

Memorandum

R-ASTR-NG-12-65
PFisher/lw/876-7418

TO See Distribution

DATE FEB 18 1965

FROM Chief, Guidance and Control Analysis Branch,
R-ASTR-NG

SUBJECT Auxiliary Propulsion Requirements for the S-IVB/IB during
J-2 Engine Firing

REFERENCE Douglas Report SM-44138 "S-IVB Stage
Separation Report" dated 10 July 1963

1. A single axis (roll) analog study of the S-IVB Vehicle after Saturn IB separation has been performed to determine the amount of propellant required for roll control of the vehicle during the J-2 Engine 481 second firing period. Roll control is obtained by pulsing a pair of 150 lb engines to produce a pure force couple about the vehicle roll axis. The engines are pulsed by the pseudo rate modulators. A minimum electrical on-time of 50 ms is insured by using the Minimum Pulse Duration Device. The 50 ms on-time is necessary to maintain a reasonable specific impulse (211 seconds) during pulsed operation. The deadband in roll is $\pm 1^\circ$ with a modulation range to 1.6° and an $\frac{a_1}{a_0}$ ratio of 5.

2. A time history of J-2 Engine deflection for a $\pm 7^\circ$ displacement limit was obtained from the reference. These engine deflections are based on characteristics of the J-2 Engine Control System, stage separation disturbances, and J-2 ignition 3 seconds after separation. These deflections in conjunction with a 1.11 inch off-set center of gravity of the S-IVB produce a roll disturbance torque. An additional roll torque of 100 ft-lbs is introduced by exhaust swirl of the J-2 Engine.

3. The transient characteristics about the vehicle roll axis after separation are given in Figure 1. The time scale base of Figure 1 has been increased in Figure 2 to indicate the individual pulses which represent the firing of a pair of attitude engines. The steady state attitude error resulting from the exhaust swirl torque is approximately 0.7° . The swirl results in frequent attitude engine firings during firing of the J-2 Engine. A phase plane plot of roll is given in Figure 3. The amount of attitude propellant required for a 481 s J-2 firing is 13.5 pounds/module.

4. In the absence of external disturbances, roll will limit cycle between $\pm 1^\circ$. The symmetrical limit cycle of roll attitude error is shown

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R-ASTR-NG-12-65

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the S-IVB/IB during J-2 Engine Firing

in Figure 4. If the J-2 Engine exhaust swirl is omitted, the primary roll disturbance will occur because of the off-set center of gravity during the transient time of J-2 deflections. The effects of this type of disturbance is indicated in Figure 5. An expanded time scale of Figure 5 is given in Figure 6 showing the pulse frequency of the attitude engines. Figure 7 shows the roll phase plane with the resultant undisturbed steady state limit cycle.

5. Referring to the fuel requirements given in Figures 1B and 5B, it can be noted that the effect of the exhaust engine swirl torque more than doubles the otherwise sufficient quantity. Based on the magnitude of disturbances and burn time of the J-2 Engine previously mentioned, 13.5 lbs of attitude control propellants should be provided in each module for roll control during this phase of the mission. Attitude fuel requirements for cutoff of the J-2 engine are considered in the initial conditions of the S-IVB/IB orbital phase and are not included here.

J. L. Mack
J. L. Mack

7 Enc:
a/s

Approval:

F. B. Moore
for *F. B. Moore*,
Chief, Guidance and Control
Division

R-ASTR-NG-12-65

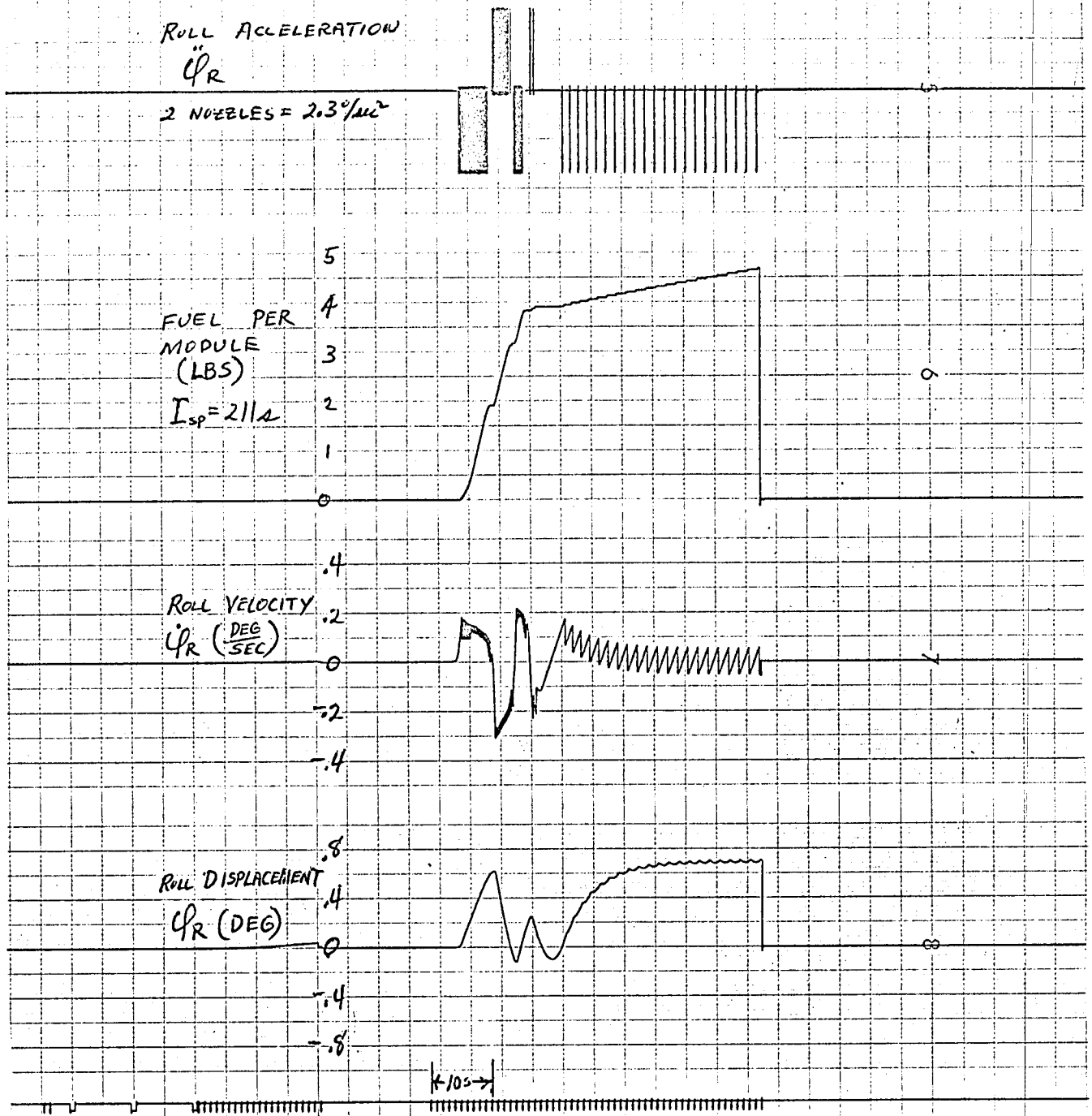
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J-2 Engine Firing

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J-2 BURN TIME
 481 s

SATURN S-IV/IB
 SEPARATION

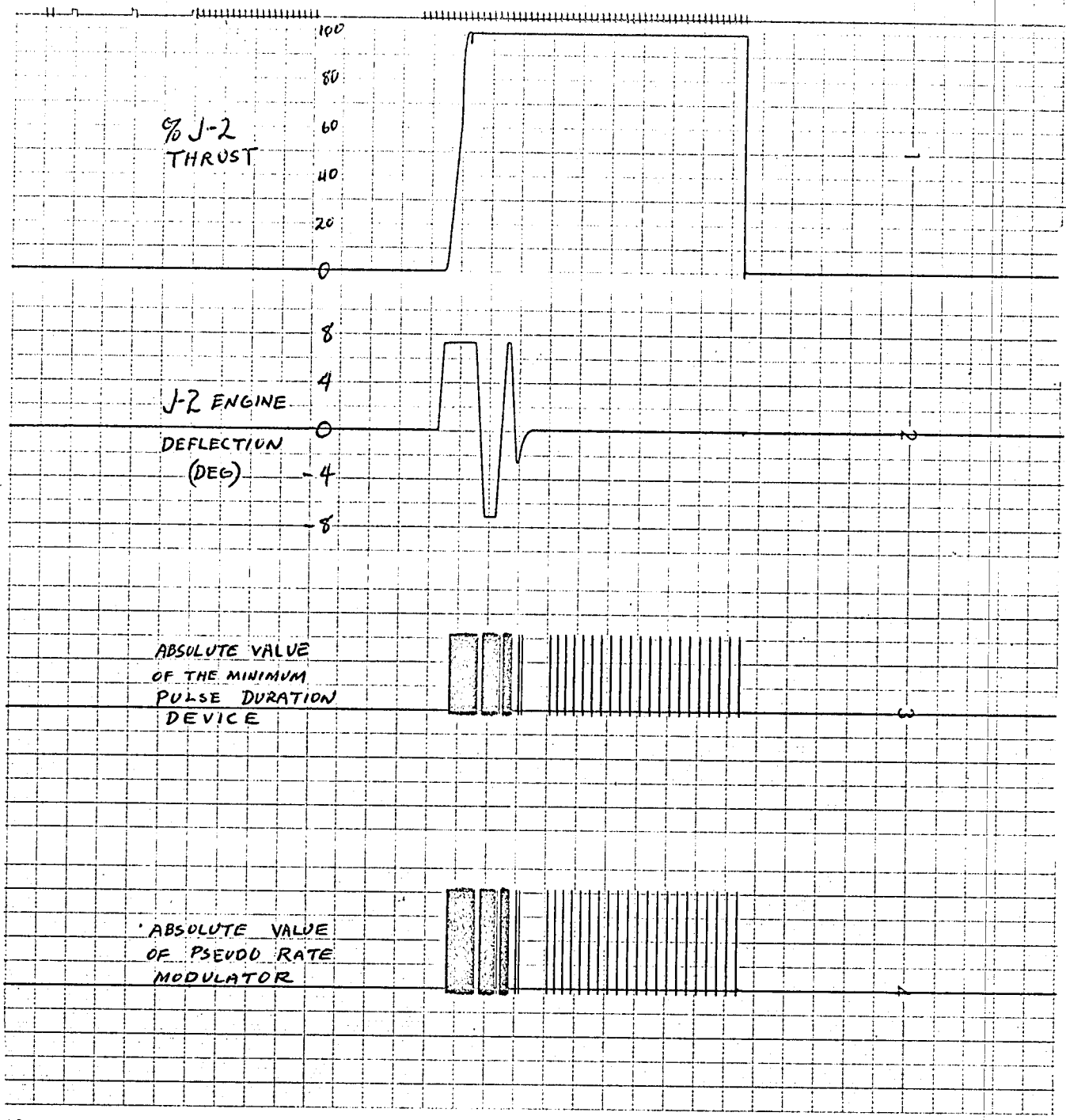
$\pm 7^\circ$ J-2 LIMIT

100 FT-LB J-2 SWIRL

C.G. OFF-SET = 1.11 INCH

FIGURE 1A

ENC 1'



15A

TOTAL FUEL
 TRANSIENT 40s = 8 lbs
 STEADY STATE 44s = 19 lbs
 BURN TIME 481 s = 27 lbs
 PER MODULE = 13.5 lbs

S-IVB/IB
 SEPARATION
 ±7° J-2 LIMIT

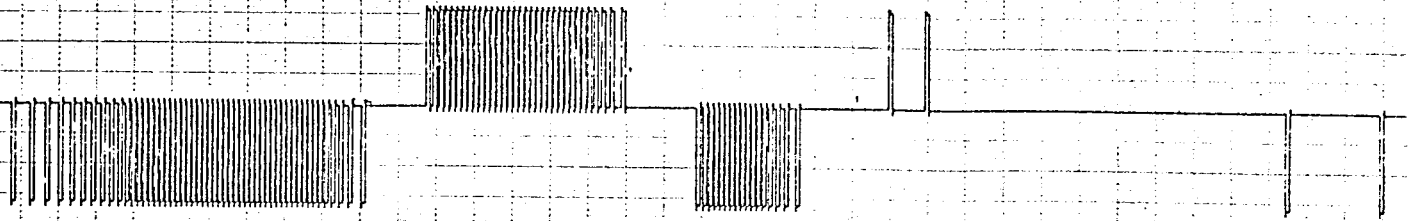
FIGURE 1B

ENC 1 2

ROLL ACCELERATION

$\ddot{\phi}_R$

2 NOZZLES = $2.3^\circ/\text{SEC}^2$



FUEL PER
MODULE
(LBS)

$I_{SP} = 211 \text{K}$

5
4
3
2
1
0

9

ROLL VELOCITY

$\dot{\phi}_R$ (DEG/SEC)

.4
.2
0
-.2
-.4

ROLL DISPLACEMENT

ϕ_R (DEG)

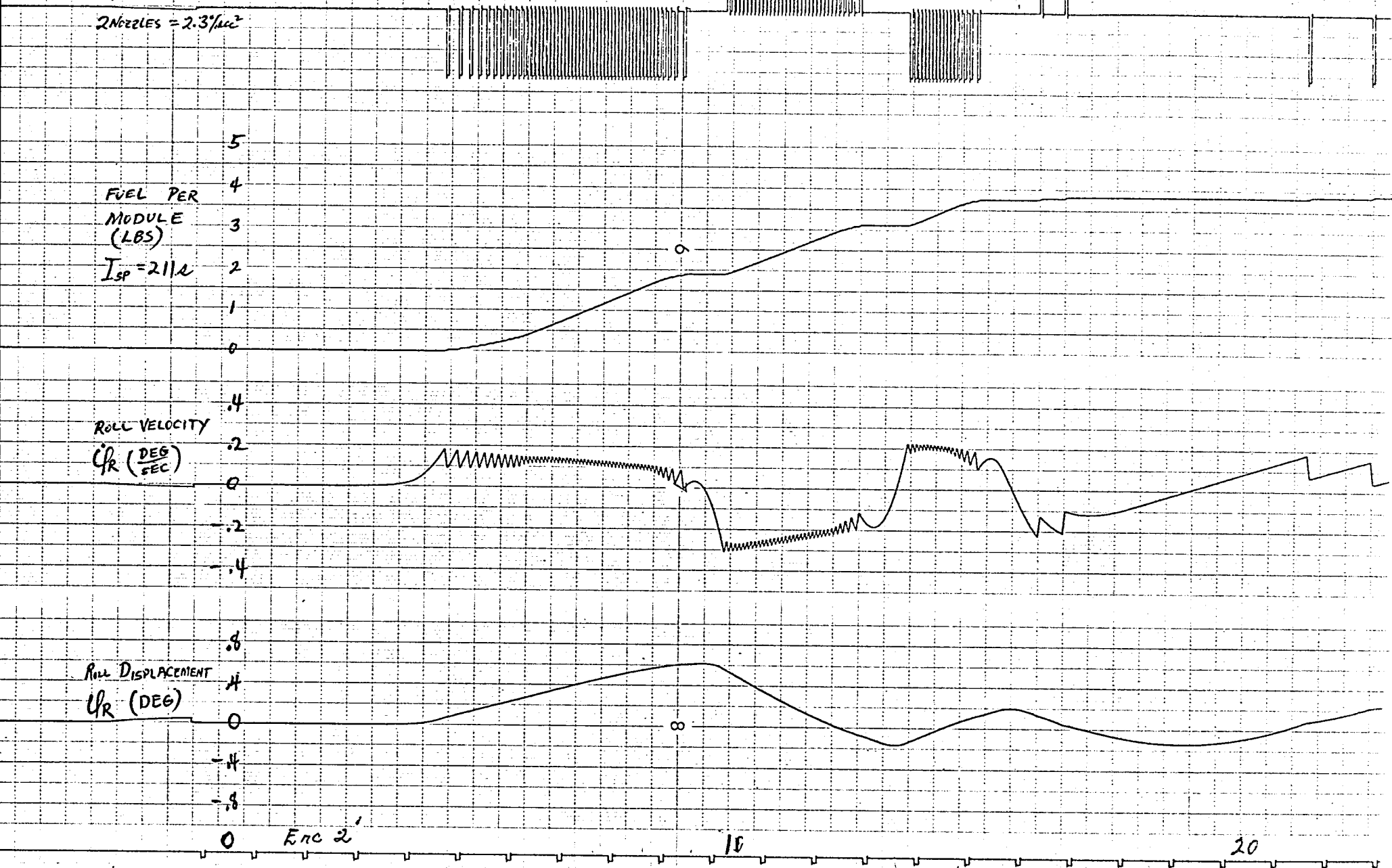
.8
.4
0
-.4
-.8

8

ENC 2'

10

20



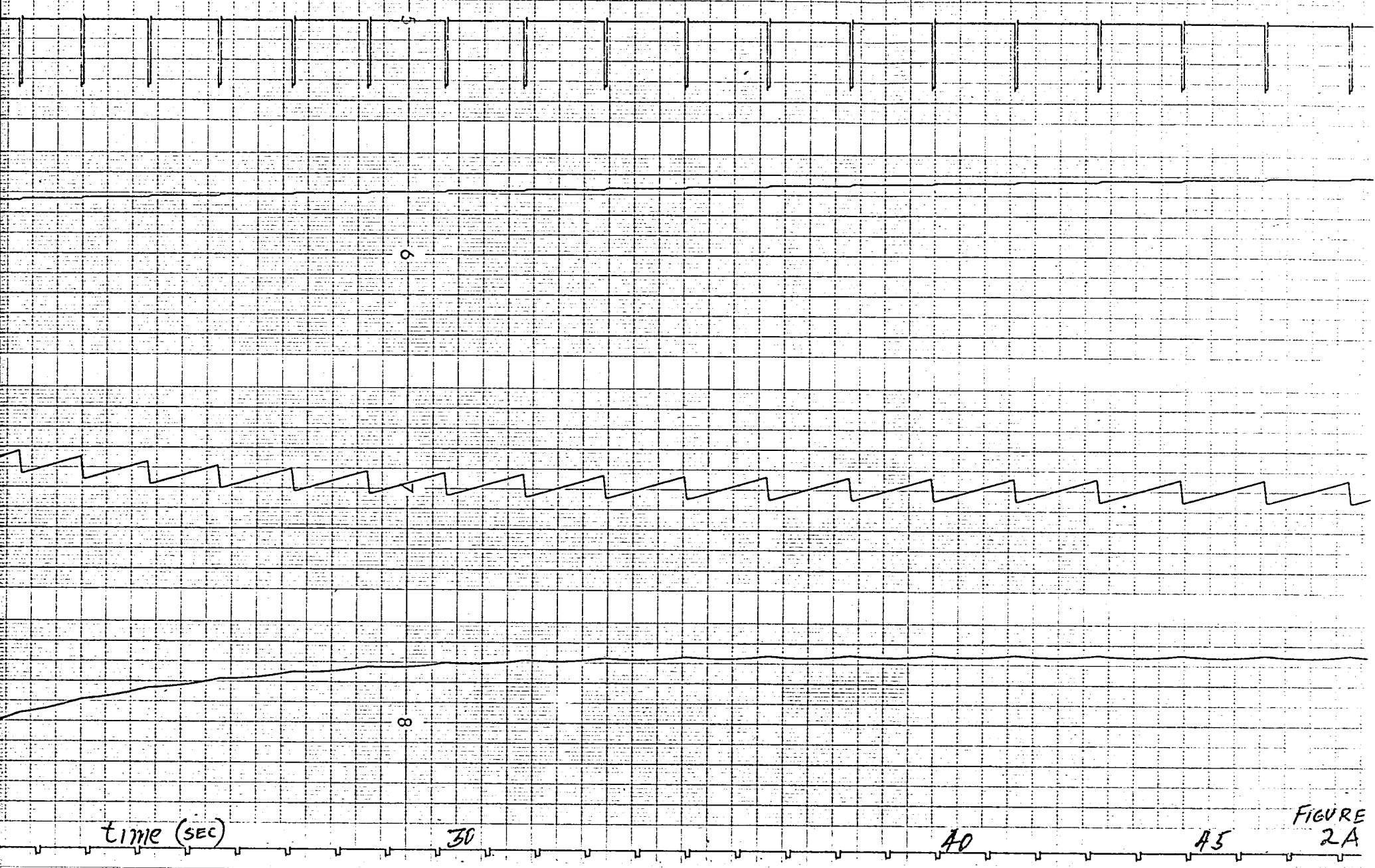
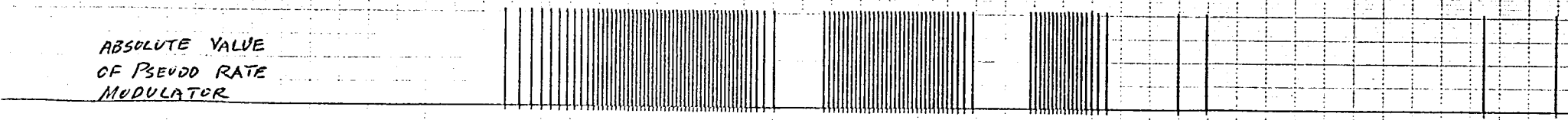
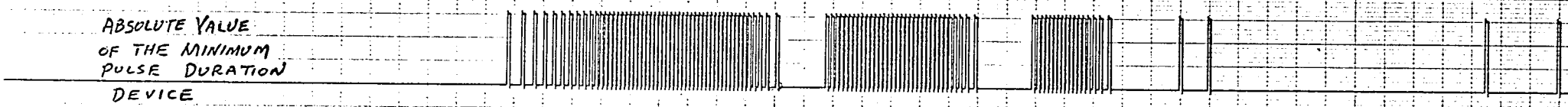
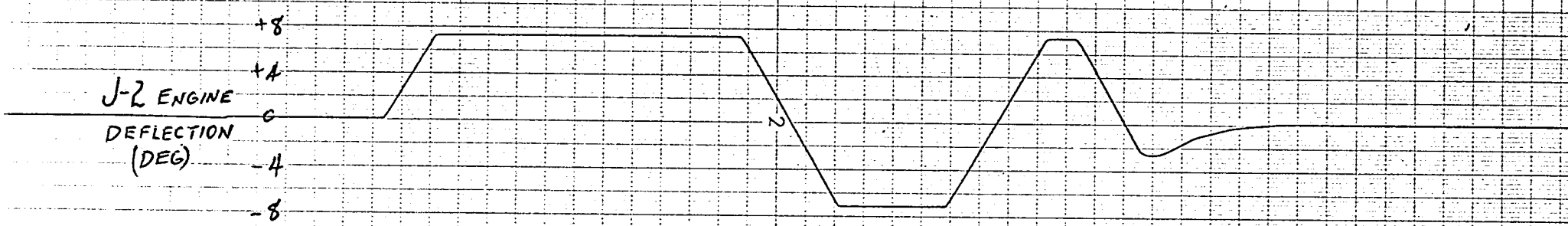
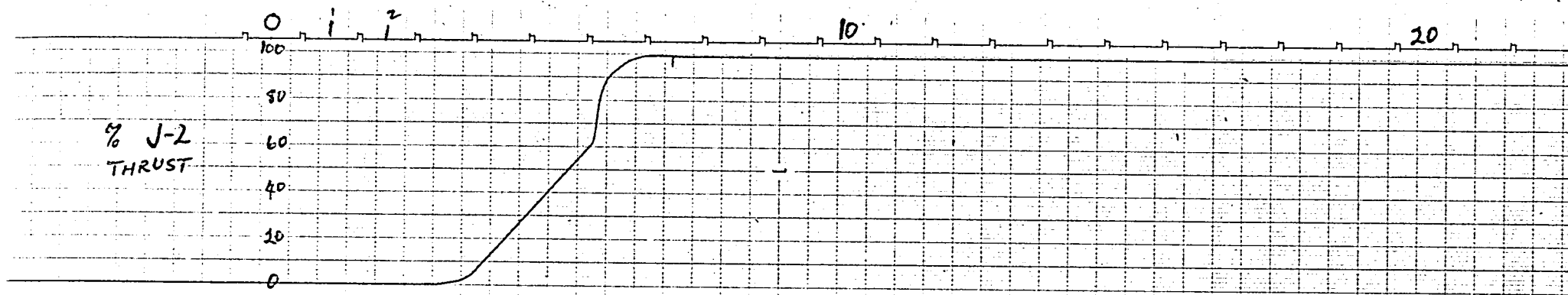


FIGURE 2A



ENC 2²

time (SEC)

30

40

45

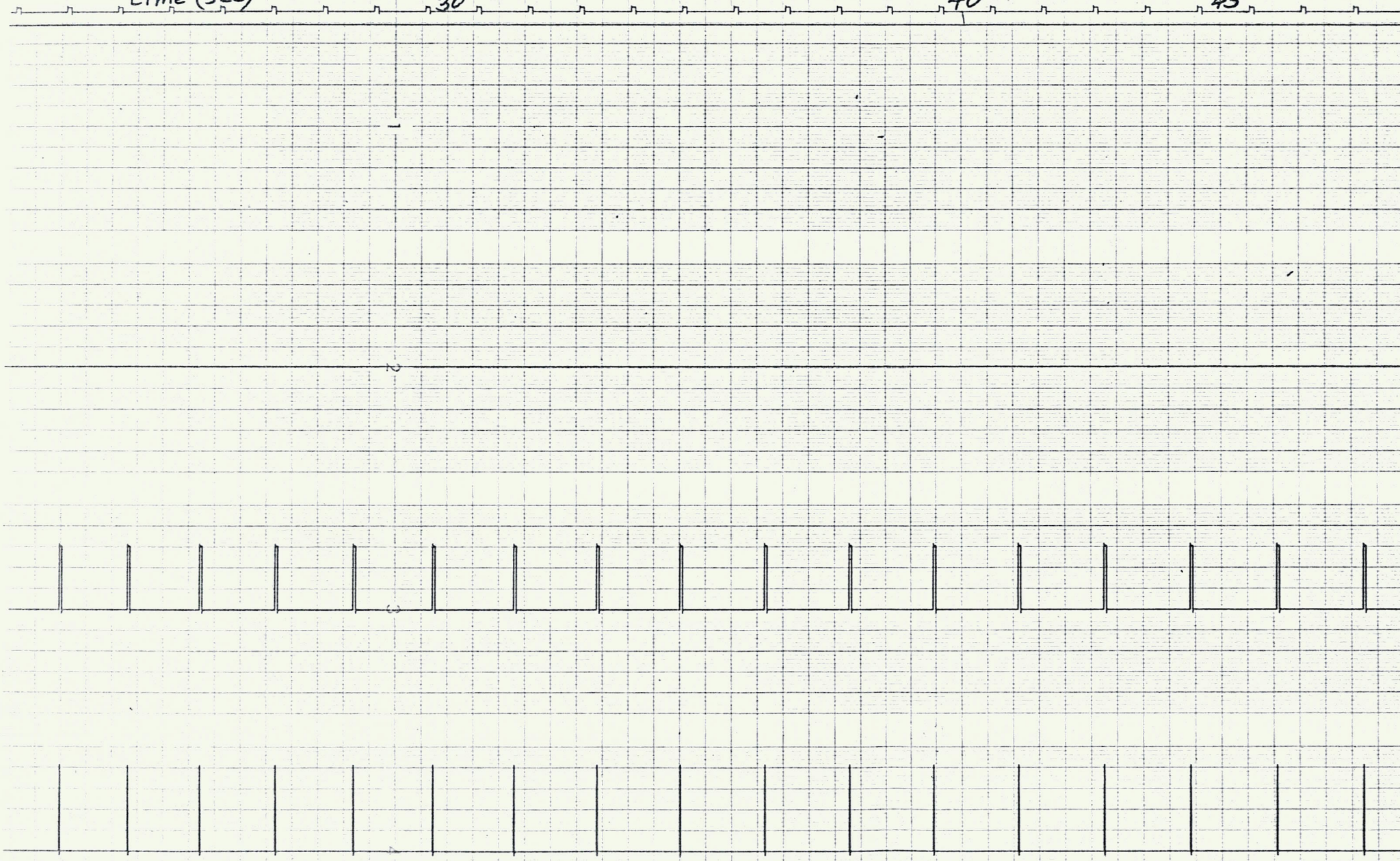
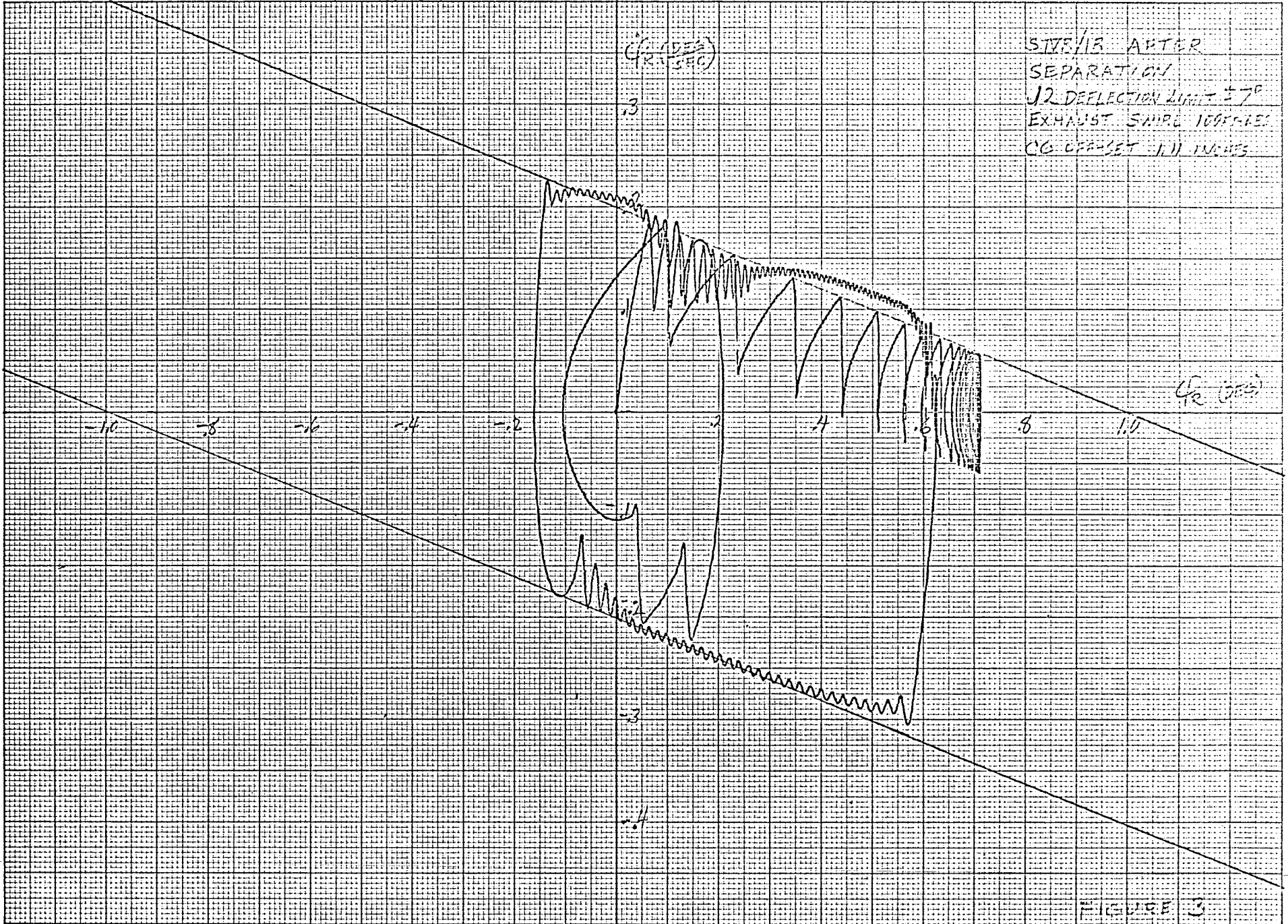


FIGURE
28

ENC 3



STEP 15 AFTER
SEPARATION
J2 DEFLECTION LIMIT 57°
EXHAUST SAMPLE 10000-100
CG OFFSET 1.11 INCHES

V_r (VOLTS)

FIGURE 3

ABSOLUTE VALUE
OF THE MINIMUM
PULSE DURATION
DEVICE

6

ABSOLUTE VALUE
OF PSEUDO RATE
MODULATOR

4

ROLL ACCELERATION
 $\ddot{\phi}_R$

5

FUEL PER
MODULE
(LBS)
 $I_{op} = 2112$

.50 LBS
.40
.30
.20
.10
0

9

ROLL VELOCITY
 $\dot{\phi}_R$ (DEG/SEC)

.04
0
-.04
-.08

7

ROLL DISPLACEMENT
 ϕ_R (DEG)

.8
-.8

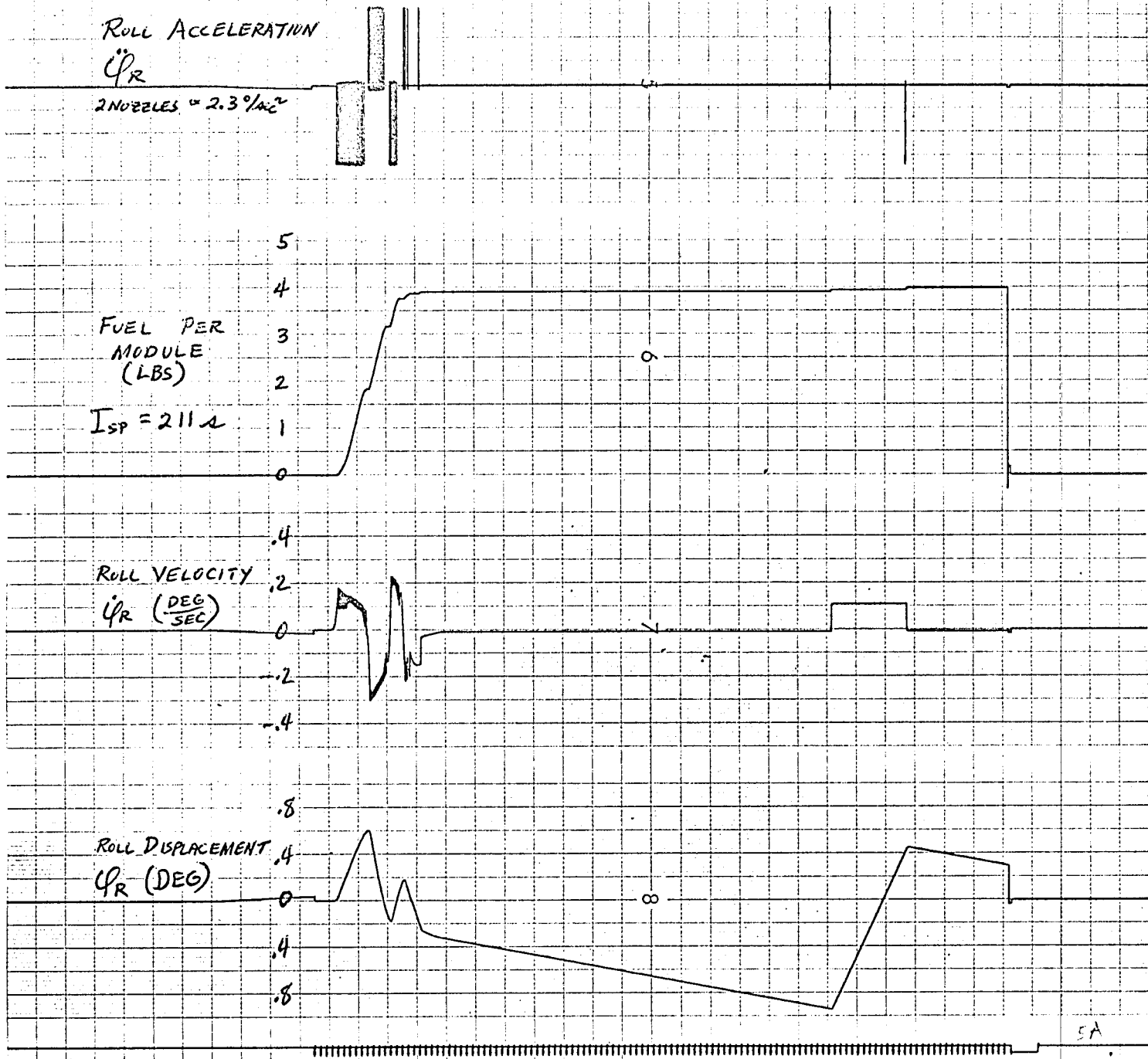
8



BF

time (SEC)

FIGURE 4



J-2 BURN TIME
 481 s

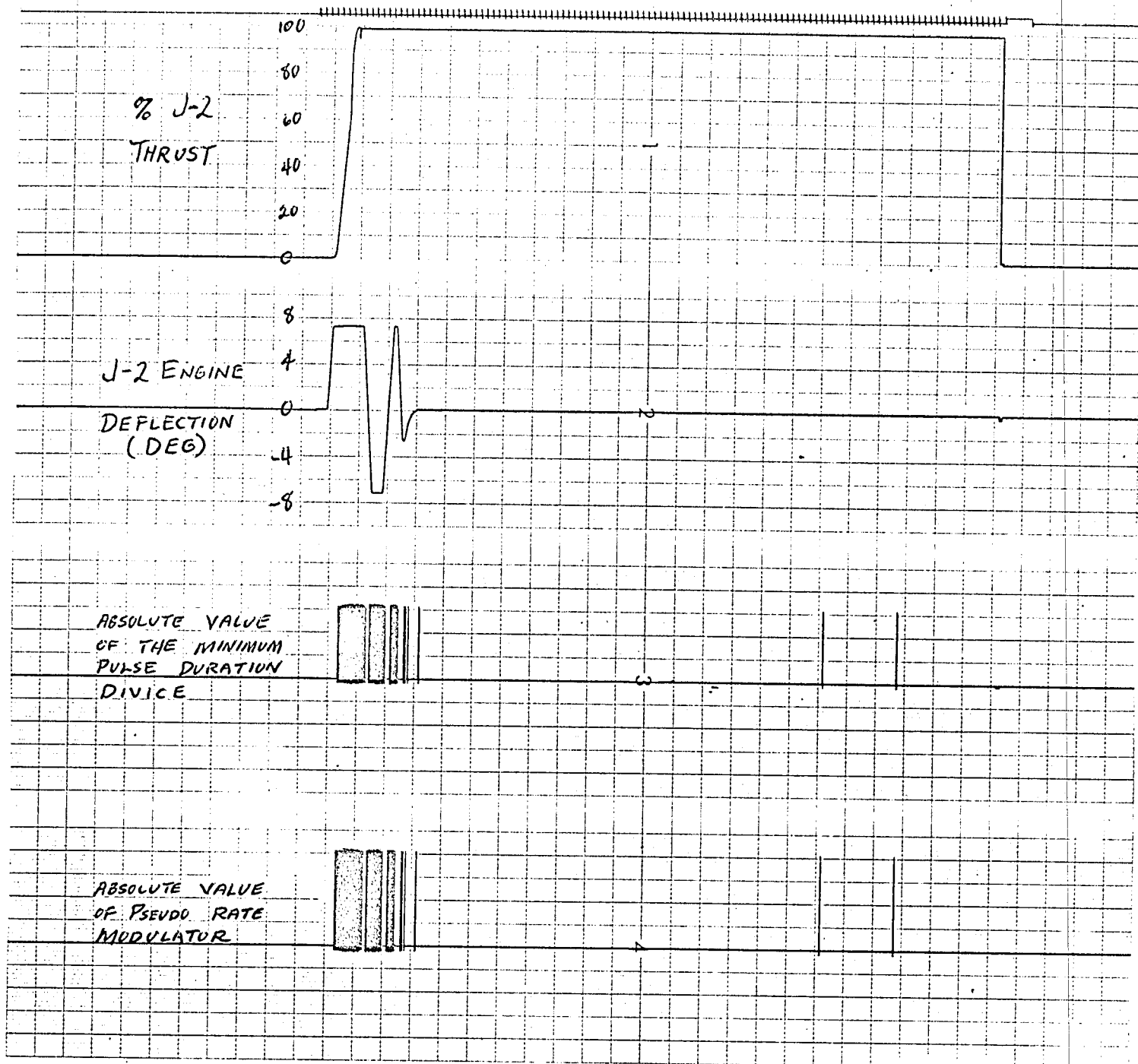
SATURN S-IVB/IB
 SEPARATION

±7° J-2 LIMIT

C.G. OFF-SET = 1.11 inch

FIGURE 5A

ENC 5'



TOTAL FUEL

TRANSIENT 16 sec = 7.5 lbs

STEADY STATE 465 sec = 1.4 lbs

TOTAL 481 sec 9 lbs

S-IVB/IB
SEPARATION

±7° J-2 LIMIT

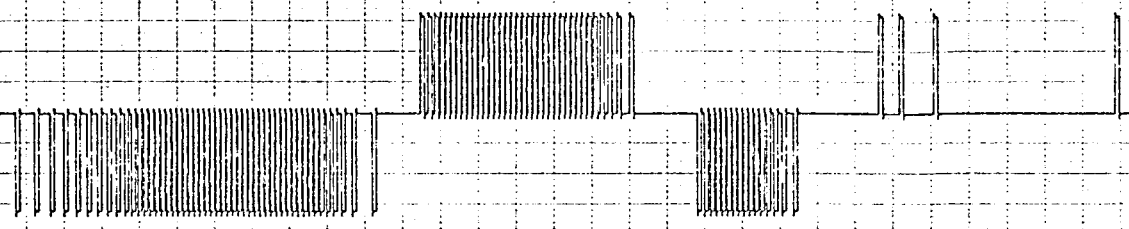
PER MODULE = 4.5 lbs

FIGURE 5B

ROLL ACCELERATION

$$\ddot{\phi}_R$$

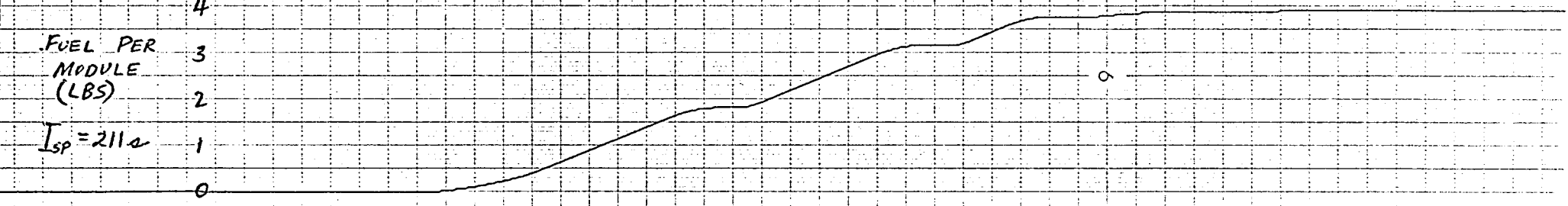
2 NOZZLES = 2.3%/ACC²



FUEL PER MODULE (LBS)

$$I_{sp} = 211 \text{ s}$$

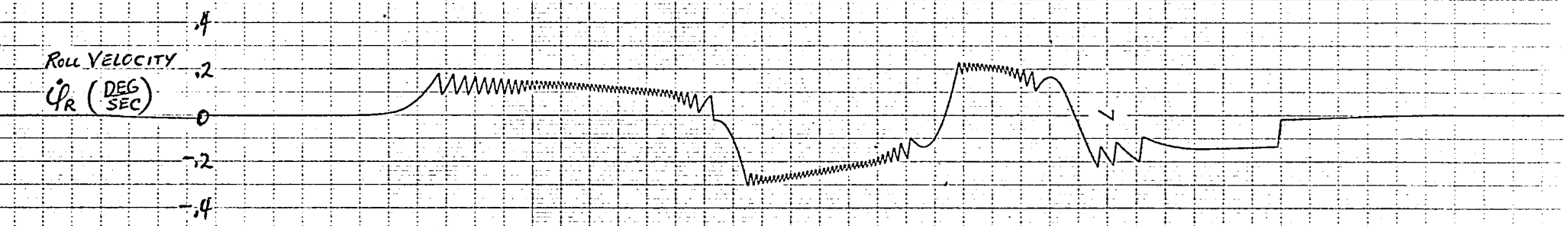
5
4
3
2
1
0



ROLL VELOCITY

$$\dot{\phi}_R \text{ (DEG/SEC)}$$

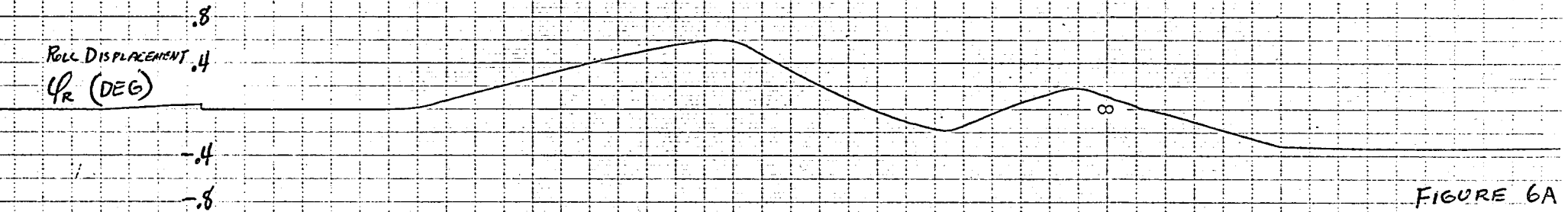
.4
.2
0
-.2
-.4



ROLL DISPLACEMENT

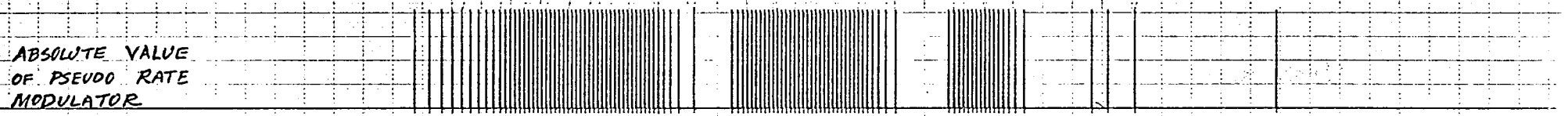
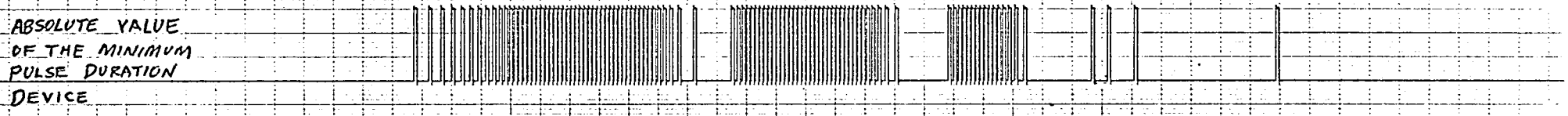
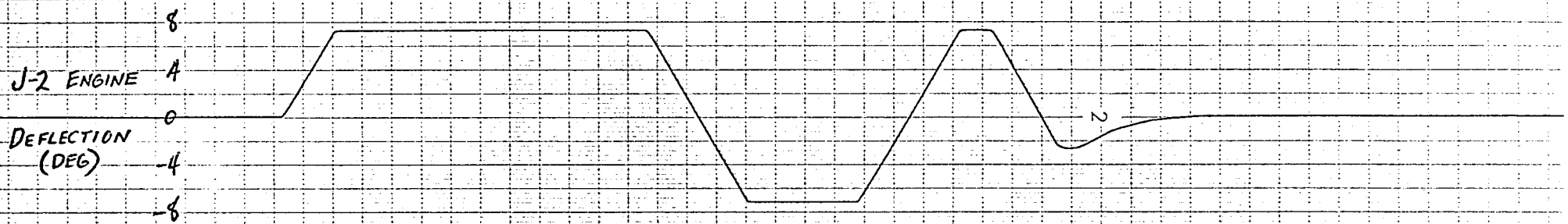
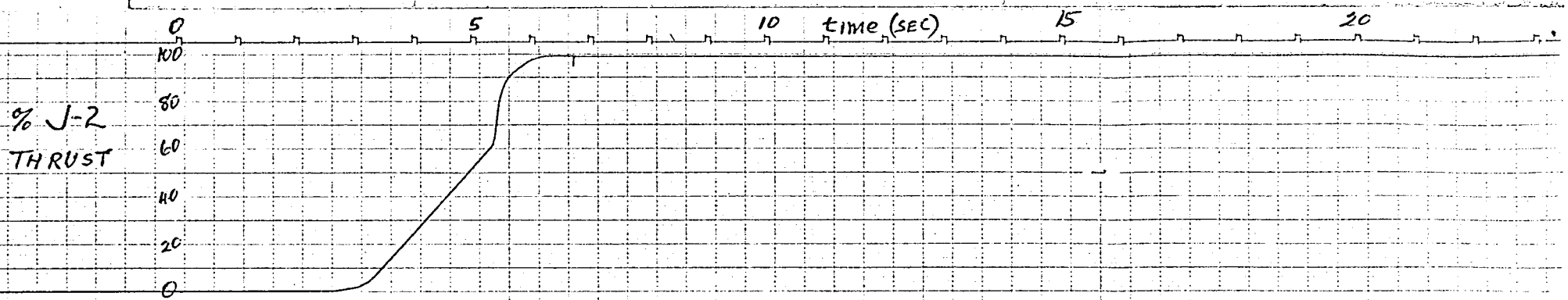
$$\phi_R \text{ (DEG)}$$

.8
.4
0
-.4
-.8



0 5 10 15 20
time (SEC)

FIGURE 6A



ENC 2

FIGURE 68

FIG 7

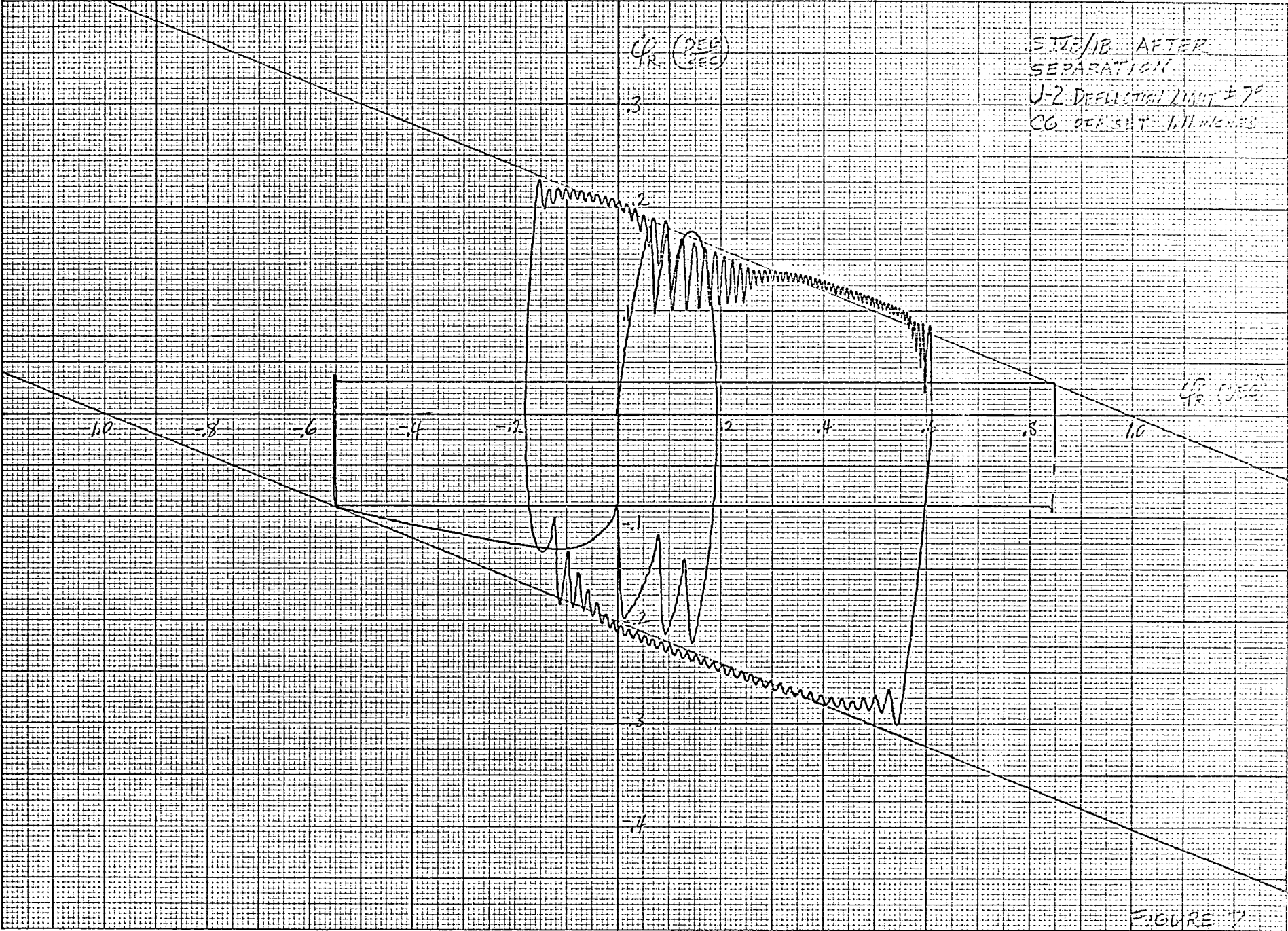


FIGURE 7