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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.2-DN-B0105-03

APU/HYDRAULIC/ACTUATOR SUBSYSTEM COMPUTER SIMULATION

ENGINEERING SYSTEMS ANALYSIS

24 MARCH 1975

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PREPARED BY: David E. Wade
Dave Wade
Subtask Manager
488-5660, X227

APPROVED BY: R. K. Hamilton
R. K. Hamilton
Task Manager
488-5660, X227

APPROVED BY: J. C. Weitekamp
J. C. Weitekamp
Technical Manager
488-5660, X232

APPROVED BY: Robert Stephens
R. R. Stephens
Project Manager
Engineering Systems Analysis
488-5660, X204

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1.0 SUMMARY

This design note documents the major developments which have taken place to date in the analysis of the power and energy demands on the APU/Hydraulic/Actuator Subsystem during the entry-to-touchdown (not including rollout) flight regime. These developments are in the form of two subroutines which were written for use with the Space Shuttle Functional Simulator (SSFS). The first subroutine calculates the power and energy demand on each of the three hydraulic systems due to control surface (inboard/outboard elevons, rudder, speedbrake, and body flap) activity. The second subroutine incorporates the R. I. priority rate limiting logic which limits control surface deflection rates as a function of the number of failed hydraulic systems.

Typical results of this analysis are included, and listings of the subroutines are presented in Appendicies A and B.

This development work was conducted under Contract Number NAS 9-13970 Task Order 60205.

2.0 INTRODUCTION

The purpose of the APU/Hydraulic/Actuator Subsystem task is to establish fluid horsepower, peak horsepower and hydraulic energy duty cycles for each control surface and for each hydraulic system, and to evaluate the effect and impact of failed hydraulic systems on current actuator requirements and vehicle dynamics. The analysis employs the SSFS in order to generate 6 DOF trajectories, with control surface deflection rates being the parameters of greatest importance. Fluid horsepower demand is calculated for each surface as a direct function of the surface rate. Horsepower demand on each hydraulic system is then determined by summing the fluid horsepower demand from the appropriate control surfaces. The horsepower time history for each hydraulic system is integrated over the entire trajectory to determine the energy requirement for each hydraulic system due to control surface activity.

Hydraulic system failure analysis is accomplished by activating the priority rate limiting logic subroutine and by rerouting the control surface fluid horsepower demand to the appropriate hydraulic system.

3.0 DISCUSSION

The main components of the APU/Hydraulic/Actuator subsystem can be seen in Figure 1. Each hydraulic system consists basically of a fuel tank, an APU, and an hydraulic pump. Each of the three identical hydraulic systems is plumbed to each actuator or hydraulic motor such that any one system can drive all control surfaces.

APU / HYDRAULIC / ACTUATOR SUBSYSTEM

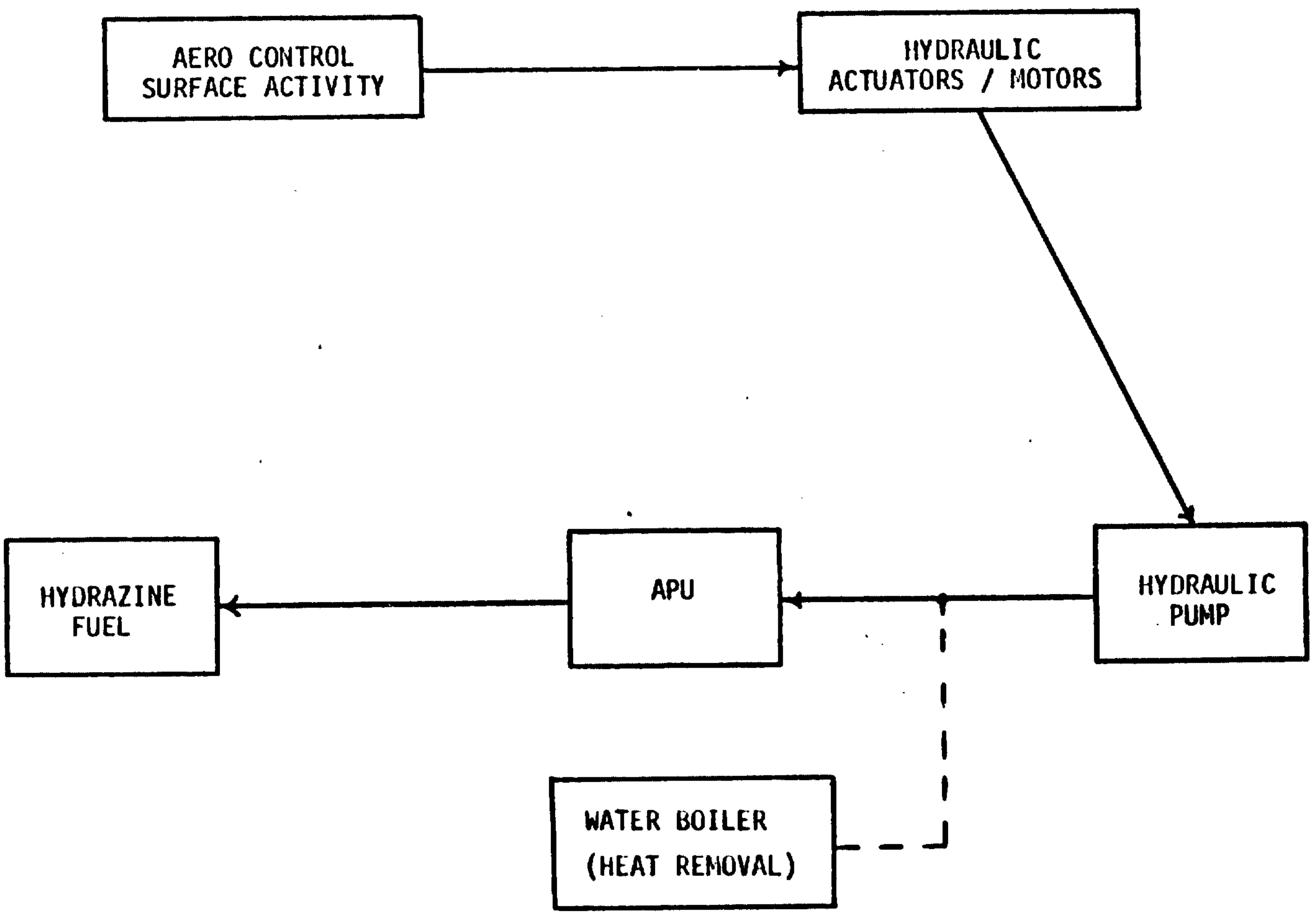

FIGURE 1

The horsepower demand on a hydraulic system (calculated at the pump) due to control surface activity is equal to the volume flow rate times the system pressure differential. The system pressure differential used here is 3000 psi. The volume flow rate is equal to the control surface deflection rate times the particular flow gradient of the actuator or hydraulic motor which corresponds to that control surface. Fluid horsepower demand is therefore calculated as follows:

$$HP_f = Q \, \Delta P \, C_{HP}$$

where $Q = K\dot{\delta}$

K = flow gradient (GPM / deg / sec)

$\dot{\delta}$ = surface deflection rate (deg / sec)

ΔP = 3000 psi

C_{HP} = .00058333

The body flap is an exception to this however, due to its unique control circuit configuration. The hydraulic flow rate is not proportional to the body flap deflection rate and an average flow rate is used (Reference B).

Horsepower demand on each hydraulic system is then determined by summing the individual demands from the appropriate control surfaces according to the loss management matrix (see Figure 2) from Reference B. As an example, the horsepower demand on hydraulic system three at any one time (with no failures) would be equal to the sum of the fluid horsepower demand of the left outboard elevon and right inboard elevon, plus one-third of the demand from the rudder, speedbrake, and body flap.

LOSS MANAGEMENT MATRIX

FAILURES	ELEVONS				RUDDER		SPEED BRAKE		BODY FLAP
	LEFT		RIGHT		LOGIC	POWER	LOGIC	POWER	
	OUTBOARD	INBOARD	INBOARD	OUTBOARD					
NONE	3	2	3	1	3	123	3	123	123
NO. 1	3	2	3	2	3	23	3	23	23
NO. 2	3	1	3	1	3	13	3	13	13
NO. 3	2	2	1	1	2	12	2	12	12
1 & 2	3	3	3	3	3	3	3	3	3
1 & 3	2	2	2	2	2	2	2	2	2
2 & 3	1	1	1	1	1	1	1	1	1

FIGURE 2

The energy requirement for each hydraulic system is calculated by integrating that system's horsepower demand over the entire trajectory. The trapezoidal rule is used and the integration time step is approximately one-tenth of a second.

In the analysis of hydraulic system failure effects, the priority rate limiting subroutine is included in the simulation. This routine will limit the control surface deflection rates based on the number of failed hydraulic systems and the available flow from the remaining system(s). The source for this logic is Reference A. The rate limits for each case are shown in Figure 3.

4.0 RESULTS

Typical preliminary power and energy results due to control surface activity are shown in Figure 4. The actuator flow gradients used were obtained from Reference B.

The SSFS models used in generating these results include ACS 15, RCS 14 and AERO 23 (June '74 aerodynamics). The Entry Guidance is the December '74 ADC Guidance with the baseline 40/30° α-profile trajectory, and entry control is the August 12, 1974 version of the RI System X Entry DAP. TAEM guidance is from the Nov. '74 RI FSSR, and control is from the Jan '75 RI FSSR. Autoland guidance and control is from the Nov '74 RI FSSR. The WIND 9 model (Reference E) was used to stimulate steady state winds and gusts/turbulence, and the ATM 6 model was used to simulate the 1962 Standard Atmosphere.

Priority Rate Limiting Logic

Control Surface Rate Limits (DEG / SEC)

	ELEVONS	RUDDER (FRL)	BODY FLAP	SPEED BRAKE * (FRL)
NO FAILURES	20.0	10.0	-3.0 +1.0	+5.0 -9.0
1 FAILURE	20.0	10.0	-3.0 +1.0	$(Q_2 - K_{QE2}\lvert\dot{\delta}_{EL}+\dot{\delta}_{ER}\rvert - K_{QR2}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\ \cos\ (35°)$ $0 \le \dot{\delta}_{SB} \le 5.0$ $-(Q_2 - K_{QE2}\lvert\dot{\delta}_{EL}+\dot{\delta}_{ER}\rvert - K_{QR2}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\ \cos\ (35°)$ $-9 \le \dot{\delta}_{SB} \le 0$
2 FAILURES	13.0	$19.65-1.408\lvert\delta_{ELEVATOR}\rvert$ $\dot{\delta}_{RUD} \le 4.45$	-1.5 +0.5	$(Q_1 - K_{QE1}\lvert\dot{\delta}_{EL}+\dot{\delta}_{ER}\rvert - K_{QR2}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\ \cos\ (35°)$ $0 \le \dot{\delta}_{SB} \le 2.50$ $-(Q_2 - K_{QE1}\lvert\dot{\delta}_{EL}+\dot{\delta}_{ER}\rvert - K_{QR2}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\ \cos\ (35°)$ $-4.45 \le \dot{\delta}_{SB} \le 0$

* SEE SPEED BRAKE "SOFT STOP" LOGIC ON FOLLOWING PAGE

FIGURE 3a

SPEED BRAKE "SOFT STOP" LOGIC (FOR $\delta_{SB} \leq 6°$, AND $\dot{\delta}_{SB} \leq 0$)

	SPEED BRAKE RATE LIMIT (FRL; DEG / SEC)
NO FAILURES	-1.0
1 FAILURE	$-(Q_2 - K_{QE_2}\lvert\dot{\delta}_{E_L} + \dot{\delta}_{E_R}\rvert - K_{QR_2}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\cos(35°)$ $-1.0 \leq \dot{\delta}_{SB} \leq 0$
2 FAILURE	$-(Q_1 - K_{QE_1}\lvert\dot{\delta}_{E_L} + \dot{\delta}_{E_R}\rvert - K_{QR_1}\lvert\dot{\delta}_{RUD}\rvert - DBFL)\cos(35°)$ $-1.0 \leq \dot{\delta}_{SB} \leq 0$

DEFINITIONS

Q_2	$\frac{\text{MAX AVAILABLE FLOW/SYSTEM}}{\text{SPEED BRAKE FLOW GRADIENT/SYSTEM}}$	39.01
K_{QE_2}	$\frac{\text{ELEVON FLOW GRADIENT}}{\text{SPEED BRAKE FLOW GRADIENT}}$	1.362
K_{QR_2}	$\frac{\text{RUDDER FLOW GRADIENT}}{\text{SPEED BRAKE FLOW GRADIENT}}$	0.650
Q_1	$\frac{\text{MAX AVAILABLE FLOW/SYSTEM}}{\text{SPEED BRAKE FLOW GRADIENT/SYSTEM}}$	18.56
K_{QE_1}	$\frac{\text{ELEVON FLOW GRADIENT}}{\text{SPEED BRAKE FLOW GRADIENT}}$	0.681
K_{QR_1}	$\frac{\text{RUDDER FLOW GRADIENT}}{\text{SPEED BRAKE FLOW GRADIENT}}$	0.650
$\dot{\delta}_{ELEVATOR}$	$1/2\ (\dot{\delta}_{E_L} + \dot{\delta}_{E_R})$	
DBFL	BODY FLAP FLOW RATE /SPEED BRAKE FLOW GRADIENT = 0.0 IF BODY FLAP FIXED = 2.503 IF BODY FLAP IN MOTION	

FIGURE 3b

TYPICAL POWER AND ENERGY RESULTS

MISSION 3B, 40/30° α ADC ENTRY GUIDANCE, AFT C.G.,
STEADY STATE WINDS + GUSTS/TURBULENCE, JUNE '74 AERODYNAMICS

CASE		HYDRAULIC SYSTEM 1		HYDRAULIC SYSTEM 2		HYDRAULIC SYSTEM 3	
		MAXIMUM SURFACE HP_f	TOTAL SURFACE ENERGY (HP-HRS)	MAXIMUM SURFACE HP_f	TOTAL SURFACE ENERGY (HP-HRS)	MAXIMUM SURFACE HP_f	TOTAL SURFACE ENERGY (HP-HRS)
NO FAILURES		55.0	2.7	76.1	4.0	101.3	5.6
1 FAILURE	#1 FAILED			96.6	6.3	96.6	6.3
	#2 FAILED	96.6	6.3			96.6	6.3
	#3 FAILED	98.8	6.3	96.6	6.3		
2 FAILURES		119.2	12.7				

FIGURE 4

Figures 5 through 33 show typical output plots from a 3B entry-to-touchdown trajectory for a two hydraulic systems failed case. Data are plotted at two second intervals throughout the trajectory and therefore some points are unavoidably missed. The rate limiting in this case had an effect on the vehicle dynamics resulting in sluggish touchdown conditions as well as extremely high peak load factor of ~ 2.6 g's. The touchdown position was 280 feet beyond the runway threshold and 176 feet wide of the runway centerline with a sink rate of 9.7 ft/sec. This compares with 3200 feet beyond the threshold, one foot from the centerline and a 4 ft/sec sink rate for the now failure case.

5.0 CONCLUSIONS

The developments presented here represent the basic foundation in the analysis of the power and energy demands on the APU/Hydraulic/Actuator Subsystem. However, there are several other factors which must be included in the total picture. It should therefore be emphasized that the power and energy data presented here is only that portion of the total which is due to control surface activity.

The additional factors which go to make up the total power and energy demand include power spool/hydraulic motor leakeage flow, control flow, pump efficiency curves, and S.F.C. curves. These factors will be dealt with in future studies, and a more detailed analysis will follow.

6.0 REFERENCES

A) Aerodynamic Control Surface Limiting - FSSR Changes, Rockwell International Internal Letter No. SSA/FSA/-74-440, 17 December 1974

B) Update of Hydraulic Subsystem Power Capability Analysis, Rockwell International Internal Letter No. 388-200-75-001, 2 January 1975

C) Space Shuttle Orbiter Approach and Landing Test, Level C, FSSR Document No. SD74-SH 1271, 30 September 1974

D) Space Shuttle Functional Simulator Engineer/Programmer User's Guide (EXEC 8) Revision 1, Lockheed Electronics Company, Inc., LEC-0178, August 1974.

E) SSFS Model Documentation Series, WIND 9, Lockheed Electronics Company, Inc., LEC-4939, November 1974

F) Entry to Touchdown Nominal 3B APU-Hydraulics Trajectory, Informal Presentation to Aaron Cohen by R. L. Barton (EX43), 21 February 1975

3B 4°/30 α WITH GUSTS 2 FAIL...

NAME WADE, D.E. DATE 3/6/75 PLOTS 2?
PROJ. 3304J DIV. CODE EX43 TAPE NO. 02...
BLDG BETA BOX BETA EXT 488-5660 x227
FORM 00 01 (02) OTHER WBS1.2

FIGURE 5

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

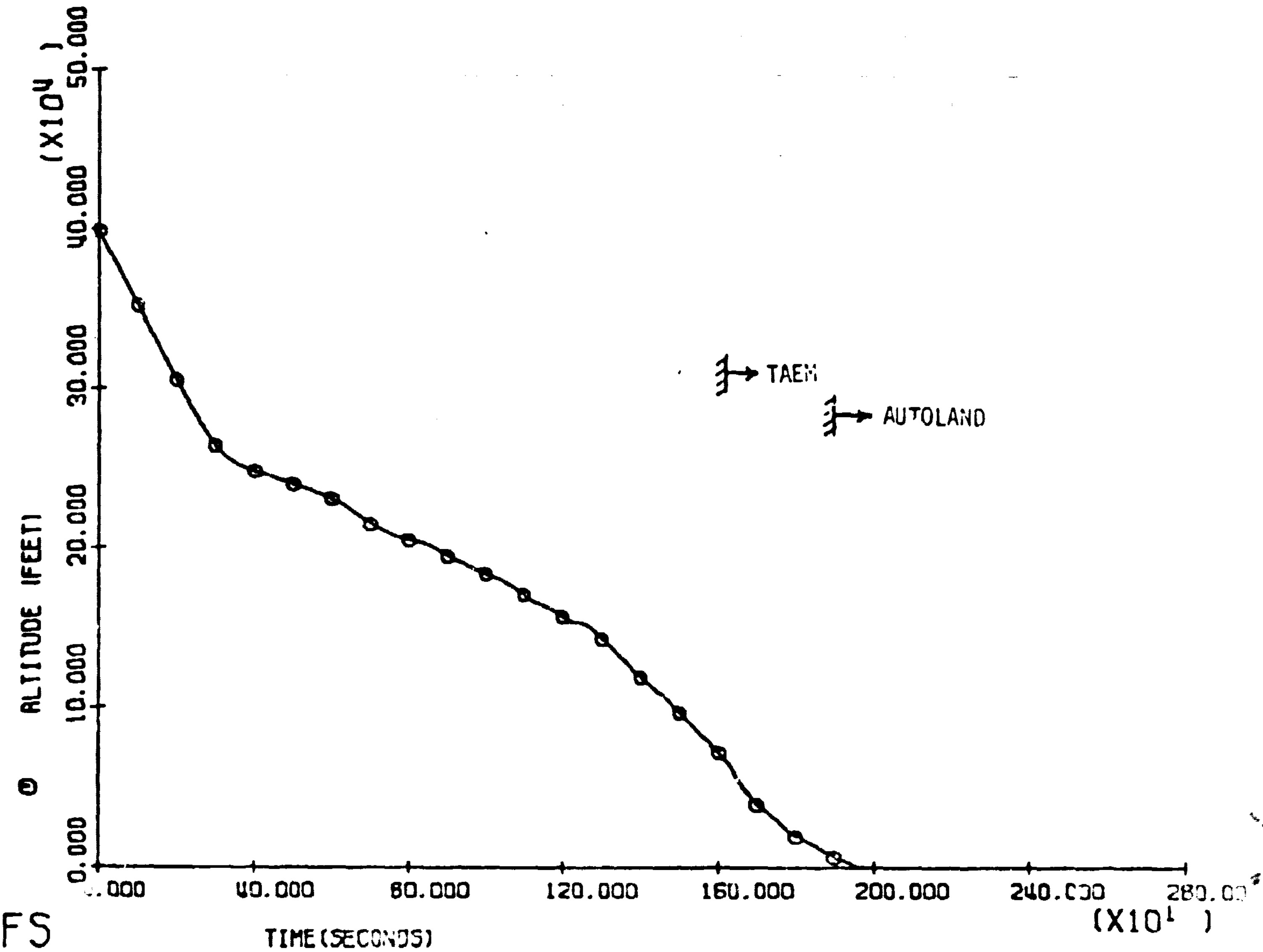

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FIGURE ALTITUDE VS TIME

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FIGURE 6

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

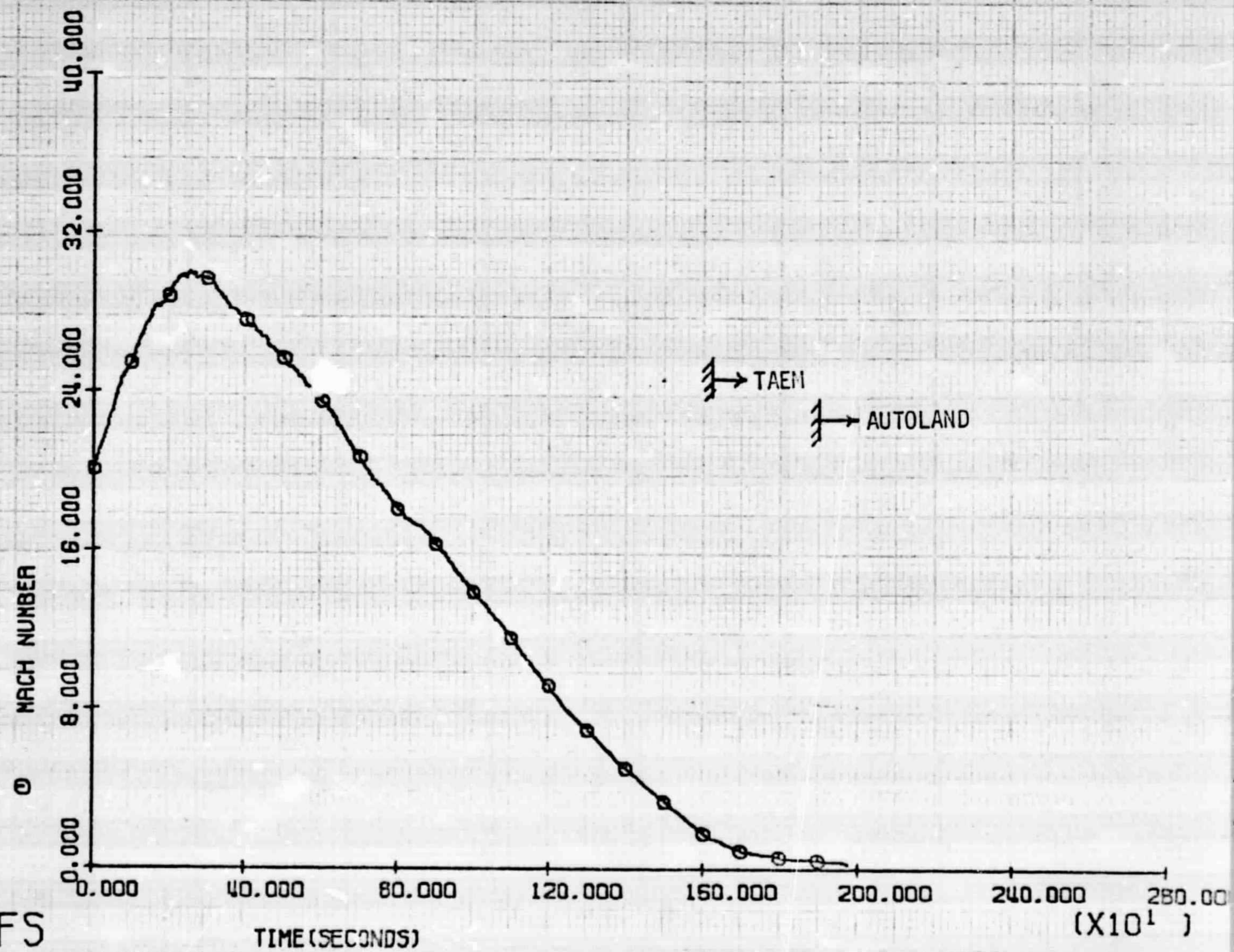

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FIGURE MACH NUMBER

FIGURE 7

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

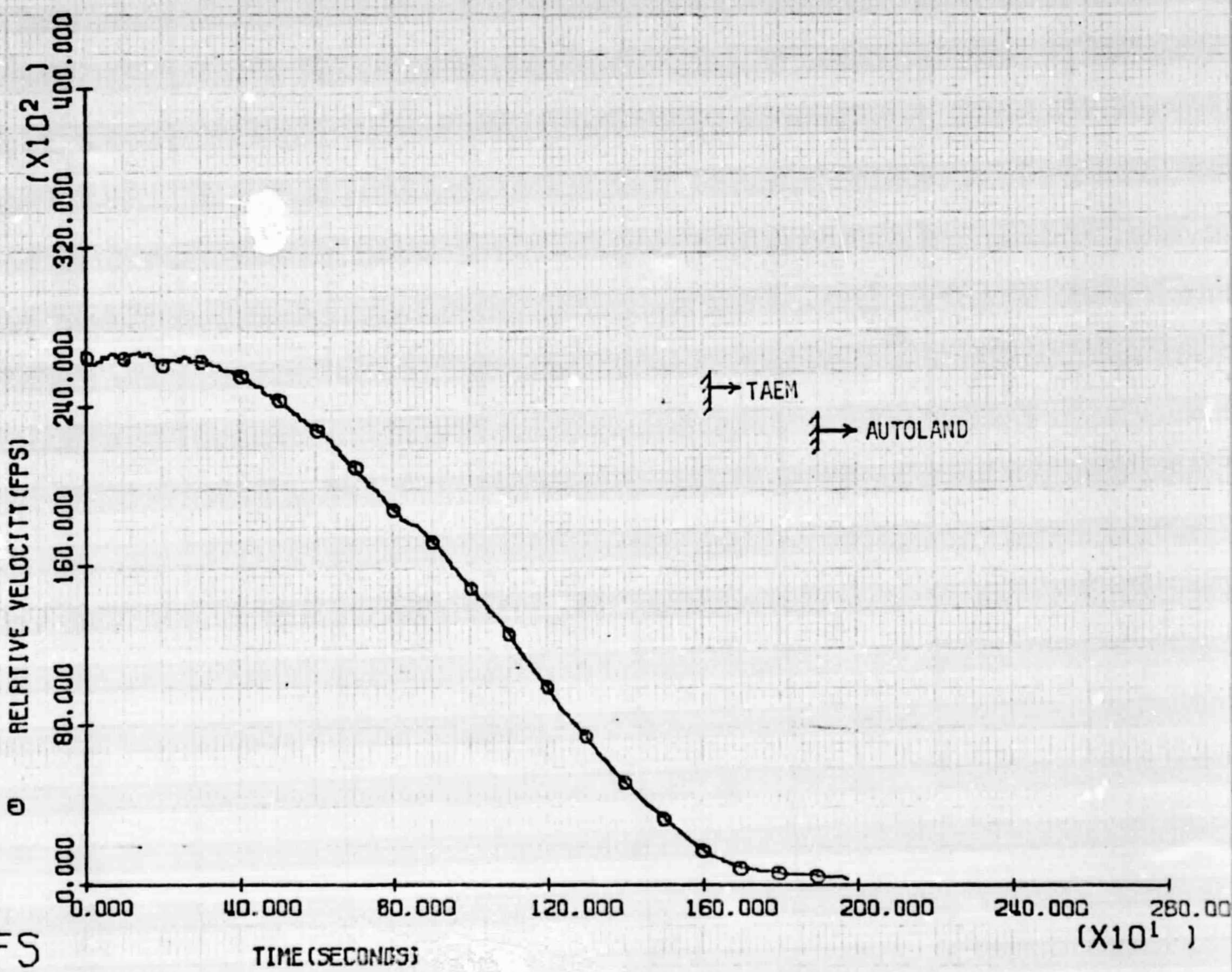

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FIGURE RELATIVE VELOCITY

FIGURE 8

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

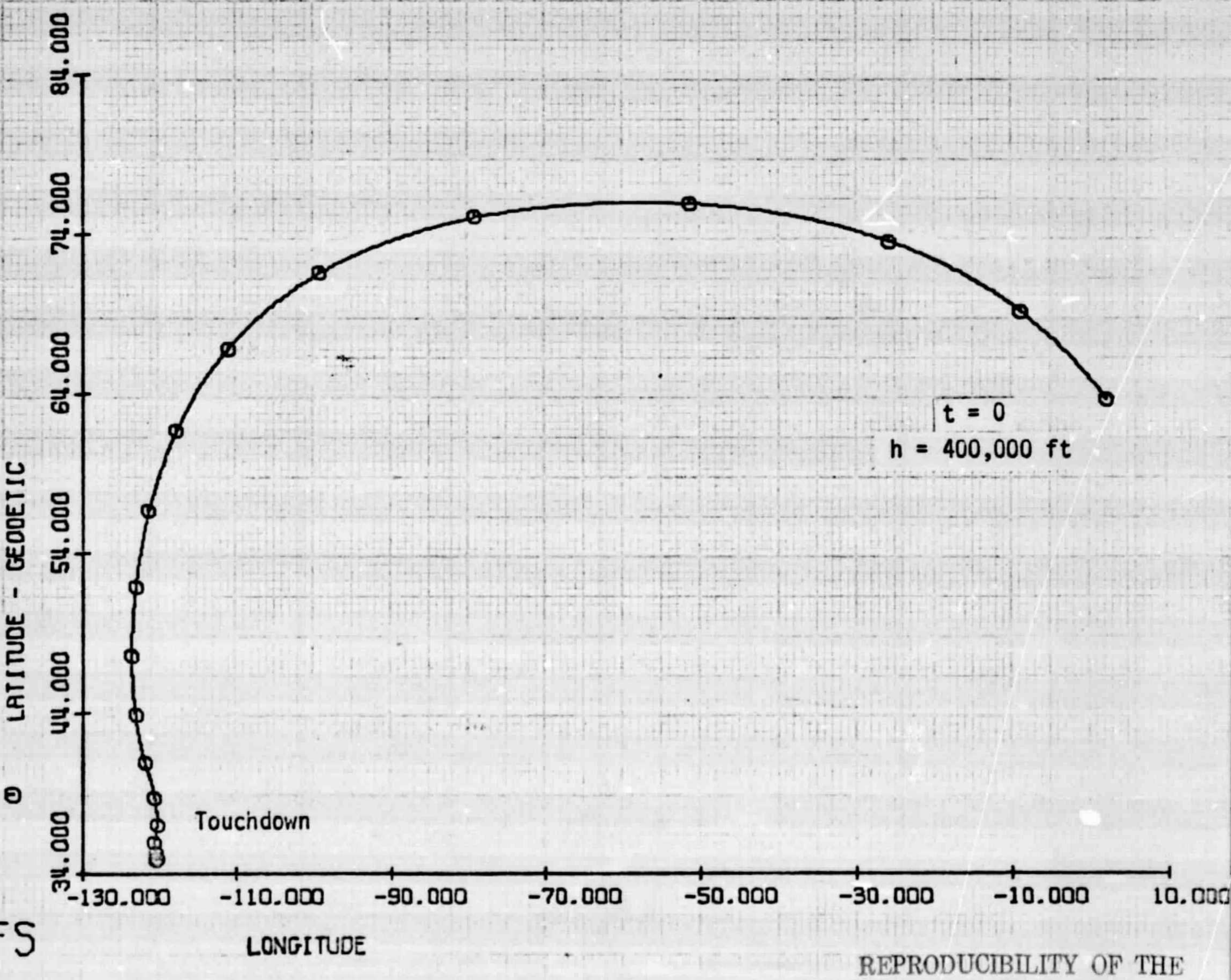

FIGURE VEHICLE LATITUDE VS LONGITUDE

FIGURE 9

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

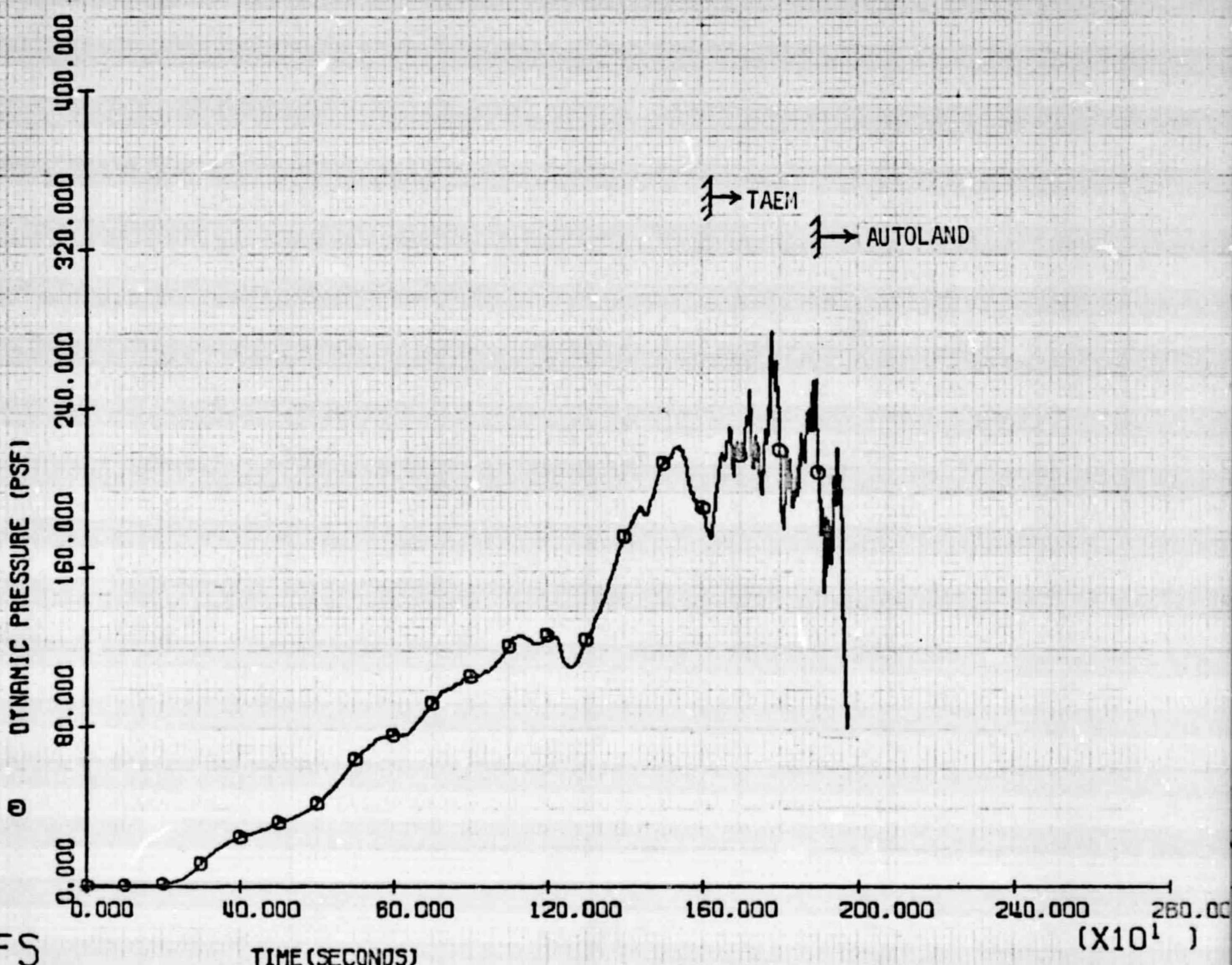

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FIGURE DYNAMIC PRESSURE

FIGURE 10

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

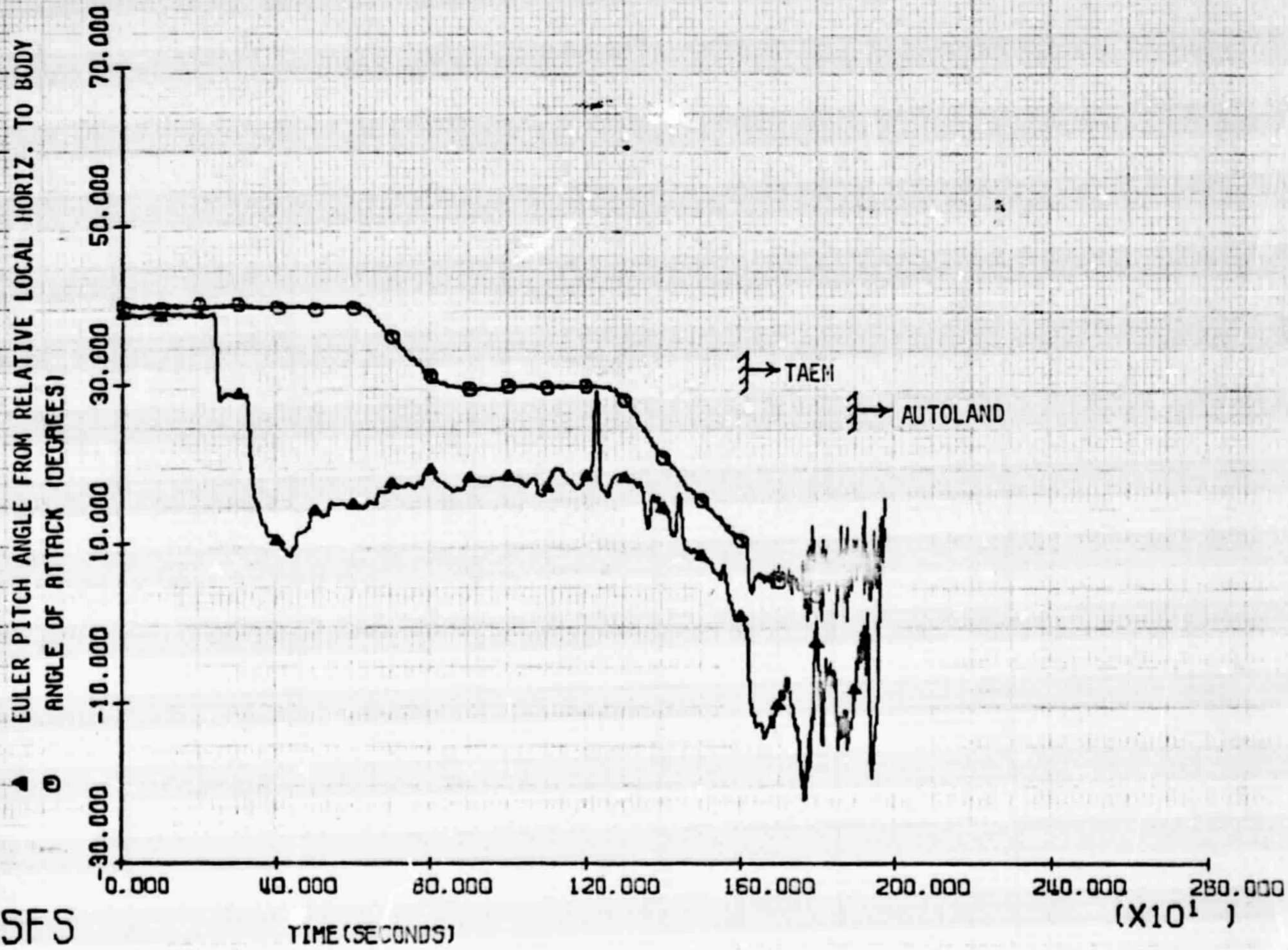

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FIGURE ATTACK AND PITCH ANGLES

FIGURE 11

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

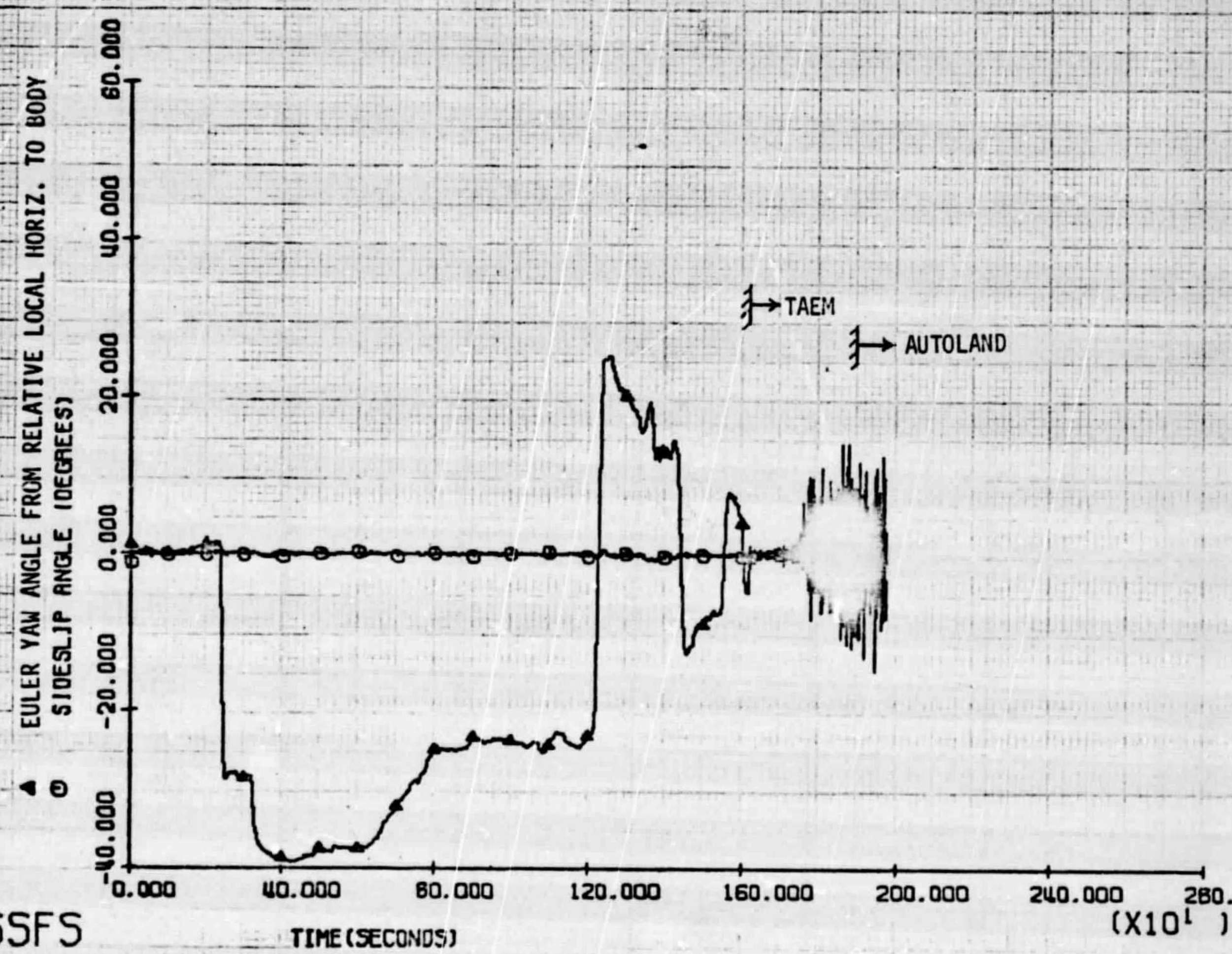

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FIGURE SIDESLIP AND YAW ANGLES

FIGURE 12

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

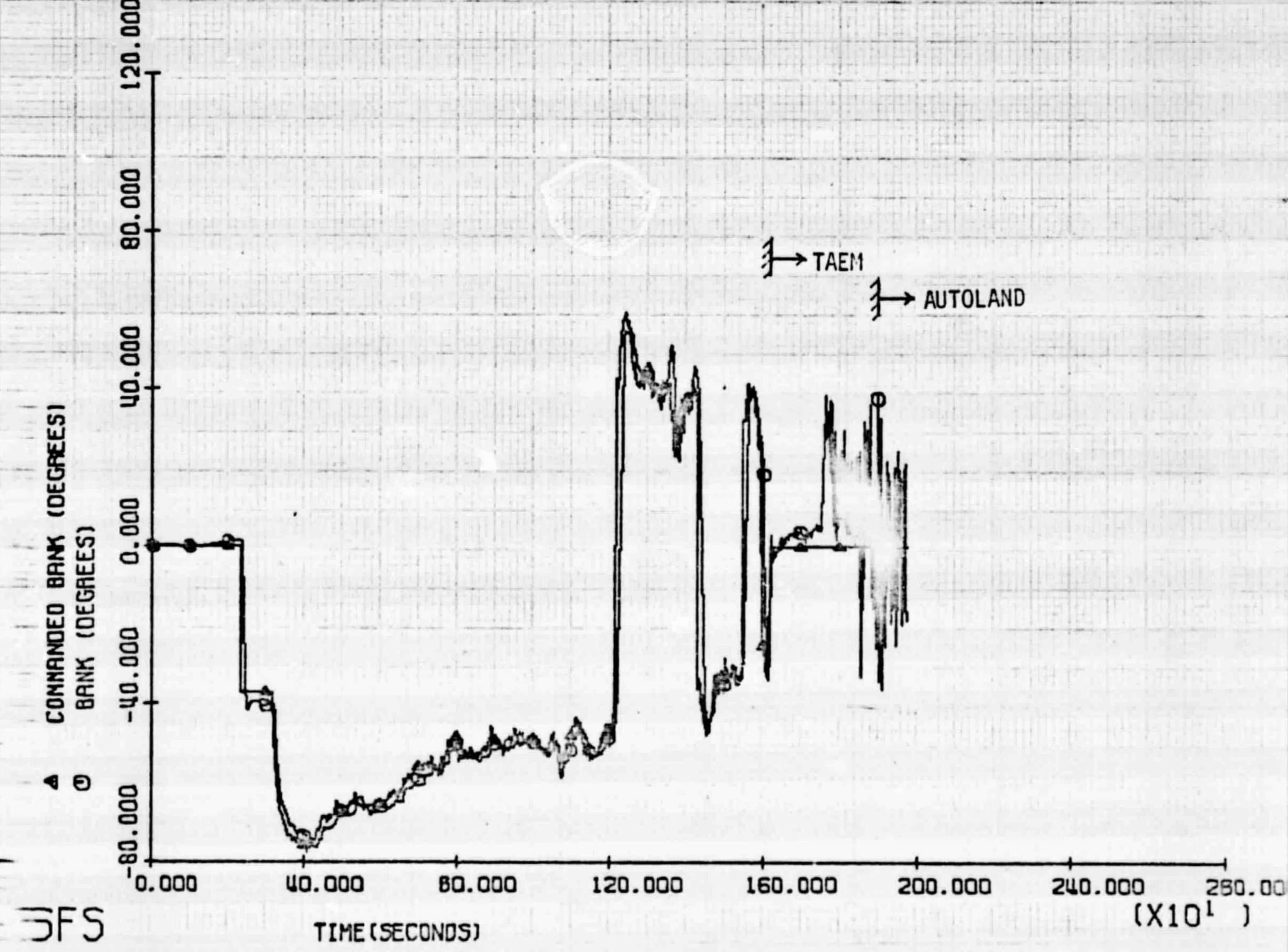

FIGURE BANK ANGLE AND COMMANDED BANK ANGLE

FIGURE 13

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

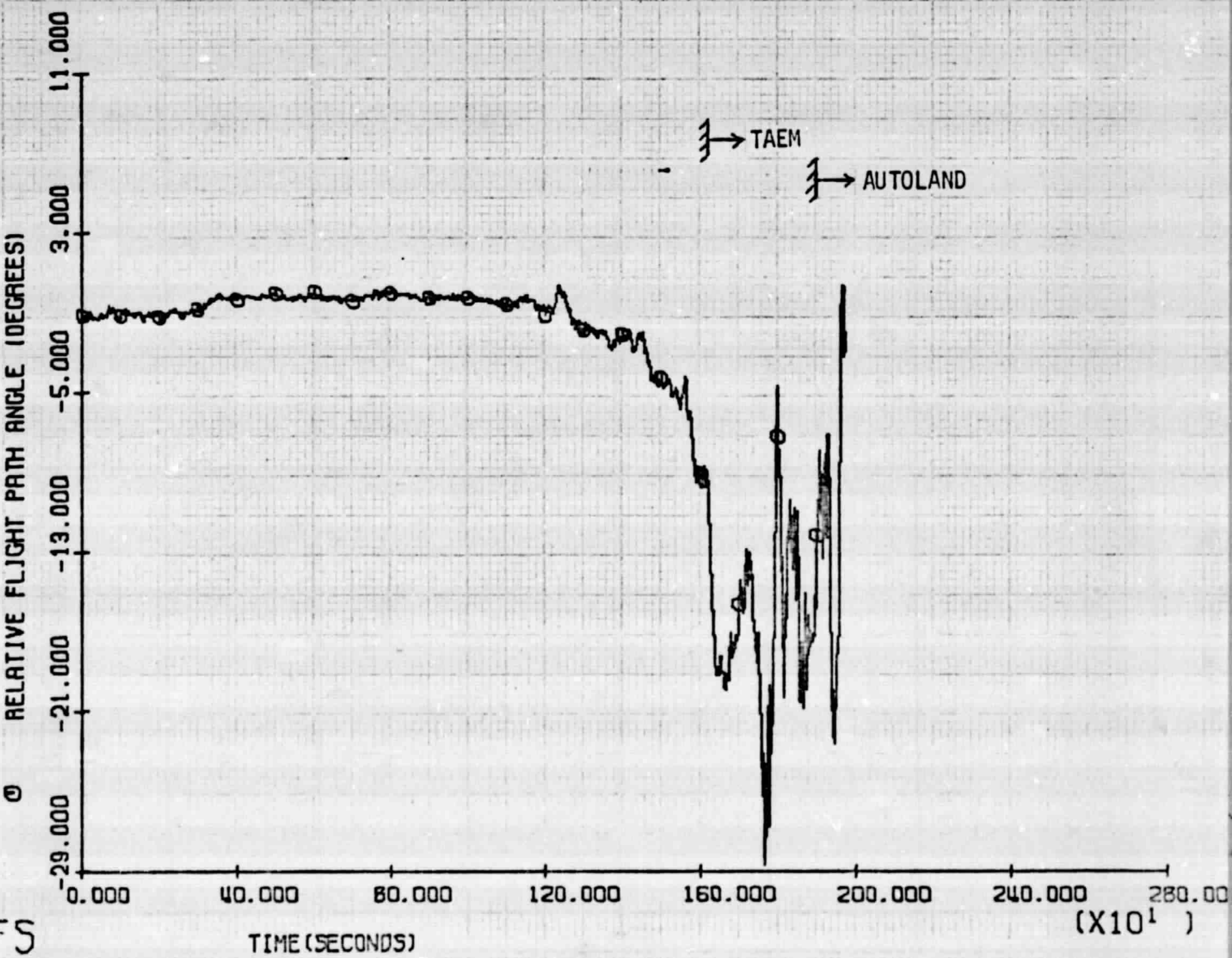

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FIGURE RELATIVE FLIGHT PATH ANGLE

FIGURE 14

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

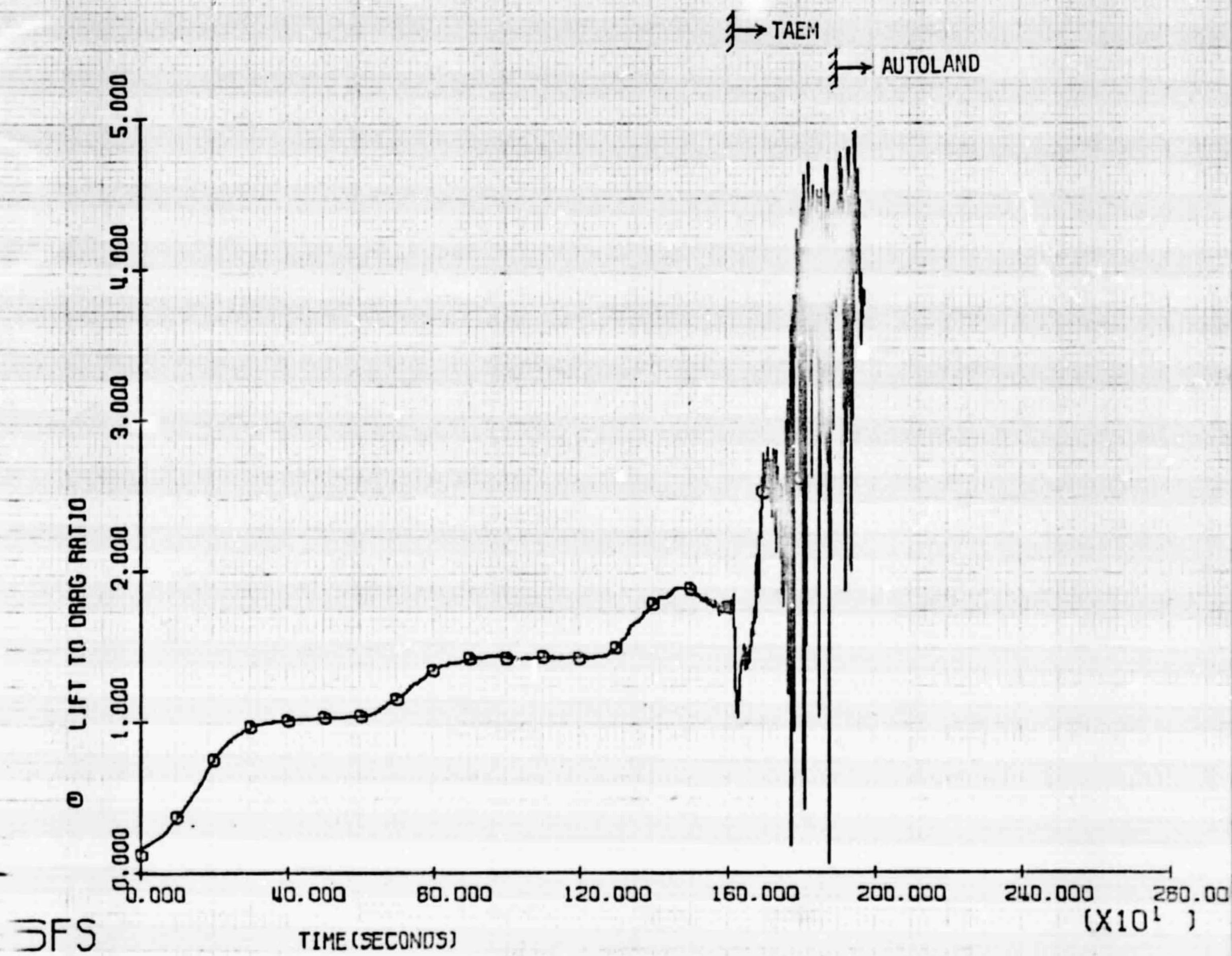

FIGURE LIFT TO DRAG RATIO

FIGURE 15

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

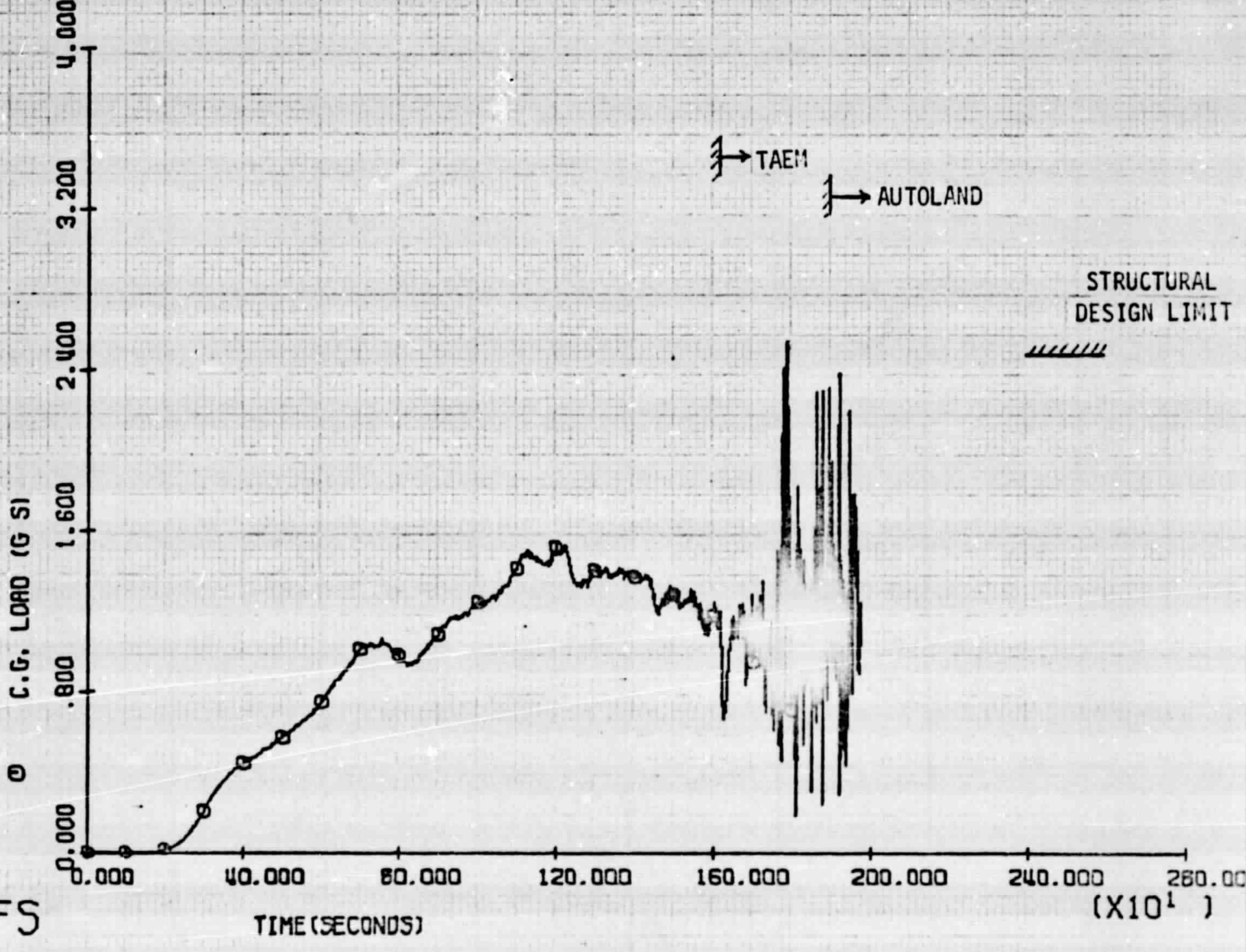

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FIGURE C.G. LOAD

FIGURE 16

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

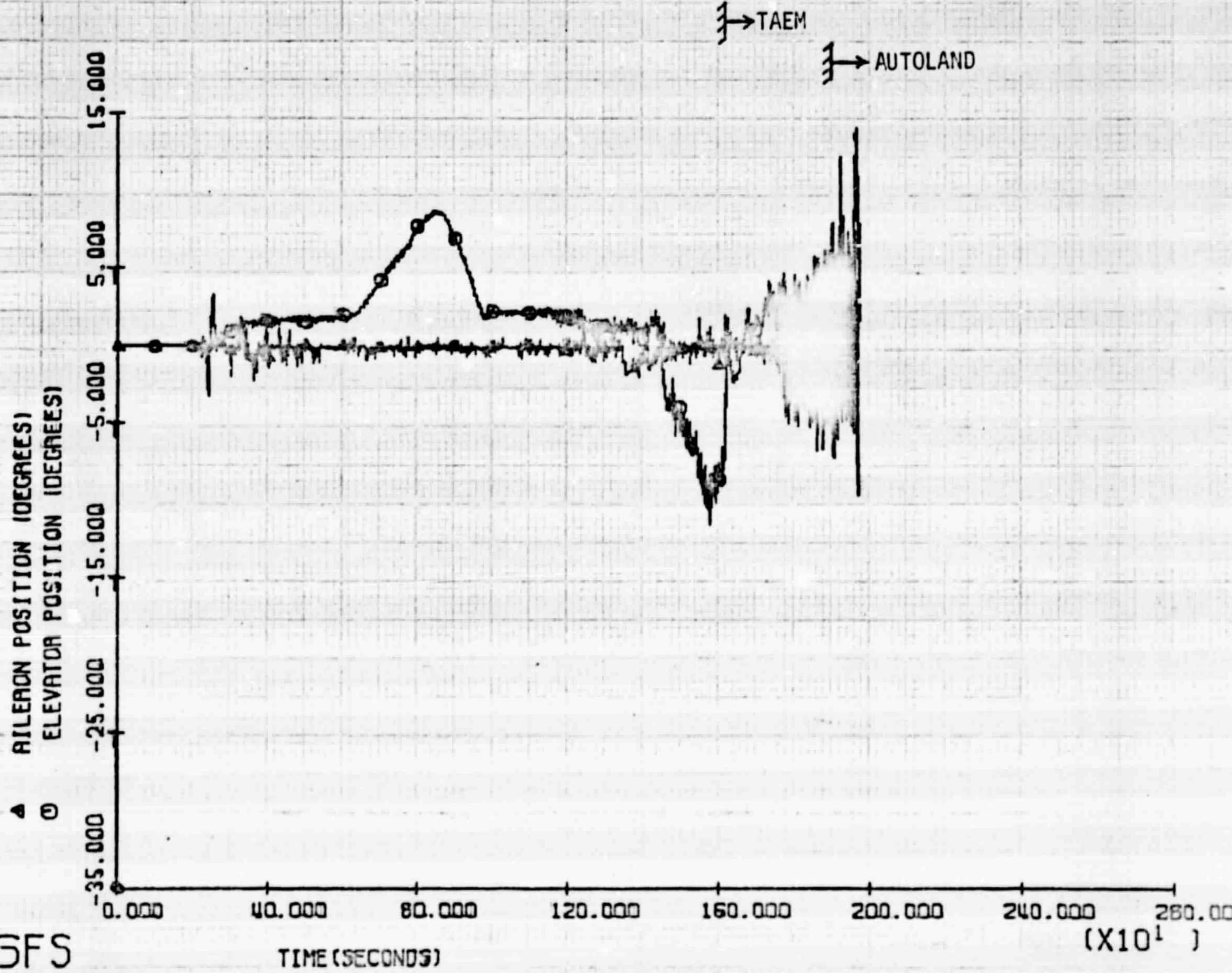

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FIGURE ELEVATOR AND AILERON POSITIONS

FIGURE 17

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

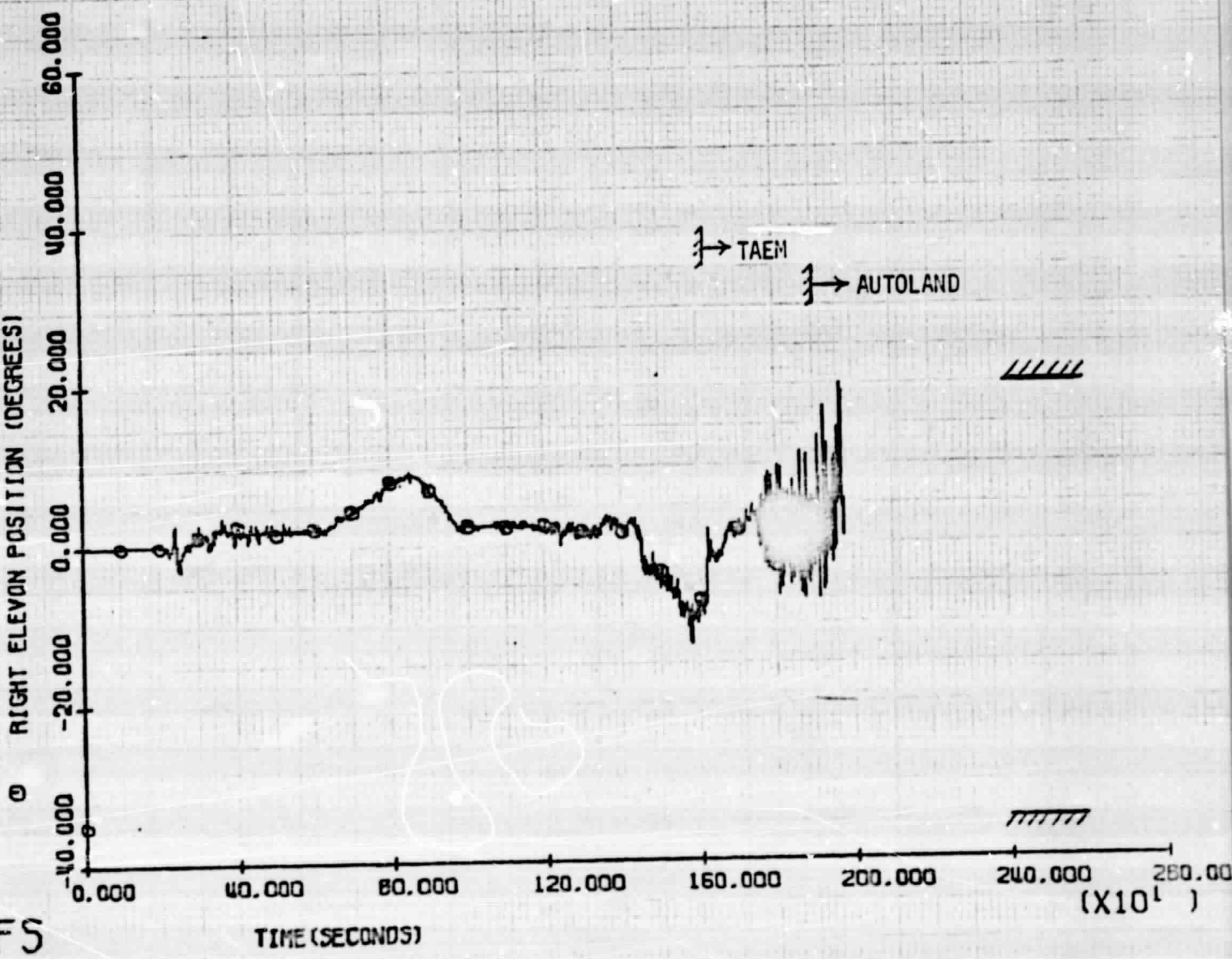

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FIGURE RIGHT ELEVON POSITION

FIGURE 18

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

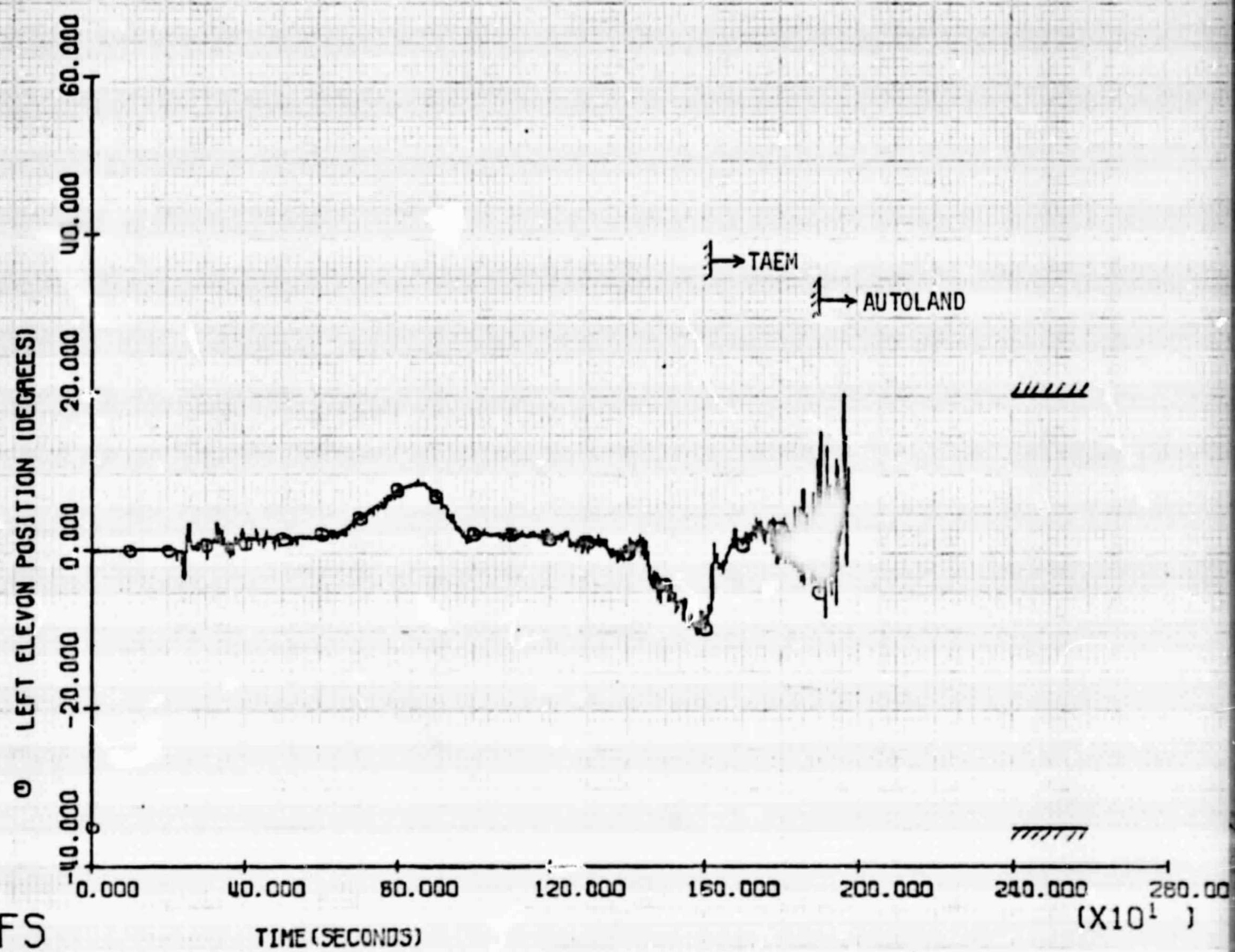

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FIGURE LEFT ELEVON POSITION

FIGURE 19

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

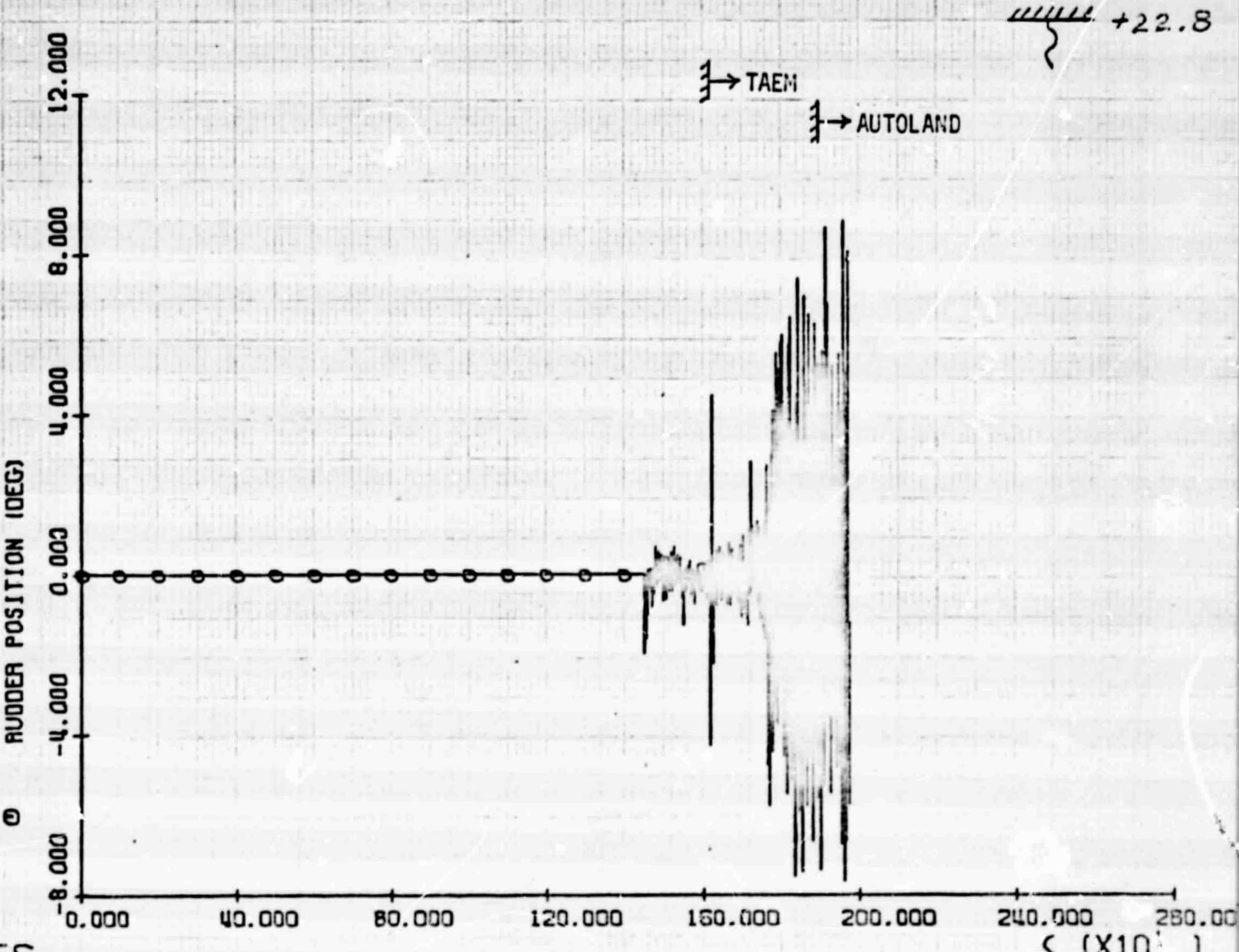

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FIGURE RUDDER POSITION

FIGURE 20

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

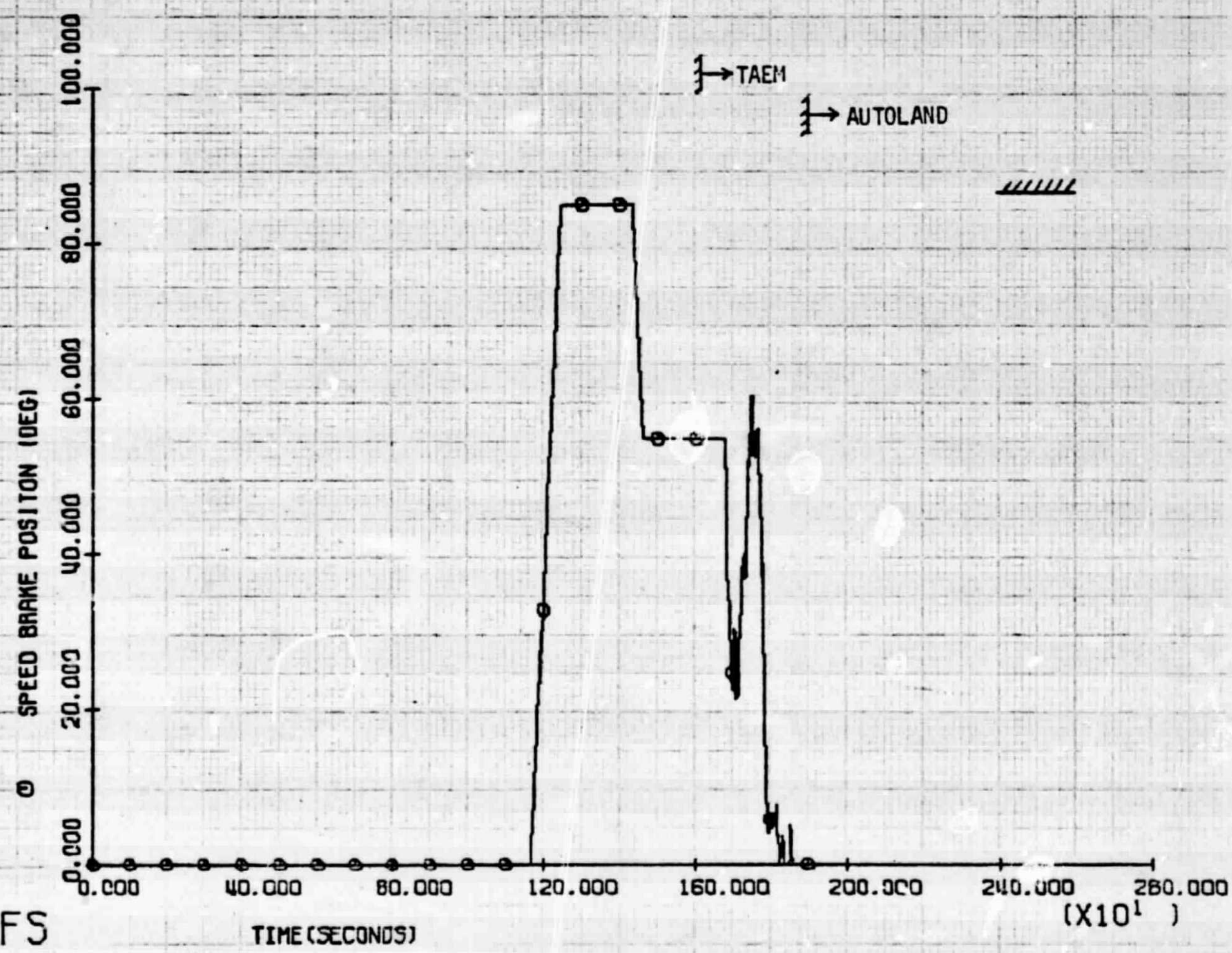

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FIGURE SPEED BRAKE POSITION

FIGURE 21

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

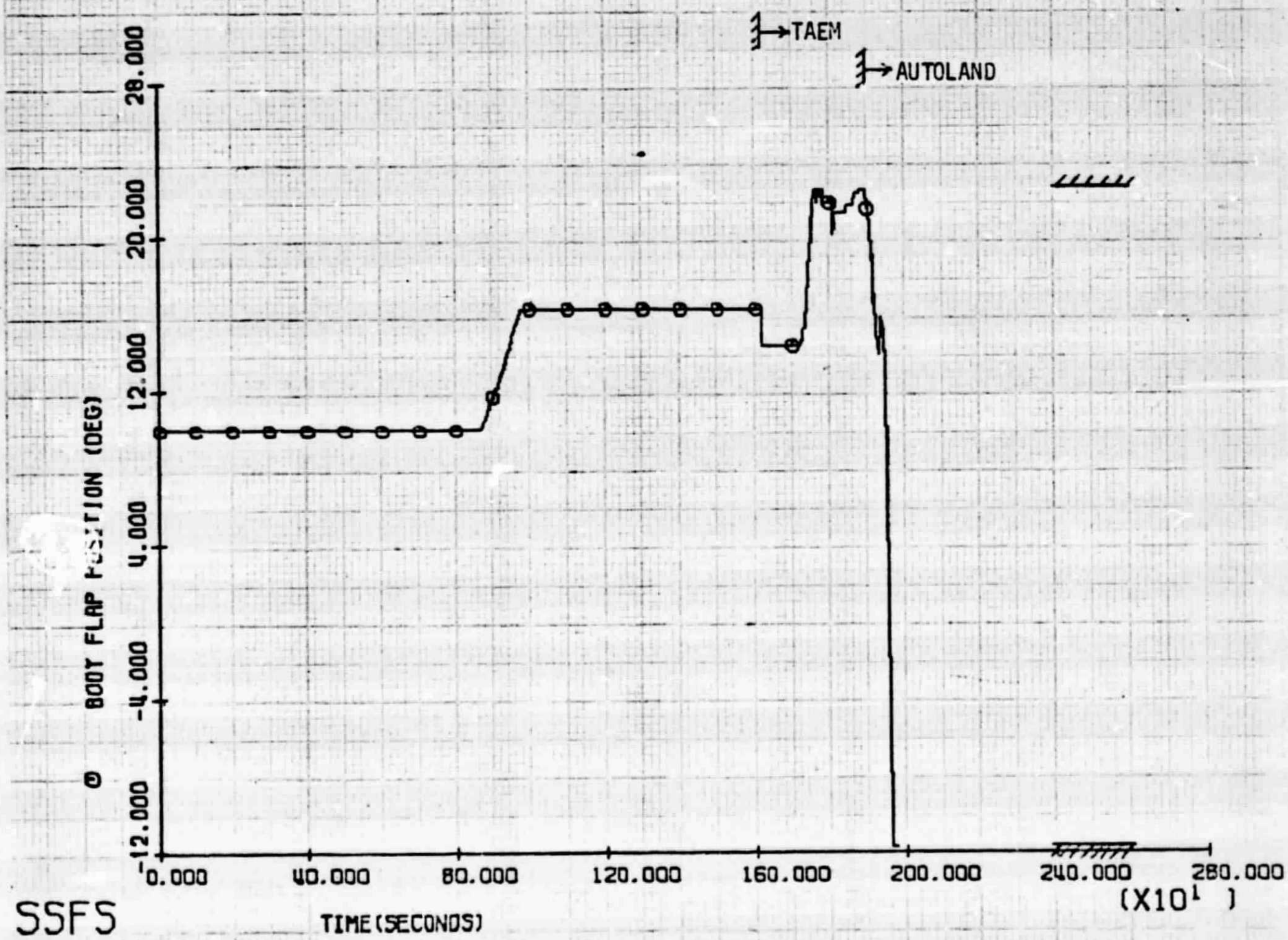

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FIGURE BODY FLAP POSITION

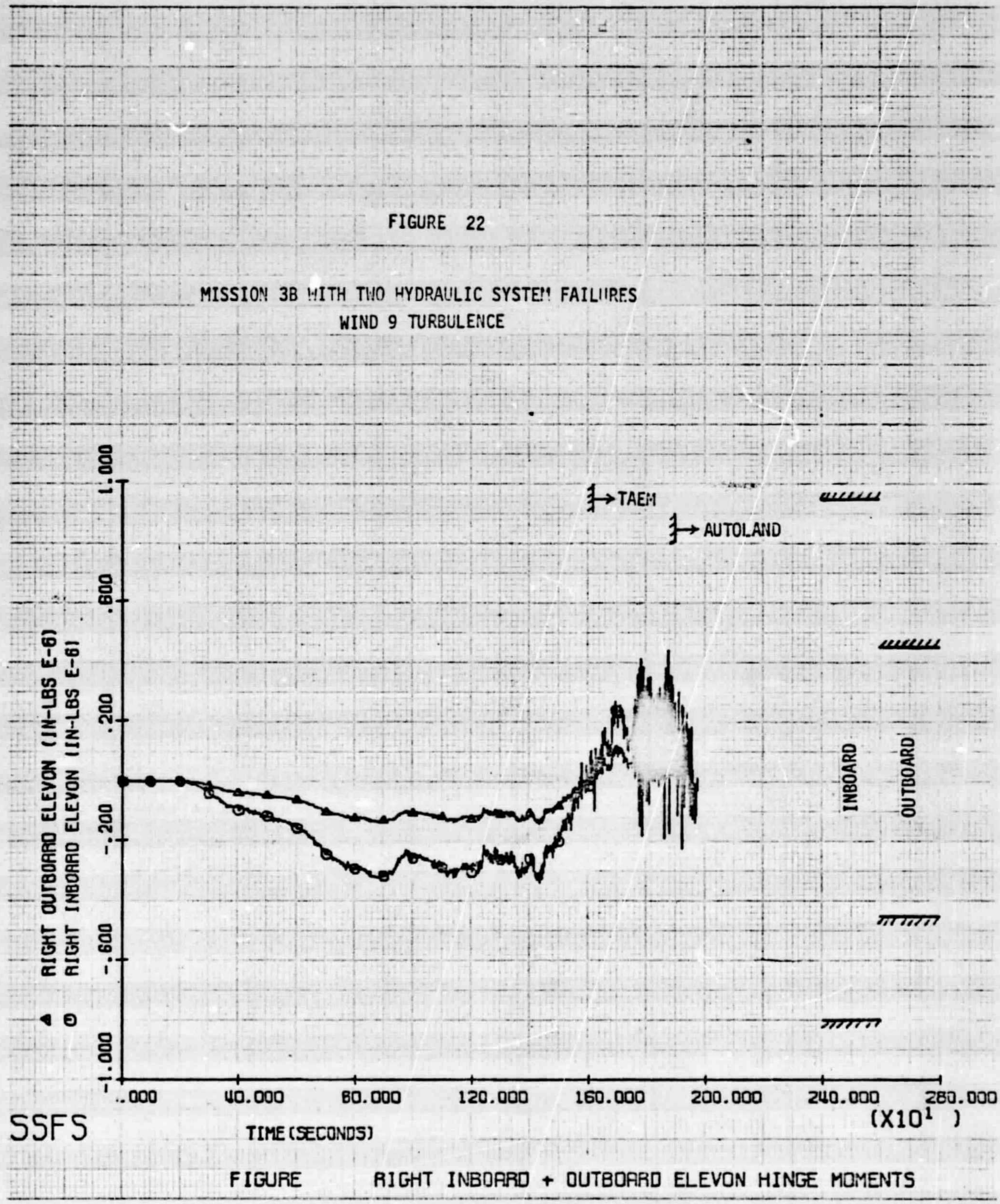
FIGURE 22
MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE
TAEM
AUTOLAND
INBOARD
OUTBOARD
1.000
.600
.200
-.200
-.600
-1.000
RIGHT OUTBOARD ELEVON (IN-LBS E-6)
RIGHT INBOARD ELEVON (IN-LBS E-6)
.000
40.000
80.000
120.000
160.000
200.000
240.000
280.000
(X10¹)
SSFS
TIME (SECONDS)
FIGURE RIGHT INBOARD + OUTBOARD ELEVON HINGE MOMENTS

FIGURE 23

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

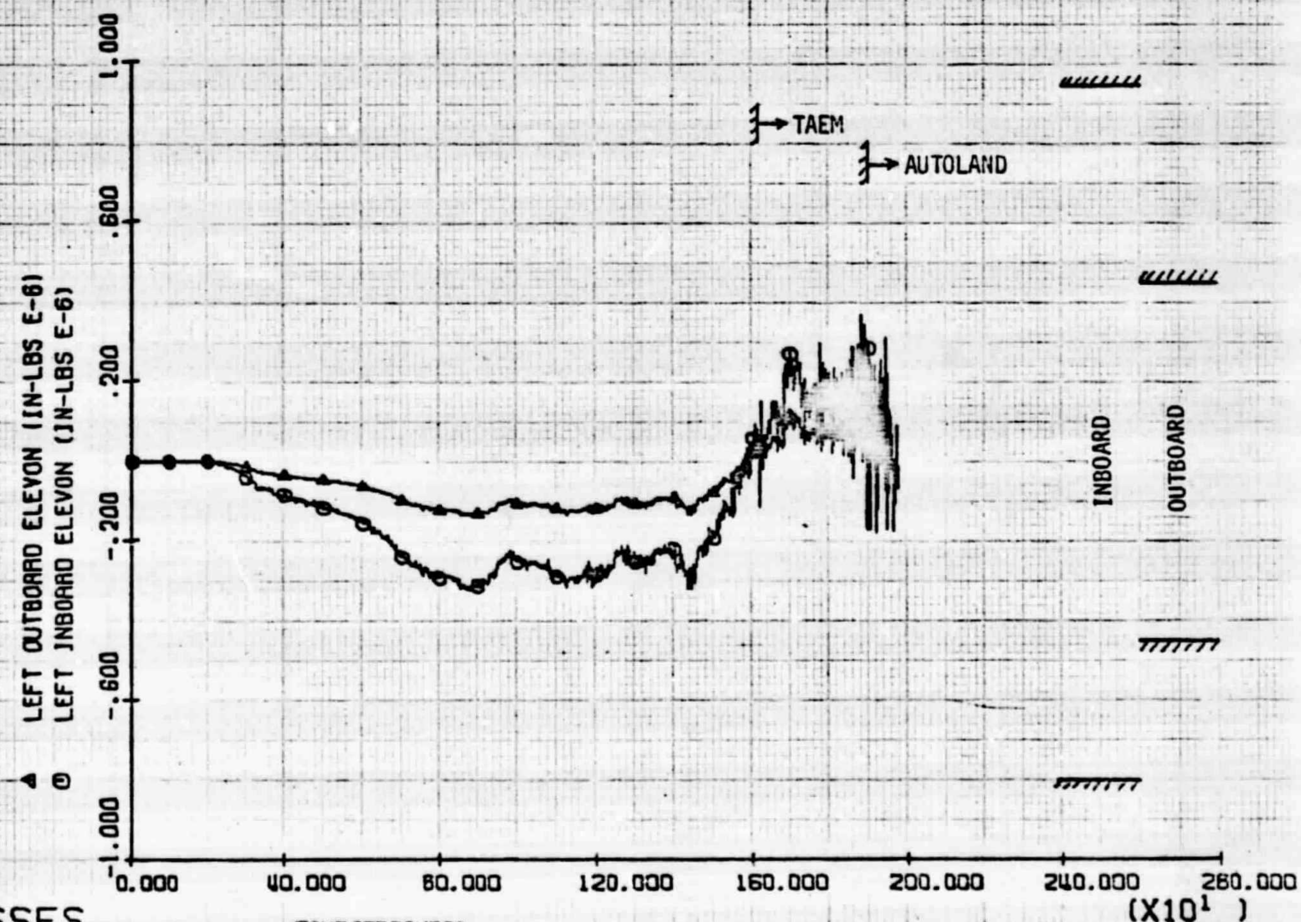

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FIGURE LEFT INBOARD + OUTBOARD ELEVON HINGE MOMENTS

FIGURE 24

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

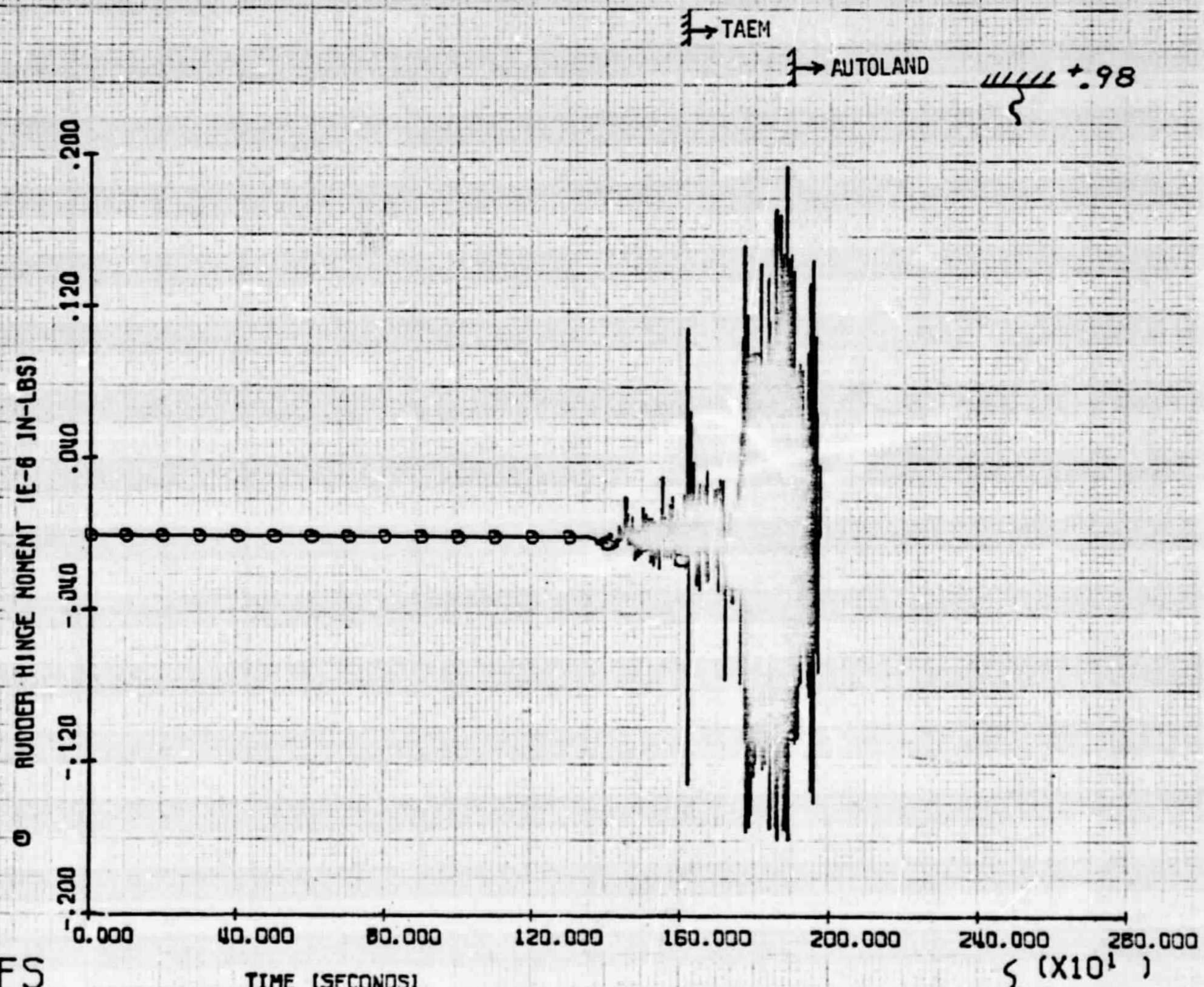

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FIGURE RUDDER HINGE MOMENT

FIGURE 25

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

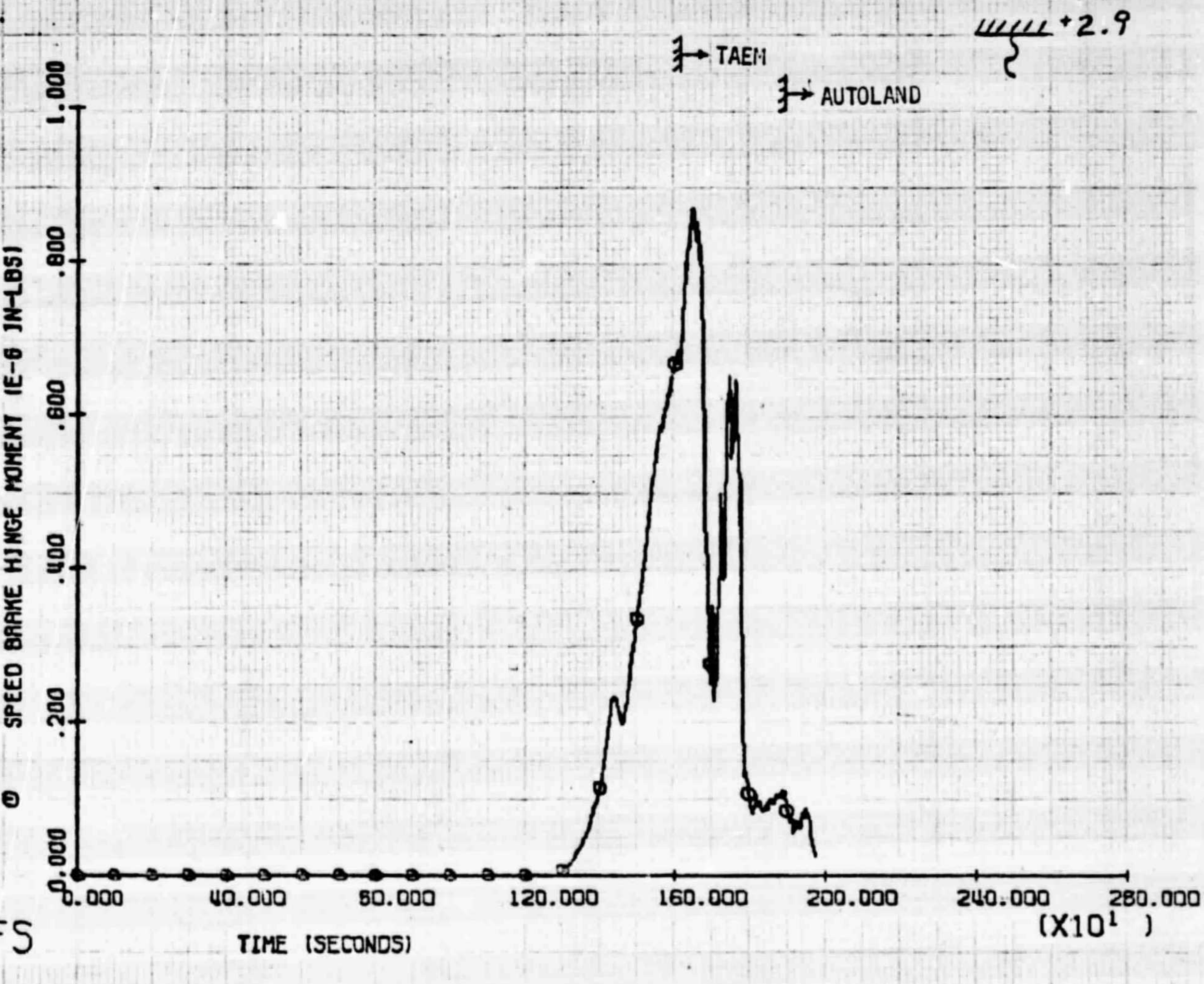

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FIGURE SPEED BRAKE HINGE MOMENT

FIGURE 26

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

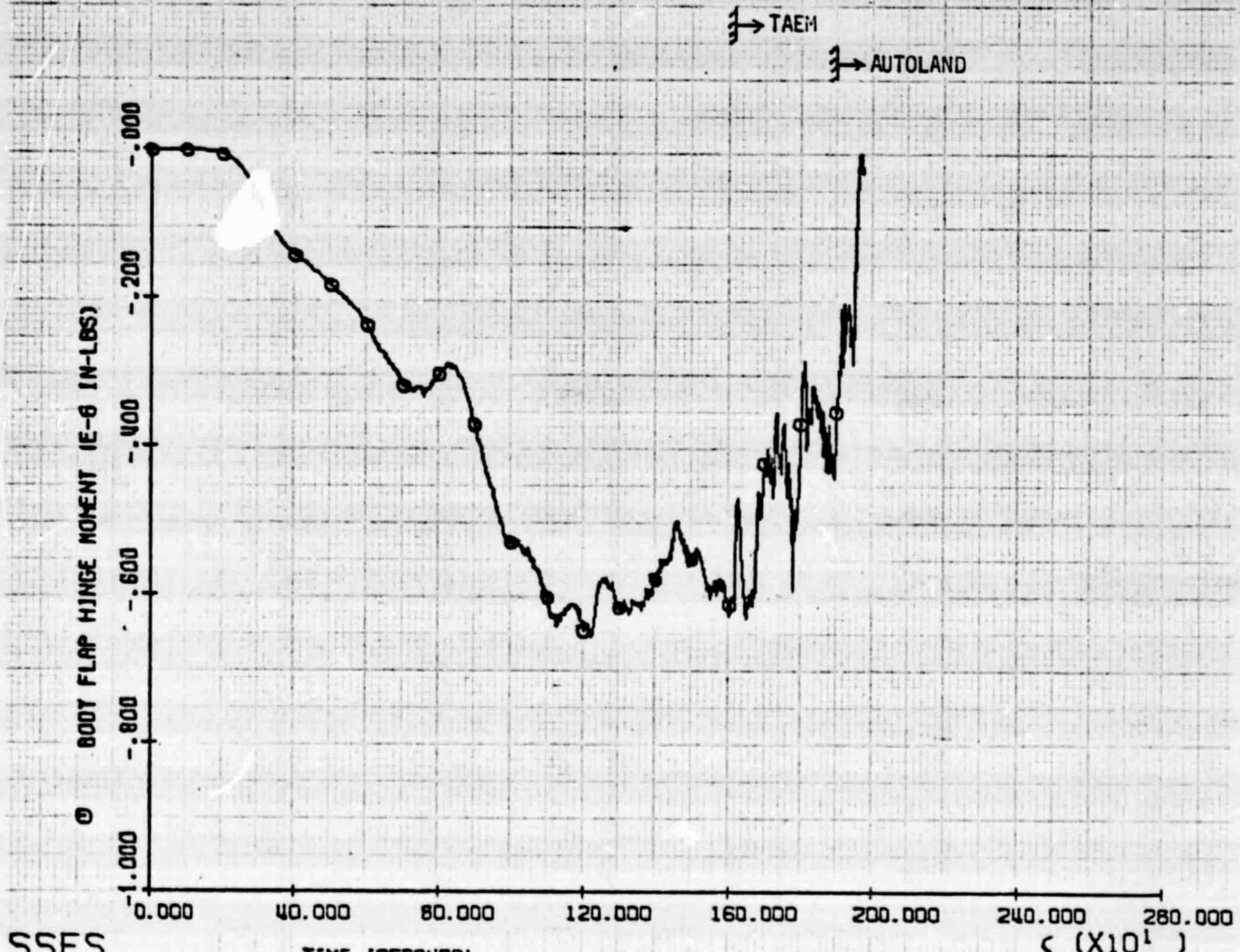

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FIGURE BODY FLAP HINGE MOMENT

- 1.17

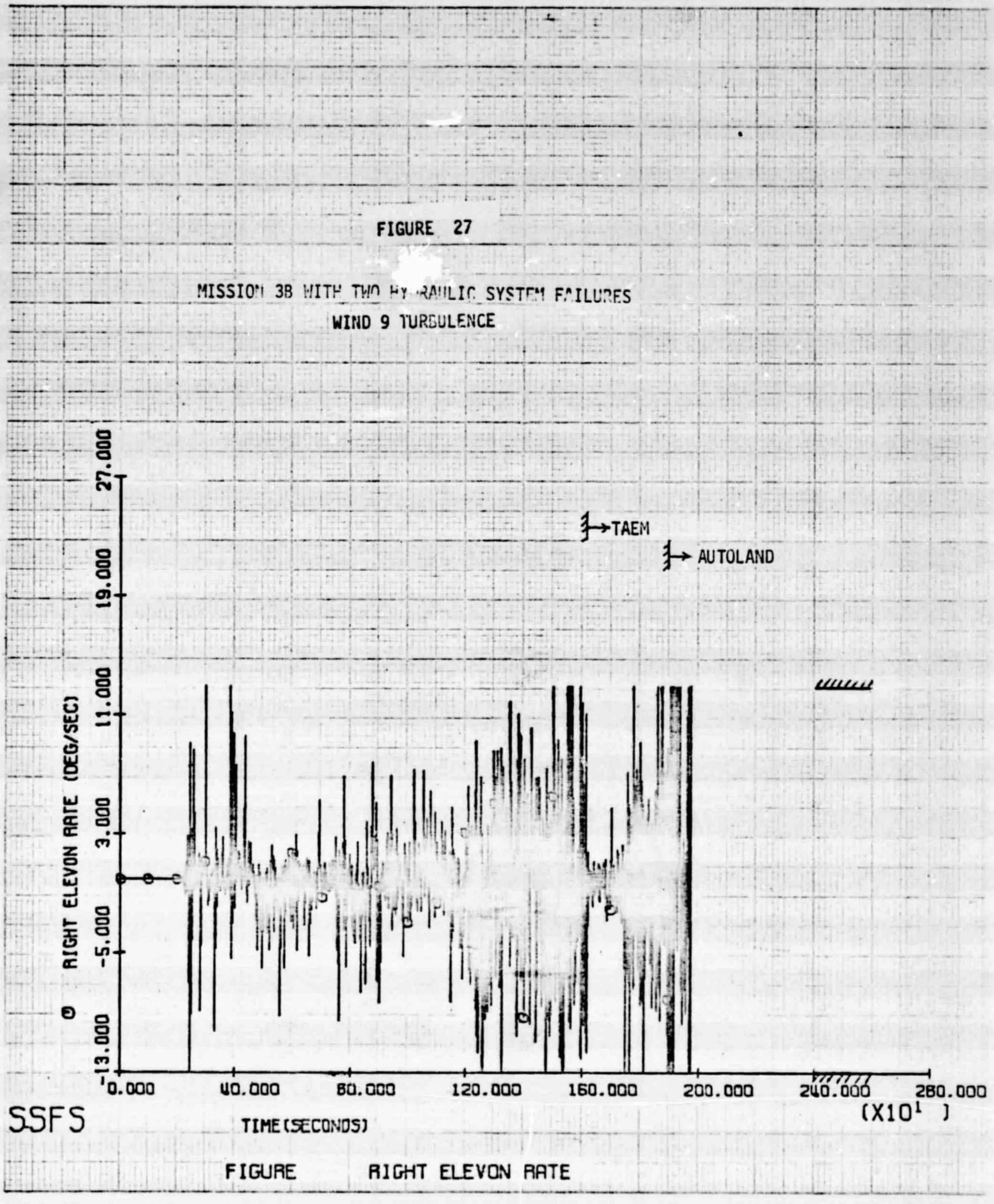
FIGURE 27
MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE
RIGHT ELEVON RATE (DEG/SEC)
27.000
19.000
11.000
3.000
-5.000
-13.000
TAEM
AUTOLAND
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280.000
(X10¹)
SSFS
TIME(SECONDS)
FIGURE RIGHT ELEVON RATE

FIGURE 28

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

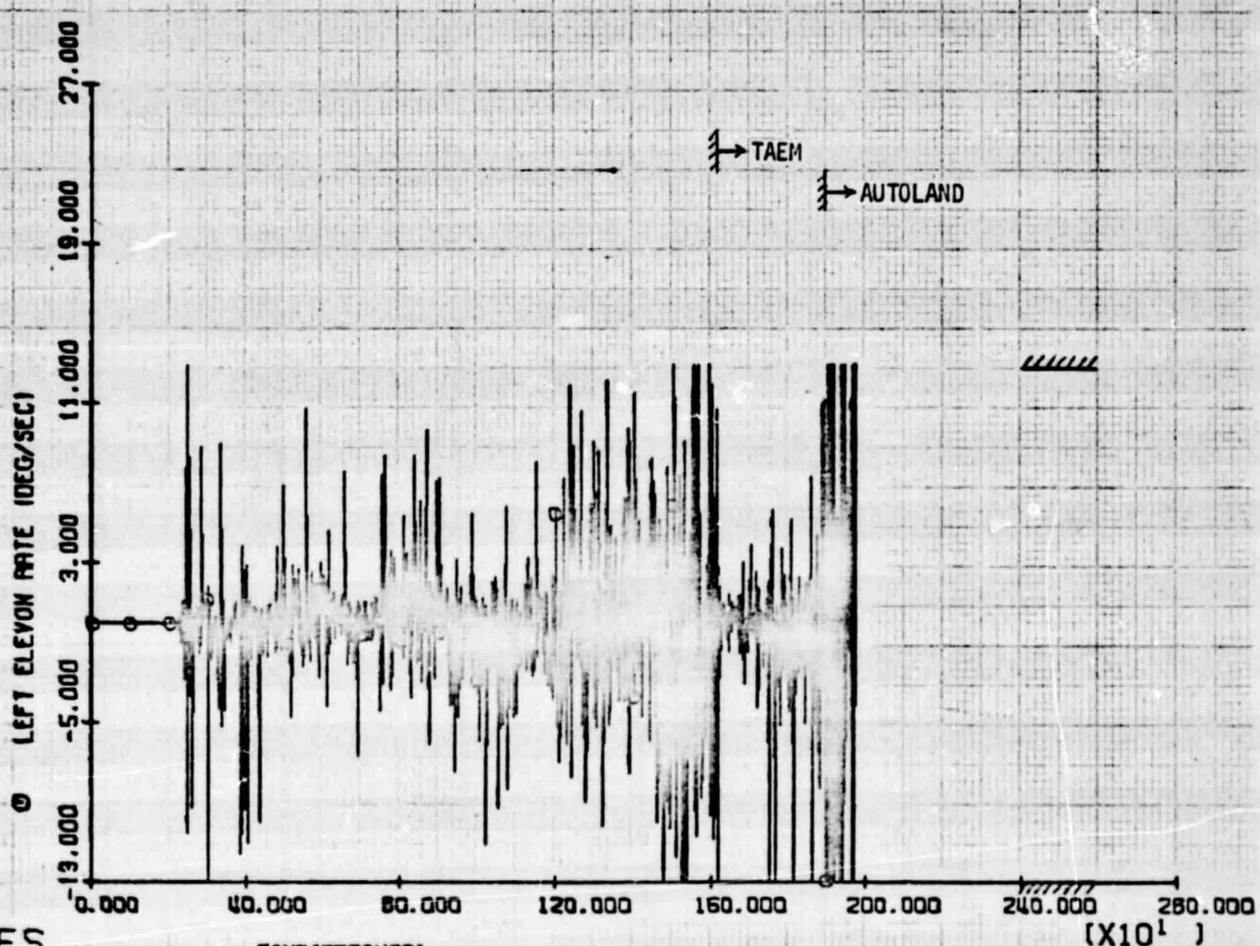

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FIGURE LEFT ELEVON RATE

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FIGURE 29

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE

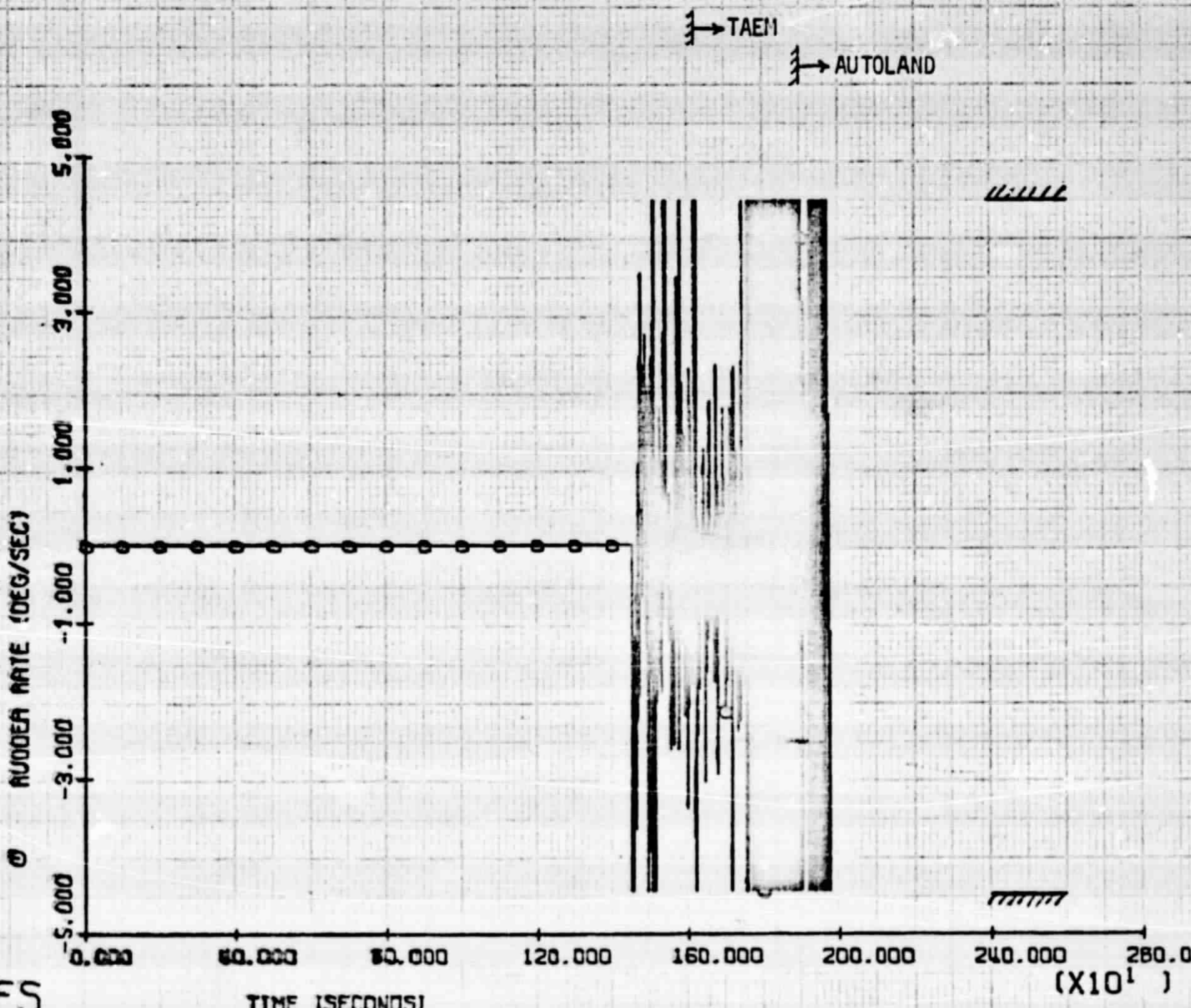

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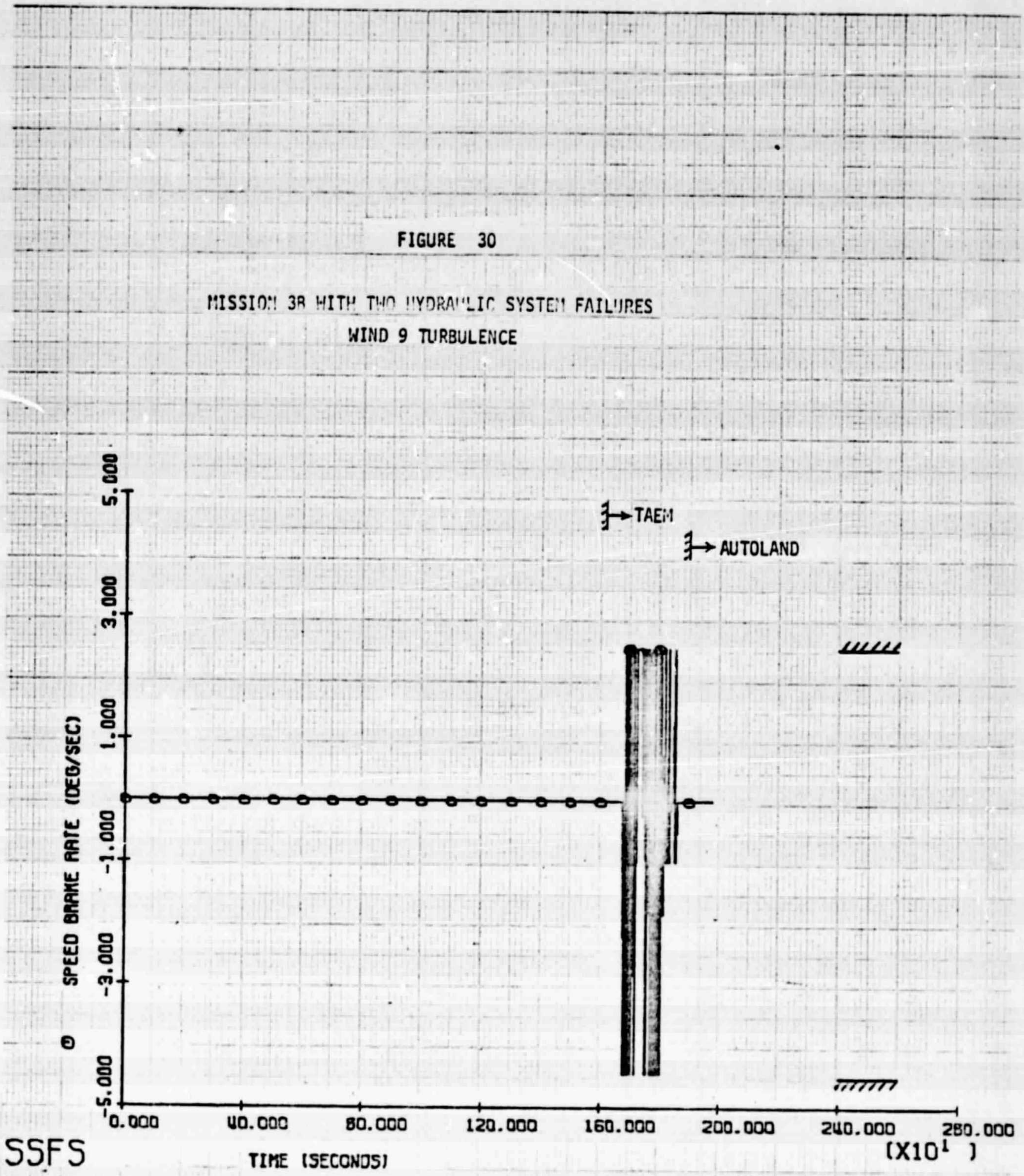
FIGURE RUDDER RATE



SSFS

FIGURE SPEED BRAKE RATE

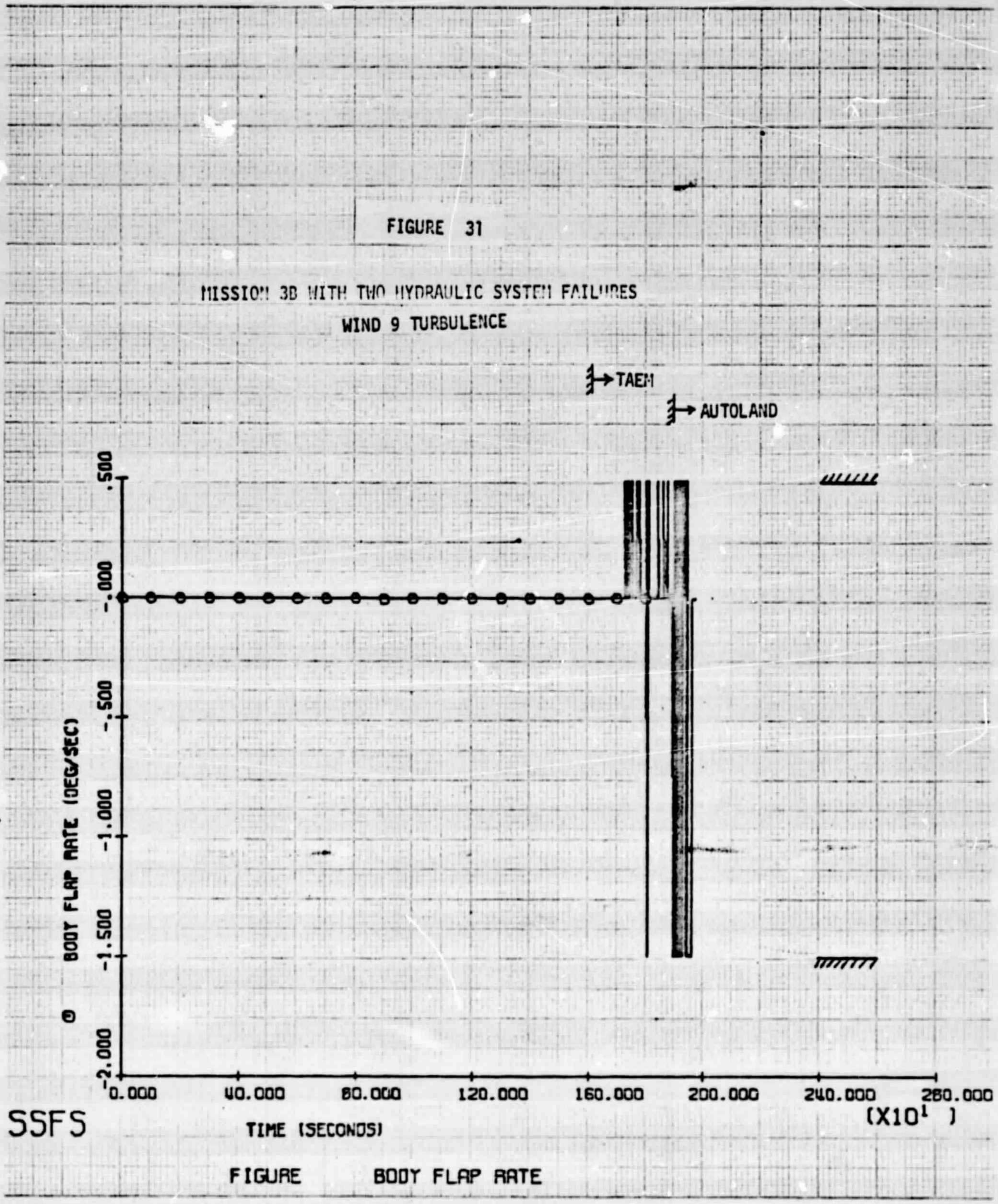


FIGURE 31
MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES
WIND 9 TURBULENCE
TAEM
AUTOLAND
BODY FLAP RATE (DEG/SEC)
.500
-.000
-.500
-1.000
-1.500
-2.000
0.000
40.000
80.000
120.000
160.000
200.000
240.000
280.000
[X10^1]
SSFS
TIME (SECONDS)
FIGURE BODY FLAP RATE

FIGURE 32

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE

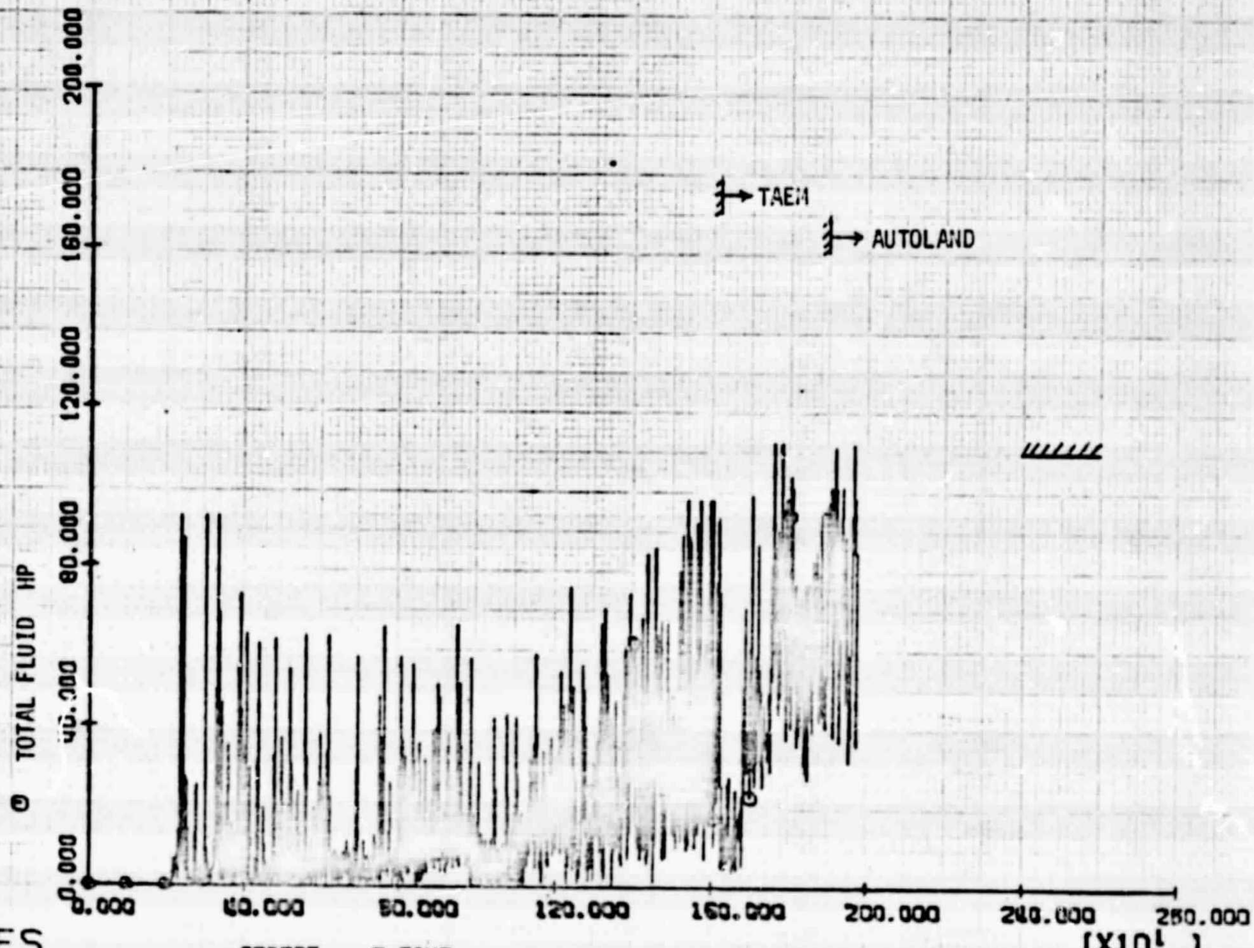
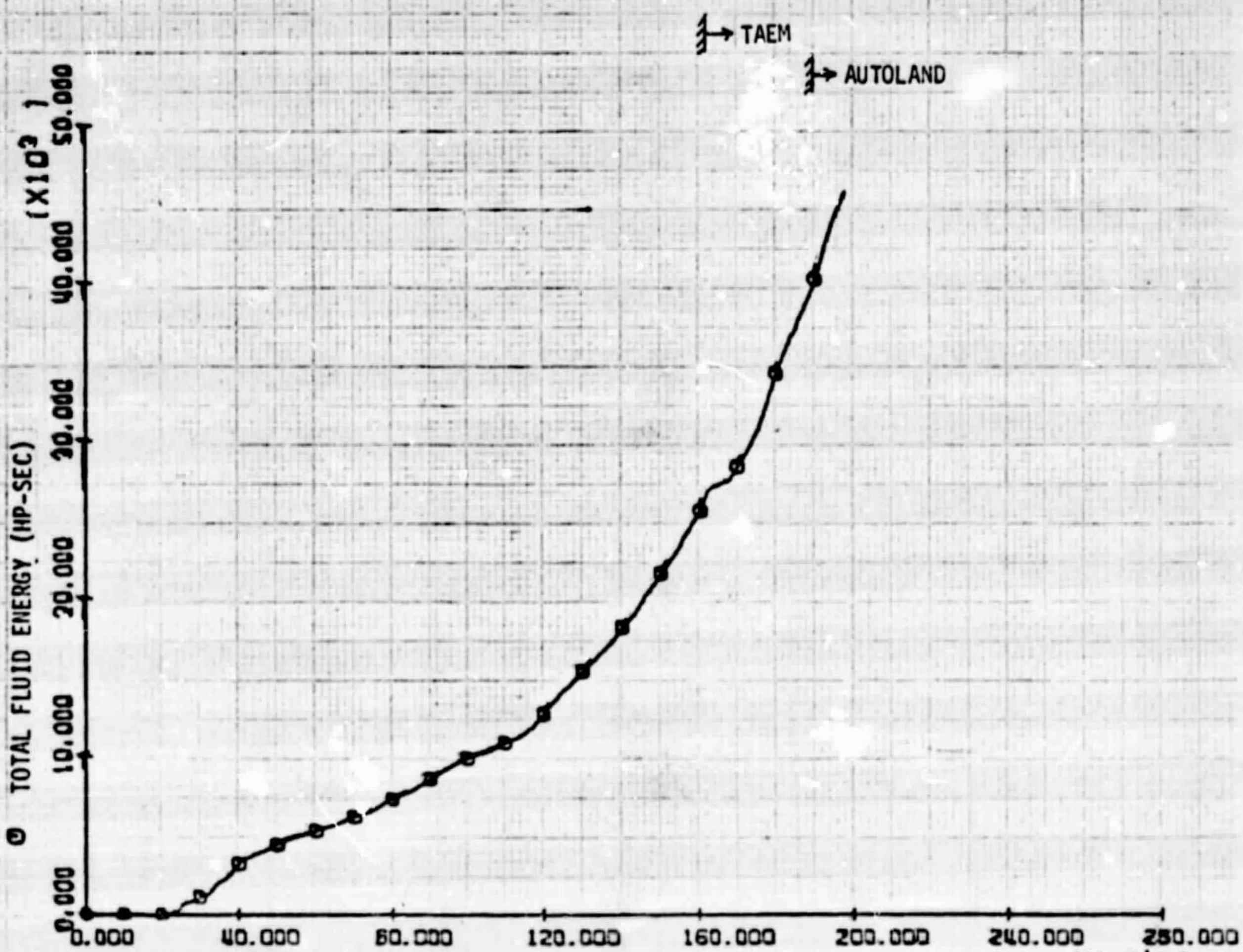


FIGURE 33

MISSION 3B WITH TWO HYDRAULIC SYSTEM FAILURES

WIND 9 TURBULENCE



SSFS

030875 & TIME

FIGURE TOTAL FLUID ENERGY

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

APPENDIX A

```
.ST PRATE
.E2C-03/08/75-03:35:47 (,0)

.BROUTINE PRATE      ENTRY POINT 000470

.ORAGE USED: CODE(1) 000472; DATA(0) 000024; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003   ACSC   000126
0004   ENVCOM 000507
0005   LECCOM 001652
0006   PRATEC 000011

.XTERNAL REFERENCES (BLOCK, NAME)

0007   COS
0010   NERR3$

.ORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001     000050 20L        0001     000172 30L        0001     000233 40L       0001     000
0001     000453 70L        0001     000461 80L        0003     000003 ACSC      0006 R   000
0003 R   000125 DDBFDN     0003 R   000124 DDBFUP     0006 R   000001 DDELV     0003 R   000
0003 R   000043 DDRELV     0003     000046 DDRF       0003 R   000121 DDRFCL    0003 R   000
0003 R   000045 DDRUD      0003 R   000003 DRF        0005 R   001650 DTR       0004     000
0006 R   000003 KWE1       0006 R   000006 KWE2       0006 R   000004 KQR1      0006 R   000
0006 I   000010 N          0006     000000 PRATEC     0006 R   000002 Q1        0006 R   000
0004     000506 TIME


         1.            SUBROUTINE PRATE
         2.            REAL KWE1,KQR1,KWE2,KGR2
         3.            COMMON/ACSC/ACSC(1)
         4.            COMMON/ENVCOM/ENV(1)
         5.            COMMON/LECCOM/LEC(1)
         6.            COMMON/PRATEC/PRATEC(9)
         7.            EQUIVALENCE(ENV(327),TIME)
         8.            EQUIVALENCE(LEC(937),DTR)
         9.            EQUIVALENCE(LEC(938),RTD)
        10.            EQUIVALENCE(ACSC( 4),DRF    ) , (ACSC(12),DDEMAX),
        11.           1            (ACSC(15),DDRMAX) , (ACSC(18),DDRFUP),
        12.           2            (ACSC(21),DDBF  ) , (ACSC(36),DDRELV),
        13.           3            (ACSC(37),DDELV ) , (ACSC(38),DDRUD ),
        14.           4            (ACSC(39),DDRF  ) , (ACSC(82),DDRFCL),
        15.           5            (ACSC(85),DDBFUP) , (ACSC(86),DDBFDN)
        16.            EQUIVALENCE(PRATEC( 1),DDFL   ) , (PRATEC( 2),DDELV ),
        17.           1            (PRATEC( 3),Q1    ) , (PRATEC( 4),KWE1   ),
        18.           2            (PRATEC( 5),KQR1  ) , (PRATEC( 6),Q2     ),
        19.           3            (PRATEC( 7),KWE2  ) , (PRATEC( 8),KGR2   ),
        20.           4            (PRATEC( 9),N     )
```

```
      DATA Q1 / 20.68 /
      DATA KQE1 / 0.681 /
      DATA KQR1 / 0.650 /
      DATA Q2 / 39.01 /
      DATA KQE2 / 1.362 /
      DATA KQR2 / 0.650 /
      DATA N / 1 /
C
C                          *** PRIORITY RATE LIMITING LOGIC ***
C                          THIS ROUTINE DETERMINES CONTROL SURFACE DEFLECTION
C                          RATE LIMITS AS A FUNCTION OF THE NUMBER OF FAILED
C                          HYDRAULIC SYSTEMS.
C                          SOURCE: 12 DEC 74 RI IL "AERODYNAMIC CONTROL SURFAC
C                          LIMITING - FSSR CHANGES"
C
      DBFL=0.0
      IF(DDBF.GT.0.0) DBFL=2.503
      IF(DDBF.LT.0.0) DBFL=2.503
      IF(2-N)10,20,50
   10 CONTINUE
C                          3 HYDRAULIC SYSTEMS OPERATING
      DDEMAX=20.0*DTR
      DDRMAX=10.0*DTR
      DDRFOP=5.0*DTR
      DDRFCL=-9.0*DTR
C                          SPEED BRAKE "SOFT STOP"
      IF(DRF.LE.6.0*DTR) DDRFCL=-1.0*DTR
      DDBFOP=-3.0*DTR
      DDBFDN=1.0*DTR
      GO TO 80
C
   20 CONTINUE
C                          2 HYDRAULIC SYSTEMS OPERATING
      DDEMAX=20.0*DTR
      DDRMAX=10.0*DTR
      DDRFOP=Q2*DTR-KQE2*ABS(DDLELV)-KQE2*ABS(DDRELV)-KQR2*ABS(DDRUD)-
     1DBFL*DTR
      DDRFOP=DDRFOP*COS(35.*DTR)
      IF(DDRFOP.GT.5.0*DTR) DDRFOP=5.0*DTR
      IF(DDRFOP.LT.0.) DDRFOP=0.
      IF(DRF.LE.6.0*DTR) GO TO 30
      DDRFCL=-(Q2*DTR-KQE2*ABS(DDLELV)-KQE2*ABS(DDRELV)-KQR2*ABS(DDRUD)-
     1DBFL*DTR)
      DDRFCL=DDRFCL*COS(35.*DTR)
      IF(DDRFCL.LT.-9.0*DTR) DDRFCL=-9.0*DTR
      IF(DDRFCL.GT.0.) DDRFCL=0.
      GO TO 40
   30 CONTINUE
C                          SPEED BRAKE "SOFT STOP"
      DDRFCL=-(Q2*DTR-KQE2*ABS(DDLELV)-KQE2*ABS(DDRELV)-KQR2*ABS(DDRUD)-
     1DBFL*DTR)
      DDRFCL=DDRFCL*COS(35.*DTR)
      IF(DDRFCL.LT.-1.0*DTR) DDRFCL=-1.0*DTR
      IF(DDRFCL.GT.0.) DDRFCL=0.
   40 CONTINUE
      DDBFOP=-3.0*DTR
      DDBFDN=1.0*DTR
```

```
      GO TO 80
C
   50 CONTINUE
C                          1 HYDRAULIC SYSTEM OPERATING
      DDEMAX=13.0*DTR
      DDELV=.5*(DDLELV+DDRELV)
      DDRMAX=19.65*DTR-1.408*ABS(DDELV)
      DDRMAX=DDRMAX*COS(35.*DTR)
      IF(DDRMAX.GT.4.45*DTR) DDRMAX=4.45*DTR
      DDRFOP=Q1*DTR-KQE1*ABS(DDLELV)-KQE1*ABS(DDRELV)-KQR1*ABS(DDRUD)-
     1DDBFL*DTR
      DDRFOP=DDRFOP*COS(35.*DTR)
      IF(DDRFOP.GT.2.50*DTR) DDRFOP=2.50*DTR
      IF(DDRFOP.LT.0.) DDRFOP=0.
      IF(DRF.LE.6.0*DTR) GO TO 60
      DDRFCL=-(Q1*DTR-KQE1*ABS(DDLELV)-KQE1*ABS(DDRELV)-KQR1*ABS(DDRUD)-
     1DDBFL*DTR)
      DDRFCL=DDRFCL*COS(35.*DTR)
      IF(DDRFCL.LT.-4.45*DTR) DDRFCL=-4.45*DTR
      IF(DDRFCL.GT.0.) DDRFCL=0.
      GO TO 70
   60 CONTINUE
C                          SPEED BRAKE @SOFT STOP@
      DDRFCL=-(Q1*DTR-KQE1*ABS(DDLELV)-KQE1*ABS(DDRELV)-KQR1*ABS(DDRUD)-
     1DDBFL*DTR)
      DDRFCL=DDRFCL*COS(35.*DTR)
      IF(DDRFCL.LT.-1.0*DTR) DDRFCL=-1.0*DTR
      IF(DDRFCL.GT.0.) DDRFCL=0.
   70 CONTINUE
      DDBFUP=-1.5*DTR
      DDBFDN=0.5*DTR
   80 CONTINUE
      RETURN
      END

OF COMPILATION:          NO  DIAGNOSTICS.
```

```
R 000036 TFPS3X     0006 R 000033 TFPTMX      0006 R 000114 TP1X2M      0006 R 000115 T
R 000117 TP2X3M     0006 R 000107 TP3X1M      0006 R 000113 TP3X2M      0004 R 000506 I
```

APPENDIX B

```
      SUBROUTINE FMP
      COMMON/ACSC/ACSC(1)
       COMMON/ENVCOM/ENV(1)
      COMMON/LECCOM/LECCOM(1)
      COMMON/FMPC/FMPC(81)
      DATA C /0./
      REAL LELVNR
       EQUIVALENCE(ENV(327),TVEH)
      EQUIVALENCE(ACSC(37),LELVNR)
      EQUIVALENCE(ACSC(36),RELVNR)
      EQUIVALENCE(ACSC(38),RUDRAT)
      EQUIVALENCE(ACSC(39),SBRATE)
      EQUIVALENCE(ACSC(21),BFRATE)
      EQUIVALENCE(LECCOM(937),DTR)
      EQUIVALENCE(LECCOM(938),RTD)   , (FMPC(1),FPELU)    ,
     1            (FMPC(2),FPELI)    , (FMPC(3),FPERU)    ,
     2            (FMPC(4),FPERI)    , (FMPC(5),FPRUD)    ,
     3            (FMPC(6),FPSB)     , (FMPC(7),FPBF)     ,
     4            (FMPC(8),FPEL)     , (FMPC(9),FPER)     ,
     5            (FMPC(10),FPS1)    , (FMPC(11),FPS2)    ,
     6            (FMPC(12),FPS3)    , (FMPC(13),FPET)    ,
     7            (FMPC(14),FPRT)    , (FMPC(15),FPT)     ,
     8            (FMPC(16),FPELMX)  , (FMPC(17),FPERMX)  ,
     9            (FMPC(18),FPETMX)  , (FMPC(19),FPRTMX)  ,
     1            (FMPC(20),FPTMX)   , (FMPC(21),FPS1MX)  ,
     2            (FMPC(22),FPS2MX)  , (FMPC(23),FPS3MX)  ,
     3            (FMPC(24),TFPELX)  , (FMPC(25),TFPERX)  ,
     4            (FMPC(26),TFPETX)  , (FMPC(27),TFPRTX)  ,
     5            (FMPC(28),TFPTMX)  , (FMPC(29),TFPS1X)  ,
     6            (FMPC(30),TFPS2X)  , (FMPC(31),TFPS3X)
      EQUIVALENCE(FMPC(32),FEER)     , (FMPC(33),FEEL)    ,
     1            (FMPC(34),FERUR)   , (FMPC(35),FESB)    ,
     2            (FMPC(36),FEBF)    , (FMPC(37),FES1)    ,
     3            (FMPC(38),FES2)    , (FMPC(39),FES3)    ,
     4            (FMPC(40),FPERL)   , (FMPC(41),FPELL)   ,
     5            (FMPC(42),FPRUDL)  , (FMPC(43),FPSBL)   ,
     6            (FMPC(44),FPBFL)   , (FMPC(45),FPS1L)   ,
     7            (FMPC(46),FPS2L)   , (FMPC(47),FPS3L)   ,
     8            (FMPC(48),TVEHL)   , (FMPC(49),DTC)
      EQUIVALENCE(FMPC(50),FET)      , (FMPC(51),FPS2X1)  ,
     1            (FMPC(52),FPS3X1)  , (FMPC(53),FPS1X2)  ,
     2            (FMPC(54),FPS3X2)  , (FMPC(55),FPS1X3)  ,
     3            (FMPC(56),FPS2X3)  , (FMPC(57),FES1X2)  ,
     4            (FMPC(58),FES1X3)  , (FMPC(59),FES2X1)  ,
     5            (FMPC(60),FES2X3)  , (FMPC(61),FES3X1)  ,
     6            (FMPC(62),FP1X2L)  , (FMPC(63),FP1X3L)  ,
     7            (FMPC(64),FP2X1L)  , (FMPC(65),FP2X3L)  ,
     8            (FMPC(66),FP3X1L)  , (FMPC(67),FP3X2L)
      EQUIVALENCE(FMPC(68),C      )  , (FMPC(69),FP2X1M)  ,
     1            (FMPC(70),TP2X1M)  , (FMPC(71),FP3X1M)  ,
     2            (FMPC(72),TP3X1M)  , (FMPC(73),FP1X2M)  ,
     3            (FMPC(74),TP1X2M)  , (FMPC(75),FP3X2M)  ,
     4            (FMPC(76),TP3X2M)  , (FMPC(77),FP1X3M)  ,
     5            (FMPC(78),TP1X3M)  , (FMPC(79),FP2X3M)  ,
     6            (FMPC(80),TP2X3M)
      EQUIVALENCE(FMPC(81),FES3X2)
C
C                             SUBROUTINE FMP IS CALLED BY ACS15.
```

```
C
C
C                                          COMPUTE FLUID HORSE POWER FOR EACH SURF
C
      FPELO=ABS(LELVNR)*RTD*3000.*0.719*.00058333
      FPELI=ABS(LELVNR)*RTD*3000.*1.321*.00058333
      FPERO=ABS(RELVNR)*RTD*3000.*0.719*.00058333
      FPERI=ABS(RELVNR)*RTD*3000.*1.321*.00058333
      FPRUD=ABS(RUDRAT)*RTD*3000.*1.947*.00058333/COS(35.*DTR)
      FPSB =ABS(SBRATE)*RTD*3000.*2.996*.00058333/COS(35.*DTR)
      FPBF=0.0
      IF(BFRATE.GT.0.0) FPBF=1.938*3000.*.00058333
      IF(BFRATE.LT.0.0) FPBF=2.500*3000.*.00058333
      FPEL=FPELO+FPELI
      FPER=FPERO+FPERI
      FPET=FPEL+FPER
      FPRT=FPRUD+FPSB
      FPT=FPET+FPRT+FPBF
C
C                                   HYDRAULIC SYSTEM POWER AND ENERGY ANALYSIS
C
      FAILSW=1.
C                                              FAILSW=0. ZERO OR ONE HYD SYS FAIL
C                                                      2. TWO HYD SYSTEMS FAILED
      IF(FAILSW-0.)170,100,170
C
C                                   NORMAL OR SINGLE SYSTEM FAILURE OPERATION
C
  100 FPS1=FPERO+FPRUD/3.+FPSB/3.+FPBF/3.
      FPS2=FPELI+FPRUD/3.+FPSB/3.+FPBF/3.
      FPS3=FPELO+FPERI+FPRUD/3.+FPSB/3.+FPBF/3.
      FPS2X1=FPELI+FPERO+FPRUD/2.+FPSB/2.+FPBF/2.
      FPS3X1=FPELO+FPERI+FPRUD/2.+FPSB/2.+FPBF/2.
      FPS1X2=FPELI+FPERO+FPRUD/2.+FPSB/2.+FPBF/2.
      FPS3X2=FPELO+FPERI+FPRUD/2.+FPSB/2.+FPBF/2.
      FPS1X3=FPERI+FPERO+FPRUD/2.+ FPSB/2.+FPBF/2.
      FPS2X3=FPELI+FPELO+FPRUD/2.+FPSB/2.+FPBF/2.
C
C                                              SAVE MAX VALUES
C
      IF(FPEL.LT.FPELMX) GO TO 10
      FPELMX=FPEL
      TFPELX=TVEH
   10 IF(FPER.LT.FPERMX) GO TO 20
      FPERMX=FPER
      TFPERX=TVEH
   20 IF(FPET.LT.FPETMX) GO TO 30
      FPETMX=FPET
      TFPETX=TVEH
   30 IF(FPRT.LT.FPRTMX) GO TO 40
      FPRTMX=FPRT
      TFPRTX=TVEH
   40 IF(FPT.LT.FPTMX) GO TO 50
      FPTMX=FPT
      TFPTMX=TVEH
   50 IF(FPS1.LT.FPS1MX) GO TO 60
      FPS1MX=FPS1
```

```
      TFPS1X=TVEH
   60 IF(FPS2.LT.FPS2MX) GO TO 70
      FPS2MX=FPS2
      TFPS2X=TVEH
   70 IF(FPS3.LT.FPS3MX) GO TO 80
      FPS3MX=FPS3
      TFPS3X=TVEH
   80 CONTINUE
      IF(FPS2X1.LT.FP2X1M) GO TO 81
      FP2X1M=FPS2X1
      TP2X1M=TVEH
   81 IF(FPS3X1.LT.FP3X1M) GO TO 82
      FP3X1M=FPS3X1
      TP3X1M=TVEH
   82 IF(FPS1X2.LT.FP1X2M) GO TO 83
      FP1X2M=FPS1X2
      TP1X2M=TVEH
   83 IF(FPS3X2.LT.FP3X2M) GO TO 84
      FP3X2M=FPS3X2
      TP3X2M=TVEH
   84 IF(FPS1X3.LT.FP1X3M) GO TO 85
      FP1X3M=FPS1X3
      TP1X3M=TVEH
   85 IF(FPS2X3.LT.FP2X3M) GO TO 86
      FP2X3M=FPS2X3
      TP2X3M=TVEH
   86 CONTINUE
C
C                                        INTEGRATE FLUID HORSE POWER
C
      DTC=TVEH-TVEHL
      FEER=.5*(FPER+FPERL)*DTC+FEER
      FEEL=.5*(FPEL+FPELL)*DTC+FEEL
      FERDR=.5*(FPRUD+FPRUDL)*DTC+FERDR
      FESB=.5*(FPSB+FPSBL)*DTC+FESB
      FEBF=.5*(FPBF+FPBFL)*DTC+FEBF
      FELT=FEER+FEEL
      FERT=FERDR+FESB
      FET=FELT+FERT+FEBF
      FES1=.5*(FPS1+FPS1L)*DTC+FES1
      FES2=.5*(FPS2+FPS2L)*DTC+FES2
      FES3=.5*(FPS3+FPS3L)*DTC+FES3
      FES2X1=.5*(FPS2X1+FP2X1L)*DTC+FES2X1
      FES3X1=.5*(FPS3X1+FP3X1L)*DTC+FES3X1
      FES1X2=.5*(FPS1X2+FP1X2L)*DTC+FES1X2
      FES3X2=.5*(FPS3X2+FP3X2L)*DTC+FES3X2
      FES1X3=.5*(FPS1X3+FP1X3L)*DTC+FES1X3
      FES2X3=.5*(FPS2X3+FP2X3L)*DTC+FES2X3
C
C                                        SAVE LAST VALUES
C
      TVEHL=TVEH
      FPERL=FPER
      FPELL=FPEL
      FPRUDL=FPRUD
      FPSBL=FPSB
      FPBFL=FPBF
```

```
      FPS1L=FPS1
      FPS2L=FPS2
      FPS3L=FPS3
      FP1X2L=FPS1X2
      FP1X3L=FPS1X3
      FP2X1L=FPS2X1
      FP2X3L=FPS2X3
      FP3X1L=FPS3X1
      FP3X2L=FPS3X2
      GO TO 330
  170 CONTINUE
C
C                            TWO SYSTEMS FAILED OPERATION
C
      IF(FPT.LT.FPTMX) GO TO 171
      FPTMX=FPT
      TFPTMX=TVEH
  171 DTC=TVEH-TVEHL
      FET=.5*(FPT+FPTL)*DTC+FET
      FPTL=FPT
      TVEHL=TVEH
  330 CONTINUE
      RETURN
      END

D OF COMPILATION:          NO  DIAGNOSTICS.

   -----      OFT/ETTAAL
```