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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

1.3-DN-C0203-006

ROLL MANEUVER EVALUATION

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ROLL MANEUVER EVALUATION

1.0 INTRODUCTION

The current roll maneuver to the flight azimuth following lift-off is achieved by commanding roll attitude using a linear profile with no roll rate command. The linearity of this command profile implies an infinite acceleration to a constant roll rate; the vehicle cannot instantaneously achieve this rate, so the actual roll attitude lags the commanded attitude throughout the maneuver. The roll attitude error which thus develops can be reduced by augmenting the attitude command with a rate command and utilizing finite slopes on the rate command to give the vehicle time to accelerate. It is the purpose of this document to present results obtained from commanding various roll attitude and rate combinations to perform the maneuver.

2.0 DISCUSSION

Four combinations of roll rate/attitude commands were implemented in the SSFS in table lookup form for simulation of Missions 1, 2, and 3A, with no wind. This document presents the results of Mission 2, which requires the largest roll maneuver (142.2 degrees). All three missions provided similar results.

The four combinations will be referred to as maneuvers A, B, C, and C_{mod}; a brief discussion of each maneuver follows:

(1) Maneuver A (current)
Source: GNC Data Book (June 1974) Attitude is commanded in a linear ramp (Figure 1), with no rate command.

(2) Maneuver B
Source: Baseline Reference Mission, Revision A (JSC 75-FM-47, May 1974)
The rate command profile is trapezoidal, implying an instantaneously achieved constant acceleration of 2 degrees/sec^2 to the constant rate of 9 degrees/sec (Figure 2A).

The attitude command profile is smoothed by piecewise linear

approximations to the curve describing the implied acceleration (Figure 2B).

(3) Maneuver C
Source: Lockheed Memo 641-04114-8 (April 1974)
The rate command profile is smoothed by piecewise linear approximations to the curve describing a physically realizable change in acceleration, i.e. the constant acceleration of 6 degrees/sec^2 is given time to be developed by the vehicle (Figure 3A).

The attitude command profile is smoothed by ramps approximating the implied acceleration (Figure 3B).

(4) Maneuver C_{mod}
Source: This document (MDAC 1.3-DN-C0203-006, March 1975)
This rate and attitude command combination is a linearized form of Maneuver C.

The rate command profile is a trapezoid with acceleration ramps at 6 degrees/sec^2, and the attitude command is a ramp at 9 degrees/sec (Figures 4A and 4B).

See Tables I-IV for specific table lookup points for these commanded maneuvers.

The varying degrees of profile complexity suggest an evaluation of the necessity of filtering the rate and attitude commands for desired performance; thus each maneuver type was simulated with commands both filtered and unfiltered. Filters were digital forms of simple low-pass analog filters with time constants of .1 second for both rate and attitude commands.

The sample rate for these simulations was 10 Hz, and accompanying graphical results were plotted at this frequency.

3.0 RESULTS

Addition of a roll rate command to enhance the roll attitude command yields the following general results:

(1) Roll attitude error is greatly reduced because the time during which the vehicle is accelerating to the proper rate is accounted for by a finite acceleration slope on the rate command; thus there is less discrepancy between what the vehicle is commanded to do and what it is physically capable of doing. Roll attitude errors and roll rates developed by each type of maneuver are pictured in Figures 5, 6, 7, and 8, with specific maximum values given in Tables V AND VI.

(2) Aerodynamic loads are increased slightly due to the fact that the finite accelerations to the roll rate increase the overall duration of the roll maneuver, such that the constant roll rate persists into regions of greater dynamic pressure (angle of attack and sideslip angle develop from the performance of a pitch maneuver concurrent with the roll maneuver). Maximum values are acceptable (see Tables V AND VI).

(3) Engine gimbal requirements vary for each command combination,

and are shown in Figures 9, 10, 11, and 12. Maximum values are summarized in Tables VII and VIII. All duty cycle requirements are acceptable and the maximum deflections required to initiate and terminate the maneuver are also acceptable in that enough actuator travel remains available for control of disturbances. A possible exception is the C_{mod} maneuver with unfiltered commands, which requires almost half the available travel shortly after initiation of the commands (Table VIII). Filtering the commands for the C_{mod} maneuver drops the maximum gimbal deflections to more acceptable levels.

(4) Gimbal deflection histories for the B maneuver in Figures 9 through 12 exhibit oscillations during acceleration transients. These oscillations are control system response to the breakpoints in the attitude command occurring during linear portions of the rate command. Because these low-frequency gimbal oscillations will tend to excite bending modes, the B maneuver is deemed unacceptable.

4.0 CONCLUSION

The C maneuver provides acceptable results with unfiltered commands, but it requires the maximum number of software storage locations of the three rate and attitude command combinations evaluated. The C_{mod} maneuver requires a minimum of storage locations, but the commands must be filtered to yield acceptable results.

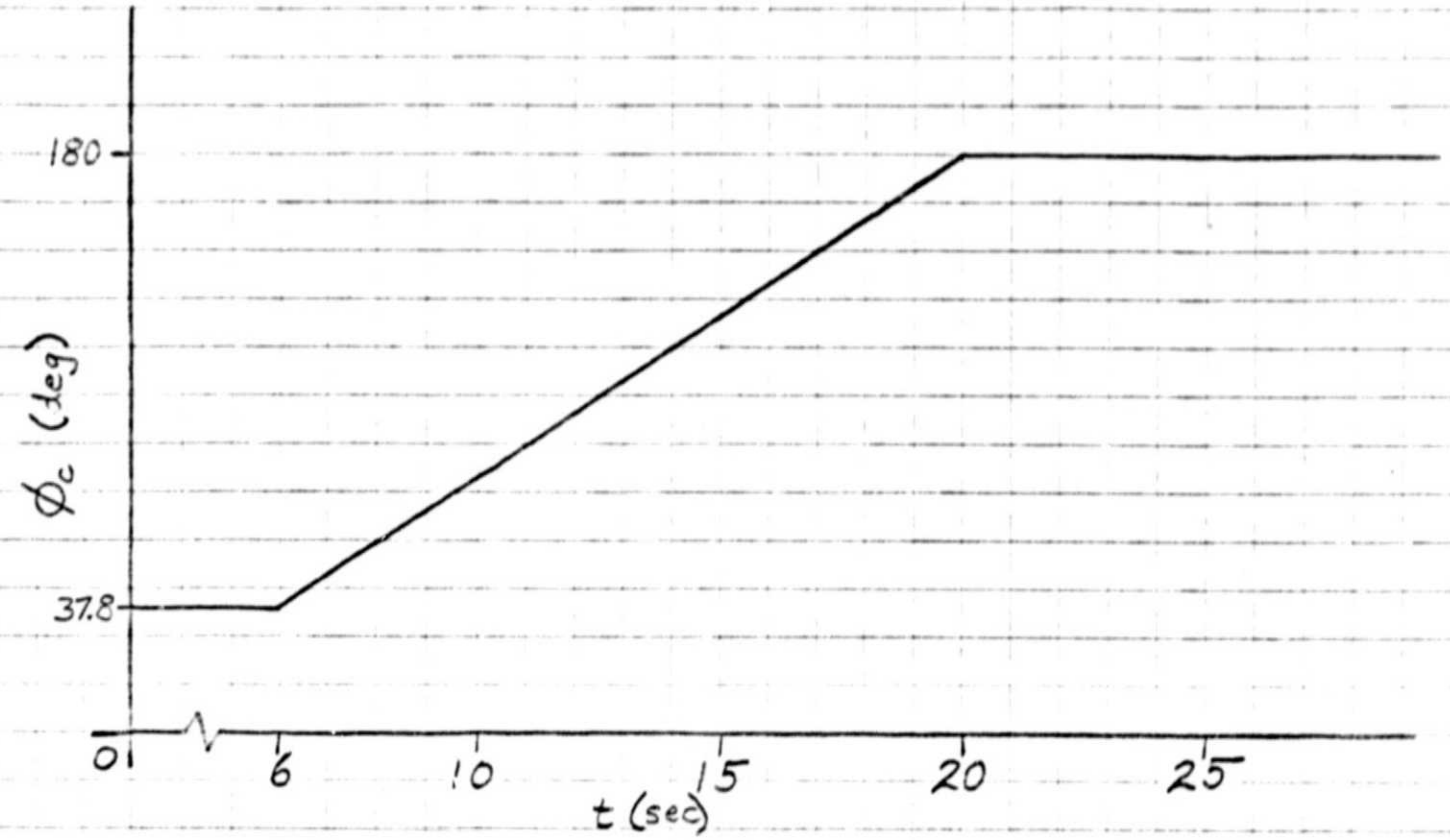

FIGURE 1. ROLL ATTITUDE COMMAND
MANEUVER A, MISSION 2

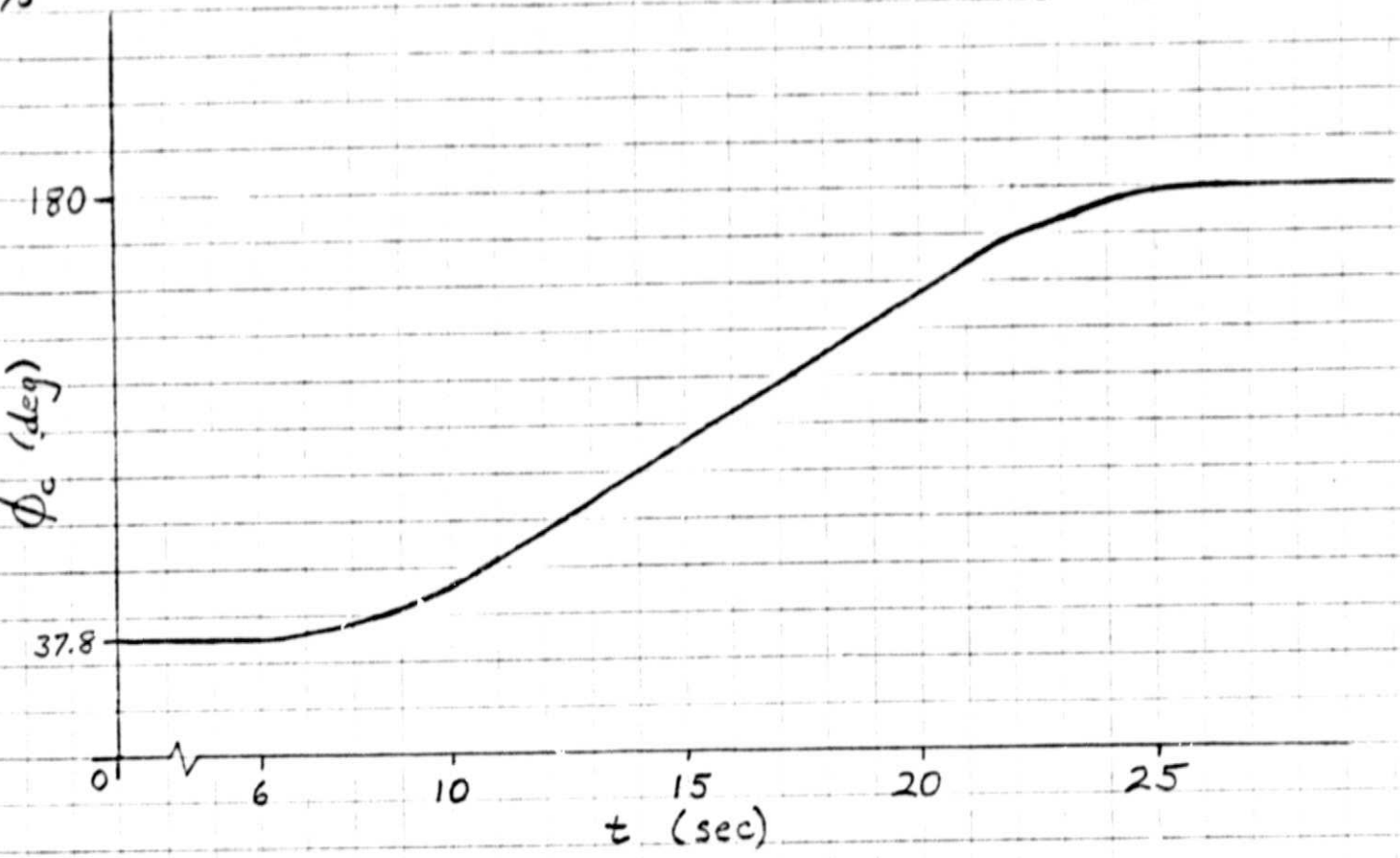

FIG 2B. ROLL ATTITUDE COMMAND
MANEUVER B, MISSION 2

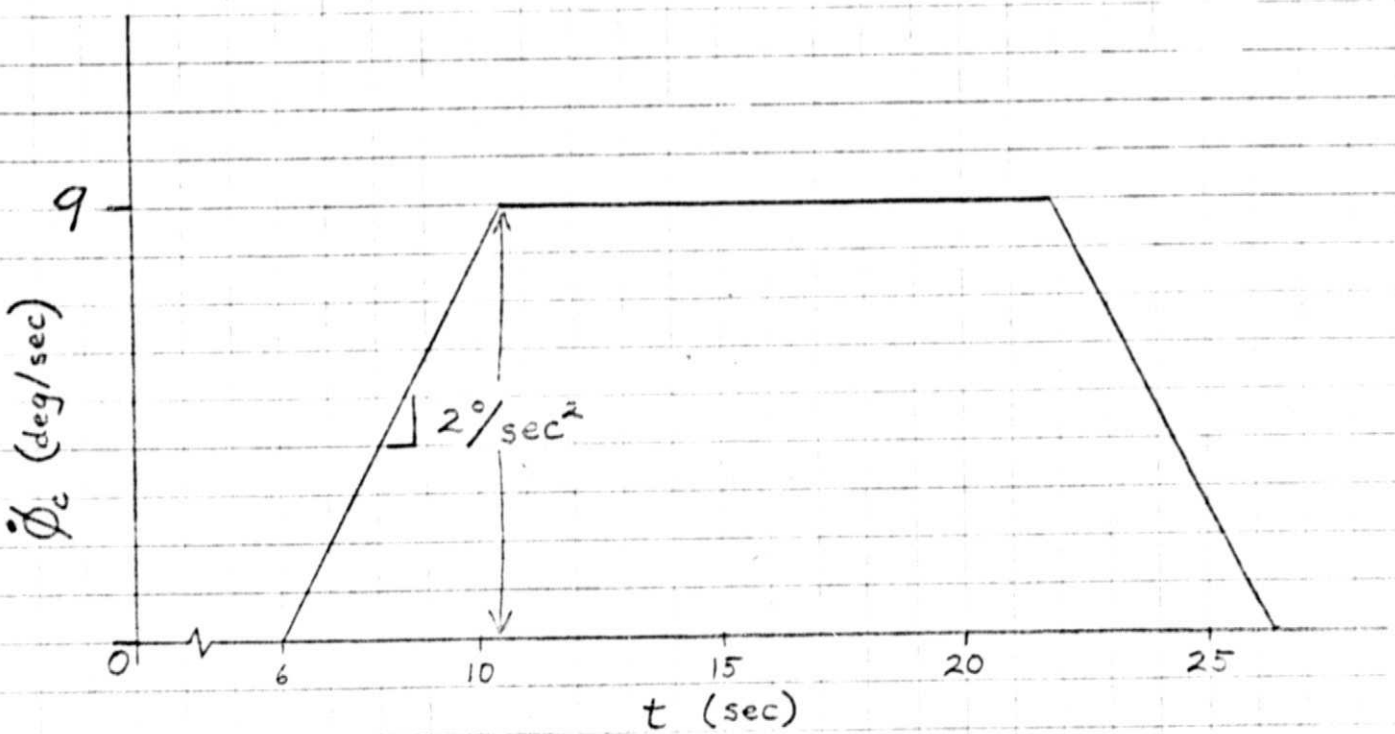

FIGURE 2A. ROLL RATE COMMAND

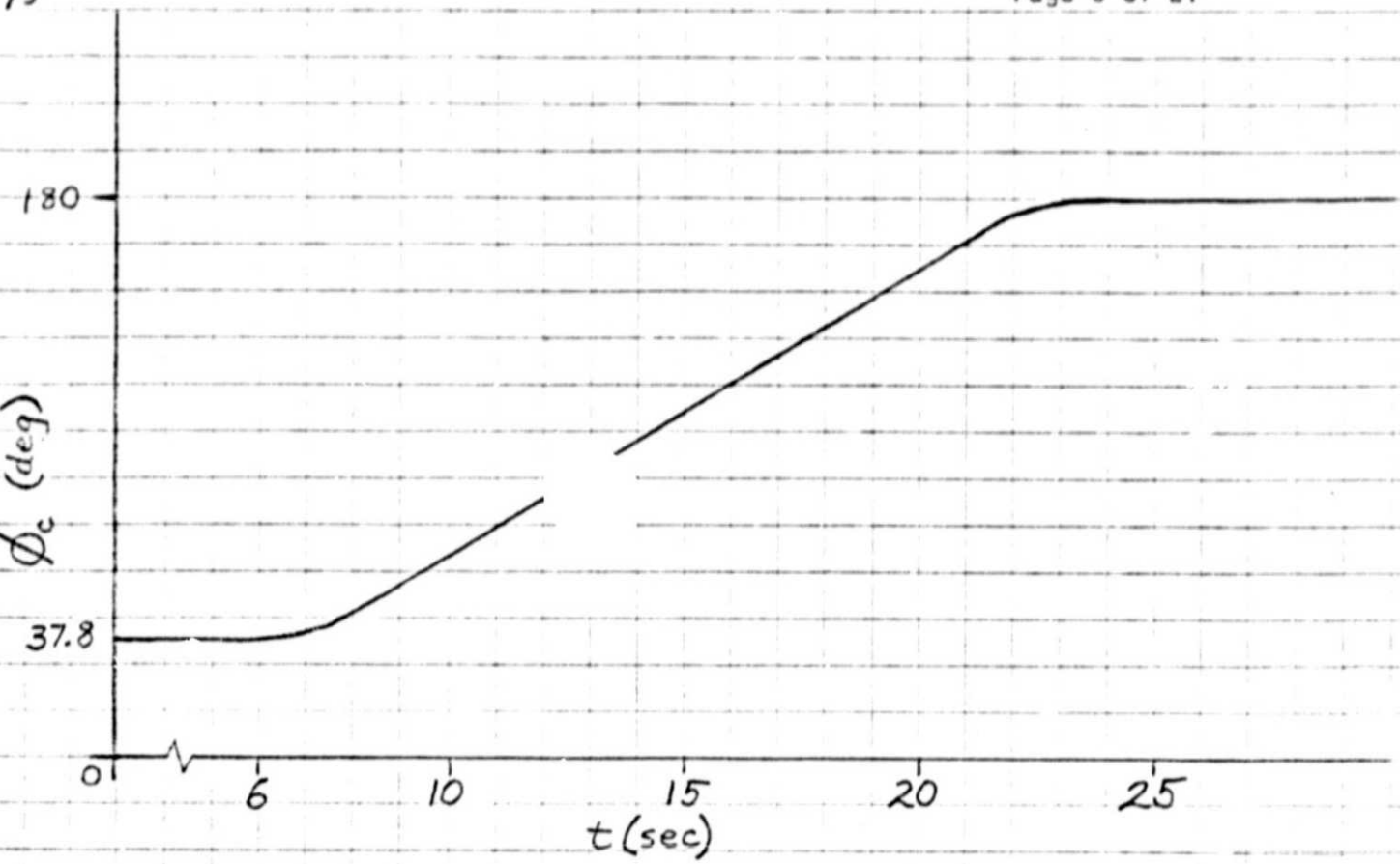

FIGURE 3B. ROLL ATTITUDE COMMAND
MANEUVER C, MISSION 2

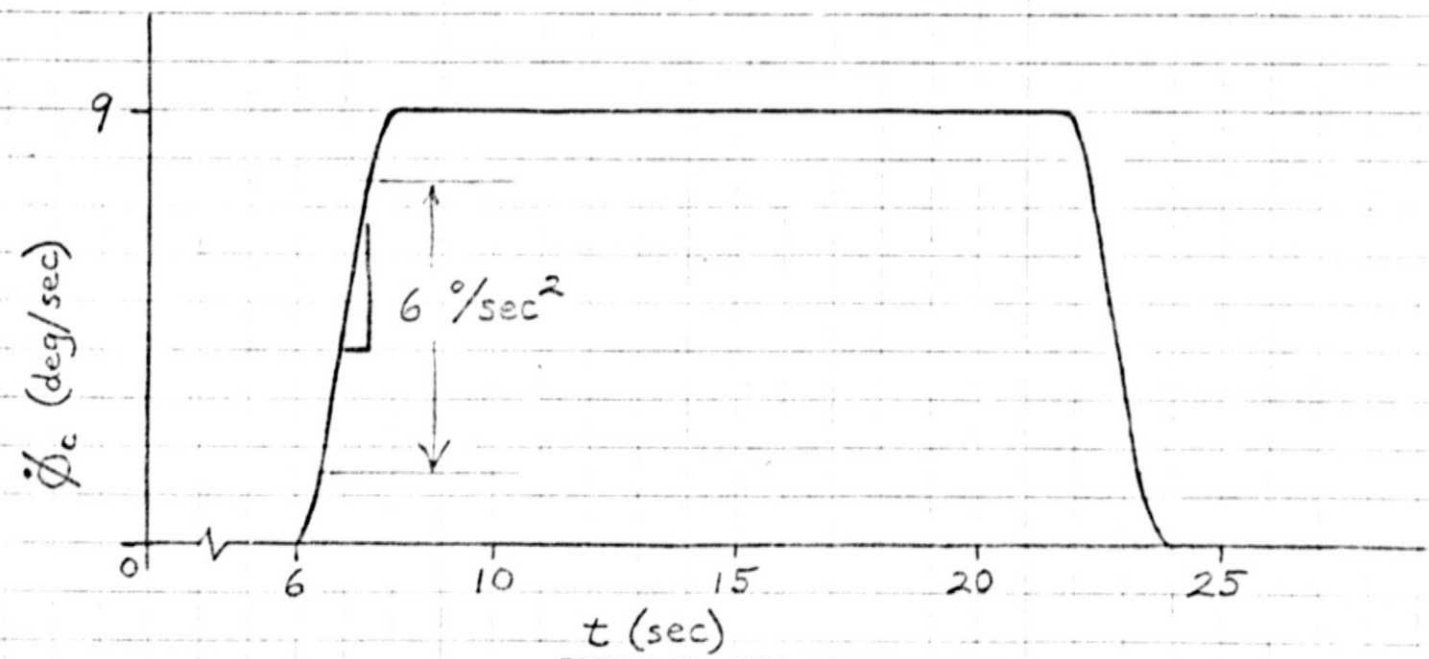

FIGURE 3A. ROLL RATE COMMAND

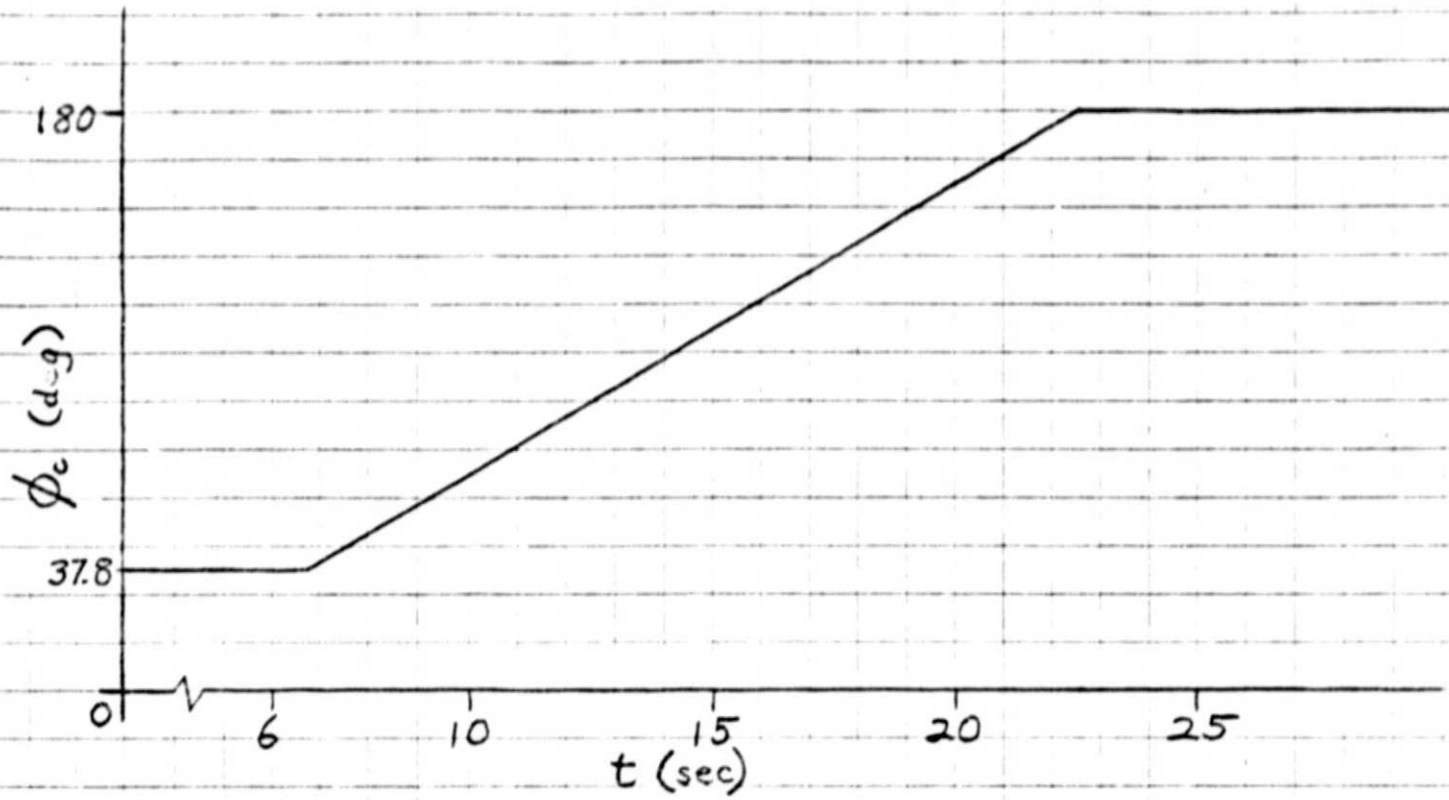

FIGURE 4B. ROLL ATTITUDE COMMAND
MANEUVER C_{MOD}, MISSION 2

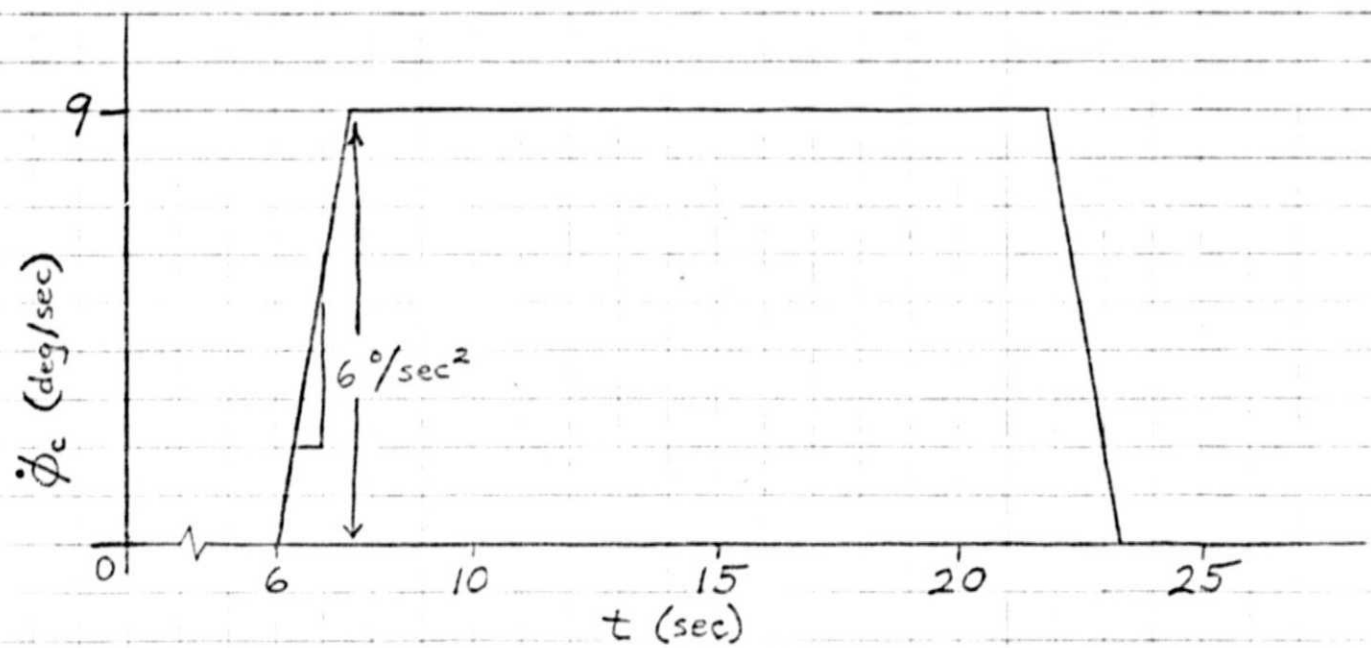

FIGURE 4A. ROLL RATE COMMAND

MISSION 2, MANEUVER A		
t (sec)	ϕ_c (deg)	ϕ_c (rad)
0.	37.8	.659734
6.	37.8	.659734
20.	180.	3.141593
600.	180.	3.141593

TABLE I

MISSION 2, MANEUVER B				
t (sec)	ϕ_c (deg)	ϕ_c (rad)	t (sec)	$\dot{\phi}_c$ (deg/sec)
0.	37.8	.659734	0.	0.
6.	37.8	.659734	6.	0.
7.	39.	.680678	10.5	9.
8.	42.	.733038	21.8	9.
9.	47.	.820305	26.3	0.
10.	54.	.942478	999.	0.
10.5	58.	1.012291		
21.8	160.	2.792527		
22.3	164.	2.862340		
23.3	171.	2.984513		
24.3	176.	3.071779		
25.3	179.	3.124139		
26.3	180.	3.141593		
600.	180.	3.141593		

TABLE II

MISSION 2, MANEUVER C				
t (sec)	ϕ_c (deg)	ϕ_c (rad)	t (sec)	$\dot{\phi}_c$ (deg/sec)
0.	37.8	.659734	0.	0.
6.	37.8	.659734	6.	0.
6.5	38.03	.663749	6.1	.25
7.	39.53	.689929	6.4	.925
7.5	42.53	.742288	6.5	1.5
8.	46.8	.816814	7.5	7.5
21.8	171.	2.984513	7.6	8.075
22.3	175.27	3.059039	7.9	8.975
22.8	178.27	3.111398	8.	9.
23.3	179.77	3.137578	21.8	9.
23.8	180.	3.141593	21.9	8.975
600.	180.	3.141593	22.2	8.075
			22.3	7.5
			23.3	1.5
			23.4	.925
			23.7	.25
			23.8	0.
			600.	0.

TABLE III

MISSION 2, MANEUVER C mod			
t	ϕ_c (deg)	t	$\dot{\phi}_c$ (deg/sec)
0	37.8	0.	0.
6.75	37.8	6.	0.
22.55	180.	7.5	9.
600.	180.	21.8	9.
		23.3	0.
		600.	0.

TABLE IV

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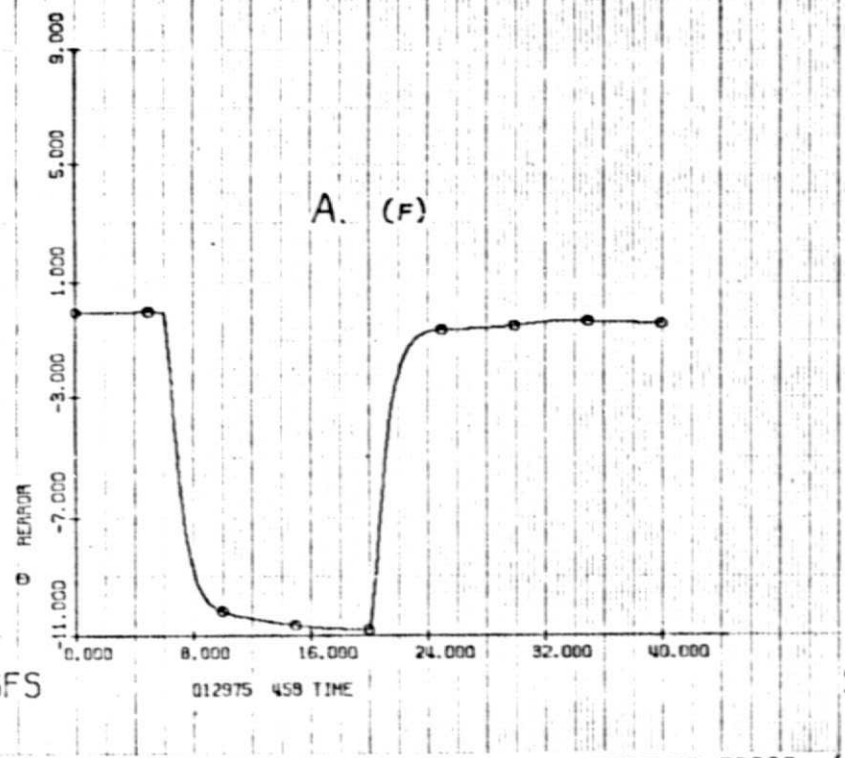
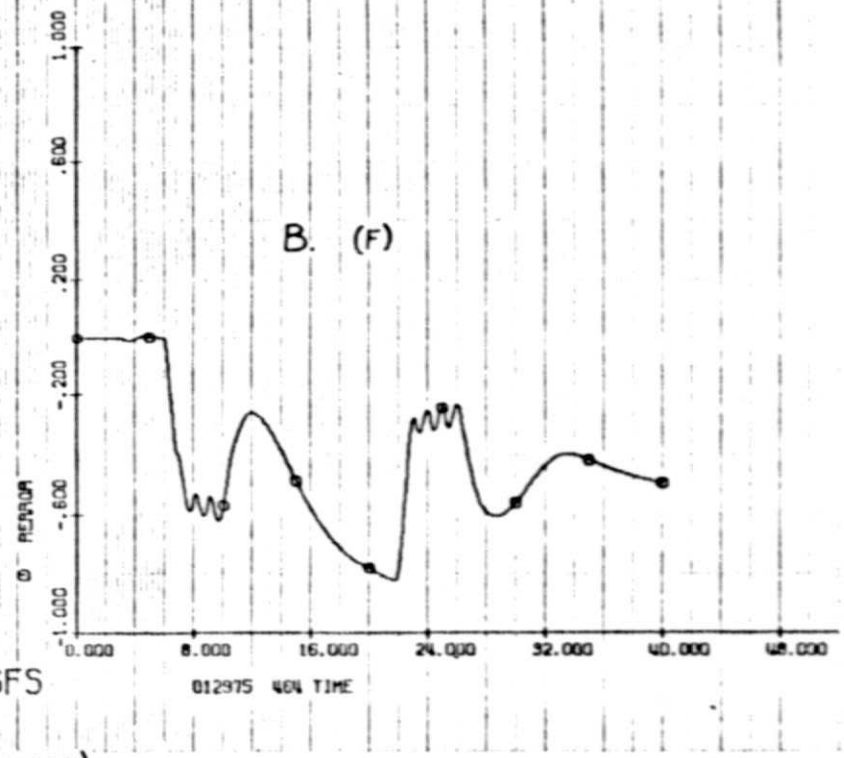
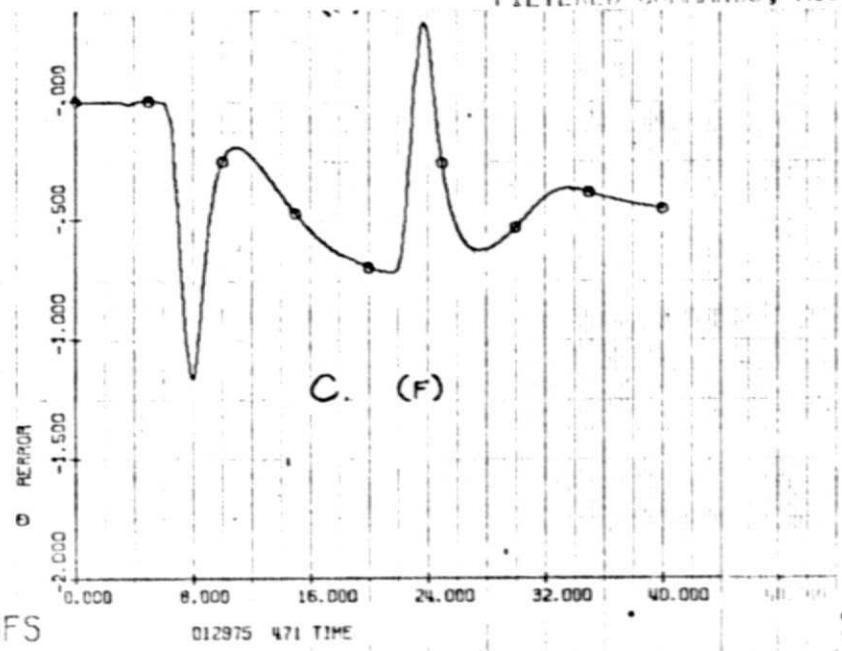




ROLL ATTITUDE ERROR (degrees)
FILTERED COMMANDS, MISSION 2



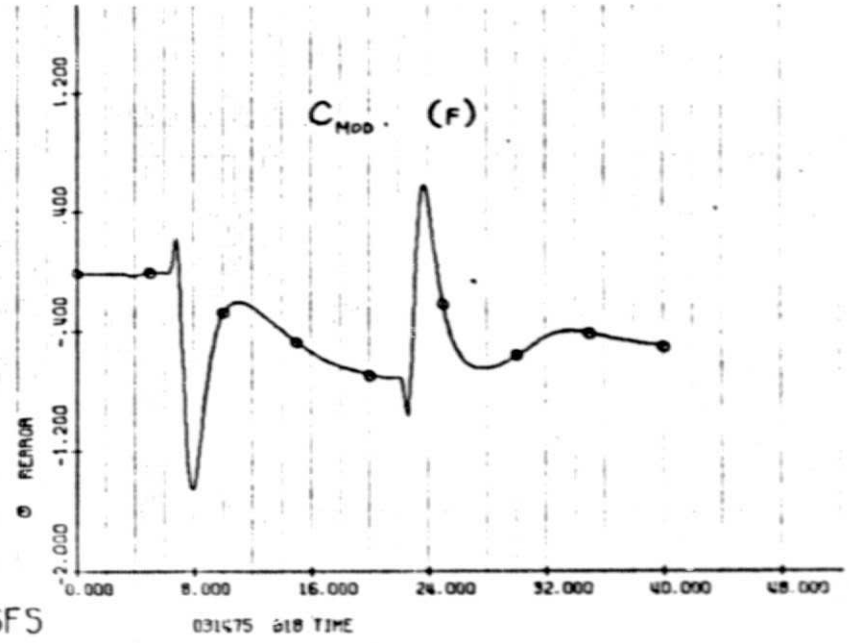
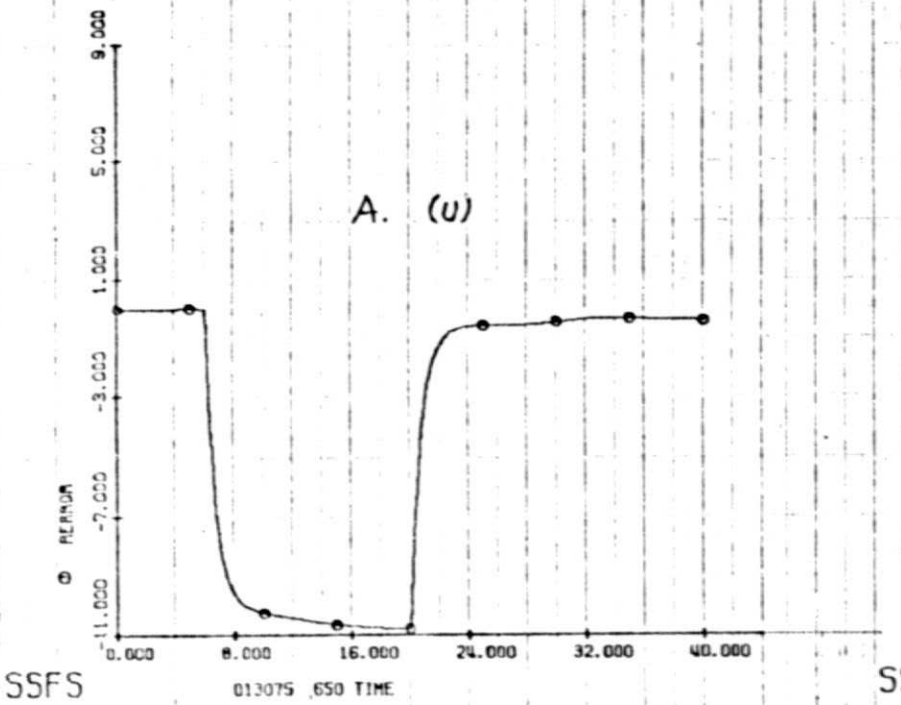
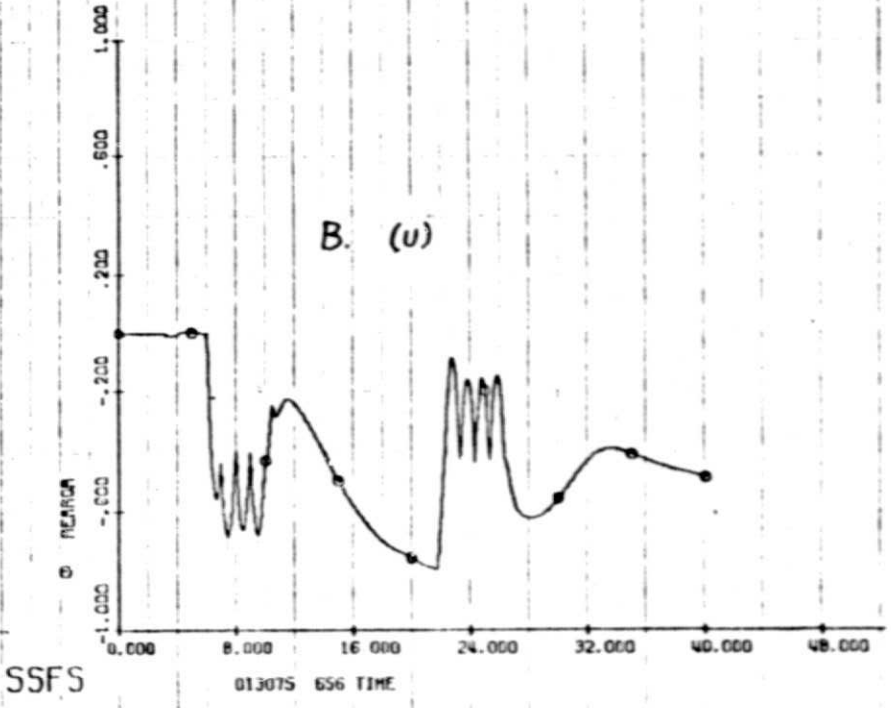
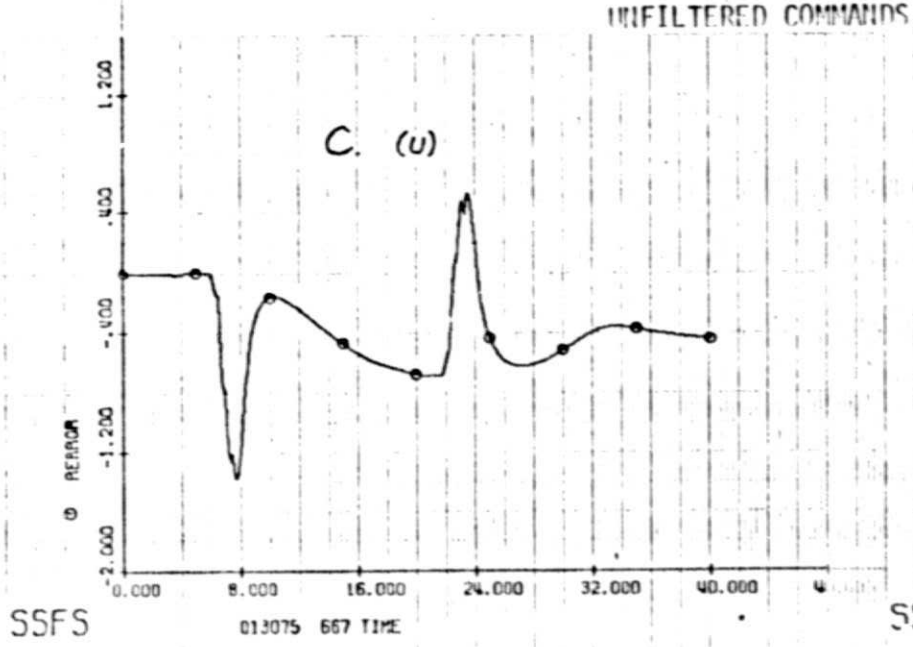


FIGURE 5





ROLL ATTITUDE ERROR (degrees)
UNFILTERED COMMANDS, MISSION 2



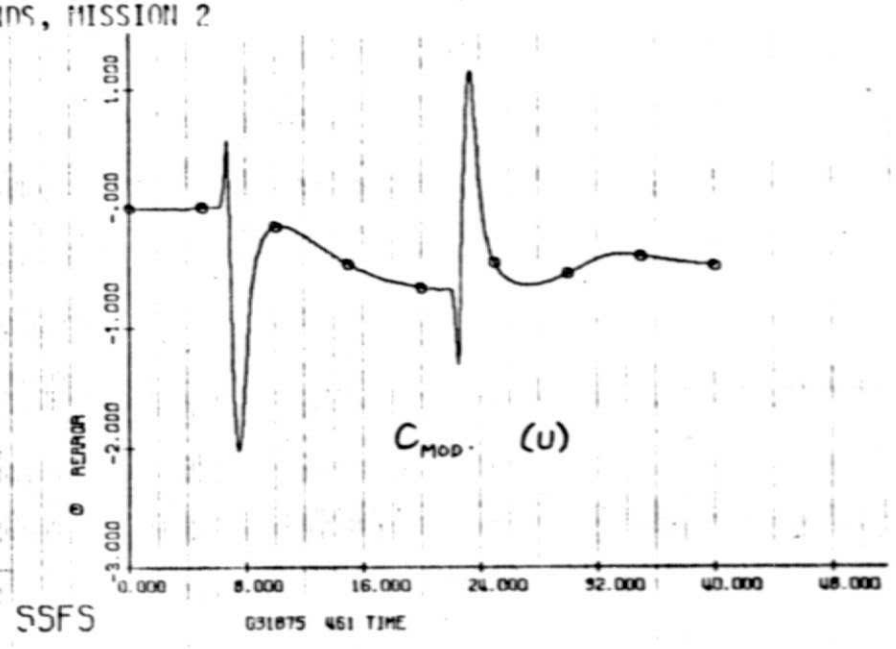


FIGURE 6

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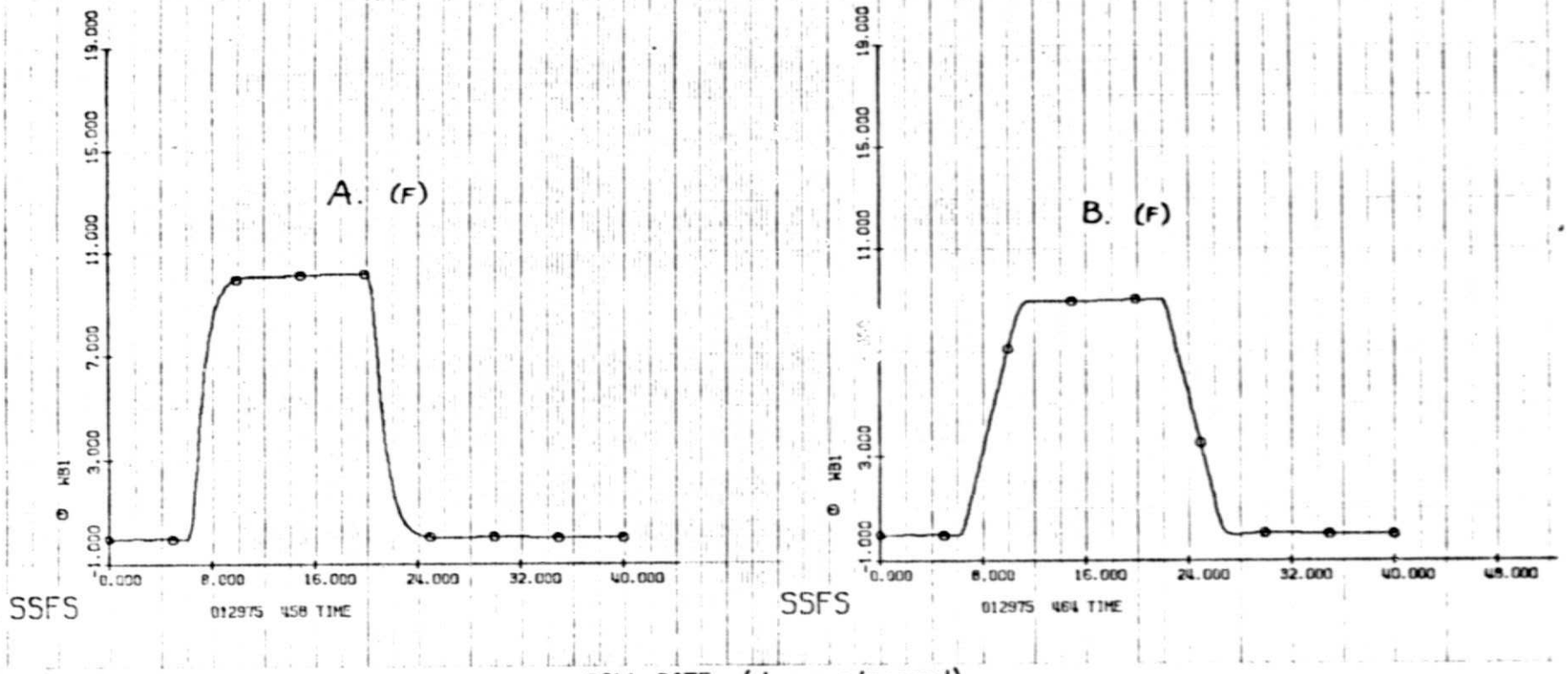

FIGURE 7

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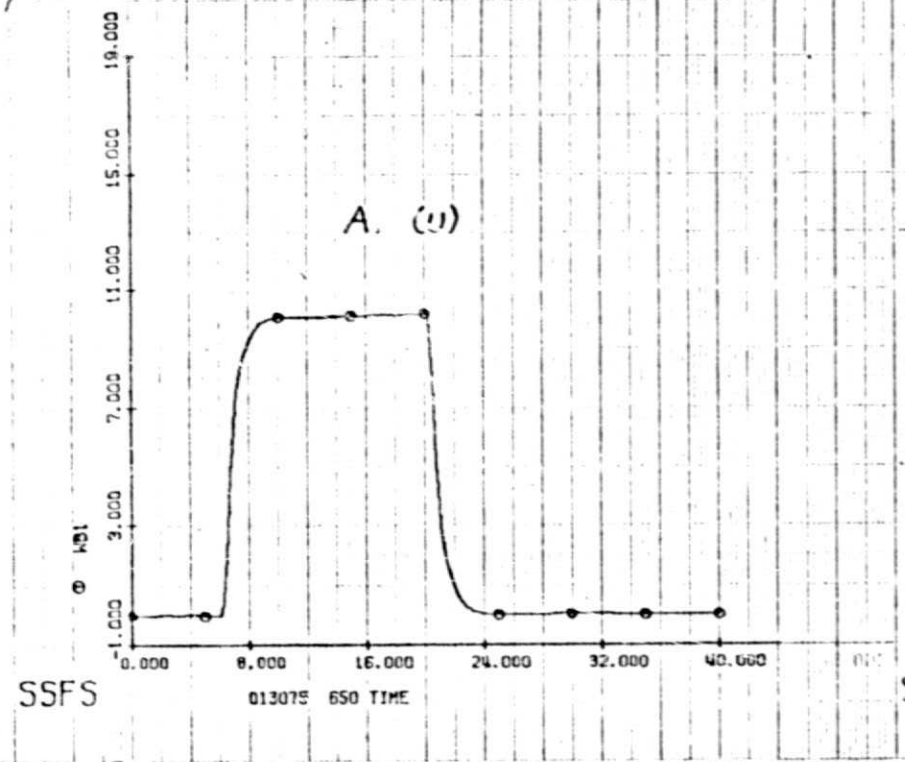
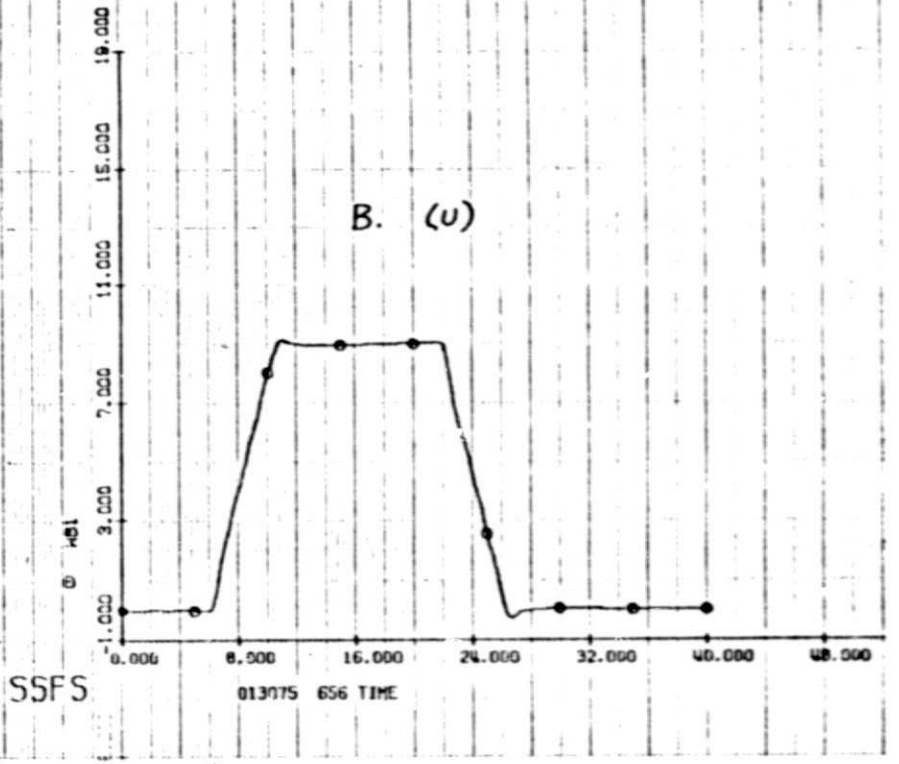
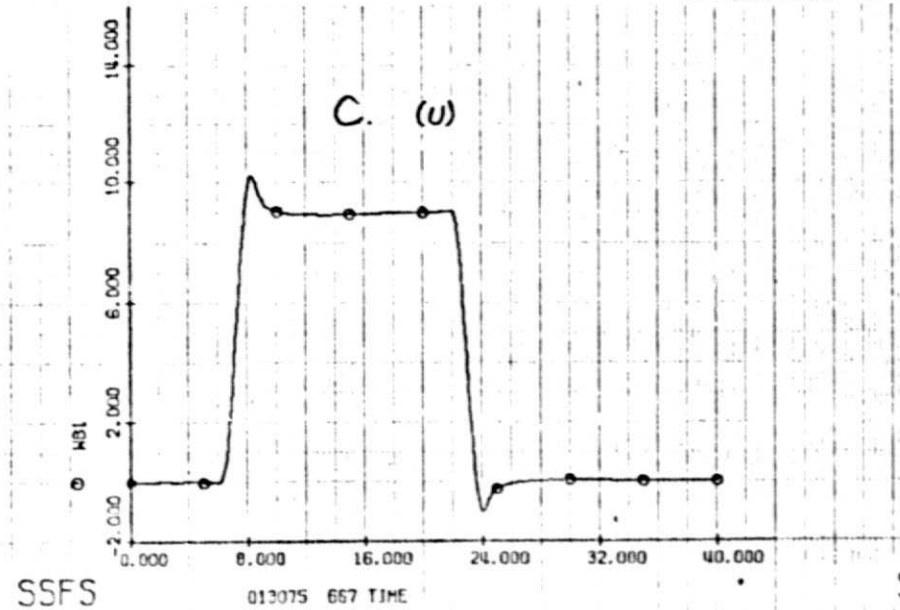




ROLL RATE (degrees/second)
UNFILTERED COMMANDS, MISSION 2



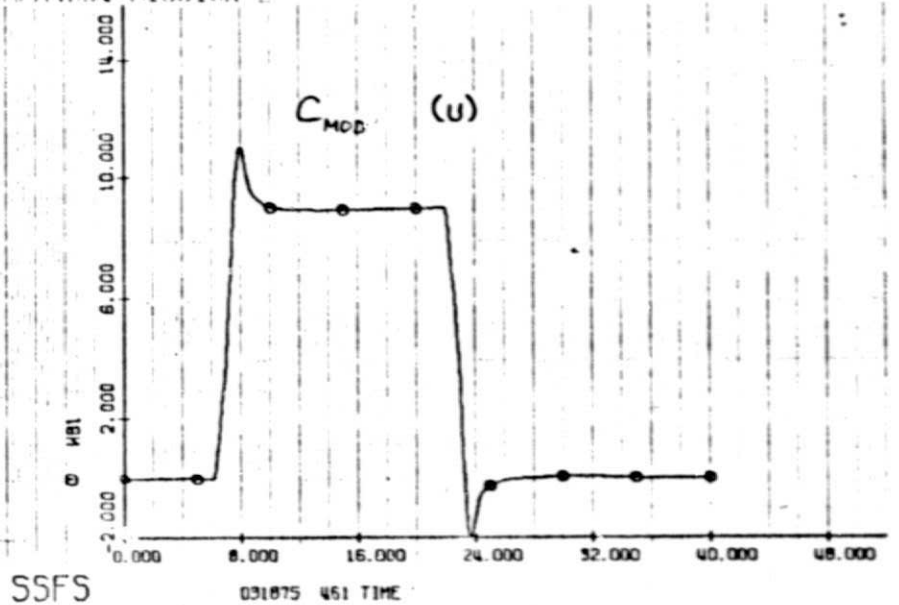
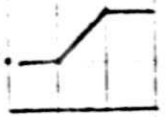
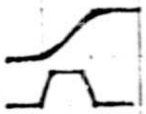
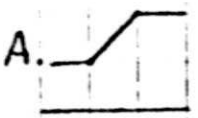


FIGURE 2

PARAMETER (maximum value to t = 40 secs)	ROLL MANEUVER COMMAND TYPE			
	A. 	B. 	C. 	$C_{mod.}$ 
$q\alpha$ (psf-deg)	-555 @ 22.1	-688 @ 25.6	-632 @ 23.7	-602 @ 23.5
q/β (psf-deg)	952 @ 19.1	1217 @ 21.6	1086 @ 20.7	1077 @ 20.7
ϕ_{error} (deg)	-10.79 @ 19.9	-0.82 @ 21.8	-1.16 @ 8.0	-1.46 @ 7.9
p (deg/sec)	10.16 @ 20.1	9.02 @ 21.9	9.37 @ 8.9	9.68 @ 8.7

FILTERED COMMANDS, MISSION 2

TABLE V

PARAMETER (maximum value to t = 40 secs)	ROLL MANEUVER COMMAND TYPE			
	A. 	B. 	C. 	$C_{mod.}$ 
$q\alpha$ (psf-deg)	-525 @ 21.5	-656 @ 25.3	-606 @ 23.3	-580 @ 23.1
$q\beta$ (psf-deg)	908 @ 18.8	1169 @ 21.3	1040 @ 20.4	1032 @ 20.4
ϕ_{error} (deg)	-10.78 @ 19.6	-0.78 @ 21.8	-1.38 @ 7.7	-2.02 @ 7.5
p (deg/sec)	10.17 @ 20.1	9.14 @ 11.0	10.22 @ 8.3	11.05 @ 7.9

UNFILTERED COMMANDS, MISSION 2

TABLE VI

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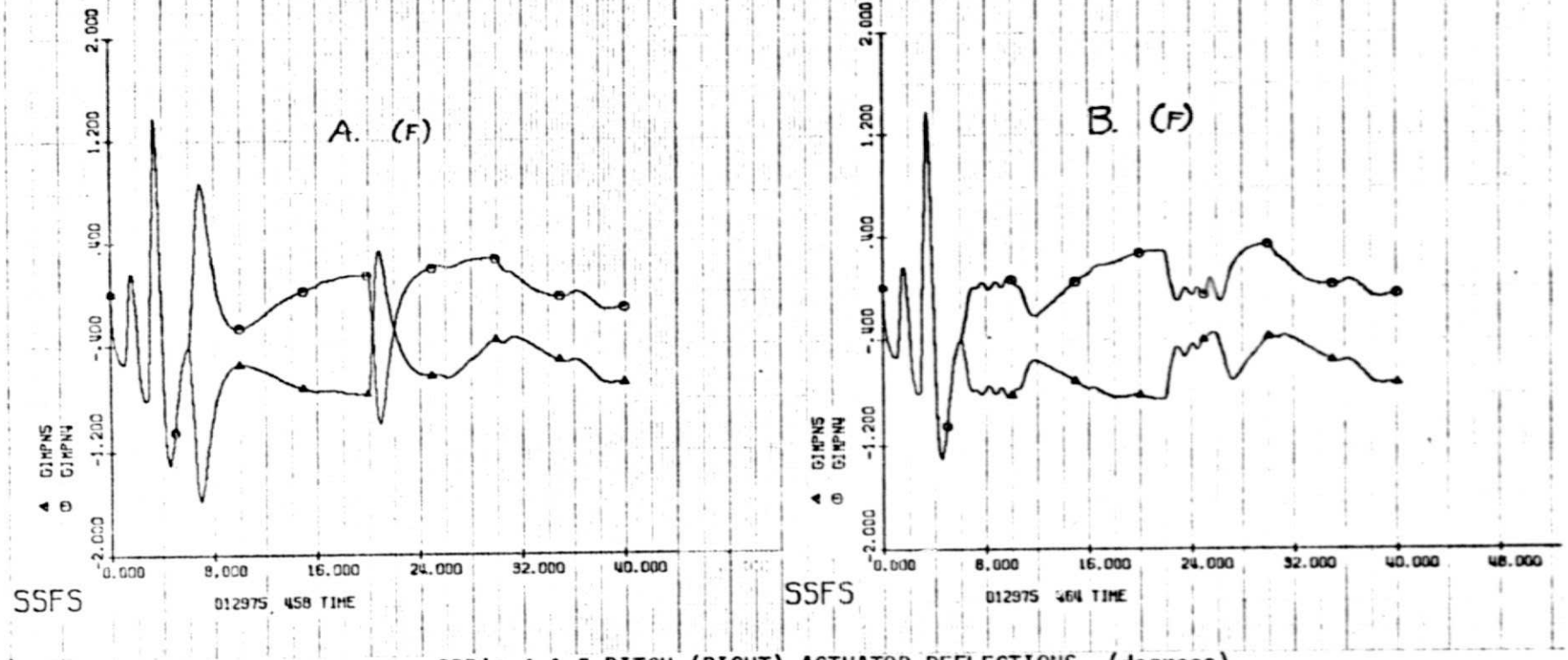

SRB's 4 & 5 PITCH (RIGHT) ACTUATOR DEFLECTIONS (degrees)
FILTERED COMMANDS, MISSION 2

FIGURE 9

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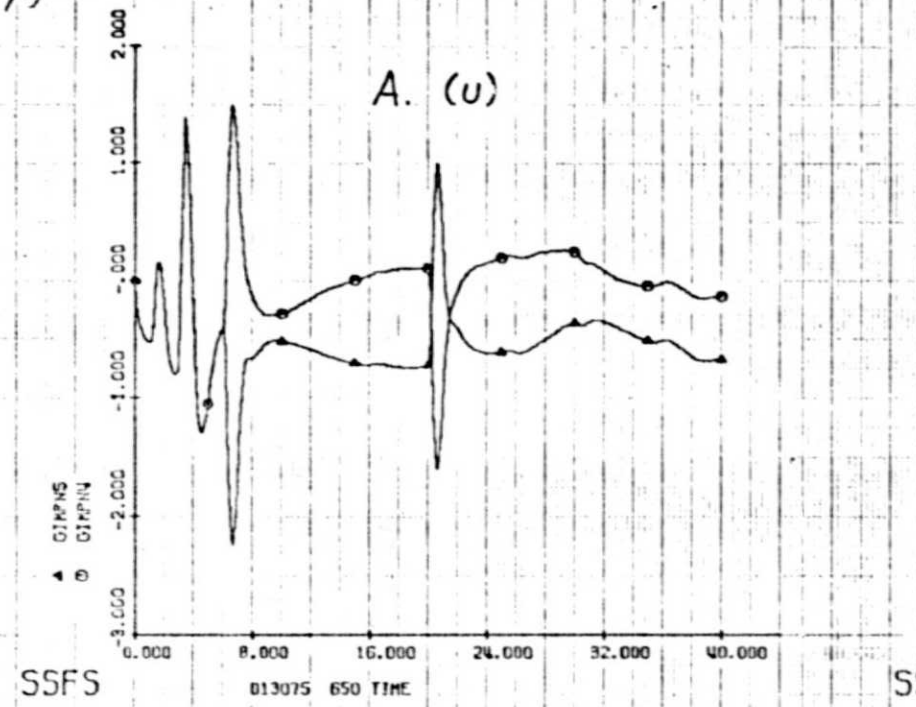
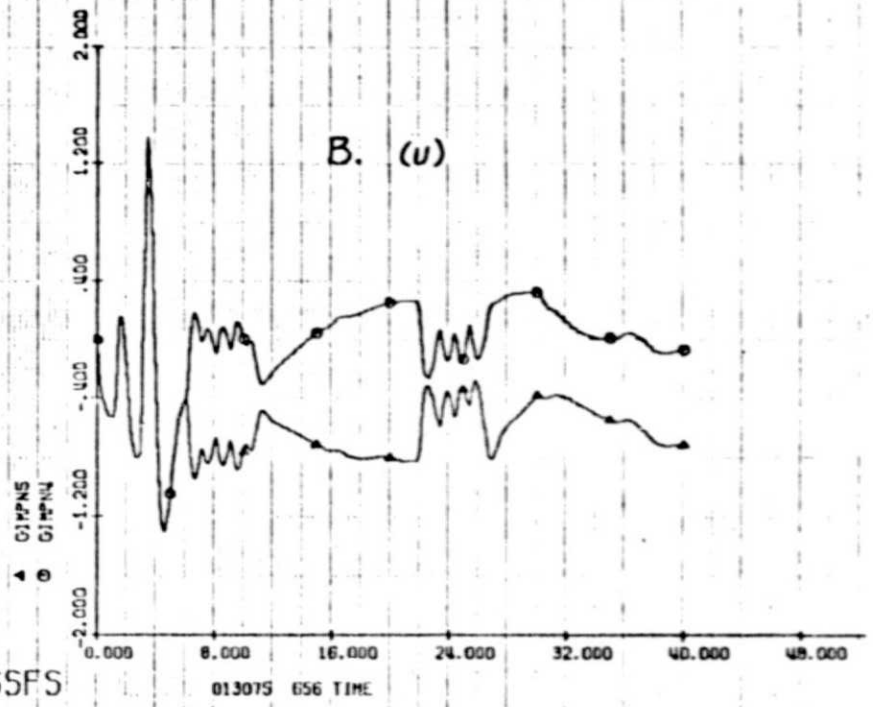
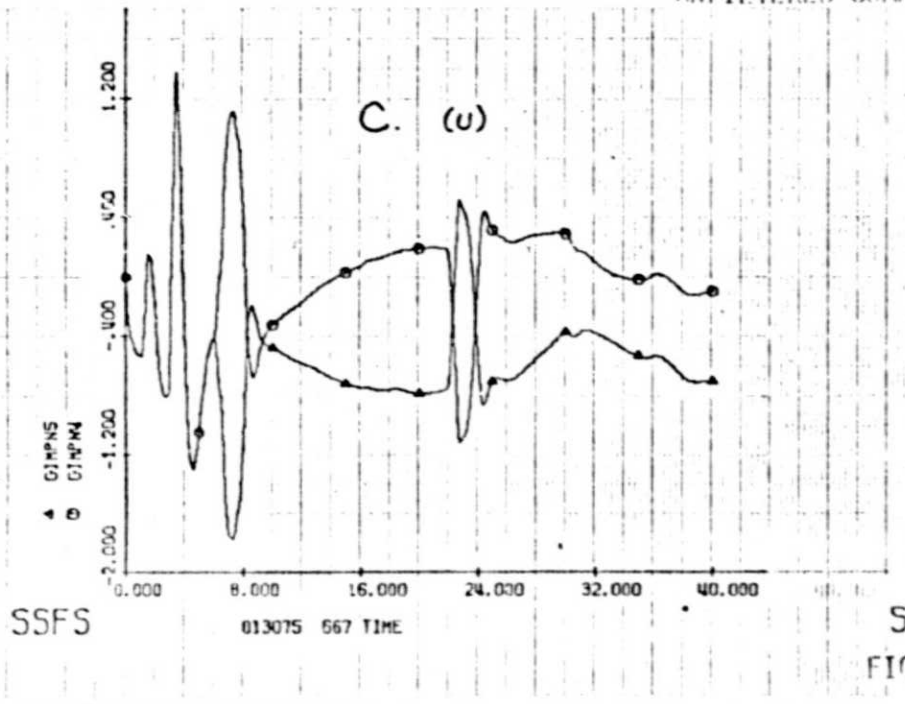




SRB's 4 & 5 PITCH (RIGHT) ACTUATOR DEFLECTIONS (degrees)
UNFILTERED COMMANDS, MISSION 2



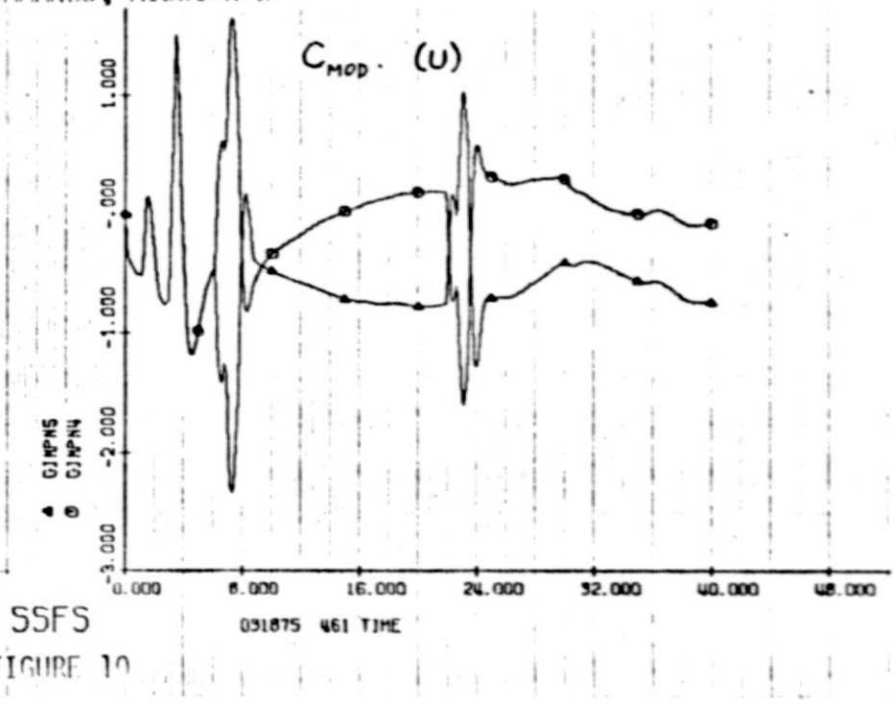
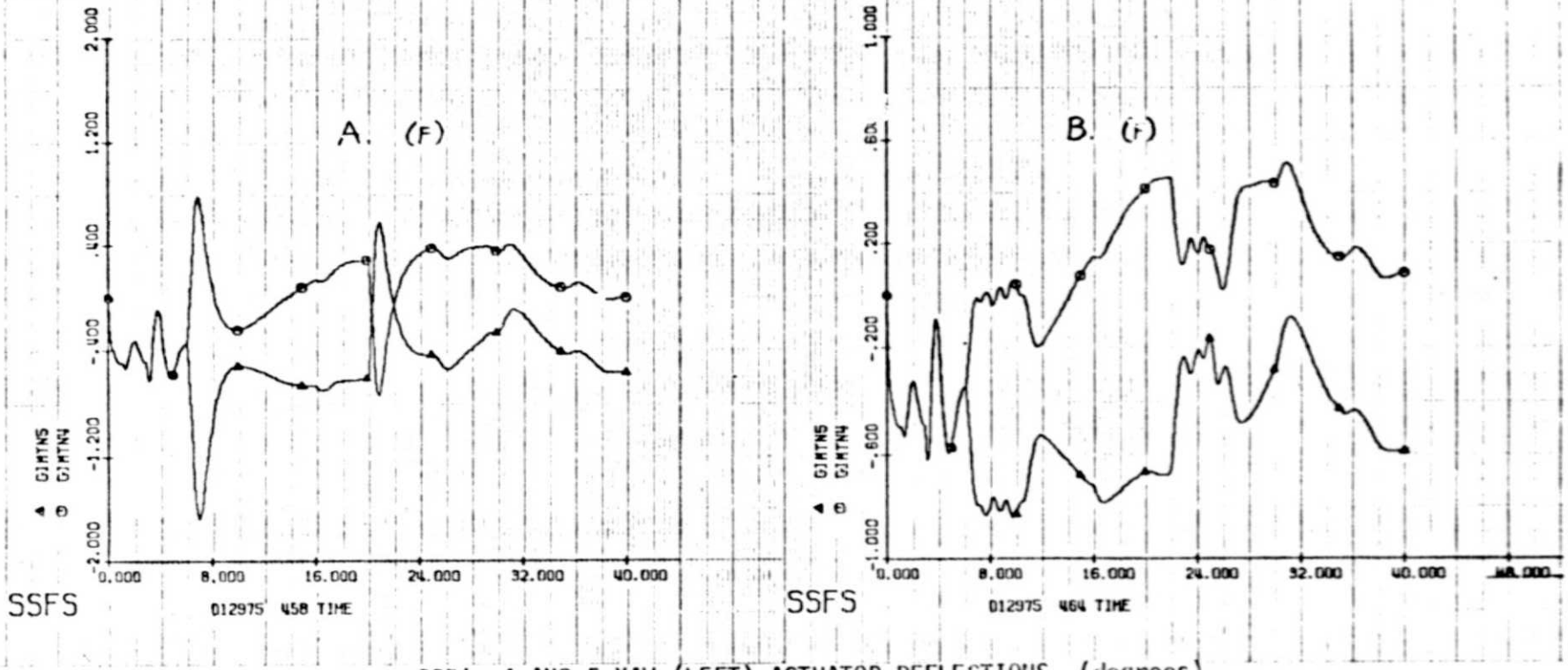


FIGURE 10



SRB's 4 AND 5 YAW (LEFT) ACTUATOR DEFLECTIONS (degrees)
FILTERED COMMANDS, MISSION 2

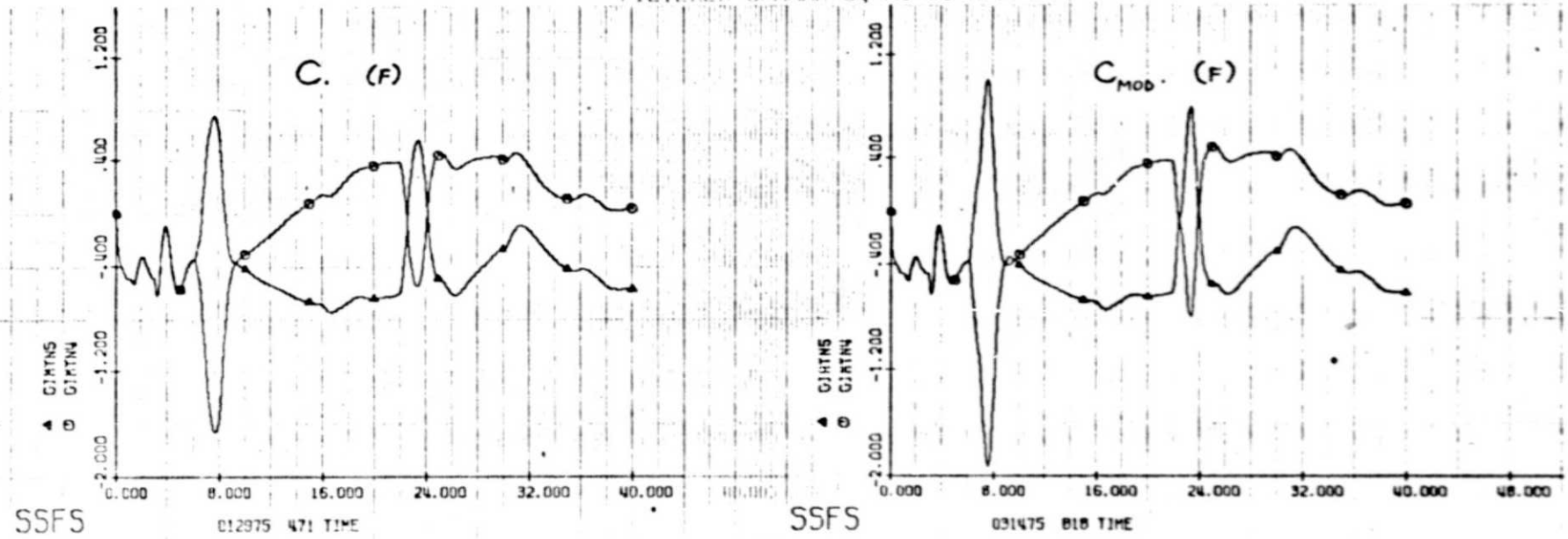
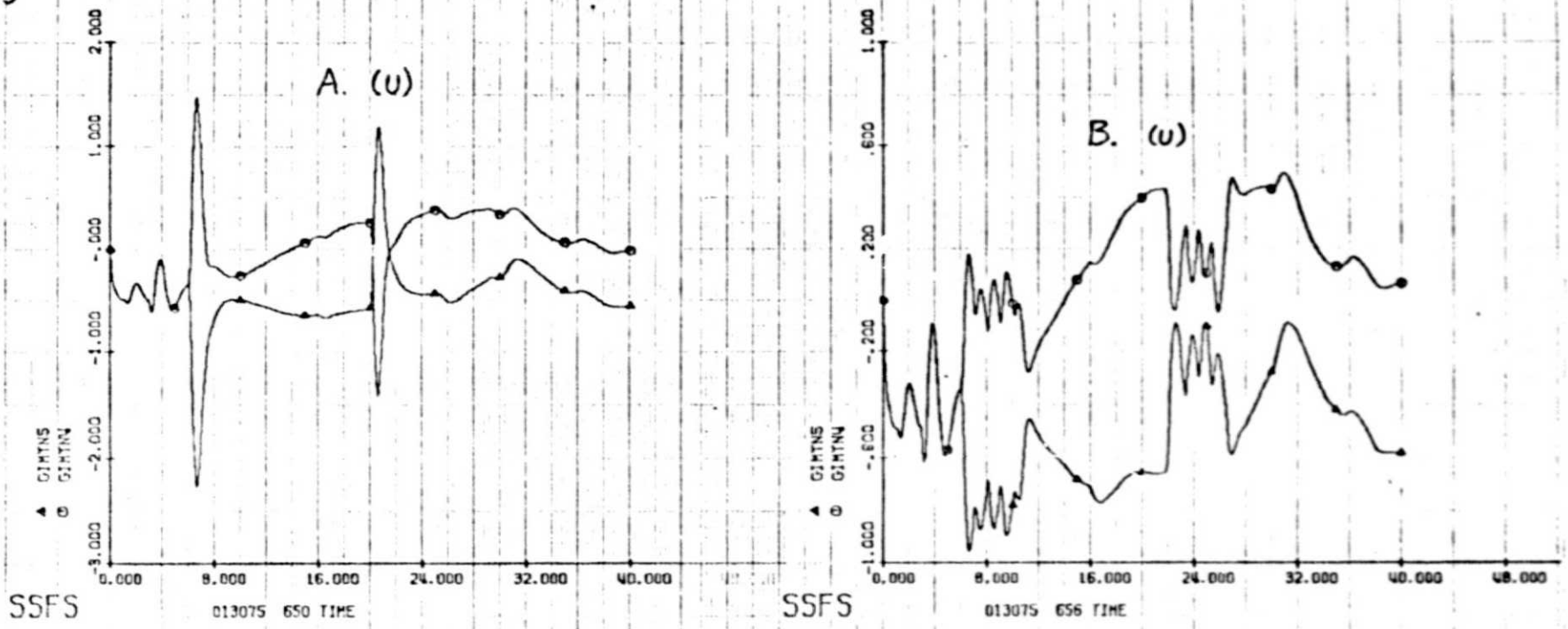
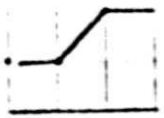


FIGURE 11



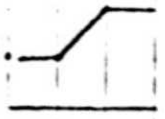
SRB's 4 AND 5 YAW (LEFT) ACTUATOR DEFLECTIONS, (degrees)
UNFILTERED COMMANDS, MISSION 2

FIGURE 12

PARAMETER (maximum value to t = 40 secs)	ROLL MANEUVER COMMAND TYPE			
	A. 	B. 	C. 	$C_{mod.}$ 
DUTY CYCLE (deg) (average of SRB's)	21.56 @ 40.0	16.87 @ 40.0	22.06 @ 40.0	15.14 @ 40.0
SRB ACTUATOR DEFLECTIONS (deg) — $\delta 4_R$	1.38 @ 3.5	1.38 @ 3.5	1.38 @ 3.5	1.50 @ 3.5
SRB ACTUATOR DEFLECTIONS (deg) — $\delta 5_R$	-1.58 @ 7.0	1.35 @ 3.5	-1.54 @ 7.7	-1.80 @ 7.6
SRB ACTUATOR DEFLECTIONS (deg) — $\delta 4_L$	0.79 @ 7.0	-0.61 @ 3.2	0.75 @ 7.7	1.01 @ 7.6
SRB ACTUATOR DEFLECTIONS (deg) — $\delta 5_L$	-1.67 @ 7.1	-0.84 @ 9.8	-1.66 @ 7.7	-1.93 @ 7.6

FILTERED COMMANDS, MISSION 2

TABLE VII

	PARAMETER (maximum value to t = 40 secs)	ROLL MANEUVER COMMAND TYPE			
		A. 	B. 	C. 	$C_{mod.}$ 
	DUTY CYCLE (deg) (average of SRB's)	26.66 @ 40.0	21.64 @ 40.0	25.68 @ 40.0	23.05 @ 40.0
SRB ACTUATOR DEFLECTIONS (deg)	$\delta 4_R$	-1.59 @ 20.7	1.38 @ 3.5	1.38 @ 3.5	1.65 @ 7.3
	$\delta 5_R$	-2.24 @ 6.7	1.35 @ 3.5	-1.78 @ 7.3	-2.34 @ 7.3
	$\delta 4_L$	1.47 @ 6.7	-0.61 @ 3.2	0.97 @ 7.3	1.55 @ 7.3
	$\delta 5_L$	-2.26 @ 6.7	-0.96 @ 6.7	-1.92 @ 7.3	-2.44 @ 7.3

UNFILTERED COMMANDS, MISSION 2

TABLE VIII