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RESULTS OF THE GEMINI I CENTRIFUGE PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Houston, Texas

April 30, 1964

NASA GENERAL WORKING PAPER NO. 10,026

RESULTS OF THE GEMINI I CENTRIFUGE PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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RESULTS OF THE GEMINI PHASE I CENTRIFUGE PROGRAM

(ENGINEERING EVALUATION AND PILOT FAMILIARIZATION)

SUMMARY

The results of this program, conducted at Johnsville, Pennsylvania during the period of July 1, 1963 through August 2, 1963, indicate that the present Gemini cockpit displays and controls configuration pertinent to launch and reentries are satisfactory (with a few minor exceptions). The Gemini reentry control problem presented no difficulty to the pilot. The generalized lunar reentry acceleration profiles had no significant effect on the pilot or on his performance.

INTRODUCTION

This report presents major results of the Gemini I Centrifuge Program conducted at the United States Naval Air Development Center's Aviation Medical Acceleration Laboratory, July 1, 1963 through August 2, 1963. The generalized Lunar reentry phase of the program utilizing the Gemini centrifuge fixture is included in Appendix A.

The program was conducted by the Spacecraft Operations Branch personnel of Flight Crew Support Division, Manned Spacecraft Center, Houston, with the assistance of personnel of the McDonnell Aircraft Corporation (MAC) and the Naval Air Development Center. Crew Systems Division provided suit support and the Center Medical Operations Office provided medical support for this program.

The centrifuge and associated McDonnell Aircraft Corporation and NASA equipment simulated the command pilot's position of the Gemini spacecraft (configuration as of July 1, 1963). The controls and displays necessary for the pilot to perform the required tasks during launch and reentry were active.

The objectives of the program were:

1. To perform an engineering evaluation of Gemini spacecraft cockpit hardware critical to launch and reentry.

2. Familiarize pilots with typical Gemini launch and reentry acceleration profiles and associated tasks.

3. Evaluate prototype Gemini pressure suit under acceleration loads.

4. To study the possible adverse effects on the pilot sustained high acceleration loads that could conceivably be encountered during a Lunar Reentry into the earth's atmosphere (see Appendix A.)

NOTATIONS AND SYMBOLS

C	maximum spacecraft diameter, ft
g	gravitational acceleration, ft/sec^2
h	altitude, ft
$\dot{h}$	time rate of change of altitude, ft/sec
I_x	moment of inertia about spacecraft X axis, slug - ft^2
I_y	moment of inertia about spacecraft Y axis, slug - ft^2
I_z	moment of inertia about spacecraft Z axis, slug - ft^2
a_x, a_y, a_z	Computed acceleration in each axis, ft/sec^2
a_T	computed total acceleration, ft/sec^2
m	mass of spacecraft, slugs
p	spacecraft roll rate about spacecraft X axis, rad/sec
q	spacecraft pitch rate about spacecraft Y axis, rad/sec
r	spacecraft yaw rate about spacecraft Z axis, rad/sec
$\dot{p}, \dot{q}, \dot{r}$	time rate of change of p,q,r, rad/sec^2
$\bar{q}$	dynamic pressure, lb/ft^2
S	reference area used in computing aerodynamic forces and moments, ft^2
u	spacecraft velocity component in X direction, ft/sec

v	spacecraft velocity component in Y direction, ft/sec
w	spacecraft velocity component in Z direction, ft/sec
V_T	total velocity component, ft/sec
X_a	aerodynamic force in X direction, lb
Y_a	aerodynamic force in Y direction, lb
Z_a	aerodynamic force in Z direction, lb
α_T	total angle of attack between free stream velocity and X axis, rad
β_T	total angle between free stream velocity and Z axis, rad
γ	flight path angle, rad
η	roll angle used in aerodynamics, rad
ϕ, θ, ψ	conventional euler angles measured between moving earth axes and spacecraft axes, rad
ϕ_g, θ_g, ψ_g	display drive angles measured between moving earth axes and spacecraft axes, rad
ω	angular rotation of centrifuge arm - rad/sec

APPARATUS AND EQUIPMENT

The referenced reports (references 1 and 2) define the trainer specifications and operation, equations of motion, task description, sequence of events and other pertinent material necessary to fully implement the evaluation and familiarization portion of the program. Figures 1, 2, and 3 are photographs of the trainer installed in the centrifuge gondola. Several controls and displays were static and installed for completeness and realism. The active controls and displays consisted of the following.

Controls

1. Ejection seat "D" ring

2. Abort handle

3. Attitude controller

4. Boost insert switch

5. Retro switch

6. Pilot ready switch (installed only for this program)

7. Attitude control selection switch (RATE CMD and DIRECT CMD functions)

Command Astronauts Main Panel

1. All attitude and rate indicator

2. Event timer

3. Stage I Engine underpressure light

4. Stage II Engine underpressure light

5. Staging light

6. Stage I tank pressure gages (fuel and oxidizer)

7. Stage II tank pressure gages (fuel and oxidizer)

8. Longitudinal Accelerometer

Center Panel and Pedestal

1. Fairing JETT switch

2. SEP SPCFT tel-light/switch

3. O_2 high rate tel-light/switch

4. BTRY PWR tel-light

5. RCS tel-light/switch

6. SEP OAMS lines tel-light/switch

7. SEP ELEC tel-light/switch

8. SEP ADAPT tel-light/switch

9. ARM AUTO RETRO tel-light/switch

10. MAN FIRE RETRO switch

11. START COMP tel-light/switch

In order to provide the most realistic simulation possible, small changes in the sequence of events from those specified in reference 1 were required. Therefore, a revised sequence of events for each complete case is given in Appendix B. Exceptions are cases 6 and 7 which were reentries only. It was not possible to mechanize a full six-degree of freedom simulation due to computer limitations at the Aeronautical Computer Laboratory at NADC. In order to achieve the desired reliability and repeatibility, the time rate of change of altitude ($\dot{h}$) was programed for all reentries. Pilot control inputs were closed loop with respect to flight displays and consequently presented a realistic control task for spacecraft dynamics. Appendix D contains the equations of motion used to mechanize the simulation.

PROCEDURES

A total of seven cases were simulated during this program and are summarized below. A complete sequence of events for the first five cases is included in Appendix B.

1. A normal launch acceleration profile with a normal, modulated lift reentry.

2. An abort situation occurring below 70,000 ft. (T = 85).

3. An abort situation occurring just prior to staging (T = 145 seconds) with a maximum lift reentry.

4. An abort situation occurring just after staging (T = 150) with a maximum lift reentry.

5. An abort situation occurring just prior to insertion (T = 326 with a maximum lift reentry.

6. A reentry representing the highest abort reentry acceleration load (flying a maximum lift profile) that could occur with an abort along the nominal launch flight path and a velocity of 14,800 FPS.

7. A maximum lift reentry representing the acceleration loads equal to the design limit of the Gemini spacecraft (15 g). The initial conditions were a velocity of 19,000 FPS and a flight path angle of 7.6°. The initial velocity condition of

19,000 FPS was chosen because above this velocity the reentry becomes heat critical rather than 'g' critical. A 7.6° flight angle was chosen because it required a 5.46° deviation from the nominal flight path angle (γ = 2.19°) to achieve the peak reentry acceleration load of 15 g's.

The pilot had the option of utilizing either the rate command or the direct control modes of operation. The majority of the runs were made using the direct control mode because the rate command mode represented a fairly simple task.

Figures 4 through 12 represent typical recorded data for each case during the program. Figures 4, 5, 6, 7 and 8 show different normal reentries from orbit. Each figure represents a different impact point. Figure 9 is an abort reentry in which the abort was initiated just prior to staging (T = 145 seconds). Figure 10 is an abort reentry in which the abort was initiated just prior to insertion (T = 327 seconds). Figure 11 is the worst case abort reentry that could occur assuming an abort at 14,800 FPS along the nominal launch flight path. Figure 12 shows the spacecraft design limit abort reentry (INITIAL conditions of V = 19,000 FPS, γ = 7.6°).

Each of the figures shows complete reentries. Generally launches are not shown because all launch profiles were the same. The recorded data for each run was:

1. Computed total acceleration, a_T
2. Computed acceleration in each axis, a_x, a_y, a_z
3. Measured acceleration in each axis, a_x, a_y, a_z
4. Dynamic pressure, $\bar{q}$
5. Total velocity, V_T
6. Altitude, h
7. Angle of attack, α
8. Fuel consumption, percent
9. Roll Rate, p
10. Pitch rate, q
11. Yaw rate, r

12. Spacecraft velocity component in Y direction, v

13. Spacecraft velocity component in Z direction, w

14. Aerodynamic roll angle, η

15. Roll director needle position (ϕ Actual - ϕ Command - p)

16. Stick position in all three axes

17. Control torque in each axis

18. Spacecraft attitudes

DISCUSSION OF RESULTS

Three pilots participated in the engineering evaluation portion of the program. Each pilot wore the latest Gemini prototype pressure suits and individually contoured seats. Runs were accomplished with the suits both pressurized and unpressurized. Twelve pilots participated in the familiarization runs, however, only two pilots participated in cases 6 and 7. Table I gives a complete tabulation of static and dynamic runs for each participant in the program. This table also gives the run conditions, that is, control mode, suit condition, which were complete runs, and which were "reentry only" runs.

Each pilot was debriefed upon completion of his scheduled series of runs. Appendix C presents a list of the questions asked each pilot. The following paragraphs summarize the pilot debriefing comments, with primary emphasis on comments made by the three engineering evaluation pilots.

Hand controller.- As originally designated and installed the Gemini hand controller required 28 in-lbs torque for full deflection (±10°) in the pitch and roll axes and 12.5 in-lbs torque for full deflection (±10°) in the yaw axis. These torques were reduced approximately 25% in each axis to 8.5 in-lbs torque for full deflection in the yaw axis, and 21 in-lb torque in the pitch and roll axes. Greater satisfaction was then expressed with the design and operation of the controller in all modes of operation during reentry. Pilot consensus was that the handle grip should be individually contoured.

Ejection seat and support (pressure suit runs only).- General dissatisfaction was expressed with the backboard contours used during this program. The "D" Ring was not evaluated since it was undergoing redesign at the time. Some blocking of the head rest was required to position the head properly with respect to the back and the panel. Calf supports and

heel stirrups were too small and prevented feet and legs from being restrained properly.

Restraint system.- A universal restraint harness was used for this program; therefore, no valid evaluation of the restraint system was obtained. However, buckles and latches were spacecraft hardware and pilot comments concerning these items were than their design and operation was satisfactory.

Pressure suit.- The latest personal fitted Gemini prototype pressure suits were used for the engineering evaluation runs. Generally, the suits were considered satisfactory. Some problems were encountered with fitting of the suit to the individual pilot under pressurized suit conditions. In addition, some restraint in mobility was experienced, particularly mobility of the wrist, under pressurized suit conditions.

Other controls and displays.- All other controls and displays were adequate and functionally satisfactory under acceleration loads. It was felt that the abort handle should be made larger. Dissatisfaction was expressed with the manual retrofire procedure. This procedure required that the left seat (command) pilot reach over to the sequence panel with his left hand to initiate retrofire or that the second pilot (right seat) initiate retrofire. The other and obviously undesirable alternative was for the command pilot to remove his right hand from the attitude controller to initiate a manual retrofire.

Dissatisfaction was expressed with the scaling of the flight director needles for reentry control (5 degrees per second full scale in all three axes). The scaling was increased to 10° per second full scale in all three axes early in the program, which was found to be more satisfactory for all reentry cases. The FDI's were not active during launch.

CONCLUDING REMARKS

In conclusion it can be said that the control tasks for the acceleration profile studies presented no difficulty. The scaling of 10° per second in all axes on the FDI appeared adequate for the reentry control task. Finally, more design work needs to be accomplished with the pressure suit-seat interface to provide greater pilot comfort and mobility.

REFERENCES

1. Coe, Frank S., and Higgins, Rodney: "Gemini Centrifuge Program Outline - Phase I (Engineering Evaluation and Pilot Familiarization)", NASA General Working Paper No. 10,002, December 3, 1962.

2. Mullaney, R. J.: "Gemini Centrifuge Training", McDonnell Report 9137 dated April 5, 1963.

TABLE I.-

RUN TABULATION
ENGINEERING EVALUATION
(PILOTS A,B,C SUITED)

CONDITIONS / PROBLEM	PRESSURIZED SUIT								UNPRESSURIZED SUIT							
	DIRECT CMD				RATE CMD				DIRECT CMD				RATE CMD			
	DYNAMIC		STATIC		DYNAMIC		STATIC		DYNAMIC		STATIC		DYNAMIC		STATIC	
	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R
I-A	A B		B	A C(2)	C	C				BC(3)		B C	C			
I-B	A B C		B C	A(2)						B C		B C				
I-C				C					A C			A				
I-D	A			A												
I-E	A			A												
2	A B C															
3	A B C		B B	A C					B C	B C		B C				
4	B	C C		C		C			B C		B C					
5	B	C	B						C	B		C				
TOTAL	15	3	6	11	1	2	0	0	7	9	2	8	1			

RUN TABULATION
FAMILIARIZATION
(PILOTS D THROUGH Q IN SHIRT-SLEEVES)

CONDITIONS / PROBLEM	DIRECT COMMAND				RATE COMMAND			
	DYNAMIC		STATIC		DYNAMIC		STATIC	
	C	R	C	R	C	R	C	R
I-A	DFGGHHJ JLLMMNQ	E F	G H L	DEFJJL L M N Q	K Q	K	H K Q	K K
I-B	DER	F	DERF		F			
I-C	D G	G		DGG				
I-D		D		D				
I-E	DHHJK MMNP	ELL	HMMN	DEJKL MNNP	JKN			K
2								
3	DEFFGGH HJJKKLL MNNQ	M	OFFJGH KLMN	ELQ	P		P	
4	D E			D E				
5	DEFFGG	K L	HJL	DEFGKP	KP			
6	MNN		MNN		M			
7	M N		MNN	MN				
TOTAL	64	11	31	34	12	1	4	3

NOTES:

1. C-COMPLETE RUN
2. R-RE-ENTRY RUN
3. TOTALS

	DYNAMIC	STATIC
ENGINEERING EVALUATION	38	27
FAMILIARIZATION	88	72

TABLE II.

RUN TABULATION
GENERALIZED LUNAR RE-ENTRY

PILOT \ PROBLEM		1	2	3	4
A	DYNAMIC	X	X X		
	STATIC		X		
B	DYNAMIC		+	+	+
	STATIC		+		+
C	DYNAMIC	X	+	+	X
	STATIC	X	+	+	X

NOTES:

1. PILOT "A" MADE RUNS IN PROTOTYPE GEMINI PRESSURE SUIT IN "SUIT-SOFT CONDITION"
2. X–NO ARM SUPPORT
3. +–ARM SUPPORT
4. PROBLEM 1–8g 1st PEAK
5. PROBLEM 2–6g 1st PEAK
6. PROBLEM 3–10g 1st PEAK, 6.7g PLATEAU
7. PROBLEM 4–10g 1st PEAK, 9.5g 2nd PEAK

Figure 1.- Gemini gondola installation

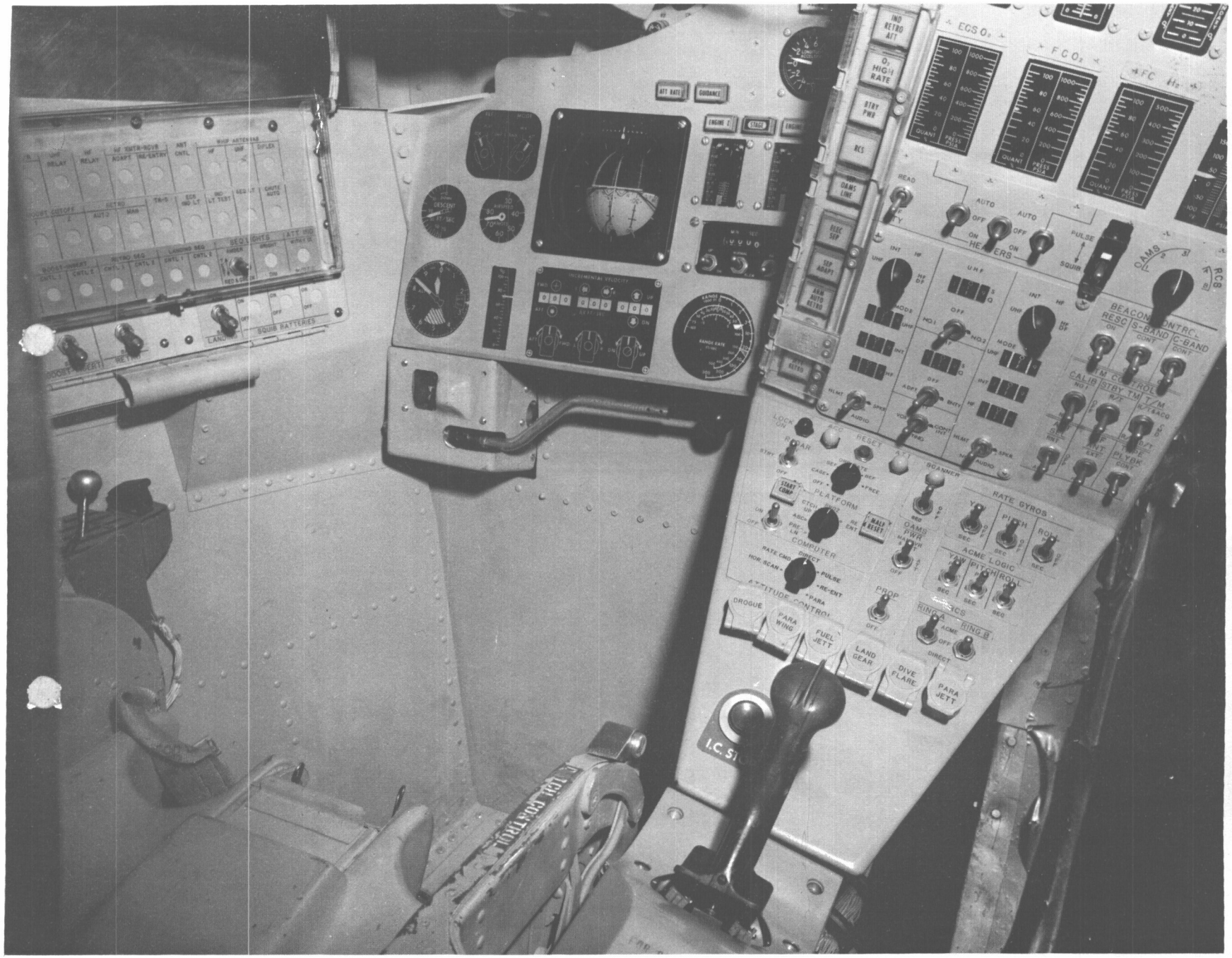
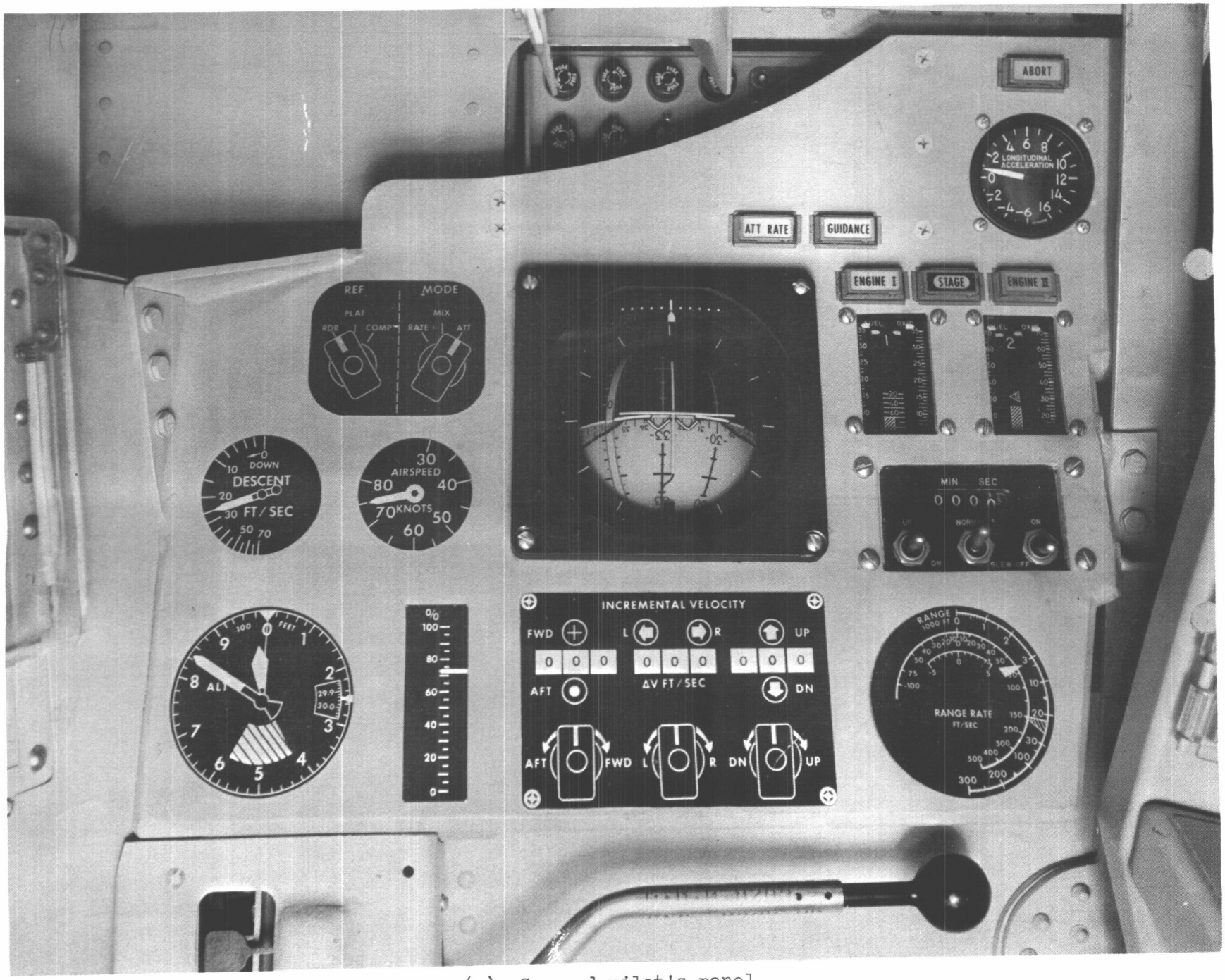
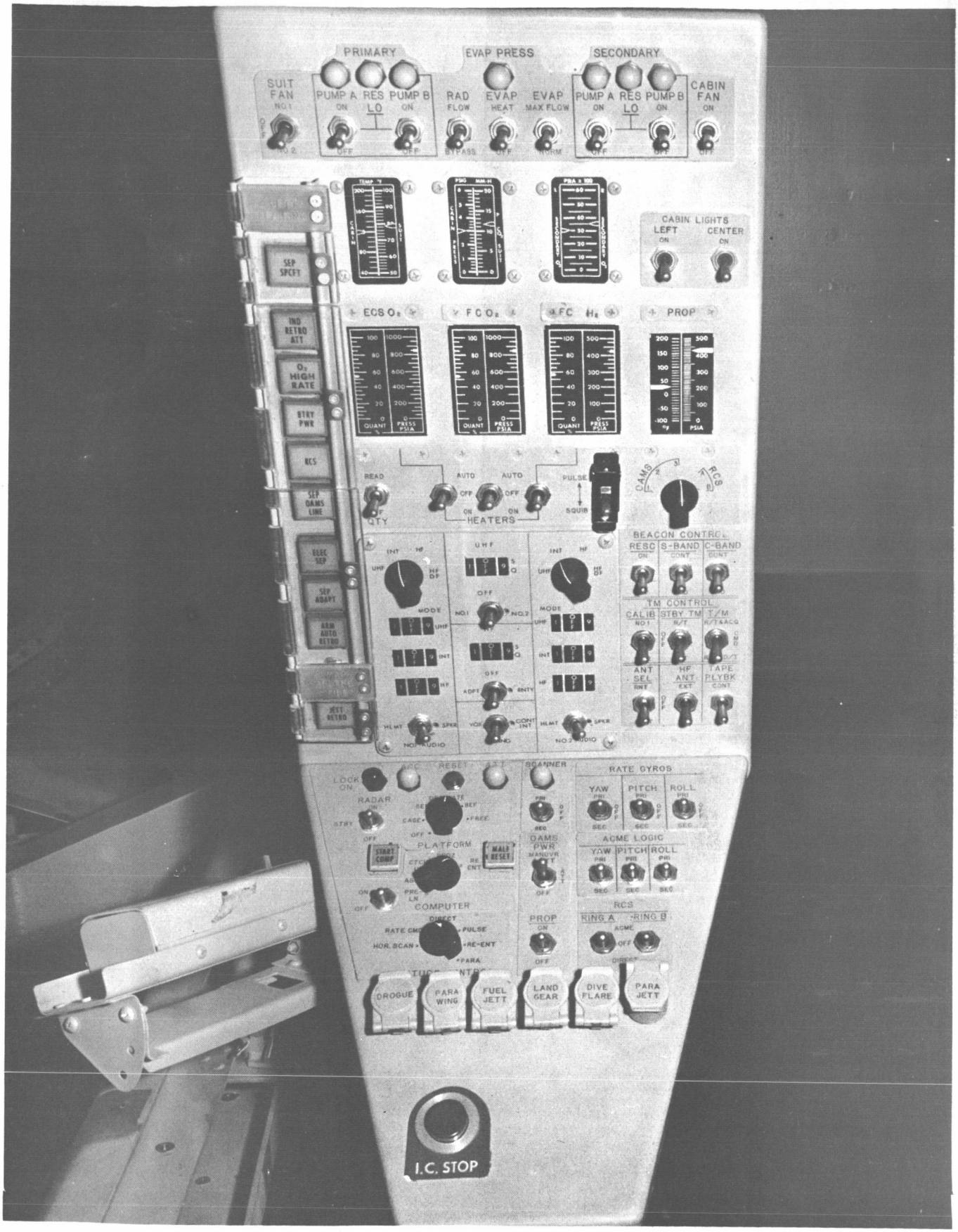


Figure 2.- Gemini command pilot's station



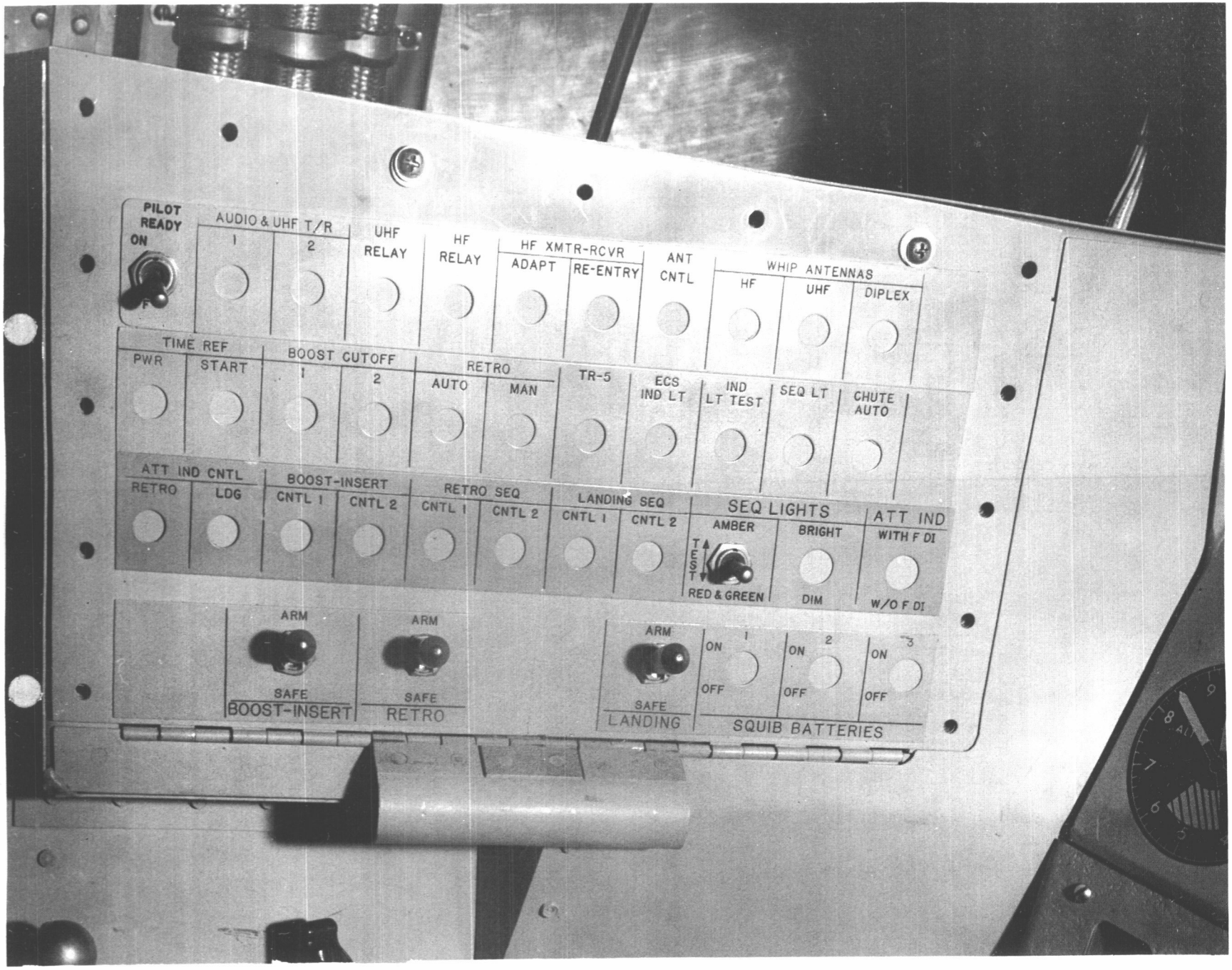
(a) Command pilot's panel

Figure 3.- Command pilot's panel



(b) Center pedestal

Figure 3.- Continued



(c) Left-hand switch/circuit breaker panel

Figure 3. Concluded

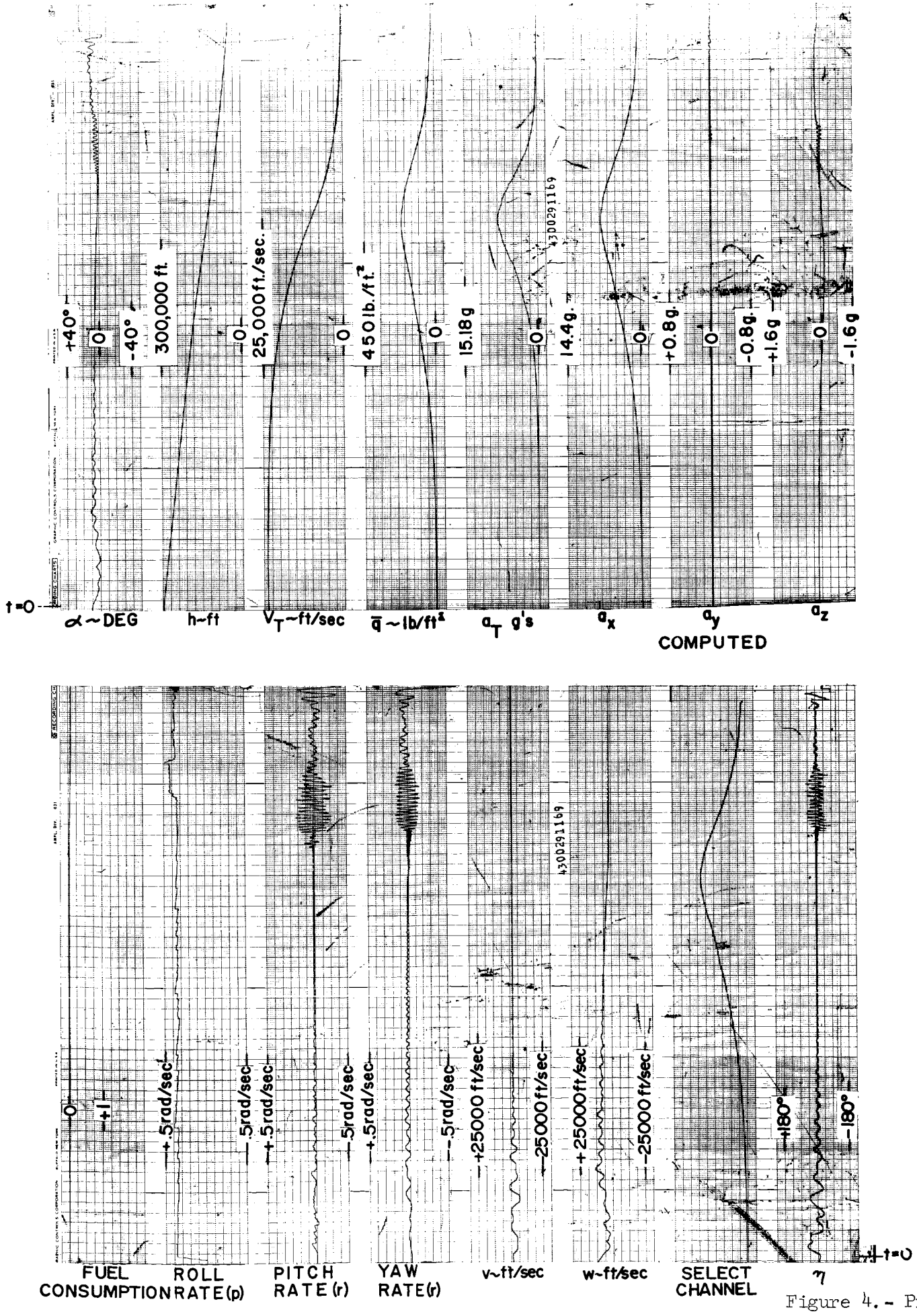
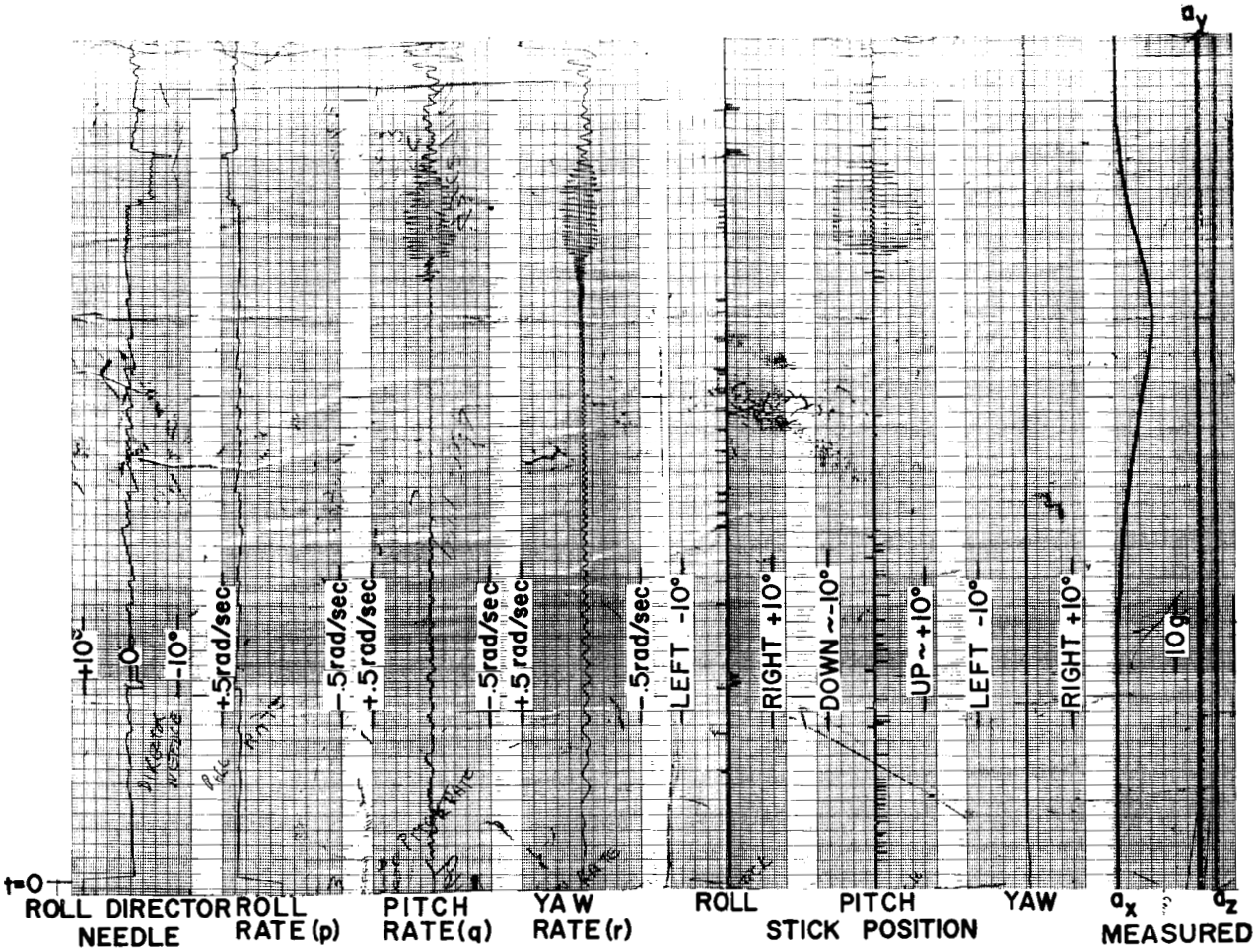
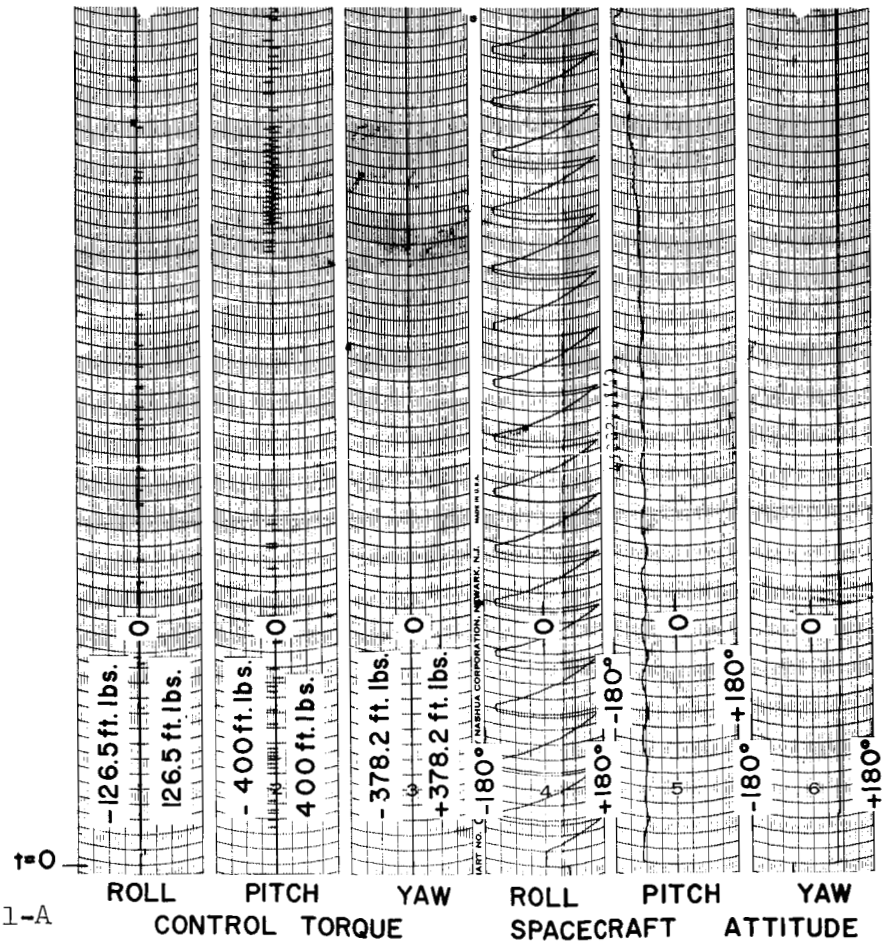

t=0
α~DEG
+40°
0
-40°
h~ft
300,000 ft.
0
V_T~ft/sec
25,000 ft./sec.
0
$\bar{q}$~lb/ft²
450 lb./ft.²
0
a_T g's
15.18 g
0
a_x
14.4 g.
0
a_y
+0.8 g.
0
a_z
-0.8 g.
+1.6 g
0
-1.6 g
COMPUTED
FUEL CONSUMPTION
0
+1
ROLL RATE (p)
+.5 rad/sec
PITCH RATE (r)
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
YAW RATE (r)
+.5 rad/sec
-.5 rad/sec
v~ft/sec
+25000 ft/sec
-25000 ft/sec
w~ft/sec
+25000 ft/sec
-25000 ft/sec
SELECT CHANNEL
η
+180°
-180°
t=0

Figure 4.- Pro





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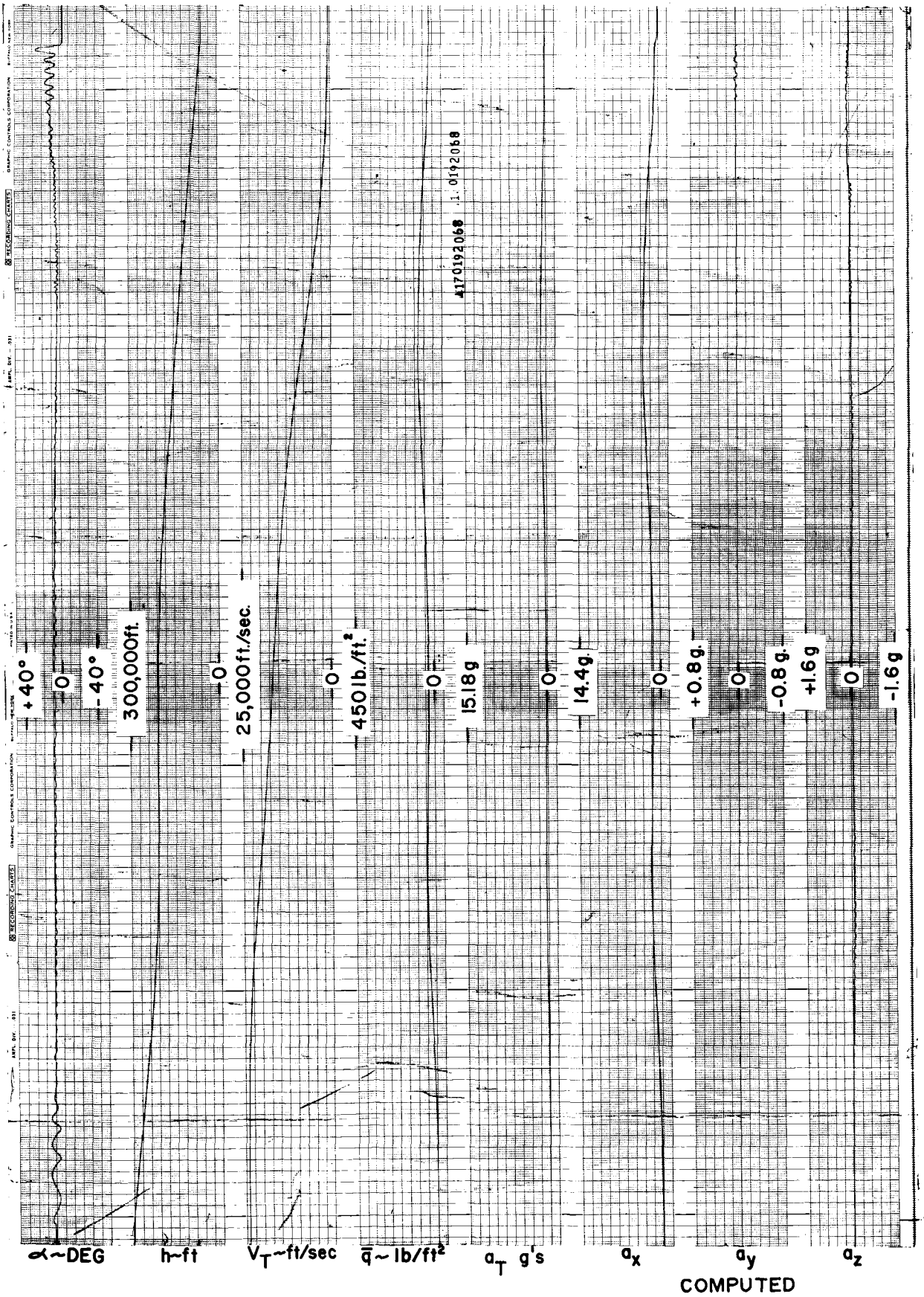
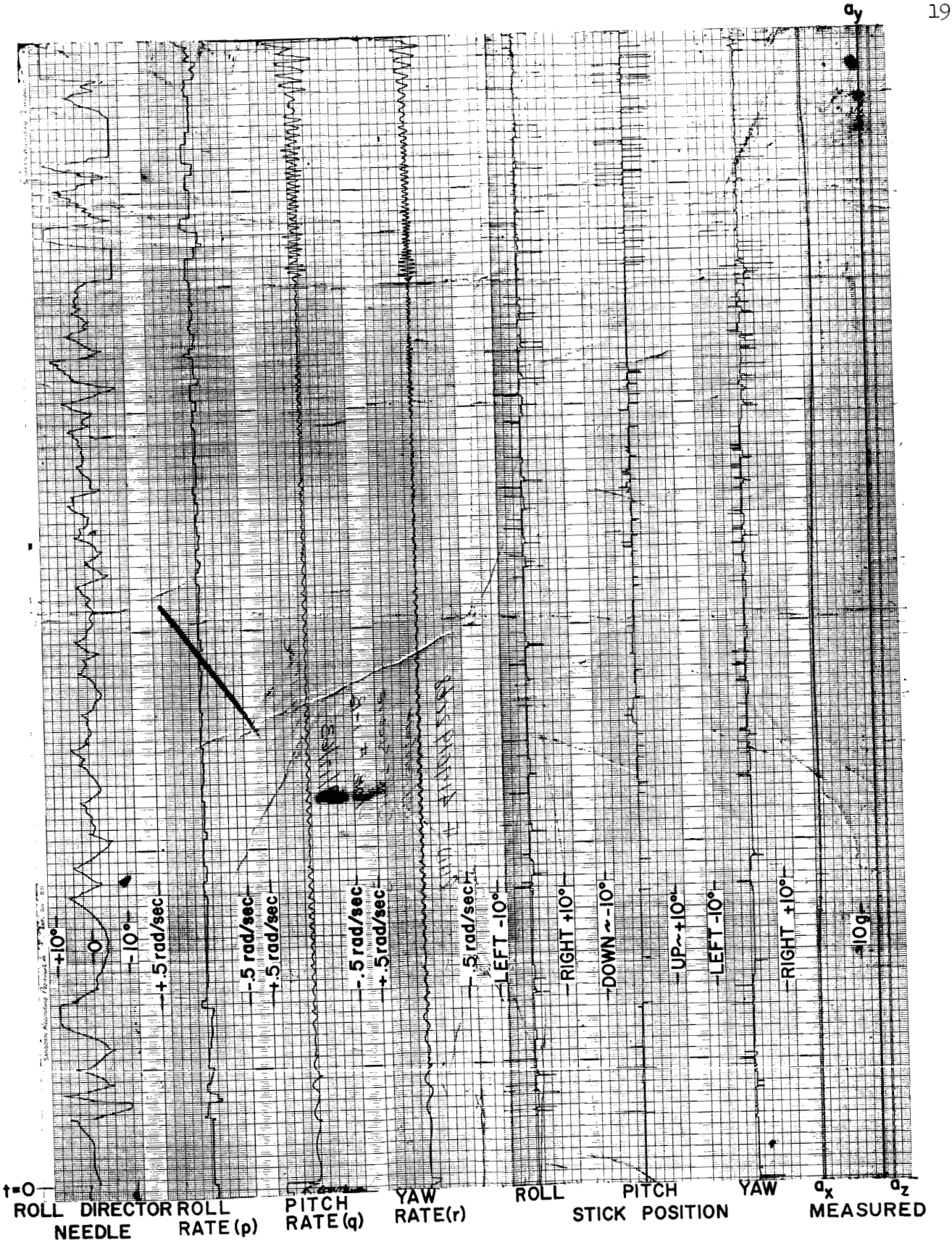


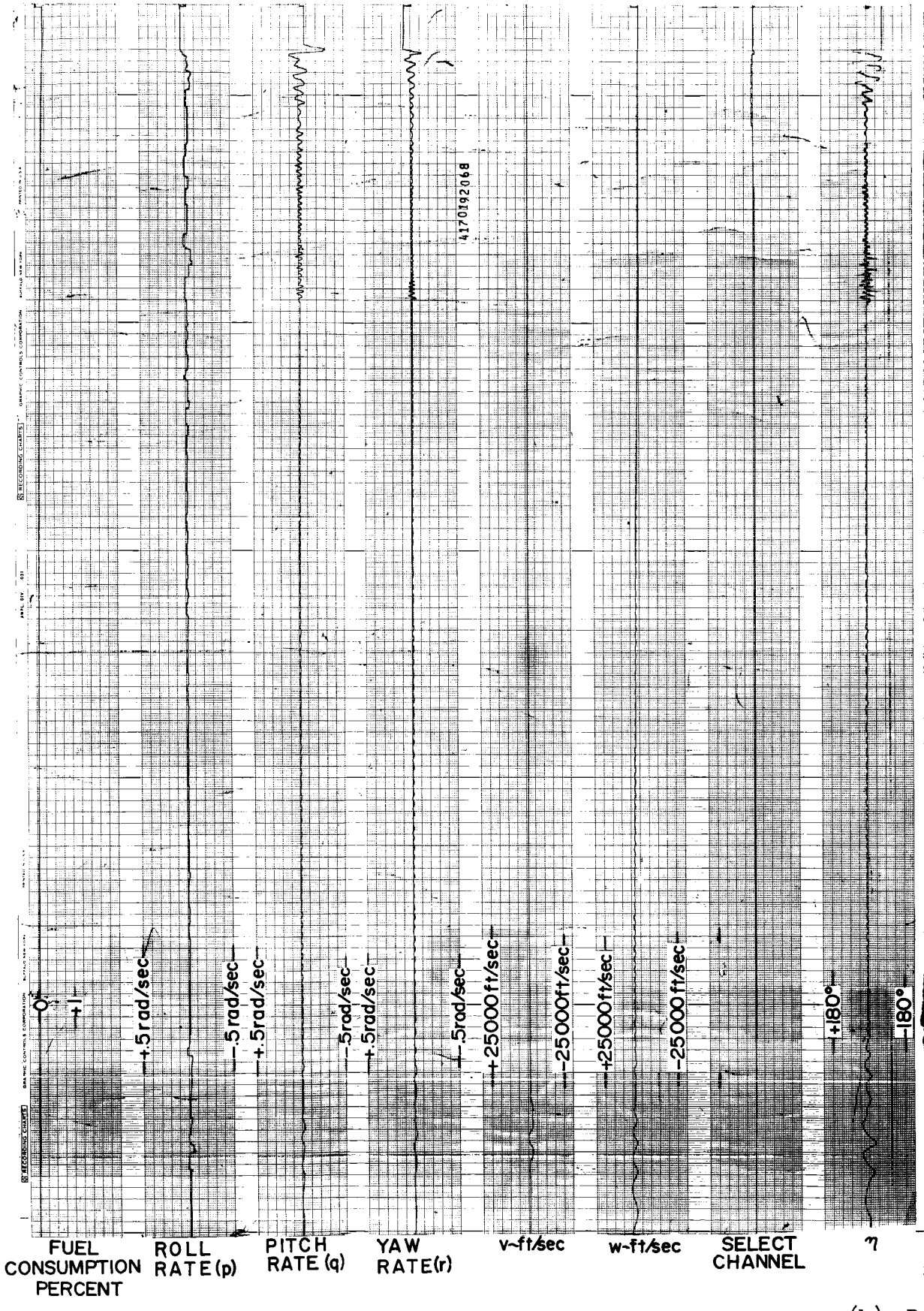
(a) Reco

Figure 5. - I



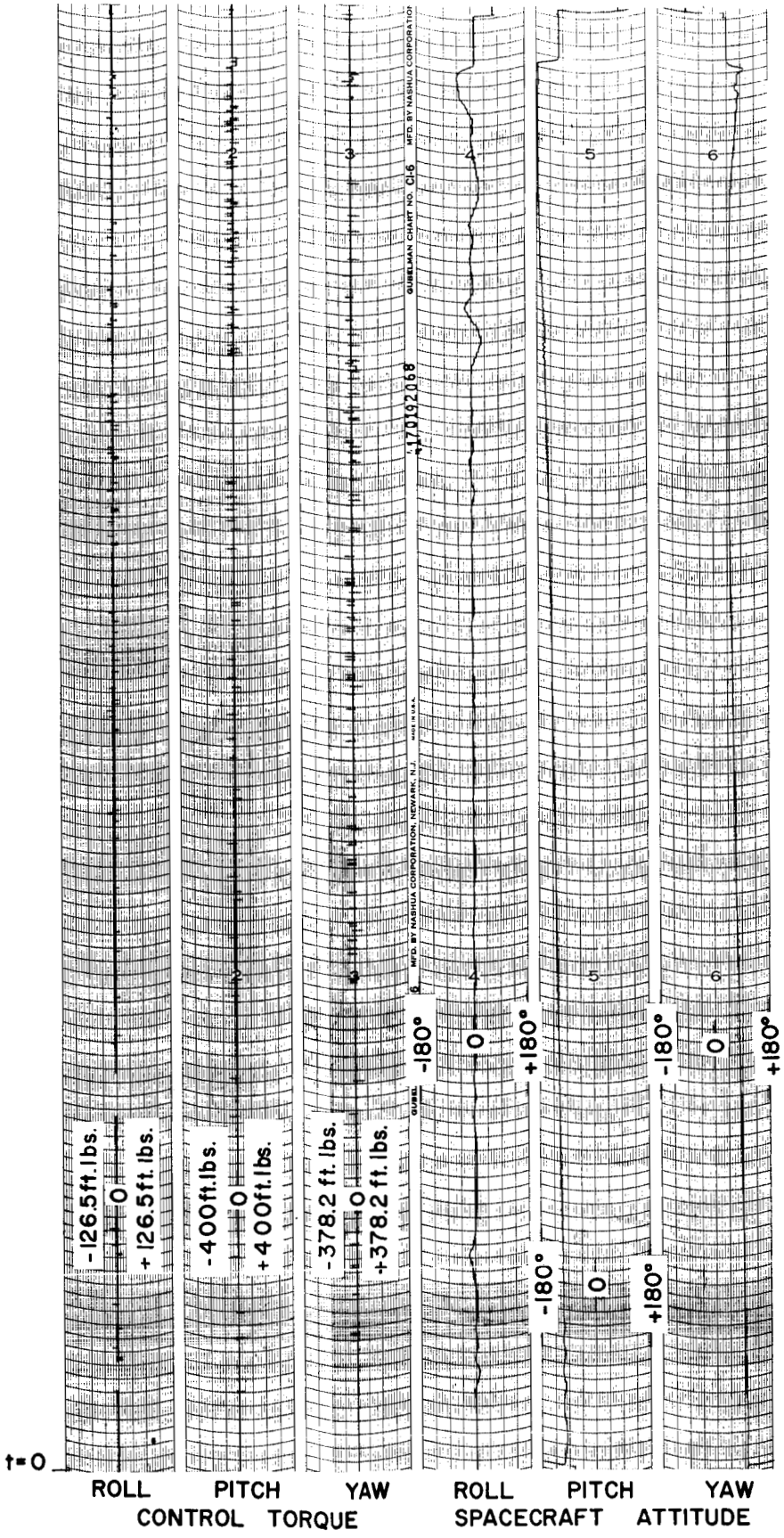
rders 1 and 2

roblem number 1-B


4170192068
0
+1
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+25000 ft/sec
-25000 ft/sec
+25000 ft/sec
-25000 ft/sec
+180°
-180°
FUEL CONSUMPTION PERCENT
ROLL RATE (p)
PITCH RATE (q)
YAW RATE (r)
v-ft/sec
w-ft/sec
SELECT CHANNEL
η

(b) Re

Figure



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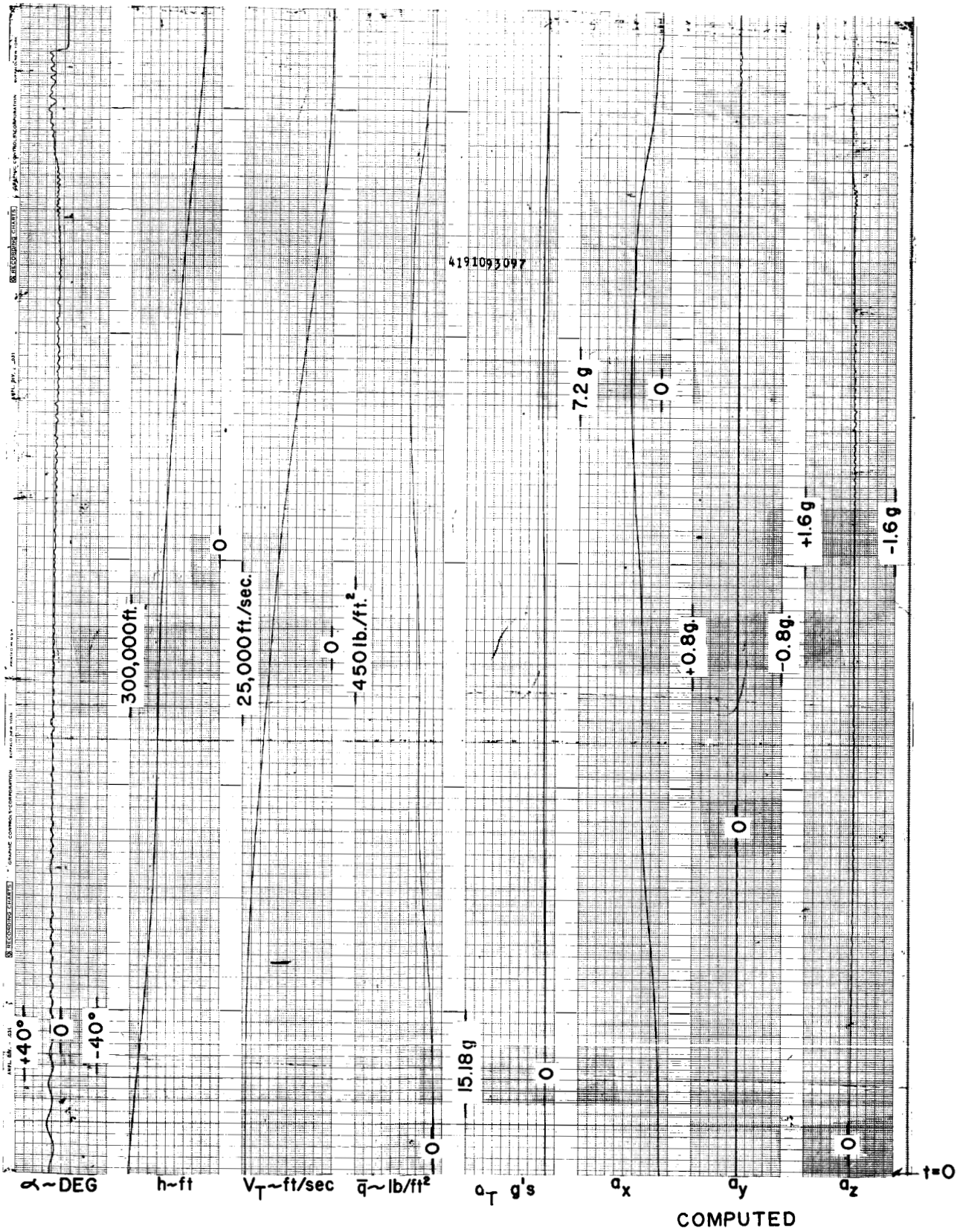
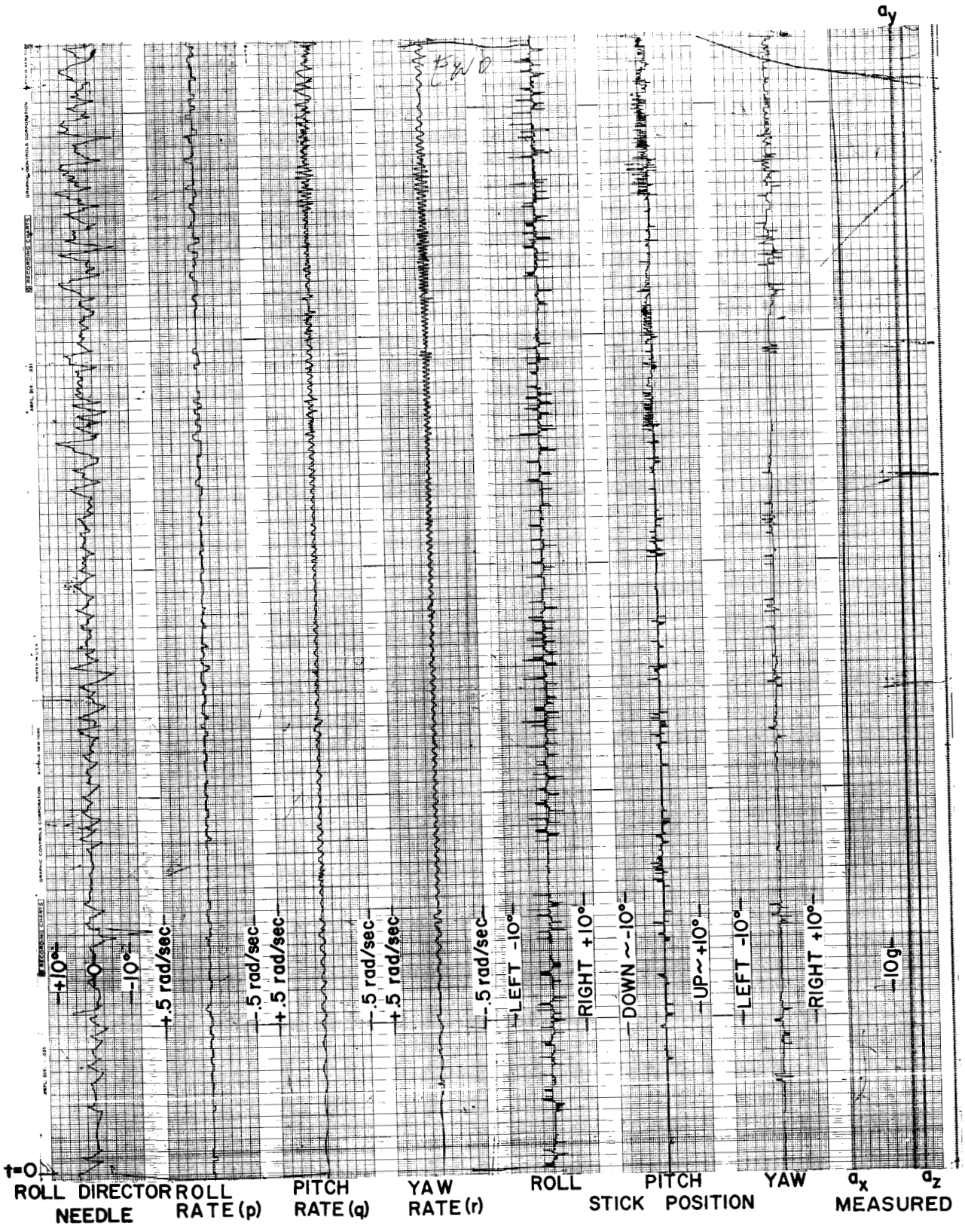
e 5.- Concluded



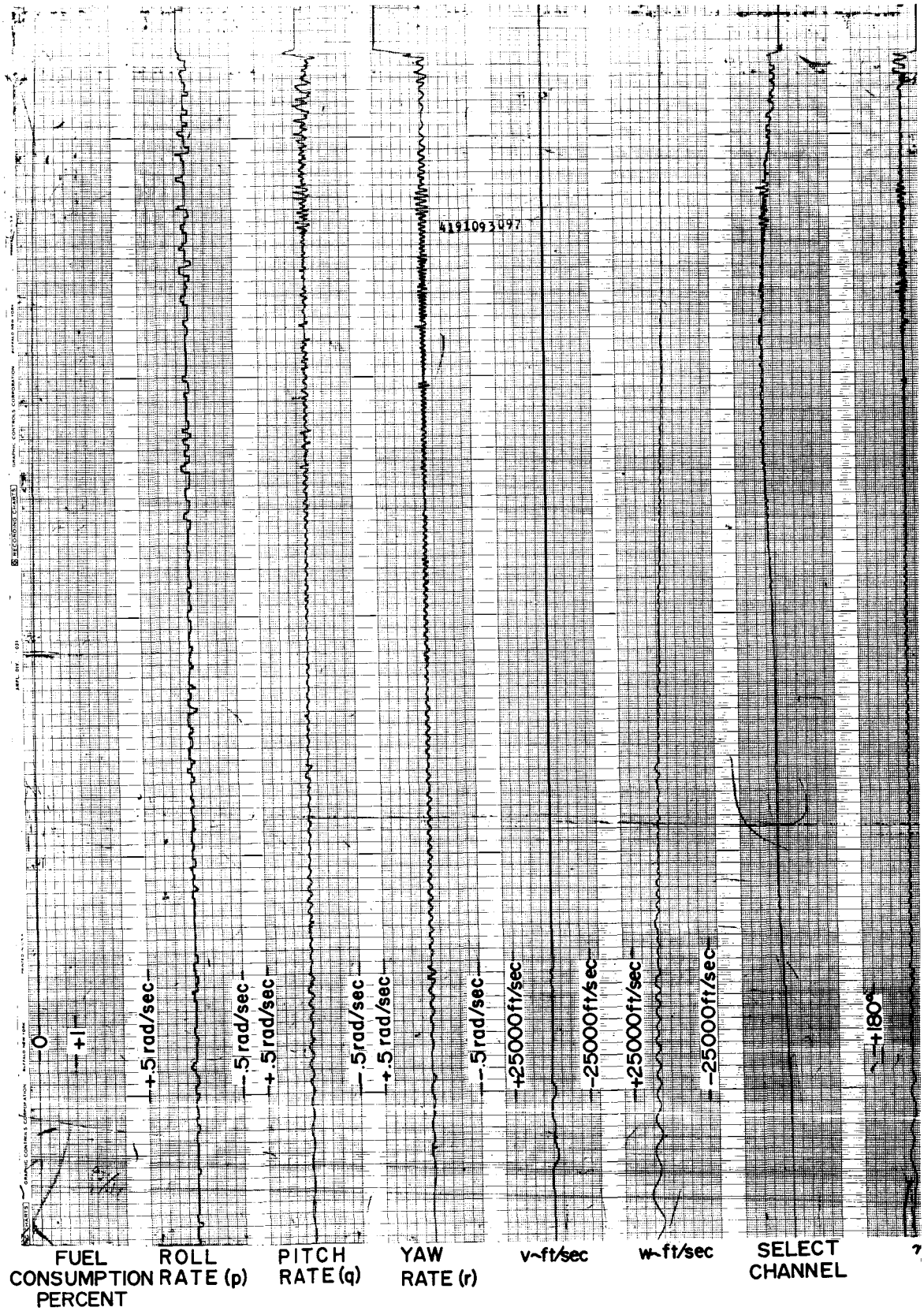
(a) Rec

Figure 6.-



orders 1 and 2

Problem number 1-C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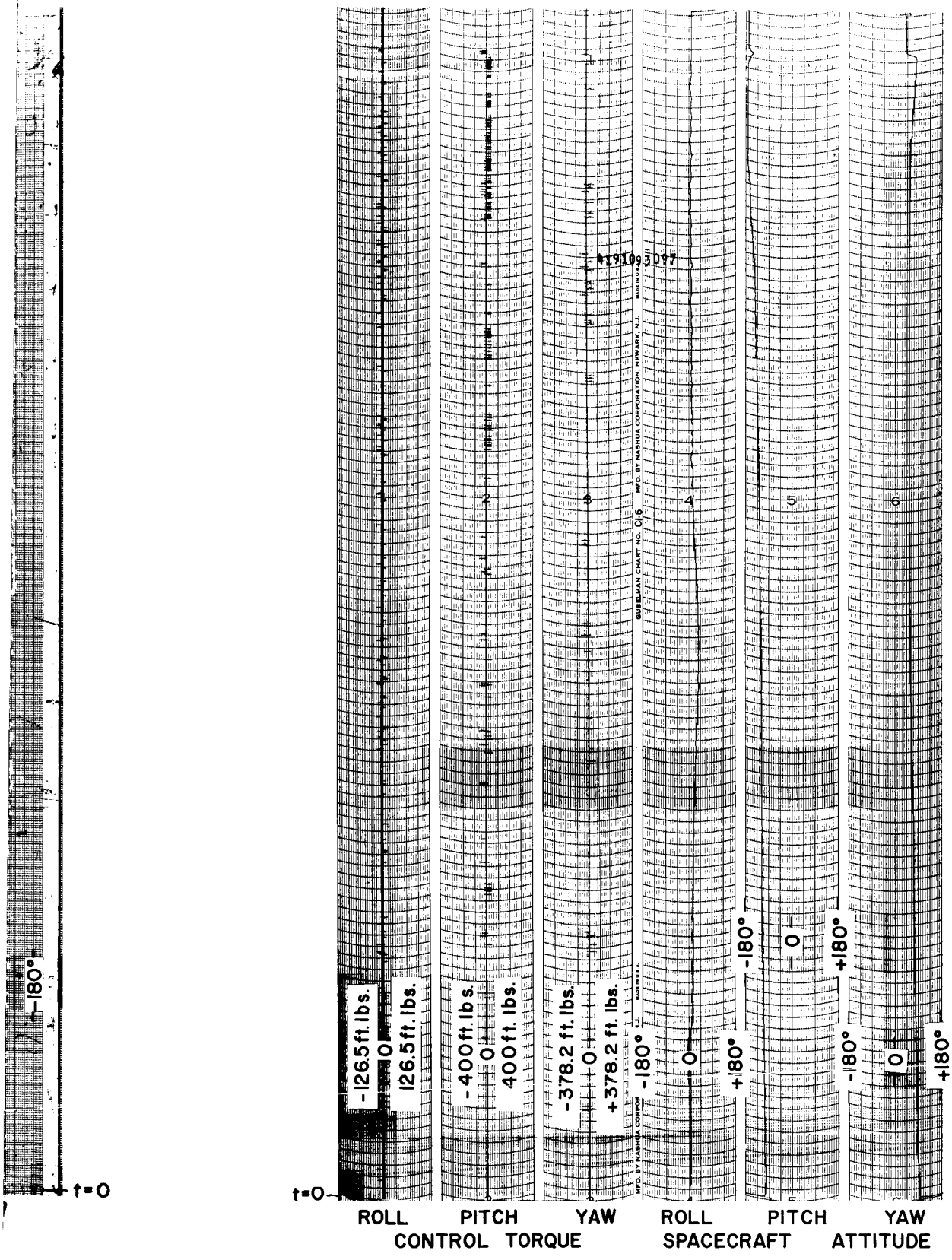
+1
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+25000 ft/sec
-25000 ft/sec
+25000 ft/sec
-25000 ft/sec
+180°
FUEL CONSUMPTION PERCENT
ROLL RATE (p)
PITCH RATE (q)
YAW RATE (r)
v-ft/sec
w-ft/sec
SELECT CHANNEL

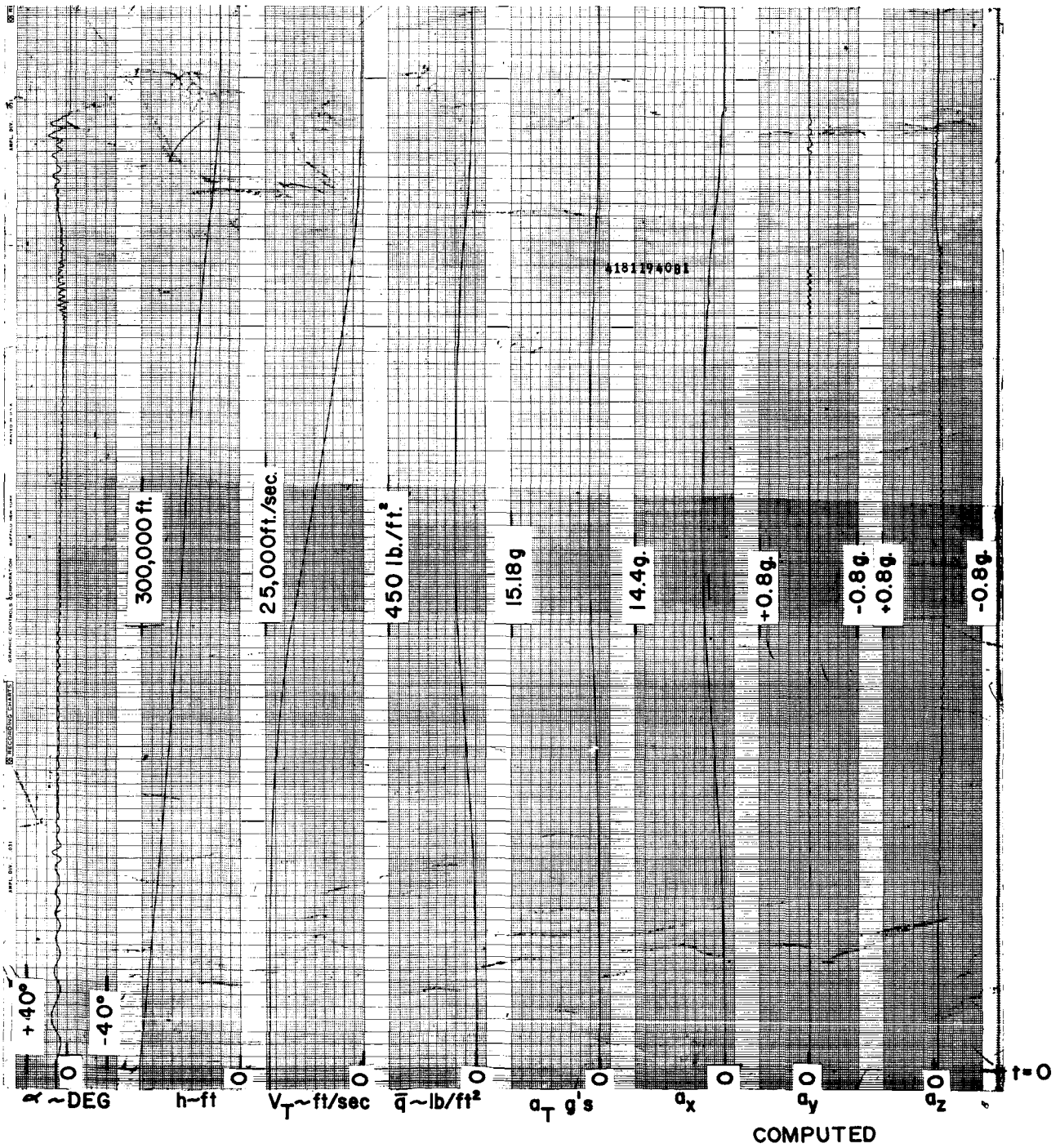
(b)

Figu



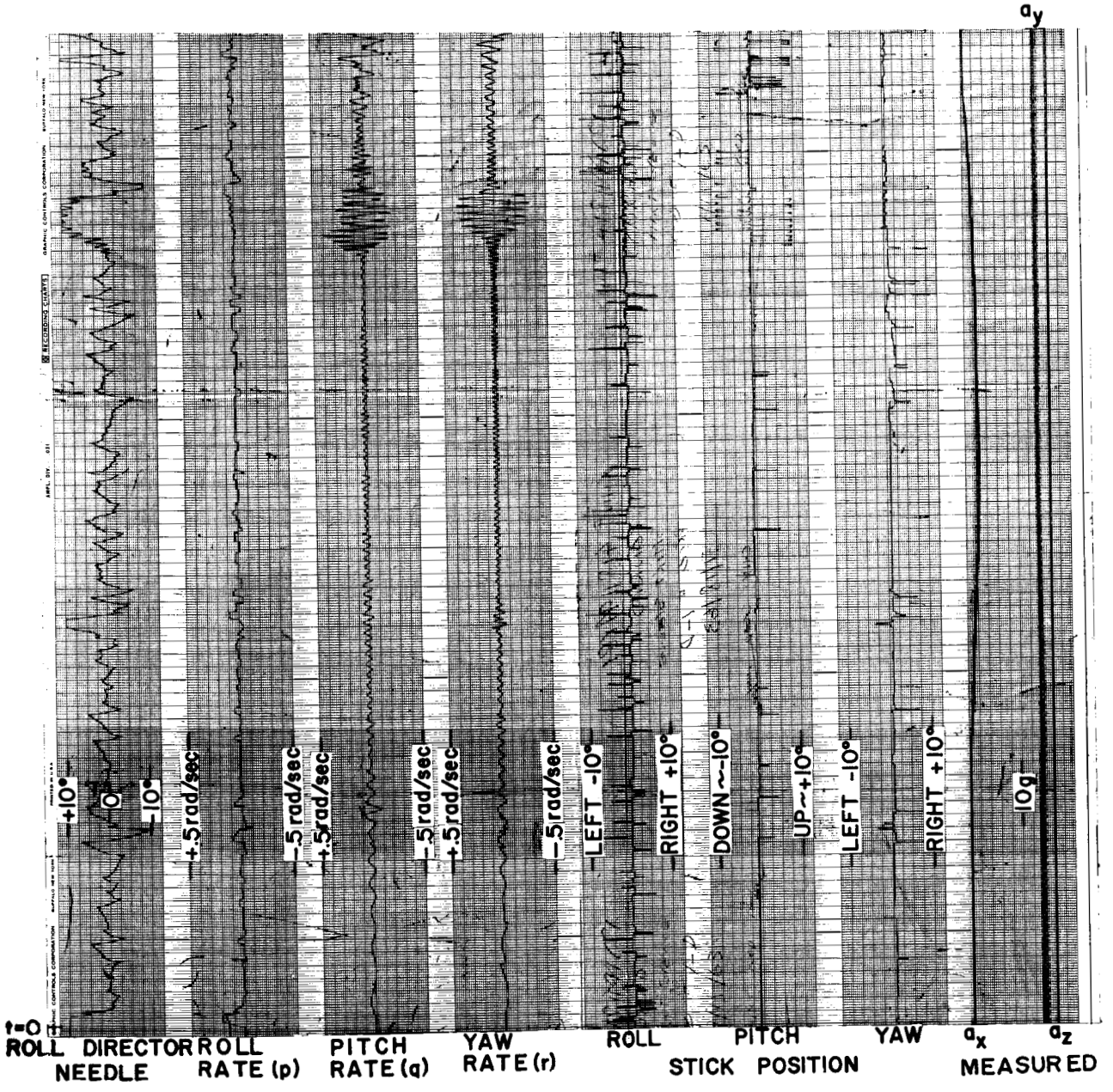
Recorders 3 and 4

ure 6. - Concluded


+40°
-40°
0
α ~DEG
300,000 ft.
0
h~ft
25,000 ft./sec.
0
V_T~ft/sec
450 lb./ft²
0
$\bar{q}$~lb/ft²
15.18g
0
a_T g's
14.4g.
0
a_x
+0.8g.
0
a_y
-0.8g.
+0.8g.
0
a_z
-0.8g.
t=0
COMPUTED

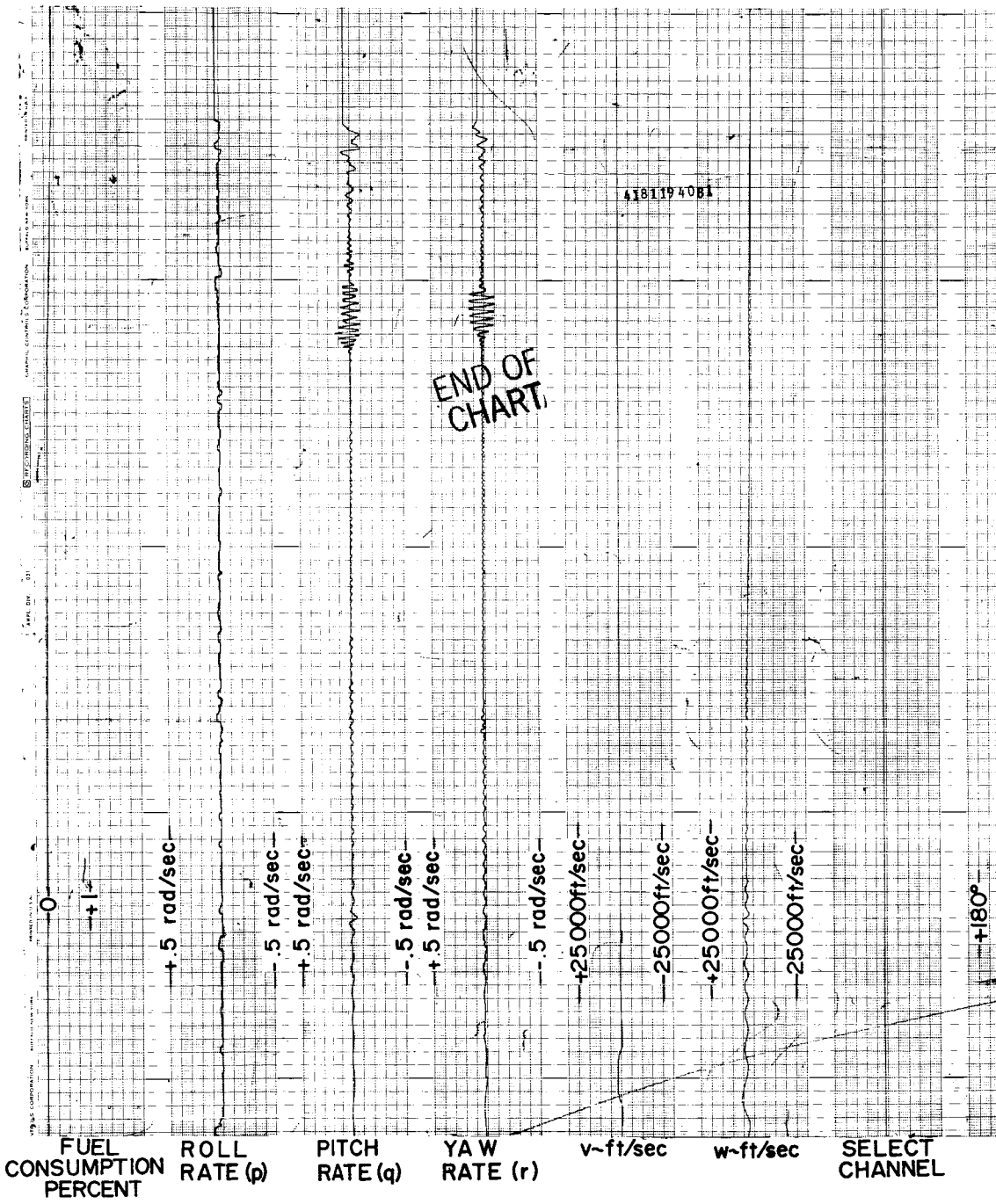
(a)

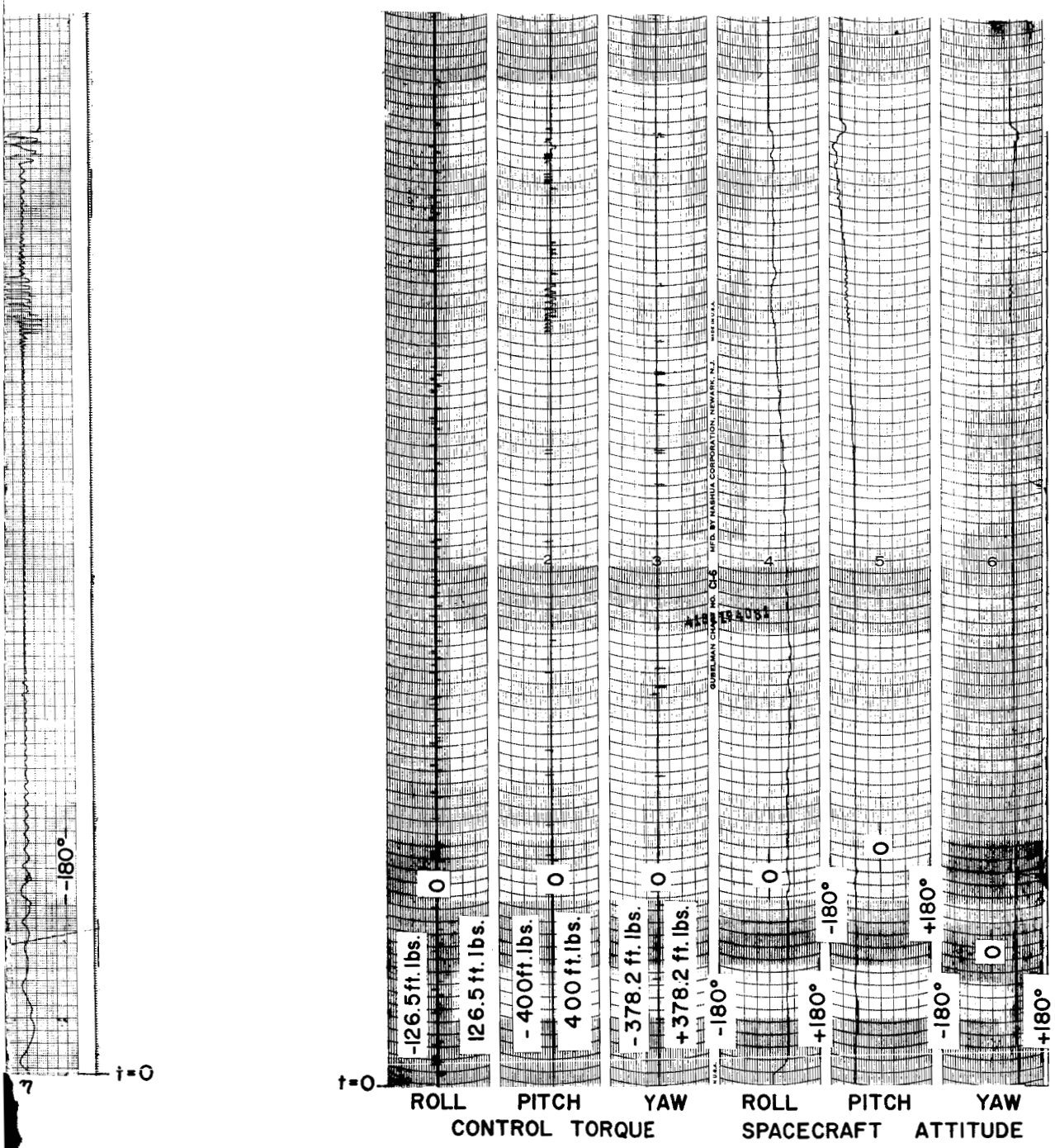
Figure 7



Recorders 1 and 2

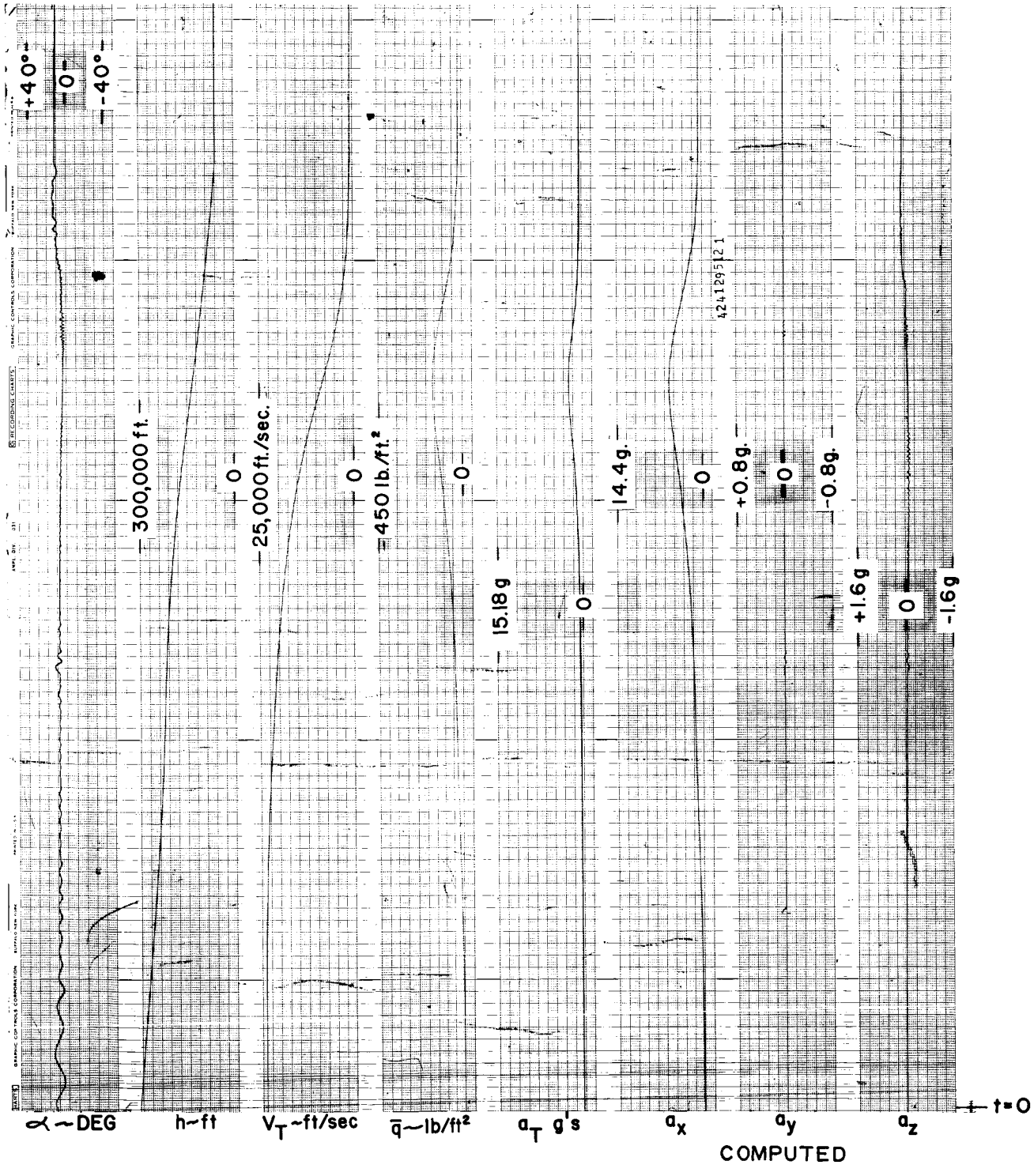
.- Problem number 1-D


END OF CHART
4181194081
0
+1
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+25000ft/sec
-25000ft/sec
+25000ft/sec
-25000ft/sec
+180°
FUEL CONSUMPTION PERCENT
ROLL RATE (p)
PITCH RATE (q)
YAW RATE (r)
v~ft/sec
w~ft/sec
SELECT CHANNEL



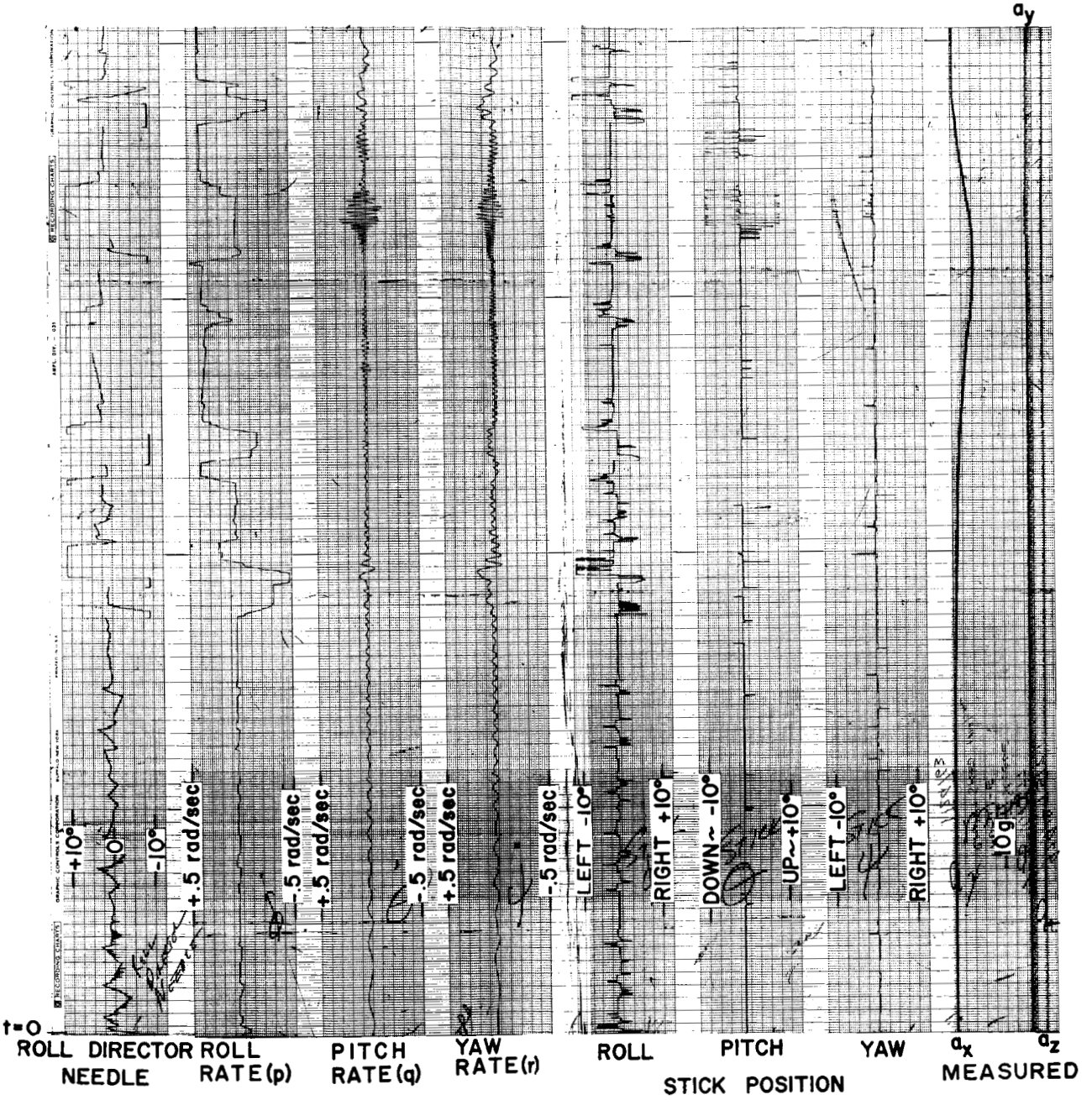
) Recorders 3 and 4

gure 7.- Concluded



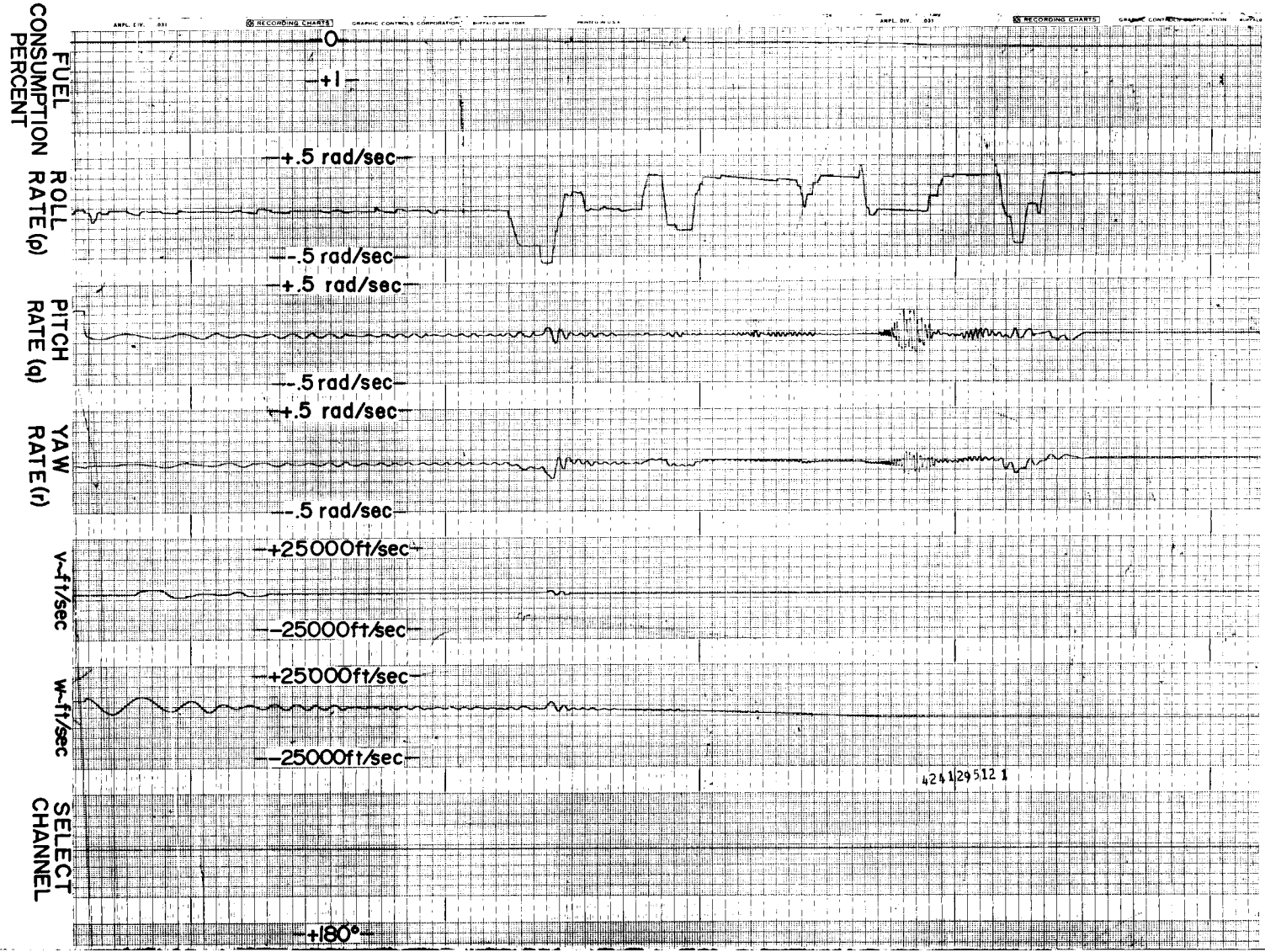
(a) Recor

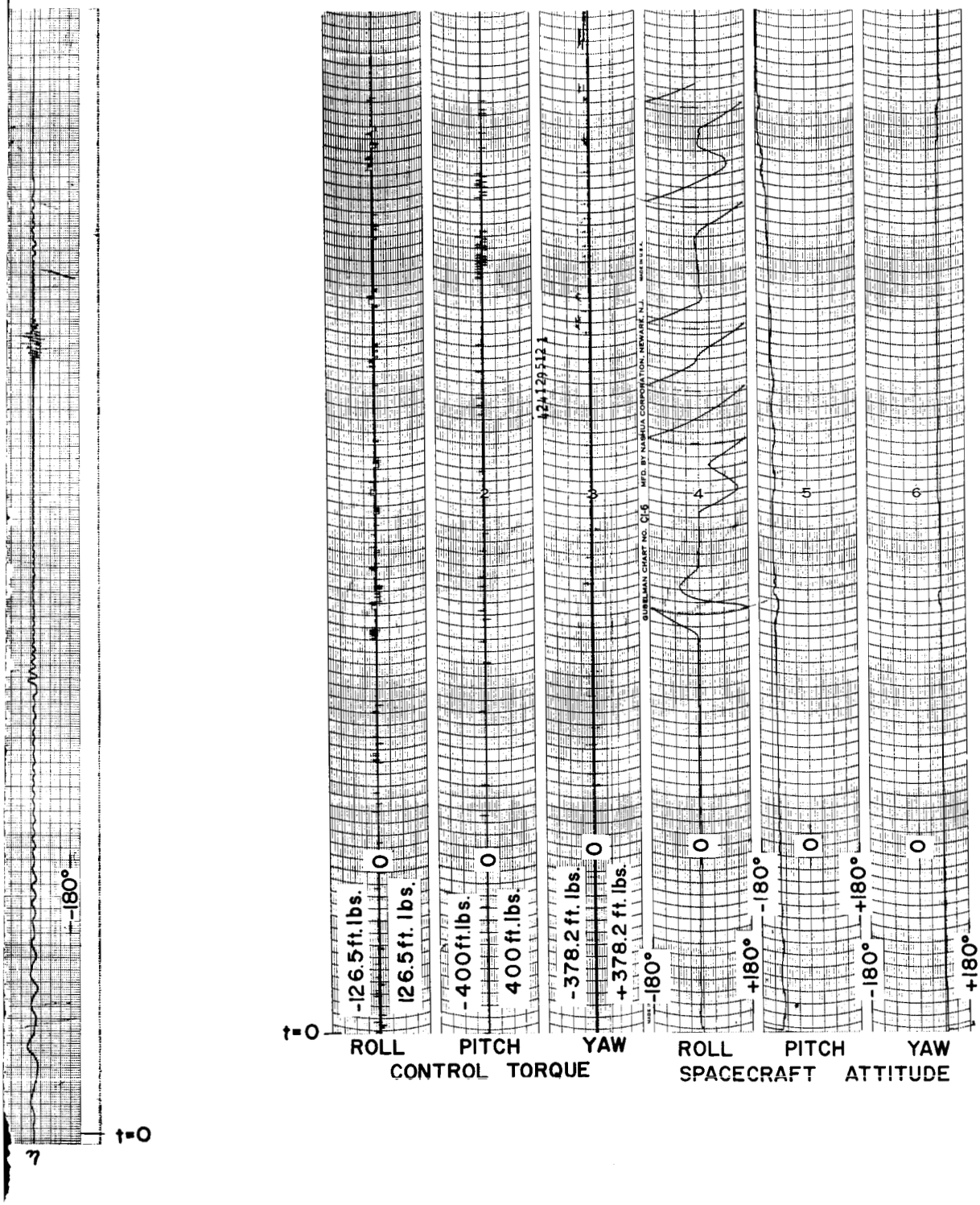
Figure 8. - Pr



lers 1 and 2

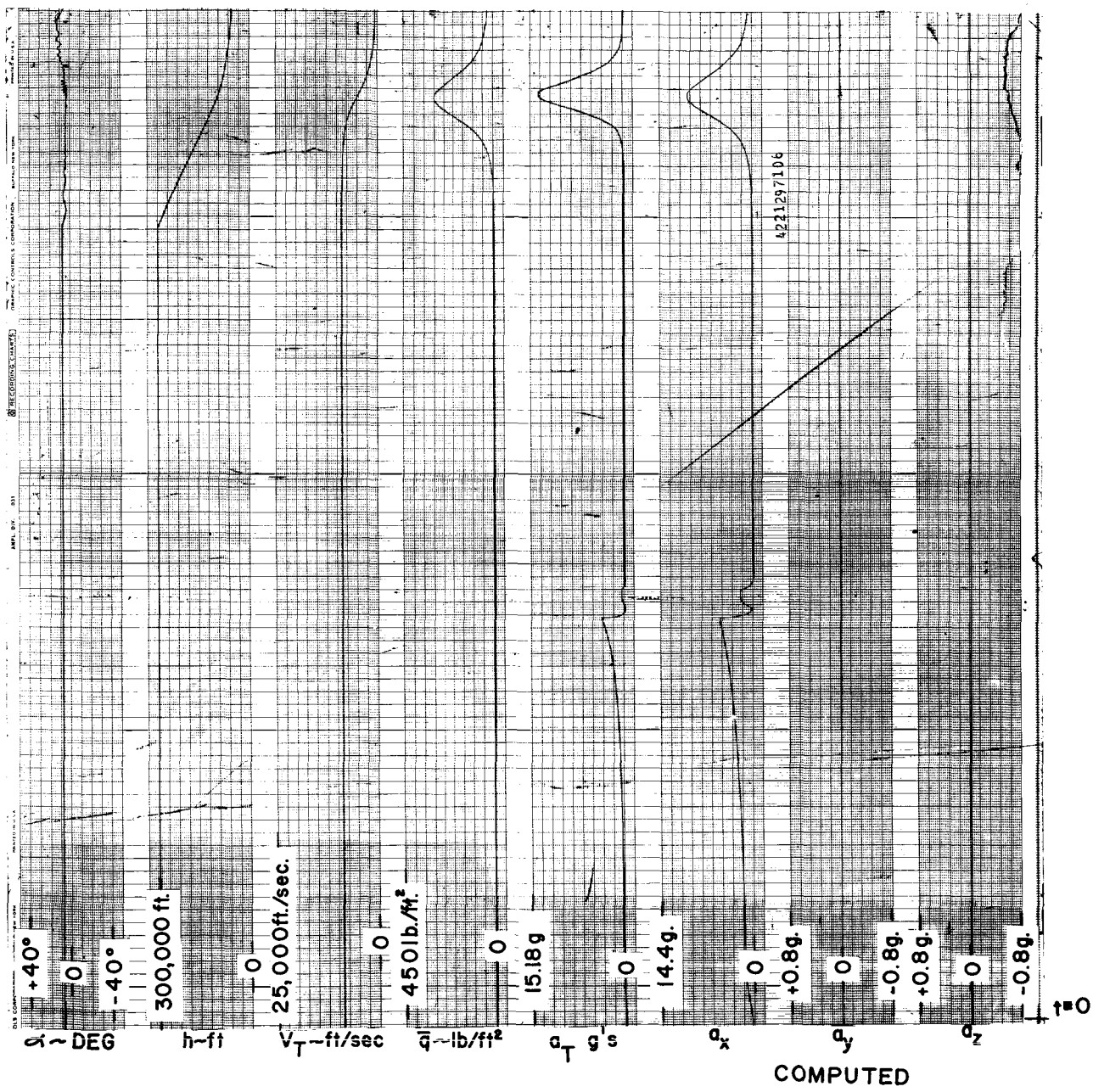
oblem number 1-E


FUEL CONSUMPTION PERCENT
0
+1
ROLL RATE (p)
+.5 rad/sec
-.5 rad/sec
PITCH RATE (q)
+.5 rad/sec
-.5 rad/sec
YAW RATE (r)
+.5 rad/sec
-.5 rad/sec
v-ft/sec
+25000ft/sec
-25000ft/sec
w-ft/sec
+25000ft/sec
-25000ft/sec
SELECT CHANNEL
+180°



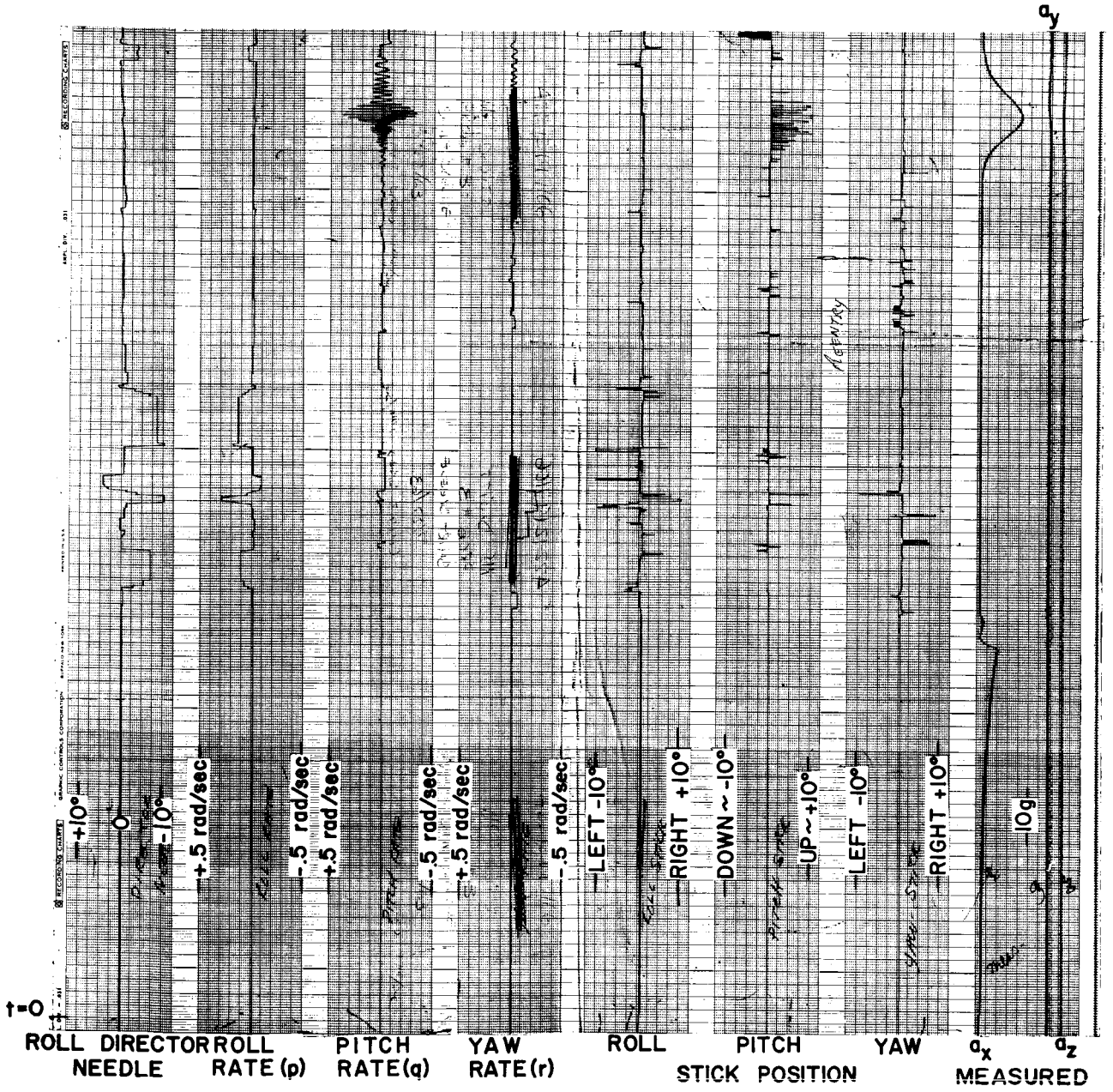
(b) Recorders 3 and 4

Figure 8.- Concluded


+40°
0
-40°
α ~ DEG
300,000 ft.
0
h~ft
25,000ft./sec.
0
V_T~ft/sec
450lb./ft.²
0
$\bar{q}$~lb/ft²
15.18g
0
a_T g's
14.4g.
0
a_x
+0.8g.
0
a_y
-0.8g.
+0.8g.
0
a_z
-0.8g.
t=0
COMPUTED
4221297106

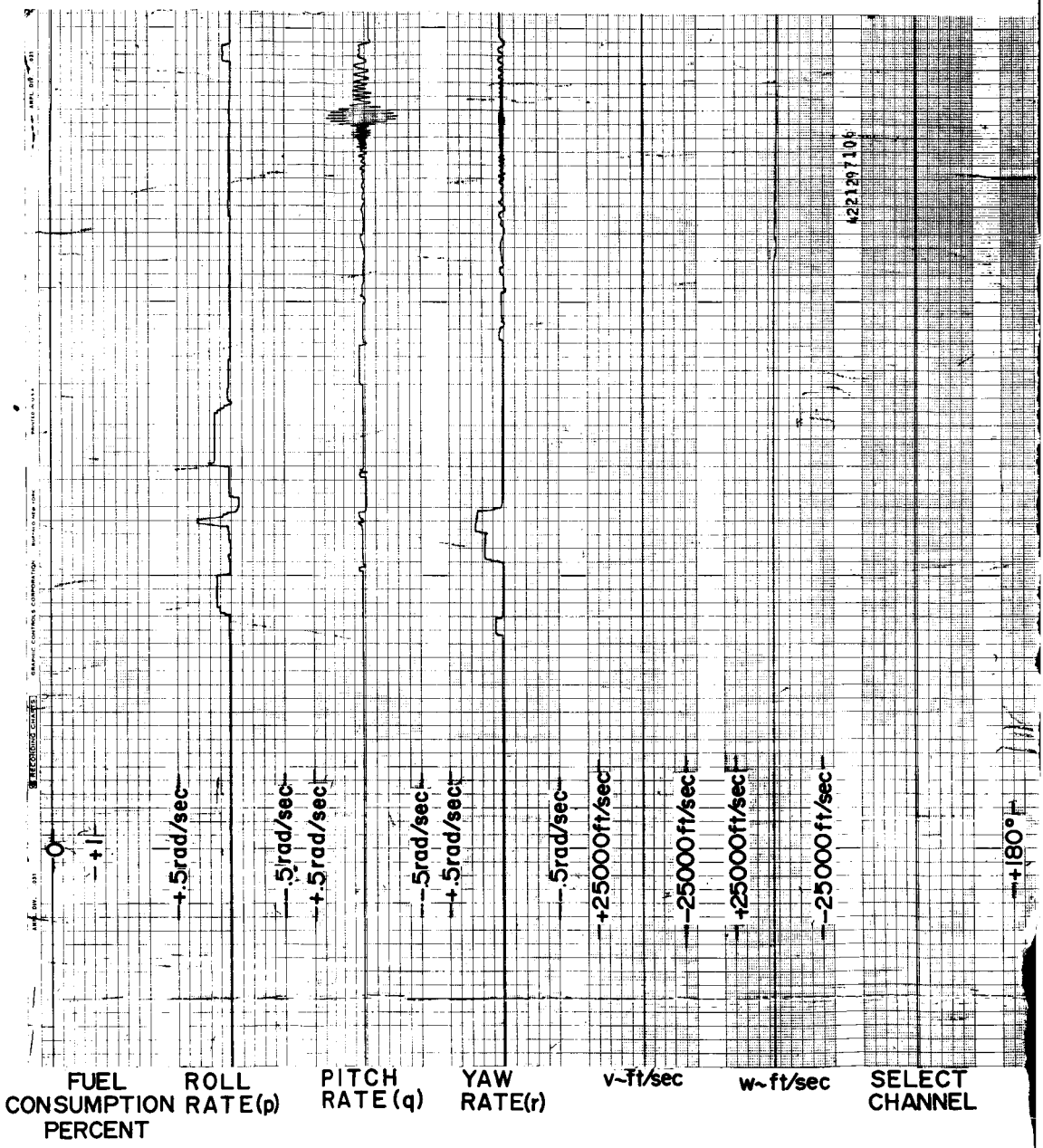
(a) R

Figure 9.



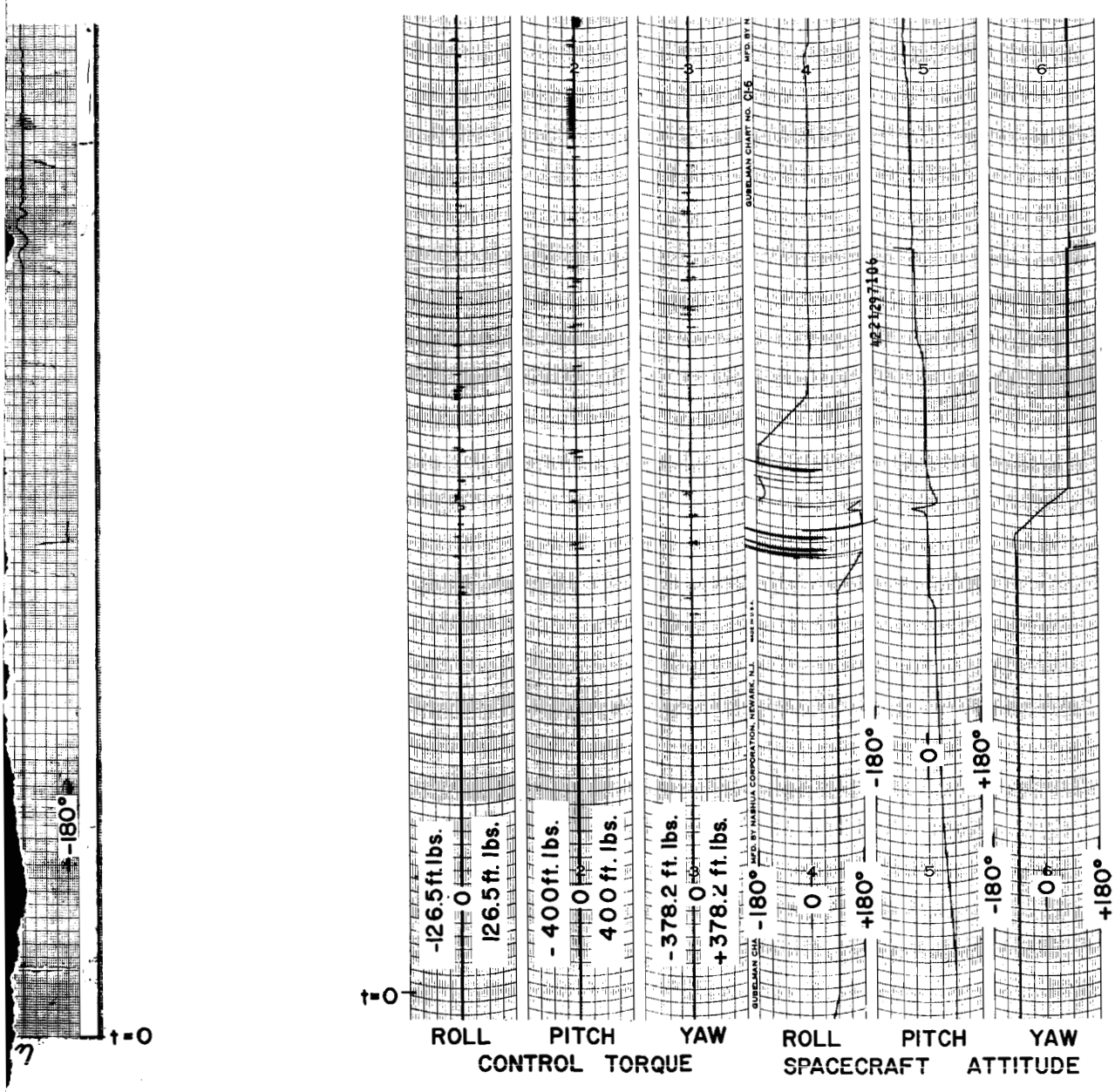
ecorders 1 and 2

· Problem number 3


0
+1
+.5rad/sec
-.5rad/sec
+.5rad/sec
-.5rad/sec
+.5rad/sec
-.5rad/sec
+25000ft/sec
-25000ft/sec
+25000ft/sec
-25000ft/sec
+180°
FUEL CONSUMPTION PERCENT
ROLL RATE(p)
PITCH RATE(q)
YAW RATE(r)
v~ft/sec
w~ft/sec
SELECT CHANNEL
4221297106

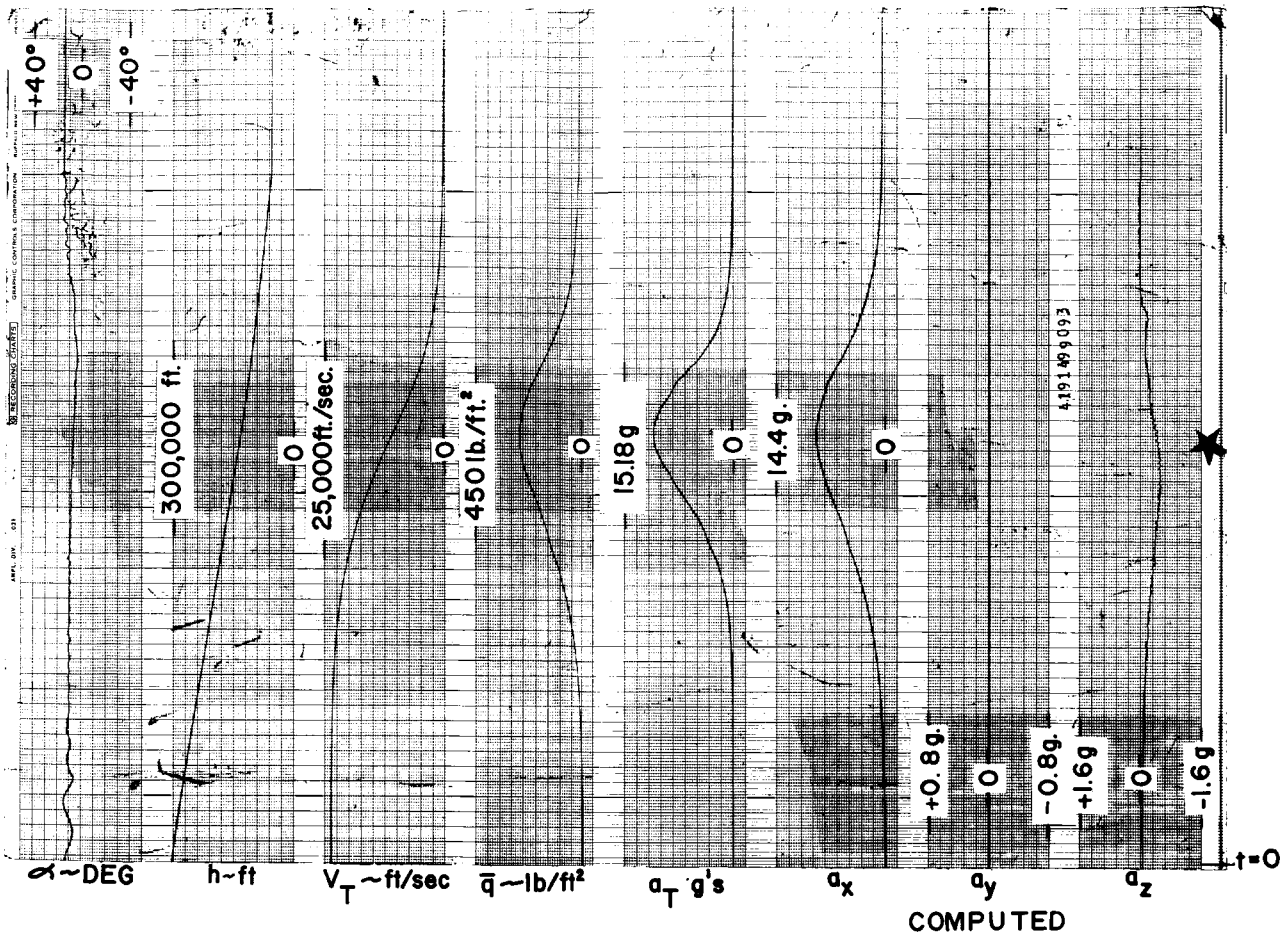
(b) F

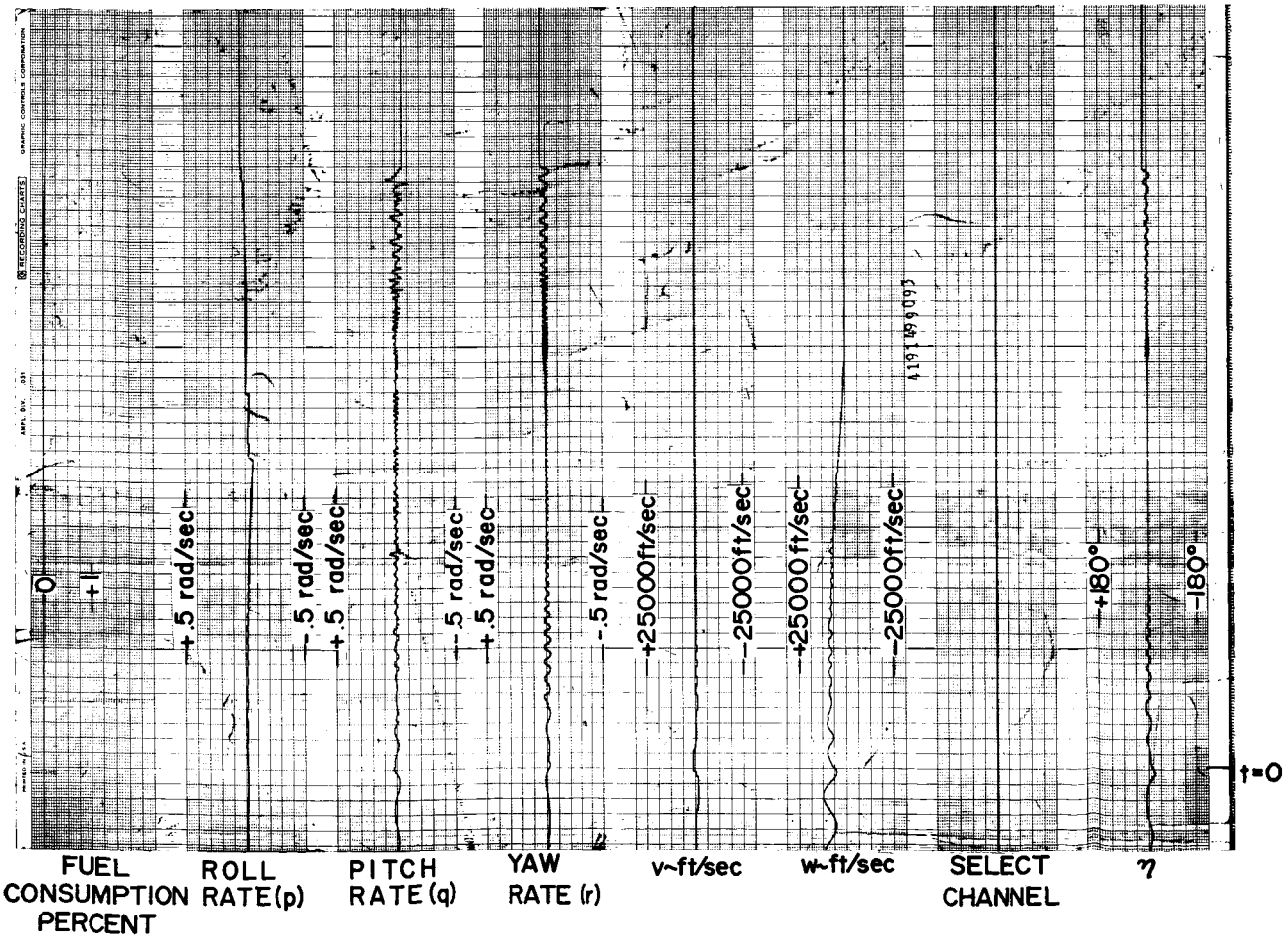
Figur

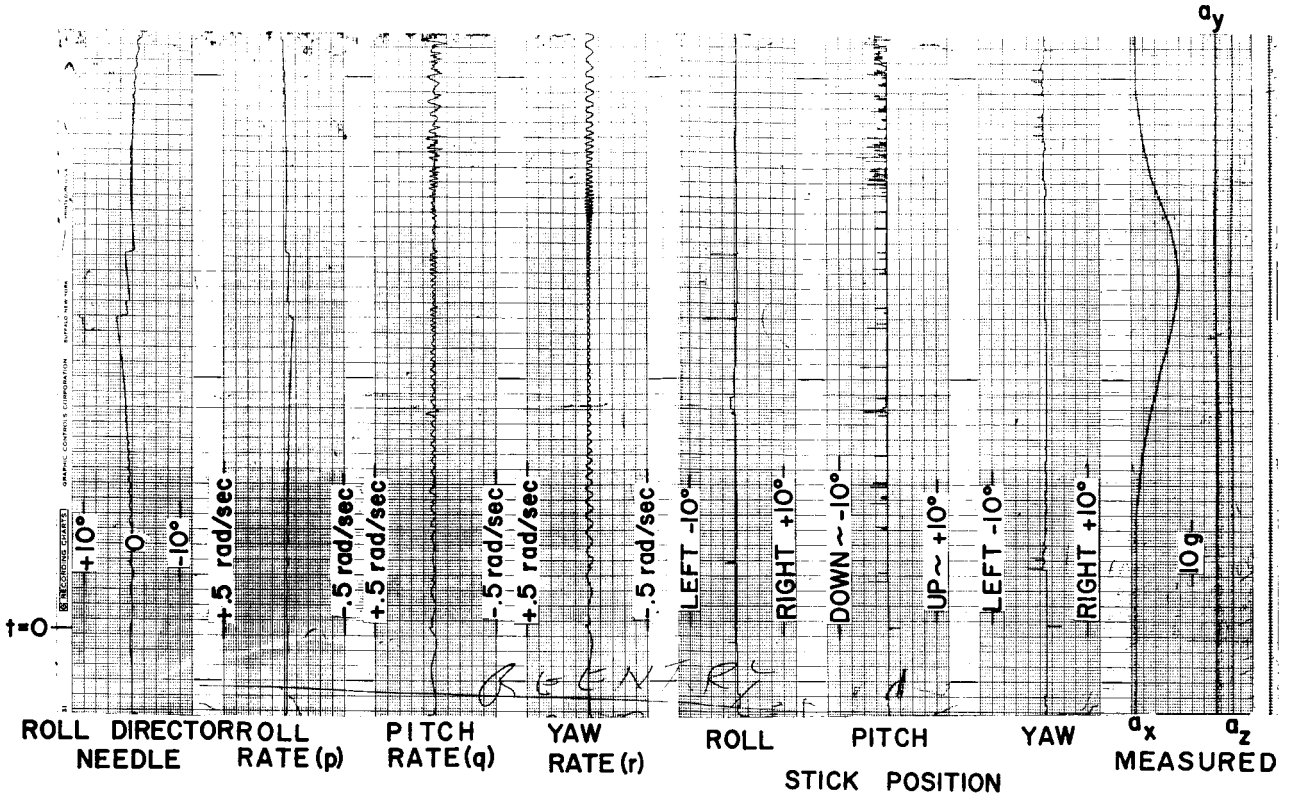


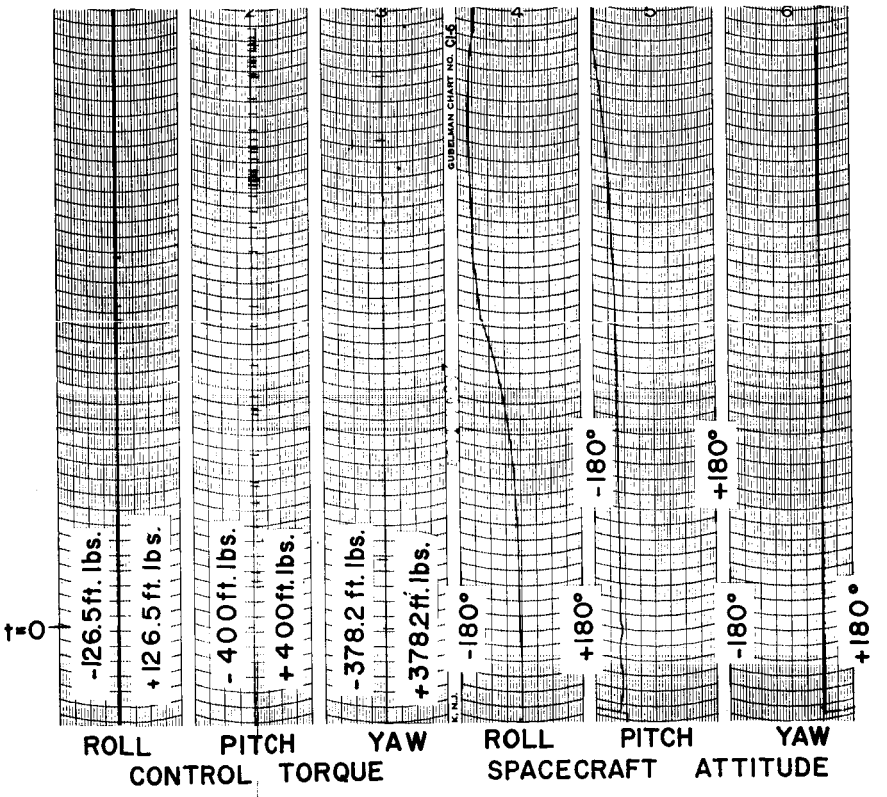
corders 3 and 4

e 9.- Concluded


+40°
0
-40°
300,000 ft.
0
25,000ft./sec.
0
450 lb./ft.²
0
15.18g
0
14.4g
0
+0.8g.
0
-0.8g.
+1.6g
0
-1.6g
t=0
α~DEG
h~ft
V_T~ft/sec
q̄~lb/ft²
a_T g's
a_x
a_y
a_z
COMPUTED


0
+1
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+25000ft/sec
-25000ft/sec
+25000 ft/sec
-25000ft/sec
+180°
-180°
t=0
FUEL CONSUMPTION PERCENT
ROLL RATE(p)
PITCH RATE(q)
YAW RATE (r)
v~ft/sec
w~ft/sec
SELECT CHANNEL
η





ure 10.- Problem number 5

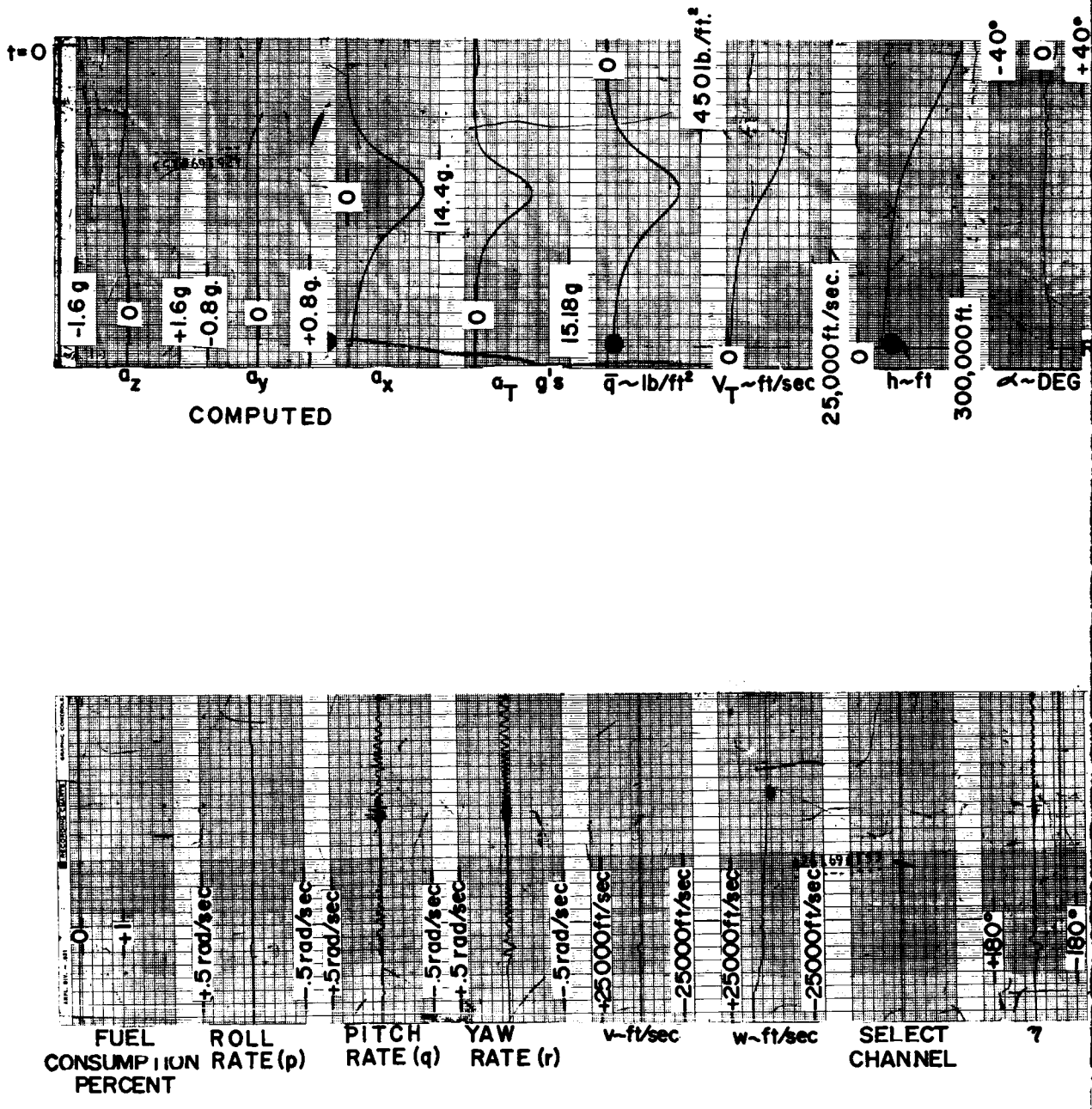
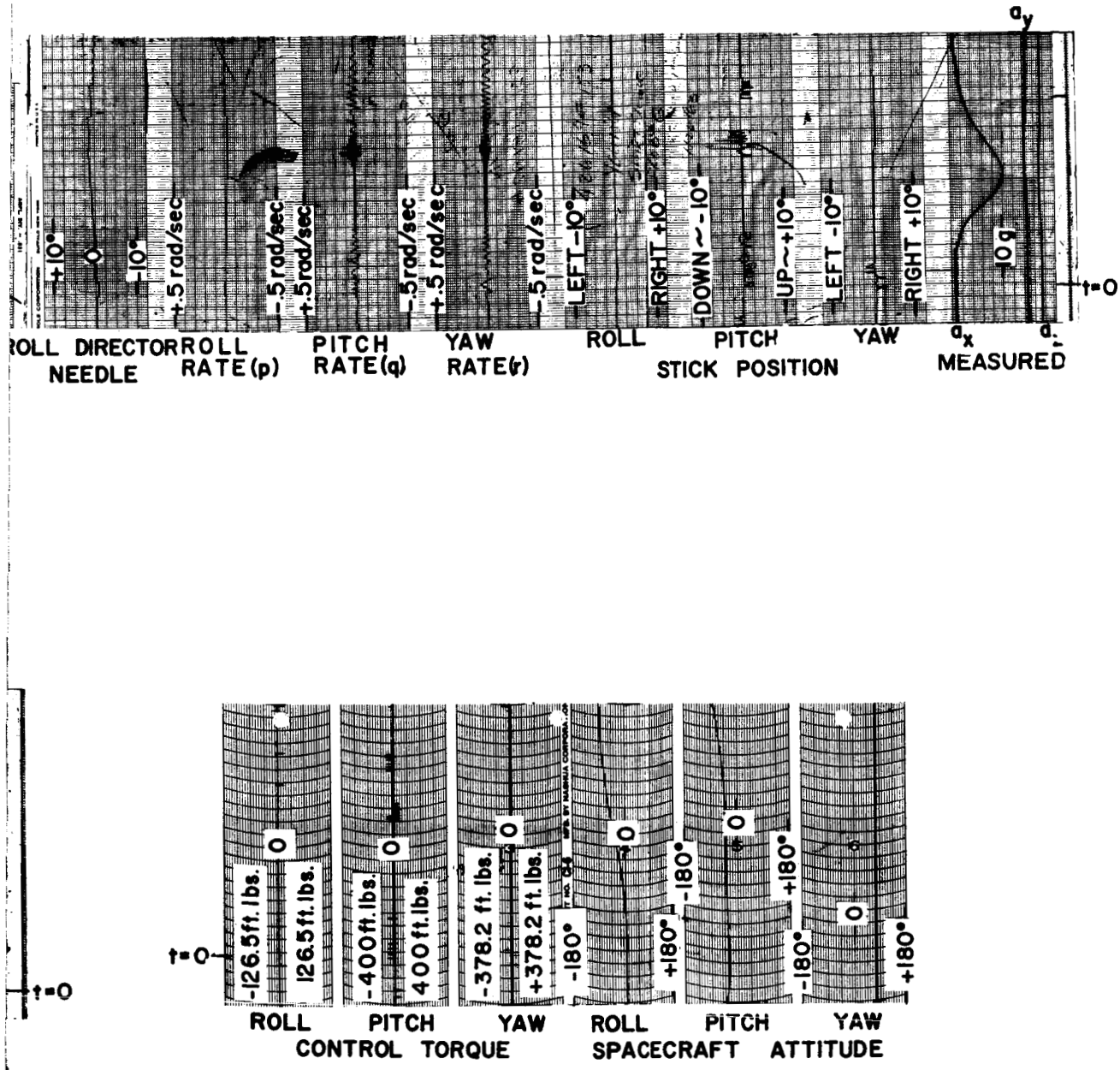
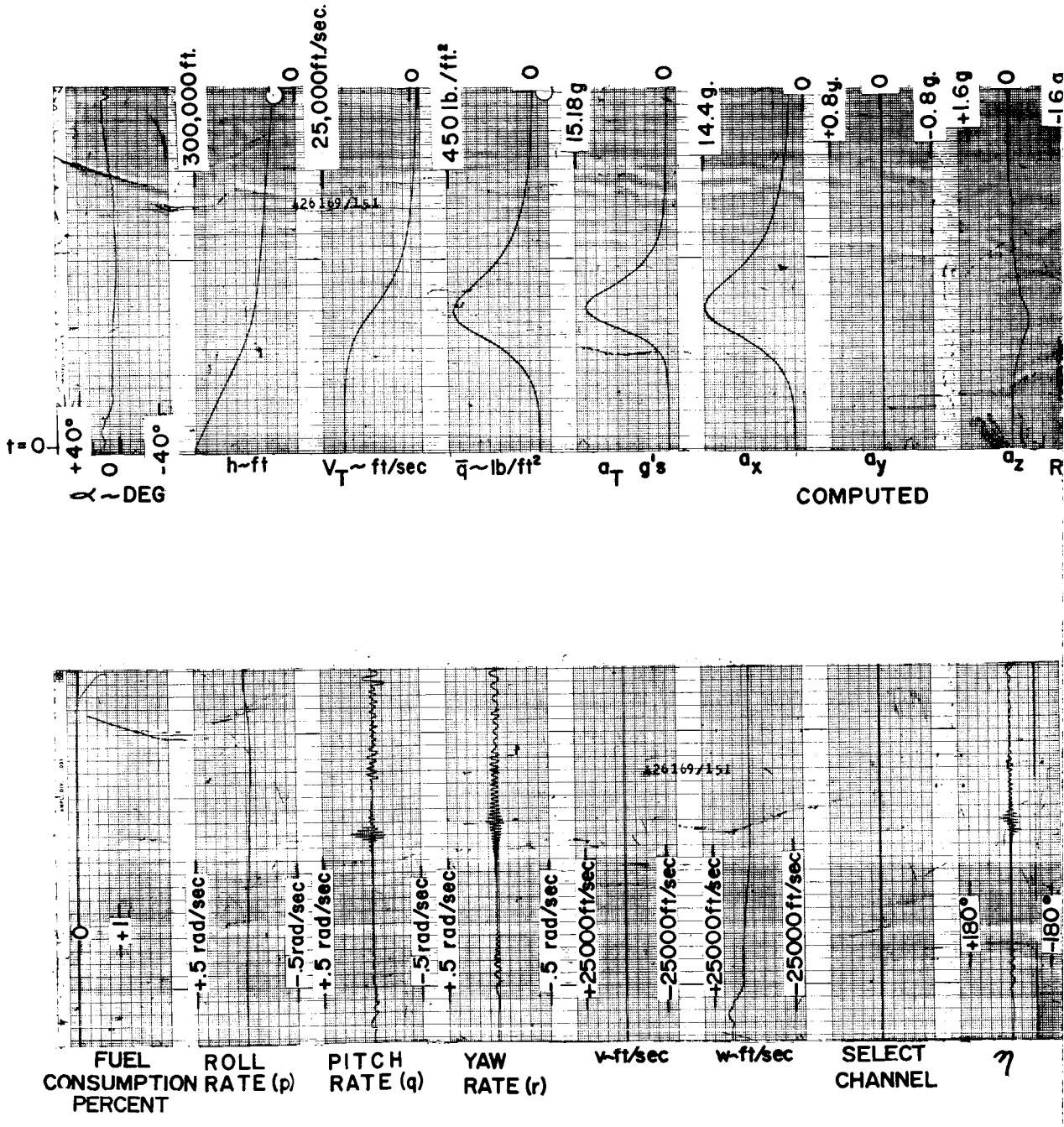

t=0
-1.6 g
0
+1.6 g
-0.8 g.
0
+0.8 g.
0
14.4 g.
0
15.18 g
0
450 lb./ft.²
0
25,000 ft./sec.
0
300,000 ft.
-40°
0
+40°
a_z
a_y
a_x
a_T g's
$\bar{q}$~lb/ft²
V_T~ft/sec
h~ft
α~DEG
COMPUTED
0
+1
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+.5 rad/sec
-.5 rad/sec
+25000 ft/sec
-25000 ft/sec
+25000 ft/sec
-25000 ft/sec
+180°
-180°
FUEL CONSUMPTION PERCENT
ROLL RATE (p)
PITCH RATE (q)
YAW RATE (r)
v-ft/sec
w-ft/sec
SELECT CHANNEL
ψ

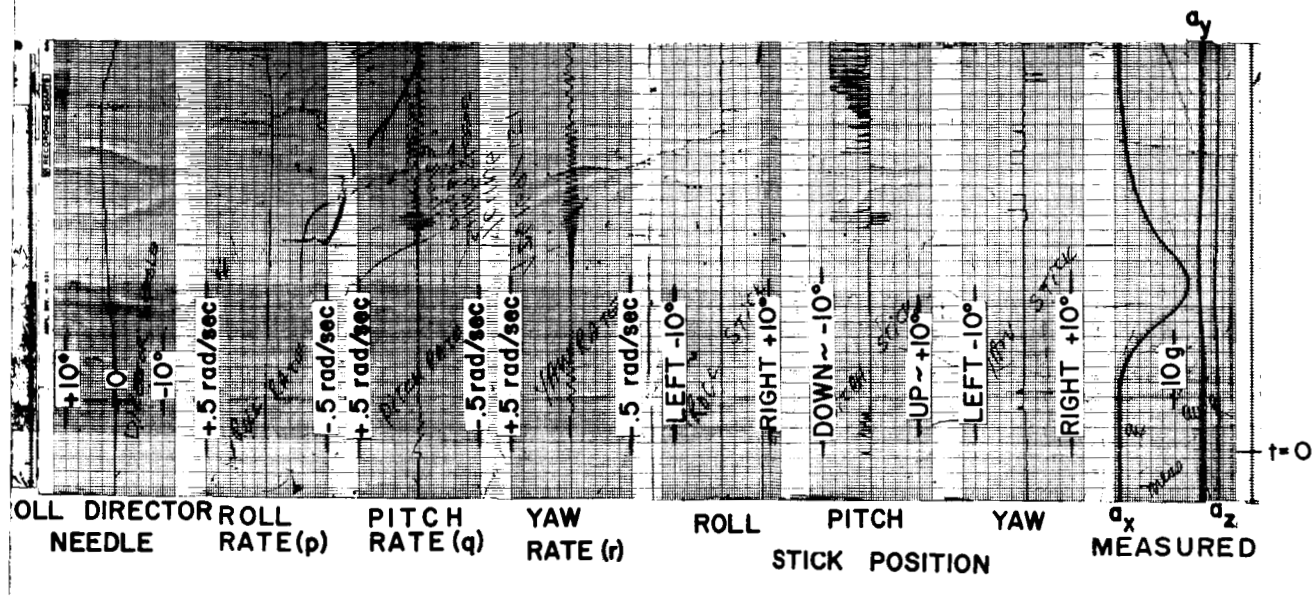
Figure 11

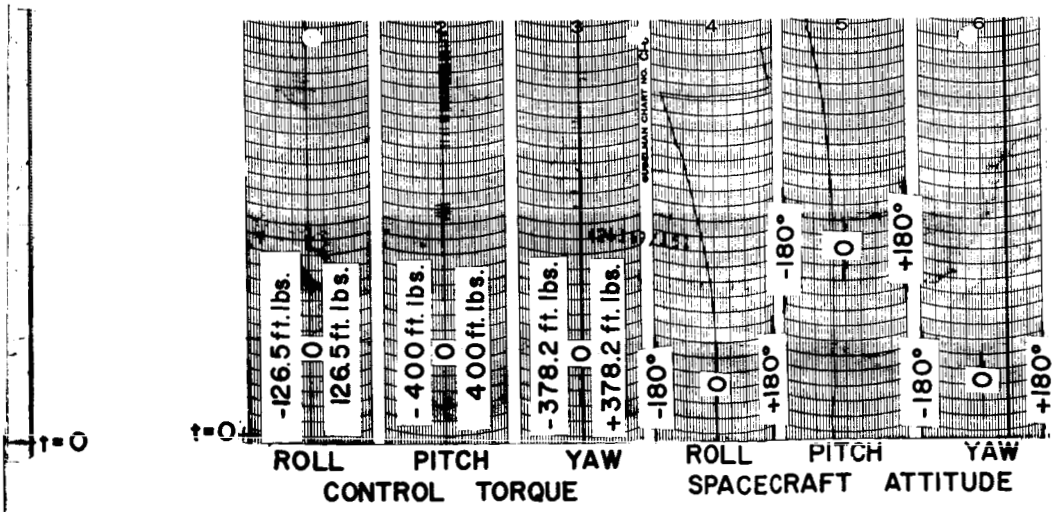


. - Problem number 6


t=0
+40°
0
-40°
α~DEG
300,000ft.
0
h~ft
25,000ft/sec.
0
V_T~ft/sec
450 lb./ft.²
0
q̄~lb/ft²
15.18g
0
a_T g's
14.4g.
0
a_x
+0.8g.
0
a_y
-0.8g.
+1.6g
0
a_z
COMPUTED
0
+1
FUEL CONSUMPTION PERCENT
+.5 rad/sec
-.5rad/sec
+.5 rad/sec
ROLL RATE (p)
-.5rad/sec
+.5 rad/sec
PITCH RATE (q)
-.5 rad/sec
YAW RATE (r)
+25000ft/sec
-25000ft/sec
v-ft/sec
+25000ft/sec
-25000ft/sec
w-ft/sec
+180°
-180°
SELECT CHANNEL
η

Figure





e 12.- Problem number 7

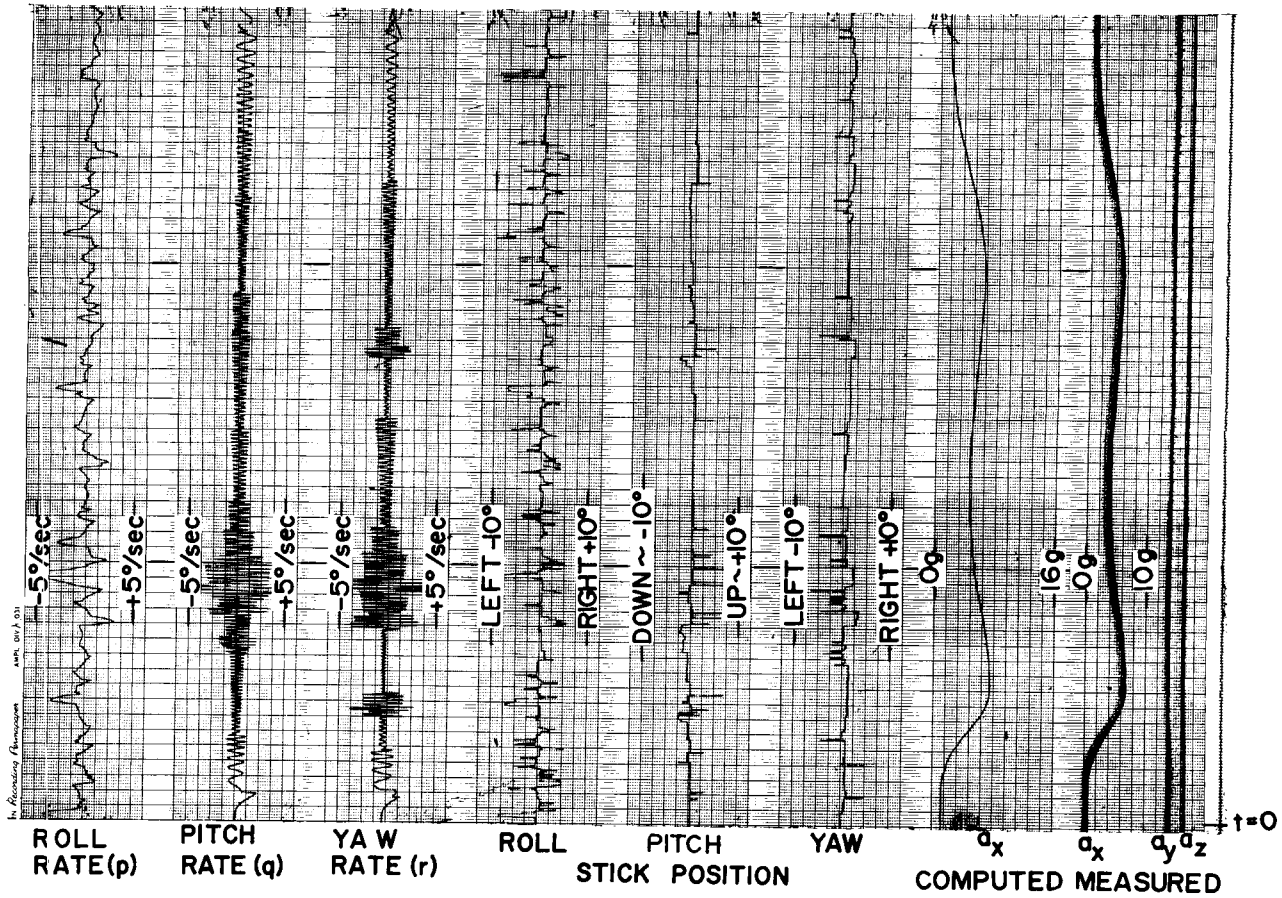
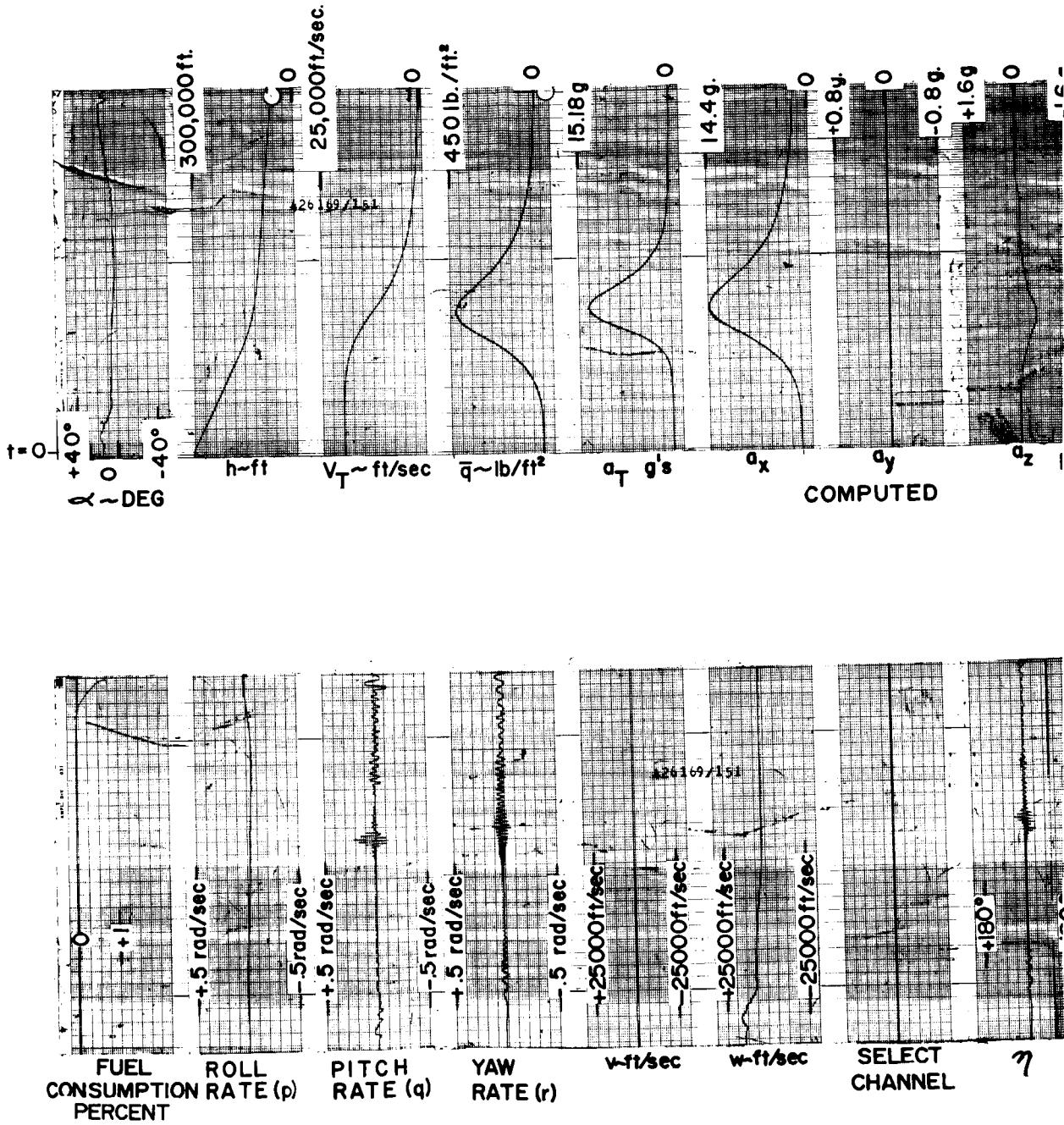


Figure 13.- Generalized Lunar reentry. Problem number 1.


t=0
+40°
0
-40°
α~DEG
300,000ft.
0
h~ft
25,000ft./sec.
0
V_T~ft/sec
450lb./ft.²
0
q̄~lb/ft²
15.18g
0
a_T g's
14.4g.
0
a_x
+0.8g.
0
a_y
-0.8g.
+1.6g
0
a_z
COMPUTED
0
+1
FUEL CONSUMPTION PERCENT
+.5 rad/sec
-.5rad/sec
ROLL RATE (p)
+.5 rad/sec
-.5 rad/sec
PITCH RATE (q)
+.5 rad/sec
-.5 rad/sec
YAW RATE (r)
+25000ft/sec
-25000ft/sec
v-ft/sec
+25000ft/sec
-25000ft/sec
w-ft/sec
+180°
SELECT CHANNEL
η

Figu

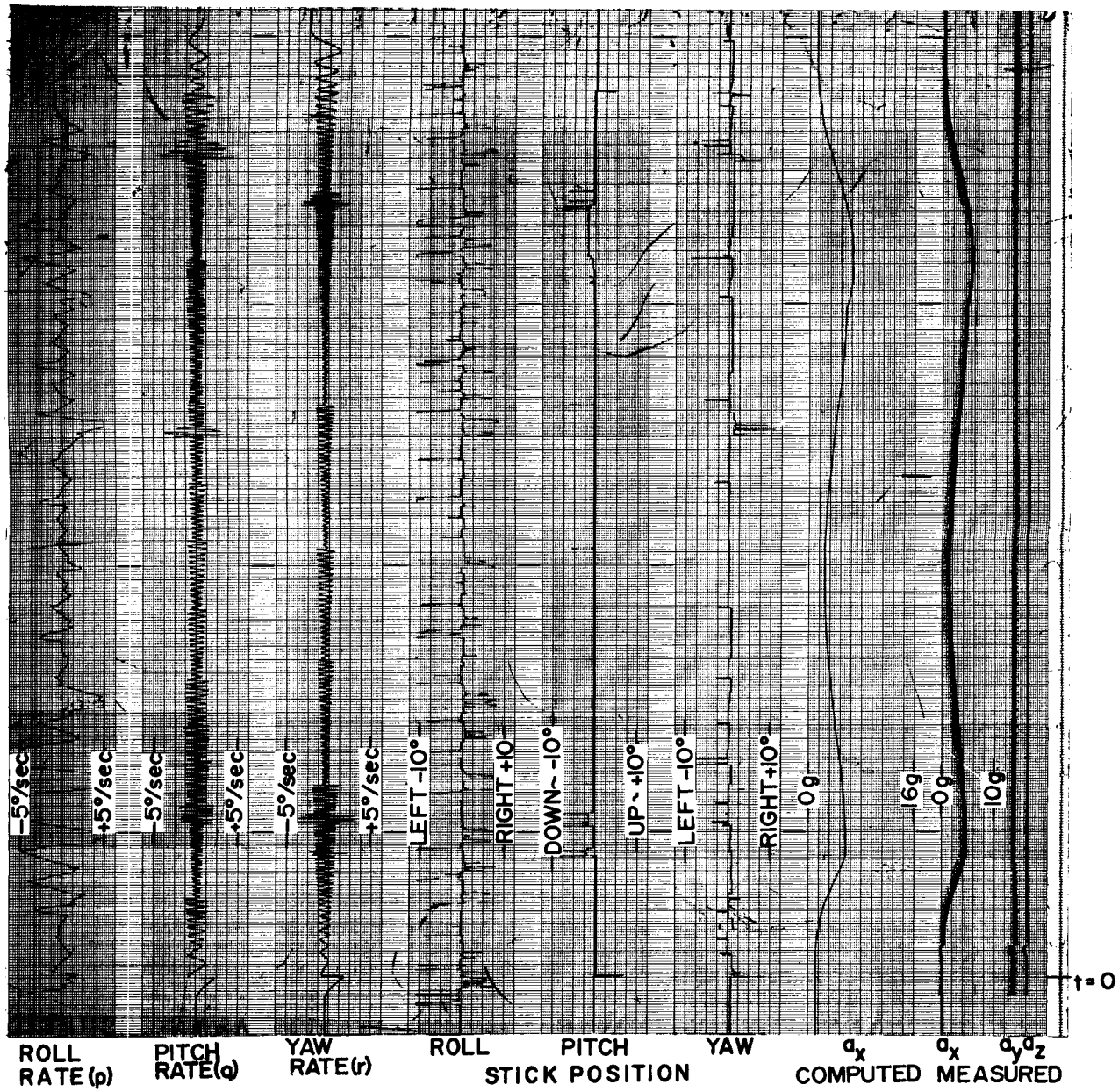


Figure 14.- Generalized Lunar reentry. Problem number 2.

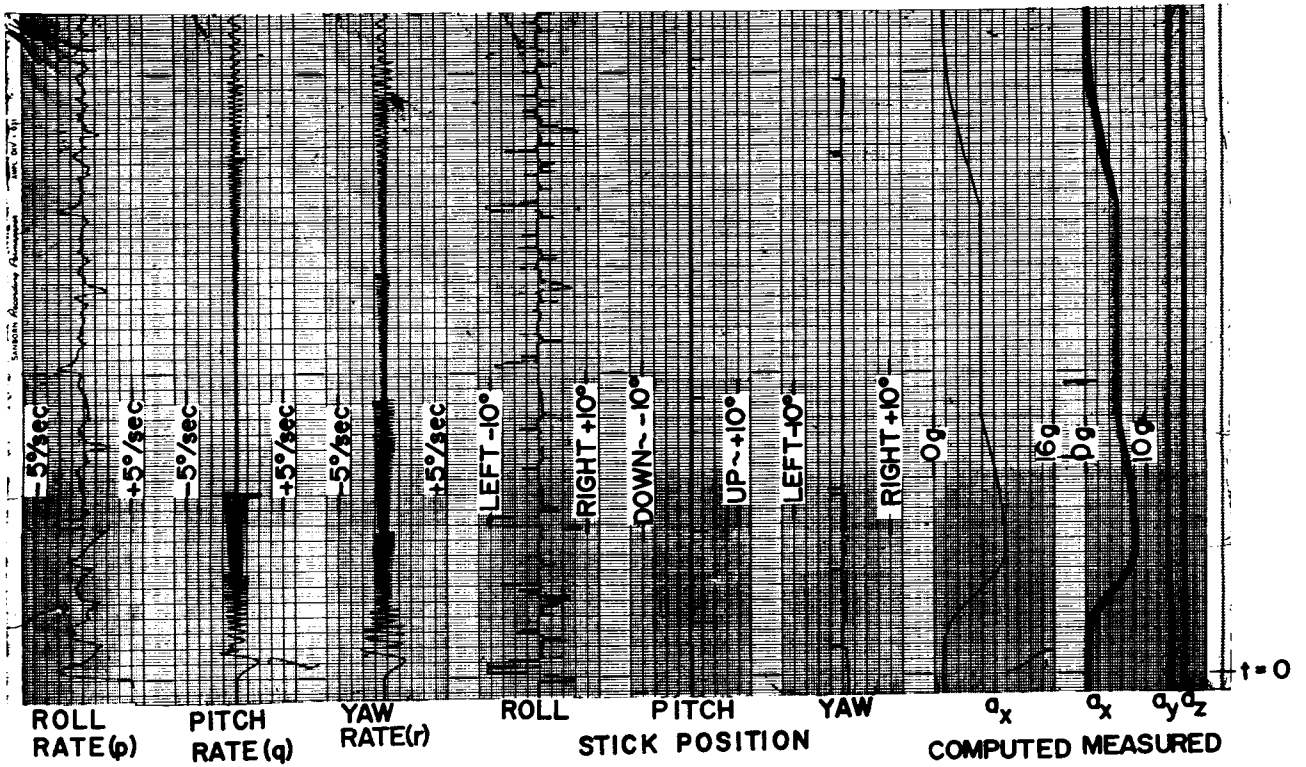


Figure 15.- Generalized Lunar reentry. Problem number 3.

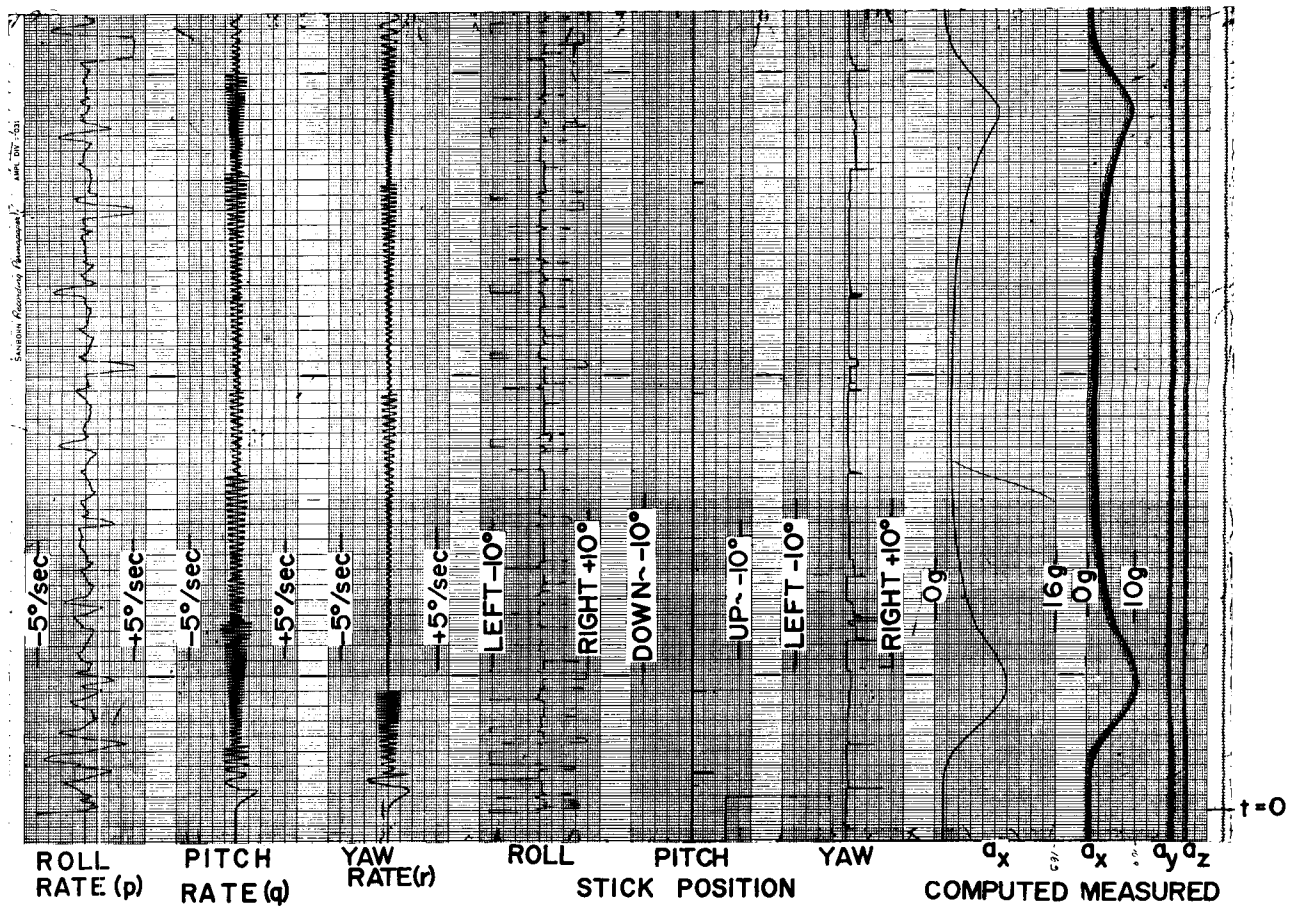


Figure 16.- Generalized Lunar reentry. Problem number 4.

APPENDIX A

GENERALIZED LUNAR REENTRIES

A brief Generalized Lunar Reentry Program consisting of four lunar reentry profiles was accomplished utilizing the Gemini fixture. (Figures 13-17.) The objective of this program was to obtain preliminary information concerning pilot ability to perform a combination rate damping and attitude control task while under sustained high acceleration loads and to obtain pilot comments concerning discomfort, blackouts, et cetera. A constant back angle to force vector of $8\frac{1}{3}°$ was used throughout this program.

The lunar reentry task consisted of a rate damping problem in pitch and yaw that was time dependent upon 'g' for both oscillation frequency and amplitude, and a bank angle control task that was independent of acceleration. The direct control mode was used for this program. The following describes the control task:

$$\text{Pitch axis } \dot{q} = \text{Cos}K_1\omega t - K_2 q + \text{pitch stick input}$$

$$\text{Yaw axis } \dot{r} = \text{Cos}K_2\omega t - K_2 r + \text{yaw stick input}$$

Where:

$$K_2 = \text{Const} = .05$$

$$K_1 = \text{Const} = .8455$$

ω - Angular velocity of centrifuge arm

$$\text{Roll axis } \dot{p} = + \text{roll stick input}$$

(Controller response about all axes = 10 deg/sec^2 upon 25% deflection of stick.

Displays:

The initial conditions displayed on the attitude ball were:

$$\phi = 180°$$
$$\theta = 0°$$
$$\psi = 180°$$

The attitude ball displayed oscillations due to pitch, roll, and yaw rates, plus a constant pitch rate corresponding approximately to the central angle traversed during the reentry. The pitch and yaw flight director needles displayed pitch and yaw rates with full scale deflection corresponding to ±5 degrees/second. Rates were damped by "flying to" the needles. The Roll Director Needle displayed mixed rates and attitude error according to:

$$\phi \text{ Actual} - \phi \text{ Command} - P$$

Roll command was generated from a triangle function generator at a frequency of 0.02 cps. ϕ command varied ±80° from the null position of 180°. Full scale deflection of the Roll Director Needle corresponded to a roll error of 20° or 20° per second and was nulled by "flying to the needle." Four pilots participated in the Generalized Lunar Reentry Study. One pilot made his series of runs using a Gemini prototype pressure suit. The remaining pilots made their runs under "shirt sleeve" conditions. A tabulation of runs made is given in Table II. Figures 13 through 16 give a typical run for each problem. Shown are:

Roll Rate
Pitch Rate
Yaw Rate
Roll Attitude
Pitch Attitude
Yaw Attitude
Measured Accelerations a_x, a_y, a_z
Computed Acceleration a_x

All pilots reported no difficulty in controlling these reentries, nor did they experience any significant visual problems, pain, or problems of any kind while undergoing the long duration 'g' loads.

APPENDIX B

SEQUENCE OF EVENTS FOR CASES 1 THROUGH 5

GEMINI CENTRIFUGE PROGRAM

CASE NO. 1

NORMAL LAUNCH AND REENTRY

Time	a_x	Event	Procedures	Communications	Remarks
-0:00:10	-	Stage I and II engine lights ON	Monitor		1. All other warning and sequence lights OFF. 2. Attitude indicator: 109.5° roll, + 90° yaw, 0° pitch.
-0:00:3	-	Stage I engine light OFF	Monitor	Confirm Ignition	1. Stage I fuel and oxidizer pressures start to decrease.
0:00:00	1.3	Lift-off; event timer starts	Monitor MDS Displays	Lift-off; timer started; Start computer light ON	1. Maximum allowable rates during first stage operation 4°/sec in pitch and yaw, 12°/sec in roll. 2. Stage II tank pressures not critical during Stage I operation. 3. To abort prior to 0:01:33 Pull "D" ring-this action stops the centrifuge and constitutes seat ejection.
0:00:05	1.4	Start booster roll program	Monitor	Roll program IN	1. At 0:00:05 the booster rolls 1.95°/sec (for 10 sec) left to the correct azimuth.
0:00:15	1.4	Roll program complete	Monitor		1. Attitude: +90° roll, +90° yaw, 0° pitch.

CASE NO. 1 - Continued

Time	a_x	Event	Procedures	Communications	Remarks
0:00:20	1.5	Start yaw program	Monitor		
0:00:30	1.6			1st Stage fuel and oxidizer pressure.	1. Attitude: +90° roll, +84° yaw, 0° pitch.
0:01:00	1.9			1st Stage fuel pressure.	1. After "T" plus fifty seconds the Stage I oxidizer tank pressure is not critical. 2. Attitude: +90° roll, +59° yaw, 0° pitch
0:01:15	2.1	Passing maximum Q	Monitor	Confirm max Q	1. Attitude: +90° roll, +48° yaw, 0° pitch.
1:32	2.5	Abort mode change	Safety and stow "D" ring	Confirm	1. Attitude: +90° roll, +40° yaw, 0° pitch. To abort (1:32-3:05): Actuate abort handle to "Booster Shutdown" position and then to "Separate Spacecraft" position 20 sec. later.
1:56	3.4				1. Attitude: +90° roll, +34° yaw, 0° pitch.
2:00	3.6	Report		1st Stage fuel press; 2nd Stage press. GO for engine ignition	1. 2nd Stage fuel tank pressure must be at least 30 psia for proper start. 2. Attitude: +90° roll, +31° yaw, 0° pitch.

CASE NO. 1 - Continued

Time	a_x	Event	Procedures	Communications	Remarks
2:30	1.4	Staging	Monitor	Staging and Second Stage ignition; fuel and O_2. Press OK	1. Staging light ON (2:30); OFF (2:30:7). 2. Engine No. 2 light OFF (2:30). 3. During Stage II operation the oxidizer pressure is not critical 4. Attitude: +90° roll, +22° yaw, 0° pitch.
3:05	1.6	Abort mode change	Unstow maneuver handle	Confirm abort mode change - fuel pressure	1. Attitude: +90° roll, +16° yaw, 0° pitch.
					To abort (3:05-5:33): 1. Actuate abort handle to "Booster Shutdown" position. 2. Depress "SEP Spacecraft" light 20 sec. later, Actuage maneuver handle for 10 sec. forward thrust. 3. Proceed with normal reentry.
3:15	1.8	Jettison Fairing	Depress "Jett Fairing Switch"	Fairings jettisoned	1. Attitude: + (0° roll, +20° yaw, 0° pitch. 2. Maximum allowable rates 10°/sec (qr) 20°/sec (p)
3:30	1.9			Fuel Pressure	1. Attitude: +90° roll, +12° yaw, 0° pitch.

CASE NO. 1 - Continued

Time	a_x	Event	Procedures	Communications	Remarks
4:00	2.3			Fuel Pressure	1. Attitude: +90° roll, 6.5° yaw, 0° pitch.
5:33	0	SECO	Monitor Engine No. 2 light ON	SECO	1. Attitude: +90° roll, -9° yaw, 0° pitch
5:52		Separate spacecraft	1. Depress "SEP Spacecraft" light. 2. Roll left 90°	SEP Spacecraft light green	Final Attitude: pitch -9° yaw 0°, roll 0°
Prior to retro sequence event timer should be reset to Tr-05:30 minutes and the S/C must be turned around to 180° yaw, 0° roll, -16° pitch.					
Tr-5:00		1. Retro attitude tel-light ON. 2. SEC O_2 tel-light ON 3. Battery power tel-light ON. 4. RCS tel-light ON.	1. Depress lights in sequence to initiate each event except "Battery Power Tel-light".		1. Lights turn from AMBER to GREEN when proper function has occurred.
-00:30		1. OAMS lines SEP tel-light ON. 2. Elect SEP tel-light ON 3. SEP Adapter tel-light ON. 4. Arm Auto Retro tel-light ON.	Depress lights in sequence.		
0	1.5	Retrofire	Depress "Fire Retro" Switch		1. 1.5 g's for 22 sec.

CASE NO. 1 - Concluded

Time	a_x	Event	Procedures	Communications	Remarks
Tr+00:45		Jett Retro tel-light ON	Depress light to separate adapter.		
01:45		Start reentry	Position spacecraft for modulated lift reentry.		1. Closed loop control

CASE NO. 2

FUEL TANK FAILURE (T+35)

Time	a_x	Event	Procedures	Communications	Remarks
-0:00:10	-	Stage I and II engine lights ON	Monitor		1. All other warning and sequence lights OFF. 2. Attitude indicator +109.5° roll, +90° yaw 0° pitch.
-0:00:03	-	Stage I engine light OFF	Monitor	Ignition	1. Stage I fuel and oxidizer pressures start to decrease.
0:00:00	1.3	Lift-off; event timer starts	Monitor MDS Displays	Lift-off; timer started. Start computer light ON.	1. Maximum allowable rates during first stage operation 4°/sec in pitch and yaw, 12°/sec in roll. 2. Stage II tank pressures not critical during Stage I operation. 3. To abort prior to 0:01:33. Pull "D" ring-this action stops the centrifuge and constitutes seat ejection.
0:00:05	1.4	Booster Roll Program Begins	Monitor	Confirm Roll Program	1. Roll Rate is 1.95°/sec left for 10 seconds to achieve proper azimuth.
0:00:15	1.4	Roll Program Completed	Monitor		1. Attitude: +90° roll; +90° yaw, 0° pitch.

CASE NO. 2 - Concluded

Time	a_x	Event	Procedures	Communications	Remarks
0:00:20	1.5	Yaw program begins	Monitor		
0:00:29	1.55	Stage I fuel pressure begins to drop			1. This is the first indication of possible malfunction.
0:00:39	1.65	Stage I fuel pressure fallen to limit for minimum structural safety	Abort	Announce Abort	1. Pilot should abort by this time. 2. Run terminates upon actuation of "D" ring.

CASE NO. 3

ABORT PRIOR TO STAGING (T+145)

Time	a_x	Event	Procedures	Communications	Remarks
-0:00:10	-	Stage I and II engine lights ON	Monitor		1. All other warning and sequence lights OFF. 2. Attitude indicator 109.5 roll, +90° yaw 0° pitch.
-0:00:03	-	Stage I engine light OFF	Monitor	Ignition	1. Stage I fuel and oxidizer pressures start to decrease.
0:00:00	1.3	Lift-off; event timer starts	Monitor MDS Displays	Lift-off; timer started. Start Computer light ON.	1. Maximum allowable rates during first stage operation 4°/sec in pitch and yaw, 12°/sec in roll. 2. Stage II tank pressure not critical during Stage I operation. 3. To abort prior to 0:01:33. Pull "D" ring this action stops the centrifuge and constitutes seat ejection
0:00:05	1.4	Start booster roll program	Monitor	Roll program IN	1. Roll rate is 1.95°/sec left for ten seconds to achieve proper azimuth.
0:00:15	1.4	Roll program complete	Monitor		1. Attitude: +90° roll, +90° yaw, 0° pitch.
0:00:20	1.5	Start yaw program	Monitor		

CASE NO. 3 - Concluded

Time	a_x	Event	Procedures	Communications	Remarks
0:00:30	1.6			1st Stage fuel and oxidizer pressure.	1. Attitude: +90° roll, +84° yaw, 0° pitch
0:01:00	1.9			1st Stage fuel pressure.	1. After "T" plus fifty seconds the Stage I oxidizer tank pressure is not critical. 2. Attitude: +90° roll, +59° yaw, 0° pitch.
0:01:15	2.1	Passing maximum Q POGO Area	Monitor	Confirm Max Q	1. Attitude: +90° roll, +48° yaw, 0° pitch.
0:01:32	2.5	Abort mode change	Safety and stow "D" ring.	Confirm abort mode change	1. Attitude: +90° roll, +40° yaw, 0° pitch.
0:01:56	3.4				1. Attitude: +90° roll, +34° yaw, 0° pitch.
0:02:00	3.6	Report		First stage fuel pressure; 2nd stage fuel pressure GO for engine ignition.	1. Prior to staging, second stage fuel pressure should be at least 30 PSIA. 2. Attitude: +90° roll, +31° yaw, 0° pitch.
0:02:25	5.3; then 0	Engine no. 2 light OFF	Abort handle to booster shutdown; then immediately to booster separate.	Inform of abort.	1. "Fire in the hole" ignition of no. 2 engine before staging.

After separation the pilot will position the S/C to roll and yaw of 180°, pitch 18°, and prepare to fly a max lift reentry.

CASE NO. 4

ABORT JUST AFTER STAGING (T+150)

Time	a_x	Event	Procedures	Communications	Remarks
-0:00:10	-	Stage I and II engine lights ON	Monitor		1. All other warning and sequence lights OFF. 2. Attitude indicator 109.5° roll, +90° yaw, 0° pitch.
-0:00:03	-	Stage I engine light OFF	Monitor	Confirm Ignition	1. Stage I fuel and oxidizer pressures start to decrease.
0:00:00	1.3	Lift-off; event timer starts	Monitor MDS Displays	Lift-off; timer started Start computer lights ON	1. Maximum allowable rates during first stage operation 4°/sec in pitch and yaw, 12°/sec in roll 2. Stage II tank pressures not critical during Stage I operation. 3. To abort prior to 0:01:33. Pull "D" ring-this action stops the centrifuge and constitutes seat ejection.
0:00:05	1.4	Start booster roll program	Monitor	Roll program IN	1. At 0:05 the booster rolls 1.95°/sec (for 10 sec) left to the correct azimuth.
0:00:15	1.4	Roll program complete	Monitor		1. Attitude: +90° roll, +90° yaw, 0° pitch.
0:00:20	1.5	Start yaw program	Monitor		
0:00:30	1.6			1st Stage fuel and oxidizer pressure.	1. Attitude: +90° roll, +84° yaw, 0° pitch.

CASE NO. 4 - Concluded

Time	a_x	Event	Procedures	Communications	Remarks
0:01:00	1.9			1st Stage fuel pressure	1. After "T" plus fifty seconds the Stage I oxidizer tank pressure is not critical. 2. Attitude: +90° roll, +59° yaw, 0° pitch.
0:01:15	2.1	Passing maximum Q POGO Area	Monitor	Confirm Max Q	1. Attitude: +90° roll, +48° yaw, 0° pitch
0:01:32	2.5	Abort mode change	Safety and stow "D" ring.	Confirm	1. Attitude: +90° roll, +40° yaw, 0° pitch. To abort (1:32-3:05): Actuate abort handle to "Booster Shutdown" position and then to "Separate Spacecraft" position 20 sec. later.
0:01:56	3.4				1. Attitude: +90° roll, +34° yaw, 0° pitch
0:02:00	3.6	Report		1st Stage fuel pressure 2nd stage press. GO for engine ignition	1. 2nd Stage fuel tank pressure must be at least 30 psia for proper start. 2. Attitude: +90° roll, +31° yaw, 0° pitch.
0:02:30	1.4	Staging. Engine no. 2 fails to ignite.	Abort handle to booster separate	Confirm abort	1. Staging light ON (2:30); OFF (2:30.7)

After separation the pilot will position S/C to: roll 180°, yaw 180°, pitch -18° and prepare to fly a max lift reentry.

CASE NO. 5

ABORT PRIOR TO INSERTION (T+326)

Time	a_x	Event	Procedures	Communications	Remarks
-0:00:10	-	Stage I and II engine lights ON	Monitor		1. All other warning and sequence lights OFF. 2. Attitude indicator 109.5° roll, +90° yaw, 0° pitch.
-0:00:03	-	Stage I engine light OFF	Monitor	Confirm Ignition	1. Stage I fuel and oxidizer pressures start to decrease.
0:00:00	1.3	Lift-off; event timer starts	Monitor MDS Displays	Lift-off; timer started; Start Computer light ON	1. Maximum allowable rates during first stage operation 4°/sec in pitch and yaw, 12°/sec in roll. 2. Stage II tank pressures not critical during Stage I operation. 3. To abort prior to 0:01:33. Pull "D" ring-this action stops the centrifuge and constitutes seat ejection.
0:00:05	1.4	Start booster roll program	Monitor	Roll program IN	1. At 0:05 the booster rolls 1.95°/sec (for ten sec) left to the correct azimuth.
0:00:15	1.4	Roll program complete	Monitor		1. Attitude: +90° roll, +90° yaw, 0° pitch.

CASE NO. 5 - Continued

Time	a_x	Event	Procedures	Communications	Remarks
0:00:20	1.5	Start yaw program	Monitor		
0:00:30	1.6			1st Stage fuel and oxidizer pressure.	1. Attitude: +90° roll, +84° yaw, 0° pitch.
0:01:00	1.9			1st Stage fuel pressure.	1. After "T" plus fifty seconds the Stage I oxidizer tank pressure is not critical. 2. Attitude: +90° roll, +59° yaw, 0° pitch.
0:01:15	2.1	Passing maximum Q POGO Area	Monitor	Confirm max Q	1. Attitude: +90° roll, +48° yaw, 0° pitch.
0:01:32	2.5	Abort mode change	Safety and stow "D" ring.	Confirm	1. Attitude: +90° roll, +40° yaw, 0° pitch. To abort (1:32-3:05): Actuate abort handle to "Booster Shutdown" position and then to "Separate Spacecraft" position 20 sec. later.
0:01:56	3.4				1. Attitude: +90° roll, +34° yaw, 0° pitch.
0:02:00	3.6	Report		1st Stage fuel press; 2nd stage press. GO for engine ignition	1. 2nd Stage fuel tank pressure must be at least 30 psia for proper start. 2. Attitude: +90° roll, +31° yaw, 0° pitch.

CASE NO. 5 - Continued

Time	a_x	Event	Procedures	Communications	Remarks
0:02:30	1.4	Staging	Monitor	Staging and Second Stage ignition; fuel and O_2 press. OK	1. Staging light ON (2:30); OFF (2:30.7) 2. Engine No. 2 light OFF (2:30) 3. During Stage II operation the oxidizer pressure is not critical. 4. Attitude: +90° roll, +22° yaw, 0° pitch.
0:03:05	1.6	Abort mode change	Unstow maneuver handle	Confirm abort mode change - fuel pressure.	1. Attitude: +90° roll, +15° yaw, 0° pitch. To abort (3:05-5:33): 2. Actuate abort handle to "Booster Shutdown" position. 3. Depress "SEP Spacecraft light 20 sec. later. Actuate maneuver handle for 10 sec. forward thrust. 4. Proceed with normal reentry.
0:03:15	1.8	Jettison Fairing	Depress "Jett Fairing Switch"	Fairings jettisoned	1. Attitude: +90° roll, +20° yaw, 0° pitch. 2. Maximum allowable rates 10°/sec (qr) 20°/sec (p)
0:03:30	1.9			Fuel Pressure	1. Attitude: +90° roll, +12° yaw, 0° pitch.

CASE NO. 5 - Concluded

Time	a_x	Event	Procedures	Communications	Remarks
0:04:00	2.3			Fuel Pressure	1. Attitude: +90° roll, +6.5° yaw, 0° pitch.
0:05:26	6.26 then to 0	1. Engine No. 1 light ON	Abort handle to Booster Shutdown. Then depress the SEP S/C tel-light/ SW 20 sec later.	Confirm abort.	Abort is initiated by activating the abort handle to the booster shutdown position then depressing the sep/SC tel-light/sw 20 seconds later.

Follow normal reentry procedure except that max lift profile will be flown. Use Problem no. 1 for procedures.

APPENDIX C

GEMINI CENTRIFUGE PROGRAM - PHASE I

ORAL DEBRIEFING QUESTIONNAIRE

Pilot_____ Date_____ Time_____

Run Number(s)_____

Run Conditions_____

_____

Hand Controller

1. Is the hand controller positioned properly for the reentry task? If the answer is no, comment.

2. Is the hand controller properly shaped? If the answer is no, comment.

3. Comment on the "feel" of controller operation. Include in your comments the following items:

   a. Breakout force during static operating conditions.

   b. Breakout force during dynamic operating conditions.

   c. Controller force gradient (i.e. pounds of force per degree controller deflection).

   d. Controller "dead band" in rate command and direct command control modes.

4. a. Did the controller tend to bind or hang up? When? Suggestions and comments.

   b. Did you accidentally cross-couple control inputs? When? Suggestions or comments.

5. Comment on the controller operation during reentry acceleration. Was there a tendency for the controller to fail to center during the dynamic runs?

6. Comment on any additional controller problems encountered under "Hard Suit" operating conditions.

7. Any additional comments or problem with the hand controller.

Ejection Seat and Support

1. Evaluate the general comfort of the seat during dynamic runs. Static runs? Any particular points of discomfort? Where?

2. Did you experience any cramps? Where?

3. Did a leg or arm go to sleep on you? Which one?

4. Is the "D" ring operation satisfactory? Are stowing and safety procedures satisfactory? Any problems? Suggestions.

5. How do you rate comfort as a function of time? In hard suit condition? Soft suit condition?

6. Any suggested changes in the egress kit, pelvic, or backboard contour? What?

Restraint System

1. Did the straps afford ample restraint? If no, where? Suggestions.

2. Did you try to loosen or tighten straps yourself? Any problems?

3. Did you notice any head movement during dynamic runs? Comment.

4. Did any of the straps bind or cause discomfort? If yes, which ones? Comments.

Pressure Suit

1. Did the suit produce any discomfort under static conditions? Dynamic conditions? Pressurized under dynamic conditions? If so, what and where? Any other comments or suggestions?

2. Any difficulty in maneuvering during periods of pressurized suit operations? Unpressurized suit operations?

Control Displays and Tasks

1. Comment on the readability and proper location of pertinent displays during launch and reentry acceleration loads. Any problems? If so, explain.

2. Comment on the location of all malfunction detection system displays pertinent to the launch phase. Any suggestions?

3. Comment on the following:

   a. Abort handle location and operation.

   b. Secondary guidance switch location and operation.

   c. Maneuver handle location and operation.

4. Comment on launch procedures and retro-grade and reentry sequences and procedures. Any problems? Any suggestions?

5. Comment on tasks. Are these realistic? Any problem areas? Suggestions for improvements?

Any comments or suggestions not covered by any of the above questions.

APPENDIX D

GEMINI REENTRY EQUATIONS

$$u = V_T \cos \alpha_T \tag{1}$$

$$\dot{v} = pw - ru + \frac{Y_a}{m} + \cos \theta \sin \phi \left(g - \frac{V_T^2}{R} \right) \tag{2}$$

$$\dot{w} = qu - pv + \frac{Z_a}{m} + \cos \theta \cos \phi \left(g - \frac{V_T^2}{R} \right) \tag{3}$$

$$X_a = \bar{q}S \, C_x \tag{4}$$

$$Y_a = \bar{q}S \, C_N \sin \eta \tag{5}$$

$$Z_a = \bar{q}S \, C_N \cos \eta \tag{6}$$

$$\sin \gamma = \frac{\dot{h}}{V_T} \tag{7}$$

$$\sin \alpha_T = \frac{\sqrt{v^2 + w^2}}{V_T} \tag{8}$$

$$\cos \beta_T = \frac{|w|}{V_T} \tag{9}$$

$$\tan \eta = \frac{v}{w} \tag{9a}$$

$$\dot{V}_T = \frac{(X_a)}{m} \cos \alpha_T + \frac{Z_a}{m} \cos \beta_T - g \sin \gamma \tag{10}$$

$$\dot{p} = \frac{(I_y - I_z)}{I_X} qr + \frac{\text{Control Torque}}{I_X} + \frac{\bar{q}S}{I_X} \left(0.121 \, C_N \sin \eta \right) \tag{11}$$

$$\dot{q} = \frac{(I_Z - I_X)}{I_Y} pr + \frac{\bar{q}S}{I_Y}\left(C\, C_m \cos\eta + \frac{C_{mq}\, C^2 q}{2V_T} - 0.121\, C_X - 0.588\, C_N \cos\eta\right) + \frac{\text{Control Torque}}{I_Y} \tag{12}$$

$$\dot{r} = \frac{(I_X - I_Y)}{I_Z} pq - \frac{\bar{q}S}{I_Z}\left(C\, C_m \sin\eta - \frac{C_{nr}\, C^2 r}{2V_T} + 0.588\, C_N \sin\eta\right) + \frac{\text{Control Torque}}{I_Z} \tag{13}$$

Euler Angles

$$\dot{\phi} = p + \dot{\Psi} \sin\theta \tag{14}$$

$$\dot{\theta} = q \cos\phi - r \sin\phi \tag{15}$$

$$\dot{\Psi} = \frac{r \cos\phi + q \sin\phi}{\cos\theta} \tag{16}$$

Gyro Angles

$$\dot{\phi}_G = p - \dot{\theta} \sin\Psi \tag{17}$$

$$\dot{\theta}_G = \frac{q \cos\phi - r \sin\phi}{\cos\Psi} \tag{18}$$

$$\dot{\Psi}_G = q \sin\phi + r \cos\phi \tag{19}$$