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EFFECTS OF PAYLOAD WEIGHT AND LENGTH ON THE MASS AND AERODYNAMIC CHARACTERISTICS OF THE APACHE AND CAJUN SOUNDING ROCKETS (CAPACHE)

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ABSTRACT

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The effects of payload weight and length on the Capache mass and aerodynamic characteristics are compiled. The characteristics are based upon assumed payload properties and should be modified, if desired, for known payload properties.

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LIST OF ILLUSTRATIONS

SYMBOLS

bo	Burnout
cg	Center of gravity
C_{m_α}	Static stability parameter, per radian
C_{N_α}	Normal force coefficient curve slope at $\alpha = 0$, per radian
cp	Center of pressure
i	Ignition
I_{xx}	Roll moment of Inertia (slug ft^2)
I_{yy}	Pitch moment of inertia (slug ft^2)
l	Total vehicle length (inches)
LA	Launch angle (degrees)
MEF	Motor empty + fins
MLF	Motor loaded + fins
PA	Payload adapter junction
pl	Propellant lost
t	Time (seconds)
W	Weight (lbs)
x	Longitudinal location measured from base (ft)
ω	Pitch natural frequency (cps)

LIST OF TABLES

EFFECTS OF PAYLOAD WEIGHT AND LENGTH ON THE MASS AND AERODYNAMIC CHARACTERISTICS ON THE APACHE AND CAJUN SOUNDING ROCKETS

(CAPACHE)

INTRODUCTION

A brief study was conducted to define the effects of payload weight and length on the mass, static margin, static stability, and natural frequency characteristics of the Apache and Cajun sounding rockets. The characteristics have been available in memorandum form for some time and have been used primarily for preliminary estimates prior to payload finalization and for routine stability analysis.

METHOD

The computer programs shown in Appendixes A and B were used in this study. For the Apache vehicle, the program input characteristics were determined through the use of references 1, 2, 3, 4, and 5. For the Cajun vehicle, the program input characteristics were determined through the use of references 2, 3, 6, 7, 8, and 9.

The study was conducted for the standard 34-inch (11-degree) nose cone and a payload diameter of 6.75 inches. A nose cone weight of 14 pounds was assumed.

Computations were performed for payload weights and lengths of:

- 40 pounds: 40, 60, and 80 inches
- 80 pounds: 40, 60, and 80 inches
- 120 pounds: 40, 60, and 80 inches

The vehicle aerodynamic characteristics were determined for the extreme drag cases: drag I and drag IV.

The following assumptions were made in determining the mass characteristics:

- Propellant center-of-gravity location is constant.
- Nose cone is of uniform density.
- Payload cylindrical section is of uniform density.
- Pitch and roll moments of inertia vary linearly with burning time.

It must be noted that the vehicle characteristics presented in the following pages are only as valid as these assumptions.

RESULTS

Apache

Table 1 shows the Apache weight and inertia input characteristics. Figures 1 through 4 show the resulting weight-time, center-of-gravity location, pitch and yaw moment of inertia, and roll moment of inertia characteristics respectively.

Table 1

Apache Weight and Inertia Input Characteristics

W_{MEF}	= 86	$(I_{yy})_{MEF}$	= 29.6
W_{MLF}	= 217	$(I_{yy})_{MLF}$	= 58
$(x_{cg})_{MEF}$	= 3.18	$(I_{xx})_{MEF}$	= 0.34
$(x_{cg})_{MLF}$	= 4.1	$(I_{xx})_{MLF}$	= 0.52
$(x_{cg})_{pl}$	= 4.71	t_i	= 20.0
x_{PA}	= 8.92	t_{bo}	= 26.4

Time (sec.)	Wt. Propellant Lost (lbs)	Time (sec.)	Wt. Propellant Lost (lbs)	Time (sec.)	Wt. Propellant Lost (lbs)
0.0	0.0	22.06	42.9	25.33	119.4
20.0	0.0	22.45	51.1	25.57	124.2
20.07	0.7	22.69	56.3	25.76	127.4
20.15	2.3	23.60	76.9	25.86	128.8
20.22	3.9	23.95	85.2	25.98	129.9
20.56	11.6	24.50	98.7	26.10	130.5
20.87	18.3	24.69	103.5	26.17	130.75
21.15	24.1	24.94	110.0	26.40	131.0
21.68	35.0	25.10	114.0	9999.0	131.0

Table 2 shows the Apache aerodynamic input characteristics. Figures 5, 6, and 7 show the resulting static margin, static stability, and natural frequency characteristics, respectively, for a zero-length launcher, 80-degree elevation launch from Wallops Island for extreme drag cases (cases I and IV).

Table 2

Apache and Cajun (Capache) Aerodynamic Input Characteristics

Mach No.	$*C_{N_\alpha}$	x_{cp} (l = 151)	x_{cp} (l = 191)	Mach No.	$*C_{N_\alpha}$	x_{cp} (l = 151)	x_{cp} (l = 191)
1.5	33.23	1.54	1.83	5.0	12.61	3.08	3.92
2.0	26.93	1.78	2.17	5.5	11.46	3.25	4.17
2.5	22.35	2.00	2.49	6.0	10.89	3.42	4.41
3.0	18.91	2.24	2.77	6.5	10.31	3.58	4.64
3.5	16.62	2.46	3.08	7.0	9.74	3.72	4.83
4.0	14.90	2.67	3.37	7.5	9.47	3.84	5.03
4.5	13.75	2.88	3.64	8.0	9.17	3.96	5.19

*Aerodynamic reference length $= \frac{6.5}{12} = 0.542$ foot

Aerodynamic reference area $= \frac{\pi(6.5)^2}{4(144)} = 0.231 \text{ foot}^2$

Figures 8 and 9 show the velocity and altitude histories for drag cases I and IV as obtained from references 4 and 5.

<u>Cajun</u>

Table 3 shows the Cajun weight and inertia input characteristics. Figures 10 through 13 show the resulting weight-time, center-of-gravity location, pitch and yaw moment of inertia, and roll moment of inertia characteristics respectively.

Table 2 shows the Cajun aerodynamic input characteristics. Figures 14, 15, and 16 show the resulting static margin, static stability, and natural frequency characteristics, respectively, for a zero-length launcher, 80-degree elevation launch from Wallops Island for extreme drag cases (cases I and IV).

Table 3

Cajun Weight and Inertia Input Characteristics

W_{MLF}	= 83	$(I_{yy})_{MEF}$	= 24
W_{MLF}	= 202	$(I_{yy})_{MLF}$	= 53
$(x_{cg})_{MEF}$	= 2.83	$(I_{xx})_{MEF}$	= 0.336
$(x_{cg})_{MLF}$	= 4.04	$(I_{xx})_{MLF}$	= 0.50
$(x_{cg})_{pl}$	= 4.78	t_i	= 17.0
x_{PA}	= 8.92	t_{bo}	= 21.0

Time (sec)	Wt. Propellant Lost (lbs)	Time (sec)	Wt. Propellant Lost (lbs)	Time (sec)	Wt. Propellant Lost (lbs)	Time (sec)	Wt. Propellant Lost (lbs)
0.0	0.0	17.50	15.2	19.55	93.9	20.35	118.7
17.0	0.0	17.65	20.2	19.80	104.7	20.40	118.9
17.05	0.3	17.80	25.3	19.94	111.0	20.50	118.95
17.08	1.0	18.20	39.9	19.96	111.9	21.00	119.0
17.10	1.7	18.40	47.6	20.00	113.5	9999.0	119.0
17.15	3.4	18.60	55.5	20.15	117.6		
17.25	6.8	19.10	75.4	20.20	118.2		
17.35	10.2	19.35	85.6	20.25	118.5		

Figures 17 and 18 show the velocity and altitude histories for drag cases I and IV as obtained from references 7 and 8.

CONCLUSIONS

As stated previously, the characteristics presented in this paper are only as valid as the aforementioned assumptions. Payloads exhibiting abnormal external configurations or weight distributions should be singularly investigated. The characteristics are presented without detailed discussion; however, four obvious conclusions are:

- The static margin and static stability histories are insensitive to payload length.
- The higher drag cases exhibit higher minimum static margins owing to decreased burnout Mach numbers.
- The undamped aerodynamic pitch frequency prior to resonance is insensitive to payload weight.
- The effects of varying payload weight and length on the undamped aerodynamic pitch frequency are small. The values of the pitch frequency at a given time are within 0.5 cps of the mean.

APPENDIX A

WEIGHT, CENTER-OF-GRAVITY LOCATION, PITCH AND ROLL MOMENT OF INERTIA DETERMINATION PROGRAM

INTRODUCTION

The enclosed equations were developed to facilitate determination of the weight, center-of-gravity location, and pitch and roll moment of inertia of the Capache sounding rocket as a function of time as required for input into the G.E. MASS Subprogram II. They are being programmed by Elva Glover of the Math and Computing Branch. An outline of the program follows:

ASSUMPTIONS

1. Propellant center-of-gravity location is constant.

2. Nose cone is of uniform density.

3. Payload cylindrical section is of uniform density.

4. Pitch and roll moments of inertia vary linearly with burning time.

SYMBOLS (See Figure A-1)

h	length of nose cone
I_{xx}	roll moment of inertia
I_{yy}	pitch moment of inertia
ℓ	length of payload cylindrical section
r	radius of payload cylindrical section
t	time
W	weight
x	longitudinal location
x_{cg}	longitudinal center-of-gravity location

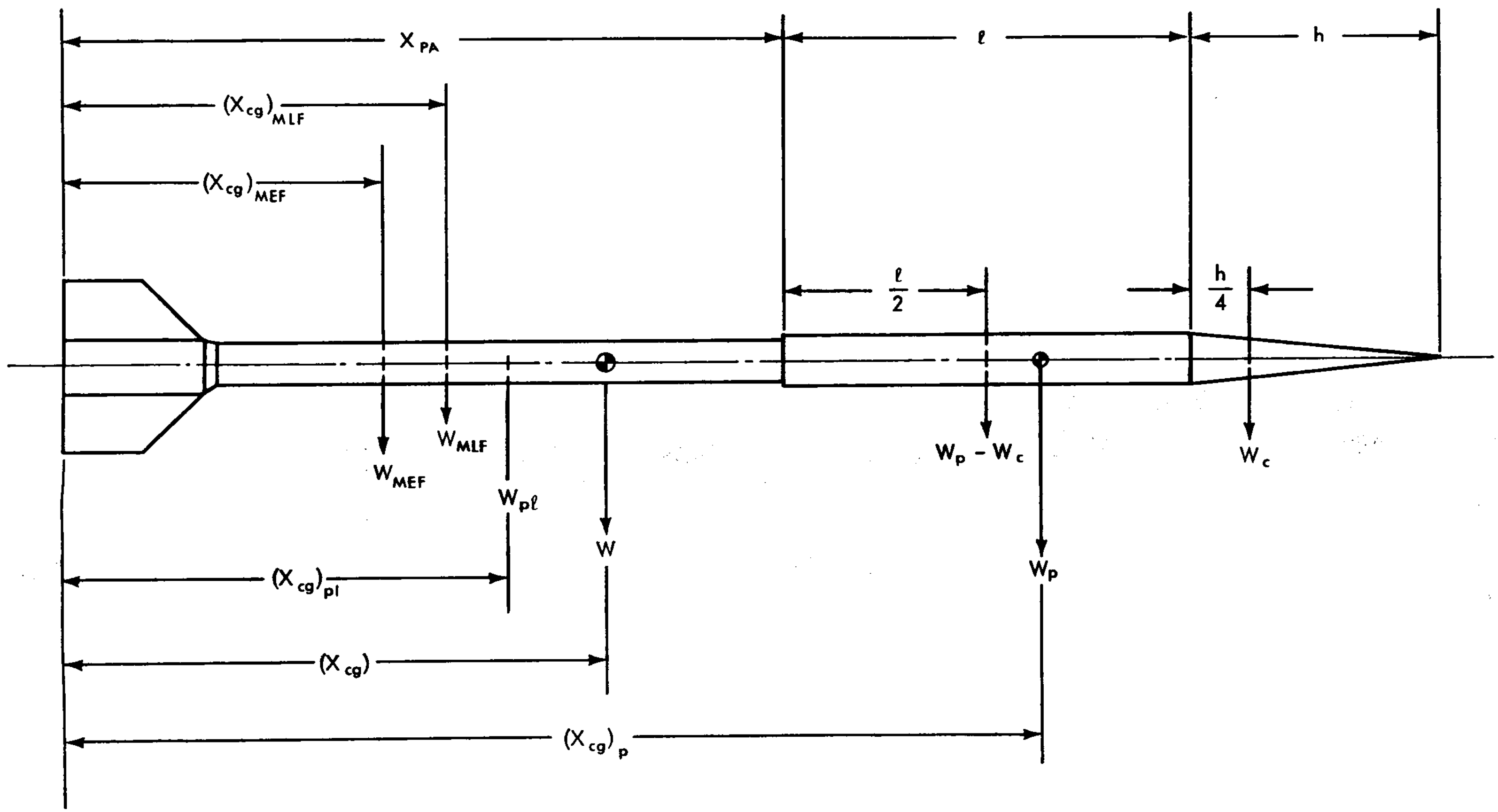

X_{PA}
ℓ
h
$(X_{cg})_{MLF}$
$(X_{cg})_{MEF}$
$\frac{\ell}{2}$
$\frac{h}{4}$
W_{MEF}
W_{MLF}
$W_{p\ell}$
W
$W_p - W_c$
W_c
W_p
$(X_{cg})_{pl}$
(X_{cg})
$(X_{cg})_p$

Figure A-1.

SUBSCRIPTS

bo	burnout
c	payload conical section
i	ignition
MF	motor + fins
MEF	motor empty + fins
MLF	motor loaded + fins
p	payload
PA	payload adapter juncture
pl	propellant lost

INPUT

<u>Constants:</u>

W_p

W_c

W_{MEF}

W_{MLF}

$(x_{cg})_{MEF}$

$(x_{cg})_{MLF}$

$(x_{cg})_{pl}$

x_{PA}

ℓ

h

r

$(Iyy)_{MLF}$

$(Iyy)_{MEF}$

t_i

t_{bo}

<u>Variable:</u> $W_{pl} = F(t)$

OUTPUT

<u>Constants:</u> W_p

h

ℓ

$(x_{cg})_p$

$(Iyy)_p$

$(Ixx)_p$

<u>Variables:</u> $W = F(t)$

$x_{cg} = F(t)$

$Iyy = F(t)$

$Ixx = F(t)$

EQUATIONS

$$(x_{cg})_p = x_{PA} + \frac{(W_p - W_c)\frac{\ell}{2} + W_c\left(\ell + \frac{h}{4}\right)}{W_p}$$

$$(Iyy)_p = \frac{\left(W_p - W_c\right)}{32.2}\left[r^2 + \left(\frac{\ell^2}{3}\right)\right]/4$$

$$+ \frac{3W_c}{32.2}\left[\left(\frac{r^2}{3}\right) + h^2\right]/5$$

$$+ \frac{\left(W_p - W_c\right)}{32.2}\left[\left(x_{PA} + \frac{\ell}{2}\right) - \left(x_{cg}\right)_p\right]^2$$

$$- \frac{W_c\,(0.75h)^2}{32.2} + \frac{W_c}{32.2}\left[x_{PA} + 0.25h + \ell - \left(x_{cg}\right)_p\right]^2$$

$$(Ixx)_p = 0.3\left(\frac{W_c}{32.2}\right)r^2 + 0.5\left(\frac{W_p - W_c}{32.2}\right)r^2$$

$$x_{cg} = \frac{W_{MLF}\left(x_{cg}\right)_{MLF} + W_p\left(x_{cg}\right)_p - W_{p1}\left(x_{cg}\right)_{p1}}{W_{MLF} + W_p - W_{p1}}$$

$$(Iyy)_{ti} = (Iyy)_{MLF} + (Iyy)_p$$

$$+ \frac{1}{32.2}\left\{W_{MLF}\left[\left(x_{cg}\right)_{MLF} - \left(x_{cg}\right)_{t_i}\right]^2\right.$$

$$\left. + W_p\left[\left(x_{cg}\right)_p - \left(x_{cg}\right)_{t_i}\right]^2\right\} \qquad t \leq t_i$$

$$(Iyy)_{t_{bo}} = (Iyy)_{MEF} + (Iyy)_p$$

$$+ \frac{1}{32.2} \left\{ W_{MEF} \left[\left(x_{cg}\right)_{MEF} - \left(x_{cg}\right)_{t_{bo}} \right]^2 \right.$$

$$\left. + W_p \left[\left(x_{cg}\right)_p - \left(x_{cg}\right)_{t_{bo}} \right]^2 \right\} \qquad t \geq t_{bo}$$

$$Iyy = (Iyy)_{t_i} - \left[(Iyy)_{t_i} - \left(I_{yy}\right)_{t_{bo}} \right] \frac{t - t_i}{t_{bo} - t_i} \qquad t_i < t < t_{bo}$$

$$(Ixx)_{t_i} = (Ixx)_p + (Ixx)_{MLF}$$

$$(Ixx)_{t_{bo}} = (Ixx)_p + (Ixx)_{MEF}$$

$$Ixx = (Ixx)_{t_i} - \left[\left(I_{xx}\right)_{t_i} - (Ixx)_{t_{bo}} \right] \frac{t - t_i}{t_{bo} - t_i} \qquad t_i \leq t \leq t_{bo}$$

$$W = W_{MLF} + W_p - W_{pl}$$

APPENDIX B

STATIC STABILITY AND NATURAL FREQUENCY PROGRAM

INTRODUCTION

In an effort to define the effects of payload weight and length on the Capache vehicle characteristics, several IBM 7094 computer programs have been developed within the Flight Performance Section. A program (herein designated WCG&I) now in use (Appendix A) determines the weight, center-of-gravity location, and pitch and roll moment of inertia as functions of payload weight and length. This appendix describes a program (designated SS&W) now completed that determines the static stability and pitch natural frequency. The input format of the SS&W program was chosen to accept output cards from the WCG&I program, thus minimizing program data transfer time. These programs have been verified by a comparison with hand calculations for flight 14.54. The programs were utilized to determine the natural frequency history for flight 14.37. They are currently being used in a parametric study to determine the effects of payload weight and length of the vehicle characteristics and natural frequency history of the Capache sounding rocket. The purpose of this appendix is to outline the SS&W program.

SYMBOLS

a	Speed of sound
Alt.	Altitude
C_{m_α}	Pitching moment coefficient curve slope
C_{N_α}	Normal force coefficient curve slope
D	Reference diameter
h	Length of nose cone
I_{yy}	Pitch moment of inertia
ℓ	Length of payload cylindrical section
M	Mach number
q	Free-stream dynamic pressure

S	Reference area$\left(\frac{\pi D^2}{4}\right)$
t	Time (sec)
V	Free-stream velocity
W_p	Payload weight (lbs)
x_{cg}	Center-of-gravity location
x_{cp}	Center-of-pressure location
ρ	Free-stream density
ω	Pitch natural frequency (cps)

STATIC STABILITY PARAMETER AND NATURAL FREQUENCY DETERMINATION PROGRAM

<u>Inputs:</u>

W_p, h, ℓ, S, D

$x_{cg} = f(t)$

V and alt. $= f(t)$ Option 1*

$C_{N_\alpha} = f(M)$

$x_{cp} = f(M, \ell_t)$

$I_{yy} = f(t)$ Option 1*

*The program was set up with two options as follows:

Option 1: Compute $\omega = f(t)$ using velocity and altitude data

Option 2: Compute $C_{m_\alpha} = f(M, t)$ for input into the G.E. MASS Program

The 1959 ARDC atmosphere equations are used to determine the atmospheric ambient conditions.

Equations:

$$\ell_t = \ell + h$$

$$q = \tfrac{1}{2}\rho V^2; \quad M = \frac{V}{a}$$

$$C_{m_\alpha} = C_{N_\alpha}\left(\frac{x_{cp} - x_{cg}}{D}\right)$$

$$\omega\ (\text{rad/sec}) = \sqrt{\frac{-C_{m_\alpha}\, q\, S\, D}{I_{yy}}}$$

$$\omega\ (\text{CPS}) = \frac{1}{2\pi}\ \omega\ (\text{rad/sec})$$

Output: Option 1*

W_p, h, ℓ, S, D

C_{m_α}, ω (rad/sec), ω (CPS), q = f(t)

Option 2*

W_p, h, ℓ, S, D

C_{m_α} = f(M, t)

*The program was set up with two options as follows:

Option 1: Compute ω = f(t) using velocity and altitude data

Option 2: Compute C_{m_α} = f(M,t) for input into the G.E. MASS Program

The 1959 ARDC atmosphere equations are used to determine the atmospheric ambient conditions.

REFERENCES

1. Jenkins, Reed B., Nike Apache Performance Handbook. NASA-GSFC X-616-62-103, July 1962.

2. Source: John H. Lane, NASA-GSFC, October 1, 1962.

3. Memorandum of April 10, 1964. Mr. Hershfield to Mr. Baumann, Subj: Principal Axis Tilt (PAT) of Apache and Payload.

4. Nike Apache Performance Trajectories, Zero-Length Launcher. Drag Case I. Wallops Island, Virginia.

5. Nike Apache Performance Trajectories. Zero-Length Launcher. Drag Case IV. Wallops Island, Virginia.

6. Lane, John H. and Kemmerer, Nancy L. Nike Cajun Sounding Rocket Performance. NASA-GSFC X-616-62-66. April 1962.

7. Nike Cajun Performance Trajectories. Zero-Length Launcher. Drag Case I. Wallops Island, Virginia.

8. Nike Cajun Performance Trajectories. Zero-Length Launcher. Drag Case IV. Wallops Island, Virginia.

9. Dobry, J. C. Weight, Balance, and Mass Moment of Inertia of the TE-M-307-2 Rocket Motor. Thiokol Chemical Corporation RER-361. April 10, 1964.

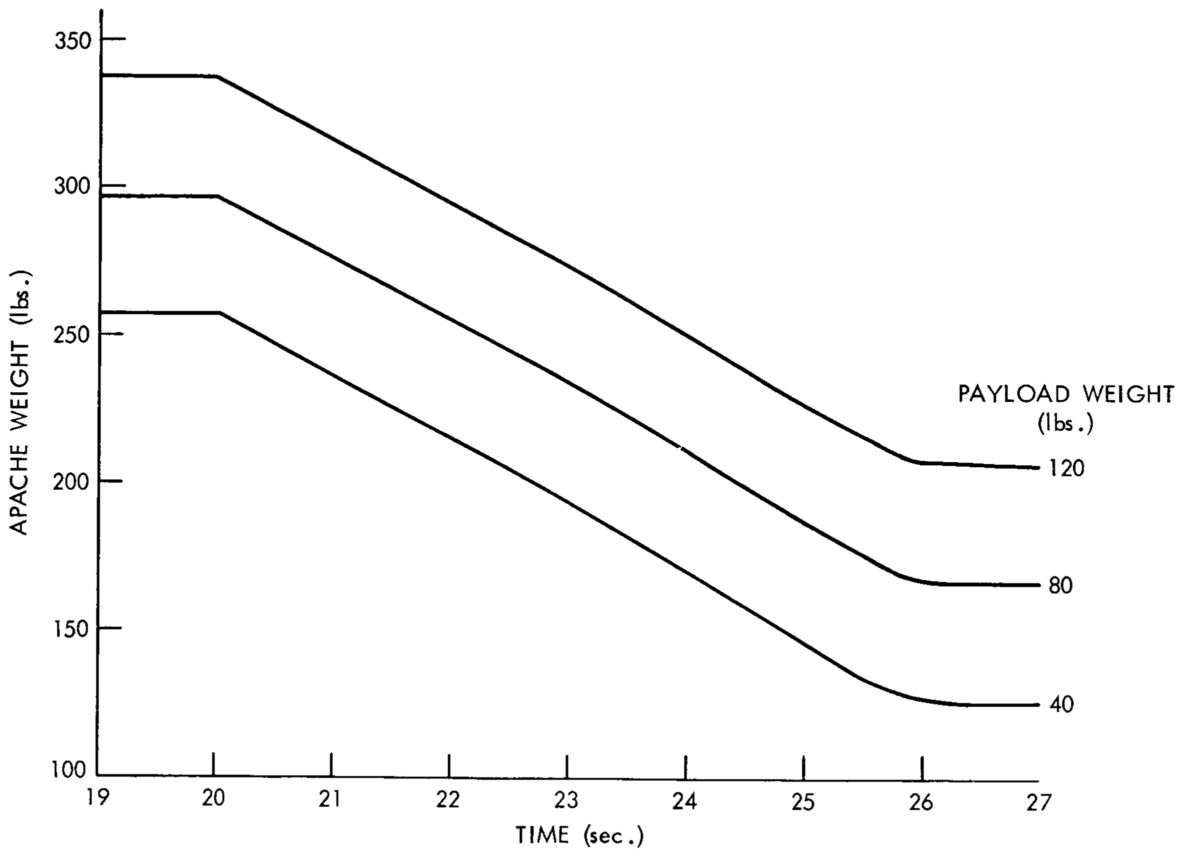


Figure 1. Effect of Payload Weight on Apache Weight-Time History

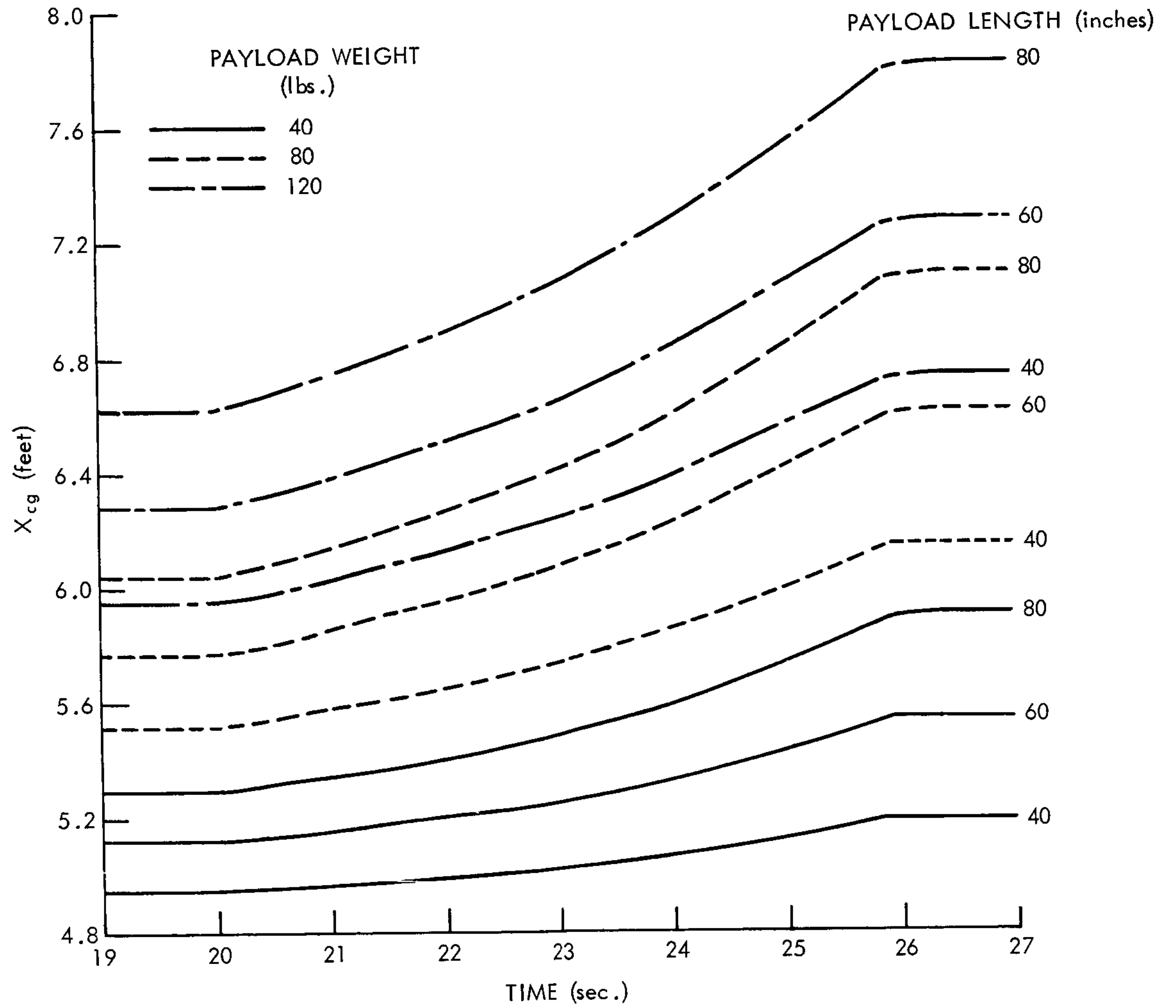


Figure 2. Effects of Payload Weight and Length on the Apache Center-of-Gravity Location

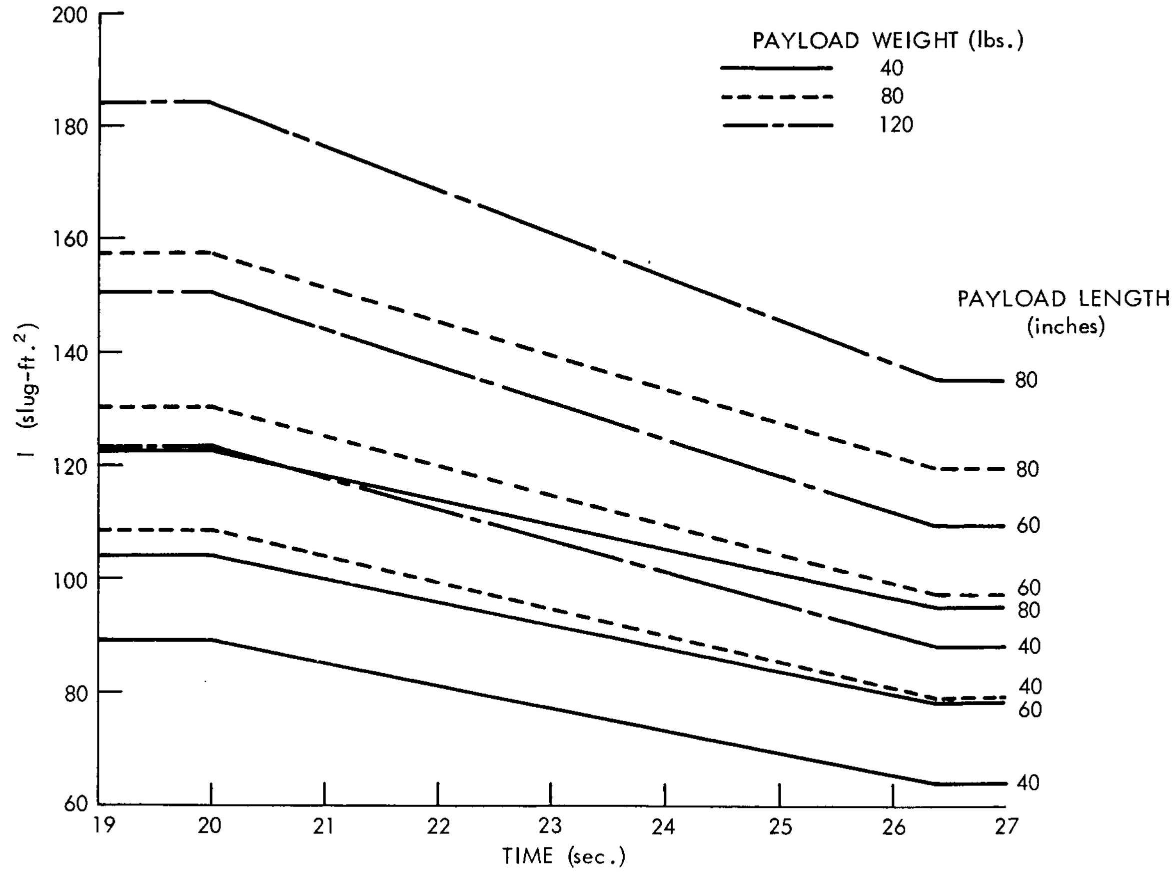


Figure 3. Effects of Payload Weight and Length on Apache Pitch and Yaw Moments of Inertia

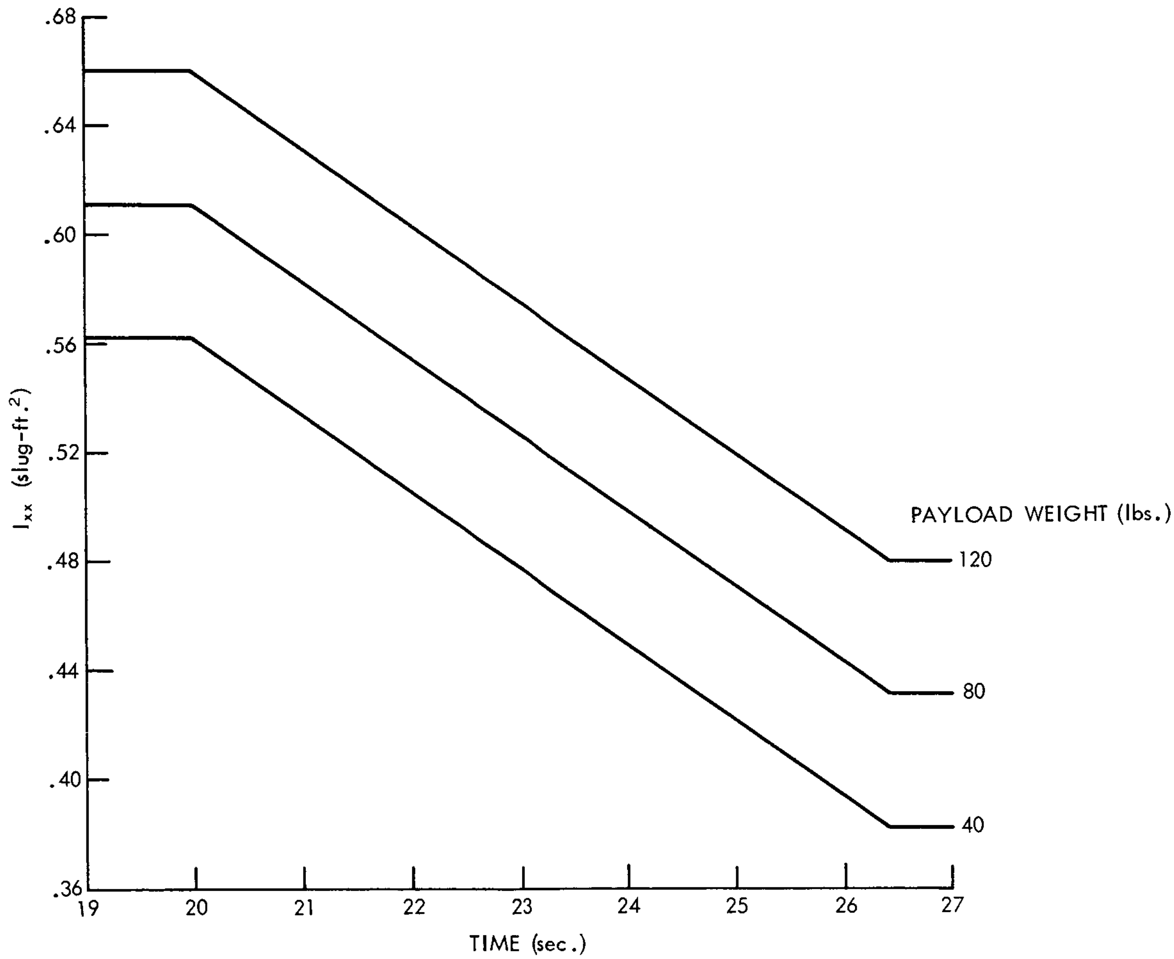


Figure 4. Effect of Payload Weight on Apache Roll Moment of Inertia

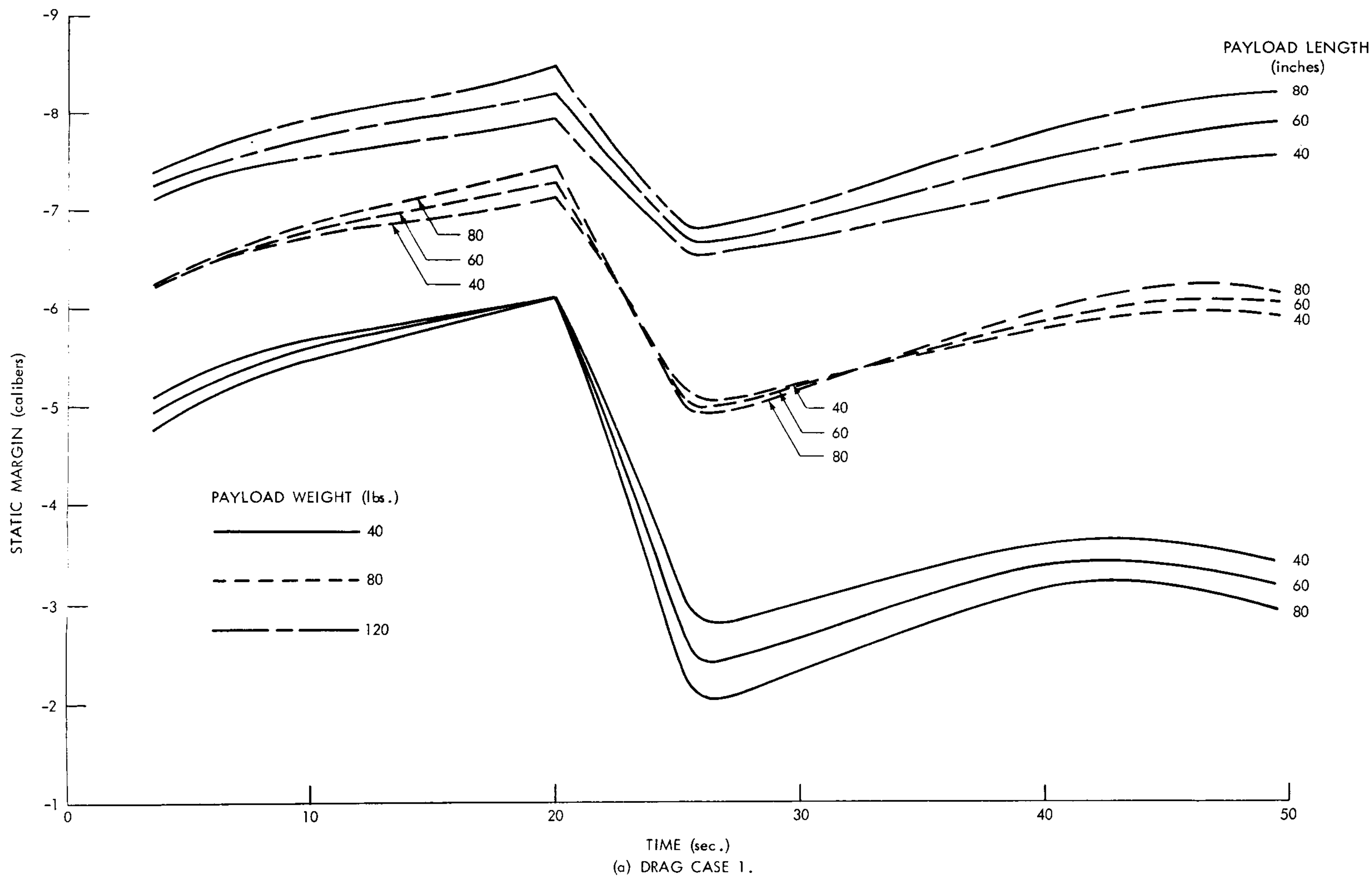
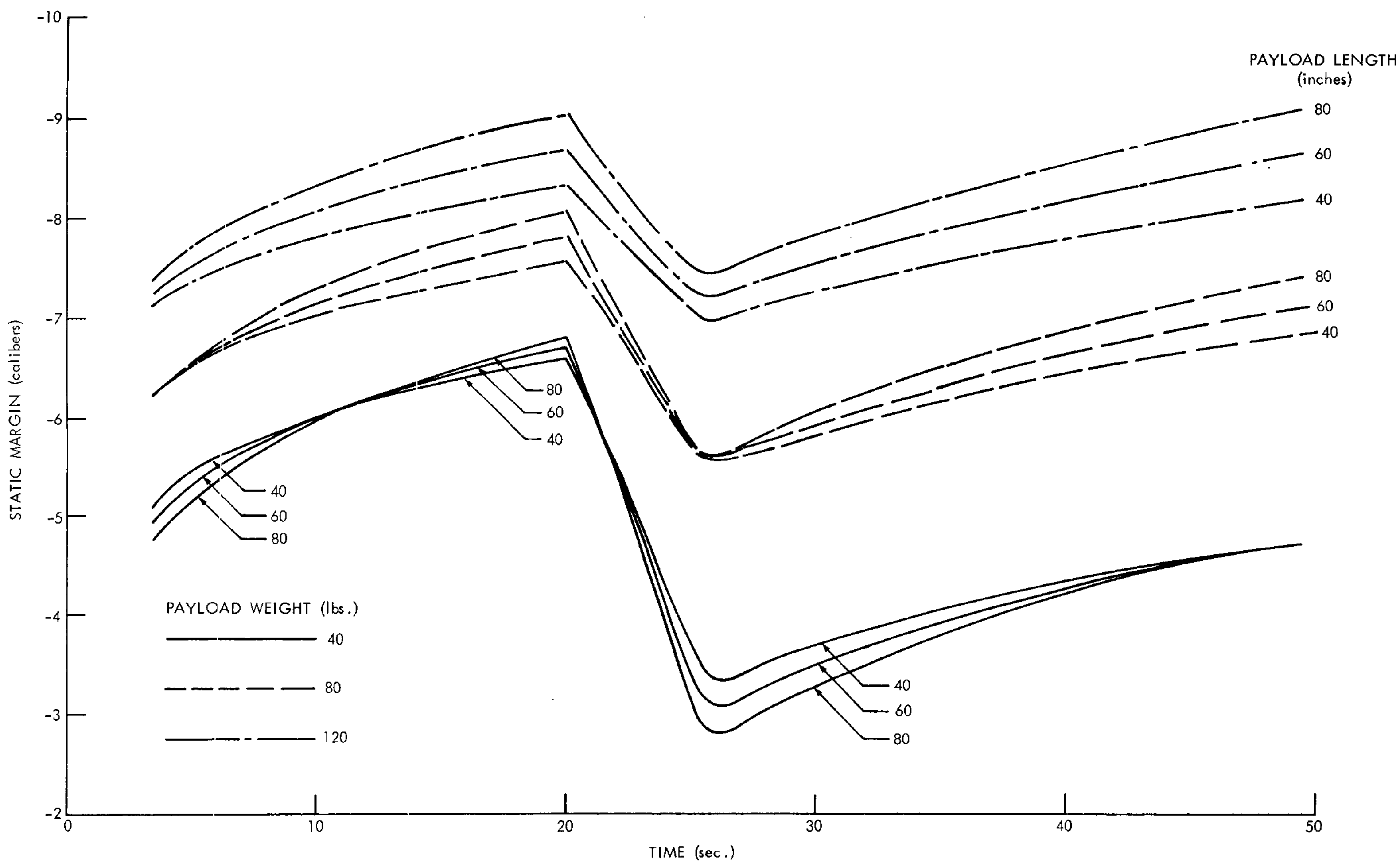
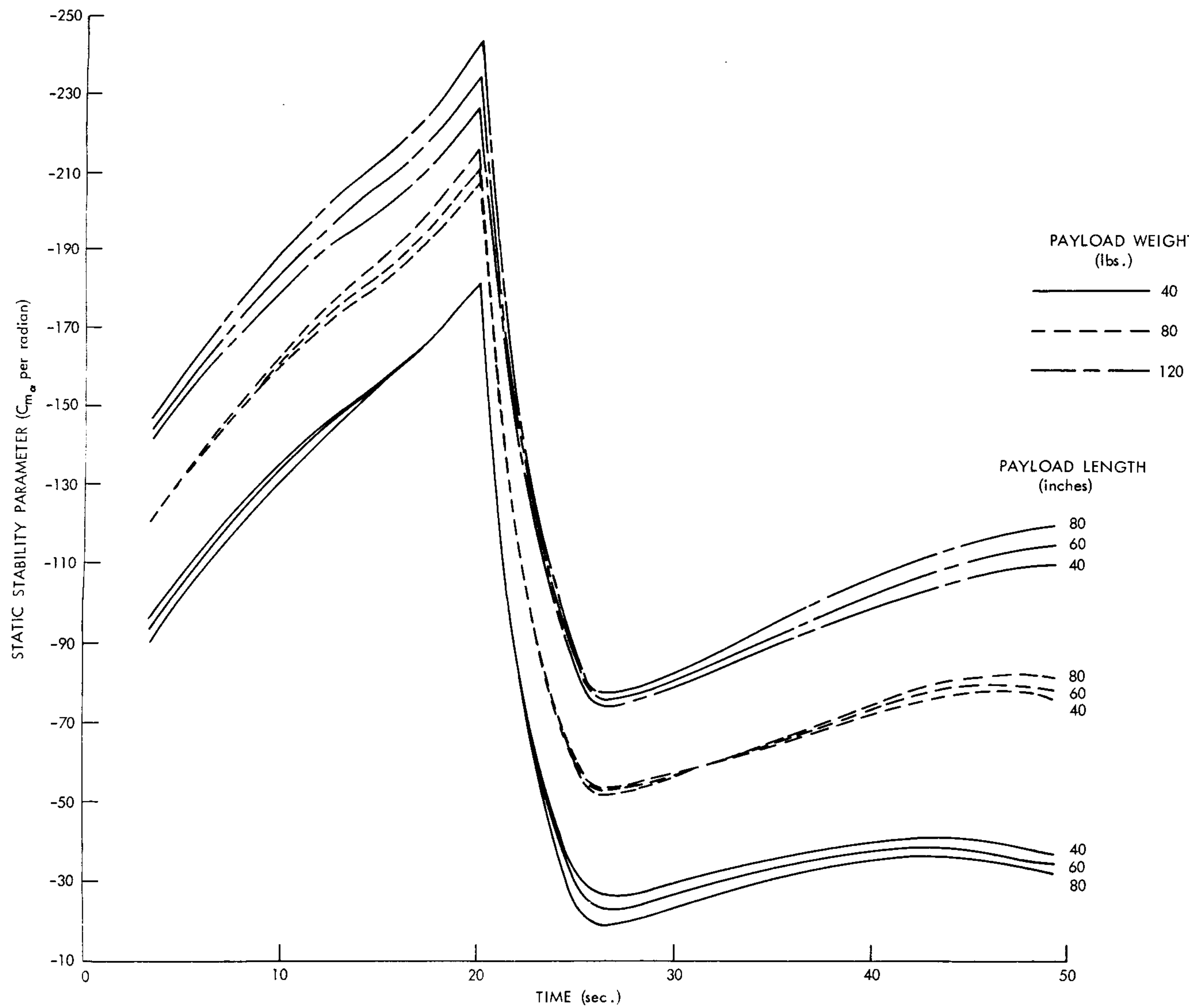


Figure 5. Effects of Payload Weight and Length on the Apache Static Margin. Wallops Island, Zero Length Launcher, L.A. = 80°



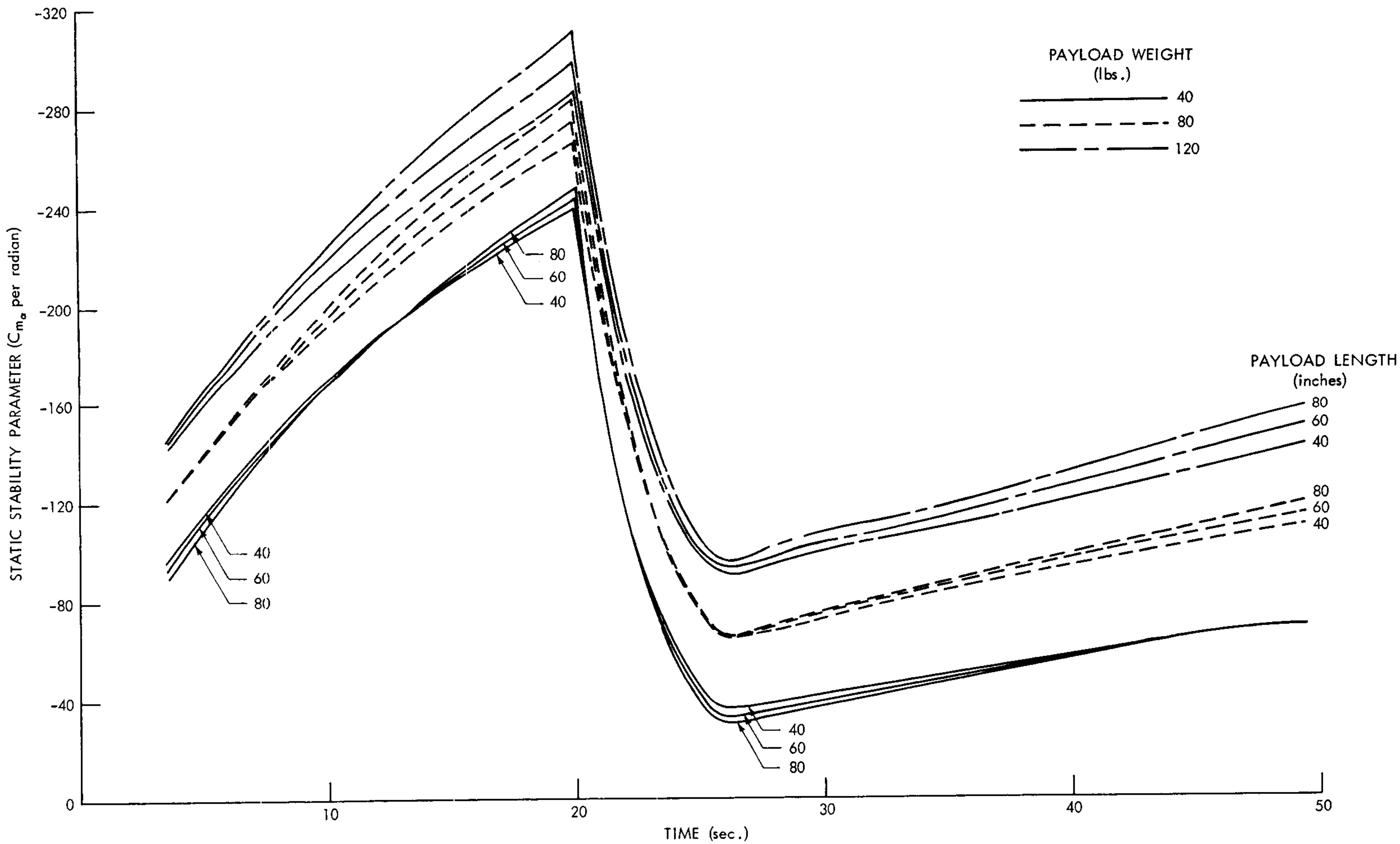
(b) DRAG CASE IV.

Figure 5. (Concluded)



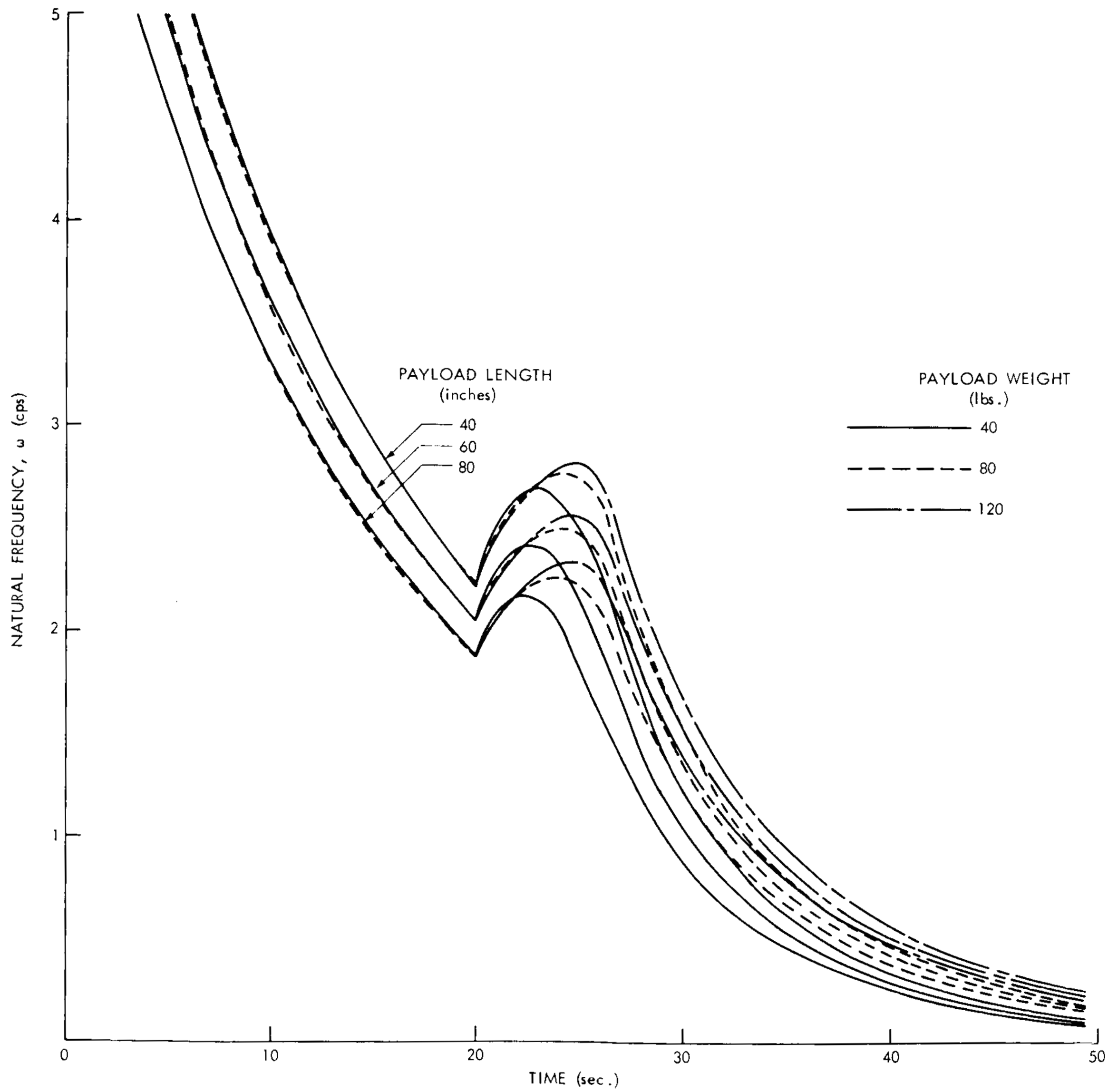
(a) DRAG CASE I

Figure 6. Effects of Payload Weight and Length on the Apache Static Stability. Wallops Island, Zero Length Launcher, L.A. = 80°



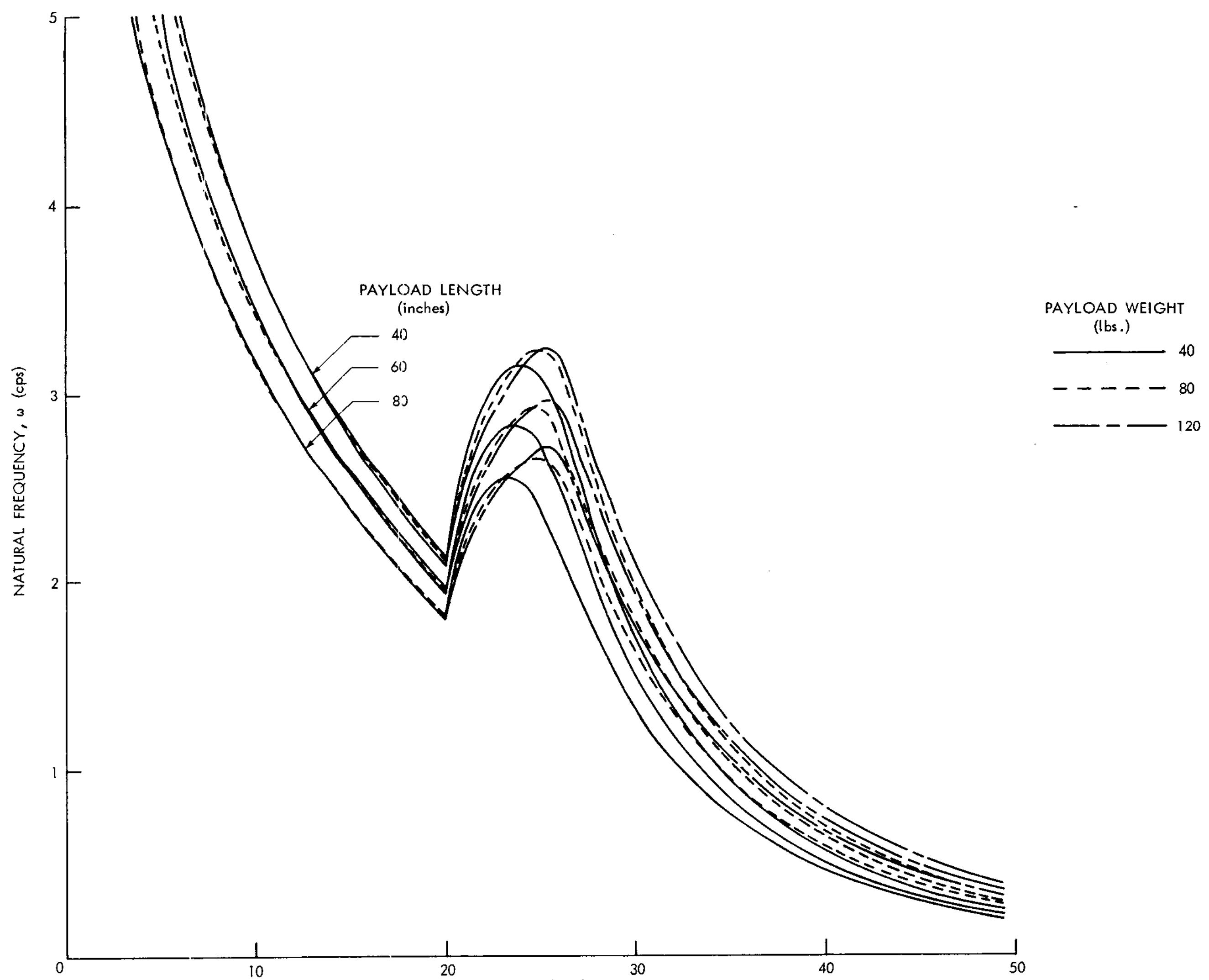
(b) DRAG CASE IV

Figure 6. (Concluded)



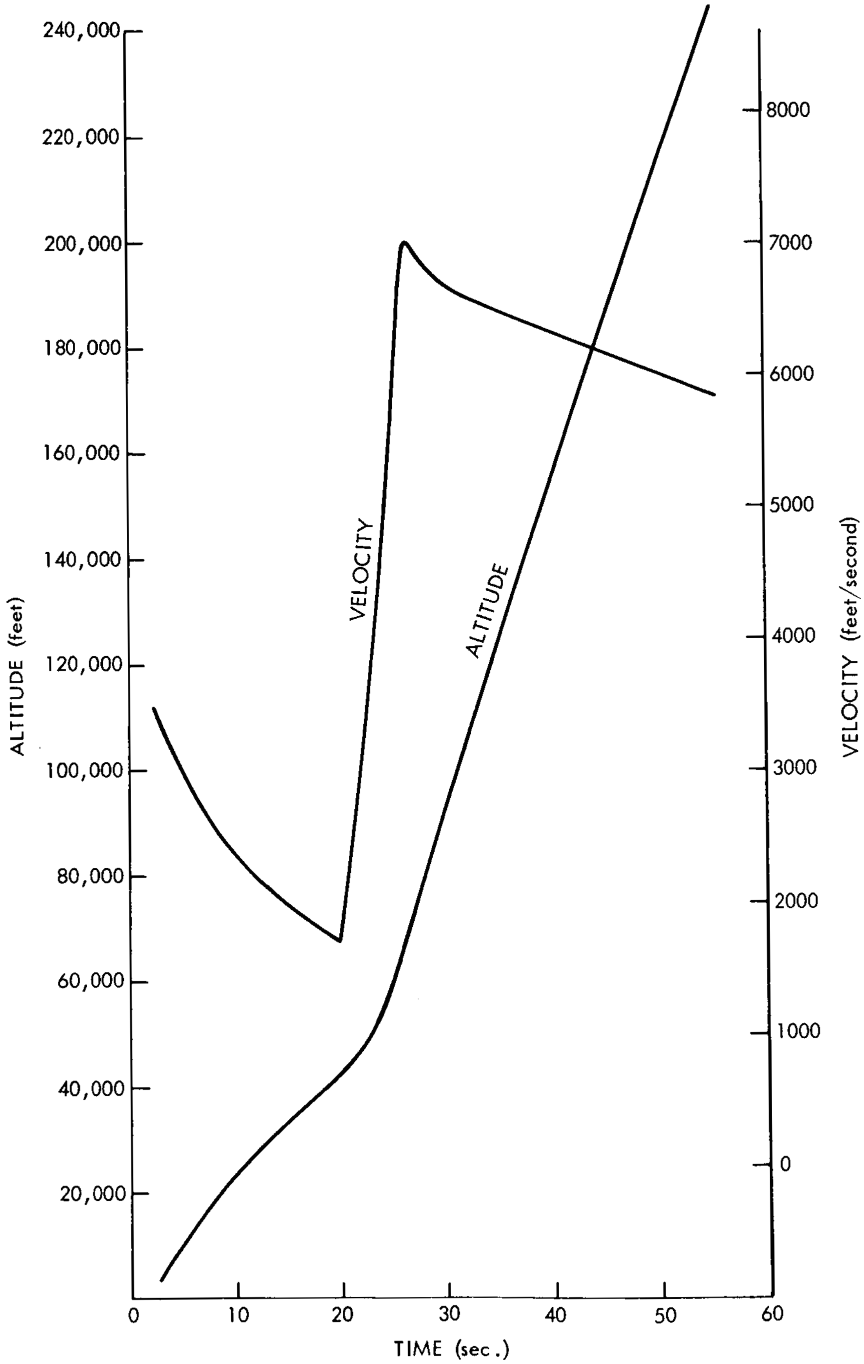
(a) DRAG CASE I

Figure 7. Effects of Payload Weight and Length on the Apache Natural Frequency. Wallops Island, Zero Length Launcher, L.A. = 80°



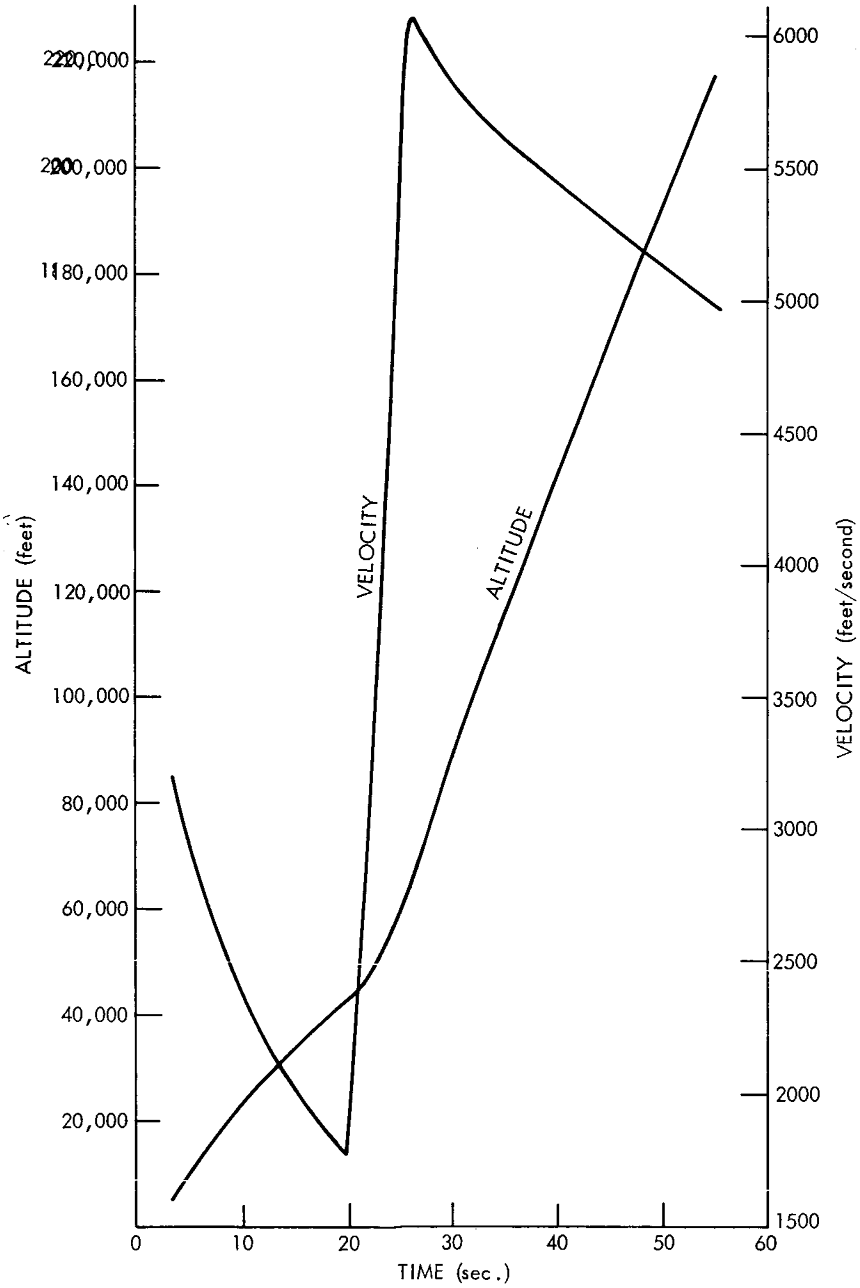
(b) DRAG CASE IV

Figure 7. (Concluded)



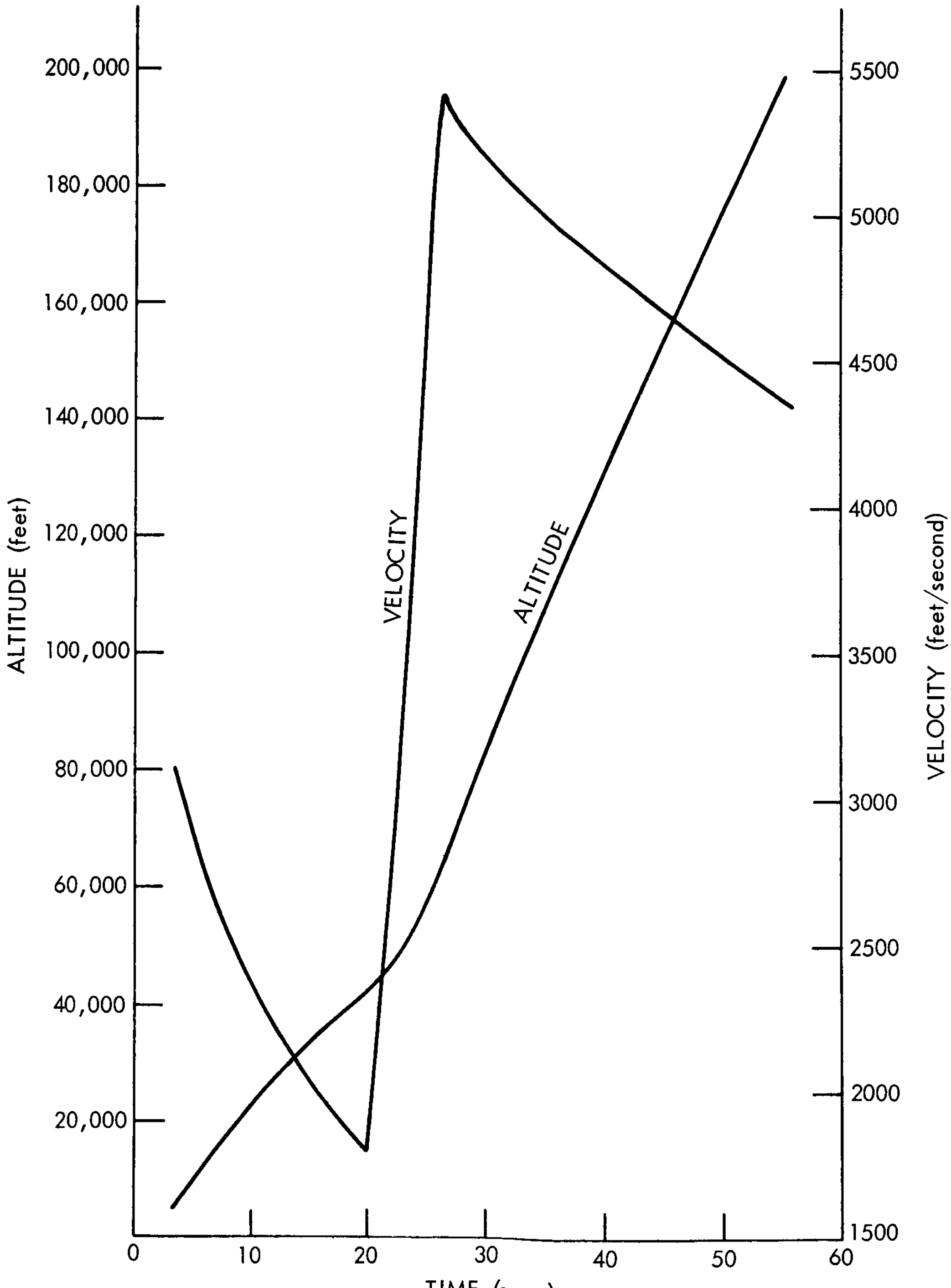
(a) PAYLOAD WEIGHT = 40 LBS.

Figure 8. Apache Velocity and Altitude Time History. Wallops Island, Zero Length Launcher, L.A. = 80°, Drag Case I



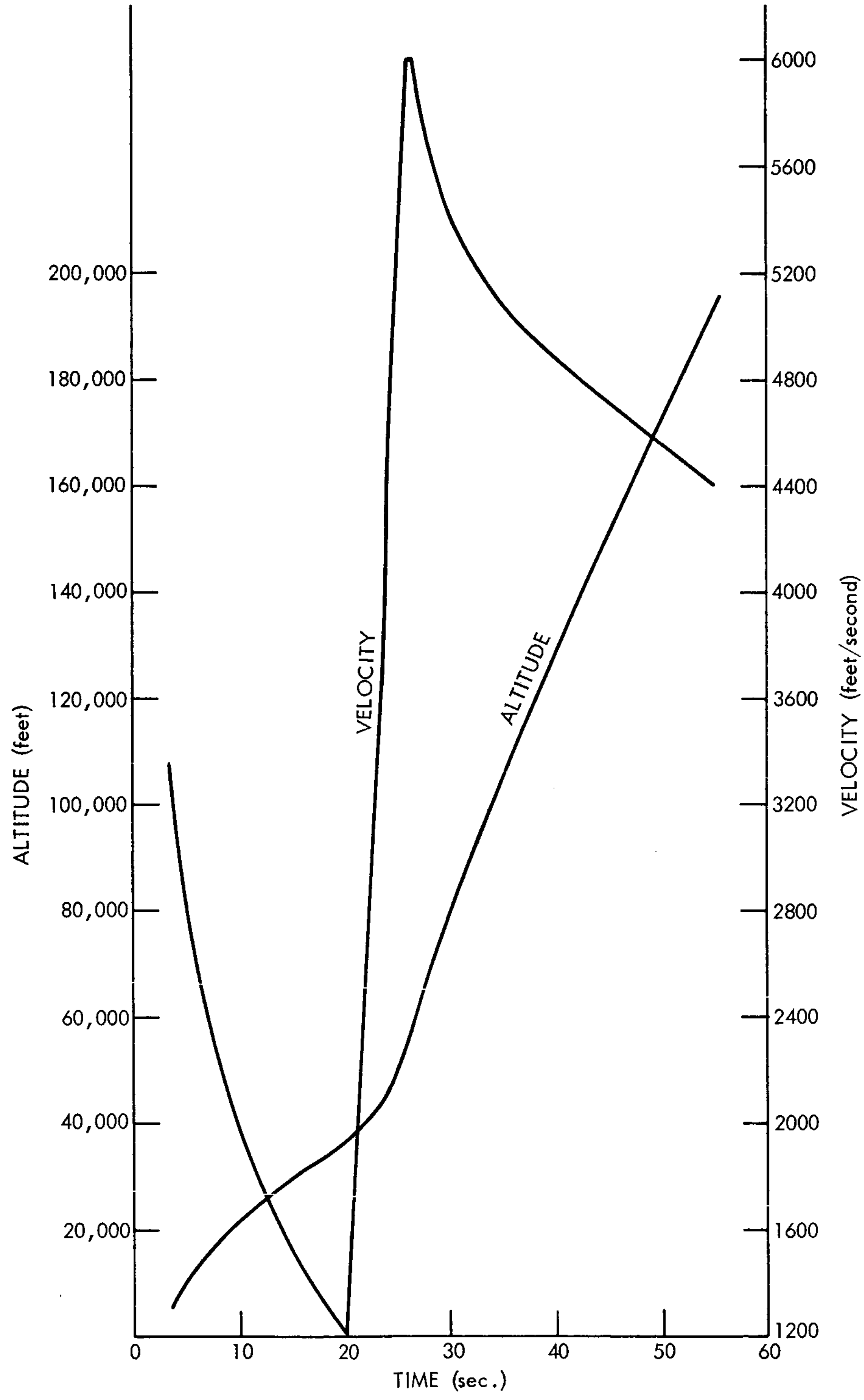
(b) PAYLOAD WEIGHT = 80 LBS.

Figure 8. (Continued)



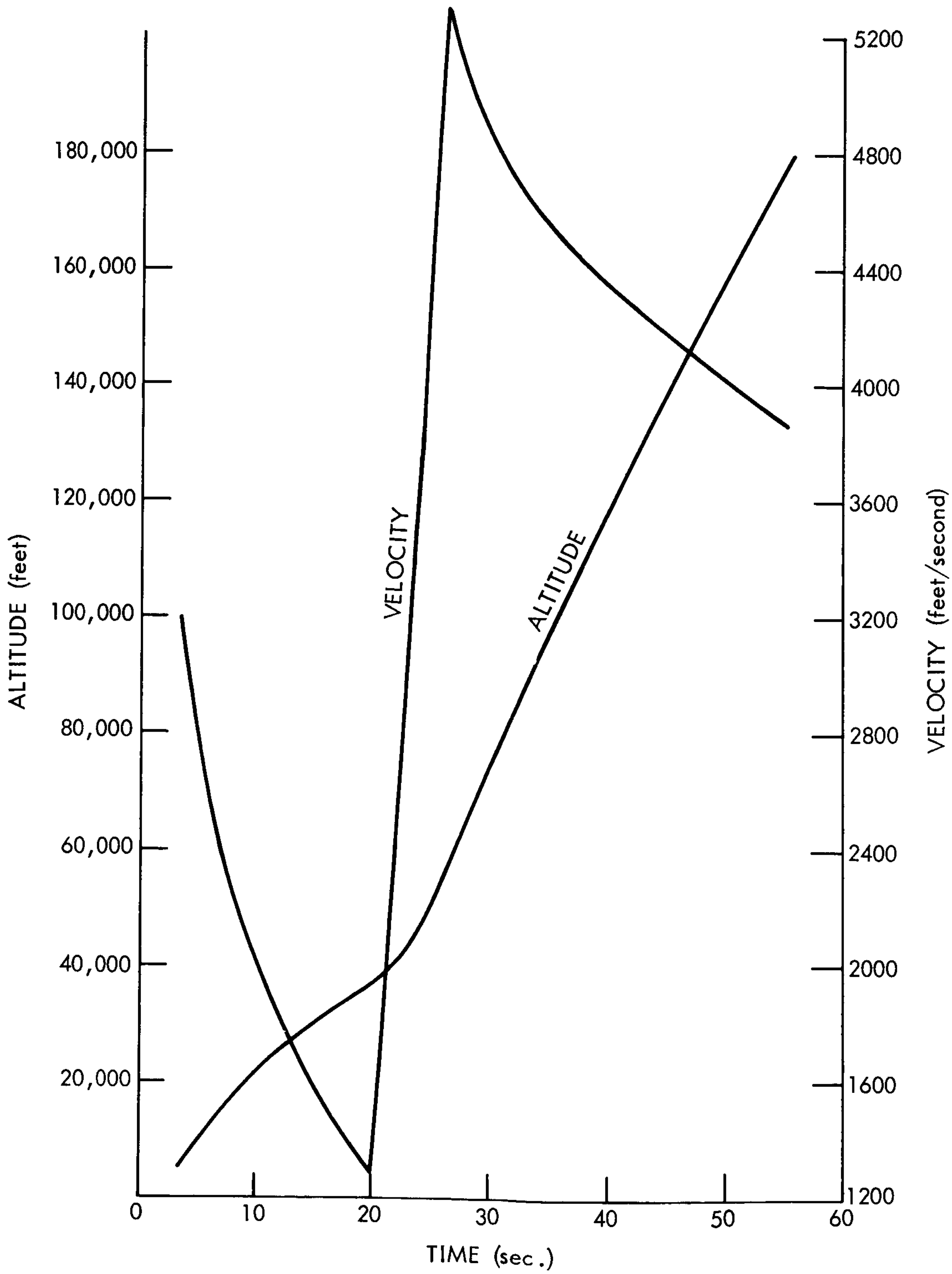
(c) PAYLOAD WEIGHT = 120 LBS.

Figure 8. (Concluded)



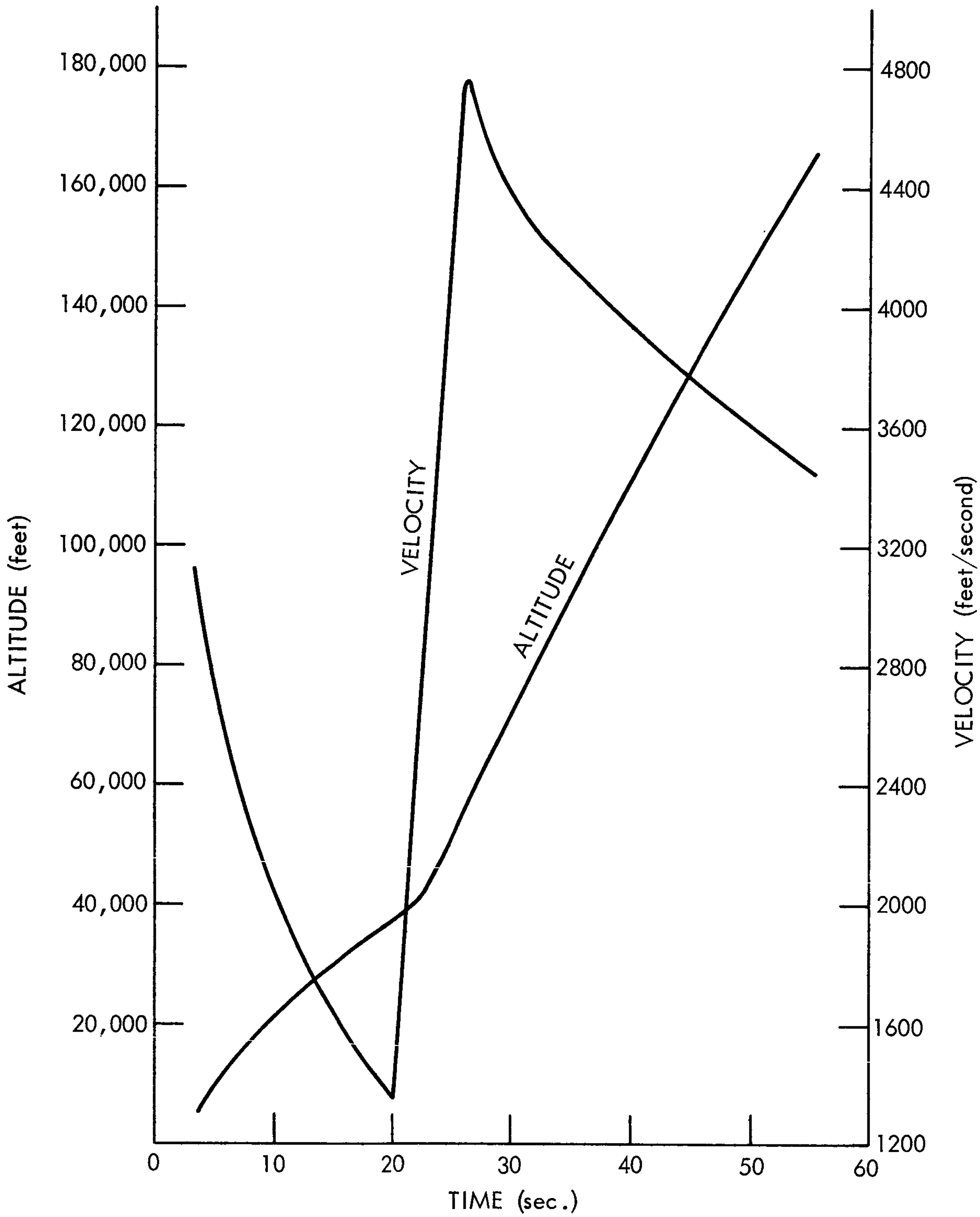
(a) PAYLOAD WEIGHT = 40 LBS.

Figure 9. Apache Velocity and Attitude Time History. Wallops Island, Zero Length Launcher, L.A. = 80°, Drag Case IV



(b) PAYLOAD WEIGHT = 80 LBS.

Figure 9. (Continued)



(c) PAYLOAD WEIGHT = 120 LBS.

Figure 9. (Concluded)

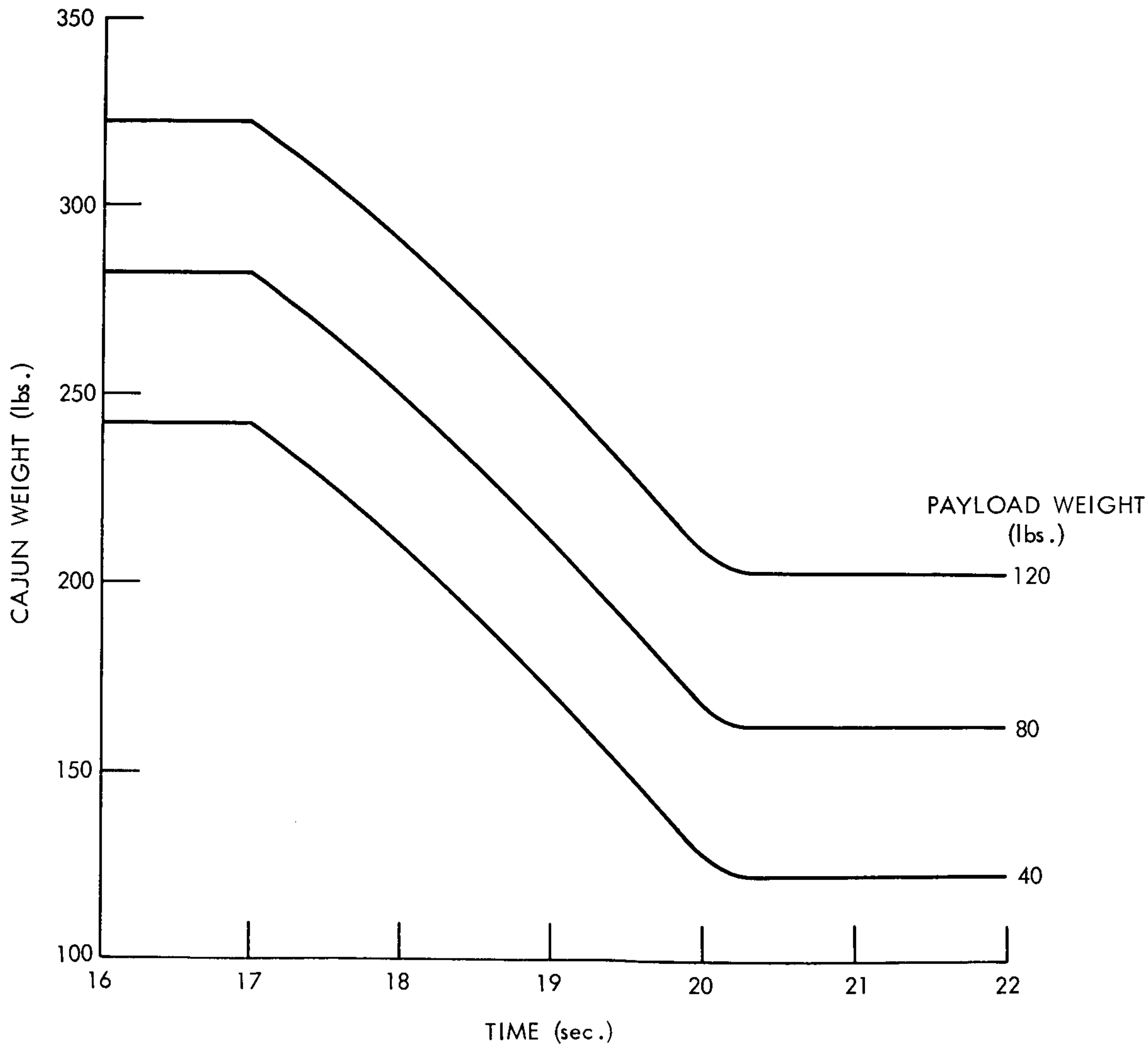


Figure 10. Effect of Payload Weight on Cajun Weight-Time History

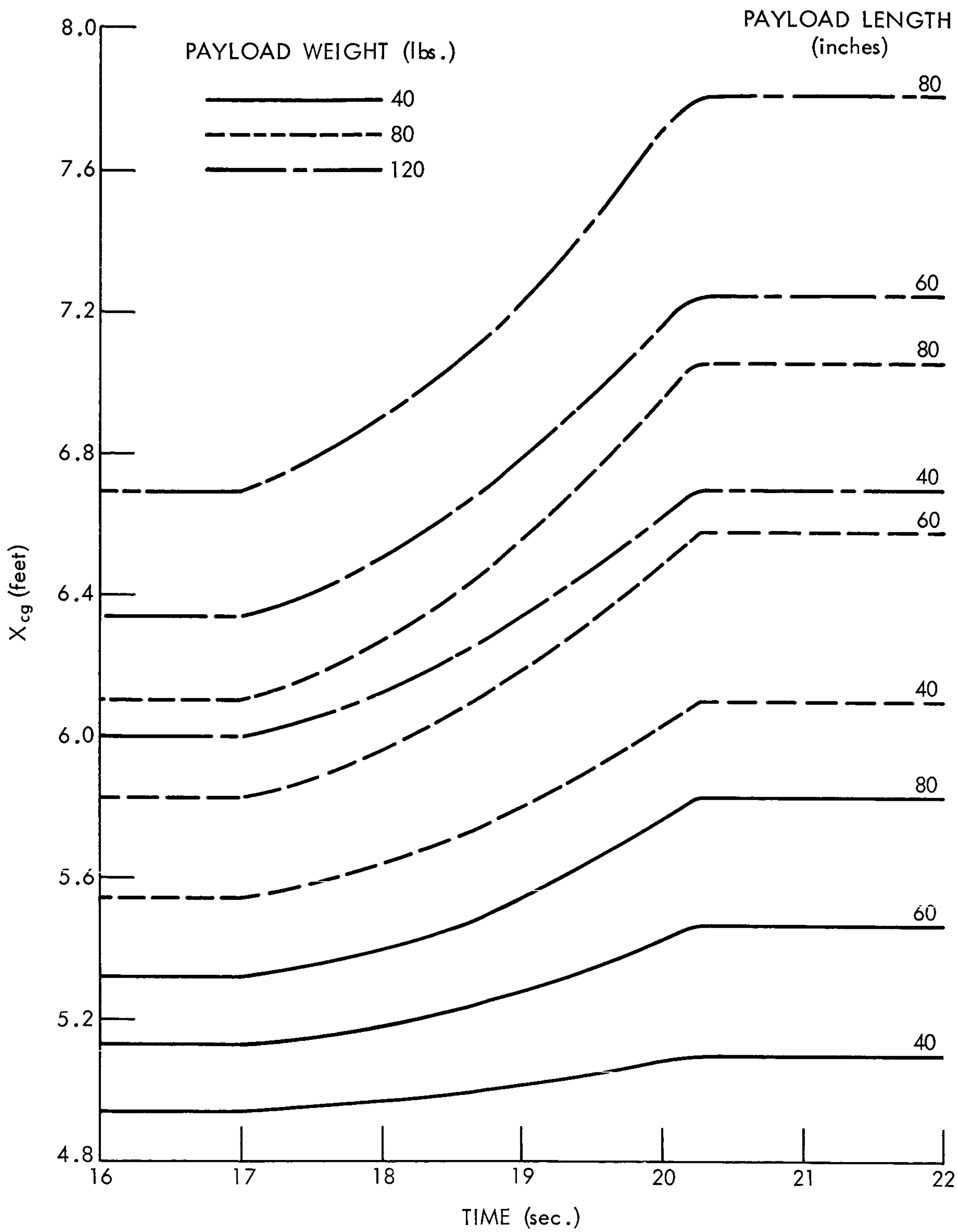


Figure 11. Effects of Payload Weight and Length on the Cajun Center-of-Gravity Location

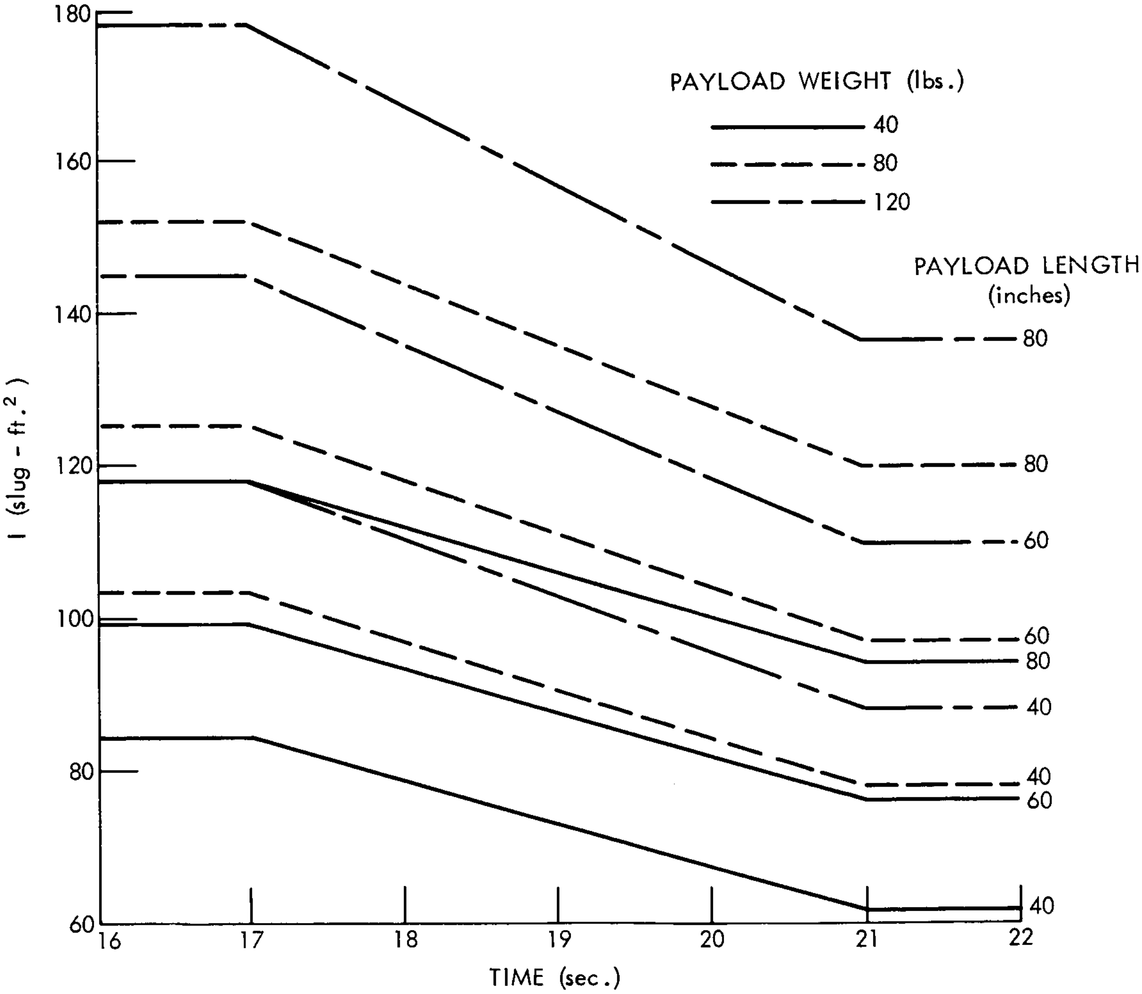


Figure 12. Effects of Payload Weight and Length on Cajun Pitch and Yaw Moments of Inertia

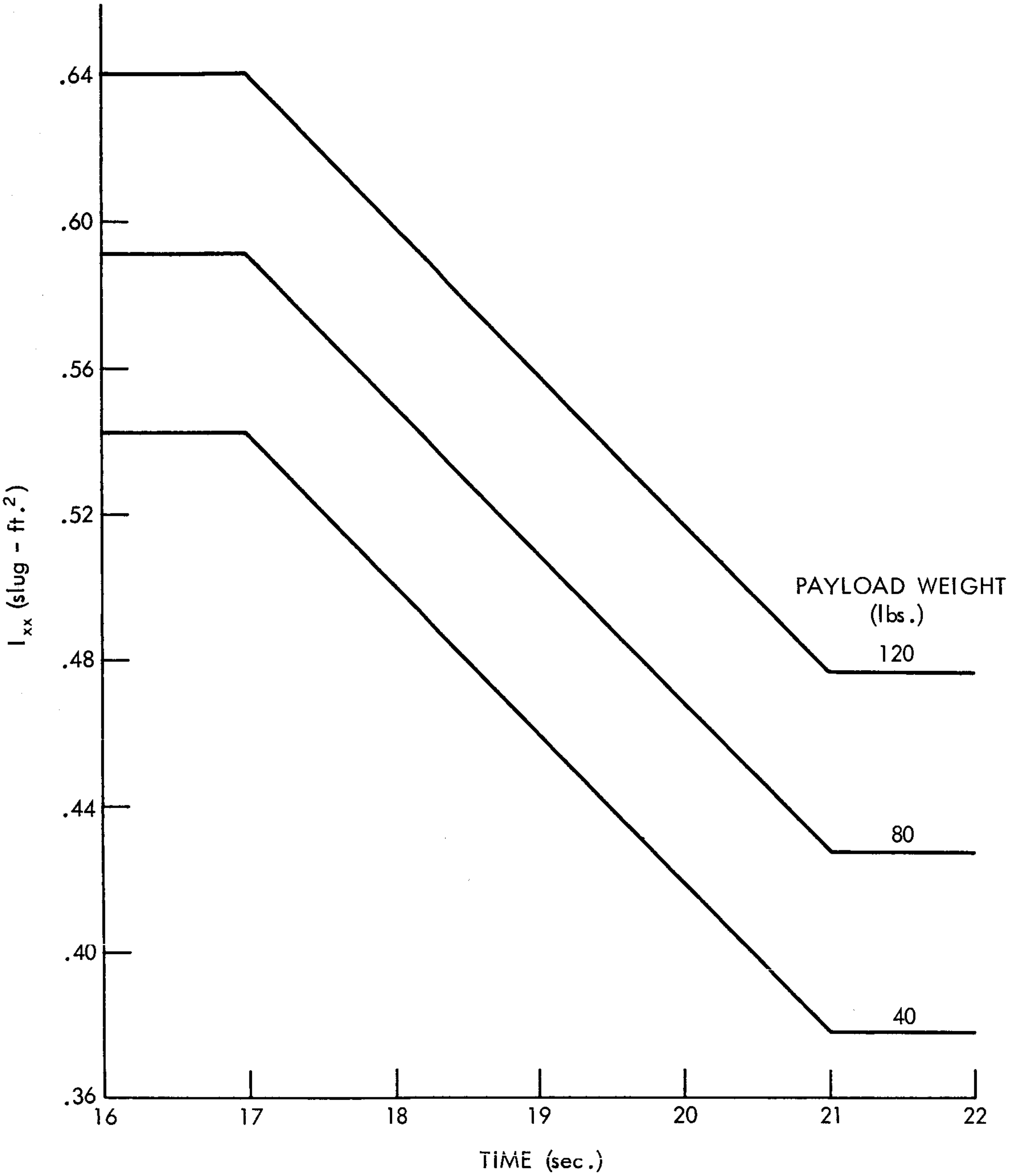


Figure 13. Effect of Payload Weight on Cajun Roll Moment of Inertia

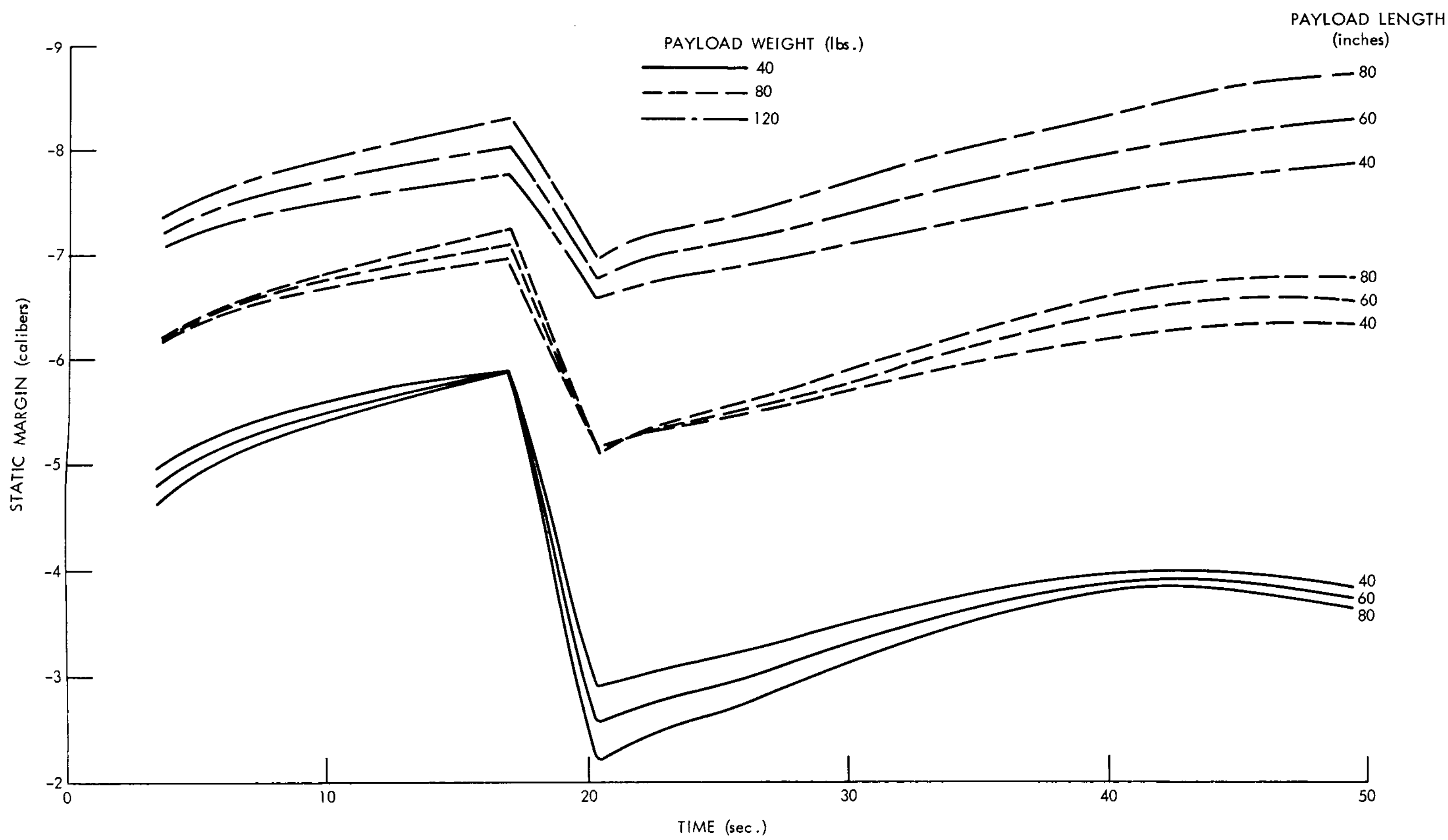


Figure 14. Effects of Payload Weight and Length on the Cajun Static Margin. Wallops Island, Zero Length Launcher, L.A. = 80°

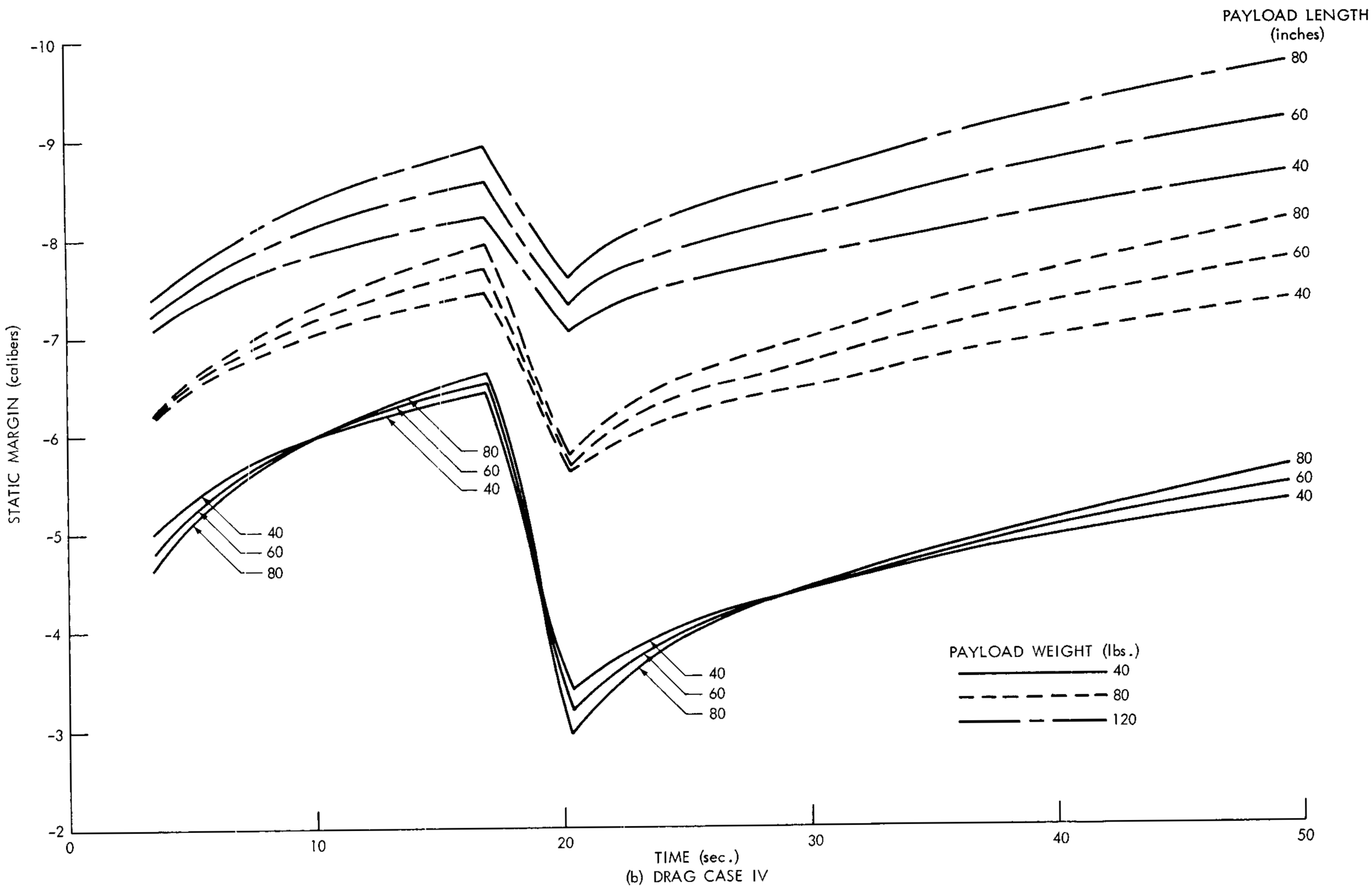
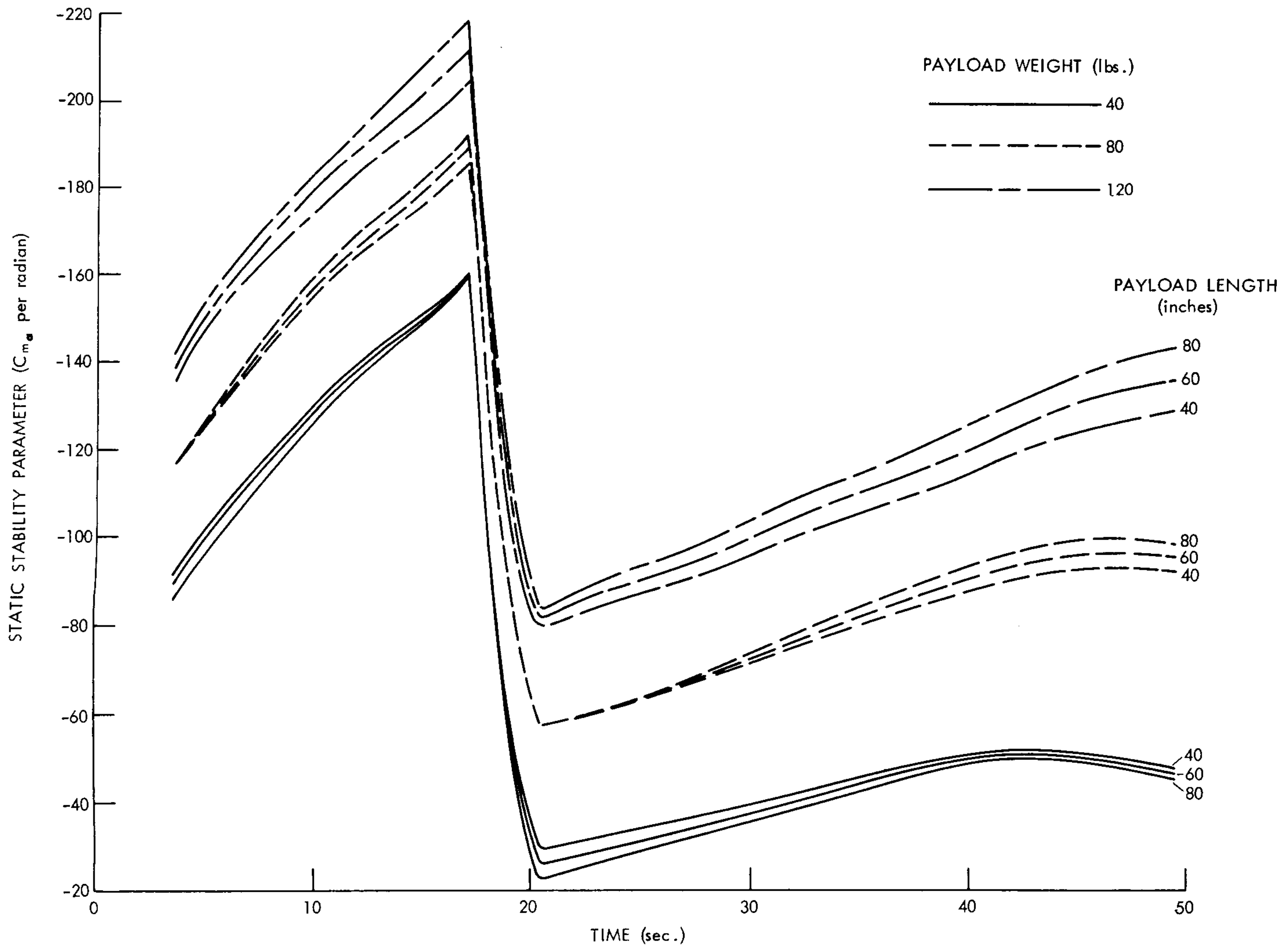
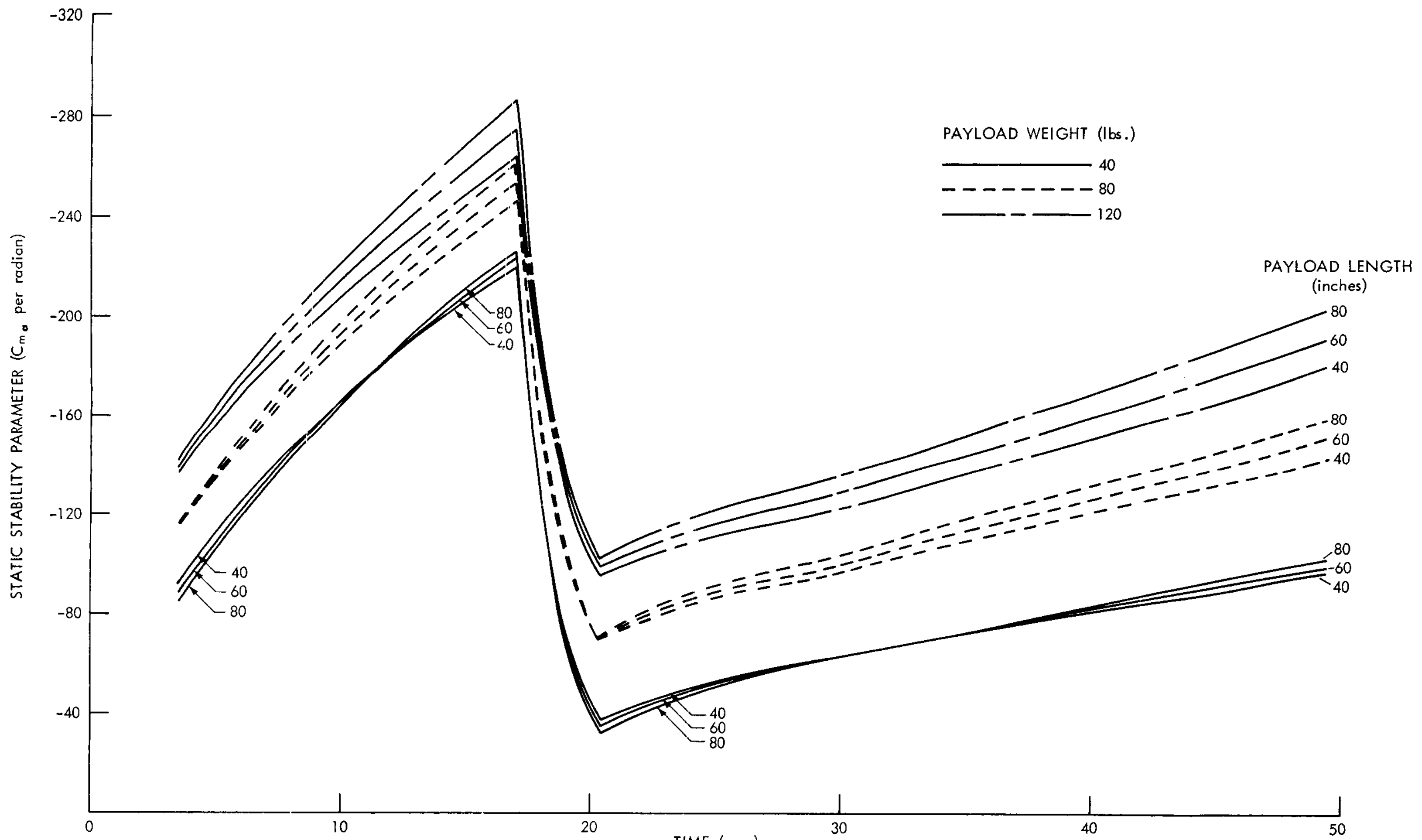


Figure 14. (Concluded)



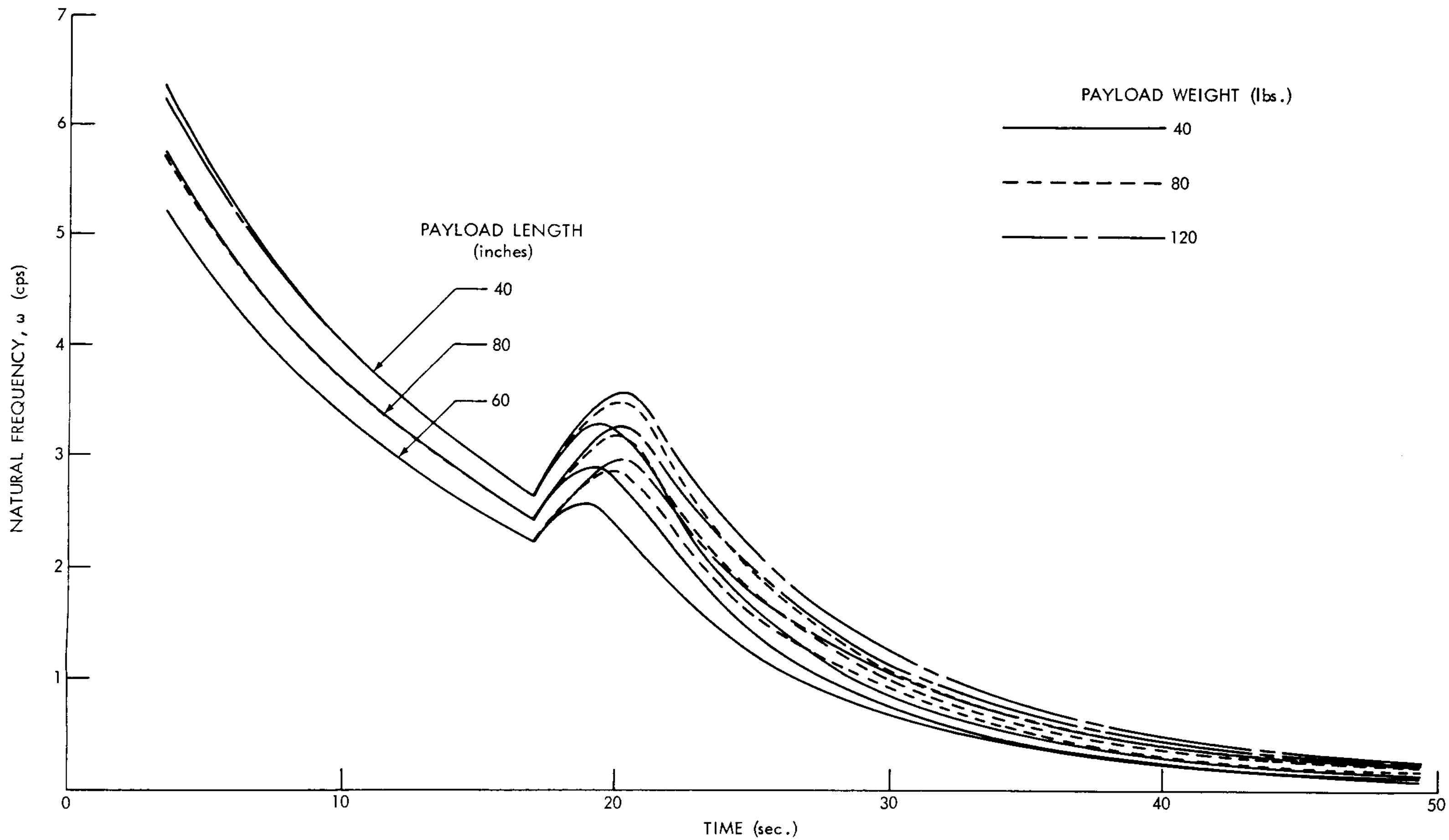
(a) DRAG CASE I

Figure 15. Effects of Payload Weight and Length on the Cajun Static Stability. Wallops Island, Zero Length Launcher, L.A. = 80°



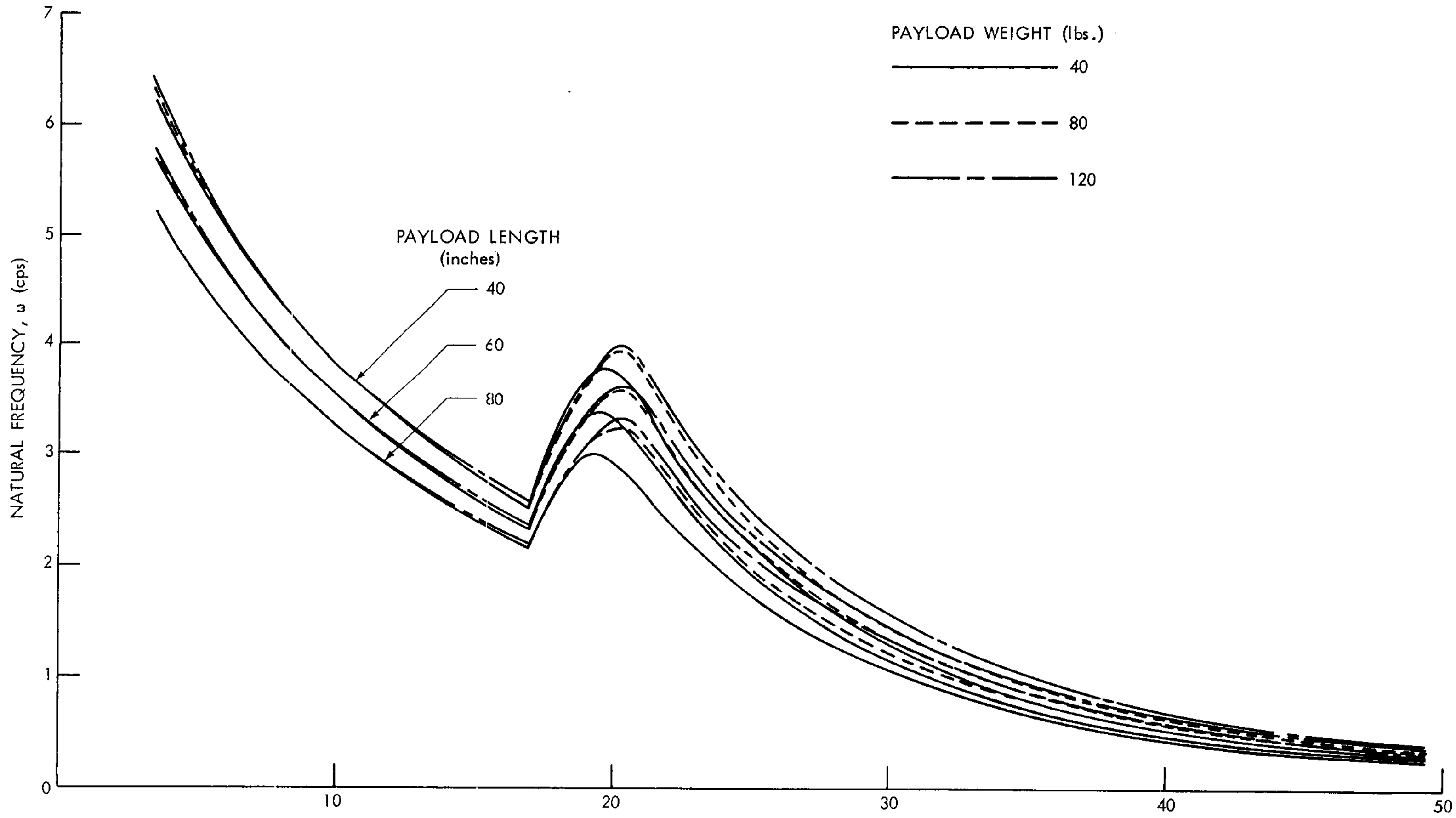
(b) DRAG CASE IV

Figure 15. (Concluded)



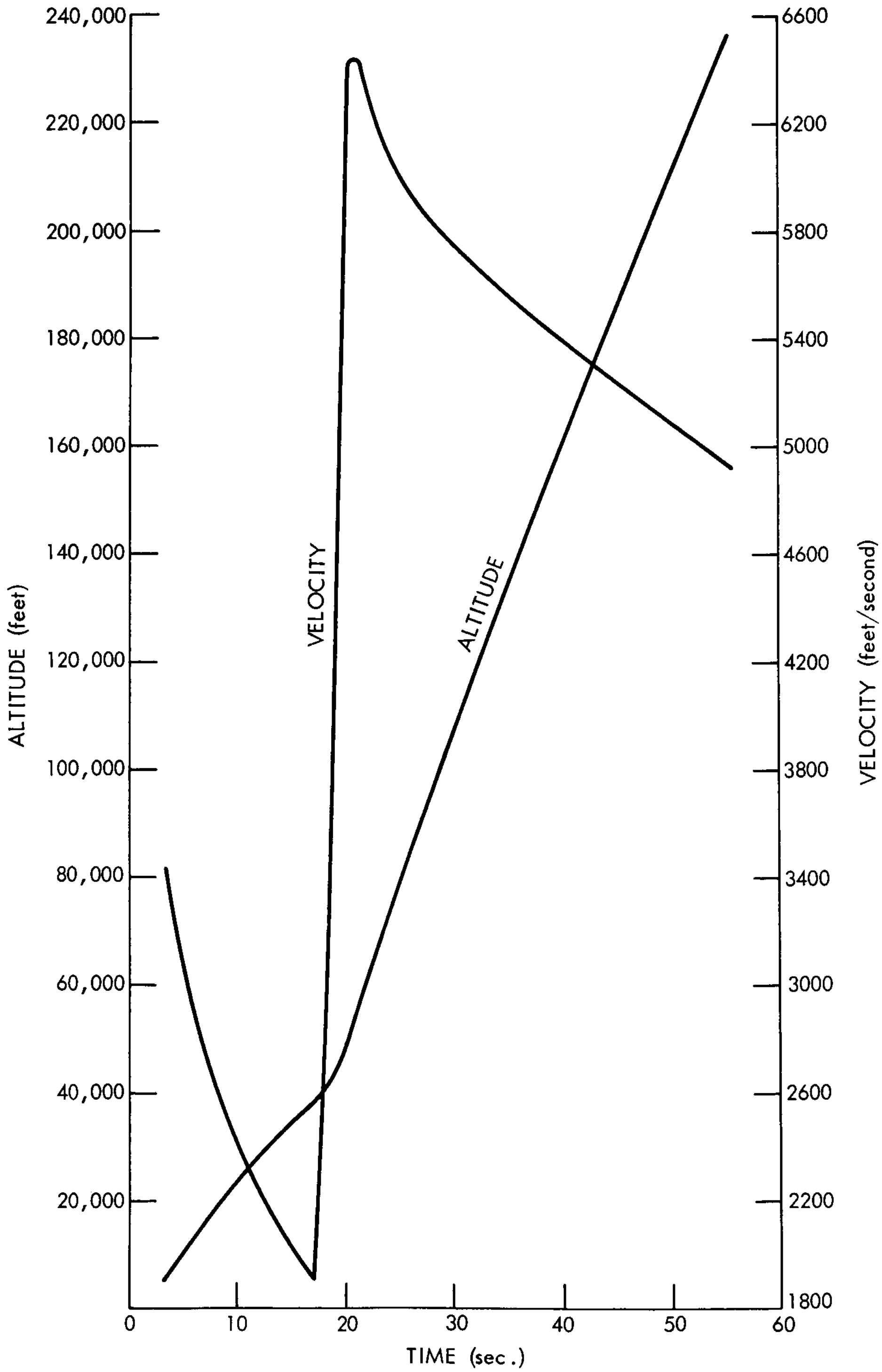
(a) DRAG CASE I

Figure 16. Effects of Payload Weight and Length on the Cajun Natural Frequency. Wallops Island, Zero Length Launcher, L.A. = 80°



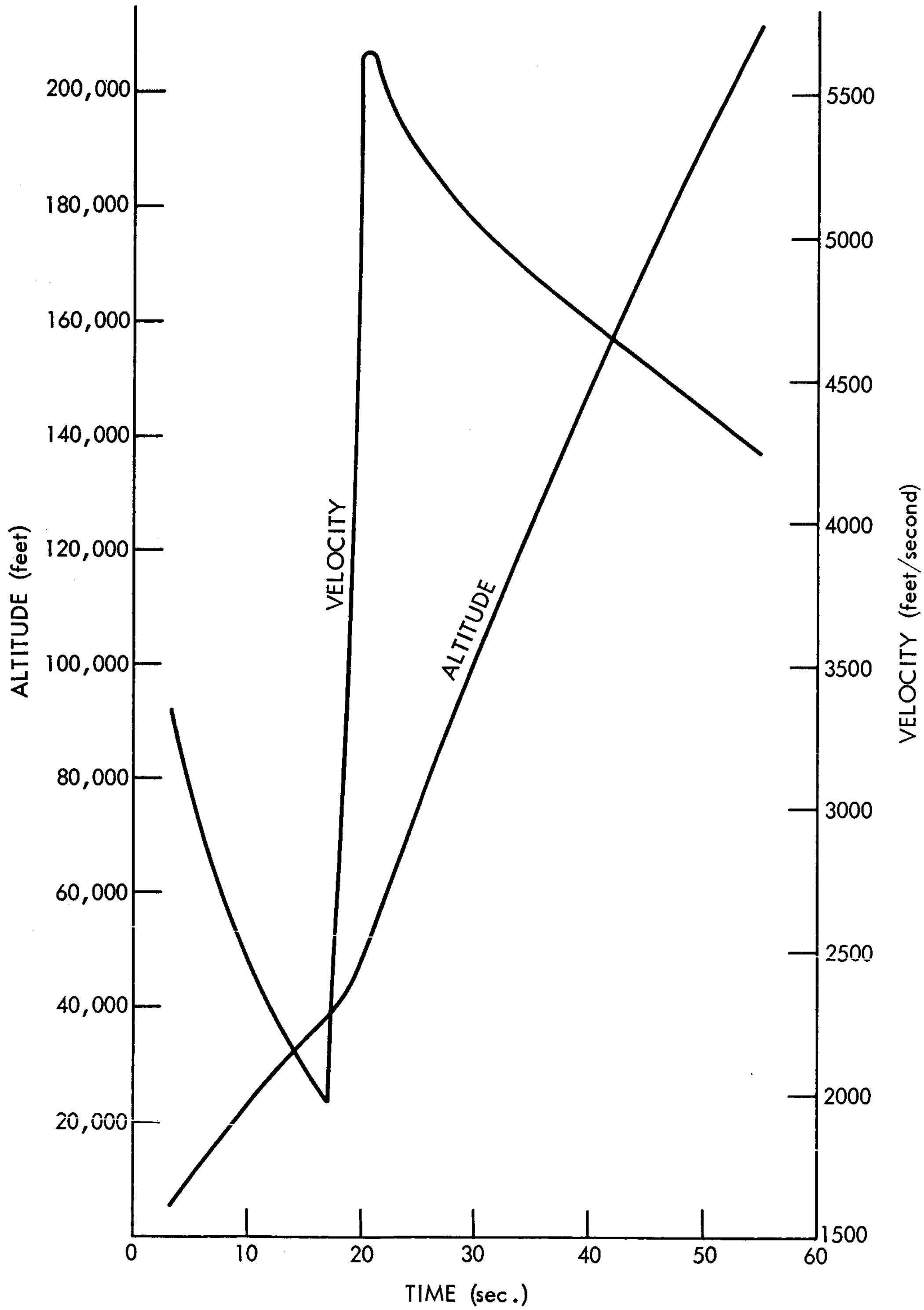
(b) DRAG CASE IV

Figure 16. (Concluded)



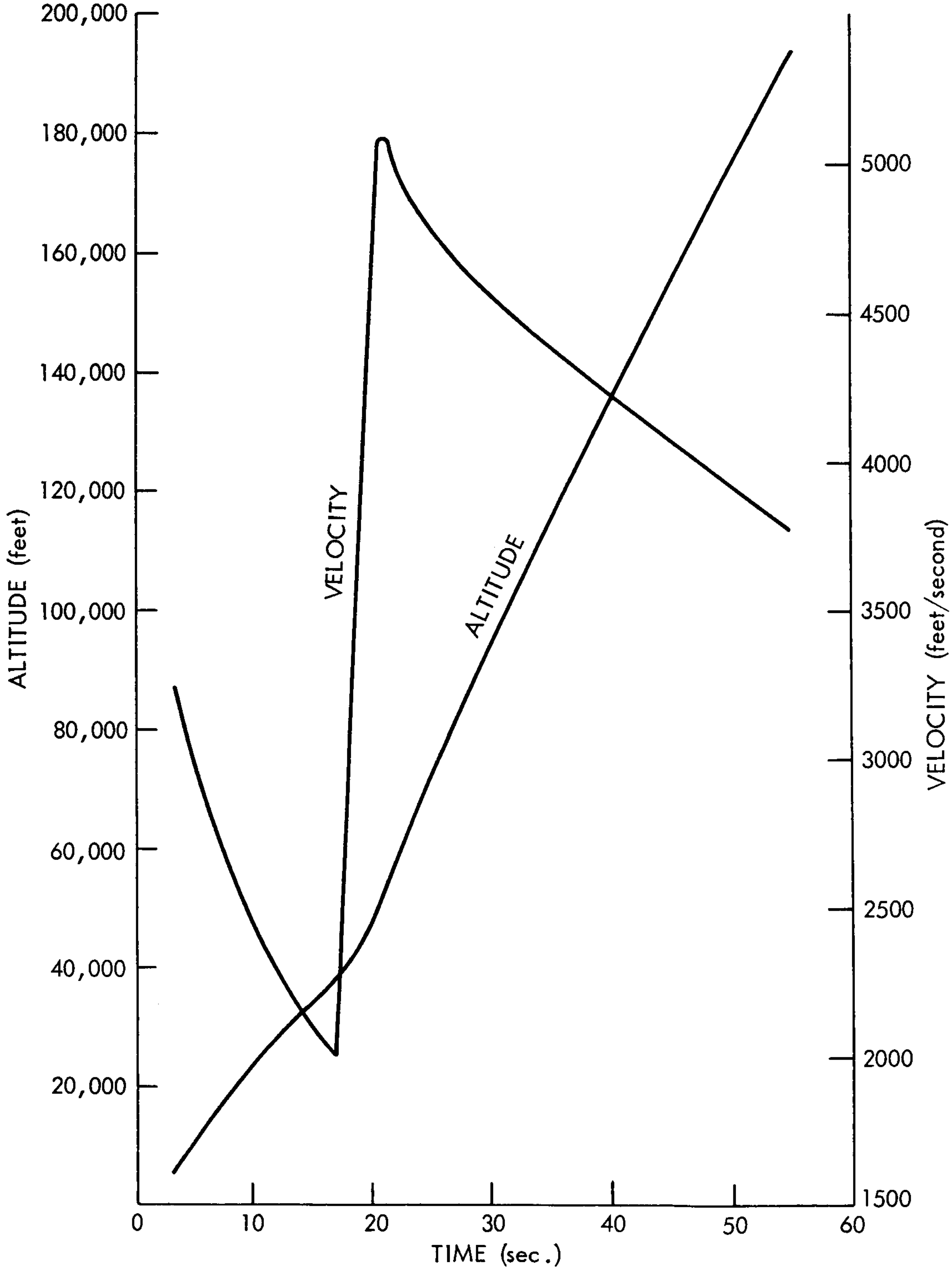
(a) PAYLOAD WEIGHT = 40 LBS.

Figure 17. Cajun Velocity and Altitude Time History. Wallops Island, Zero Length Launcher, L.A. = 80°, Drag Case I



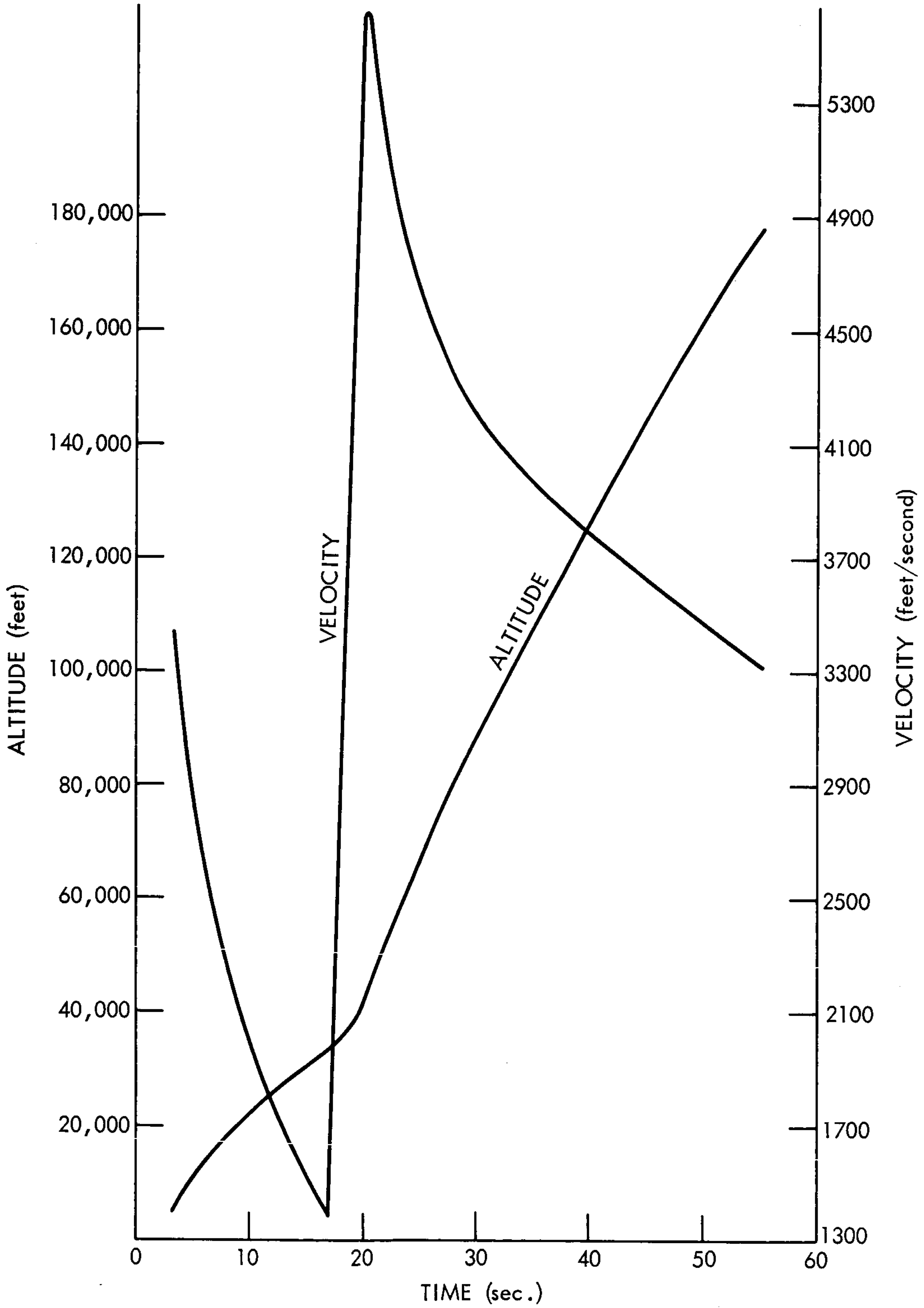
(b) PAYLOAD WEIGHT = 80 LBS.

Figure 17. (Continued)



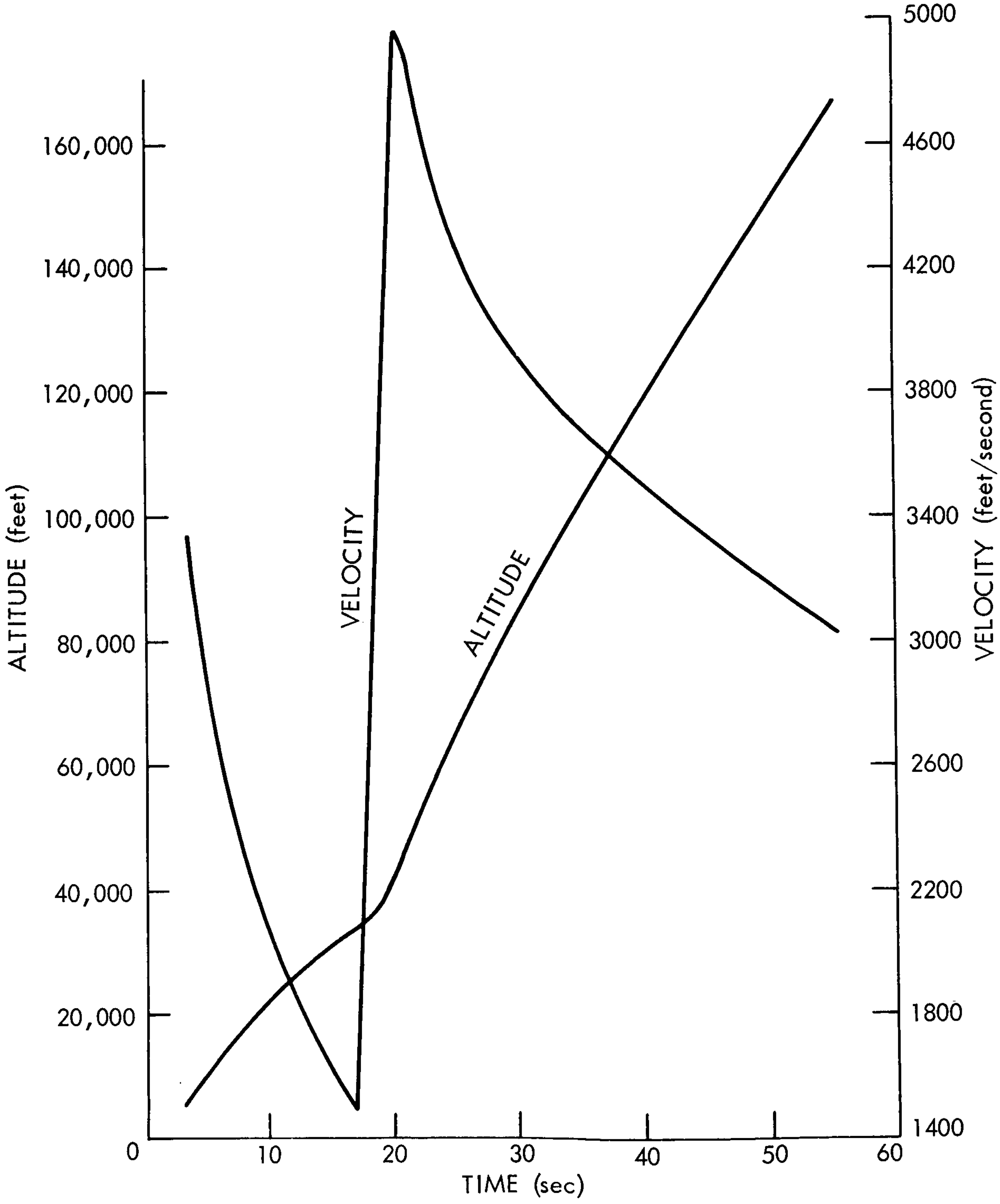
(c) PAYLOAD WEIGHT = 120 LBS.

Figure 17. (Concluded)



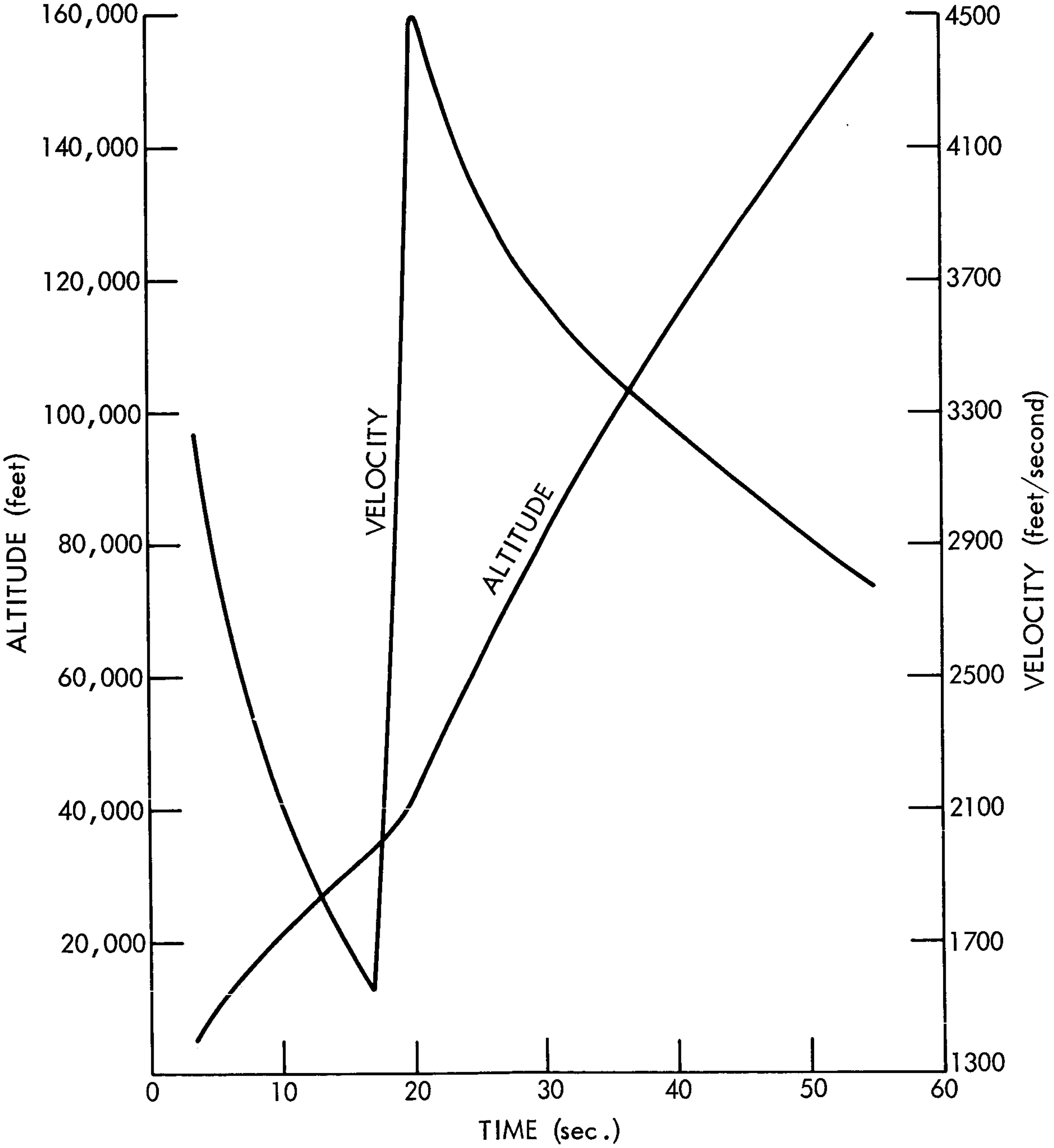
(a) PAYLOAD WEIGHT = 40 LBS.

Figure 18. Cajun Velocity and Altitude Time History. Wallops Island, Zero Length Launcher, L.A. = 80°, Drag Case IV



(b) PAYLOAD WEIGHT = 80 LBS.

Figure 18. (Continued)



(c) PAYLOAD WEIGHT = 120 LBS.

Figure 18. (Concluded)