RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
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PROFGEN: AN AIRCRAFT FLIGHT PROFILE GENERATION PROGRAM

by
Capt. M. Vinnins

PROJECT NO.
32G01

SEPTEMBER 1978
OTTAWA

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PROFGEN: AN AIRCRAFT FLIGHT PROFILE GENERATION PROGRAM

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(10) Michael F. [redacted] M. Vinnins
EM Section
Defence Electronics Division

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ABSTRACT

PROFGEN, an aircraft flight profile generation program obtained from the United States Air Force Avionics Lab, has been modified for use in the simulation of a strapdown inertial navigation system being developed at DREO. The program allows the user to specify initial flight parameters to control the dynamics of a "point mass" aircraft in three dimensions. Outputs of PROFGEN are used to drive models of inertial sensors and develop navigation algorithms. An example flight profile employed in the simulation is described.

RÉSUMÉ

PROFGEN, un programme de calcul de profils de vol d'avions obtenu du United States Air Force Avionics Lab, a été adapté à la simulation d'un système de guidage par inertie non stabilisees qu'on est en train de mettre sur pied au CRDO. Ce programme permet à l'utilisateur de préciser les paramètres de navigation initiaux pour le contrôle tridimensionnel des évolutions d'un avion ponctuel. Les données obtenues à l'aide du programme servent à alimenter des modèles de détecteurs à inertie et à établir des algorithmes de navigation. Un example d'un profil de vol appliqué à la simulation est fourni.

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PROFGEN

An Aircraft Flight Profile Generation Program

1. Background

The initial activity within the new DREO Technical Sub-Program on Navigation Technology has been devoted to research and development on strapdown inertial navigation systems (S/D INS). Included in this activity are system simulation, inertial component testing, and eventual design and testing of a complete strapdown INS. The application of such an INS would be both as an aid and a stand-alone backup to NAVSTAR Global Positioning System (GPS) User Equipment. The fact that NAVSTAR GPS is a radio navigation system makes the possibility of electronic jamming and interference a very real possibility in a military environment. An inertial navigation system is unaffected by jamming and thus can serve as an ideal backup system. Although strapdown sensor and system technology is a relatively new field, much promising work is being done by several American companies. Strapdown Technology eliminates the need for mechanically-levelled sensor platforms (gimbals) placing the burden, instead, upon computers. With recent developments in computer technology, small and efficient computers can be relied upon to carry out navigation functions on board any type of vehicle. Initial work in the navigation sub-program has involved study and simulation of a S/D INS for use in aircraft applications. Future work may involve maritime and land craft as applications arise.

The initial step in the development of the INS was the simulation of the various components of such a system. These include models of inertial sensors (gyroscopes and accelerometers), development of navigation algorithms, sensor error compensation and appropriate filtering techniques. For the purposes of the simulation, it was necessary to develop a method of driving the inertial sensors such that they appeared to be on board an aircraft. The outputs of the sensors could then be operated upon by the navigation algorithms, compensation and filters to obtain the desired 3-dimensional navigation solution.

The simulation of such an aircraft flight profile to drive the sensor models was accomplished using a computer program called PROFGEN (Profile Generation).

2. PROFGEN Definition

PROFGEN is a computer program which calculates flight path data for an aircraft moving over the earth. The program is in FORTRAN and was originally written by S.H. Musick of the Air Force Avionics Lab., WPAFB, Dayton, Ohio[1].

PROFGEN, written in 1975, was intended to support simulations requiring a six degree-of-freedom trajectory to drive them. This program was made available to the navigation subgroup in July 1977 for use in the S/D INS simulation being developed at DREO. Several useful features of the program include wander-azimuth capability, user-determined output times, computation of attitude rates (as well as attitude) and an accurate gravity model. The program is coded in modular form making it very readable and easily modified.

PROFGEN Computes:

1) position in geographic latitude, longitude and altitude.

2) velocity; componentized and presented in a local-level (navigation) frame.

3) acceleration consisting of velocity rates of change summed with gravity.

4) attitude consisting of roll, pitch and yaw, and

5) attitude rate for roll, pitch and yaw.

For the purposes of the S/D INS Simulation, the angular rates and accelerations have been modified by the DREO navigation group such that they are presented in the vehicle body frame with respect to the inertial frame (earth rotation and gravity considered). Roll, pitch and yaw are considered to be the angles between the body and navigation frame axes.

PROFGEN models a point mass responding to 4 possible flight manoeuvres specified by the user:

1) vertical turns (pitch up or down)

2) horizontal turns (with a coordinated roll)

3) sinusoidal heading changes, and

4) straight flight (great circle or rhumb line)

A coordinated turn in horizontal-plane manoeuvres means that the aircraft is rolled to an angle where the vector sum of the centrifugal turning force and the force of gravity act perpendicular to the wings.

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1. PROFGEN-A computer program for generating flight profiles S.H. Musick, Nov. 76, WPAFB, AFAL-TR-76-247.

The user of the program may select either rhumb line or great circle flight path. In rhumb line flight the aircraft maintains constant heading angle during straight flight, whereas, in a great circle path the aircraft flies in a fixed plane during straight flight maintaining this fixed plane, even when altitude changes, by correcting heading continuously. When not in straight flight the rhumb line or great circle is superimposed on the manoeuvre.

The earth is modelled within the program as an ellipsoid having values for eccentricity, semimajor axis length, spin velocity and gravitational constant as defined by the World Geodetic System 1972.

Earth's gravity is modelled as a function of latitude and altitude, having both radial and level components. This model is accurate to approximately 25μ g's.

The outputs of PROFGEN, instantaneous acceleration, velocity and position, are provided by a 5^{th} order Kutta-Merson numerical integrator which also allows variable step-size integrations, as determined by the user, to control the size and growth of errors.

There are several limitations to PROFGEN and, therefore, before describing the use of the program these should be briefly discussed:

1) Since the program models a point mass, the path coordinate frame and body coordinate frame are coincident. This means that it is not possible to simulate a slipping or crabbing motion for the aircraft.

2) There is no noise model within the program meaning that aircraft vibrations and noise cannot be simulated without additions to PROFGEN.

3) The program is very slow if the output interval desired is very short (50 outputs per second or more). This is due to the fact that the integrator must adjust its step size very finely in order to satisfy the desired output time and allowed error limitations chosen by the user. This limitation can be reduced if data is recorded from PROFGEN and later used without running the whole program again.

PROFGEN is approximately 2500 FORTRAN-coded lines long and occupies approximately 16k of core memory. The program is used on a SIGMA IX computer on the DREO site and output data is recorded on disk for later use in driving the sensor models of the S/D INS simulation.

3. Use of PROFGEN

The operation of PROFGEN is controlled by two input data namelists supplied by the user. These are PRDATA, initial problem data and PASDATA, specific data for each segment.

PROFGEN is structured such that only one of the four possible manoeuvres can be executed at a time but it can commence from any aircraft attitude. A flight profile is created by stringing together a sequence of manoeuvres, called flight segments, and specifying how long each will last. The final values of position, velocity, acceleration and attitude for each segment are used as initial values for the next segment giving uninterrupted time histories for all variables.

The user can also control aircraft acceleration within each segment, superimposing it over any manoeuvre. An additional feature of PROFGEN is the incorporation of the flight envelope for the Convair 580 aircraft into the program[2]. If roll, pitch, yaw or velocity are out of range of the vehicle's capabilities, a message is printed out to the user. It should be noted, though, that this does not stop or affect the running of PROFGEN; it only provides information to the user.

In general, then, a very realistic flight profile can be generated by the user simply by specifying initial program and flight segment parameters in the two namelists. These namelists will now be discussed in more detail.

3.1 PRDATA namelist

The PRDATA namelist specifies the initial conditions of the program and the initial aircraft parameters with which the flight profile will begin. These initial values are (as coded within the program):

- NSEGT - the number of segments in the entire flight profile.
- TSTART - the start time (usually time zero).
- VTO - initial velocity in feet per second.
- PHEADO - initial heading of path coordinate frame in degrees.
- PITCHO - initial pitch from level flight in degrees.
- ALFAO - heading from north in the navigation frame in degrees.
- LATO - initial latitude.
- LONO - initial longitude.
- ALTO - initial altitude.
- IPRNT - print out control; if set, then a formatted data printout is provided as PROFGEN runs.

---

2. The National Aeronautical Establishment Convair 580 is the aircraft on which DREO plans to flight test the developed S/D INS.

ROLRAT - rollrate, maximum allowed in degrees per second.

IDSKSWCH - enables data to be written on disk if set.

Several other plot and data storage variables exist enabling various output data options. These are dependent upon the users' needs and are not ordinarily employed. The parameters in the PRDATA namelist set all of the initial conditions required before running the program. When these parameters are initialized, the next namelist, PASDATA, is read.

3.2 PASDATA namelist

The PASDATA namelist contains the problem specifics for each segment within the flight profile. As stated above, the PRDATA parameter NSEGT is the number of segments in the flight profile. Within the PASDATA namelist each parameter will have values for every segment (i.e. if there are 20 segments then each PASDATA parameter will have 20 values, one for each segment).

The PASDATA namelist contains the following parameters:

SEGLNT - the segment length in seconds.

TURN - type of manoeuvre (any one of the 4 possible manoeuvres)

PACC - acceleration along the velocity vector (path acceleration) in g's.

TACC - maximum centrifugal acceleration in a vertical or horizontal turn (turn acceleration in g's.

HEAD - heading change desired within that segment (for turns only) in degrees.

DTO - desired output interval in seconds for disk storage.

NPRNT - desired printout interval (can be different from DTO).

ERROR - maximum error allowed in the integrator.

HMAX - maximum step size allowed in the integrator.

HMIN - minimum step size allowed in the integrator.

PITCH - desired pitch in degrees (vertical turns only).

MODE - fixed or variable step size integration option.

NPATH - nominal path, either rhumb line or great circle.

As many as 50 segments are allowed for an entire flight profile and each segment may last as long as desired by the user. An example of a PRDATA and a PASDATA namelist are shown in Figures 1 and 2 respectively.

A printout of PROFGEN's output data can be obtained by selecting a printout option in the PASDATA namelist. The printout is formatted such that a "header" is printed at the beginning of each flight segment. This header describes the segment and what happens in it; the type of manoeuvre, start and end times, time to achieve heading or pitch changes etc.

3.3 PROFGEN Outputs

The outputs provided by PROFGEN are:

TIME	-	in seconds
LAT	-	latitude
LON	-	longitude
ALPHA	-	heading of navigation frame from north in degrees
ALT	-	altitude in feet
ROLL	-	in degrees
PITCH	-	in degrees
YAW	-	in degrees
PSI	-	in degrees
DROLL	-	derivative of roll (deg/sec)
DPITCH	-	derivative of pitch (deg/sec)
DYAW	-	derivative of yaw (deg/sec)
VX	-	velocity along X axis (ft/sec) (navigation coordinate frame)
VY	-	velocity along Y axis (ft/sec) (navigation coordinate frame)
VZ	-	velocity along Z axis (ft/sec) (navigation coordinate frame)

```
E PRDISK
EDIT HERE
*TY 1-20
   1.000 &PRDATA IPROB=1,
   2.000 NSEGT=2,
   2.500 IDSKSWCH=1
   3.000 LLMECH=2,
   4.000 TSTART=0.0,
   4.500 PASPR=1,
   5.000 VTO=0.0,
   6.000 PHEADO=90.0,
   7.000 PITCHO=0.0,
   8.000 ALFAO=-90.0,
   9.000 LATO=45.0,
  10.000 LONO=-60.0,
  11.000 ALTO=0.0,
  12.000 IPRNT=1,
  13.000 IRITE=0,
  14.000 IPLOT=0,
  15.000 ROLRAT=20.0,&END
--EOF HIT AFTER 15.
*
```

Fig. 1 PRDATA Namelist

```
E PASDATAD
EDIT HERE
*TY 1-20
   1.000 &PASDTA
   1.500 ISEGPR(1)=1,1,1,1,1,1,1,1,1,1,1,1,1,
   2.000 SEGLNT(1)=30.0,120.0,30.0,120.0,300.0,120.0,240.0,120.0,300.0,120
.0,
   2.100 180.0,30.0,30.0,
   3.000 RESTRT(1)=13*0,
   4.000 TURN(1)=4.,1.,1.,2.,4.,2.,4.,2.,4.,2.,1.,1.,4.,
   4.500 NPRNT(1)=13*10,
   5.000 NPATH(1)=13*2,
   6.000 PACC(1)=0.15183,0.08,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
   6.100 -.017870,-.140,-.225,
   7.000 TACC(1)=13*10.0,
   8.000 HEAD(1)=0.0,0.0,0.0,-90.0,0.0,-90.0,0.0,-90.0,0.0,-90.0,0.0,0.0,0.0,
   9.000 PITCH(1)=0.0,10.0,-10.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,-5.0,5.0,0.0,

  10.000 DTO(1)=13*.02,
  11.000 MODE(1)=13*1,
  12.000 ERROR(1)=13*.1E-05,
  13.000 HMAX(1)=13*.1E+05,
  14.000 HMIN(1)=13*.0001,&END
--EOF HIT AFTER 14.
*
```

Fig. 2 PASDATA Namelist

VPATH - path velocity (ft/sec)

FX - force in X (ft/sec/sec)

FY - force in Y (ft/sec/sec)

FZ - force in Z (ft/sec/sec)

APATH - path acceleration (ft/sec/sec)

The format of this output can be seen on the printout, Fig. 3, along with the previously-mentioned "header" information.

4. Example Profile

As mentioned earlier, PROFGEN is used to provide the data to drive models of inertial sensors in a manner simulating that of an aircraft in motion. The test profile which has been chosen for this work is a "racetrack-shaped" profile consisting of a takeoff, vertical climb to approximately 7,000 feet, levelling out, 4 horizontal turns to the left separated by several minutes of level flight and, finally, a descent to landing. A sketch of this profile showing the length of each segment is shown in Fig. 4. The entire flight is 1750 sec (29 min. 10 secs.) long.

In order to illustrate the dynamics of PROFGEN's flight profile, plots of the various output parameters with respect to time have been included as Appendix A to this report. A close study of the plots will show that all of the variables have uninterrupted time histories over the entire flight profile. PROFGEN, as described here, is at present in use in on-going navigation system simulation.

More detailed documentation and mathematical formulations of PROFGEN are available along with sample runs for various profiles. Further information may be obtained from the Electromagnetics Section, DREO/DED.

```
BEGIN SEGMENT NUMBER  2
  INITIAL TIME                30.00000
  FINAL TIME                 150.00000
  THIS FLIGHT SEGMENT IS A VERTICAL TURN
  THE NOMINAL FLIGHT PATH OVER THE EARTH IS A RHUMB LINE
  THE INTEGRATION STEP SIZE IS VARIABLE
  THE LOCAL-LEVEL MECHANIZATION IS CONSTANT ALPHA

  THE DESIRED CHANGE-IN-PITCH IS ACHIEVED AT TIME =      30.14985517
    30.00000           .0000000          .0000000         .0000026
    .1377433E-17     -.5856030E-04     -.5856030E-04     .3033960E-42
   -.1616155E-01     -32.15644

**AIRCRAFT  SPEED IS OUTSIDE THE RANGE 50 TO 300 KNOTS.TOO FAST FOR CONVAIR'

 TIME       30.00000
      LAT          45.00000000     LON      -59.93149534     ALPHA    -90.00000000     ALT      .0000000000
      ROLL         .0000000000     PITCH     .0000000000     YAW       .0000000000     PSI     90.00000000
      DROLL        .0000000000     DPITCH    .0000000000     DYAW      .0000000000
      VX          146.6677600      VY      -.2755064781E-38  VZ        .0000000000     VPATH   146.6677600
      FX          .3033969355E-42  FY      -.1615154580E-01  FZ      -32.15643776      APATH    .0000000000
**KUTMER CALLS =           0         AT ELAPSED CPU TIME =    4.232 SEC.
    40.00000           .0000000        .1745323          .0000000
    .1620004E-04     -.5273967E-04   -.5784725E-04      6.787241
   -.1659068E-01     -31.66619


**PITCH ANGLE IS GREATER THAN 10 OR LESS THAN -20 DEGREES.
CONVAIR CANT DO THAT'**

 TIME       40.00000
      LAT          45.00000000     LON      -59.98583264     ALPHA    -90.00000000     ALT     256.3632316
      ROLL         .0000000000     PITCH    10.00000007      YAW       .0000000000     PSI     90.00000000
      DROLL        .0000000000     DPITCH    .0000000000     DYAW      .0000000000
      VX          150.4293664      VY      -.2755264781E-38  VZ       26.52475978      VPATH   152.7500022
      FX          6.767240051      FY      -.1655267989E-01  FZ      -31.66618765      APATH   1.180666667
**KUTMER CALLS =           2         AT ELAPSED CPU TIME =   11.840 SEC.
    50.00000           .0000002        .1745329          .0000020
    .1033721E-04     -.5952961E-04   -.5862532E-04      7.733092
   -.1854694E-01     -31.66335


**PITCH ANGLE IS GREATER THAN 10 OR LESS THAN -20 DEGREES.
CONVAIR CANT DO THAT'**

 TIME       50.00000
      LAT          45.00000000     LON      -59.97972314     ALPHA    -90.00000000     ALT     534.8129138
      ROLL         .0000000000     PITCH    10.00000027      YAW       .0000000000     PSI     90.00000000
      DROLL        .0000022200     DPITCH    .0000323300     DYAW      .0000000000
      VX          166.9894759      VY      -.2755064781E-38  VZ       29.44475030      VPATH   169.5655578
      FX          7.733031665      FY      -.1854694445E-01  FZ      -31.66335282      APATH   2.146666667
**KUTMER CALLS =           2         AT ELAPSED CPU TIME =   13.300 SEC.
```

Fig. 3 PROFGEN Printout Format

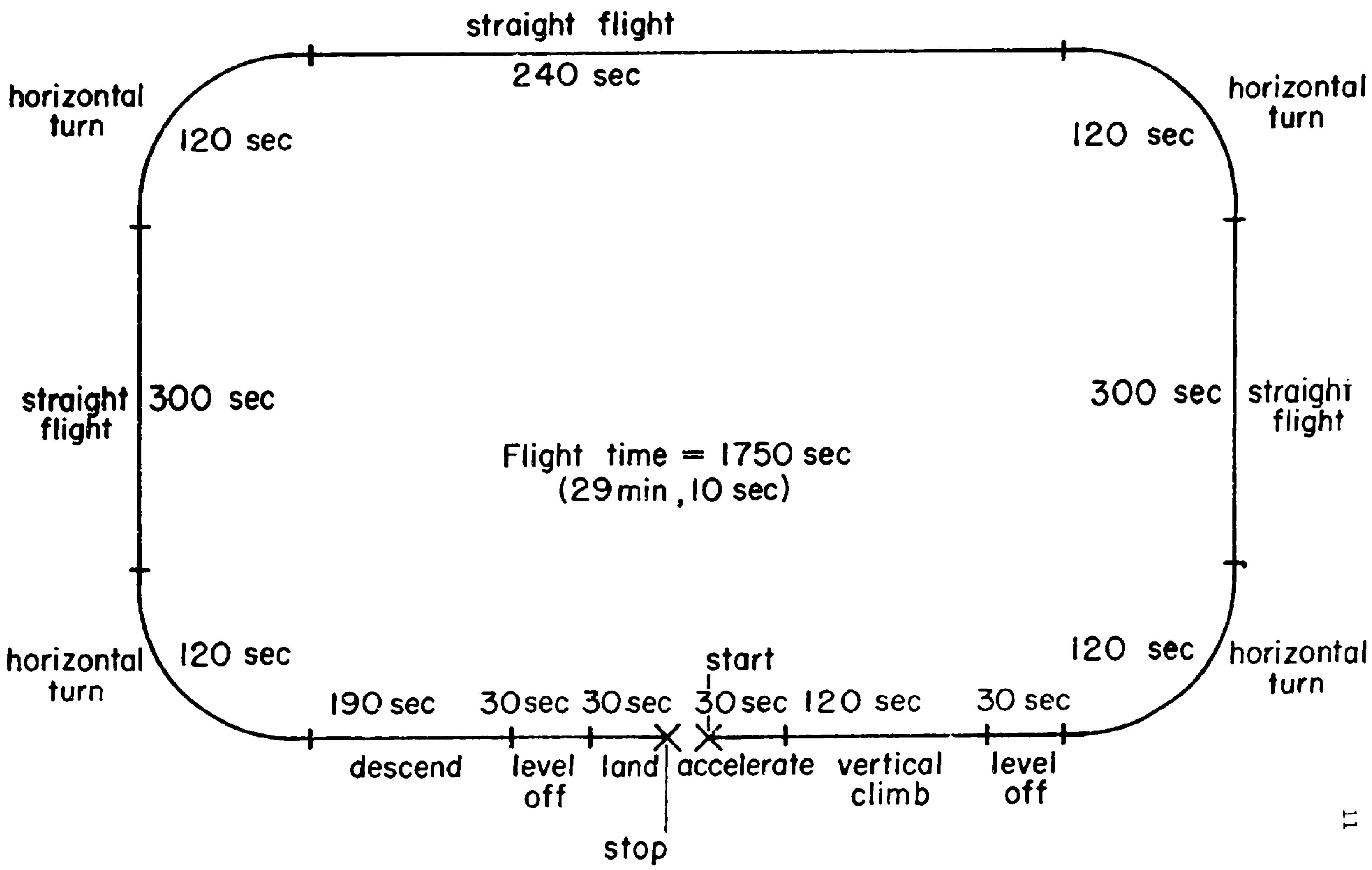
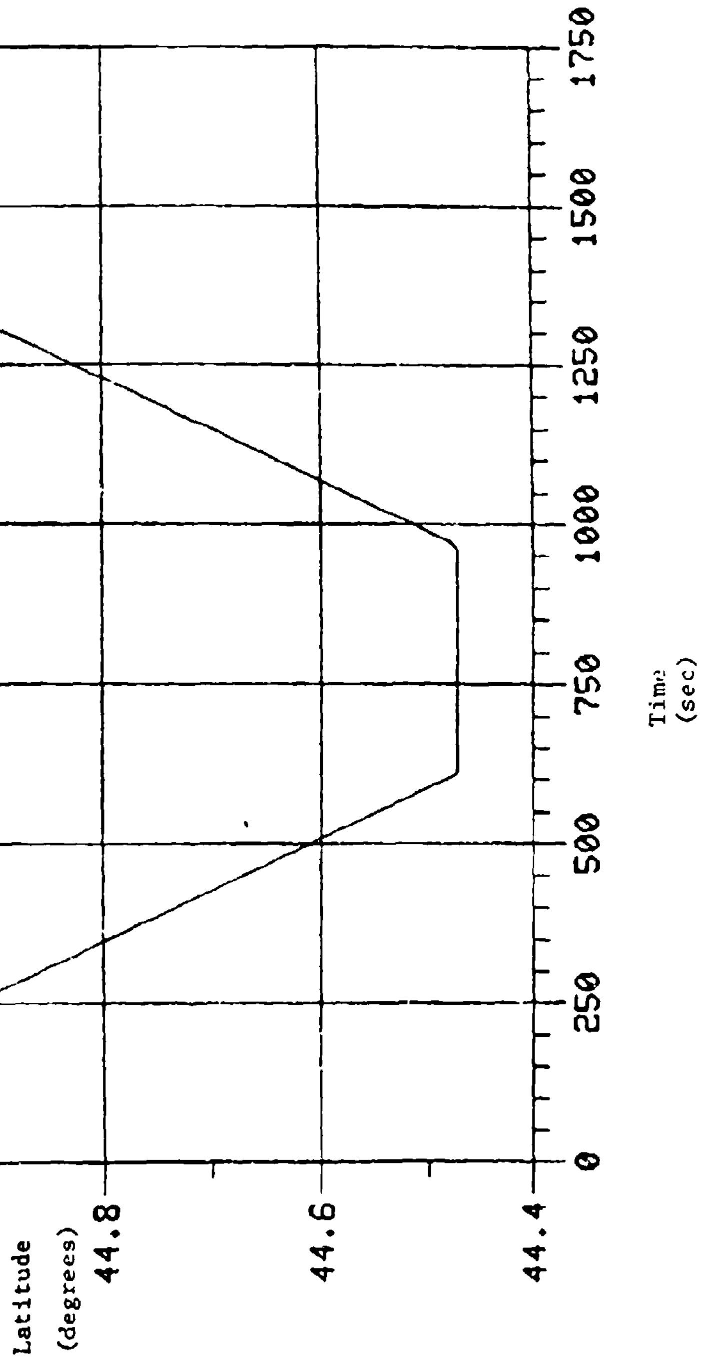
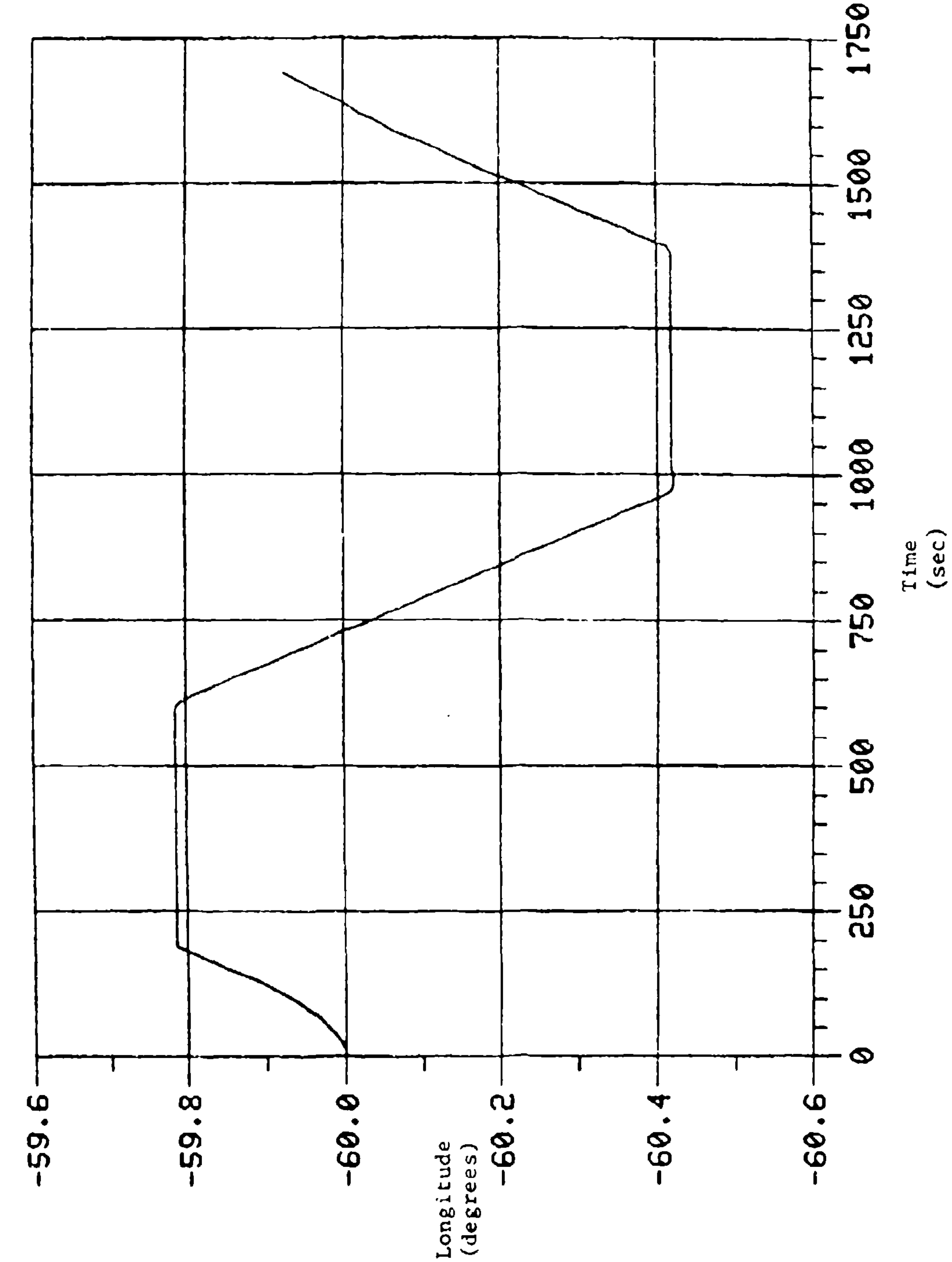


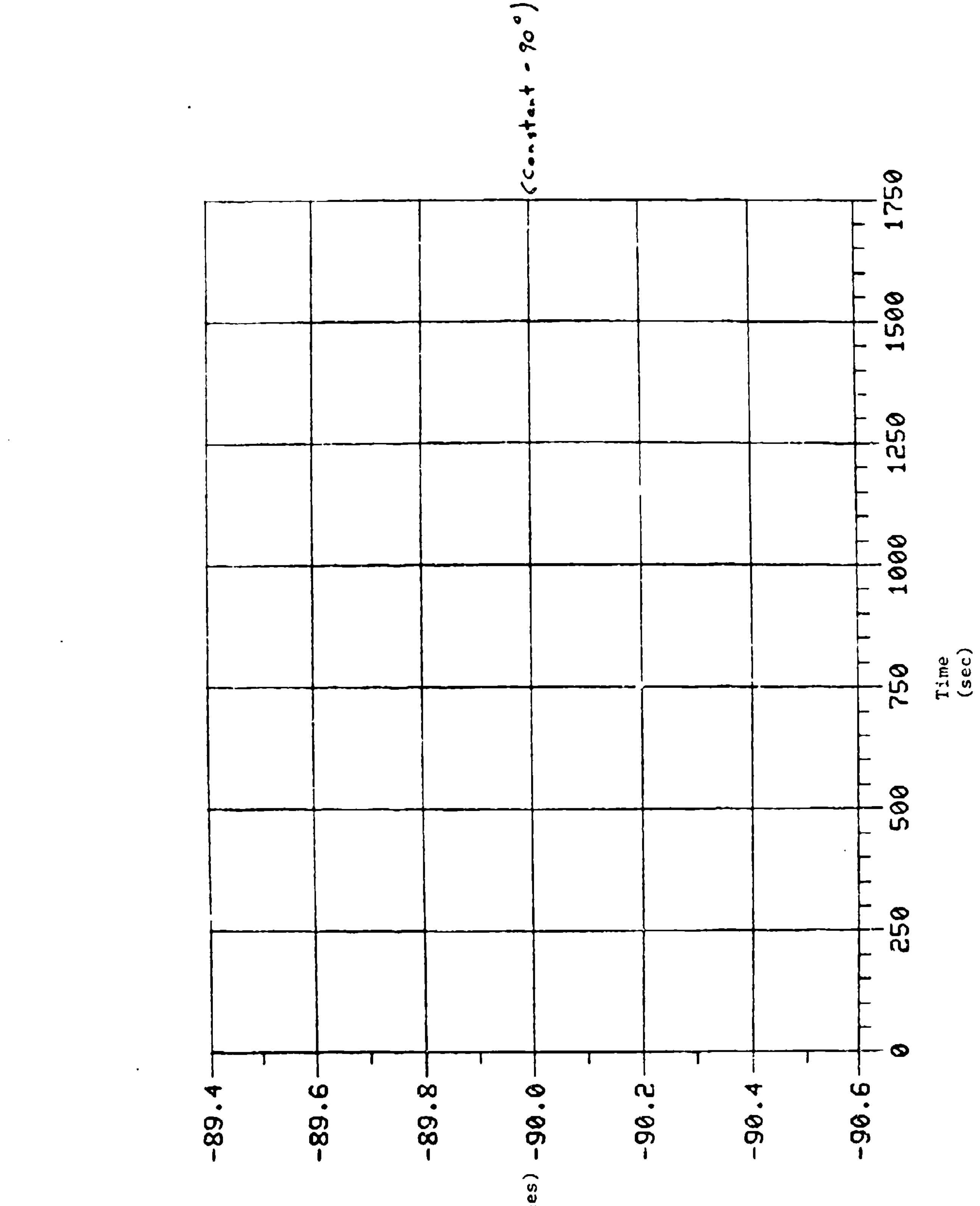
Fig. 4. 'Racetrack' Flight Profile

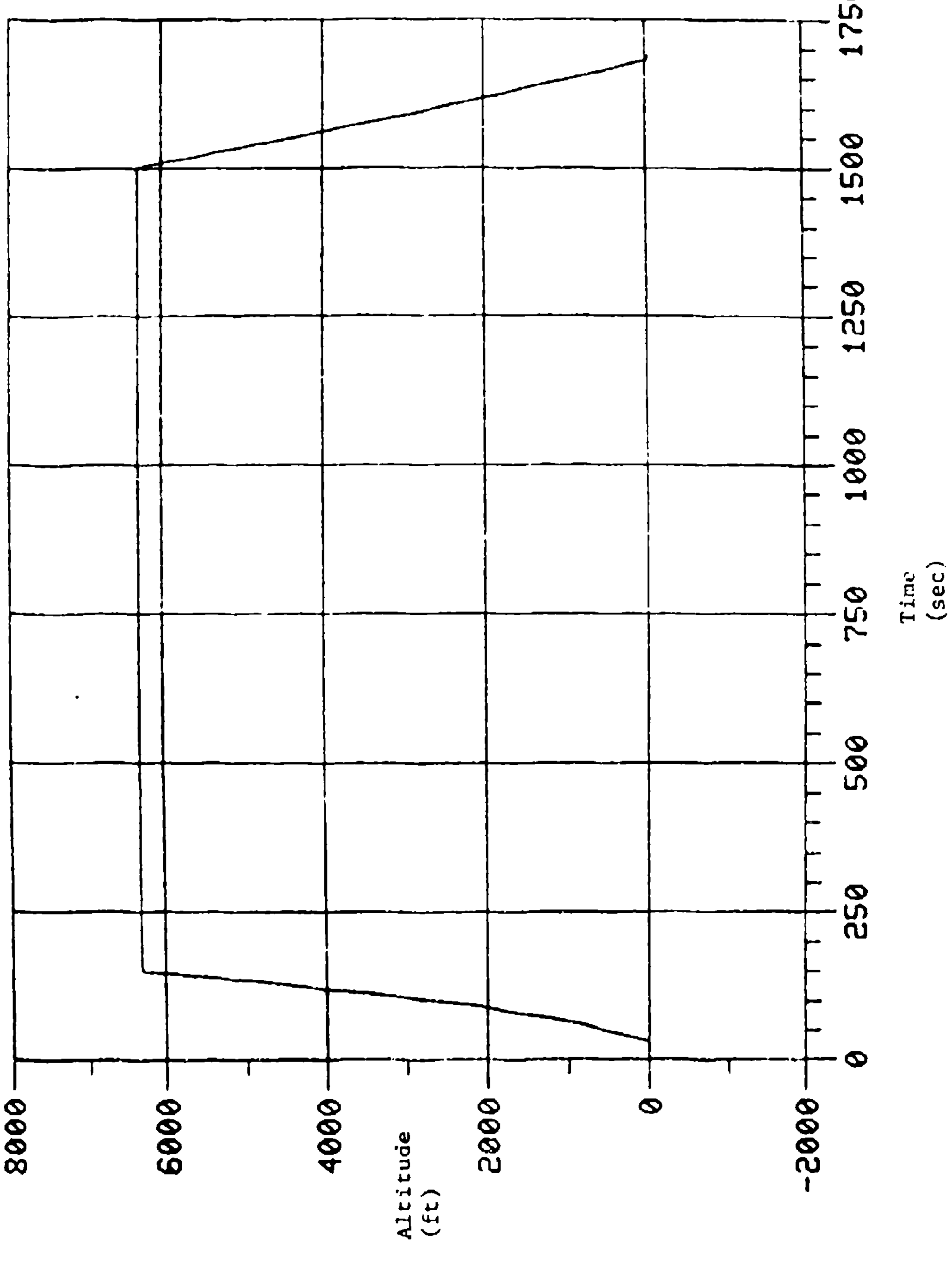
APPENDIX A

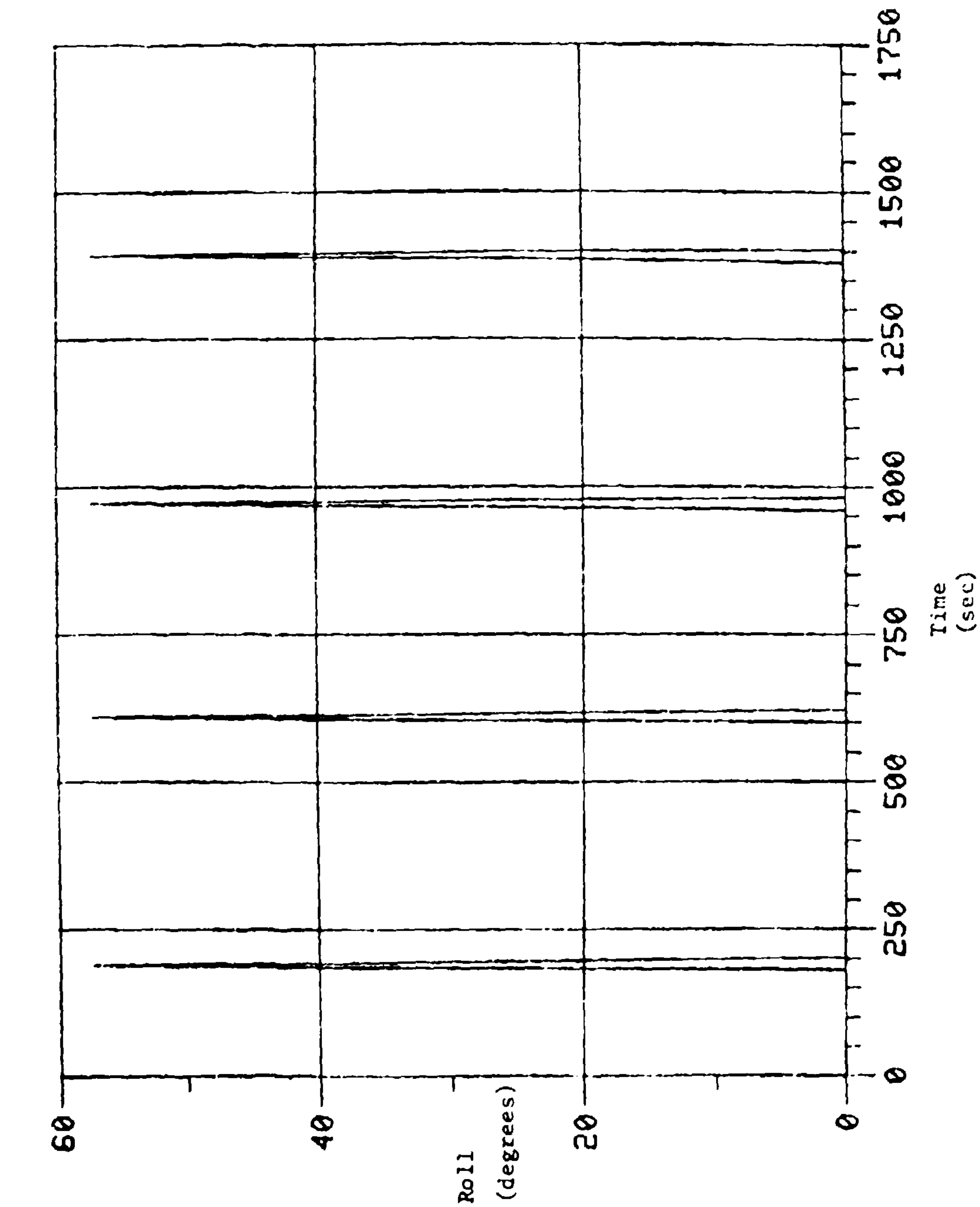
Plots of PROFGEN Parameters


45.2
45.0
44.8
44.6
44.4
Latitude
(degrees)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

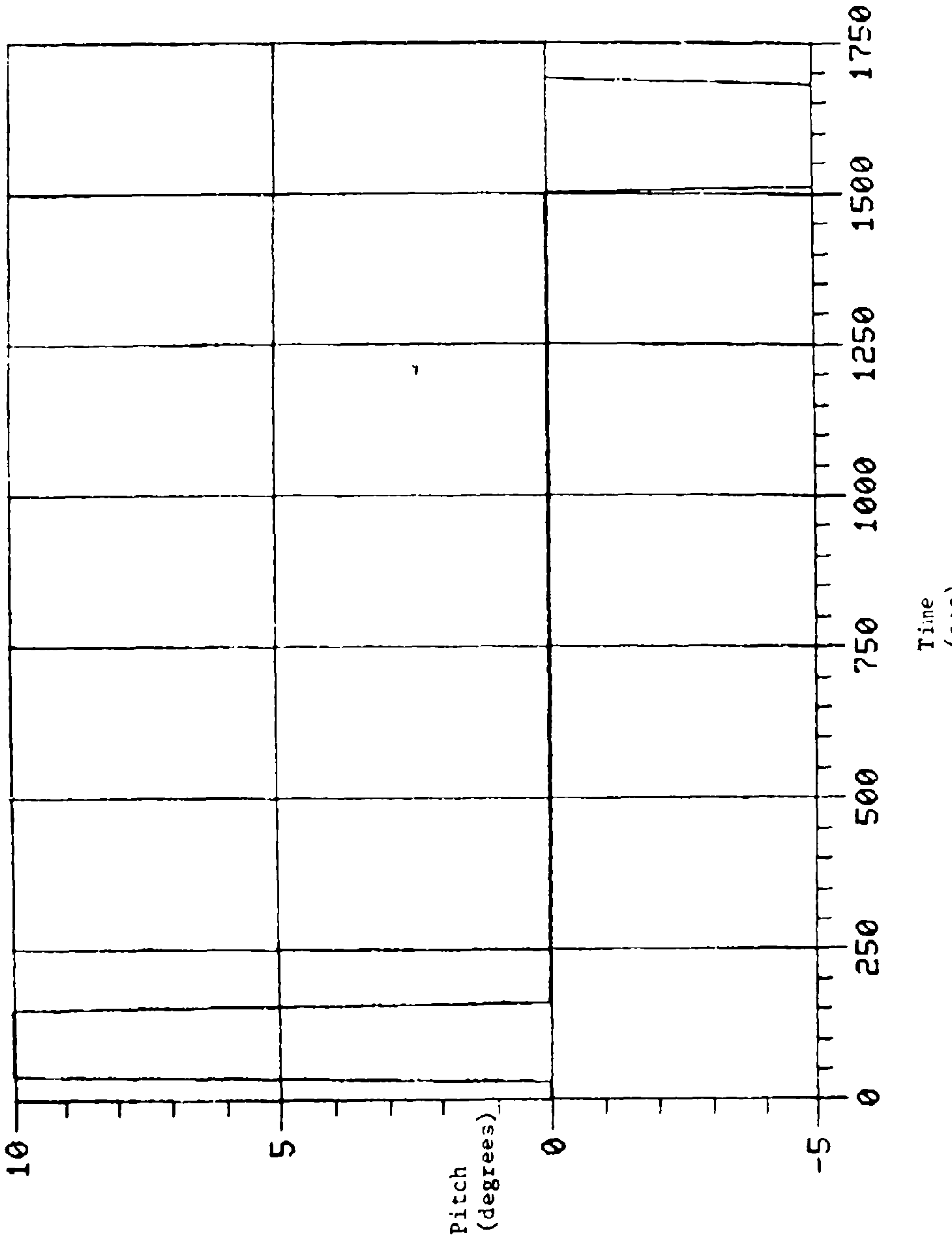

-59.6
-59.8
-60.0
-60.2
-60.4
-60.6
Longitude
(degrees)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

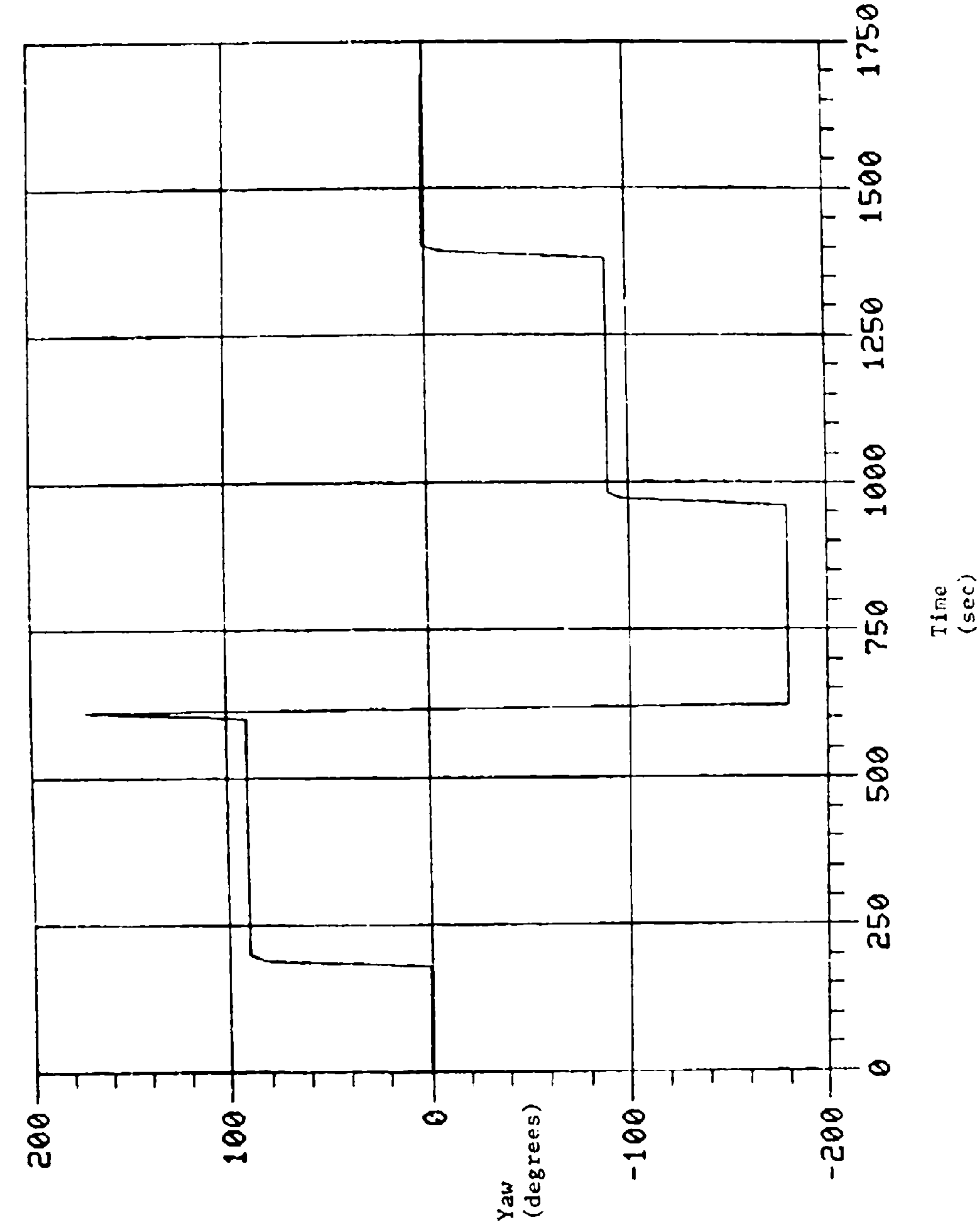

(Constant - 90°)
Alpha (degrees)
-89.4
-89.6
-89.8
-90.0
-90.2
-90.4
-90.6
Time (sec)
0
250
500
750
1000
1250
1500
1750

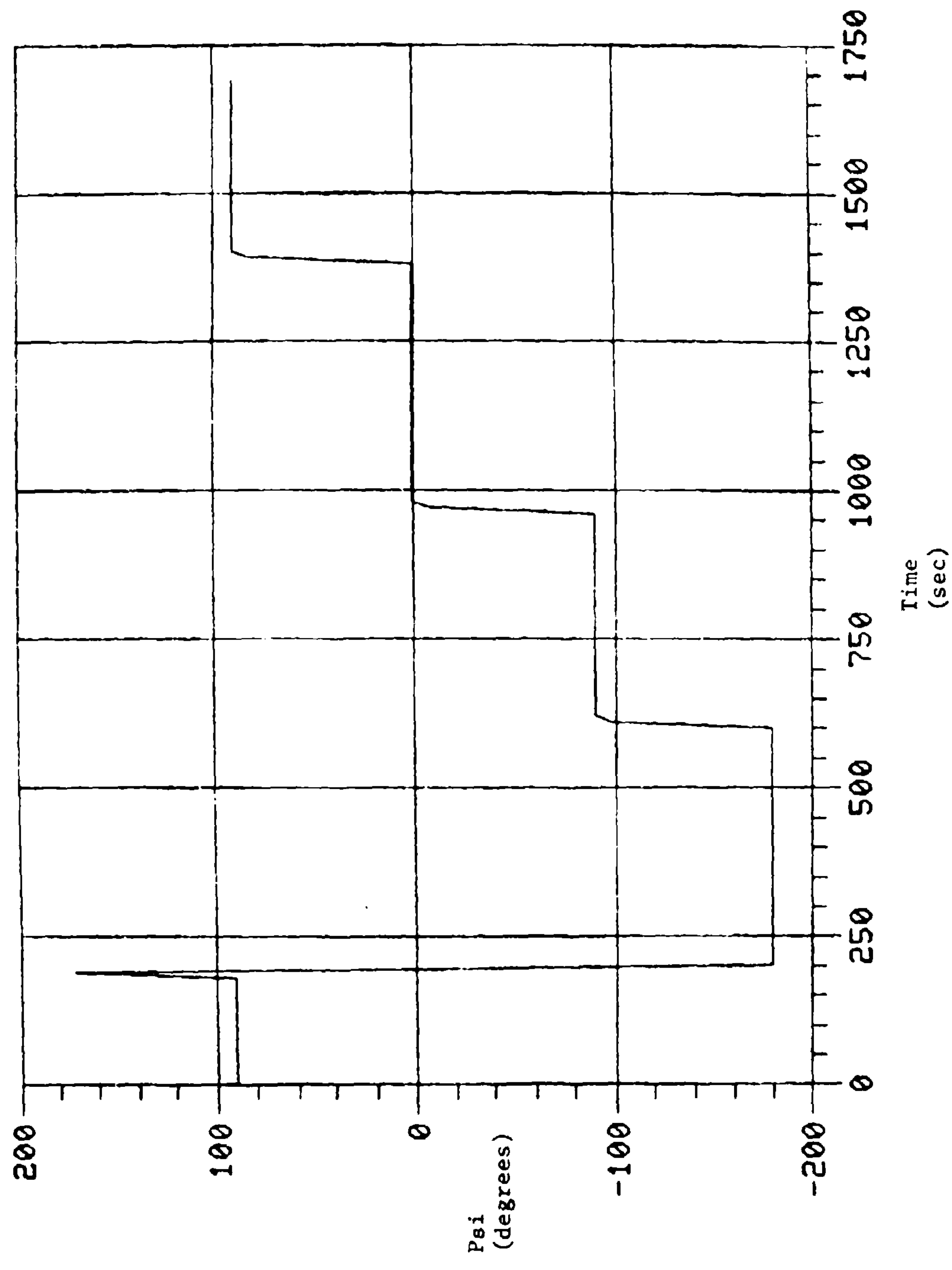

8000
6000
4000
2000
0
-2000
Altitude
(ft)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

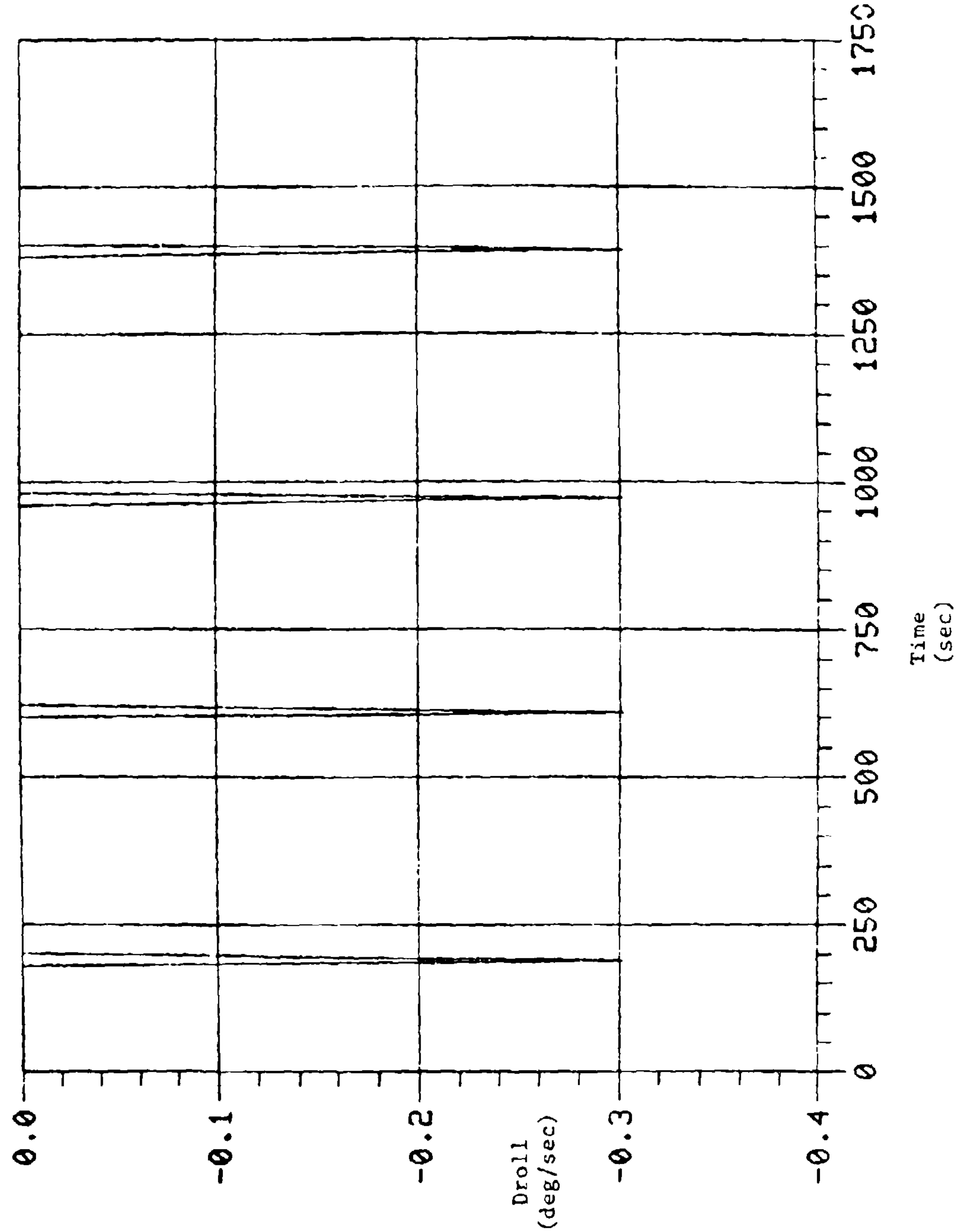


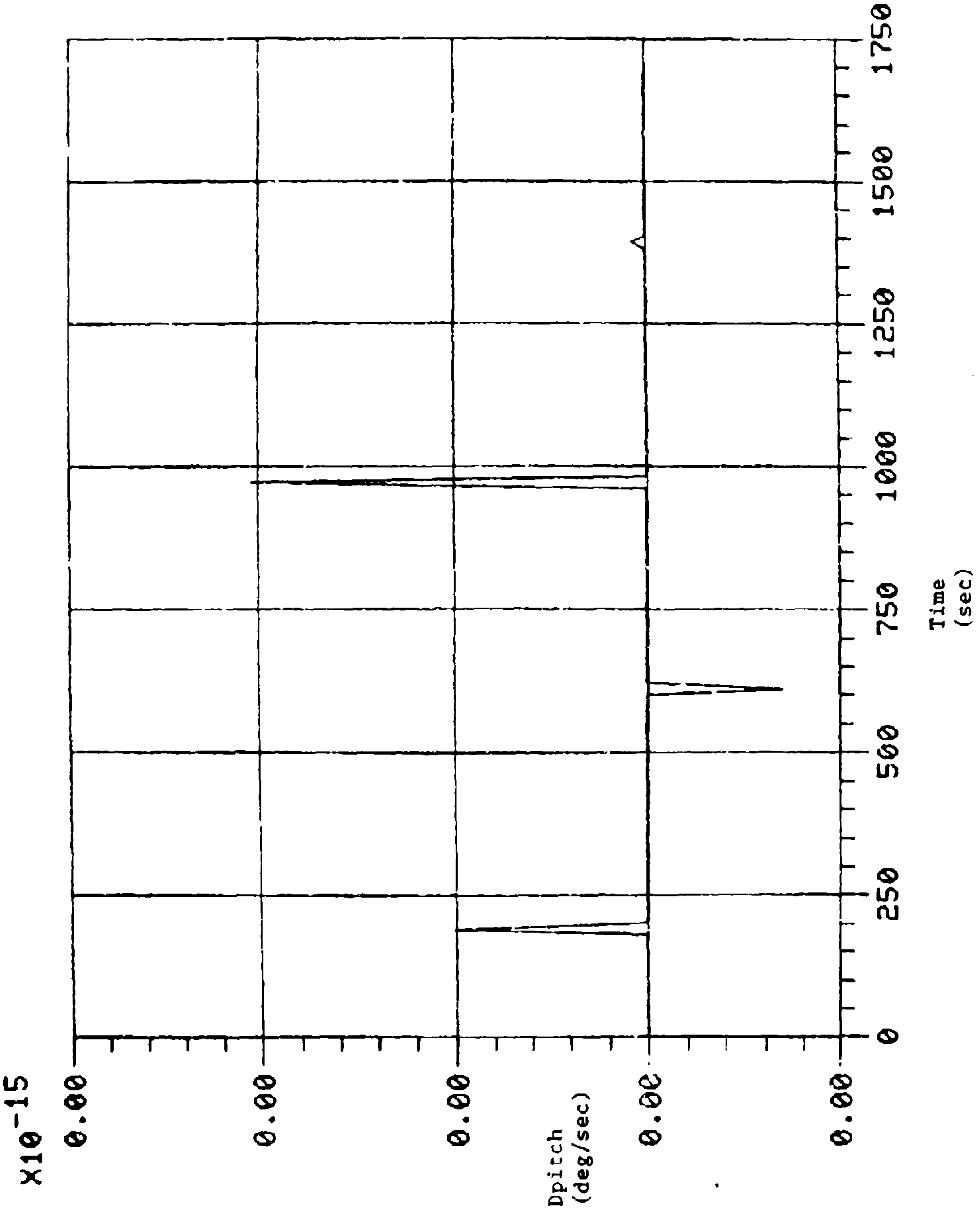
Roll
(degrees)
60
40
20
0
Time
(sec)
0
250
500
750
1000
1250
1500
1750


10
5
0
-5
Pitch (degrees)
0
250
500
750
1000
1250
1500
1750
Time (sec)

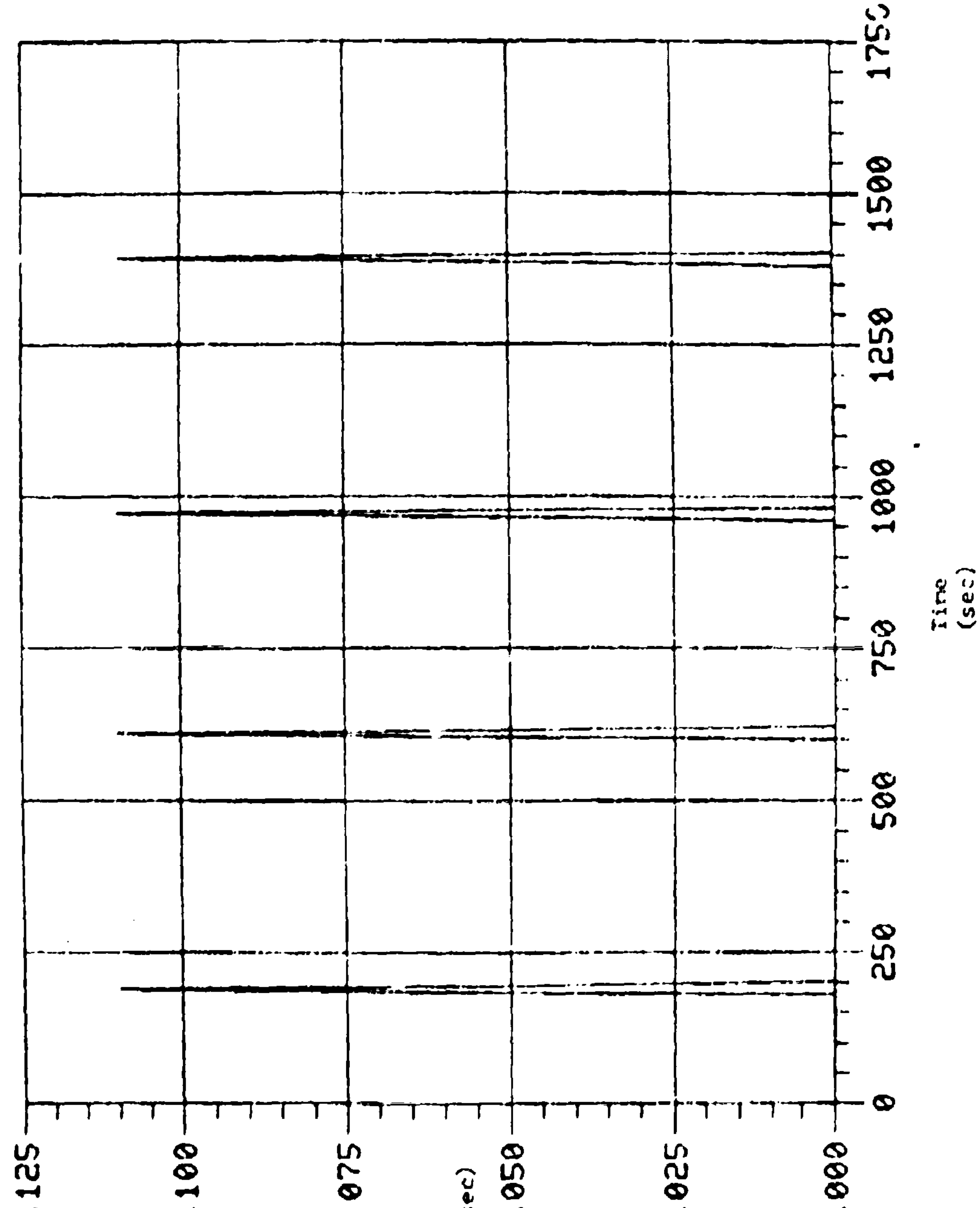

200
100
0
-100
-200
Yaw
(degrees)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

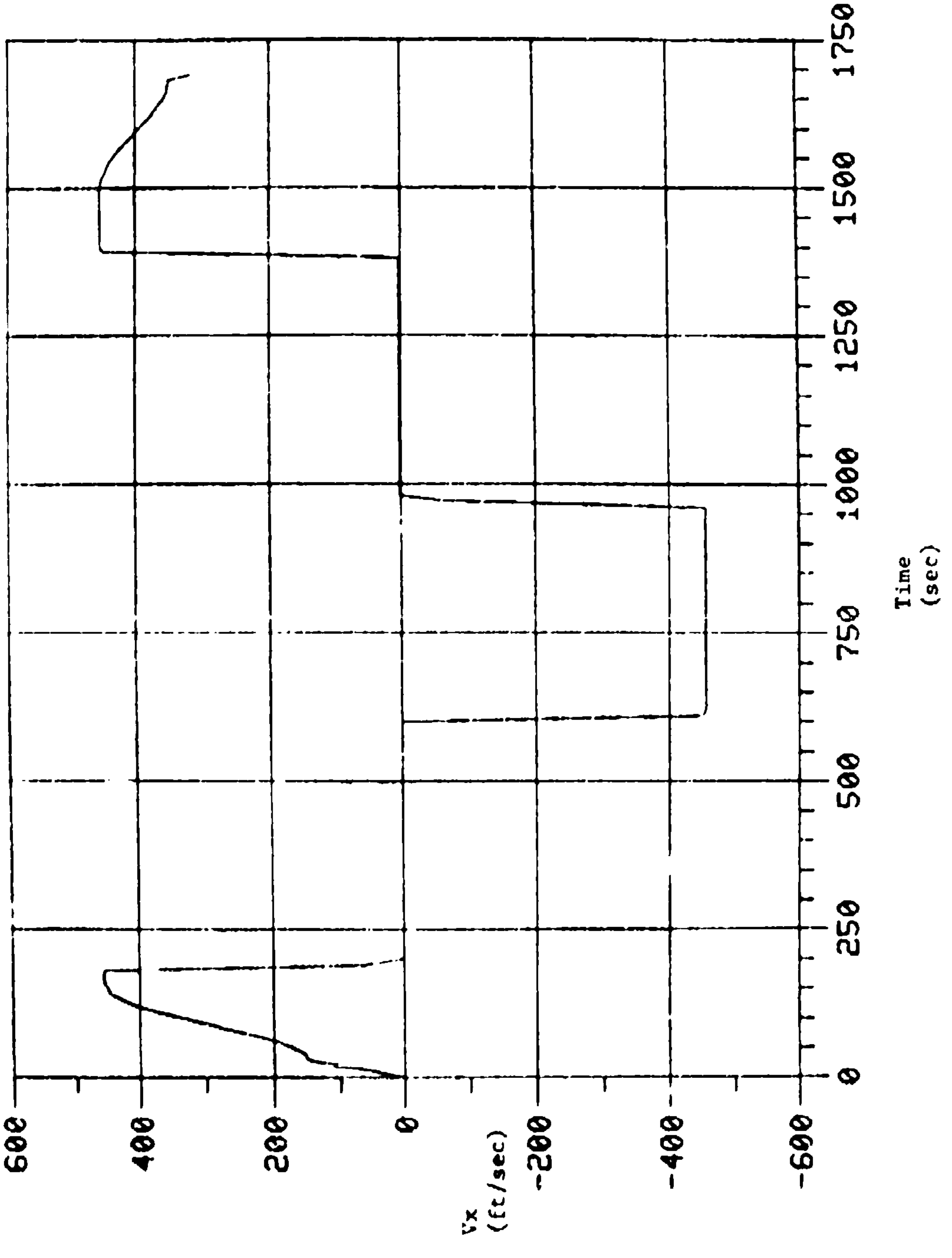

200
100
0
-100
-200
Psi
(degrees)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

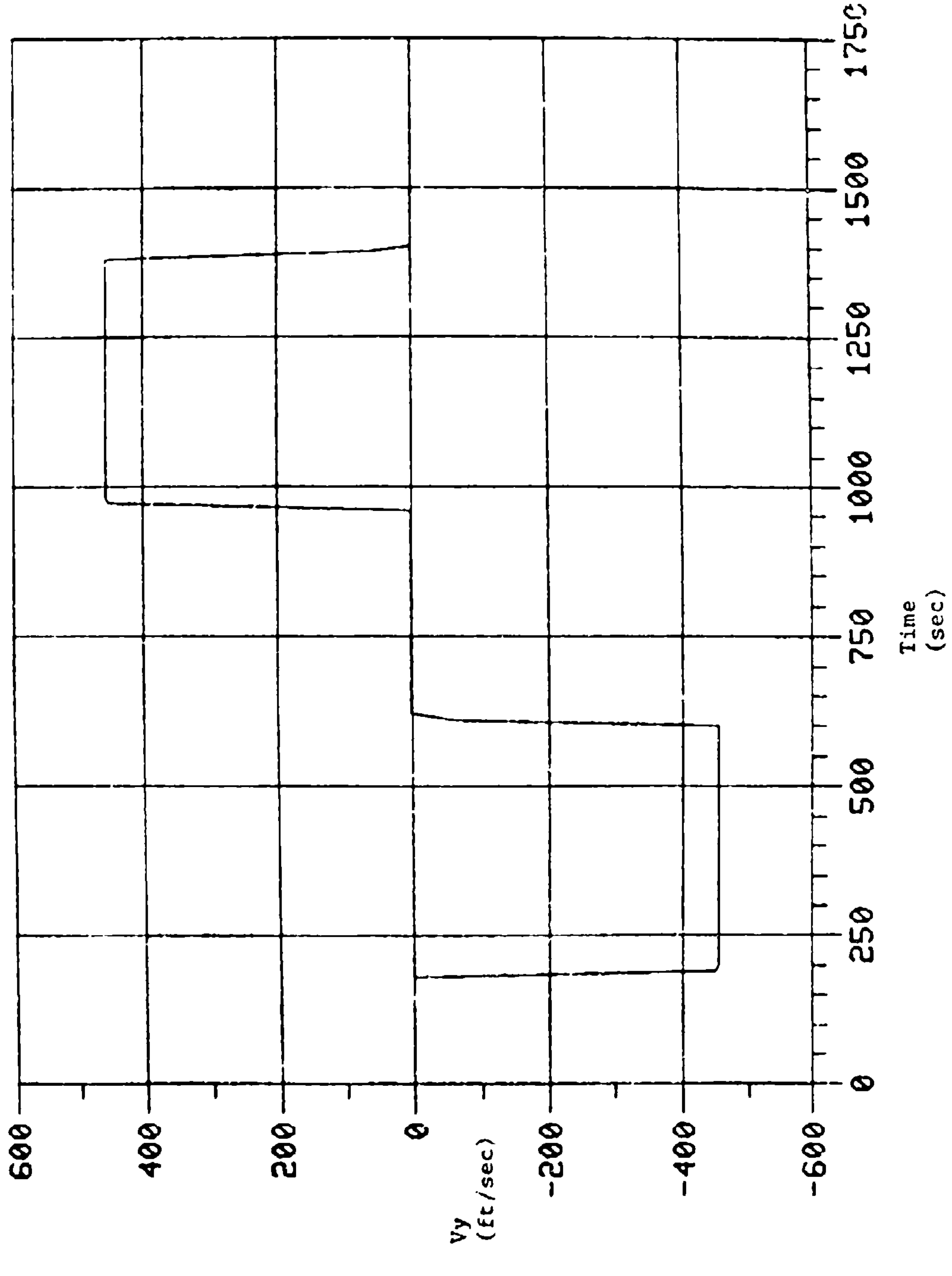

0.0
-0.1
-0.2
-0.3
-0.4
Droll
(deg/sec)
0
250
500
750
1000
1250
1500
1750
Time
(sec)



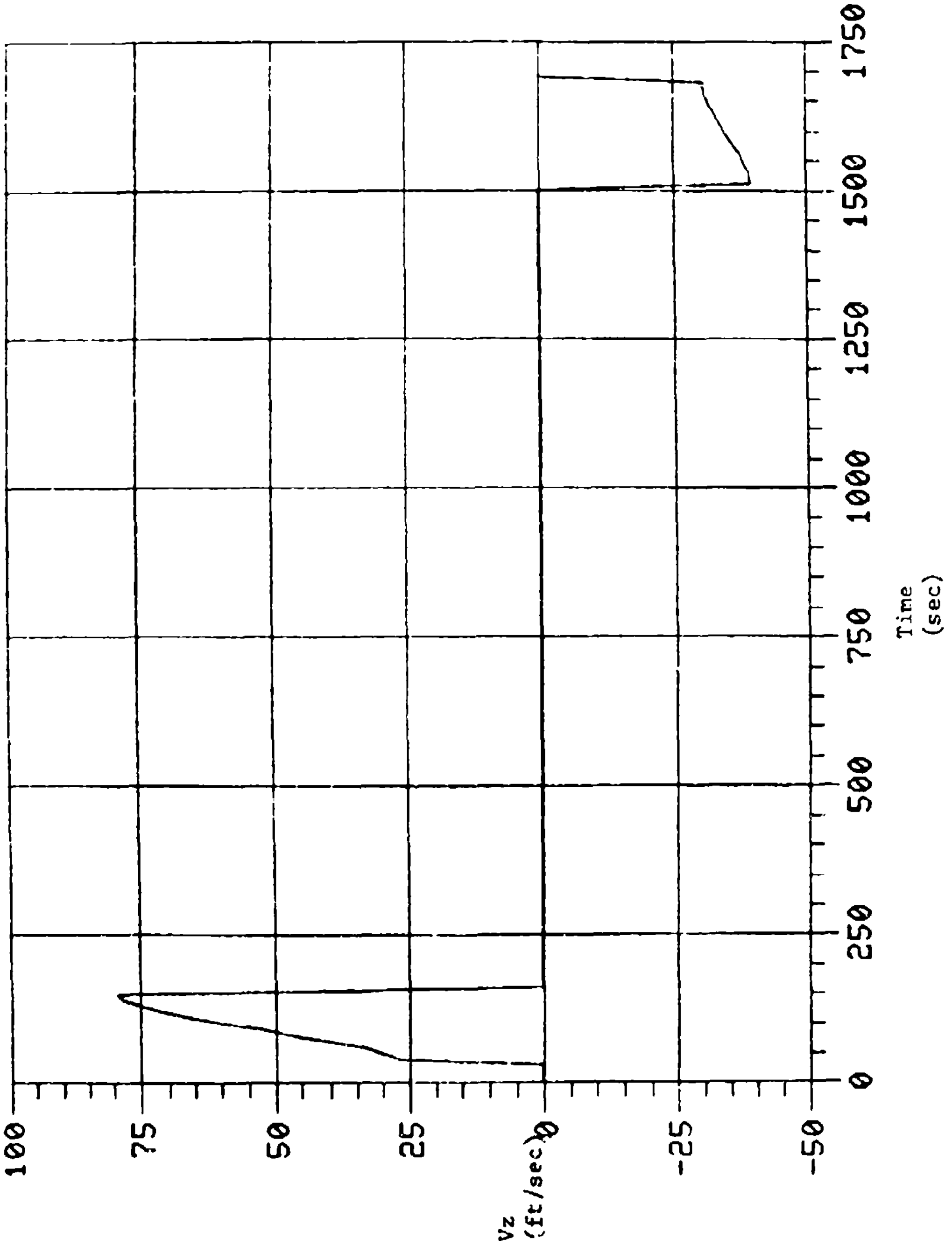
X10^{-15}
0.00
0.00
0.00
0.00
0.00
Dpitch
(deg/sec)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

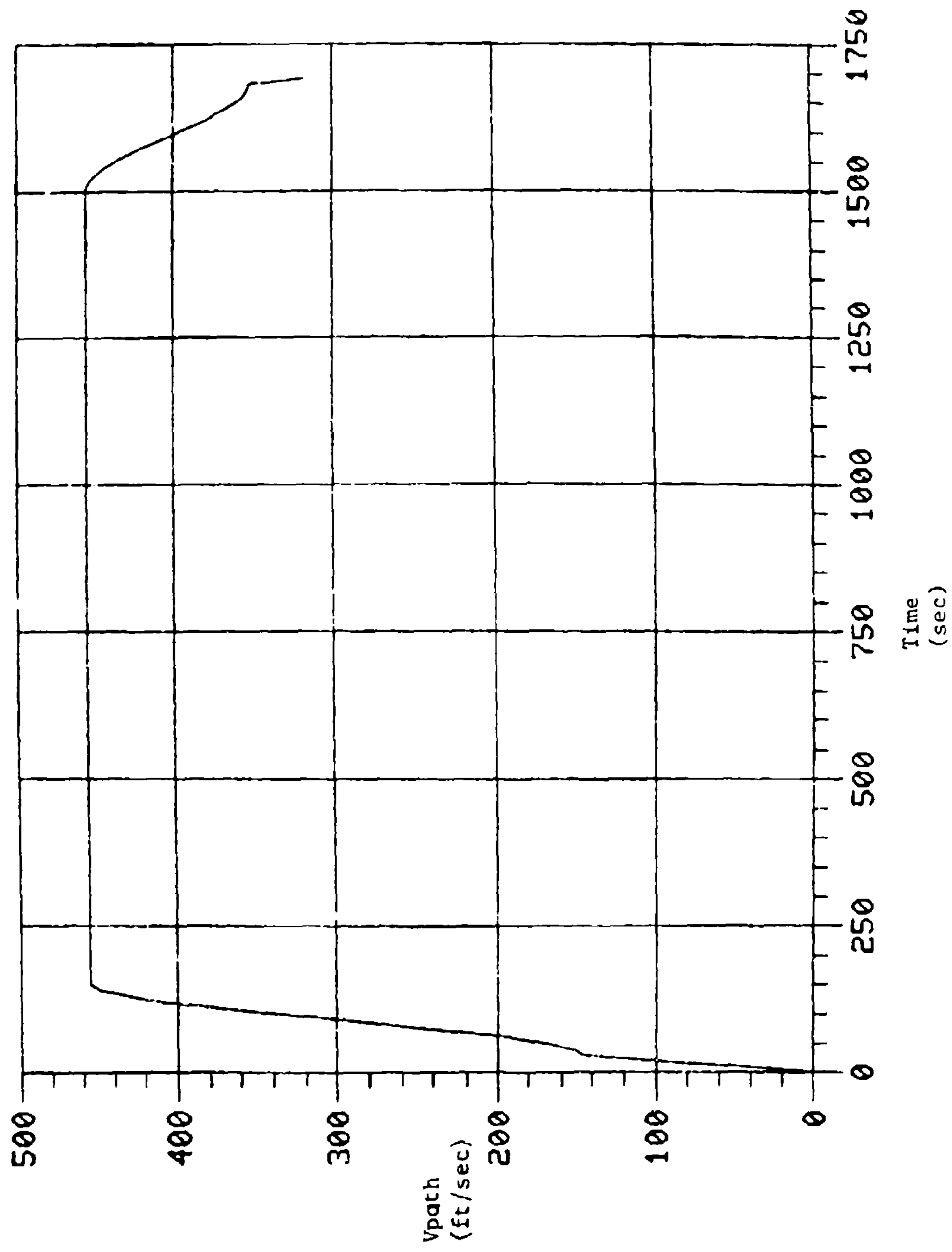

0.125
0.100
0.075
0.050
0.025
0.000
Dyaw
(deg/sec)
0
250
500
750
1000
1250
1500
1750
Time
(sec)


600
400
200
0
-200
-400
-600
Vx
(ft/sec)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

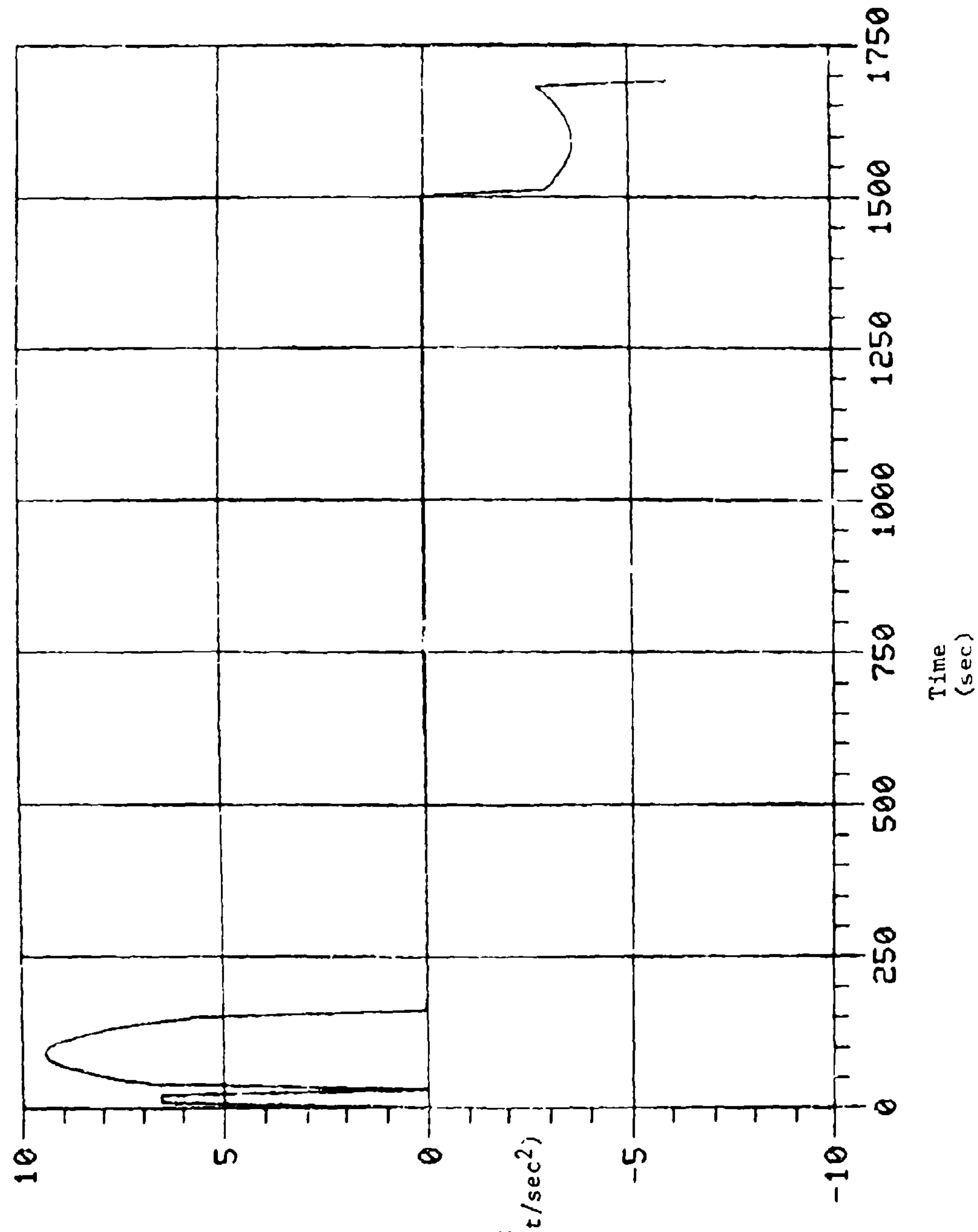


600
400
200
0
-200
-400
-600
Vy
(ft/sec)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

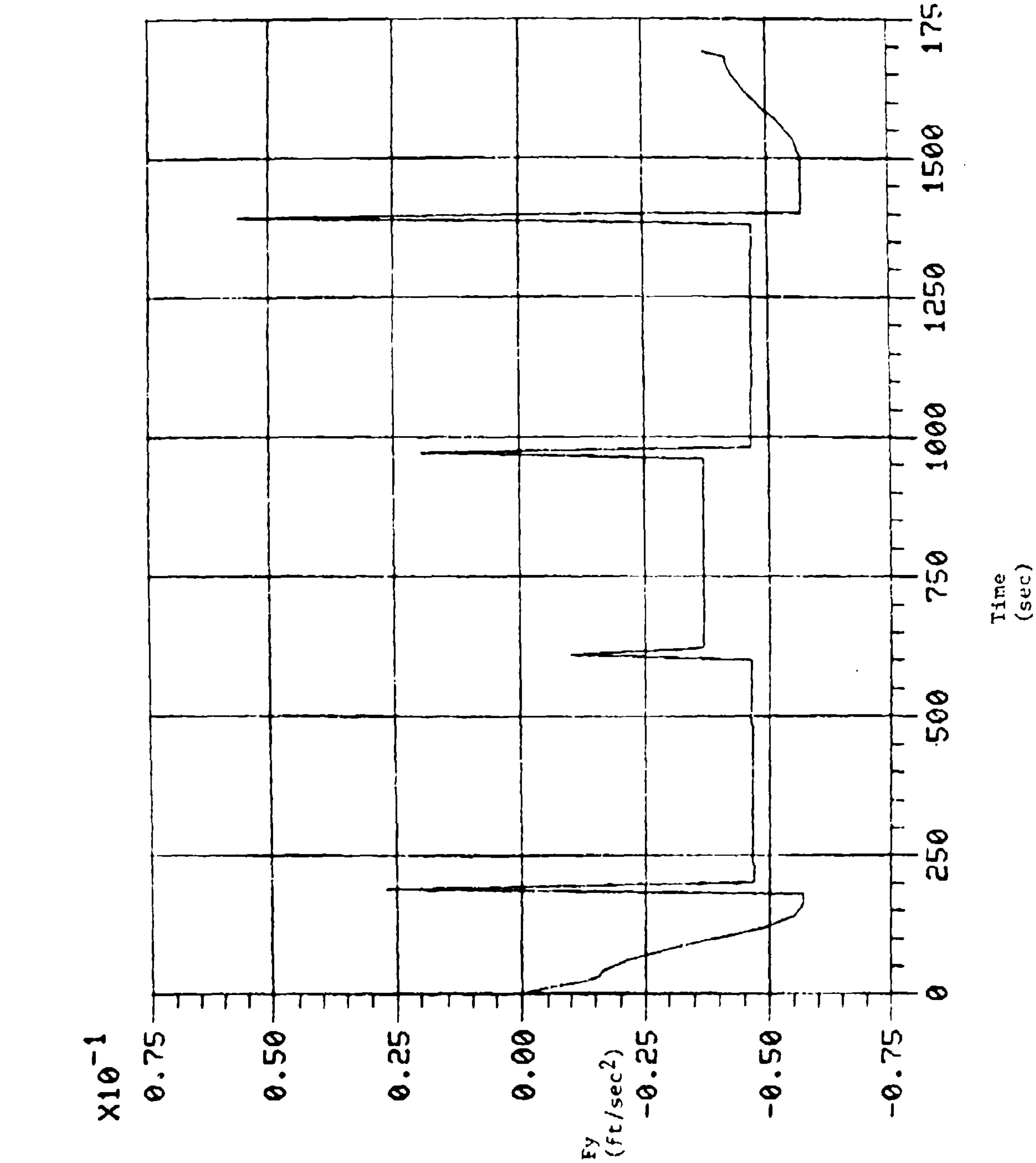

Vz
(ft/sec)
100
75
50
25
0
-25
-50
Time
(sec)
0
250
500
750
1000
1250
1500
1750

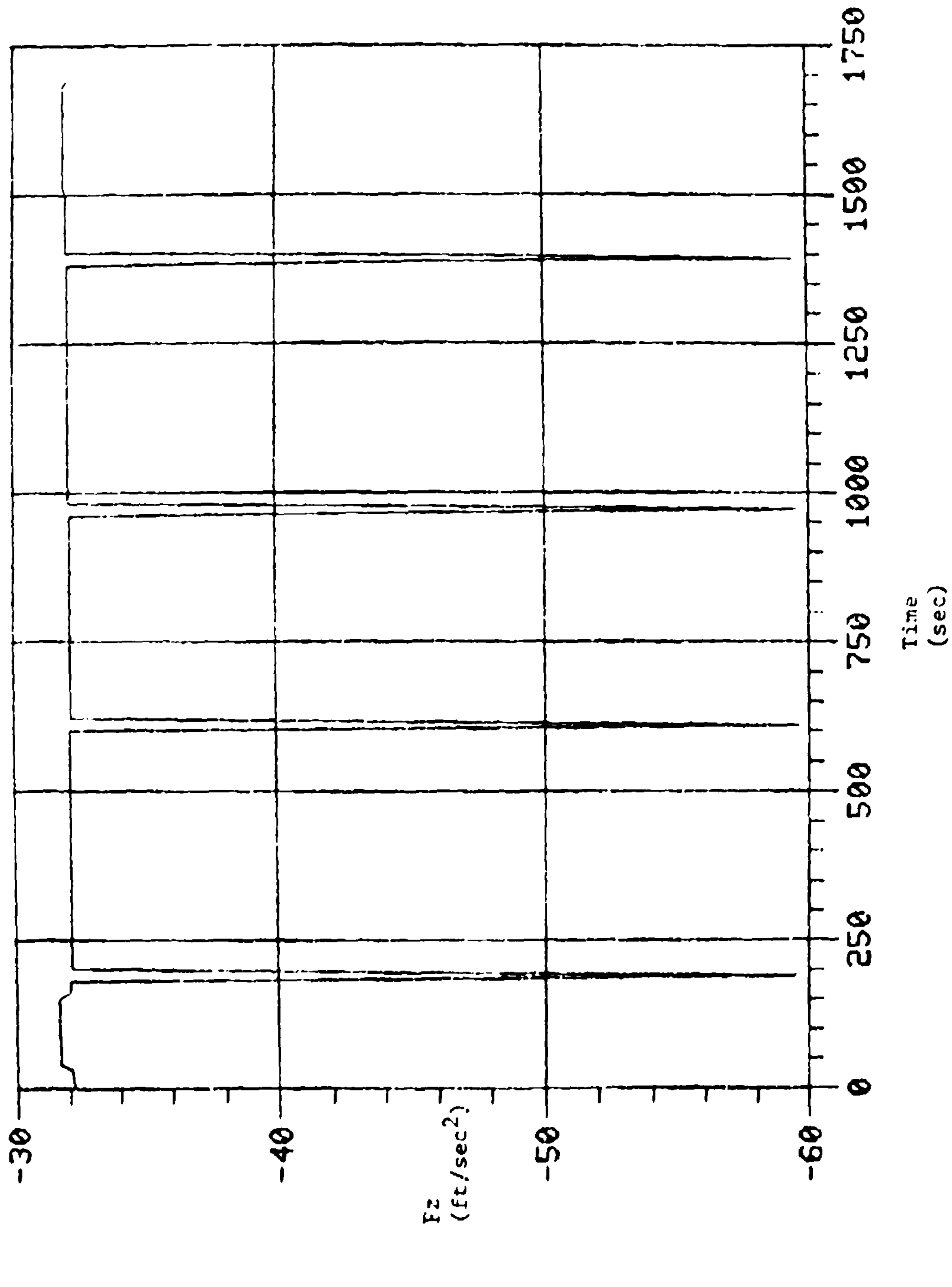


Vpath
(ft/sec)
0
100
200
300
400
500
Time
(sec)
0
250
500
750
1000
1250
1500
1750

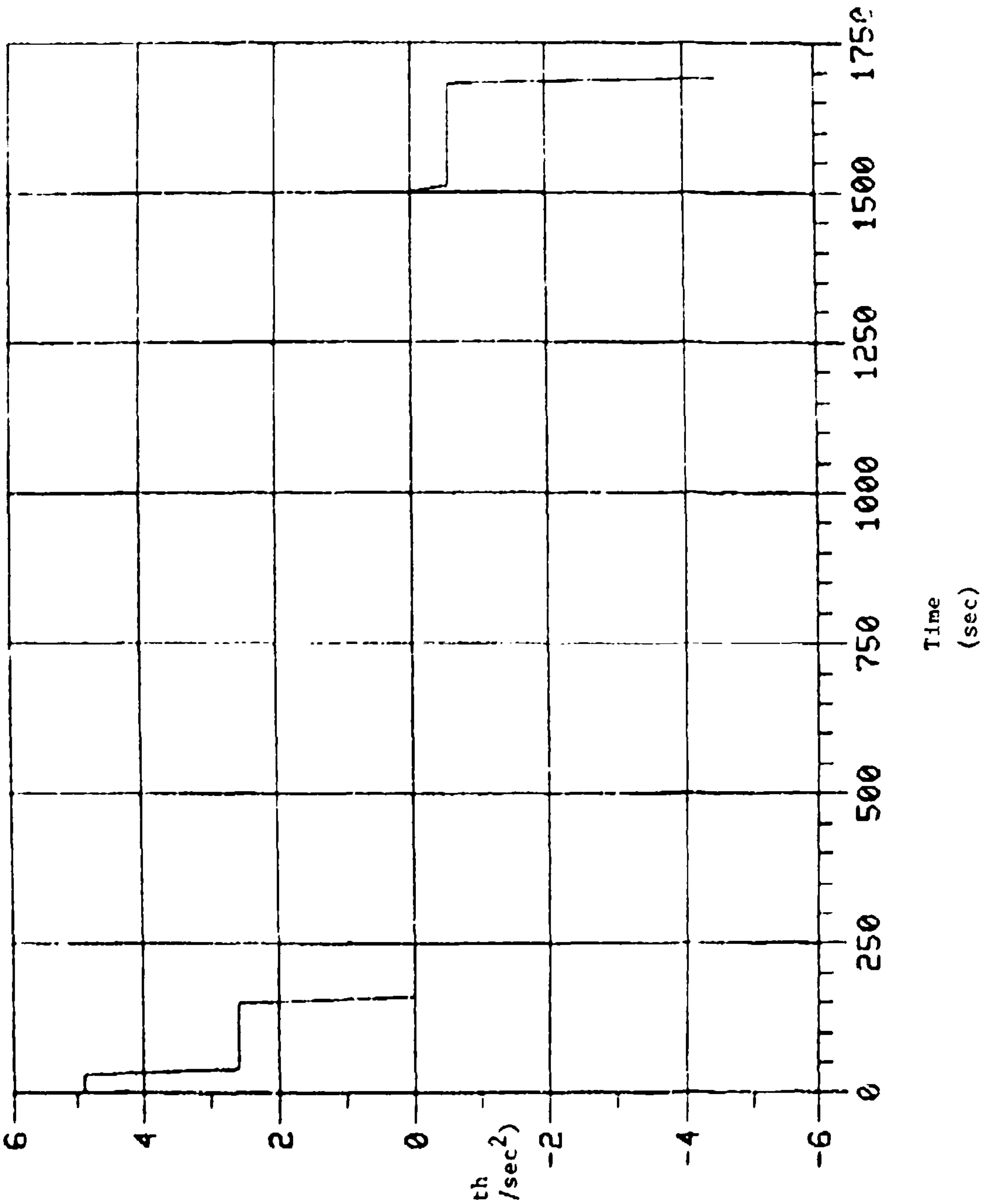


Fx
(ft/sec^2)
10
5
0
-5
-10
Time
(sec)
0
250
500
750
1000
1250
1500
1750


X10^-1
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
Fy
(ft/sec^2)
0
250
500
750
1000
1250
1500
1750
Time
(sec)



-30
-40
-50
-60
Fz
(ft/sec²)
0
250
500
750
1000
1250
1500
1750
Time
(sec)


6
4
2
0
-2
-4
-6
Apath
(ft/sec2)
0
250
500
750
1000
1250
1500
1750
Time
(sec)

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13. ABSTRACT

PROFGEN, an aircraft flight profile generation program obtained from the United States Air Force Avionics Laboratory, has been modified for use in the simulation of a strapdown inertial navigation system being developed at DREO. The program allows the user to specify initial flight parameters to control the dynamics of a "point mass" aircraft in three dimensions. Outputs of PROFGEN are used to drive models of inertial sensors and develop navigation algorithms. An example flight profile employed in the simulation is described.

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KEY WORDS

Aircraft Flight Profile Generation
Flight Simulation

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