired when the flight variables are decreasing in value, the values should be input with a negative sign.

The user should also input table control cards 101 to 106 (respectively) to obtain panel design heat load (A(1667)), normal shock viscosity (A(1657)), panel heat ratio (A(1455)), panel transition Reynolds number (A(1452)), panel thickness (A(1656)), and panel area (A(1652)). Examples of these control cards are contained in Enclosure 5. They access the tabular data tape described in Operation and Implementation. Results of the TPS calculations are stored in A(1401) to A(1749) and all are available for output. A summary page is given in the simulation when a stop condition is reached that gives maximum surface, temperatures, their times of occurrance, backface temperatures, panel thicknesses, weights, and heat loads, and totals.

SBOOM - The routine can be accessed to obtain punched output that can be used in the Sonic Boom program to predict overpressure levels. Parameters output are Mach number, altitude, and time rate of change of the variables velocity, Azimuth, and flight path angle. Also output are flight path angle, azimuth, latitude, longitude, bank angle and angle of attack. The routine may be accessed by setting A(1950) to 1. The frequency of the output is control by A(1951) to A(1998) which are input by the user. The first four locations of this group are Mach numbers that define where the output described above is to start and stop. It is divided into two phases. Output can only occur between the Mach numbers defined by A(1951) and A(1952) or A(1953) and

A(1954). Within each of these phases the output frequency can be controlled by the remaining locations. A(1955) is the A-array location of the variable that is to be tested against for the output check. The remaining locations are the values of this quantity at which the output should be done. They should be input in the order in which they will occur in the simulation, i.e., ascending or descending. If they are encountered in descending order they should be input with a negative sign.

VECWIN - The vector wind profile detailed in ref (6) has been programmed into GEMASS. The A-arrays used for input are A(1282) to A(1293). See Enclosure 2 or ref (6) for a brief description of the quantities required. Associated routines also included are TLKUP and GETDAT and a common block WND. VECWIN's use requires that a special input tape be mounted but table control cards are not required since the GEMASS table look-up routines are not used.

CLCT

This routine contains three options for open-loop guidance. The initial angle of attack is input in A(1310) and the angle of attack command A(1210) is determined from Table 42. A phugoid damping term is applied to changes in the command to obtain the actual alpha (A(1310)). The three options available to determine the bank angle are controlled by A(1360):

A(1300) = 0 ; bank angle is obtained for a constant $\dot{q}/g$ trajectory.

A(1360) = 1 ; constant bank angle from A(1380)

A(1360) = 2 ; bank angle from Table 41

To use the constant $\dot{q}/g$ trajectory, an initial bank angle must be input. This angle is maintained until pull-out ($\gamma = 0$) occurs. The heating rate at this time (from reference 11) is

$$q = K \sqrt{\frac{W}{C_L S \cos \phi}}$$

where: q is in BTU/ft^2 sec

W is the vehicle weight.

ϕ is the bank angle.

C_L is the coefficient of lift.

K is a constant of proportionality dependent upon the entry conditions

S is the reference area - 2690 ft^2.

Bank angle is then modulated to maintain this heating rate until the load factor limit (A(1363)) which is determined from Table 46 is reached. This load factor schedule is then maintained for the remainder of the trajectory by modulating bank angle. Several A-arrays have been reserved for gains in the open-loop guidance. These are A(1304), A(1305), A(1312), A(1323), and A(1327). See Enclosure (2) for the terms to which these gains are applied.

A(1361) is input
by the user for the direction of the bank angle: 0 is for right, 1 is for left. After the heading is changed from the initial heading by 90 deg. the side force coefficient (C_y) is set to zero, but the bank angle is maintained. Two options exist for determination of the aerodynamic components. If A(1359) is zero, C_L, C_D and δ_{EL} are determined from Tables 20, 16, and 45 respectively for the inviscid data. Tables 47, 48, 49 are reserved for the viscous data. The transfer to the inviscid tables should be done when A(1353) reaches a value of .005. A body flap schedule in Table 45 must be supplied also. If A(1359) is one, the trimmed aerodynamics are determined from TAERO; thus, all the requisite tables must be set up.

GEMASS ROUTINE MODS

Several routines in the GEMASS program were modified to be compatible with the entry-to-touchdown simulation. Usually these require no additional user input but where applicable these will be noted. The routines and the extent of their mods are:

TABLE - As noted in the discussion on TAERO, the trimmed data tables were read into core from a tape. The user had to input a number which indicated the C.G. to be used and TABLE would select the proper files to be used from the tape. This was removed from TABLE since C.G. position is taken into account in TAERO. The user input is no longer required.

OUT2 - Only 2000 A-arrays are now printed out since the others are being used for data storage. This was done to keep the A-array as small as possible so the simulation would fit in the available core. Note that CT (52) should now be set to 2000 and table storage should start at 2000.

INTDEP - This routine has the values of the additional independent equations to be integrated. These are angle of attack and bank angle and their rates and the speedbrake position. The rates are now stored here for phase changes.

OUT1 - This routine was modified to allow more output of results per printed page. The total number of lines possible per page is now 57 including header and two blank lines before each block of output. Normal GEMASS input is required.

ATMOS3 - Computation of atmospheric conditions during early entry was modified to be consistent with other simulations.

GRAV - The call to VECWIN was included in GRAV

TERMEX - This routine is outside the integration loop of GEMASS and is called at the end of every time step. The calls to TPS and SBOOM are made here. The hinge moment calculations are done here. Required inputs are A(1080) (flag value of one required to perform calculations) A(1088), A(1089), A(1095) (area-arm multipliers for body flap, elevon, and speedbrake. See Enclosure 5 or reference 2 for recommended values) and A(1090). This last input is an increment which is added and subtracted from the actual elevon deflection to find the maximum and minimum hinge moments that can be anticipated on the elevons due to aileron deflection or off-nominal elevon positions. Hinge moments are calculated for both the inboard and outboard elevon surfaces. The user is also required to provide table control cards to access the files from aero data tape. Enclosure 5 shows these (Tables 120 to 127). See Enclosure 2 (A(1080) to A(1096)) for an explanation of quantities used in determining hinge moments. A venting pressure indicator (A(1098)) and the local vent pressure coefficient (A(1099)) as defined by ref. (7) have also been added.

4.0 OPERATION AND IMPLEMENTATION

The GEMASS entry-to-touchdown simulation is contained on each of the first two files of tapes X07475 and X06938. A listing of a sample run deck with control cards is shown in Enclosure 5. This run deck is sufficient to simulate the OFT-1 entry trajectory. The job is divided into three phases, one for each guidance mode. The guidance inputs required for each phase are shown in the input block for that phase. It is not necessary to do this since there is no overlap in the A-array locations of the guidance inputs. Similiarly, a complete set of the output quantities are given for each phase even though this means that some of the quantities are repeated unnecessarily. This was done to allow the user to see all the output quantities in each phase. The plot input blocks for each phase have been changed to display meaningful parameters. The table control cards are input in the first phase and not changed.

After execution begins, the first card GEMASS reads sets the position in the A-array where table storage is to begin and the number of locations to allocate to table storage. The size of the A-array in the entry-to-touchdown simulation is 16000. Since the first 2000 locations are used for input, output and internal operations the remaining 14000 are available for table storage. This is sufficient for storage of all aero, TPS, hinge moment, dispersions (see Appendix I), schedules, and other user input tables in their current forms and allows approximately 1000 locations for future storage requirements. The next block of input is the CT-array.

Shown next are the user input tables. In this case, these are the elevon and speedbrake schedules (respectively) which are user required input. They are input as functions (X-argument) of Mach number. Following the tables are the case control, hollerith, and phase control cards. In the A-array input block that is next; notice that several options (i.e., TPS, hinge moments, etc) have been activated in this example. The input block has been divided into sections (as far as this is possible) that are required for GEMASS execution and those that are peculiar to the entry-to-touchdown simulation.

The comments to the right of each A-array assignment should be sufficient to define its purpose. There are a few assignments in this block that are of special interest. Note that A(1360) is set to 3 to start with the ADC guidance. The integration time step (A(53)) is 1.92 sec. as this is the rate at which the ADC guidance should be sequenced. The number of additional differential equations to be integrated (A(48)) is 5, i.e., angle of attack and bank angle rate and acceleration and speedbrake rate. Also, the stop is when the guidance mode indicator (A(1100)) becomes 4. The TAEM guidance cannot be entered until this occurs. If the user wishes to terminate the ADC guidance phase at some point other than that defined by VTAEM, then A(1100) would have to be set to 4 in the phase in which the TAEM guidance is to be used.

After the plots are set up, the table control cards define the source and location of the input data tables to be stored in the A-array. Enclosure 6 gives the file locations, size, and arguments of all tables that are currently available for use with the entry-to-touchdown simulation. The first page of this enclosure is for a special data tape (X14728) which contains many frequently used tables. The remainder of the enclosure is for the special aero data tape (X17990) that was created in order to run the simulation. For more information on this tape see reference 8.

The second phase (TAEM) of the simulation also has special input requirements. The integration time step must now be set to .96 sec. in order to properly sequence the TAEM guidance. The stop condition should be when the TAEM guidance transition criteria set A(1100) to 5. A(1100) must equal 5 for initiation of the A/L guidance. Also, the heat rate calculation (A(590)) should be turned off as it will cause the simulation to terminate due to an argument out of range for velocities less then 1200 fps. It is not required for the TPS routine since TPS has stopped by this time.

The third phase requires a time step of .16 sec. for proper sequ·ncing of the A/L guidance. The stop condition for this phase is touchdown, i.e., when A(1232) equals 1. Another possible stop condition could be when the vehicle is 18 ft. above the runway (height of the vehicle c.g. above the wheels). In this case, the runway altitude is 2220 ft. above the Fischer ellipsoid so the c.g. altitude at touchdown is 2238 ft.

A new case could now be initiated starting again with the ADC guidance. However, the input constants for the TAEM and A/L guidances must be input again. The amount of input required in these phases would be less if the input constants that do not overlap (i.e., do not have to be changed from one phase to the next) were all input in the first phase of the first case.

Enclosure 7 shows a sample Form 588 and plot request. This provides the operator with sufficient information to mount the correct tapes and start a GEMASS entry-to-touchdown simulation. If sonic boom output is to be obtained the box for punched output should be checked. Runtimes are for complete entry-to-touchdown simulations of one case per job. Additional cases would take approximately 6 min. Individual phase execution times are:

ADC guidance ~ 3.5 min.

TAEM guidance ~ 1.0 min.

A/L guidance ~ 1.5 min.

An additional 2 min. is required for reading in the program and input. The maximum runtime reflects these requirements plus some contingency. The page limit is for printing output from all time steps of a complete one case job. The plot number is applicable to the sample run deck of Enclosure 5.

5.0 RESULTS

A comparison of a GEMASS entry-to-touchdown simulation of OFT-1 with a similar trajectory obtained using SSFS (6-DOF) is shown in Enclosure 8. Points from the GEMASS trajectory are plotted on the SSFS Calcomp plots. The first eleven pages are for the complete trajectory; the remainder show in detail the flight variables from Entry/TAEM interface to touchdown.

The match between independent flight variables that are related to the vehicles position and velocity vector; i.e., dynamic pressure and altitude are generally good. Where differences do occur, they can be attributed to the two additional quasi-degrees of freedom incorporated into GEMASS. While the angle of attach and bank angle histories are similar to that of the 6-DOF program, the differing response characteristics of the entry-to-touchdown simulation, do result in small trajectory differences. An example of this can be seen in the 4000 ft. difference in downrange at Entry-TAEM interface (Enclosure 8 page 15). Although alpha and bank angle histories were similar up to this point, they differed enough from the 6-DOF simulation to cause this. The downrange error caused the differences in bank angle and alpha during the TAEM guidance phase (Enclosure 8 pages 20 and 21).

Finally, it should be noted that the method of determining the control surface positions differs between the two simulations. In the 6 DOF simulation the attitude commands going to the FCS result in control surface deflection commands coming from the FCS and going to the actuators models. The moments which result from this modeling determine the vehicle attitude and dynamics. In the 3-DOF simulation, the control surface deflections are those required to trim the vehicle at its current angle of attack. The elevon history in the 3-DOF simulation is the input elevon schedule; the body flap is used to trim the vehicle until it begins to retract to its landing position. Limits on the elevon and body flap rates are not considered. In the 6-DOF simulation, the elevon is allowed to deviate up to 1 deg. from its schedule at which time movement of the body flap begins to return the elevon to within this 1 deg. limit. Rate limits on the surfaces are considered in the 6-DOF simulation. Differences in the speedbrake position in the two simulations can be attributed to actuator dynamics in SSFS and differences in the dynamic pressure between the simulations which was caused by angle of attack differences.

6.0 CONCLUSIONS AND FUTURE WORK

The entry-to-touchdown simulation capability is operational on the Univac 1108 EXEC 2 system. Although it does not contain an Integrated Flight Control System and is a 3-DOF program, its simulation capability compares well with more sophisticated 6-DOF programs such as SSFS. Program input and usage follow the general GEMASS guidelines and requirements although there are now more options available to the user than were formerly. The user has available two types of attitude commanded guidances and one of these may be exercised in any or all of the three major modes as currently defined for the baseline Space Shuttle guidance. Simulation of the performance of several subsystems may also be done. The program is economical to use in terms of runtime which makes it a tool of considerable value in doing performance and trade studies. This facet of the program becomes particularly evident when multiple case jobs are submitted.

Enclosure 9 shows a review of the tapes and the files on those tapes that may be used with the entry-to-touchdown simulation. Enclosure 10 gives the names and phone numbers of those programmers who should be contacted if there are questions on the simulation.

The entry-to-touchdown simulation will undergo continual modification as new models are added and existing models are updated. This will be especially true of the guidance which will undoubtly have to be revised as new guidance FSSR's are issued. It may become necessary to maintain versions of the simulation for both OFT and

Operational Space Shuttle guidance configurations. A tape will be created which will contain on separate files all the inputs necessary to run any of several trajectories. All the user need to do is assign this tape in place of the scratch C-tape and start his job as though it were a second case. This process is described in Section 3.3 of the user's manual. It may be advantageous to add a Flight Control System that will more accurately simulate the "real worl control surface deflections and their rates. The simulation will soon be operational on the EXEC 8 system to preserve the program when and if the EXEC 2 system is finally phased out. It will also allow flexibility in usage as each system sometimes experiences hardware, software, and turnaround problems.

As the simulation currently exists on the Univac 1108 EXEC 2 system there is only limited opportunity for future growth. Less than 100 actual core locations are not used for program or storage. The growth limitation may be alleviated by dumming out routines that are not required by the user for his simulation. The routines to which this may be done, the resulting core mode available, and an example of the input necessary to achieve this are shown in Enclosure 11. This process may be temporary or new tapes may be created with these dummy routines. Note that this last option would permanently lose some of the GEMASS program capability. This is especially true of the EXECT 1, EXECT 5, and EXECT 8 routines which control several of the other subprograms. This problem could also be solved by further segmentation of the subprogram 33 segment. This would involve loading only one guidance routine at a time. The open or closed loop guidance would not be loaded if it were not to be used. This would require remapping the program. A disadvantage of this will be an increase in runtime (how much is unknown at this time) as the program tape must be read again for each guidance; for a multiple case job this would have to be done several times.

As changes are made to the GEMASS program they will be reported as updates or appendices to this design note.

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(2) "Orbiter Vehicle", Aerodynamic Design Data Book, Vol. 1. Space Division, Rockwell International Corporation, SD 72-SH-0060-1J (December 1975)

(3) IL SEH-ITA-74-156, "RI Houston Simplified Weight Synthesis Program Content", from G. W. Mauss to C. L. Statham dated 4 Nov. 1974. Rev. 1, IL SEH-ITA-74-197, 11 Dec. 1974, Rev. 2, IL SEH-ITA-75-81, 21 March 1975, Rev. 3, IL SEH-ITA-75-192, 21 July 1975, Rev. 4, Minutes of Seventeenth Entry Panel Meeting, 22 and 23 Jan. 1976

(4) "Alpha-Winds Correlation for GEMASS", Engineering Analysis Division, MDTSCO, 1.2-TM-B0105-332 (25 June 1975)

(5) Space Shuttle Flight Systems Performance Data Book, Vol. 2, "Descent", Space Division, Rockwell International Corporation, SD 73-SH-0178-2A (May 1976)

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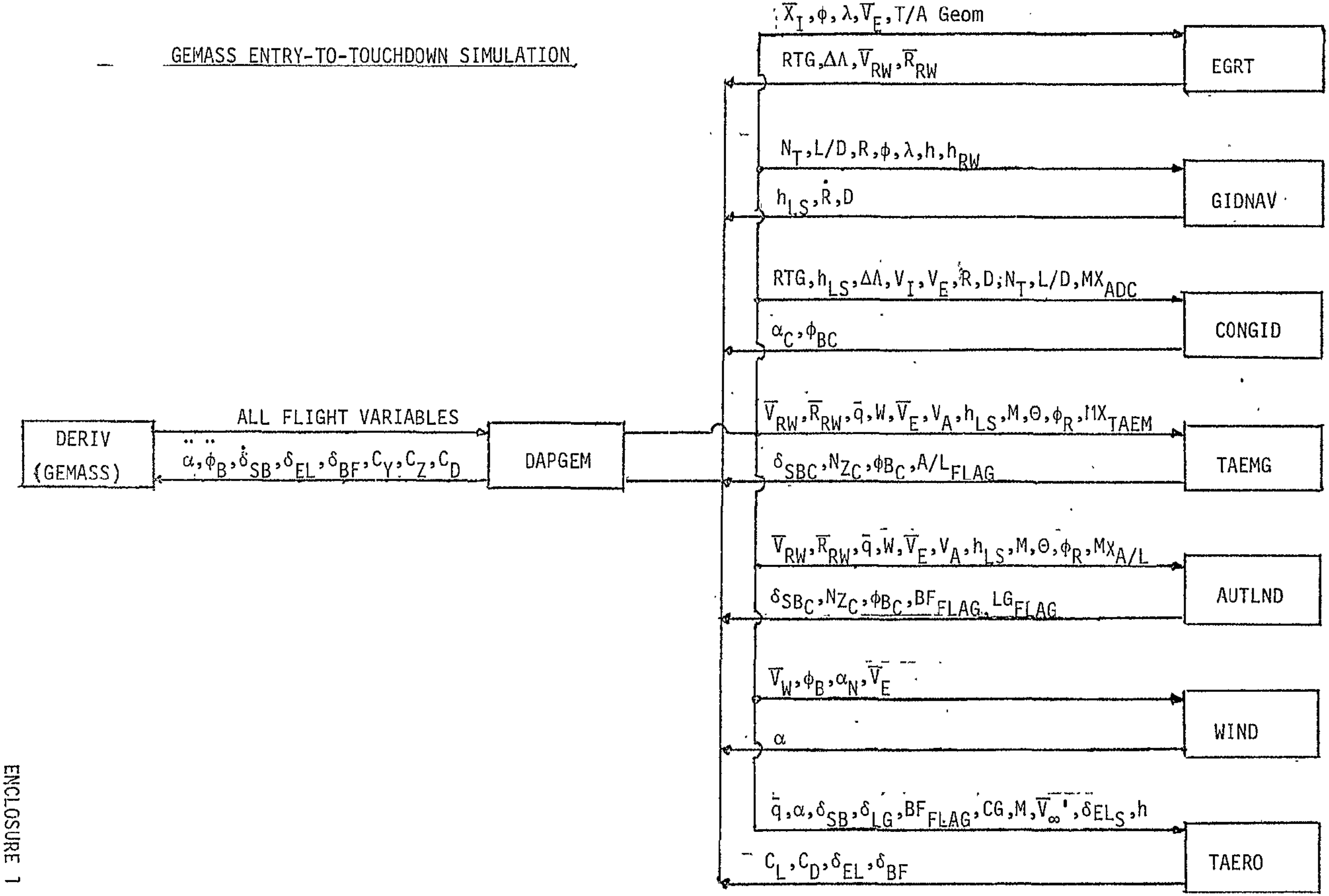
(8) "Special Request Mach-Segmented Rearranged Orbiter (OV102) Aero Data Tape", Engineering Analysis Division, MDTSCO, 1.2-TM-B0605-1012 (28 Dec. 1976)

(9) "Missile and Satellite Systems Program", A. J. Dennison and J. F. Butter; Defense Electronics Div., General Electric Company, Technical Information Series (Feb. 1962)

(10) "Space Shuttle Functional Simulator", Revision B. JSC-06726, April 1976 (Volume I, II, and III).

(11) W.H.T. Tech, "Dynamics and Thermodynamics of Planetary Entry", Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1963

GEMASS ENTRY-TO-TOUCHDOWN SIMULATION



Definition of Variables

A/L_{FLAG}	Approach and Landing initiation flag
BF_{FLAG}	Body flap retract flag
C_D	Drag coefficient
C_L	Lift coefficient
C_Y	Side force coefficient
C_Z	Vertical lift coefficient
CG	Center of gravity location
D	Drag acceleration
h	Geodetic altitude
h_{LS}	Altitude above landing site
h_{RW}	Runway altitude
L/D	Lift-to-drag ratio
LG_{FLAG}	Landing gear deployment flag
MX_{ADC}	ADC guidance mission dependent constants
MX_{TAEM}	TAEM guidance mission dependent constants
$MX_{A/L}$	A/L guidance mission dependent constants
M	Mach number
N_T	Normal load factor
N_{ZC}	Load factor command
$\bar{q}$	dynamic pressure
R	Magnitude of radius vector from earth center

Definition of Variables

$\dot{R}$	Altitude rate
$\bar{R}_{RW}$	Position vector in runway coordinates
RTG	Range-to-go
T/A geom	Target and approach geometry
V_A	Airspeed
$\bar{V}_E$	Relative velocity vector
$\bar{V}_I$	Inertial velocity vector
$\bar{V}_{RW}$	Velocity vector is runway coordinates
$\bar{V}_W$	Wind vector
$\bar{V}_\infty$	Viscous intruction parameter
W	Weight
$\bar{X}_I$	Position vector
α	angle of attack
α_c	Commanded angle of attack
α_N	Navigated angle of attack
$\ddot{\alpha}$	Angle of attack acceleration
$\Delta\Lambda$	Heading error
δ_{BF}	Body flap position
δ_{EL}	Elevon position
δ_{ELS}	Scheduled elevon position
δ_{LG}	Landing gear deployment ratio

Definition of Variables

δ_{SB}	Speedbrake position
$\dot{\delta}_{SB}$	Speedbrake rate
δ_{SB_c}	Speedbrake command
Θ	Euler pitch angle
λ	Longitude
ϕ	Geodetic latitude
ϕ_B	Bank angle
ϕ_{B_C}	Commanded bank angle
$\ddot{\phi}_B$	Bank angle rate
ϕ_R	Euler roll angle

A-ARRAY FOR ENTRY-TO-TOUCHDOWN SIMULATION

A-Array	Definition
1000-1005	Not used
1006	Density scale height-ft
1007-1009	Not used
1010-1024	Used to compute heat rate and load
1025	Not used
1026-1028	X-Y-Z wind component post-multipliers
1029	Density increment post-multiplier
1030-1033	Post-multipliers for aero data uncertainties
1034	Post-multiplier for altitude rate error
1035	Post-multiplier for range-to-go error
1036	Not used
1037	Pressure factor post-multiplier
1038	Sound speed factor post-multiplier
1039	Viscosity factor post-multiplier
1040	Flag for altitude error: 0-off, 1-on
1041	Altitude error-ft
1042	Altitude error post-multiplier
1043-1050	Not used
1051	Velocity error-fps
1052	Bank angle error-deg
1053	Angle of attack error-deg
1054	Altitude rate error selector: 1-WTR, 2-ETR
1055	Altitude rate error-fps

A-Array	Definition
1056	Range-to-go error selector: 1-WTR, 2-ETR
1057	Range-to-go error-NMI
1058-1059	Not used
1060	Aero uncertainty series selector: 1-10
1061	C_D uncertainty
1062	C_L uncertainty
1063	Density factor selector: 1-70^{0}N Hot, 2-ETR Hot, 3-70^{0}N Cold, 4-ETR Cold
1064	N/S wind profile selector: 1-N, 2-S
1065	E/W wind profile selector: 1-E, 2-W
1066-1079	Not used
1080	Hinge moment computation indicator: 0-Off, 1-On
1081	Body flap hinge moment-in-lbs
1082	Inboard elevon hinge moment-in-lbs
1083	Outboard elevon hinge moment-in-lbs
1084	Inboard elevon hinge moment with positive def. increment-in-lbs
1085	Outboard elevon hinge moment with positive def. increment-in-lbs
1086	Inboard elevon hinge moment with negative def. increment-in-lbs
1087	Outboard elevon hinge moment with negative def. increment-in-lbs
1088	Body flap area-arm-ft^{2}in
1089	Elevon area-arm-ft^{2}in
1090	Delta deflection to be considered on the elevons-deg

A-Array	Definition
1091	Body flap hinge moment coefficient
1092	Inboard elevon hinge moment coefficient
1093	Outboard elevon hinge moment coefficient
1094	Speedbrake hinge moment coefficient
1095	Speedbrake area-arm-ft^2in
1096	Speedbrake hinge moment-in-lbs
1097	Not used
1098	Corrected venting pressure indicator - psi
1099	Local vent pressure coefficient
1100	Guidance mode indicator: 3-ADC, 4-TAEM, 5-A/L
1101-1110	CALP0-constant coefficients of alpha command segments-deg
1111-1120	CALP1-linear coefficients of alpha command segments-^{o}/fps
1121-1130	CALP2-quadratic coefficients of alpha command segments-$^o/fps^2$
1131-1140	VALP-velocity breakpoints between alpha command segments-fps
1141	NALP-number of alpha command segments less one
1142	AK-describes slope between temp. control and eq. glide phases
1143	AK1-describes slope between drag quadratics
1144	VA-velocity of zero slope of second drag quadratic-fps
1145	VA1-velocity of intersection of drag quadratics-fps
1146	VA2-velocity of zero slope of first drag quadratic-fps
1147	VB1-start velocity of eq. glide phase-fps
1148	VS1-describes slope of drag profile of eq. glide phase-fps

A-Array	Definition
1149	ALFM-constant-g phase drag-fps^2
1150	PREBNK-initial entry bank angle-deg
1151	EEF4-energy value of transition phase drag profile anchor point-ft^2/sec^2
1152	DF-drag value of transition phase drag profile anchor point-fps 2
1153	RPT1-range from anchor point to WP2-NMI
1154	VTRAN-transition phase start velocity-fps
1155	ETRAN-transition phase start energy-ft^2sec^2
1156	VQ-constant of ranging velocity-fps
1157	GS1-roll smoothing parameter between drag quadratics
1158	GS2-roll smoothing parameter between TC&EG phases
1159	GS3-roll smoothing parameter between EG&CG phases
1160	GS4-roll smoothing parameter between CG and transition phases
1161	RTLATD-geod. latitude of redesignation target point-deg
1162	RTLONG-longitude of redesignation target point-deg
1163	RTALTD-altitude above Fischer ellipsoid of redesignation target point-ft
1164	ICSS (CSSRYLAMP) - control stick steering flap - 0 automatic mode, 1 CCS mode
1165	RRAZ-azimuth of redesignation runway-deg (E of N+, W of N-)
1166	ITREDS-redesignation flag: 0-no redesignation, 1-redesignate
1167	VREDS-velocity at which redesignation is to occur-fps
1168	Dynamic pressure to start trim aero-psf

A-Array	Definition
1169	XWP2-X coordinate of way point 2-ft
1170	RAZ nominal runway azimuth-deg (E of N+, W of N-)
1171	RTURN-radius of heading alignment circle-ft
1172	DBAR-distance from WP2 to X-coordinate of HAC-ft
1173	VRDT - velocity to start alt. rate feedback - fps
1174	ACN1 - time constant for alt. rate feedback - sec.
1175	DDLIM - max. delta drag for alt. rate feedback - ft/sec^2
1176	ZK1 - gain for alt. rate feedback
1177	D230 - Initial valve of ref. drag at VB1 - ft/sec^2
1178	IPHASE-guidance phase indicator all modes
1179	LODV-commanded L/D
1180	IRWID(RWID) Runway identification index (RW number)
1181	D23-reference drag at VB1-fps^2
1182	DREFP-reference drag acceleration-fps^2
1183	RDTRF-reference h-dot with HSCDDOT correction-fps
1184	ALDREF-reference L/D
1185	Redesignation runway identification index
1186-1188	RG-vehicle X-Y-Z in RW coordinates-ft
1189-1191	VG-vehicle velocity components in RW coordinates-fps
1192	RTE1-altitude of nominal target point above the Fischer ellipsoid-ft
1193	IGUIDE-first pass indicator for EGRT
1194	XLFAC-Load factor in fps^2
1195	DELAZ-heading alignment error-deg
1196	HLS-height above landing site-ft

A-Array	Definition
1197	TRANGE-range to way point 2-NMI
1198	RDOTGN (RDOT) - h-dot with dispersions-fps
1199	DRAGG-actual drag acceleration-fps^2
1200	VTAEM - nominal velocity for TAEM initiation - fps
1201	MANP (AUTOPLAMP) - Manual pitch control indicator; 0-auto, 1-manual
1202	MANRY (AUTORYLAMP) - Manual roll control indicator; 0-auto, 1-manual
1203	MANBF (RETRACTBF) - Body flap retract flag; 0-active, 1-retract
1204-1206	Not used
1207	Velocity at which to stop alpha-wind correlation-fps
1208	Not used
1209	NZC-commanded N_Z change-g's
1210	Commanded angle of attack-deg
1211	Initial angle of attack-deg
1212	Navigated angle of attack-deg
1213	Not used
1214	$K_{\dot{\alpha}}$-gain on alpha rate $(2\zeta_{\alpha}\omega_{N_{\alpha}})$
1215	$K\alpha$-gain on alpha error $(\omega^2 N_{\alpha})$
1216	$\dot{\alpha}_{max}$ maximum alpha rate-dps
1217	$\ddot{\alpha}_{max}$ maximum alpha acceleration-dps^2
1218	$\ddot{\alpha}$-actual alpha acceleration-dps^2

A-Array	Definition
1219	$\dot{\alpha}$-actual alpha rate-dps
1220	Speedbrake deflection in hinge line plane (0 to 98.6^{o}) deg
1221	Reference (nominal) SB def in hinge line plane-deg
1222	Commanded SB deflection in hinge line plane-deg
1223	SB deflection in waterline plane (0 to 87.2^{o})-deg
1224	Landing gear flag; o-Up, 1-Down
1225	Body flap retract position-deg
1226	Body flap retract limit-deg
1227	Landing gear increment post-multiplier
1228	Landing gear deployment rate-1/sec
1229	Not used
1230	Commanded bank angle-deg
1231	Initial bank angle-deg
1232	IWOW (WOWLON) - weight-on-wheels flag
1233	Not used
1234	$K_{\dot{\phi}}$-gain on bank angle rate $(2\zeta_{\phi}\omega N_{\phi})$
1235	K_{ϕ}-gain on bank angle error (ωN_{ϕ}^{2})
1236	$\dot{\phi}_{max}$-maximum bank angle rate-dps
1237	$\ddot{\phi}_{max}$-maximum bank angle acceleration-dps^{2}
1238	Actual bank angle acceleration-dps^{2}
1239	Actual bank angle rate-dps
1240	Not used
1241	Actual bank angle-rad

A-Array	Definition
1242	DRPRED - range to minimum energy pt. - ft
1243	DNZCF - filtered unlimited N_{zc} - g's
1244	EN - reference energy over weight - ft
1245	PHIC - unlimited roll command - deg.
1246	HERROR - alt. error - ft
1247	HREF - ref. altitude - ft
1248	QBERR - dynamic pressure error - psf
1249	QBREF - ref dynamic pressure - psf
1250	Not used
1251	THETAN - navigated pitch angle - rad

A-Array	Definition
1252	PHIBN-navigated roll angle-rad
1253-1270	Aero component table look-up results
1253	$C_{L_{BASIC}}$ and $C_{N_{BASIC}}^{*}$
1254	$C_{D_{BASIC}}$ and $C_{A_{BASIC}}^{*}$
1255	$C_{m_{BASIC}}$
1256	ΔC_L Speedbrake (SB)
1257	$\Delta C_{D_{SB}}$
1258	$\Delta C_{m_{SB}}$
1258	$\Delta C_{m_{SB}}$
1259	$\Delta C_{L_{BF}}$ and ΔC_N^* Body Flap (BF)
1260	$\Delta C_{D_{BF}}$ and $\Delta C_{A_{BF}}^{*}$
1261	$\Delta C_{m_{BF}}$
1262	$\Delta C_{L_{EL}}$ and ΔC_N^* Elevon (EL)
1263	$\Delta C_{D_{EL}}$ and $\Delta C_{A_{EL}}^{*}$
1264	$\Delta C_{m_{EL}}$
1265	ΔC_L Landing Gear (LG)
1266	ΔC_{D-LG}
1267	ΔC_{m-LG}
1268	ΔC_L Ground Effects (GE)
1269	ΔC_{D-GE}
1270	ΔC_{m-GE}

* Aero Data tape contains normal and axial force coefficients in the viscous intraction regime. TAERO does necessary conversions after look-up.

A-Array	Definition
1271	X-cg position-inches aft of forward position
1272	Z-cg position-inches below nominal
1273	Scheduled elevon deflection-deg
1274	Elevon deflection used in aero components determination-deg
1275	Body flap deflection used in aero component determination-deg
1276	Height parameter for ground effects determination
1277	Mach number switch value for inviscid tables
1278	HREFTD (HREFTDOT) - ref. alt. rate-flare/shallow glide - fps
1279	HDTERR (HDOTERROR) - alt. rate error - fps
1280	HRFDOT (HREFDOT) - ref. alt. rate - final flare - fps
1281	Commaned bank angle-deg
1282	Flag for VECWIN routine: 0-Off, 1-On
1283	Wind type selector
1284	Probability of vector wind ellipse
1285	Clocking angle from North-deg
1286	Shear/Gust altitude-ft
1287	Probability of conditional shear circle
1288	Profile selector (geographic)
1289	Profile selector (month)
1290	Shear factor
1291	Gust factor
1292	Delta clocking angle on shear circle
1293	Delta clocking angle on gust

A-Array	Definition
1294	Magnitude of resultant wind velocity vector-fps
1295	Wind azimuth-deg from North in direction wind is blowing
1296-1299	Not used
1300	Previous value of atmospheric density-slugs/ft^3
1301	Previous value of altitude-ft
1302	d_ρ/d_η-slugs/ft^4
1303	d_{N_T}/d_V-1/sec
1304	Gain on d_{N_T}/d_V
1305	Gain on N_T
1306-1308	Interim calculations in open loop guidance
1309	Delta load factor-g's
1310	Actual angle of attack-deg
1311	Predicted load factor-g's
1312	Gain on predicted load factor
1313-1317	Interim calculations in open loop guidance
1318-1319	Not used
1320-1322	Interim calculations in open loop guidance
1323	Gain for h-dot variation
1324-1326	Interim calculations in open loop guidance
1327	Gain for density variation

A-Array	Definition
1328-1331	Interim calculations for open loop guidance
1332-1339	Not used
1340-1345	Interim calculations for open loop guidance
1346-1348	Not used
1349	Commanded heat rate-BTU/ft^2sec
1350	Commanded load factor-g's
1351	Ambient temperature - ^oK
1352	Temperature ratio
1353	Viscous interaction parameter - $\bar{V}_\infty$
1354	Proportionality constant in temperature - viscosity relationship - $\bar{C}'_\infty$
1355	LAM
1356	L/D
1357	Not used
1358	Viscous interaction switch-over value for aero data
1359	Aero indicator for CLCT: 0-CL, CD from tables, 1-use TAERO
1360	Guidance mode indicator: 3-ADC, 4-TAEM, 5-A/L 0-con. g, 1-con. ϕ, 2- ϕ from table
1361	Bank indicator in CLCT: 0-Bank right, 1-Bank left
1362	C_L total
1363	Load factor limit-g's
1364-1379	Not used
1380	Actual bank angle-deg
1381-1389	Not used
1390	Heat rate post-multiplier
1391-1397	Not used
1398-1399	Interim calculations for open loop guidance

A-Array	Definition
1400	Flag for TPS calculation; 0-no calculations, 1-do TPS
1401-1433	Surface temperatures-^{o}F
1434-1438	Bare top temperatures-^{o}R
1439	Not used
1440-1444	Bare top temperatures-^{o}R
1445-1451	Not used
1452	Transition Re-1/ft
1453	Turbulent Re-ft
1454	Normal shock Re-1/ft
1455	Panel heat ratio
1456	Turbulent heating multiplier
1457	Not used
1458-1461	TPS stop conditions
1462-1494	Maximum surface temperatures-^{o}F
1495-1499	Maximum bare top temperatures-^{o}R
1500	Not used
1501-1505	Maximum bare top temperatures-^{o}R
1506-1538	Time of maximum temperature-sec
1539-1543	Time of maximum bare top temperature-sec
1544	Not used

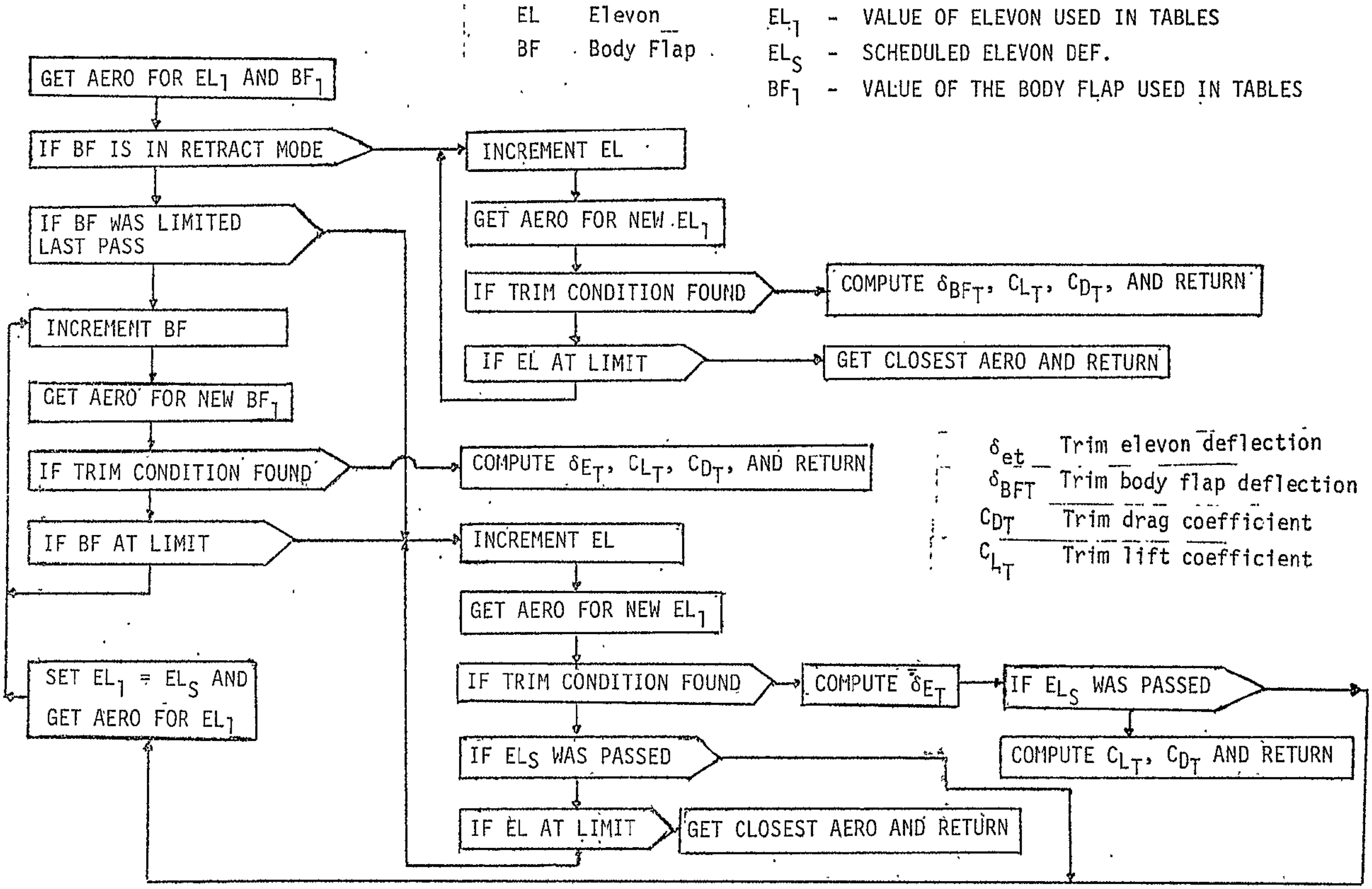
A-Array	Definition
1545-1549	Time of maximum bare top temperature-sec
1550-1574	Panel LRSI weights-lbs
1575-1599	Panel HRSI weights-lbs
1600	Angle of attack-deg
1601-1625.	Panel thickness-in
1626-1650	Backface temperatures-^{o}F above 350
1651	Number of panels
1652	Panel area-ft^2
1653	Heat rate-BTU/ft^2/sec
1654	Freestream gas temperature-^{o}F
1655	Panel number
1656	Panel thickness-in
1657	Normal shock viscosity
1658	Heat load-BTU/ft^2
1659	Total TPS weight-lbs
1660	Normal shock pressure-atm
1661	Normal shock enthalpy
1662	Not used
1663	Deflection factor multiplier
1664	Body flap deflection-deg

A-Array	Definition
1665	Elevon deflection-deg
1666	Deflection angle-deg
1667	Panel design heat load-BTU/ft^2
1668	Panel heat pulse time-sec
1669	Total panel area-ft^2
1670	Average panel heat load-BTU/ft^2
1671	Total LRSI weight-lbs
1672	Total HRSI weight-lbs
1673-1677	Bare top temperatures-^{o}F
1678	Not used
1679-1683	Bare top temperatures-^{o}F
1684-1716	Panel heat loads-BTU/ft^2
1717-1749	Panel heat rate-BTU/ft^2-sec
1750-1800	Not used
1801-1802	CUBC3 (CUBICC3) - coefficients for HREF - 1/ft
1803-1804	CUBC4 (CUBICC4) - coefficients for HREF - 1/ft^2
1805-1806	DREMAX (DELREMAX) - delta range used to compute EMAX - ft.
1807-1808	EDELNZ - delta E/W for energy limits - ft
1809-1810	EDRS - slope of E/W for S-turn
1811-1814	EMEPC1 - constant E/W used for MEP determination - ft
1815-1818	EMEPC2 - slope of E/W used for MEP determination
1819-1822	ENC1 - constant E/W used for ref. energy - ft
1823-1826	ENC2 - slope of E/W used for ref. energy
1827-1828	EOWSPT - range for energy ref. index determination - ft
1829-1830	ES1 - constant E/W used for S-turn - ft

A-Array	Definition
1831-1832	GAMSGS - Steep glide slope angle - deg
1833-1834	HALI - Altitude of Minimum Energy Point - ft
1835-1836	HFTC - Altitude of Nominal Entry Point - ft
1837-1838	PBGC - Lower limit of initial ref. glide slope
1839-1840	QBC2 - Slope of ref. dynamic pressure with range - psf/ft
1841-1842	QBRLL - ref. dynamic pressure lower limit - psf
1843-1844	QBRUL - ref. dynamic pressure upper limit - psf
1845-1846	RMINST - Min. range to start S-turn - ft
1847-1848	RN1 - Range constant of energy computations - ft
1849-1850	XA - Steep glide slope ground intercept - ft
1851	Time from start of phase for ground intercept change - sec
1852	Velocity for ground intercept change - fps
1853	Altitude for ground intercept change - ft
1854	Range for ground intercept change - ft
1855	Ground intercept change flag
1856-1870	Not used
1871-1872	DSBCTD- Speedbrake deflection at touchdown - deg
1873-1876	HK - Constant -G circle center altitude - ft
1877-1878	SIGMA - Exponential distance - ft
1879-1880	VREF - Ref. airspeed - fps
1881-1884	XK - Constant -G circle center range - ft
1885-1888	R - Constant -G circle radius - ft
1889-1892	XEXP - Exponential capture distance - ft
1893	HGEAR - Gear deployment alt. - ft
1894-1949	Not used

1950	Flag for sonic boom output: 0-no sonic boom; 1-do sonic boom
1951	Mach # to start sonic boom output - phase 1
1952	Mach # to stop sonic boom output - phase 1
1953	Mach # to start sonic boom output - phase 2
1954	Mach # to stop sonic boom output - phase 2
1955	A-array location to quanity for output check
1956-1998	Values of A(A(1955)) at which output is to be done
1999	Counter for sonic boom output

DETERMINATION CONTROL SURFACE DEFLECTIONS AND TRIM AERODYNAMICS



ENCLOSURE 3

TABLES FOR ENTRY-TO-TOUCHDOWN SIMULATION

TABLE NO.	QUANTITY	INDEX
1	$W_E(0)_{ig}$, ft/sec	335
2	$W_E(0)jg$, ft/sec	336
3	$W_E(0)k_g'$, ft/sec	337
4	P_∞ / P'_∞	338
5	$\rho_\infty / \rho'_\infty$	339
6	C_∞ / C'_∞	340
7	μ_∞ / μ'_∞	341
8	P'_∞, lbs/in^2	342
9	ρ'_∞ - slugs/ft^3	344
10	C'_∞ - ft/sec	345
11	μ'_∞ - lbs sec/ft^2	349
39	K, Heating Option 1	597
40	Scheduled elevon-deg	1221
41	ϕ_C - deg	1380
42	α_C - deg	1210
46	N_{T_C} - g's	1363
50	Scheduled speedbrake -deg	1273
51	$C_{L_{basic}}$ - low mach	1253
52	$C_{D_{basic}}$ - low mach	1254
53	$C_{m_{basic}}$ - low mach	1255
54	C_L—Speed Brake (SB) - low mach	1256
55	$C_{D_{SB}}$ - low mach	1257
56	$C_{m_{SB}}$ - low mach	1258
57	C_L — Body Flap (BF) - low mach	1259
58	$C_{D_{BF}}$ - low mach	1260

ENCLOSURE 4
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TABLE NO.	QUANTITY	INDEX
59	$C_{m_{BF}}$ - low mach	1261
60	C_L — Elevon (EL) - low mach	1262
61	$C_{D\,EL}$ - low mach	1263
62	$C_{m\,EL}$ - low mach	1264
63	C_L — Landing Gear (LG)	1265
64	$C_{D_{LG}}$	1266
65	$C_{m\,LG}$	1267
66	C_L — Ground Effects (GE)	1268
67	$C_{D_{GE}}$	1269
68	$C_{m_{GE}}$	1270
69	$C_{L_{basic}}$ - high mach	1253
70	$C_{D_{basic}}$ - high mach	1254
71	$C_{m_{basic}}$ - high mach	1255
72	$C_{L_{SB}}$ - high mach	1256
73	$C_{D_{SB}}$ - high mach	1257
74	$C_{m_{SB}}$ - high mach	1258
75	$C_{L_{BF}}$ - high mach	1259
76	$C_{D_{BF}}$ - high mach	1260
77	$C_{m_{BF}}$ - high mach	1261
78	$C_{L_{EL}}$ - high mach	1262
79	$C_{D_{EL}}$ - high mach	1263
80	$C_{m_{EL}}$ - high mach	1264
81	C_D inviscid uncertainty	1061
82	C_L inviscid uncertainty	1062

TABLE NO.	QUANTITY	INDEX
83	C_D viscous uncertainty	1061
84	C_L viscous uncertainty	1062
85	altitude rate error-fps	1055
86	Range-to-go - NMI	1057
87	altitude error - ft	1041
91	$C_{N_{basic}}$ viscous	1253
92	$C_{A_{basic}}$ viscous	1254
93	$C_{m_{basic}}$ viscous	1255
94	$C_{N_{BF}}$ viscous	1259
95	$C_{A_{BF}}$ viscous	1260
96	$C_{m_{BF}}$ viscous	1261
97	$C_{N_{EL}}$ viscous	1262
98	$C_{A_{EL}}$ viscous	1263
99	$C_{m_{EL}}$ viscous	1264
101	Panel design heat loads	1667
102	Normal shock viscosity	1657
103	Panel heat ratios	1455
104	Panel Reynolds no.	1452
105	Panel thickness - in	1656
106	Panel areas - ft^2	1652
120	$C_{H_{SB}}$ - low mach	1094
121	$C_{H_{BF}}$ - low mach	1091
122	$C_{H_{EI}}$ - low mach	1092
123	$C_{H_{EO}}$ - low mach	1093

TABLE NO.	QUANTITY	INDEX
124	$C_{H_{SB}}$ - high mach	1094
125	$C_{H_{BF}}$ - high mach	1091
126	$C_{H_{EI}}$ - high mach	1092
127	$C_{H_{EO}}$ - high mach	1093
The following are required if CLCT is used and A(1359) = 0		
16	C_D - inviscid drag coefficient	417
20	C_L - inviscid lift coefficient	1362
44	Body Flap Schedule	1664
45	δ_{EL} - inviscid elevon deflection	1665
47	C_D - viscous drag coefficient	417
48	C_L - viscous lift coefficient	1362
49	δ_{EL} - viscous elevon deflection	1665

```
Z RUN M70663,EX43,BETA,3304J,E062,P,10,6                    RANDY WAIBEL
 PL-1
 ASG A=X07475
 ASG F=X14728
 ASG H=X17990
 ASG C=C
 ASG B,D,G,X,Z
 XQT CUR
 TRW A
 IN A
 TRI A
 XQT SGGEM
X14000,2001,152,1$
F1331000,1231000,2000121,2322213,1222313*     CT22-26
F1132000,1323212,2223312,1133000*             CT27-30
F2000231,2000221,1311000,2000121*             CT31-34
F1131000,0,2000331,2000321,2000211*           CT35-39
F2000231,2000121,2000331,2000221*             CT40-43
F1131000,2000321,1311000,0,2000211*           CT44-48
F0,3.1415927,2300,2000,1.57079632*            CT49-53 (0,PI,NTAB,A,PI/2)
F1331000,1321000,2000211,2000121*             CT54-57
F1131000,0,1231000,1221000,1311000*           CT58-62
F1311000,1231000,1221000,2000211*             CT63-66
F1331000,1321000,0,2000121,1131000*           CT67-71
F1331000,1321000,2000211,2232123,1133222*     CT72-76
F1312000,1122233,2223132,1313000*             CT77-80
F1133000,1223312,2212323,2000132,2313222*     CT81-85
F1322213,1121000,2000231,1331000*             CT86-89
F1.4,1311000,0,2000211,0*                     CT90-94
F1111000,0,1211000,0,1311000*                 CT95-99
F1200,20,38,25,16*                            CT100-104 (X,Y PLOTS)
F4.092E23,0,5.02394106,0,3.440329E-8*         CT105-109
F0,0,0,0,0,0,0,0,0,0,0$                       CT110-120 (NOT USED)
F20925741,20855591,7.292115E-5*               CT1-3 (A,B FOR FE, OMEGA E.)
F32.146502,.05218839,4.760188E-5*             CT4-6 (A0,A1,A2 FOR FE)
F20902910,32.217,6076.1033,57.295779*         CT7-10(RE,G,FT/NM,DEG/RAD)
F14.695833,2.37692E-3,1116.4,3.73717E-7*      CT11-14(PSL,RHOSL,CLS,MUSL)
F32.174$                                      CT15(GWM,CT16-21 COM. INT.)
X2$
X4,1$
X15$                         SPEEDBRAKE SCHEDULE
F1,0,5,1*
F0,4000,5000,8000,10000,0*
F65,65,98.6,98.6,0$
X4,2$
X17$                         ELEVON SCHEDULE
F1,0,6,1*
F0.9,1.5,3,5,8,12,0*
F4,-3,-3,2.5,2.5,-2$
```

```
X1,0,0,1$
    ENTRY-TO-TOUCHDOWN SIMULATION, ADC GUIDANCE
X0,192,55,1,3,1,33$
F48,5*                                                  ADD. EQUA. INTEGRATED
F50,1*                                                  OBLATE EARTH
F51,0*                                                  WIND/ATMO INDICATOR
F52,30*                                                 62 US STANDARD ATMO.
F53,1.92*                                               INTEGRATION STEP SIZE
F56,0*                                                  RUNGE-KUTTA INTEGRATION
F57,0*                                                  CONSTANT TIME STEP
F58,0*                                                  SINGLE PRECISION
F59,3*                                                  HIGHEST OUTPUT ROUTINE
F63,1*                                                  AERO LOADS COMPUTED
F64,2*                                                  POS. INPUT OPTION GEOD.
F65,7*                                                  VEL INPUT OPT INER. GD.

F100,0,101,0*                                           CURRENT & INITIAL TIMES
F102,0*                                                 RELATIVE LONGITUDE
F106,-176.83,107,26.75,108,400451*                      INITIAL LONG.,LAT.,ALT.
F126,25549,180,-1.48,181,62.53*                         INITIAL VELOCITY VECTOR
F1211,40,1231,0*                                        INITIAL ALPHA AND PHI
F1664,5*                                                INITIAL BF POSITION

F143,181449*                                            VEHICLE WEIGHT
F1271,16.1,1272,0.8*                                    MID. C.G.
F156,2690.0,158,1.0*                                    REF AREA & LENGTH
F587,1,588,-1.0,589,0*                                  POST-MULTIPLIERS

F1168,2*                                                QBAR TO START TRIM AERO
F1358,.005*                                             VBAR SWITCH
F1277,1.2*                                              MACH FOR AERO TABLE SW.
F1226,-3.6*                                             FINAL BODY FLAP POS.
F1228,.1*                                               LG DEPLOYMENT RATE

F650,1,653,200,656,2*                                   OUT1,OUT2,OUT3 FREQ.
F701,6,702,63*                              OUTPUT
F703,0100,704,0108,705,0120,706,0117*         TIME,ALT,V(REL),V(AIR)
F707,0126,708,1310,709,1210*                  V(IN),ALPHA(ACT),ALPHA(COM)
F710,1178,711,0110,712,0121,713,0180*         PHASE,R(EC),GAM(RGD),GAM(IGC)
F714,0127,715,1380,716,1281*                  GAM(IGD),PHI(ACT),PHI(COM)
F717,0106,718,0107,719,0122,720,0181*         LONG,LAT(GD),AZ(RGD),AZ(IGC)
F721,0128,722,1665,723,1664*                  AZ(IGD),DELE,DELBF
F724,0401,725,0109,726,0418,727,1362*         M,LAT(GC),CY,CL
F728,0614,729,1082,730,1081*                  NT,HMIE,HMBF
F731,0402,732,1353,733,0421,734,0417*         QBAR,VBAR,CZ,CD(CX)
F735,1311,736,1085,737,1220*                  NT(EST),HMOE,DELSB(HL)
F738,0591,739,0411,740,1343,741,1356*         QDOT,RE,RHOV(N),LID
F742,1179,743,1096,744,1223*                  LODV,HMSB,DELSB(WL)
F745,0592,746,1426,747,1431,748,0351*         QT,TCP1,TCP6,RHO
F749,1184,750,1199,751,1313*                  ALDREF,DRAG,HDOT
F752,1429,753,1428,754,1432,755,1351*         TCP4,TCP3,TCP7,TAMB
F756,1181,757,1182,758,1183*                  D23,DREF,HDREF
F759,1427,760,1430,761,1433,762,1098*         TCP2,TCP5,TCP8,DP
F763,1099,764,0579,765,1197*                  CPV,R(GC),R(TG)
```

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F1236,5,1237,1.7*                                     MAX ROLL RATE & ACCEL
F1216,5,1217,1*                                       MAX ALPHA RATE & ACCEL
F1214,2,1215,2*                                       KALPHADOT,KALPHAERROR
F1234,.7365,1235,.2712*                               KPHIDOT,KPHIERROR

F1360,3*                                              GUIDANCE MODE INDICATOR
F173,-117.84,174,34.9*                                TARGET LONG & LAT
F1101,4.6822224,1111,3.153373E-3,1121,0*              CALPO,CALP1,CALP2-QUAD1
F1102,-77.337005,1112,0.0192356,1122,-7.8834E-7*      CALPO,CALP1,CALP2-QUAD2
F1103,40,1113,0,1123,0*                               CALPO,CALP1,CALP2-QUAD3
F1131,10200,1132,12200,1133,27000*                    VALP (1-3)
F1141,3*                                              NALP
F1142,-2.48188,1143,-2.99933*                         AK,AK1
F1156,5000,1144,30538.5,1145,23E3,1146,30538.5*       VQ,VA,VA1,VA2
F1147,20000,1148,25885.3,1173,23000,1200,2500*        VB1,VS1,VRDT,VTAEM
F1149,31*                                             ALFM
F1150,0*                                              PREBNK
F1152,21,1153,20.96,1151,2.0E6*                       DF,RPT1,EEF4
F1154,9500,1155,5.0602E7*                             VTRAN,ETRAN
F1157,.02,1158,.02,1159,.025,1160,.03*                GS1,GS2,GS3,GS4
F1174,80*                                             ACN1
F1175,2*                                              DDLIM
F1176,1*                                              ZK1
F1177,16.5*                                           D230
F1169,0*                                              XWP2
F1170,-169.84,1180,17*                                RW 17 AZIMUTH AND ID
F1171,20000*                                          RTURN
F1172,31993*                                          DBAR
F1192,2220*                                           EAFB HT ABOVE FE

F1400,1*                                              TPS CALCULATIONS
F590,2*                                               HEATING INDICATOR
F595,1.0*                                             VEHICLE NOSE RADIUS
F1390,.82                                             HEAT RATE MULTIPLIER
F1434,680,1435,680,1436,680,1437,680,1438,680*        INITIAL BARE TOP
F1440,680,1441,680,1442,680,1443,680,1444,680*        TEMPERATURES
F1458,591,1459,108,1460,-1.0,1461,-80000*             TPS STOP CONDITIONS
F1651,25*                                             NO. OF PANELS

F1080,1*                                              CALCULATE HINGE MOMENTS
F1088,10935,1089,19047,1095,9331* BF,EL,SB AREA-ARMS FT2-IN
F1090,4*                                              DELTA EL FOR AILERONS

F1312,1.3*                                            G PRED. AMP. FACTOR
F1323,-.0100,1327,2.E6,1304,-1250,1305,.5*            QDOT & G CONTROL GAINS
F600,1,601,100,602,4$                                 PHASE STOP CONDITION
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Enclosure 5
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X1,24,0$

1182  REF DRAG-FT/SEC2
1199  ACT DRAG-FT/SEC2
1183  REF HDOT - FPS
1198  ACT HDOT - FPS
1179  LODV
1181  D23
1197  RANGE-TO-GO-NMI
1356  L/D
1210  ALPHA COM - DEG
 100  TIME - SEC
 120  V RELATIVE  FT/SEC
 108  ALTITUDE - FT
 402  DYN PRESS  LB/FT2
1664  BF DEFLECTION- DEG
1665  EL DEFLECTION- DEG
1310  ALPHA - DEG
1281  BANK ANGLE - DEG
1380  BANK ANGLE - DEG
 614  LOAD FACTOR - G
 121  GAMMA - DEG
1081  HINGE MOM BF IN-LB
1082  IN  EL HM - IN-LBS
1083  OUT EL HM - IN-LBS
 591  Q DOT BTU/FT2/SEC

X9;25$

X100,0591,-1
X100,0108,-2
X100,0120,+1
X100,0402,-1
X100,0121,-1
X120,0108,-1
X120,1665,-2
X120,1664,+1
X120,1197,-1
X120,1356,-1
X120,1179,0
X120,1182,-1
X120,1199,0
X120,1183,-1
X120,1198,0
X120,1181,-1
X1197,1182,-1
X120,1081,-1
X120,1082,-1
X120,1083,-1
X120,1310,-1
X120,1210,+0
X120,1380,-1
X120,1281,+0
X120,0614,-1$
```

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F40,04,01,0120,0000,0000,1221,00,0587,00,0000,0000,000$ SB SCHEDULE
F50,04,02,0401,0000,0000,1273,00,0587,00,0000,0000,000$ EL SCHEDULE
F51,10,36,0401,1310,0000,1253,00,0587,00,0401,1277,069$ CLB  LO MACH
F52,10,37,0401,1310,0000,1254,00,0587,00,0401,1277,070$ CDB  LO MACH
F53,10,38,0401,1310,0000,1255,00,0587,00,0401,1277,071$ CMB LO  MACH
F54,10,39,1310,1223,0401,1256,00,0587,00,0401,1277,072$ CLSB LO MACH
F55,10,40,1310,1223,0401,1257,00,0587,00,0401,1277,073$ CDSB LO MACH
F56,10,41,1310,1223,0401,1258,00,0587,00,0401,1277,074$ CMSB LO MACH
F57,10,42,1310,1275,0401,1259,00,0587,00,0401,1277,075$ CLBF LO MACH
F58,10,43,1310,1275,0401,1260,00,0587,00,0401,1277,076$ CDBF LO MACH
F59,10,44,1310,1275,0401,1261,00,0587,00,0401,1277,077$ CMBF LO MACH
F60,10,45,1310,1274,0401,1262,00,0587,00,0401,1277,078$ CLEL LO MACH
F61,10,46,1310,1274,0401,1263,00,0587,00,0401,1277,079$ CDEL LO MACH
F62,10,47,1310,1274,0401,1264,00,0587,00,0401,1277,080$ CMEL LO MACH
F63,10,52,0410,1310,0000,1265,00,1227,00,0000,0000,000$ CLLG LO MACH
F64,10,53,0410,1310,0000,1266,00,1227,00,0000,0000,000$ CDLG LO MACH
F65,10,54,0410,1310,0000,1267,00,1227,00,0000,0000,000$ CMLG LO MACH
F66,10,55,1310,1276,1274,1268,00,0587,00,0000,0000,000$ CLGE LO MACH
F67,10,56,1310,1276,1274,1269,00,0587,00,0000,0000,000$ CDGE LO MACH
F68,10,57,1310,1276,1274,1270,00,0587,00,0000,0000,000$ CMGE LO MACH
F69,10,24,0401,1310,0000,1253,00,0587,00,1353,1358,091$ CLB  HI MACH
F70,10,25,0401,1310,0000,1254,00,0587,00,1353,1358,092$ CDB  HI MACH
F71,10,26,0401,1310,0000,1255,00,0587,00,1353,1358,093$ CMB  HI MACH
F72,10,27,1310,1223,0401,1256,00,0587,00,0000,0000,000$ CLSB HI MACH
F73,10,28,1310,1223,0401,1257,00,0587,00,0000,0000,000$ CDSB HI MACH
F74,10,29,1310,1223,0401,1258,00,0587,00,0000,0000,000$ CMBF HI MACH
F75,10,30,1310,1275,0401,1259,00,0587,00,1353,1358,094$ CLBF HI MACH
F76,10,31,1310,1275,0401,1260,00,0587,00,1353,1358,095$ CDBF HI MACH
F77,10,32,1310,1275,0401,1261,00,0587,00,1353,1358,096$ CMBF HI MACH
F78,10,33,1310,1274,0401,1262,00,0587,00,1353,1358,097$ CLEL HI MACH
F79,10,34,1310,1274,0401,1263,00,0587,00,1353,1358,098$ CDEL HI MACH
F80,10,35,1310,1274,0401,1264,00,0587,00,1353,1358,099$ CMEL HI MACH
F91,10,01,1310,1353,0000,1253,00,0587,00,0000,0000,000$ CNB  VISCOUS
F92,10,02,1310,1353,0000,1254,00,0587,00,0000,0000,000$ CAB  VISCOUS
F93,10,03,1310,1353,0000,1255,00,0587,00,0000,0000,000$ CMB  VISCOUS
F94,10,04,1275,1353,1310,1259,00,0587,00,0000,0000,000$ CNBF VISCOUS
F95,10,05,1275,1353,1310,1260,00,0587,00,0000,0000,000$ CABF VISCOUS
F96,10,06,1275,1353,1310,1261,00,0587,00,0000,0000,000$ CMBF VISCOUS
F97,10,07,1274,1353,1310,1262,00,0587,00,0000,0000,000$ CNEL VISCOUS
F98,10,08,1274,1353,1310,1263,00,0587,00,0000,0000,000$ CAEL VISCOUS
F99,10,09,1274,1353,1310,1264,00,0587,00,0000,0000,000$ CMEL VISCOUS
F101,08,17,1655,0000,0000,1667,00,0587,00,0000,0000,000$ DES. HEAT LOADS
F102,08,18,1660,1661,0000,1657,00,0588,00,0000,0000,000$ NOR. SHOCK VIS.
F103,08,19,1655,1600,0000,1455,01,1390,00,0000,0000,000$ HEAT RATIOS
F104,08,20,1655,1600,0000,1452,01,0587,00,0000,0000,000$ TRANS. RE NO.
F105,08,27,1655,1658,0000,1656,01,0587,00,0000,0000,000$ THICKNESS
F106,08,28,1655,0000,0000,1652,00,0587,00,0000,0000,000$ PANEL AREAS
F120,10,48,1310,1223,0401,1094,00,0587,00,0401,1277,124$ CHSB LO MACH
F121,10,49,1310,1664,0401,1091,00,0587,00,0401,1277,125$ CHBF LO MACH
F122,10,50,1310,1665,0401,1092,00,0587,00,0401,1277,126$ CHEL LO MACH
F123,10,51,1310,1665,0401,1093,00,0587,00,0401,1277,127$ CHEO LO MACH
F124,10,20,1310,1223,0401,1094,00,0587,00,0000,0000,000$ CHSB HI MACH
F125,10,21,1310,1664,0401,1091,00,0587,00,0000,0000,000$ CHBF HI MACH
F126,10,22,1310,1665,0401,1092,00,0587,00,0000,0000,000$ CHEL HI MACH
F127,10,23,1310,1665,0401,1093,00,0587,00,0000,0000,000$ CHEO HI MACH
```

```
X1,1,0,1$
 ENTRY-TO-TOUCHDOWN SIMULATION, TAEM GUIDANCE
X0,128,0,0,0,0,33$

F1801,-8.E-7,1802,0*                                  CUBC3    (1,2)
F1803,4E-13,1804,0*                                   CUBC4    (1,2)
F1805,54000,1806,0*                                   DREMAX   (1,2)
F1807,4000,1808,0*                                    EDELNZ   (1,2)
F1809,.69946182,1810,0*                               EDRS     (1,2)
F1811,-1988,1812,0,1813,16400,1814,0*                 EMEPC1   (1,1)(2,1)(1,2)(2,2)
F1815,.5155494,1816,0,1817,.265521,1818,0*            EMEPC2   (1,1)(2,1)(1,2)(2,2)
F1819,10787,1820,0,1821,20897,1822,0*                 ENC1     (1,1)(2,1)(1,2)(2,2)
F1823,.6005,1824,0,1825,.46304,1826,0*                ENC2     (1,1)(2,1)(1,2)(2,2)
F1827,110000,1828,0*                                  EOWSPT   (1,2)
F1829,90000,1830,0*                                   ESI      (1,2)
F1831,-24,1832,0*                                     GAMSGS   (1,2)
F1833,10018,1834,0*                                   HALI     (1,2)
F1835,12018,1836,0*                                   HFTC     (1,2)
F1837,.0962891,1838,0*                                PBGC     (1,2)
F1839,-1.2857E-3,1840,0*                              QBC2     (1,2)
F1841,210,1842,0*                                     QBRLL    (1,2)
F1843,300,1844,0*                                     QBRUL    (1,2)
F1845,152000,1846,0*                                  RMINST   (1,2)
F1847,36456.6,1848,0*                                 RN1      (1,2)
F1849,-5000,1850,0*                                   XA       (1,2)
F1851,2000,1852,0,1853,0,1854,-2E6*                   GLIDE SLOPE CHANGE COND.

F701,6,702,63*                                 OUTPUT
F703,0100,704,0108,705,0120,706,0117*          TIME,ALT,V(REL),V(AIR)
F707,0126,708,1310,709,1210*                   V(IN),ALPHA(ACT),ALPHA(COM)
F710,1178,711,0110,712,0121,713,0180*          PHASE,R(EC),GAM(RGD),GAM(IGC)
F714,0127,715,1380,716,1281*                   GAM(IGD),PHI(ACT),PHI(COM)
F717,0106,718,0107,719,0122,720,0181*          LONG,LAT(GD),AZ(RGD),AZ(IGC)
F721,0128,722,1665,723,1664*                   AZ(IGD),DELE,DELBF
F724,0401,725,0109,726,0418,727,1362*          M,LAT(GC),CY,CL
F728,0614,729,1082,730,1081*                   NT,HMIE,HMBF
F731,0402,732,1244,733,0421,734,0417*          QBAR,EN,CZ,CD(CX)
F735,1311,736,1085,737,1220*                   NT(EST),HMOE,DELSB(HL)
F738,1249,739,0411,740,1343,741,1356*          QBREF,RE,RHOV(N),LID
F742,1222,743,1096,744,1223*                   DSBCAT,HMSB,DELSB(WL)
F745,1248,746,1247,747,1246,748,0351*          QBERR,HREF,HERROR,RHO
F749,1209,750,1199,751,1313*                   NZC,DRAG,HDOT
F752,1186,753,1187,754,1188,755,1351*          XRW,YRW,ZRW,TAMB
F756,1243,757,1245,758,1242*                   DNZCF,PHIC,DRPRED
F759,1189,760,1190,761,1191,762,1098*          XDOTRW,YDOTRW,ZDOTRW,DP
F763,1099,764,0579,765,1197*                   CPV,R(GC),R(TG)

F1234,1.1312,1235,.64*                                KPHIDOT,KPHIERROR
F1216,5,1217,20*                                      ALPHA RATE & ACCEL MAX
F1236,20,1237,50*                                     ROLL RATE & ACCEL MAX
F53,.96*                                              INTEGRATION TIME STEP
F590,0*                                               STOP QDOT CALULATION
F602,5$                                               PHASE STOP CONDITION
```

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XI,24,0$

1197  RANGE-TO-GO-NMI
1210  ALPHA COM - DEG
 100  TIME - SEC
 120  V RELATIVE  FT/SEC
 108  ALTITUDE - FT
 402  DYN PRESS  LB/FT2
1664  BF DEFLECTION- DEG
1665  EL DEFLECTION- DEG
1310  ALPHA - DEG
1281  BANK ANGLE - DEG
1380  BANK ANGLE - DEG
1209  NOR.LOAD COM-G
 614  LOAD FACTOR - G
 121  GAMMA - DEG
1081  HINGE MOM BF IN-LB
1082  IN  EL HM - IN-LBS
1083  OUT EL HM - IN-LBS
1187  CROSSRANGE - FT
1186  DOWNRANGE - FT
1188  H ABOVE RW-FT
1247  HREF - FT
1223  SB DEFLECTION-DEG
1096  SB HM - IN-LBS
1249  QBAR REF - PSF

X9,25$

X100,0108,-2
X100,0120,+1
X120,402,-1
X120,1249,0
X100,0121,-1
X120,0108,-1
X120,1665,-2
X120,1664,+1
X120,1081,-1
X120,1082,-1
X120,1083,-1
X120,1310,-1
X120,1210,+0
X120,1380,-1
X120,1281,+0
X120,1209,-1
X120,1188,-1
X120,1247,0
X120,1197,-1
X100,1187,-1
X100,1186,0
X120,1223,-1
X120,1096,-1
X1186,1187,-1
X120,0614,-1$
```

```
X1,1,0,1$
    ENTRY-TO-TOUCHDOWN SIMULATION, AUTOLAND GUIDANCE
X0,093,0.0,0.0,33$

F1871,0,1872,0*                                    DSBCTD  (1,2)
F1873,17000,1874,0,1875,0,1876,0*                  HK      (1,1)(2,1)(1,2)(2,2)
F1877,868.4,1878,0*                                SIGMA   (1,2)
F1879,503,1880,0*                                  VREF    (1,2)
F1881,-1875,1882,0,1883,0,1884,0*                  XK      (1,1)(2,1)(1,2)(2,2)
F1885,16800,1886,0,1887,0,1888,0*                  R       (1,1)(2,1)(1,2)(2,2)
F1889,-4300,1890,0,1891,0,1892,0*                  XEXP    (1,1)(2,1)(1,2)(2,2)
F1893,900*                                         HGEAR

F701,6,702,63*                                 OUTPUT
F703,0100,704,0108,705,0120,706,0117*        TIME,ALT,V(REL),V(AIR)
F707,0126,708,1310,709,1210*                 V(IN),ALPHA(ACT),ALPHA(COM)
F710,1178,711,0110,712,0121,713,0180*        PHASE,R(EC),GAM(RGD),GAM(IGC)
F714,0127,715,1380,716,1281*                 GAM(IGD),PHI(ACT),PHI(COM)
F717,0106,718,0107,719,0122,720,0181*        LONG,LAT(GD),AZ(RGD),AZ(IGC)
F721,0128,722,1665,723,1664*                 AZ(IGD),DELE,DELBF
F724,0401,725,0109,726,0418,727,1362*        M,LAT(GC),CY,CL
F728,0614,729,1082,730,1081*                 NT,HMIE,HMBF
F731,0402,732,1278,733,0421,734,0417*        QBAR,HREFTD,CZ,CD(CX)
F735,1311,736,1085,737,1220*                 NT(EST),HMOE,DELSB(HL)
F738,1279,739,0411,740,1343,741,1356*        HDTERR,RE,RHOV(N),LID
F742,1222,743,1096,744,1223*                 DSBCAT,HMSB,DELSB(WL)
F745,1248,746,1247,747,1246,748,0351*        QBERR,HREF,HERROR,RHO
F749,1209,750,1199,751,1313*                 NZC,DRAG,HDOT
F752,1186,753,1187,754,1188,755,1232*        XRW,YRW,ZRW,IWOW
F756,1224,757,1203,758,1280*                 LWRL,IRETBF,HREDOT
F759,1189,760,1190,761,1191,762,1098*        XDOTRW,YDOTRW,ZDOTRW,DP
F763,1099,764,0579,765,1197*                 CPV,R(GC),R(TG)

F1201,0,1202,0*                                        AUTO PITCH & ROLL IND.
F53,.16*                                               INTEGRATION TIME STEP
F601,1232,602,1$                             PHASE & CASE STOP CONDITION
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```
X1,24,0$

1356  L/D
1197  RANGE-TO-GO-NMI
1210  ALPHA COM - DEG
 100  TIME - SEC
 120  V RELATIVE  FT/SEC
 108  ALTITUDE - FT
 402  DYN PRESS  LB/FT2
1664  BF DEFLECTION- DEG
1209  NOR.LOAD COM-G
1665  EL DEFLECTION- DEG
1310  ALPHA - DEG
1281  BANK ANGLE - DEG
1380  BANK ANGLE - DEG
 614  LOAD FACTOR - G
 121  GAMMA - DEG
1081  HINGE MOM BF IN-LB
1082  IN  EL HM - IN-LBS
1083  OUT EL HM - IN-LBS
1187  CROSSRANGE - FT
1186  DOWNRANGE - FT
1188  H ABOVE RW-FT
1247  HREF - FT
1223  SB DEFLECTION-DEG
1096  SB HM - IN-LBS
X9,25$

X100,1356,-1
X100,0108,-2
X100,0120,+1
X100,0402,-1
X100,0121,-1
X120,0108,-1
X120,1665,-2
X120,1664,+1
X120,1081,-1
X120,1082,-1
X120,1083,-1
X120,1310,-1
X120,1210,+0
X120,1380,-1
X120,1281,+0
X120,1223,-1
X120,1096,-1
X120,1209,-1
X1186,1187,-1
X120,1188,-1
X120,1247,0
X120,1197,-1
X100,1187,-1
X100,1186,0
X120,0614,-1$

SC4020
X9,0,800$

  ECF
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A-ARRAY LOCATIONS OF ARGUMENTS, RESULT AND POST MULTIPLIER

TAPE NO. X14728

DATA	X-ARG	Y-ARG	Z-ARG	RESULT	POST-MULTIPLIER	FILE#	SIZE
DESIGN HEAT LOADS	1655	-	-	1667	587	17	55
NORMAL SHOCK VISCOSITY	1660	1661	-	1657	588	18	251
LOCAL HEAT RATIOS	1655	1600	-	1455	1390	19	465
TRANSITION REYNOLDS NO.	1655	1600	-	1452	587	20	465
INSULATION THICKNESS	1655	1658	-	1656	587	27	575
PANEL AREA	1655	-	-	1652	587	28	55
CORRELATED INV. C_D DIS.	1060	401	-	1061	1030	60	83
CORRELATED INV. C_L DIS.	1060	401	-	1062	1031	61	83
CORRELATED VIS. C_D DIS.	1060	1353	-	1061	1032	62	53
CORRELATED VIS. C_L DIS.	1060	1353	-	1062	1033	63	53
NORTH/SOUTH WIND PROFILE	1064	108	-	335	1026	64	30
EAST/WEST WIND PROFILE	1065	108	-	336	1027	65	30
DESIGN DENSITY PROFILE	1063	108	-	339	1029	66	113
ALTITUDE RATE ERROR	1054	120	-	1055	1034	67	99
RANGE-TO-GO ERROR	1056	120	-	1057	1035	68	87

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS			DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
	X	Y	Z					
VISCOUS LONGITUDINAL								
$C_{N_{\bar{V}_\infty}}$	α	$\bar{V}_\infty$	-	3.11-11,12,13 & TABLE 3.11-2	1/82	123	-	-
$C_{A_{\bar{V}_\infty}}$	↓	↓	↓	↓	2/83	123	-	-
$C_{m_{\bar{V}_\infty}}$	↓	↓	↓	↓	3/84	123	-	-
VISCOUS BODY FLAP								
$\Delta C_{N_{BF_{\bar{V}_\infty}}}$	δ_{BF}	$\bar{V}_\infty$	α	3.11-3a,b & TABLE 3.11-3	4/91	575	-	-
$\Delta C_{A_{BF_{\bar{V}_\infty}}}$	↓	↓	↓	↓	5/92	575	-	-
$\Delta C_{m_{BF_{\bar{V}_\infty}}}$	↓	↓	↓	↓	6/93	575	-	-
VISCOUS ELEVON								
$\Delta C_{N_{e_{\bar{V}_\infty}}}$	δ_e	$\bar{V}_\infty$	α	3.11-4a & TABLE 3.11-4	7/88	785	-	-
$\Delta C_{A_{e_{\bar{V}_\infty}}}$	↓	↓	↓	↓	8/89	785	-	-
$\Delta C_{m_{e_{\bar{V}_\infty}}}$	↓	↓	↓	↓	9/90	785	-	-

* NOTE: Data Book reference stands for Figure Number unless otherwise noted
** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS			DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
	X	Y	Z					
AERO UNCERTAINTIES								
$\Delta C_{L_{TV}}$	TYPE	M	-	3.12-1	10/117	54	16	.25-10.0
$\Delta C_{D_{TV}}$	↓	↓	↓	3.12-2	11/118	54	↓	↓
$\Delta C_{m_{TV}}$	↓	↓	↓	3.12-1	12/119	54	↓	↓
$\Delta C_{L_{V_\infty TV}}$	↓	$\bar{V}_\infty$	↓	3.12-12	13/131	36	-	-
$\Delta C_{D_{V_\infty TV}}$	↓	↓	↓	3.12-13	14/132	36	-	-
$\Delta C_{m_{V_\infty TV}}$	↓	↓	↓	3.12-11	15/133	36	-	-
$\Delta C_{N_{\alpha TV}}$	↓	M	↓	3.12-10	16/146	54	16	.25-10.0
$\Delta C_{m_{\alpha TV}}$	↓	↓	↓	3.12-9	17/147	54	↓	↓
$\Delta C_{m_{e_{TV}}}$	↓	↓	↓	3.12-9	18/148	54	↓	↓
$\Delta C_{h_{e_{TV}}}$	↓	↓	↓	3.12-6	19/128	54	↓	↓

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** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS			DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
	X	Y	Z					
HINGE MOMENTS								
Ch_{SB}	α	δ_{SB}	M	3.6-18-20	20/29	469	9	1.2-10.0
Ch_{BF}	↓	δ_{BF}	↓	3.6-30-31	21/62	379	↓	↓
Ch_{e_I}	↓	δ_e	↓	3.6-2-17	22/77	1059	↓	↓
Ch_{e_O}	↓	δ_e	↓	3.6-2-17	23/78	1059	↓	↓
BASIC LONGITUDINAL								
C_L	M	α	-	TABLE 3.1-1	24/1	190	10	1.2-20.0
C_D	↓	↓	↓	TABLE 3.2-2	25/2	190	↓	↓
C_m	↓	↓	↓	TABLE 3.3-1	26/3	190	↓	↓
SPEEDBRAKE								
$\Delta C_{L_{SB}}$	α	δ_{SB}	M	3.5-51-66	27/19	748	9	1.2-10.0
$\Delta C_{D_{SB}}$	↓	↓	↓	3.5-51-66	28/21	748	↓	↓
$\Delta C_{m_{SB}}$	↓	↓	↓	3.5-51-66	29/23	748	↓	↓

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** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS X	GEMASS ARGUMENTS Y	GEMASS ARGUMENTS Z	DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
BODY FLAP								
$\Delta C_{L_{BF}}$	α	δ_{BF}	M	3.5-84,86,88	30/39	379	9	1.2-10.0
$\Delta C_{D_{BF}}$	↓	↓	↓	3.5-84,86,88	31/40	379	↓	↓
$\Delta C_{m_{BF}}$	↓	↓	↓	3.5-83,85,87	32/41	379	↓	↓
ELEVON EFFECTIVENESS								
ΔC_{L_e}	α	δ_e	M	3.5-1-7	33/12	1377	9	1.2-10.0
ΔC_{D_e}	↓	↓	↓	3.5-8-16	34/13	1377	↓	↓
ΔC_{m_e}	↓	↓	↓	3.5-17-22	35/14	1377	↓	↓
BASIC LONGITUDINAL								
C_L	M	α	-	TABLE 3.1-1	36/1	173	9	.25-1.3
C_D	↓	↓	↓	TABLE 3.2-2	37/2	173	↓	↓
C_m	↓	↓	↓	TABLE 3.3-1	38/3	173	↓	↓
SPEEDBRAKE								
$\Delta C_{L_{SB}}$	α	δ_{SB}	M	3.5-51-66	39/19	748	9	.25-1.3
$\Delta C_{D_{SB}}$	↓	↓	↓	3.5-51-66	40/21	748	↓	↓
$\Delta C_{m_{SB}}$	↓	↓	↓	3.5-51-66	41/23	748	↓	↓

* NOTE: Data book reference stands for Figure Number unless otherwise noted
** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS X	Y	Z	DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
BODY FLAP								
$\Delta C_{L_{BF}}$	α	δ_{BF}	M	3.5-84,86,88	42/39	379	9	.25-1.3
$\Delta C_{D_{BF}}$	↓	↓	↓	3.5-84,86,88	43/40	379	↓	↓
$\Delta C_{m_{BF}}$	↓	↓	↓	3.5-83,85,87	44/41	379	↓	↓
ELEVON EFFECTIVENESS								
ΔC_{L_e}	α	δ_e	M	3.5-1-7	45/12	1153	9	.25-1.3
ΔC_{D_e}	↓	↓	↓	3.5-8-16	46/13	1153	↓	↓
ΔC_{m_e}	↓	↓	↓	3.5-17-22	47/14	1153	↓	↓
HINGE MOMENTS								
Ch_{SB}	α	δ_{SB}	M	3.6-18-20	48/29	469	9	.25-1.3
Ch_{BF}	↓	δ_{BF}	↓	3.6-30-31	49/62	379	↓	↓
Ch_{e_I}	↓	δ_e	↓	3.6-2-17	50/77	829	↓	↓
Ch_{e_O}	↓	δ_e	↓	3.6-2-17	51/78	829	↓	↓

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** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SEGMENTED AND REARRANGED OV102 AERO DATA TAPE INFORMATION

TAPE NO. X17990

COEFFICIENT	GEMASS ARGUMENTS			DATA BOOK REFERENCE *	FILE **	NSIZE	NUMBER OF M VALUES	MACH RANGE IN FILE
	X	Y	Z					
LANDING GEAR								
$\Delta C_{L_{LG}}$	-	α	-	3.1-5	52/42	25	-	-
$\Delta C_{D_{LG}}$	↓	↓	↓	3.1-5	53/43	25	-	-
$\Delta C_{m_{LG}}$	↓	↓	↓	3.1-5	54/44	25	-	-
GROUND EFFECTS								
$\Delta C_{L_{GE}}$	α	h/b	δ_e	3.10-1-4	55/45	661	-	-
$\Delta C_{D_{GE}}$	↓	↓	↓	3.10-5-8	56/76	661	-	-
$\Delta C_{m_{GE}}$	↓	↓	↓	3.10-9-12	57/46	661	-	-
						A-array location of variables		
							α 1310	
							$\bar{V}$ 1353	
							M 401	
TOTAL DATA POINTS ON THIS TAPE						27906		
							δ_e 1274	
							δ_{BF} 1275	
							δ_{SB} 1223	
							h/b 1276	

* NOTE: Data book reference stands for Figure Number unless otherwise noted
** NOTE: Number after / represents corresponding file number on basic OV102 Aero Data Tapes

SAMPLE INPUT INSTRUCTIONS

INSTRUCTIONS FOR CENTRAL COMPUTER COMPLEX COMPUTER RUNS

(DO NOT FILL IN SHADED AREAS) WBS 1.2

PROGRAMMER'S COMMENTS

1108 EXEC II

PROGRAMMER	BADGE NO	BOX NO	PHONE NO	DATE	PRIORITY & INITIALS
RANDY WAIBEL	M70663	BETA	483-5260 X226	4/26/77	DT-1

DIVISION CODE	PROG NO.	PROJ NO	EST TIME	MAX TIME	PAGES OUTPUT	SEQ NO.
EX43	E062	3304J	8	10	6	

OPERATING SYSTEM		TYPE OF RUN	NO TAPES	NO FASTR FILES	NO. DRUM FILES
1108 EXEC II ☑	3200 SCOPE ☐	PROD. ☑ TEST ☐	4	5	0
1108 EXEC VIII ☐	3200 SMARTS ☐	OTHER (EXPLAIN BELOW)			
1108 COBOL ☐	3200 OTHER ☐				

INPUT TAPES UNIT	REEL NO	FILE NAME	WORKING TAPES	OUTPUT TAPES UNIT	REEL NO	FILE NAME	SAVE	PERMANENT FASTRAND FILES
A	X07475 or		C				S	
	X06938						S	
H	X17990						S	
F	X14728						S	
							S	
							S	

4060 ☑	REEL NO	FILE NO	PUNCHED OUTPUT ☐	REEL NO.	NO CARDS
16 MM ☑ 35 MM ☐					

CAL COMP PLOT ☐	REEL NO.	NO PLOTS	ACTUAL TIME USAGE
		60	STOP

ABNORMAL STOPS		SYSTEM OPERATOR	SYSTEM NO	
EXCESS OUTPUT	☐			START
EXCESS TIME	☐		PAGES OUTPUT	
OTHER (EXPLAIN BELOW)	☐			

OPERATORS COMMENTS

JSC FORM 548A REV MAY 72) U S GOVERNMENT PRINTING OFFICE 1975—671 549/2

MICROFILM PLOT LABEL

JSC Form 2079 (Rev Dec 74) NASA-JSC

PROGRAMMER	ROOM	DATE
RANDY WAIBEL	BETA	4/26/77
TYPE FILM	TAPE DENSITY	NO. COPIES
(16) 35 105		1
TRACK	PROCESSING REQUESTED	
7 9	4060	

COMMENTS

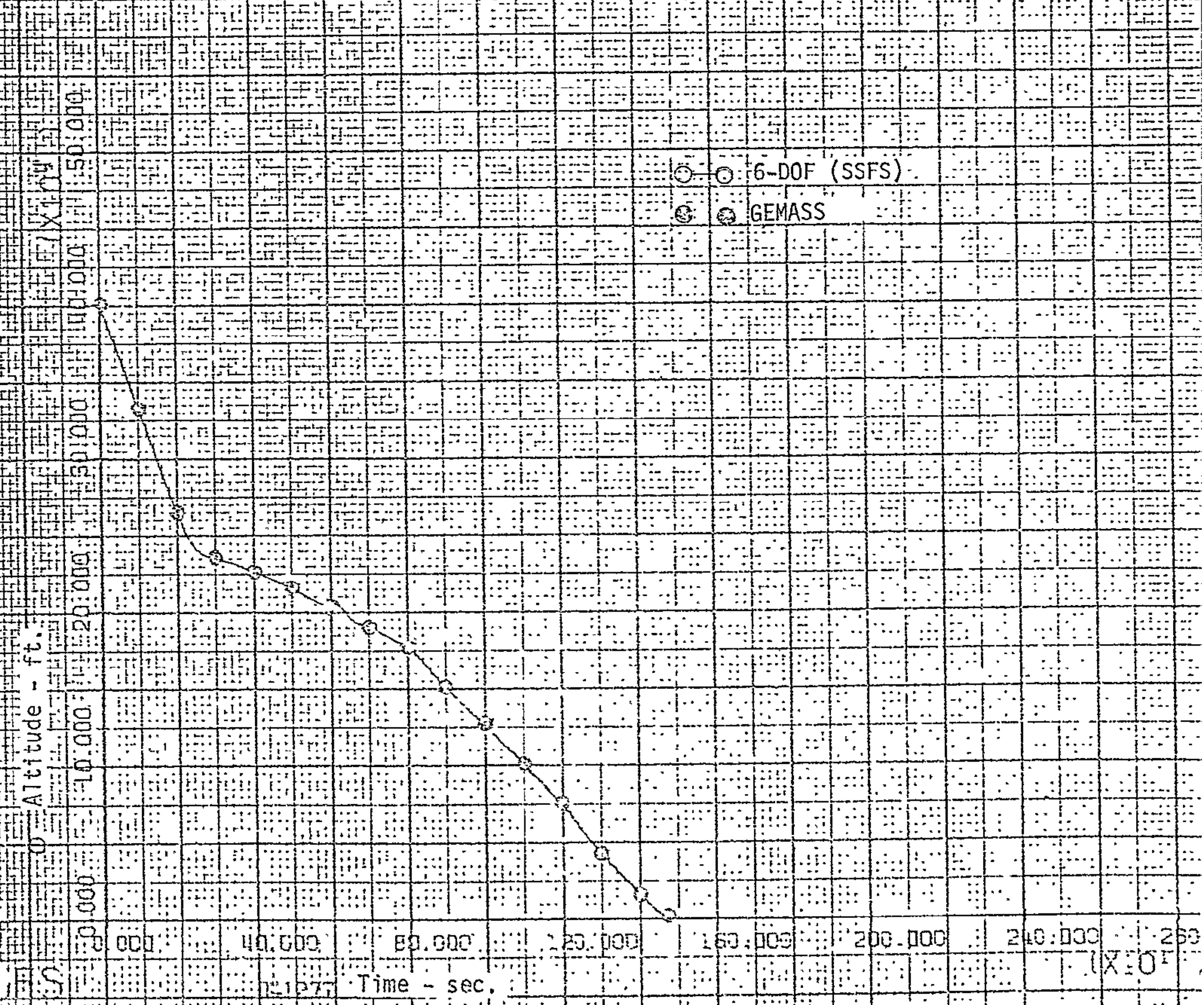
WBS 1.2 OFT-1 TRAJECTORY

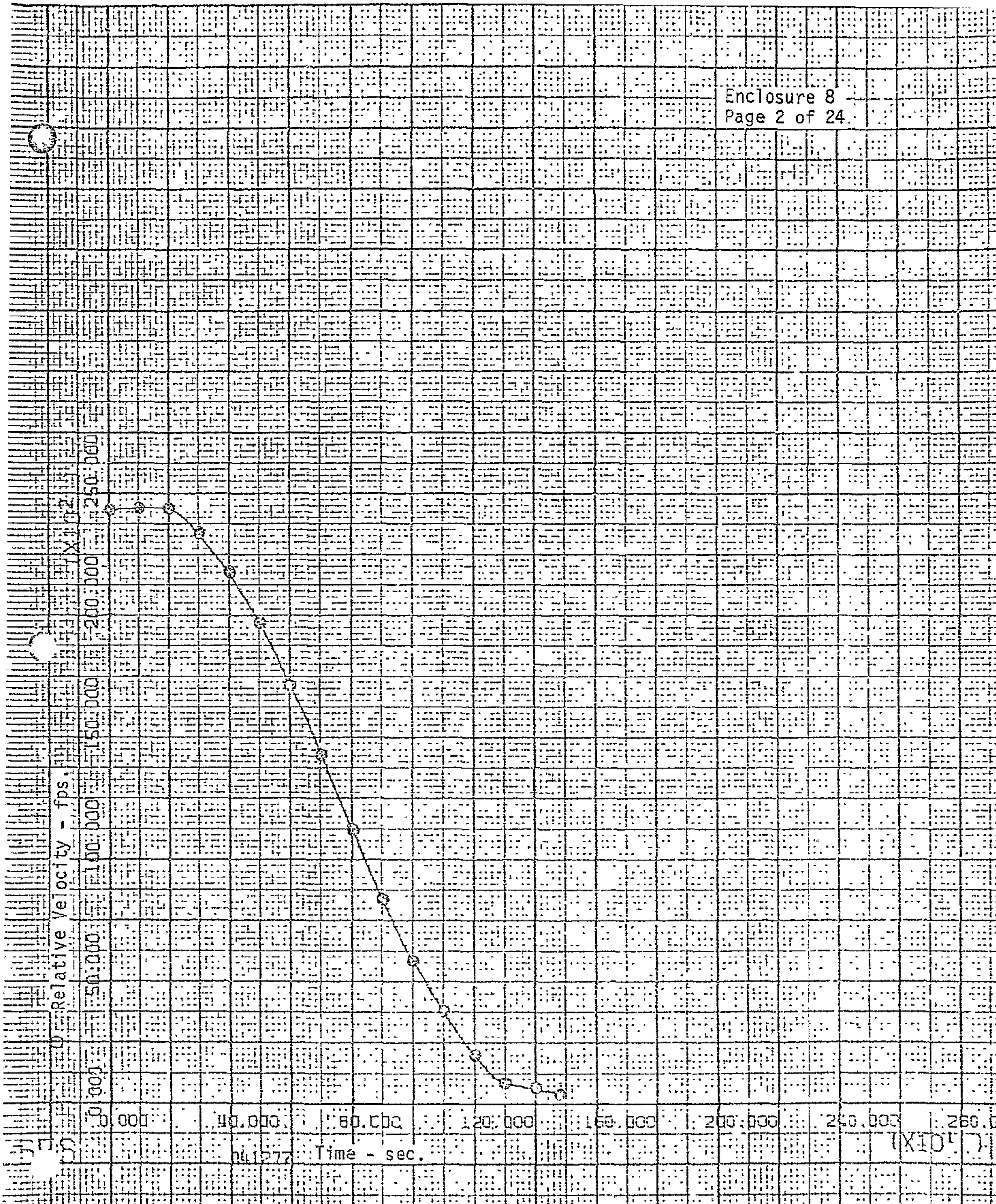
OPERATION USE ONLY

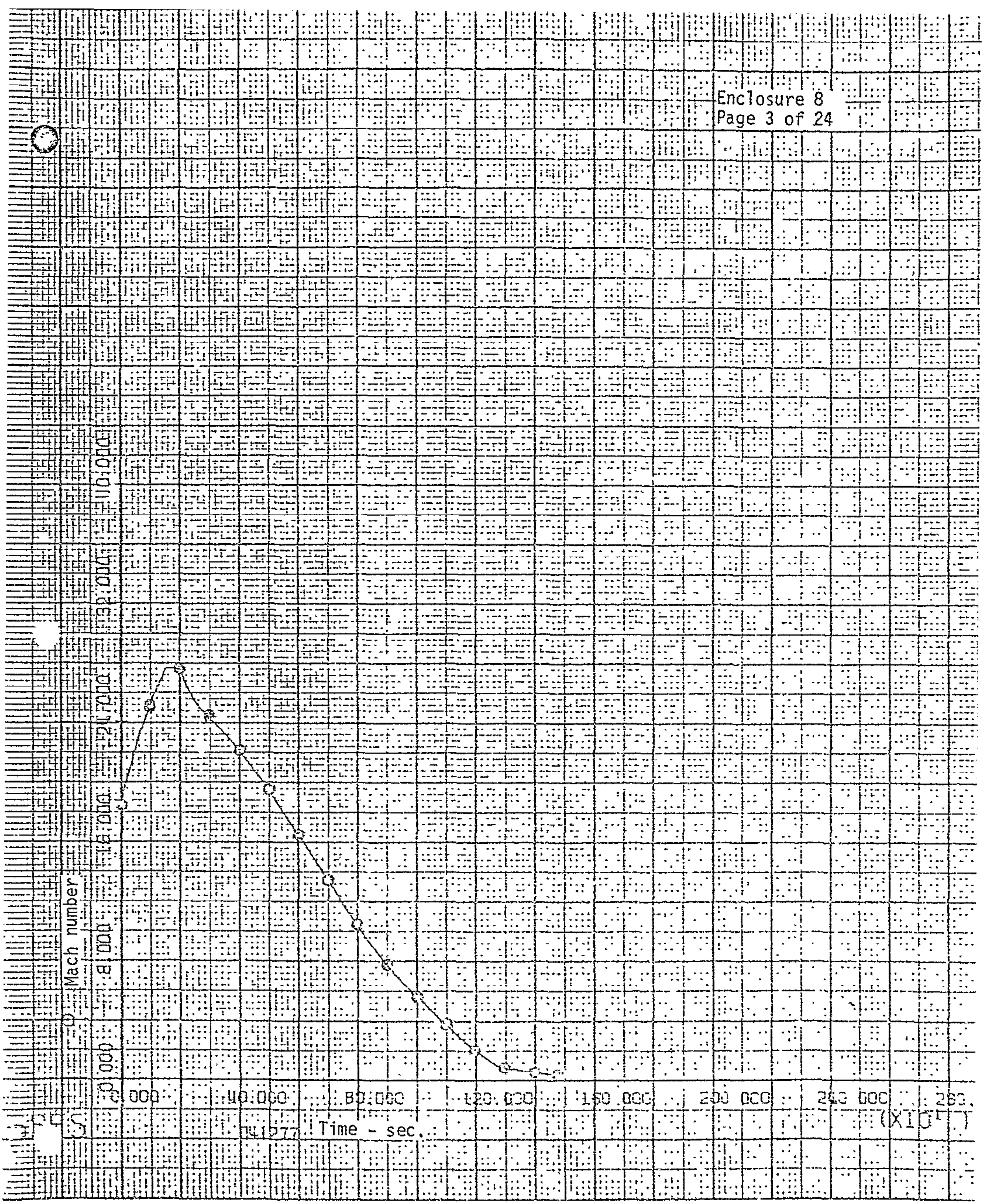
SEQUENCE NO.	DRIVE NO.	REEL NO.

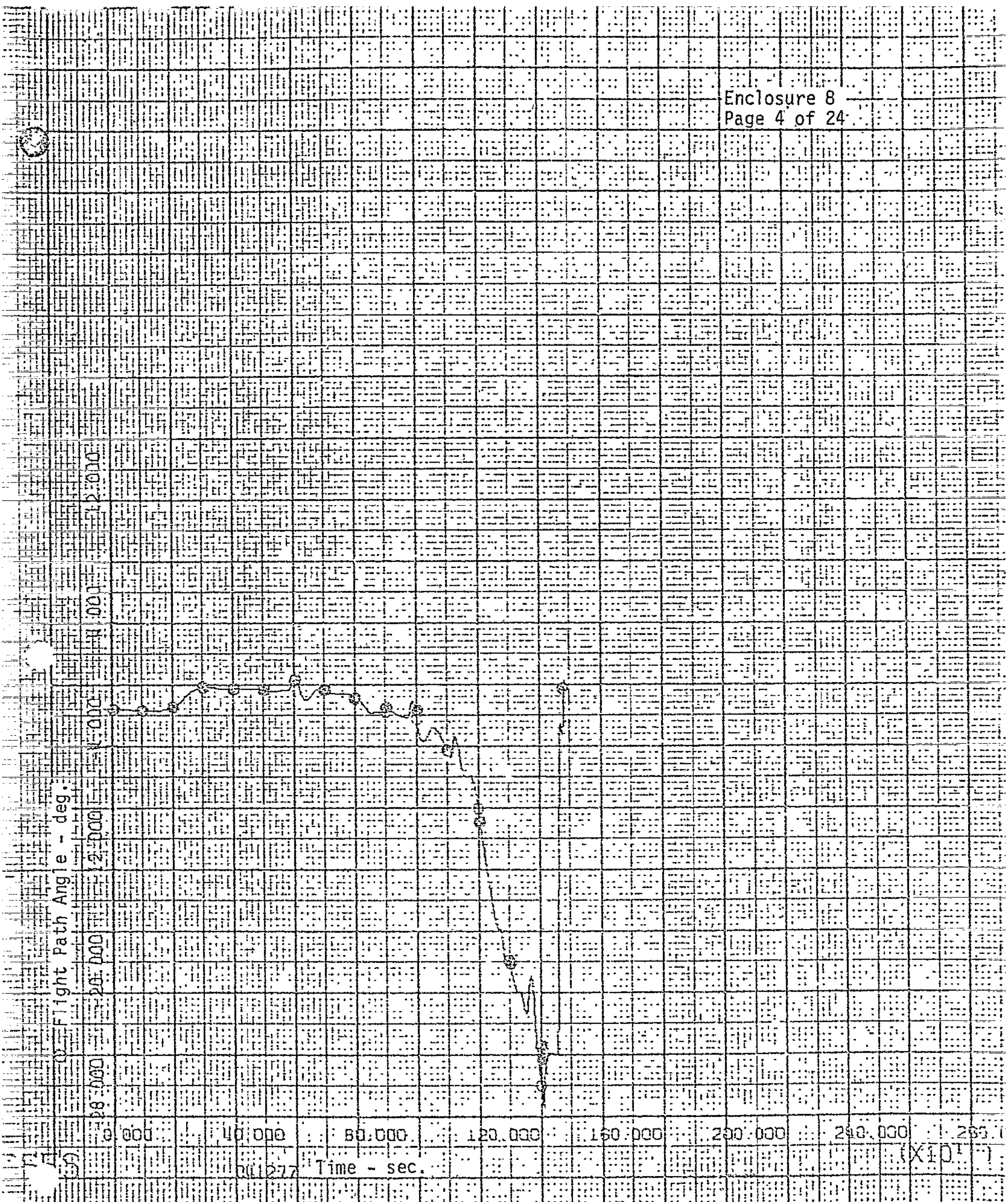
COMPARISON OF GEMASS ENTRY-TO-TOUCHDOWN SIMULATION WITH 6-DOF SIMULATION (SSFS)

Entry Interface-to-Touchdown




Relative Velocity - fps.
(X10^2)
0.000
50.000
100.000
150.000
200.000
250.000
Time - sec.
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280.0
(X10^1)


Mach number
0.000
8.000
16.000
24.000
32.000
40.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280.
(X10^1)
Time - sec.
041277



ORIGINAL PAGE IS
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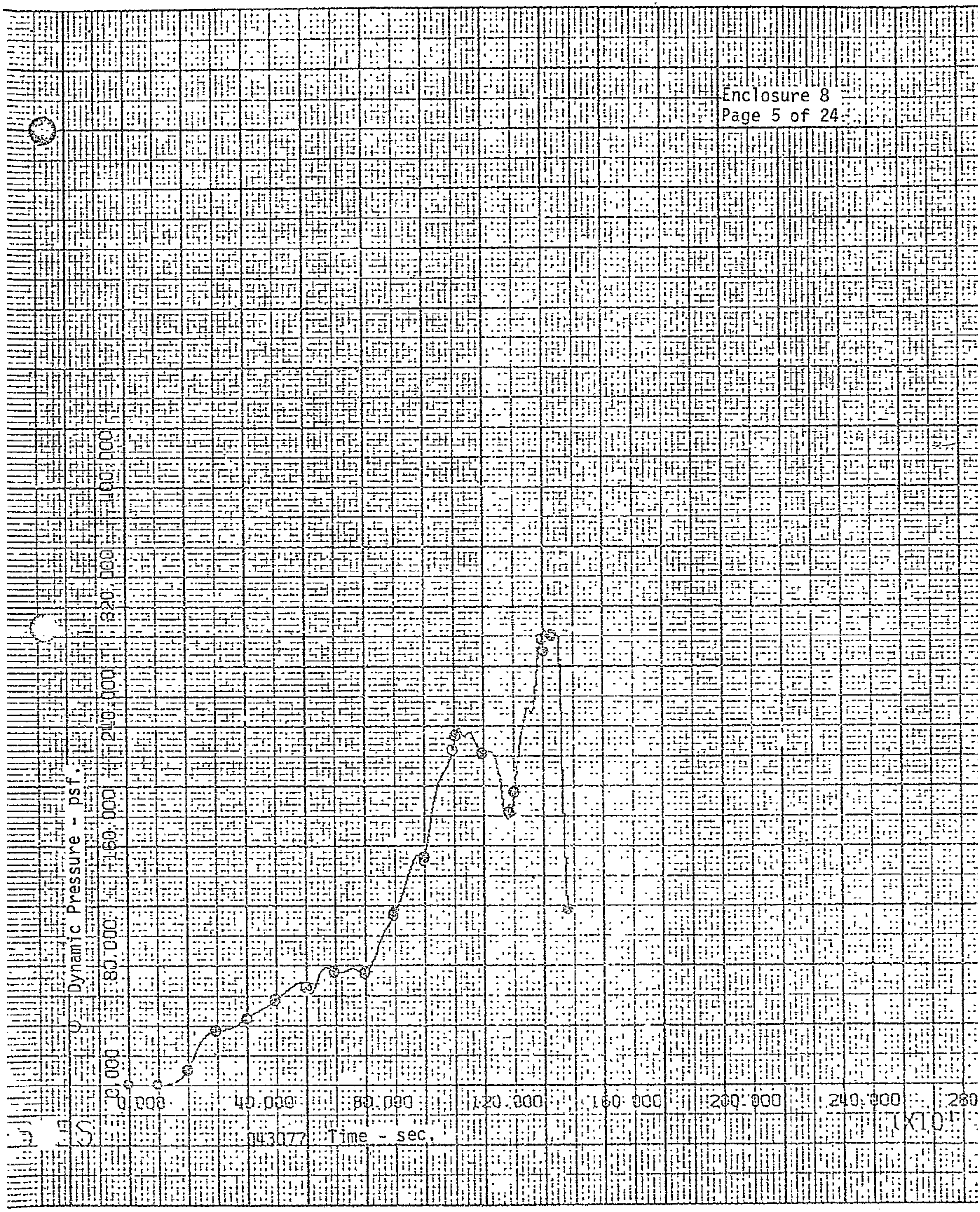
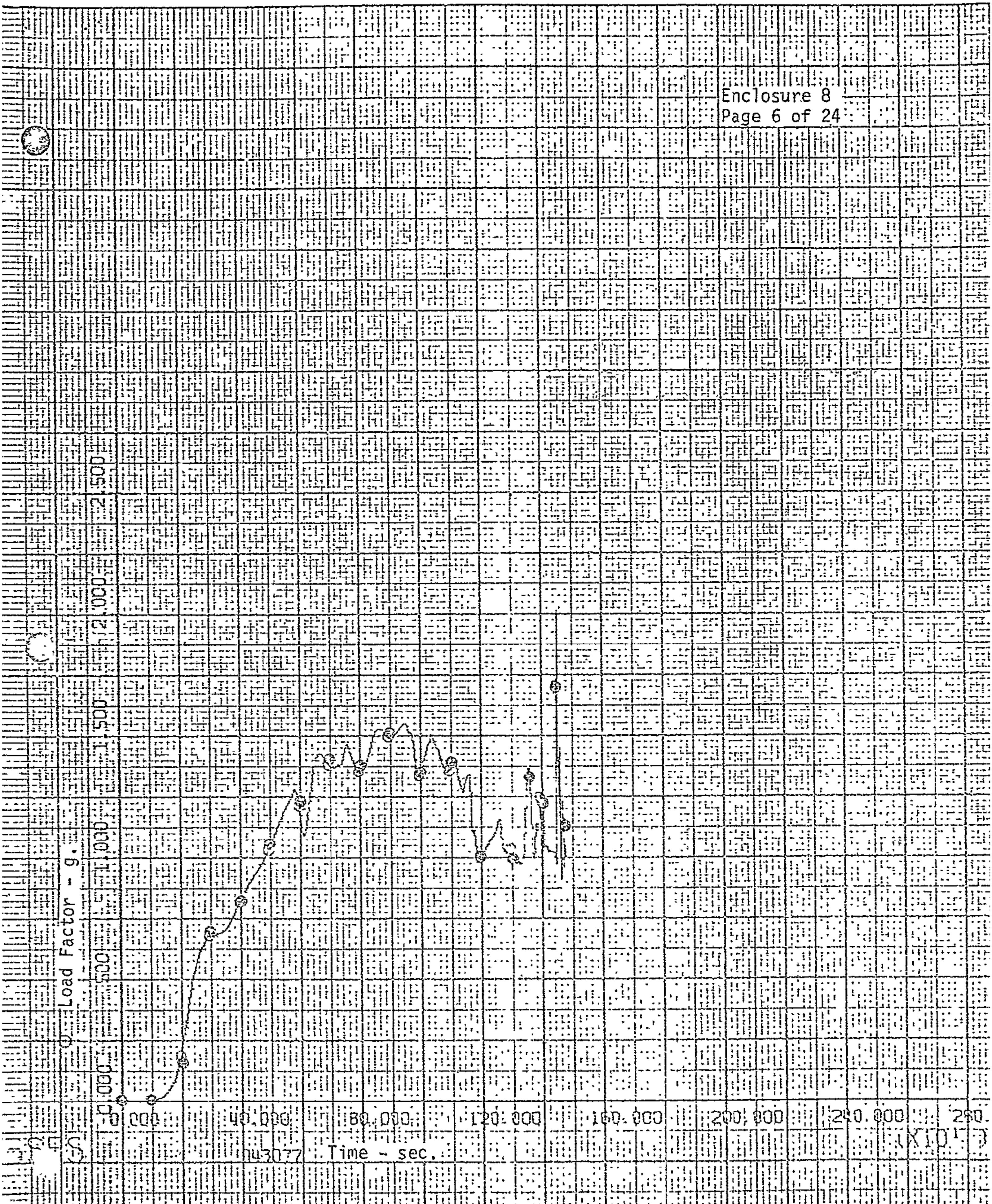
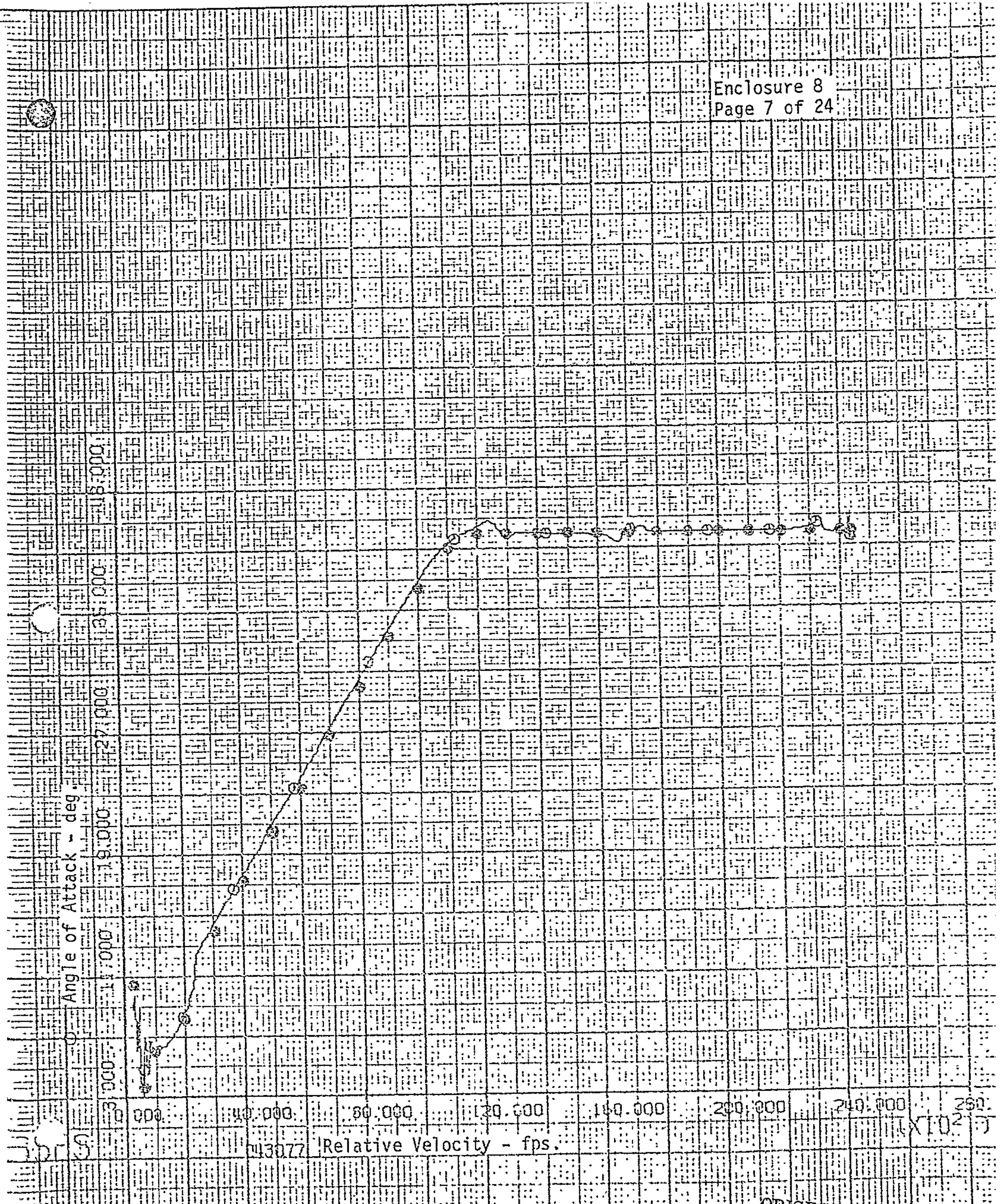
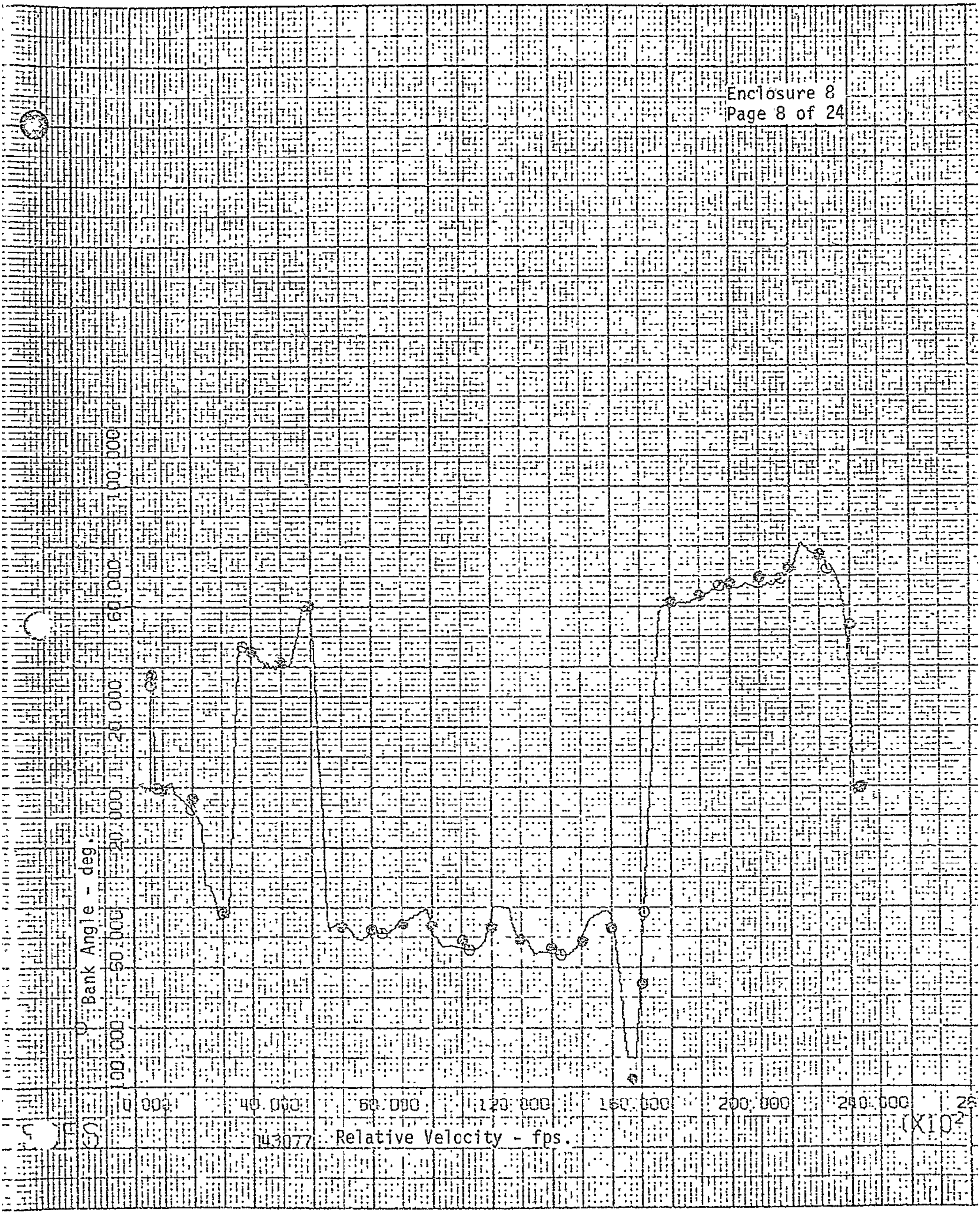
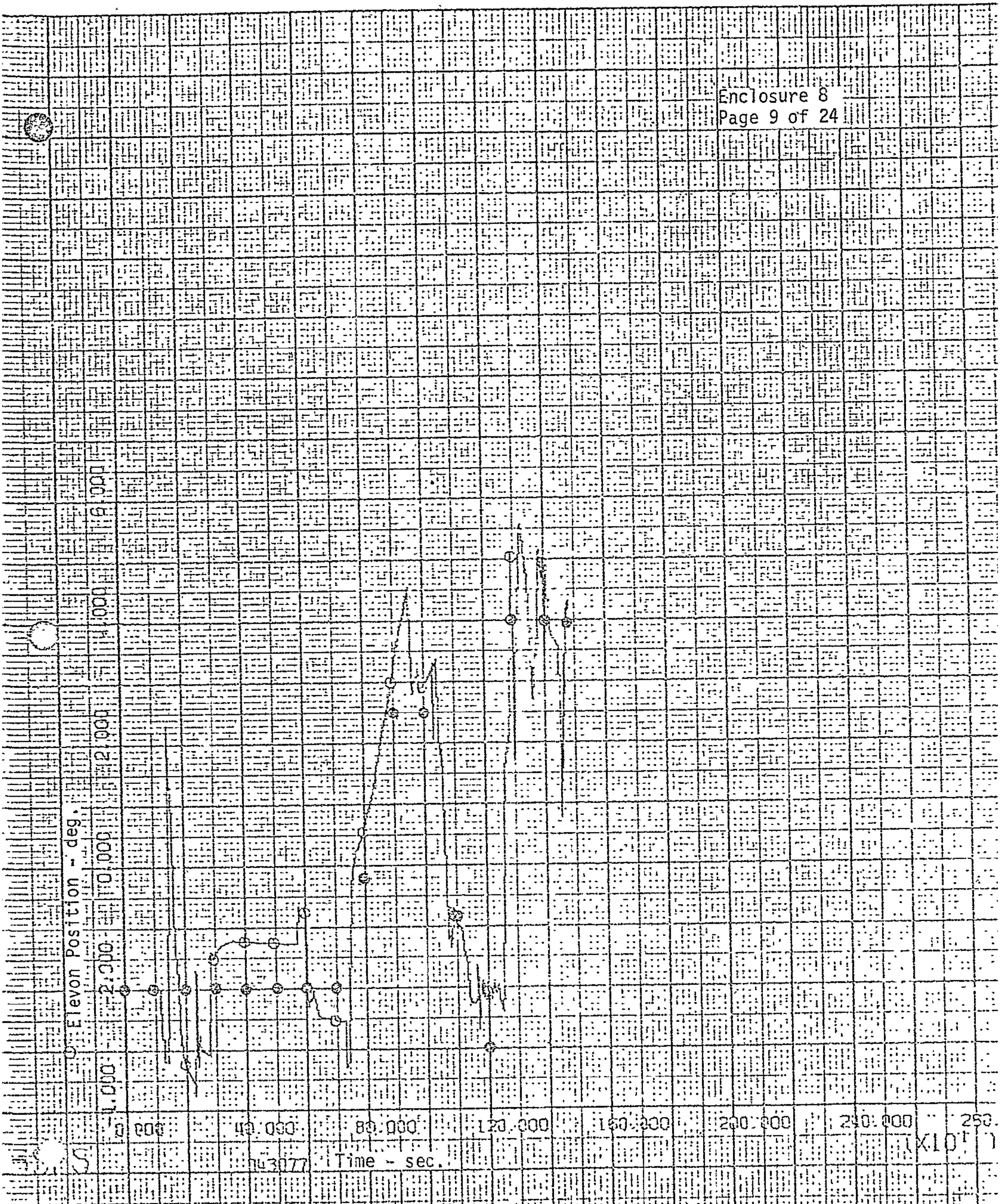
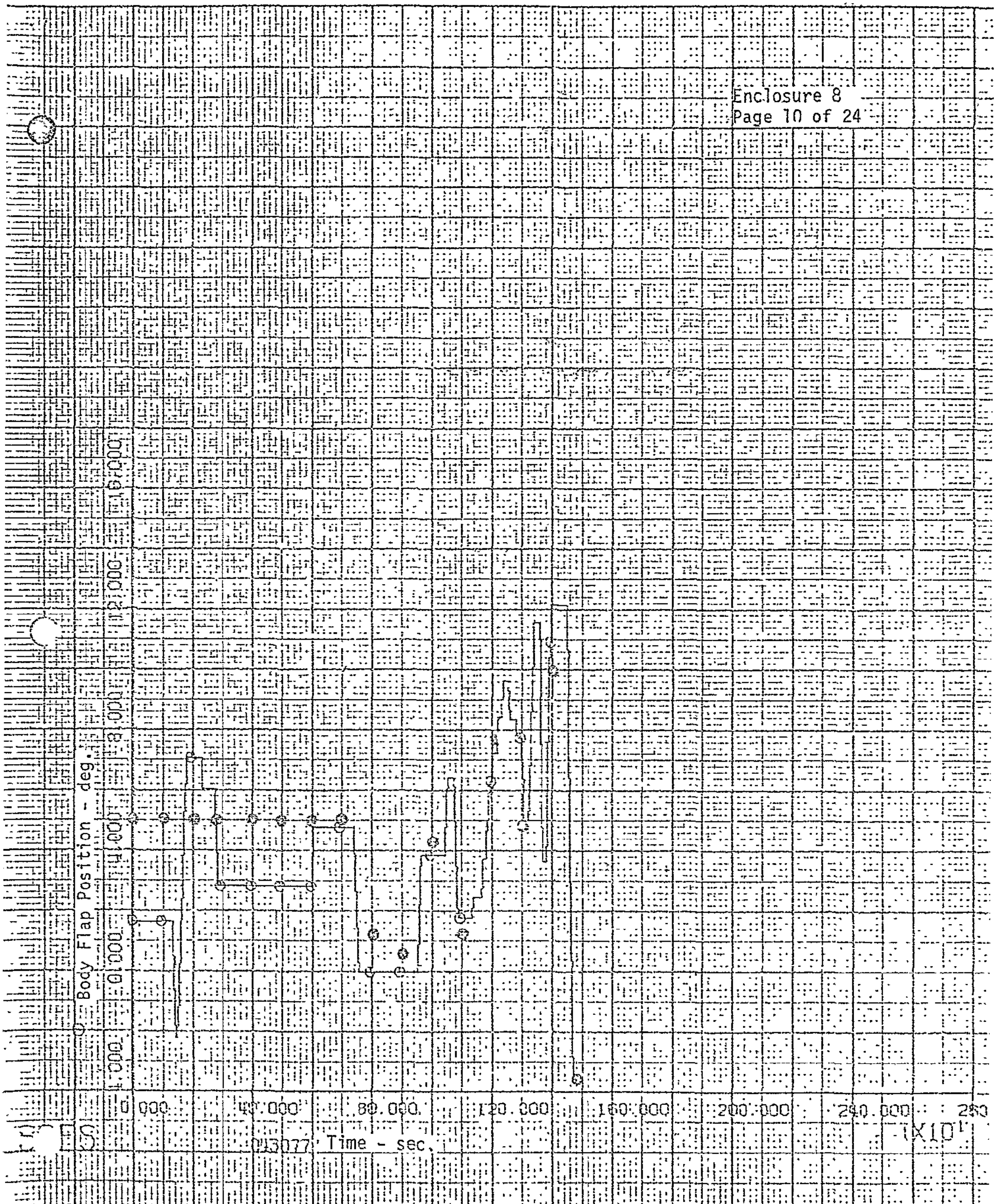

Dynamic Pressure - psf.
0.000
80.000
160.000
240.000
320.000
400.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280
(X10¹)
043077 Time - sec.


Load Factor - g.
0.000
0.500
1.000
1.500
2.000
2.500
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280.
(X10^1)
Time - sec.


Angle of Attack - deg.
3.000
11.000
19.000
27.000
35.000
43.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280
X10²
Relative Velocity - fps.
43077


Bank Angle - deg.
-100.000
-60.000
-20.000
20.000
60.000
100.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
(X10²)
Relative Velocity - fps.
143077


Elevon Position - deg.
6.000
4.000
2.000
0.000
-2.000
-4.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
(X10¹)
Time - sec.



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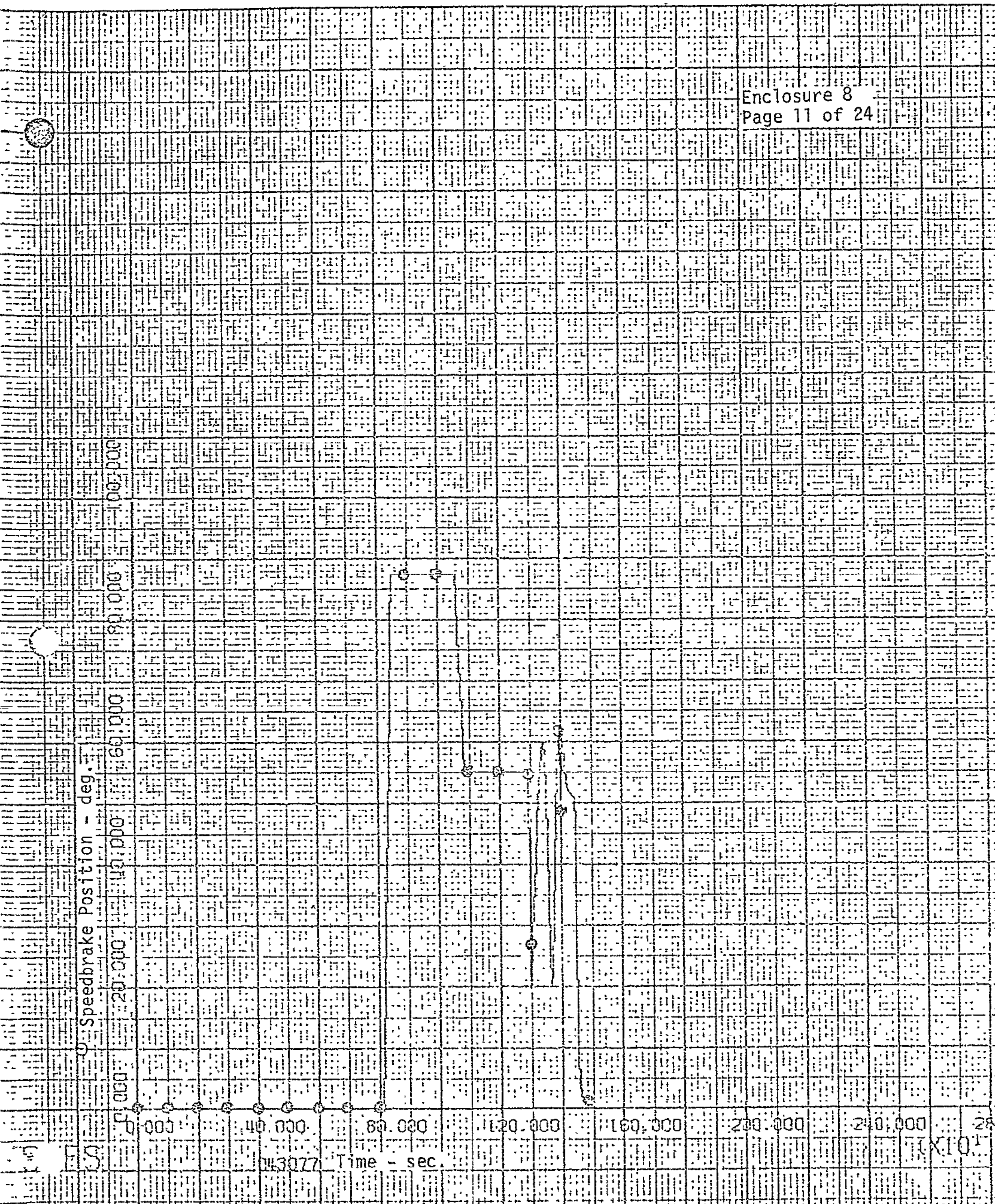
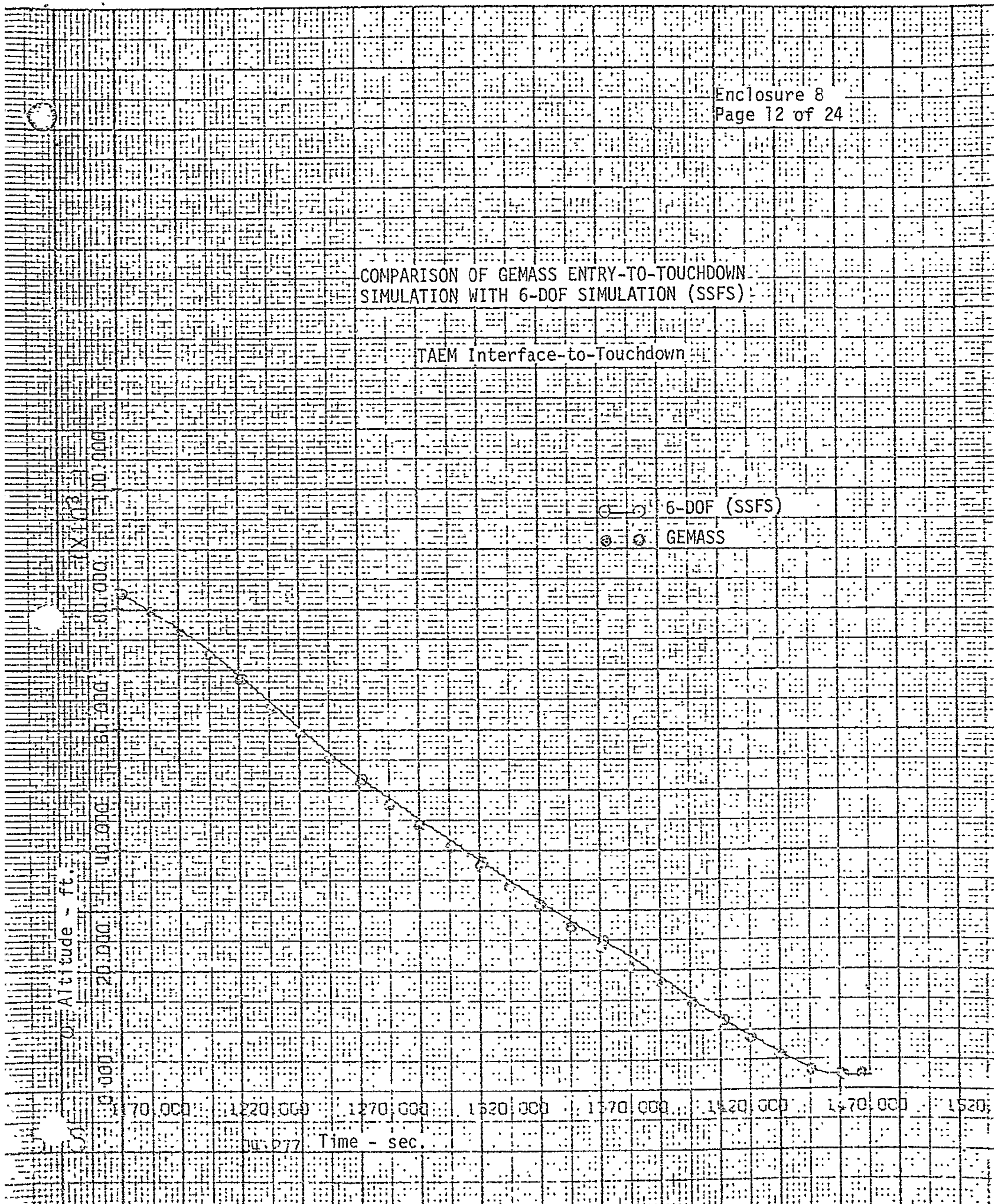
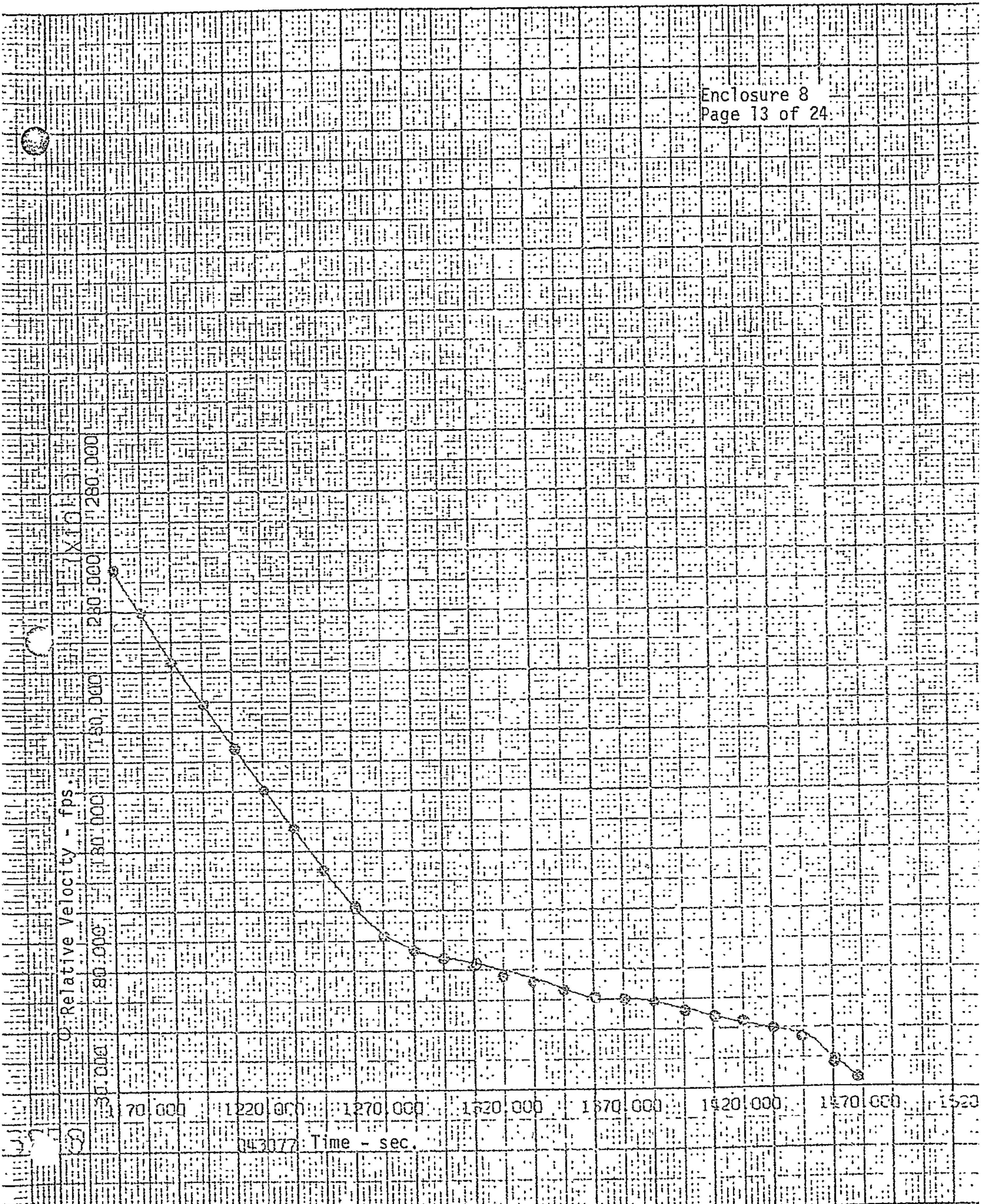

Speedbrake Position - deg.
0.000
20.000
40.000
60.000
80.000
100.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280
(X10¹)
3077
Time - sec.

C-2


Enclosure 8
Page 12 of 24
COMPARISON OF GEMASS ENTRY-TO-TOUCHDOWN
SIMULATION WITH 6-DOF SIMULATION (SSFS)
TAEM Interface-to-Touchdown
6-DOF (SSFS)
GEMASS
Altitude - ft. X10³
0.000
20.000
40.000
60.000
80.000
100.000
1170.000
1220.000
1270.000
1320.000
1370.000
1420.000
1470.000
1520.
Time - sec.



ORIGINAL PAGE IS
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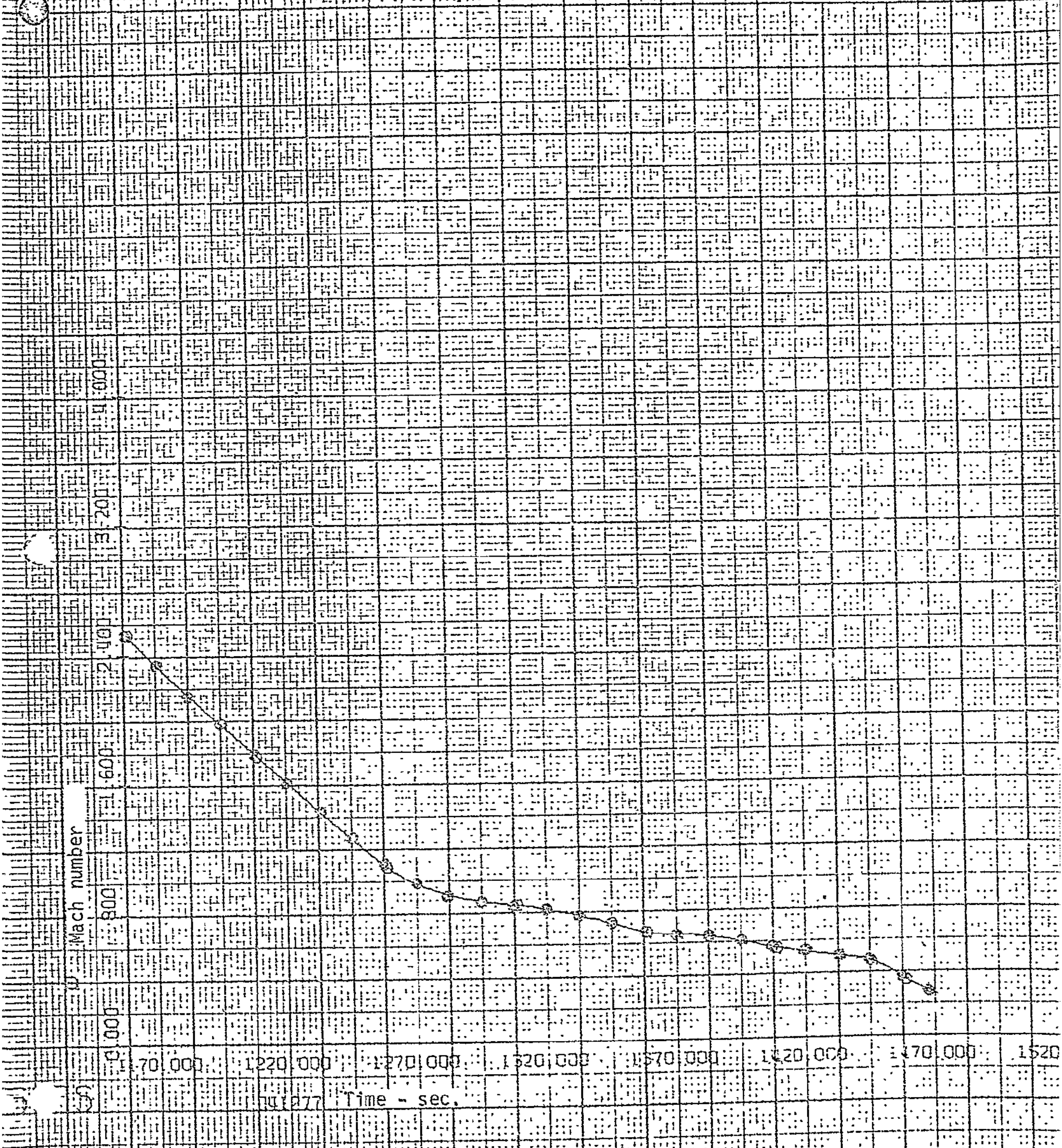

ORIGINAL PAGE IS
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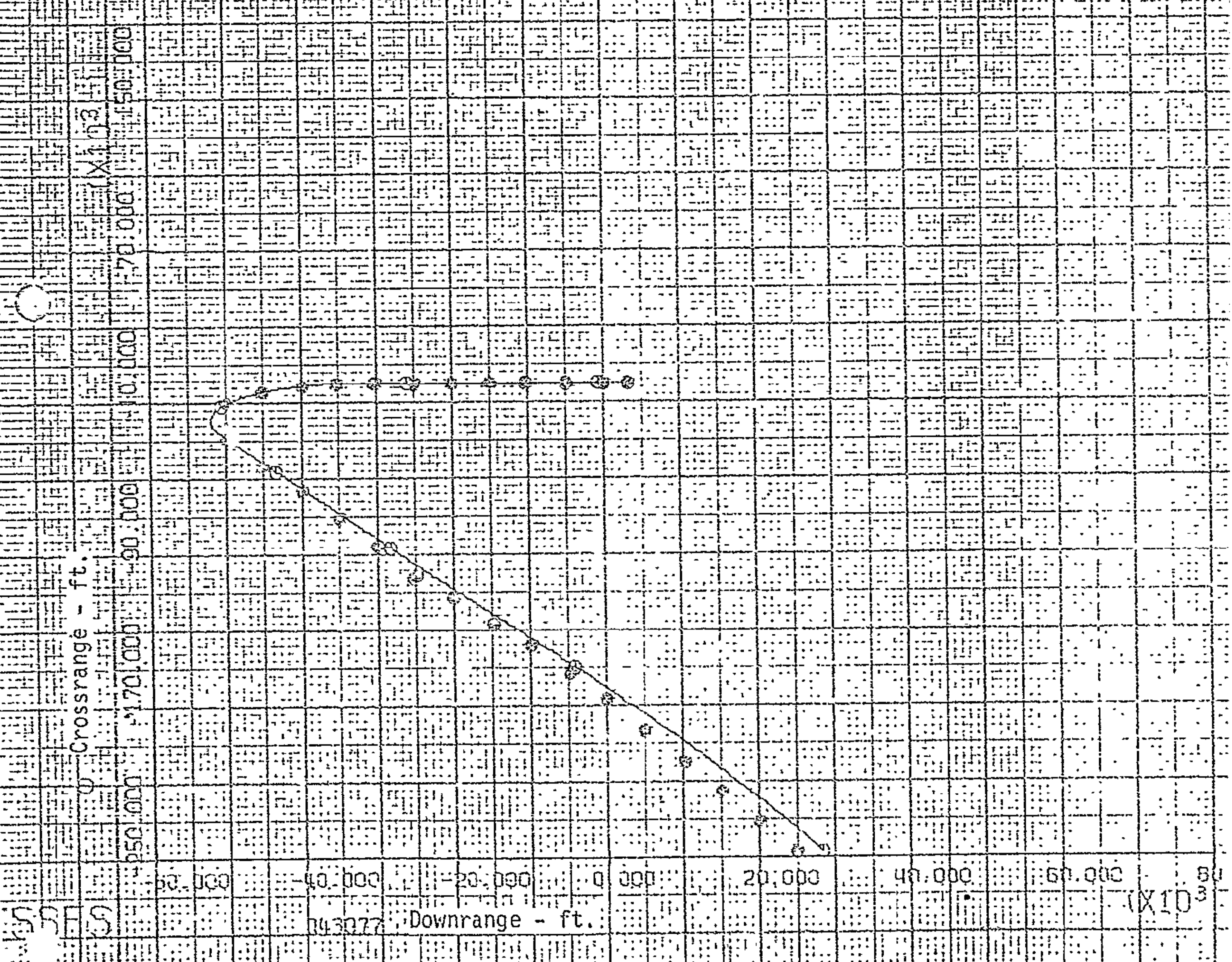
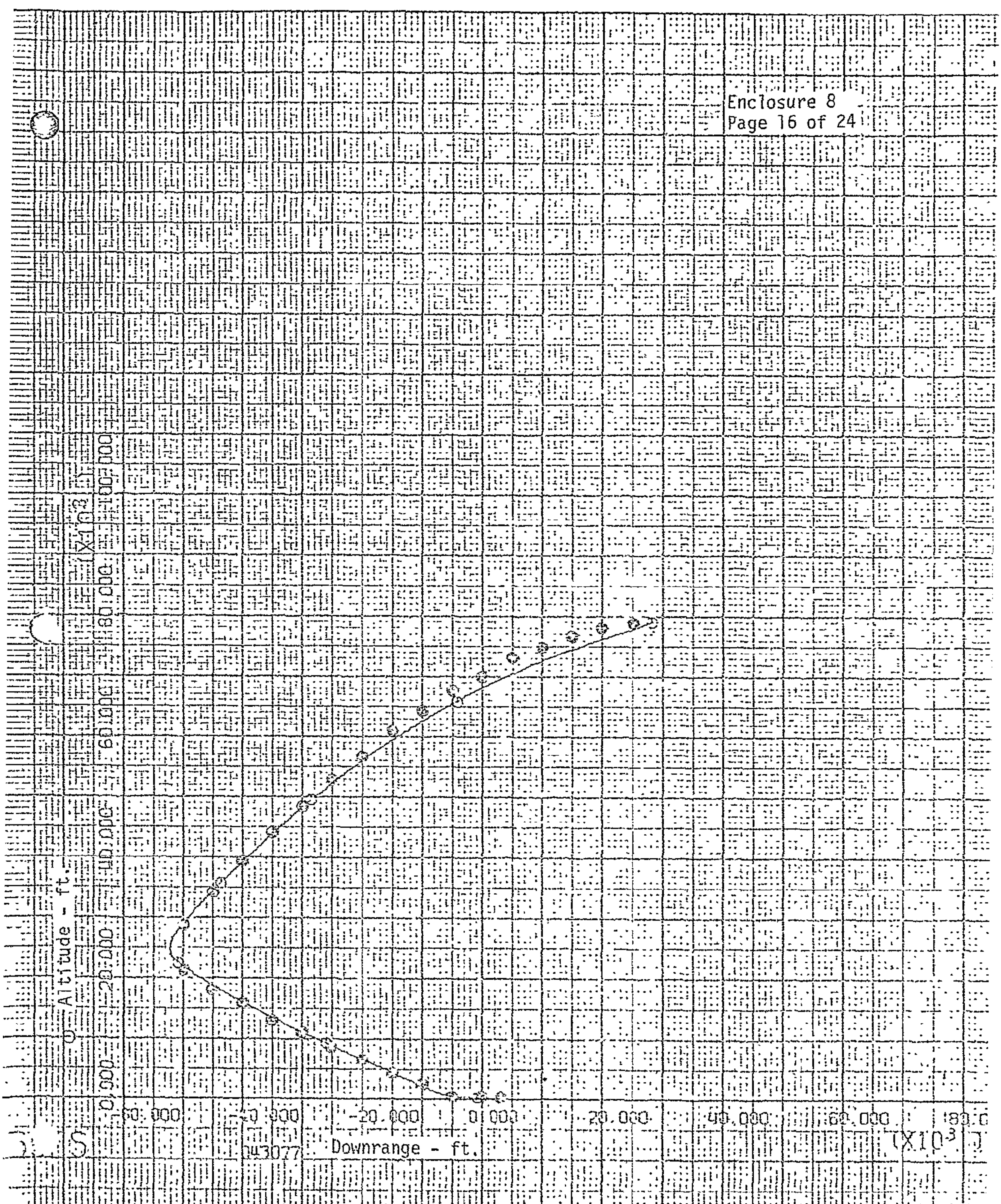
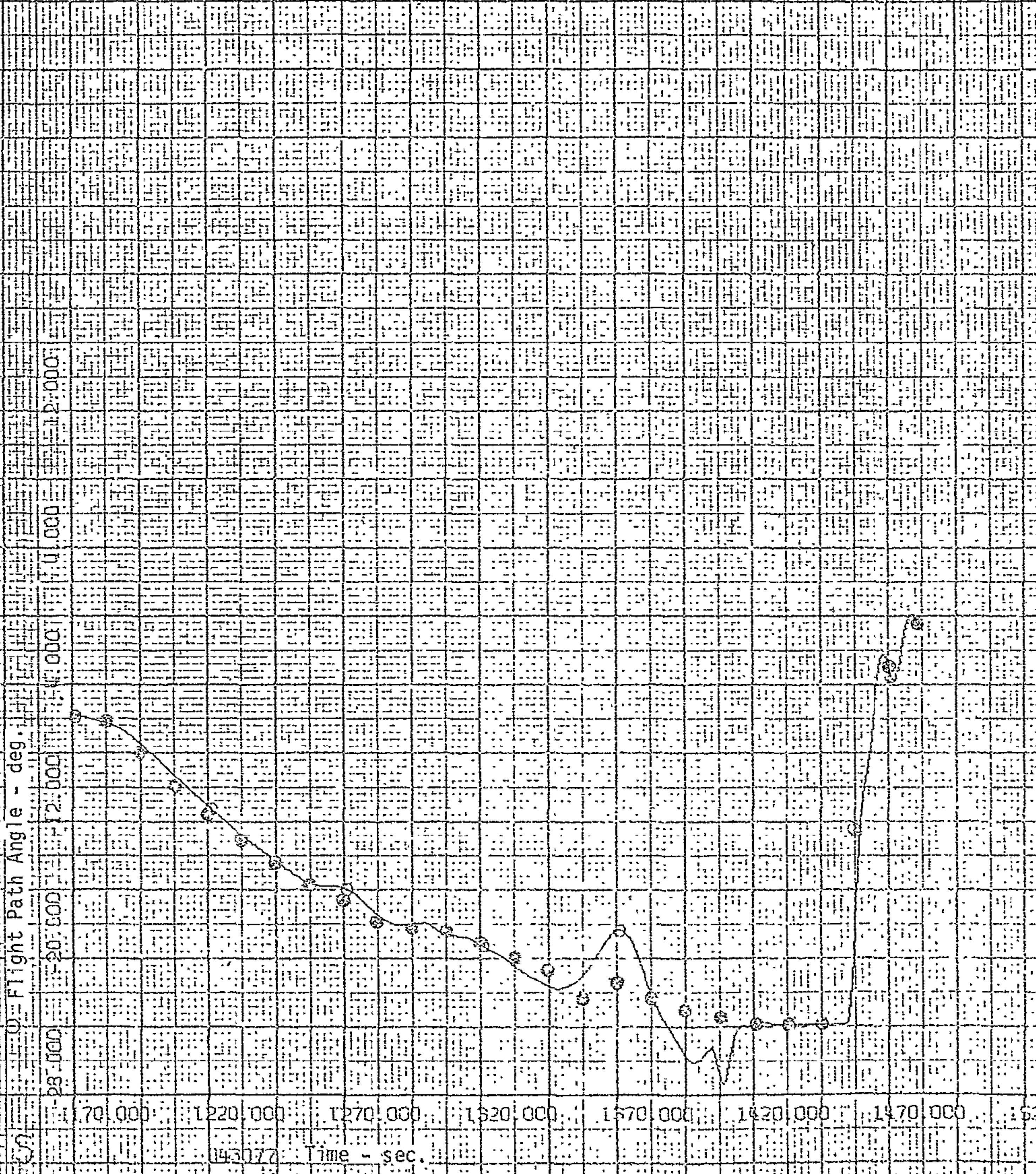
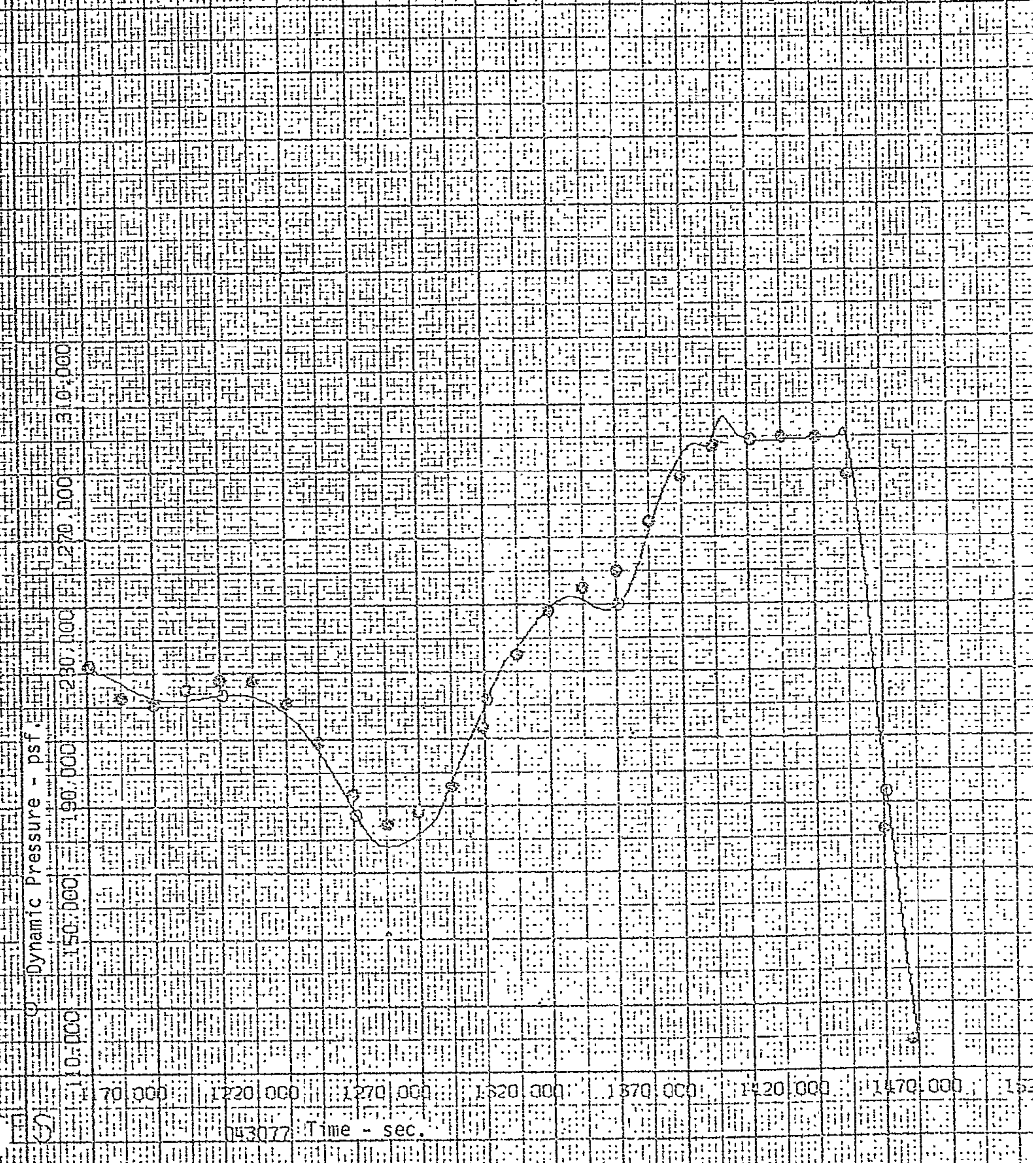
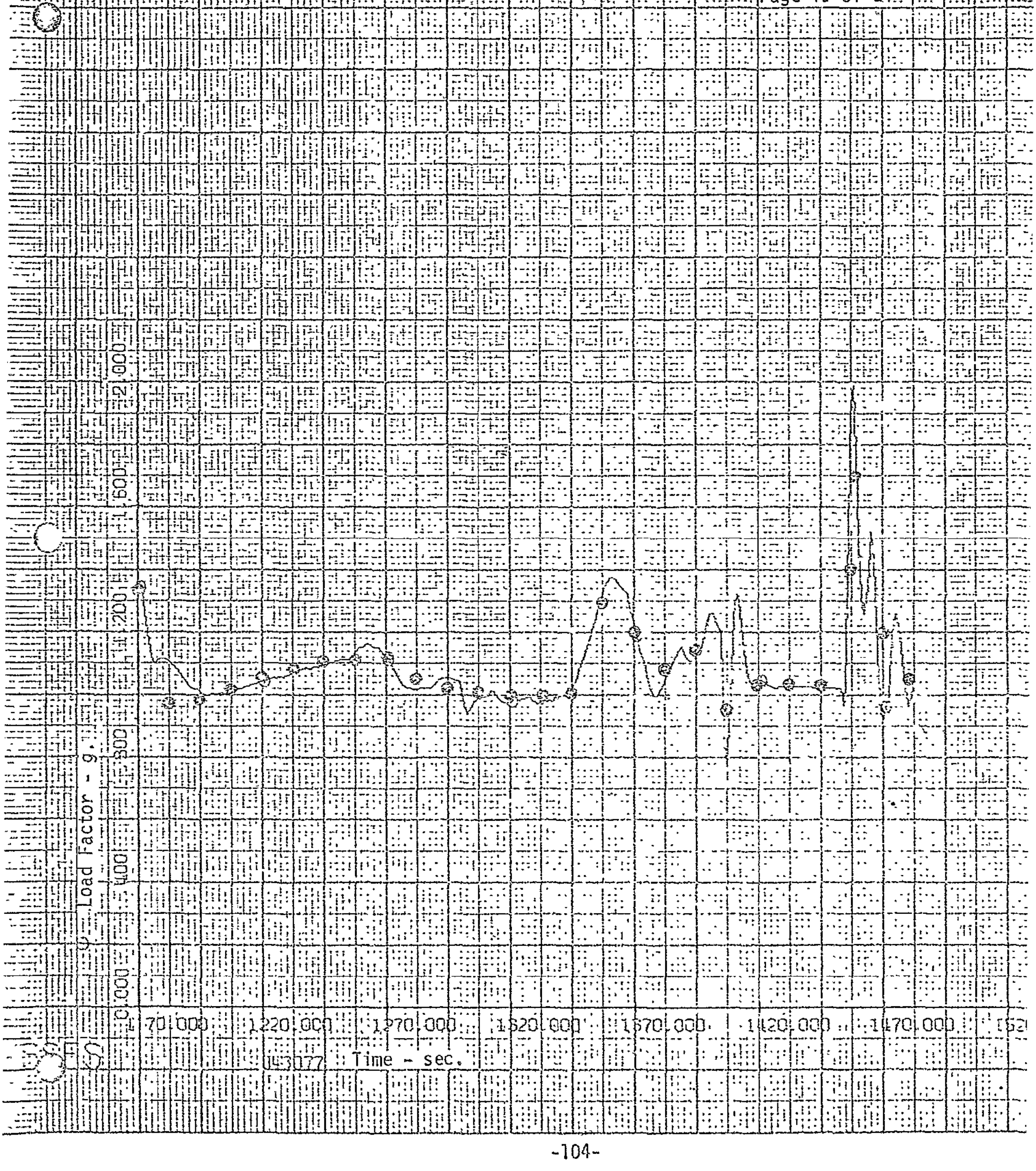
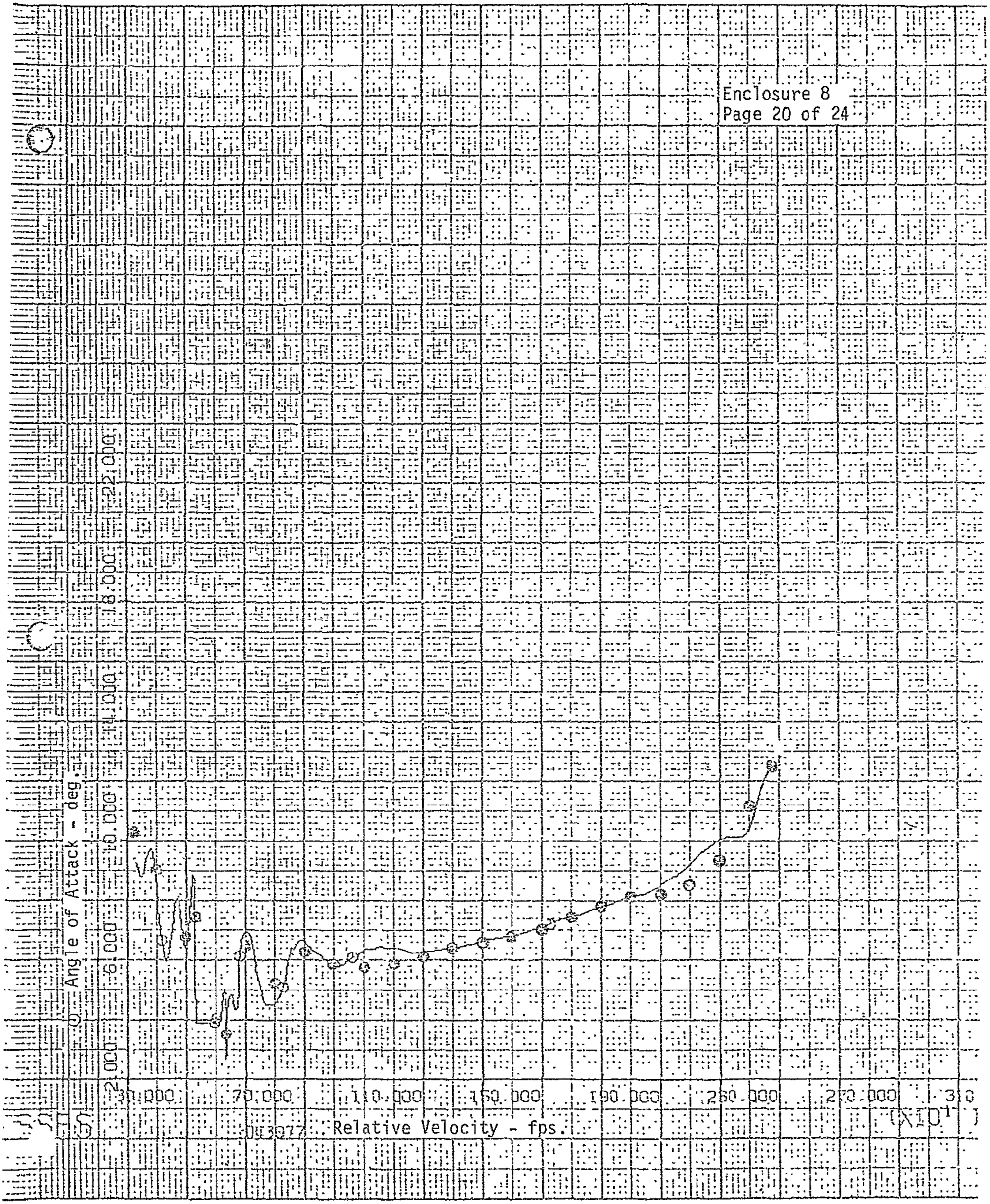

Crossrange - ft.
250,000
170,000
90,000
10,000
70,000
150,000
(X10^3)
-60,000
-40,000
-20,000
0,000
20,000
40,000
60,000
80
(X10^3)
Downrange - ft.

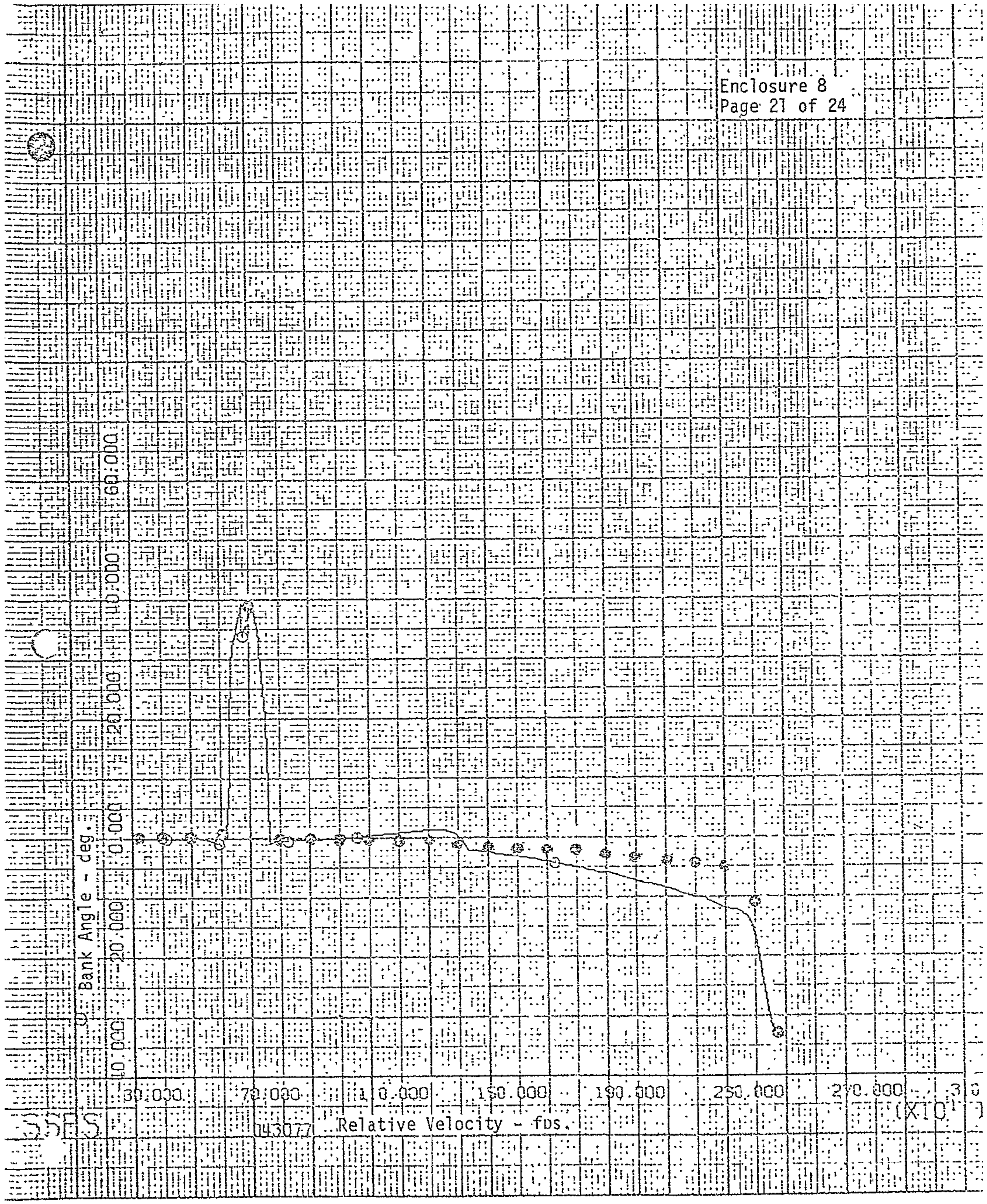

Altitude - ft.
(X10^3)
0.000
20.000
40.000
60.000
80.000
100.000
-60.000
-40.000
-20.000
0.000
20.000
40.000
60.000
80.0
(X10^3)
Downrange - ft.
043077

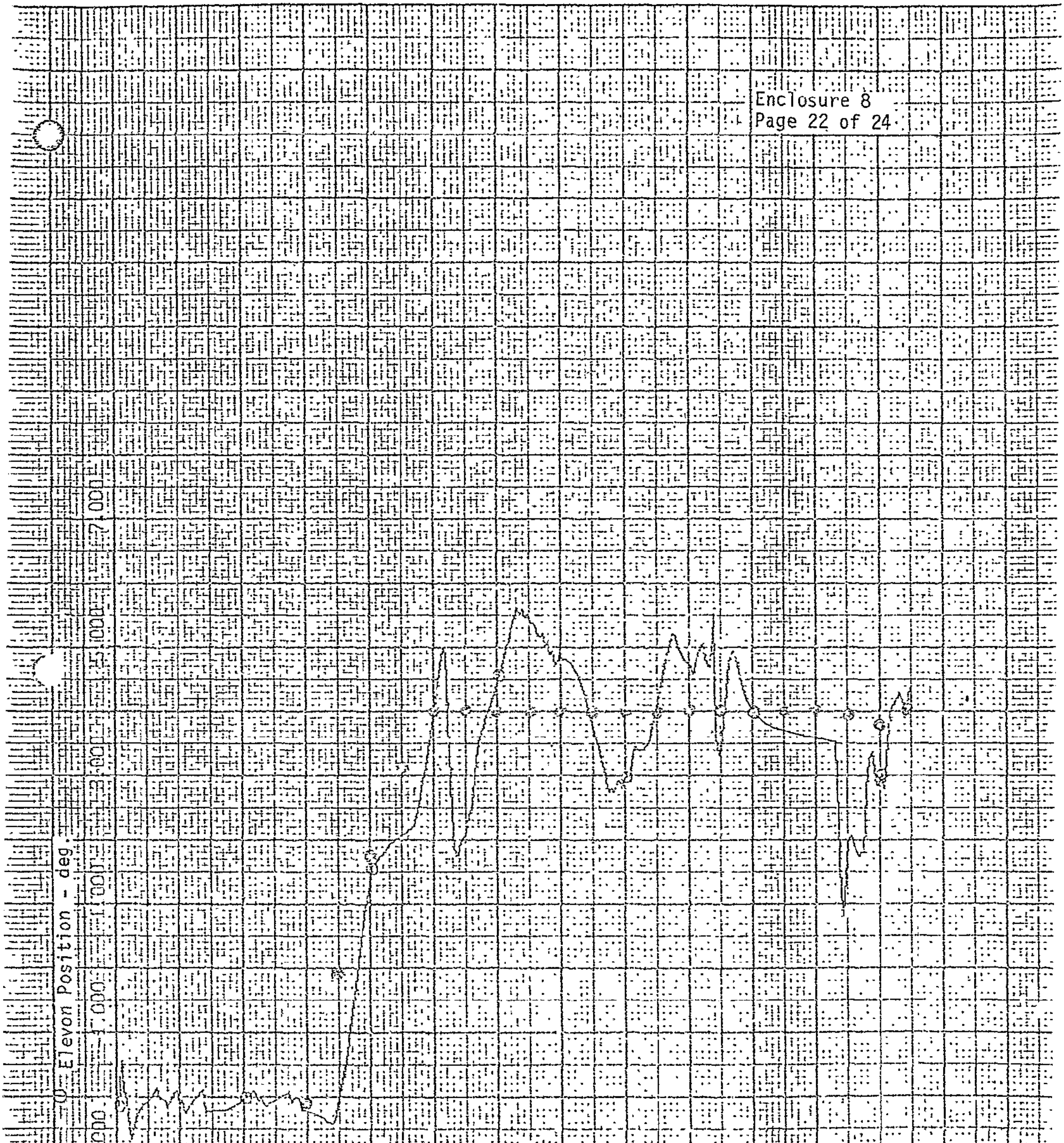

Flight Path Angle - deg.
-12.000
-4.000
4.000
12.000
20.000
28.000
1170.000
1220.000
1270.000
1320.000
1370.000
1420.000
1470.000
043077
Time - sec.


Dynamic Pressure - psf
110.000
150.000
190.000
230.000
270.000
310.000
1170.000
1220.000
1270.000
1320.000
1370.000
1420.000
1470.000
Time - sec.


Load Factor - g.
0.000
.400
.800
1.200
1.600
2.000
1170.000
1220.000
1270.000
1320.000
1370.000
1420.000
1470.000
Time - sec.


Angle of Attack - deg.
2.000
6.000
10.000
14.000
18.000
22.000
30.000
70.000
110.000
150.000
190.000
230.000
270.000
310
(X10^{1})
Relative Velocity - fps.


Bank Angle - deg.
60.000
40.000
20.000
0.000
-20.000
-40.000
30.000
70.000
110.000
150.000
190.000
250.000
270.000
(X10^{1})
Relative Velocity - fps.
043077



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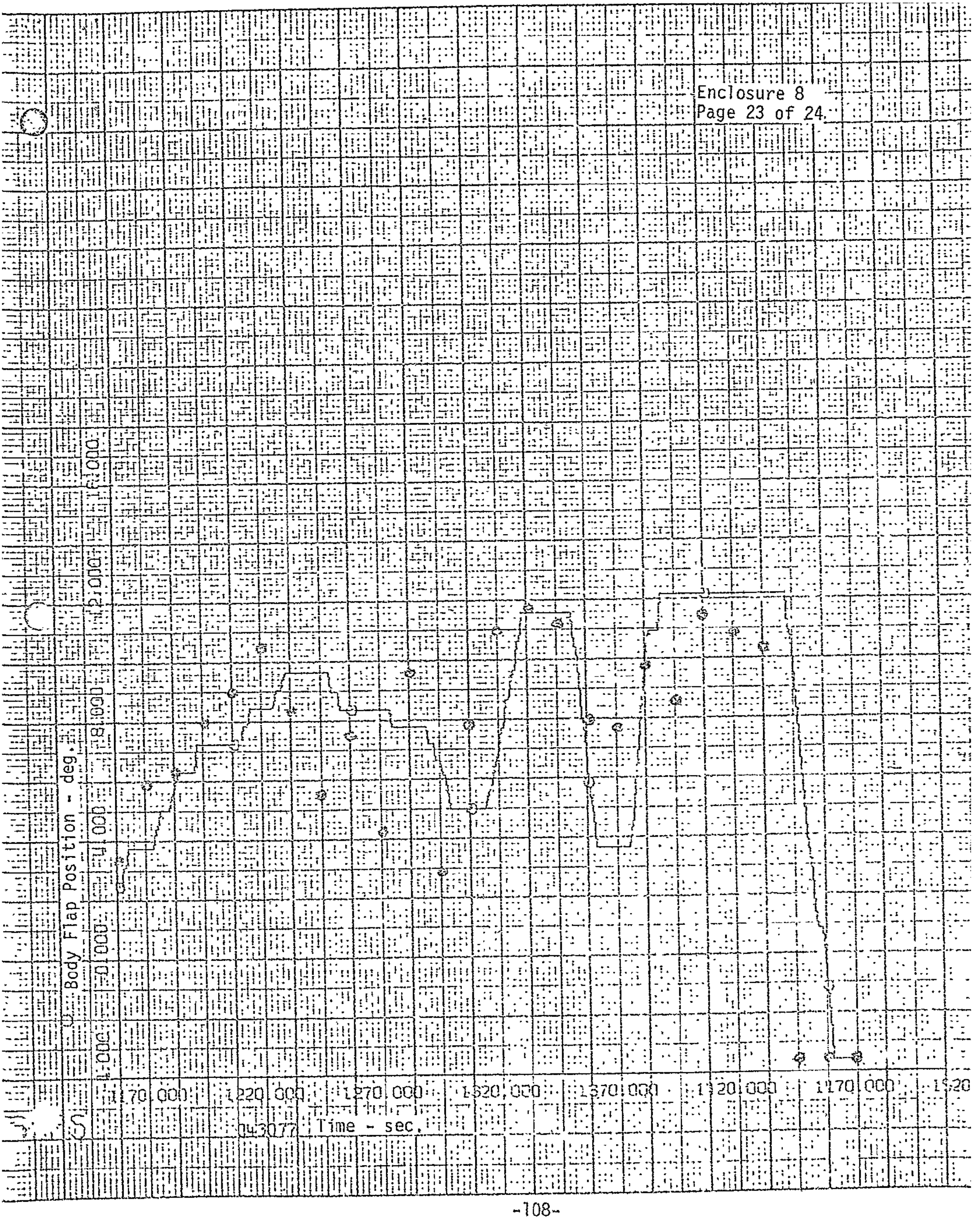
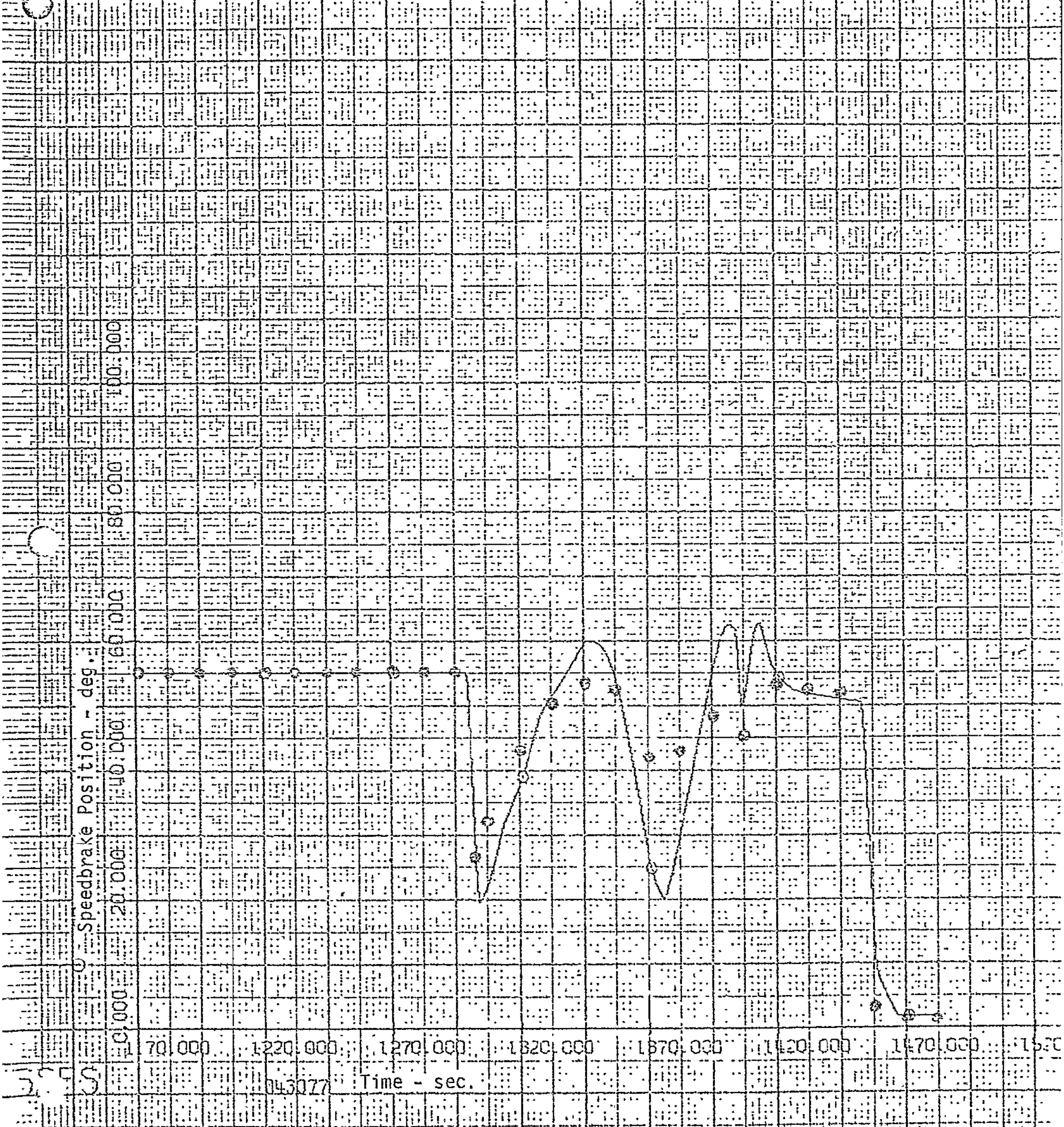

Body Flap Position - deg.
4.000
0.000
4.000
8.000
12.000
16.000
1170.000
1220.000
1270.000
1320.000
1370.000
1470.000
1520
043077
Time - sec.


Speedbrake Position - deg.
0.000
20.000
40.000
60.000
80.000
100.000
1170.000
1220.000
1270.000
1320.000
1370.000
1420.000
1470.000
Time - sec.
043077

FILE STRUCTURES

	TAPE	FILE(s)
GEMASS ENTRY-TO-TOUCHDOWN SIMULATION	X07475	1 OR 2
	X06938	1 OR 2
AERO DATA	X17990	1 TO 57
TABULAR DATA	X14728	17 TO 20, 27, 28, AND 60 TO 68

PROGRAMMERS

DR. F. GARCIA, JR.	NASA/EX4	PH. 483-5557
K. M. MORRISON	NASA/EX4	PH. 483-5557
R. H. WAIBEL	MDTSCO/WBS 1.2	PH. 488-5660 X 226

POTENTIAL CORE REDUCTIONS

ROUTINE		OCTAL DATA STORAGE	OCTAL CODE STORAGE
RADAR	NOT	424	563
HOUR	REQUIRED	31	170
ORBIT	FOR	144	270
ROCKM2	ENTRY-TO	17	111
BODY M2	TOUCHDOWN	23	33
CLCT	SIMULATION	37	720
TPS		537	1653
SBOOM		100	276
DAPGEM		147	1230
AUTLND		270	2302
TAEMG		313	2613
WIND		45	201
CONGID		306	2541
GIDNAV		15	64
EGRT		137	735
TAERO[2]		166	1236
VECWIN		2303	2442
EXECT1		AT LEAST 1671[3]	?[3]
EXECT5		?[4]	?[4]
EXECT8		?[5]	?[5]

SAMPLE OF DUMMY ROUTINE

```
FOR  RADAR, RADAR
     SUBROUTINE RADAR
     RETURN
     END
```

NOTES:

(1) Additional 1181 decimal locations available in A-array.

(2) See Enclosure 6 for additional A-array locations made available by not using Aero Data Tape. 2966 decimal locations available for not using hinge moment calculations.

(3) Overlain; reduction determined by other program mods in use; not required for entry-to-touchdown simulation; controls use of subprogram 44.

(4) Same as 3 except controls subprograms 21, 22, 23, and 24.

(5) Same as 3 except controls subprogram 35.

APPENDIX I

DISPERSIONS

The ability to run several dispersion sources (i.e., off-nominal conditions) with an entry-to-touchdown trajectory have been included in the simulation. These are:

1) Guidance, Navigation, and Control error
2) Atmosphere (neutral)
3) Winds
4) Aerodynamic errors

Some of these existed with previous forms of the GEMASS simulation, but more options are available with the current program. Also, a data tape (X17428) has been provided that contains tables of dispersion values. The following discussion of the error sources deal with the options available and how to use the tape. Enclosure 6 gives additional information on the use of this tape.

GN&C Error Sources

In order to simplify the running of dispersed trajectories with GN&C error sources a number of modifications to GEMASS were made. The error sources that have been identified as attributable to guidance and control are:

1. Angle of attack
2. Bank angle
3. Relative velocity
4. Altitude rate
5. Range to go
6. Altitude

The angle of attack and bank angle errors are induced via the respective pitch and roll dynamic equations in DAPGEM. When the quantities resulting from these equations are integrated to give the actual angles, the actual steady state angle of attack and bank angle will differ from the commanded angles by the desired error source value. Implementation of the error sources in this way allow the commanded angles to remain unchanged throughout the program. Both error source values are input in degrees. The angle of attack and bank angle errors are input in A(1053) and A(1052), respectively.

The relative velocity error is input in feet per second and is added internally to the actual relative velocity. This modified velocity is then used for all guidance routines. It is input via A(1051).

The capability to look-up an altitude rate error is provided in GIDNAV. This error is added to the actual altitude rate and this modified rate is used for the guidance routines. The use of this option is controlled by A(1054). If this quantity is greater then one, Table 85 will look-up the altitude rate error, A(1055). A(1034) is reserved as a post-multiplier. The following options are available from the tabular data tape:

A(1054) = 1 The WTR error profile will be called

= 2 The ETR error profile will be called

In a similar manner a range-to-go error can be looked-up in EGRT. This quantity is then added to the nominal range-to-go in the guidance routines. The use of this option is controlled by A(1056). If this quantity is greater than one, Table 86 will look-up the range-to-go error, A(1057). A(1035) is reserved as a post-multiplier. The following options are available from the tabular data tape:

A(1056) = 1 The WTR error profile will be called

= 2 The ETR error profile will be called

The capability to look-up an altitude error is provided in GIDNAV. This error is then added to the actual altitude and the result is used for the guidance routines. The use of this option is controlled by A(1040). If this quantity is greater than one,

Table 87 will look-up the altitude error, A(1041), A(1042) is reserved as a post-multiplier. No tables for this are on the tabular data tape.

Note that for the altitude rate and the range-to-go errors the user may provide his own tables if desired. The tables on the tabular data tape are set up with the y-arguments being the profile selector numbers (A(1054) and A(1056)) and relative velocity as the X-arguments.

Atmosphere

GE-MASS has been modified to allow two methods of selecting the multipliers to nominal neutral atmospheric quantities. This option is controlled by A(51) with the control card multipliers determined from the A-array input. The quantities affected are:

A(350) actual atmospheric pressure

A(351) actual atmospheric density

A(352) actual atmospheric sound speed

A(353) actual atmospheric viscosity

If: A(51) = 0 no table look-up, multipliers are unity - nominal neutral atmosphere

A(51) = 1, the following operations will be performed:

A(350) = A(342) * (1. + A(338))

A(351) = A(344) * (1. + A(339))

A(352) = A(345) * (1. + A(340))

A(353) = A(349) * (1. + A(341))

Where: A(338) to A(341) are determined by Tables 4 to 7 respectively and have the following post multiplier or default values reserved:

A(338): A(1037)

A(339): A(1029)

A(340): A(1038)

A(341): A(1039)

A(342), A(344), A(345), and A(349) are the nominal neutral atmospheric pressure, density, speed of sound and viscosity. A(51) = -1, the following operations are performed:

A(350) = A(342) * A(338)

A(351) = A(344) * A(339)

A(352) = A(345) * A(340)

A(353) = A(349) * A(341)

Four density tables compatible with the option A(51) = 1 are available on the tabular data tape. The density multiplier is determined from Table 5 and the Y-position on this table control card is used to determine the density profile. A(1063) is reserved for this option and the following profile are available:

A(1063) $\leq$ 1 70° North Hot

= 2 ETR Hot

= 3 70° North Cold

$\geq$ 4 ETR Cold

The X-argument of this table is altitude and the density multipliers are to be used with the USSA 1962.

If the A(51) = -1 option is chosen, a table of multipliers in the form described for this option must be provided along with a referencing table control card. Furthermore, post-multipliers of unity should be assigned to A(1037), A(1038), and A(1039) if the pressure, sound speed, and viscosity profiles are not to be changed. If the nominal density (A(344)) is desired unchanged, a table control card to assign a default multiplier of unity should be included in the input decks.

Winds

The way in which wind velocity components are determined has not been changed from the previous GEMASS procedure; i.e., table look-ups. However, several A-array locations have been reserved for use as post-multipliers and profile indicators. Tables of design wind profiles as functions of altitude down to 65K feet are on the tabular data tape. One table is used for the North or South wind profiles and another is used for the East or West wind profiles. The X-argument in each table is used to select the profile desired. Two A-array's reserved for this selection are:

A(1064) - East/West Wind Profile

$\leq$ 1 = East

$\geq$ 2 = West

A(1065) - North/South Wind Profile

$\leq$ 1 = North

$\geq$ 2 = South

Separate post-multipliers for each of the wind components have been reserved. They are:

A(1026) X-wind component post-multiplier

A(1027) Y-wind component post-multiplier

A(1028) Z-wind component post-multiplier

Aerodynamic Error Sources

Calls to TABLE in TAERO allow the user add increments to both the trimmed C_L and C_D determined by that routine. This option is controlled by the value in A-array 1060.

If: A(1060) $\leq$ 0.5 then no increments are added to C_L and C_D.

If: A(1060) > 0.5 the values are looked up in their appropriate tables and added to the nominal values.

Tables of correlated aero data uncertainties are available on the tabular data tape. The Y-arguments are Mach number or the viscous interaction parameter whichever is appropriate for the flight regime. The X-argument is A(1060) and is the series of aerodynamic uncertainty to be used. (See ref 5, sec. 9.1.2.1 for the definition of these). The following post-multiplier values have been reserved for use with this option:

A(1030): Inviscid C_D Uncertainty

A(1031): Inviscid C_L Uncertainty

A(1032): Viscous C_D Uncertainty

A(1033): Viscous C_L Uncertainty