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THE DYNAMICS OF AN EJECTION SEAT CATAPULT WITH A "LIVE LOAD"

EDWARD G. U. BAND

WYLE LABORATORIES—PAYNE DIVISION

AUGUST 1971

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13. ABSTRACT

This report is aimed towards determining the effects on catapult performance of using it to propel a live load. The report describes how an analytical model is built up using a previously developed lumped parameter representation of the human body and ejection seat together with a simple direct stroking catapult. Using this catapult, which is characterized by a sinusoidal type development of propulsive force, the difference between the live load and an equivalent rigid load is, in fact, rather small. Two seat weights were used to determine whether the damping effect of the rather large original seat mass was important but it did not appear to be so in this case. Finally an initial velocity impulse was simulated which demonstrated that slightly more rapid ejections could be achieved with this method without overloading the spine. The importance of the work described in this report is considered to be rather in the development of the model, which can be used for a wide range of similar problems, than in the results of the small number of problems tested.

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SUMMARY

Previously developed catapult theory and a previously developed dynamic model of the man/seat system are combined in the work described in this report to investigate the interrelationship between the catapult and the ejected crew member. In view of the relatively slow build-up of driving force in the catapult simulated, there are only minor differences between the trajectories of "live" loaded seats and rigid masses. This is true even when the seat mass is reduced to zero. The advantage of using the "live" load model is that it allows the loads and deflections experienced in various parts of the body to be represented. Of particular interest are the spinal loads. Again the oscillation of spinal load is not very significant during a normally slow build up of catapult force. The last case simulated included an initial velocity impulse which resulted in considerable spinal load oscillations, but again showed only small differences between the overall trajectories and catapult forces with live and rigid load cases.

FOREWORD

The research covered in this report was performed in partial fulfillment of Contract No. F33615-70-C-1420, by the Payne Division of Wyle Laboratories, between March 1, 1970 and April 15, 1971.

The Air Force Program Monitor for this contract was Mr. James W. Brinkley of the Impact Branch, Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory, Aerospace Medical Division of the U. S. Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

This technical report has been reviewed and is approved.

CLINTON L. HOLT, Colonel, USAF, MC
Commander
Aerospace Medical Research Laboratory

LIST OF SYMBOLS

A_G	Propellant grain burning area
A_P	Catapult piston area
ATR	Arctangent-of-a-ratio block in analog program listing
a	Coefficient of p^n in burning rate Equation 13b
B	Bang-bang block in analog program listing
b	Coefficient of p in burning rate Equation 13a
C	Cosine block in analog program listing
C_P	Coefficient of heat at constant pressure
c	Coefficient of $\dot{p}$ in burning rate Equations 13a, 13b
D_A	Aerodynamic drag force
E	Total energy released by burning propellant
$\dot{E}$	Rate of propellant energy release
E_o	Value of E when $t = 0$
F_C	Catapult force
F_D	Total force on drogue stabilizer
F_R	Rocket force
F_{x_i}	Total force of spring and damper unit i in x direction
F_{z_j}	Total force of spring and damper unit j in z direction
G	Gain block in analog program listing
g	Acceleration due to gravity
I	Integration block in analog program listing
K	Constant block in analog program listing
L_A	Aerodynamic lift force
M	Magnitude block in analog program listing
M_A	Aerodynamic pitching moment
m	Mass of gas in catapult chamber
m_o	Initial mass of gas at time $t = 0$
m_i	Mass of component i

LIST OF SYMBOLS (Continued)

n	Exponent of p in burning rate Equation 13b
o	Offset block in analog program listing
P	Positive clipper block in analog program listing
p	Absolute pressure in catapult chamber
p_o	Value of p at time t = 0
q_s	Angular pitch rate of seat and occupant
Q	Combustion energy released by catapult fuel per unit mass
R	Relay block in analog program listing
r	Fuel burning rate (velocity)
S	Sine block in analog program listing
$S1$	Special block in analog program listing (Computes $U_s = u_s \cos\theta_s + w_s \sin\theta_s$)
$S2$	Special block in analog program listing (Computes $W_s = w_s \cos\theta_s - u_s \sin\theta_s$)
T	Temperature of gas in catapult chamber
T_o	Value of T at time t = 0
t	Time from initiation of catapult firing
U	Unit delay block in analog program listing
U_s	Velocity of seat in X direction
u	Velocity in x direction
V	Volume in catapult chamber
V_o	Value of V when t = 0
W	Weighted summer block in analog program listing
W_s	Velocity of seat in Z direction
w_i	Velocity in z direction of component i
X	Multiplier block in analog program listing
X_s	Coordinate of seat origin in space axes
x_i	Coordinate of component i in seat axes
y_c	Stroke of catapult
$\dot{y}_c$	Catapult valocity ($= -w_s$)
Z_s	Coordinate of seat origin in space axes

LIST OF SYMBOLS (Concluded)

z_i	Coordinate of component i in seat axes
α	Efficiency of catapult combustion
β	Angle between rocket thrust line and x seat axis
γ	Ratio of specific heats of gas in catapult chamber
θ_s	Angular orientation of seat axes in space
ϕ	Angle between resultant seat velocity vector at system cg and seat x axis
ϕ'	Angle between resultant velocity vector at drogue location and seat x axis
ρ	Density of gas in catapult chamber
ρ_o	Value of ρ when $t = 0$
+	Sum block in analog program listing
/	Divide block in analog program listing
**	Power block in analog program listing

SECTION I

INTRODUCTION

A considerable amount of work has been conducted in developing a dynamic representation of the human body in an ejection seat (references 1 and 2) and also, at Frankford Arsenal, a careful analysis has been completed of the dynamics of solid fuel catapults (reference 3). The purpose of the work described in this report is to investigate the interrelationship of the catapult and the human seat occupant. The motion of the seat affects the burning rate, the build up of pressures, loads and acceleration in the catapult. Therefore, the substitution of a dynamic load for the rigid driven mass assumed in reference 3, will affect the performance of the catapult itself.

This study was conducted by adapting the eleven-degree-of-freedom dynamic model of a rocket powered free flight man/seat system developed in reference 2. The catapult phase of the ejection was inserted prior to the rocket propelled free flight phase, so that the whole ejection sequence is now modelled as far as the man/seat separation and parachute opening stages. These could, of course, be incorporated at a later date.

SECTION II

ANALYSIS OF CATAPULT/MAN/SEAT PERFORMANCE

Catapult Performance

A simplified direct stroking catapult is represented in figure 1. The methodology described below can readily be adapted to represent the more realistic catapult configuration described in reference 2, but in view of the exploratory nature of this study, the extra complication was not considered to be justified.

If r is the burning rate of the catapult grain (with the dimensions of a velocity), the mass rate of burning is

$$\dot{m} = A_G \rho_G r \qquad (1)$$

where A_G = burning area
ρ_G = grain density

The total mass of gas in the catapult, assuming no leakage or venting, is

$$m = \int_o^t A_G \rho_G r \, dt + m_o \qquad (2)$$

where m_o = initial mass of gas in initial free volume

If Q is taken as the energy released by burning a unit mass of the grain, the rate of energy release by the catapult fuel may be written as

$$\dot{E} = Q A_G \rho_G r \qquad (3)$$

and the total energy released is given by

$$E = \int_o^t Q A_G \rho_G r \, dt + E_o \qquad (4)$$

$$E = E_o = \int_o^t Q A_G \rho_G r \, dt \qquad (4a)$$

where E_o = energy contained by gas in initial free volume.

The total volume available for the gas is

$$V = A_P y_o + \int_o^t A_G r \, dt + V_o \qquad (5)$$

where $A_P y_o$ = Volume created by motion of the piston;

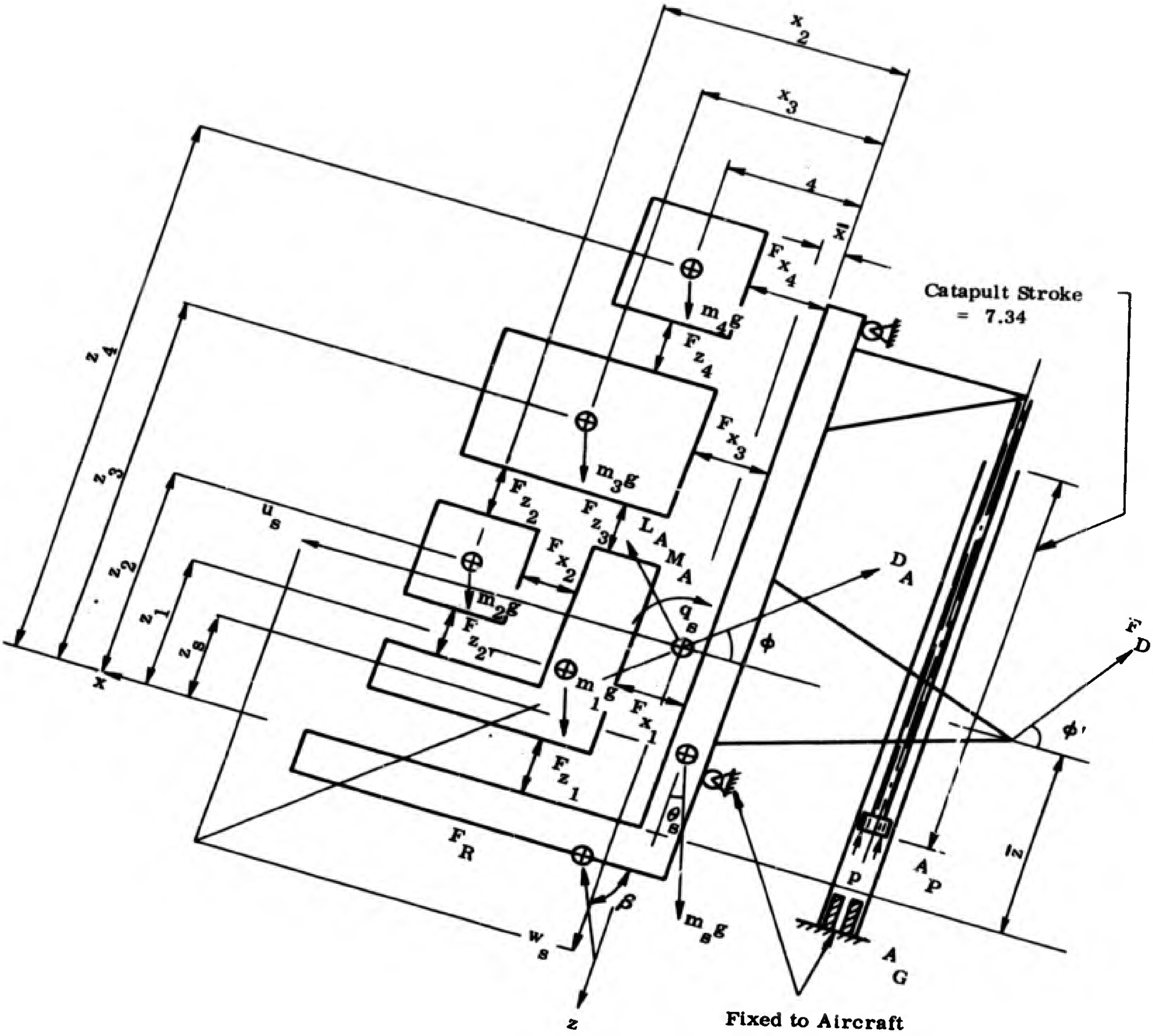


Figure 1. Dynamic Model of a Direct Stroking Catapult, Escape Seat and Seat Occupant

$\int_0^t A_G r\, dt$ = Volume created by burning of the grain;

and V_o = Initial free volume

The density of the gas is therefore

$$\rho = m/V = \frac{\int_0^t A_G \rho_G r\, dt + m_o}{A_P y_o + V_o + \int_0^t A_G r\, dt} \tag{6}$$

and the initial density ρ_o occuring at time t = 0 is given by

$$\rho_o = m_o/V_o$$

If T is the gas temperature, and R is the gas constant, the pressure is

$$p = \rho RT = \frac{RT\left[\int_0^t A_G \rho_G r\, dt + m_o\right]}{A_P y_o + V_o + \int_0^t A_G r\, dt} \tag{7}$$

and the initial pressure is given by

$$p_o = \rho_o RT_o = RT_o(m_o/V_o)$$

To determine the temperature of the gas, an energy balance is required. The energy released by the burning grain may appear as thermal energy in the gas, thermal energy absorbed by the catapult structure, or thermal and mechanical energy absorbed by the load. The first law of thermodynamics requires that

$$E = mC_pT + A_P \int_0^{y_c} p\, dt_c + E' \tag{8}$$

and initially

$$E_o = m_oC_pT_o$$

where E = Total energy:

mC_pT_o = Gaseous energy

$A_P \int_0^{y_c} p\, dy_c$ = Mechanical energy delivered to the piston

E' = Energy losses by conduction, etc.

The efficiency of the catapult may therefore be defined as

$$\alpha = \frac{mC_pT + A_P\int_o^{y_o} p\, dy_c - E_o}{E - E_o} \qquad (9)$$

Rearrangement of equation 9 yields

$$C_pT = \frac{\alpha(E - E_o) - A_P\int_o^{y_c} pdy_c}{m} + \frac{E_o}{m} \qquad (10)$$

Since $C_p = (\gamma/\gamma - 1)R$

$$RT = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{\alpha(E - E_o) - A_P\int_o^{y_c} p\, dy_c}{m} + \frac{E_o}{m}\right)$$

and

$$RT_o = (\gamma - 1/\gamma)(E_o/m)$$

Substituting for $(E - E_o)$ from equation 4a and for m from equation 2

$$RT = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{\alpha\int_o^t QA_G\rho_G r\, dt - A_P\int_o^{y_c} p\, d\, y_c}{\left[\int_o^t A_G\rho_G r\, dt + m_o\right]}\right) + RT_o(m_o/m) \qquad (11)$$

Combining with equation 7 yields

$$p = \frac{(\gamma - 1/\gamma)\,(\alpha\int_o^t QA_G\,{}_G r\, dt - A_P \quad p\, dy_c) + RT_om_o}{A_Py_c + V_o + \int_o^t A_G r\, dt} \qquad (12)$$

$$\rho_o = RT_om_o/V_o = RT_o\rho_o$$

There are two empirical approximations in general use for the burning rate

$$r = a + bp + c\dot{p} \qquad (13a)$$

$$r = ap^n + c\dot{p} \qquad (13b)$$

also

$$dy_c = dy_c/dt(dt) = \dot{y}_c\, dt$$

and

$$RT_om_o = p_oV_o$$

Substituting these into equation 12 yields

$$p = \frac{(\gamma - 1/\gamma)[\alpha\int_o^t Q A_G \rho_G (a + bp + c\dot{p})\, dt - A_P \int_o^t p\, y_c\, dt] + p_o V_o}{[A_p y_c + V_o + \int_o^t A_G (a + bp + c\dot{p})\, dt]} \qquad (14a)$$

or

$$p = \frac{(\gamma - 1/\gamma)[\alpha\int_o^t Q A_G \rho_G (ap^n + c\dot{p})\, dt - A_P \int_o^t p\, \dot{y}_c\, dt] + p_o V_o}{[A_P y_c + V_o + \int_o^t A_G (ap^n + c\dot{p})\, dt]} \qquad (14b)$$

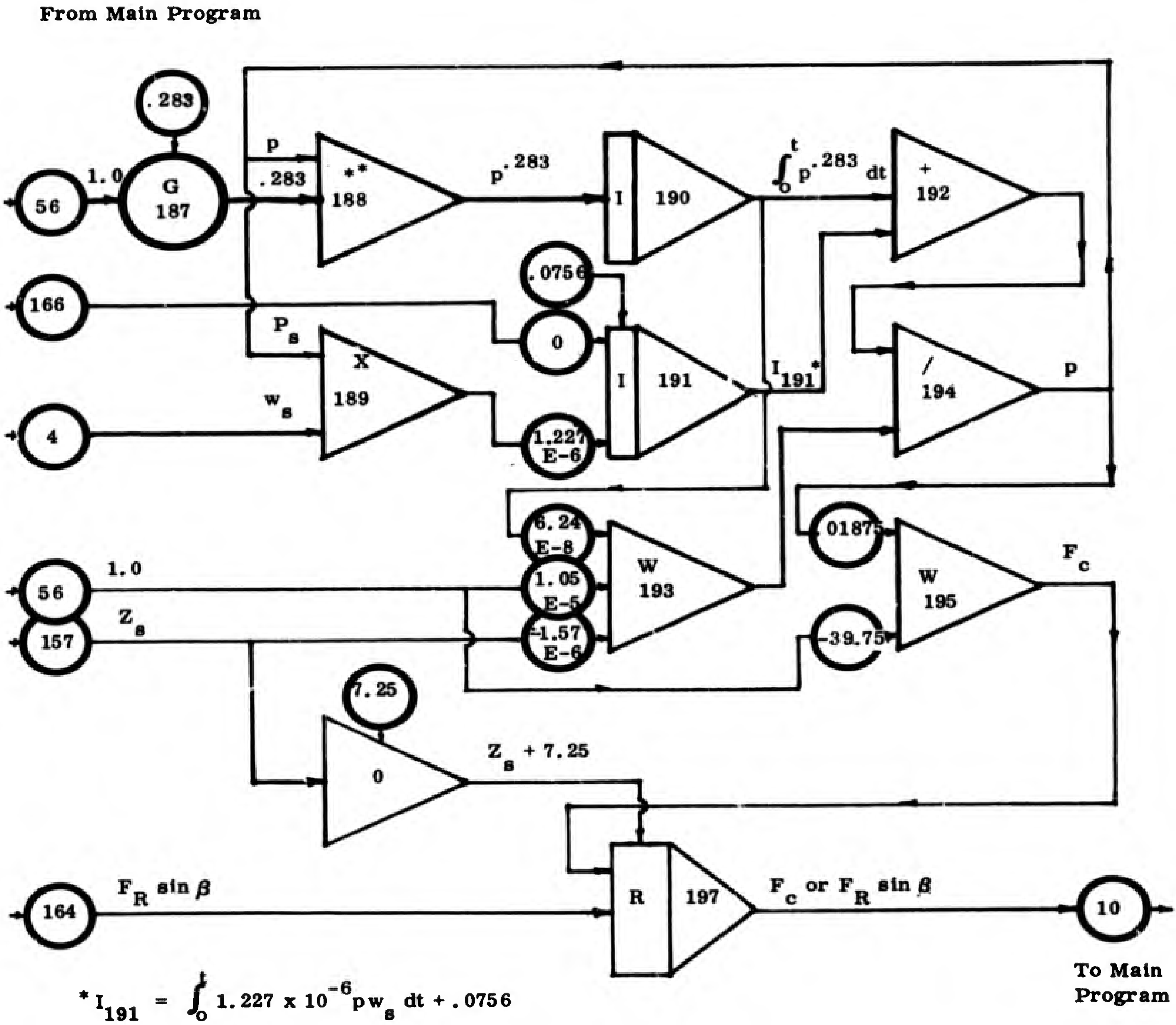
In order to incorporate this catapult force into the ejection seat model program (BAND5 in reference 2), the additional analog units shown in figure 2 are required.

The relay at the bottom of figure 2 allows the free flight rocket force to be substituted for the stroking catapult force when the catapult reaches the end of its stroke. Other relays are incorporated to restrain the seat to move along rails parallel to the seat back until the end of the catapult stroke.

Numerical Solution of Equation 14b

Substituting values from reference 3 in equation 14b, we have

$r = .039p^{.283}$ for r in in/sec units and p in lb/in^2
$ = 7.96 \times 10^{-4} p^{.283}$ for r in ft/sec units and p in lb/ft^2
$\gamma = 1.26$
$\alpha = .66$
$Q = 3.1 \times 10^5$ ft lb/lb $= 10^7$ ft lb/slug
$A_G = 136.5$ in^2 $= .949$ ft^2
$\rho_G = .057$ lb/in^3 $= 3.06$ slug/ft^3
p is given by equation 14b - lb/ft^2
$A_P = 2.7$ in^2 $= .01875$ ft^2
$y_c = Z_s/\cos 10^o$ $= -1.015\, Z_s$ ft
$\dot{y} =$ $= -w_s$ ft/sec
$V_o = 220$ in^3 $= 0.1273$ ft^3



$$*I_{191} = \int_0^t 1.227 \times 10^{-6} p w_s \, dt + .0756$$

Figure 2. Analog Representation of Equation 14b.

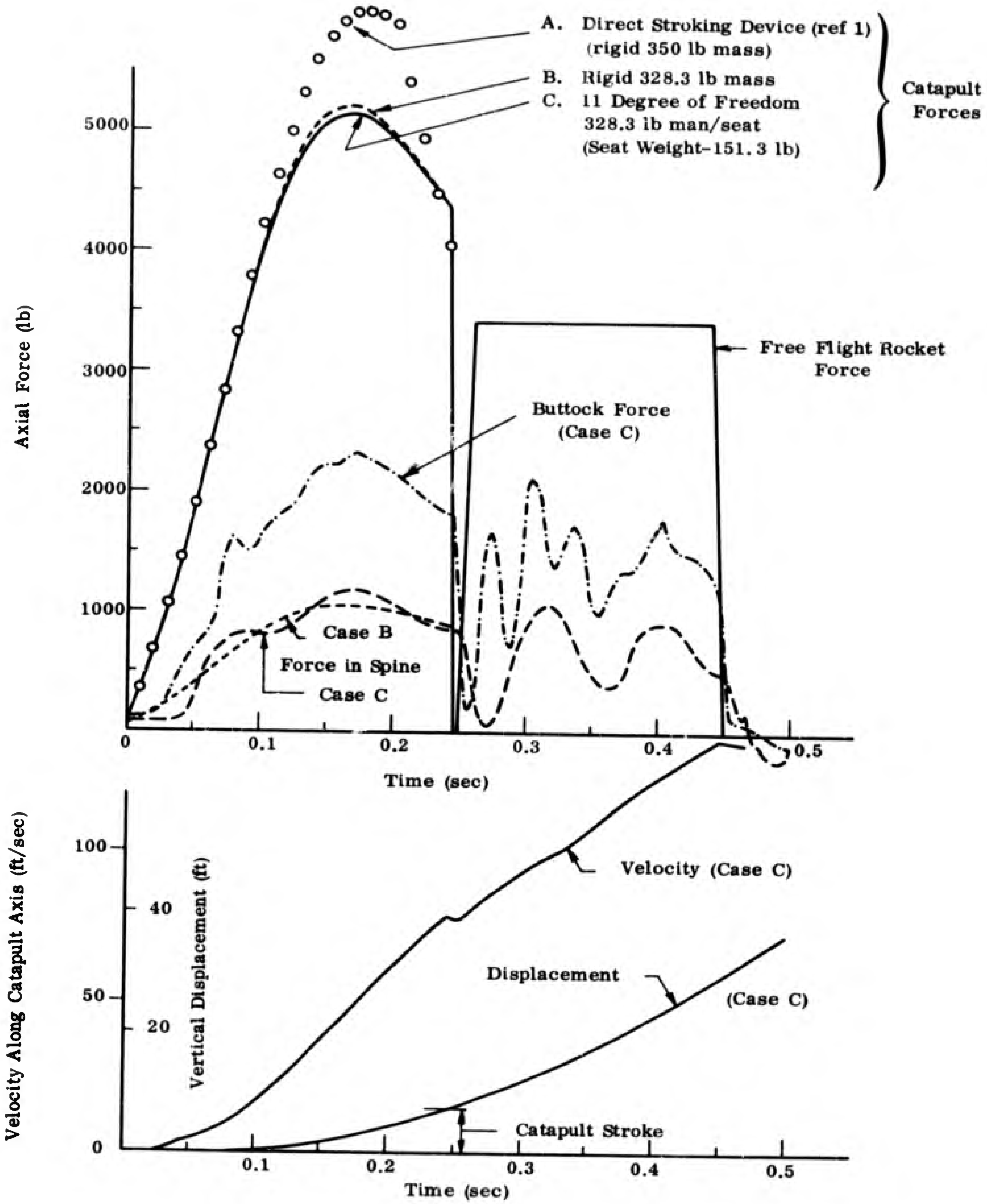


Figure 3. Characteristics of Catapult/Rocket Ejection of Man/Seat Combination

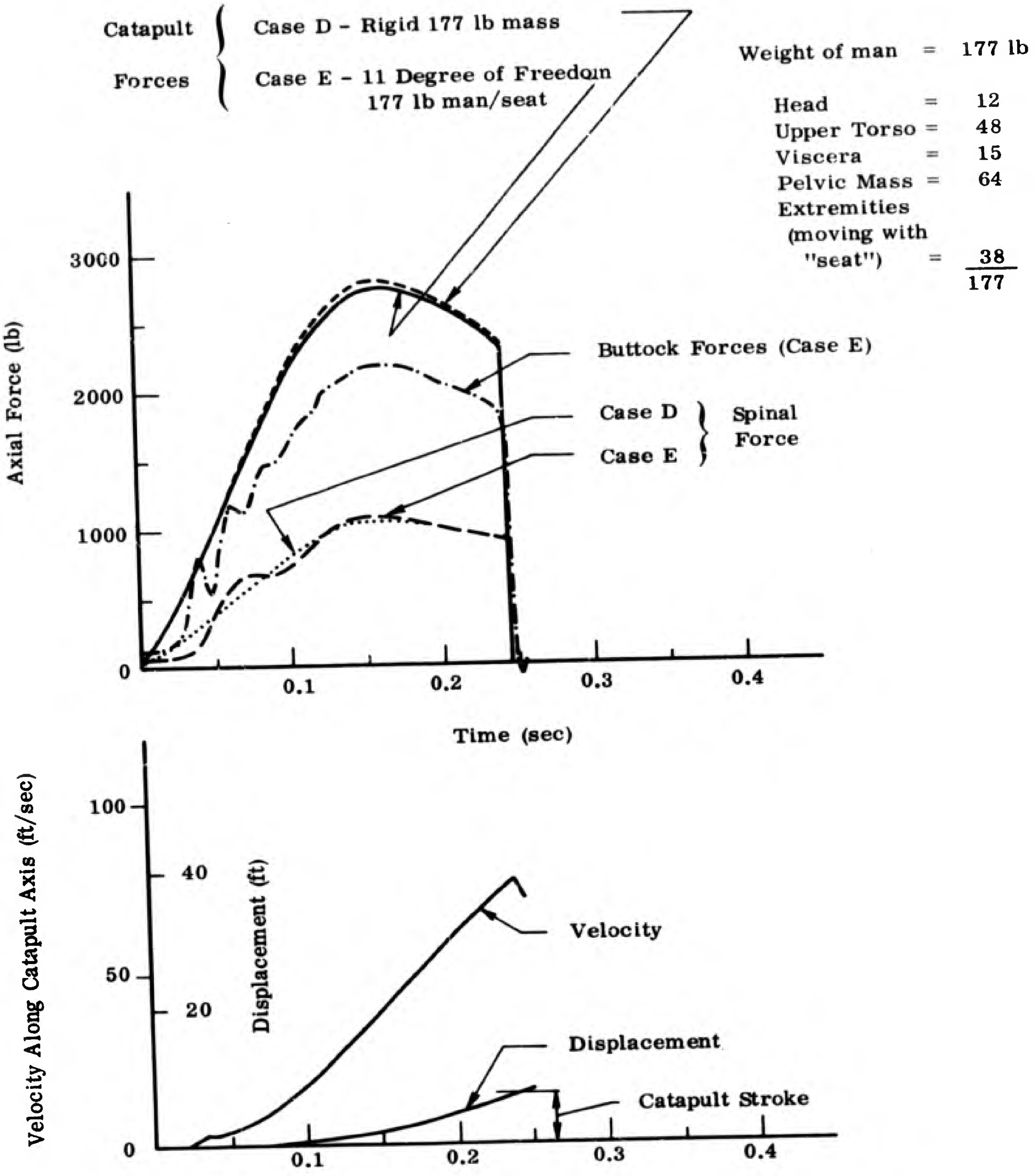


Figure 4. Characteristics of Catapult Ejection of Man Only (with zero weight seat)

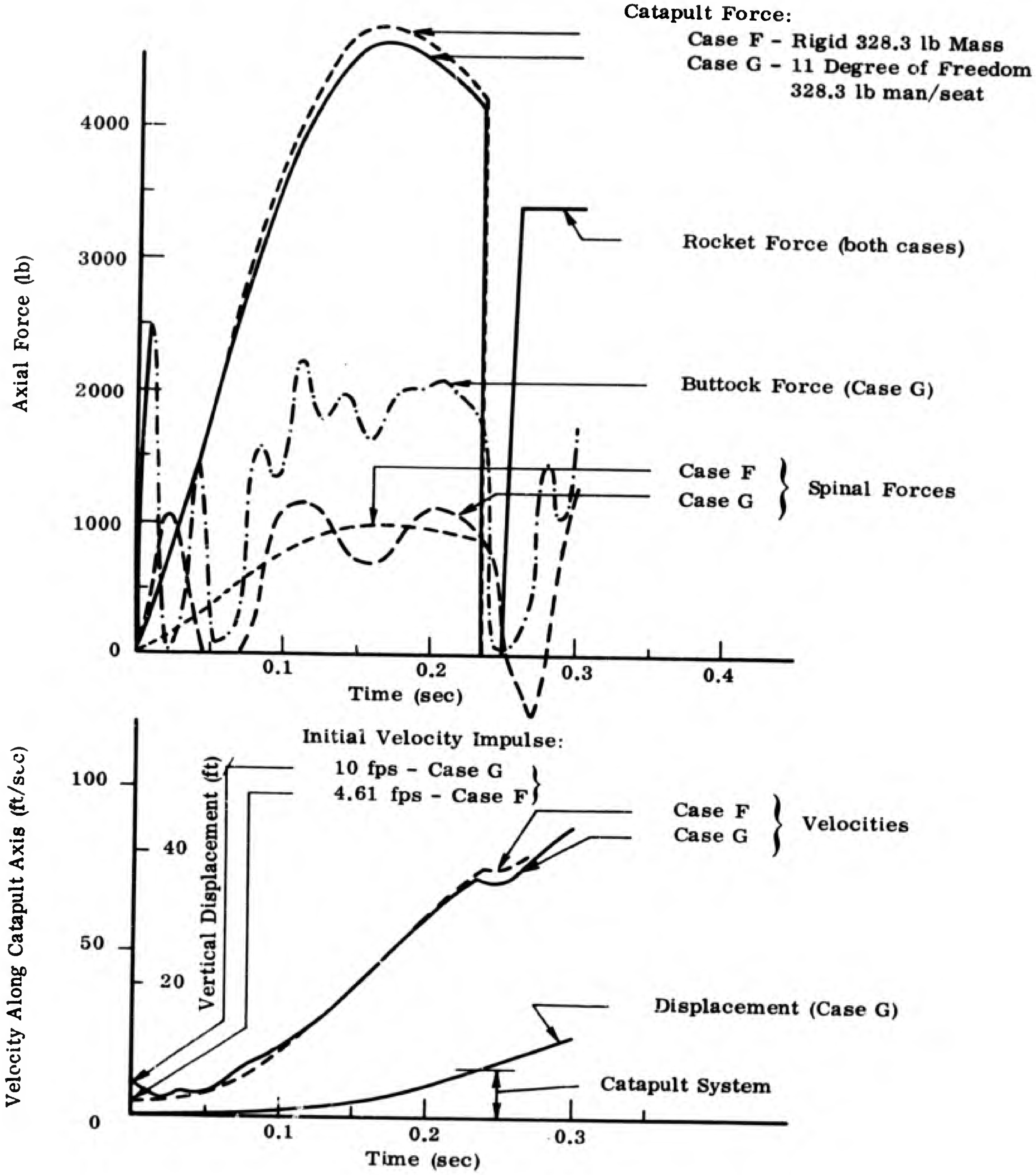


Figure 5. Characteristics of Catapult Ejection of Man/Seat System with Initial Velocity Impulse

$p_o = 50 \text{ lb/in}^2 \qquad = 7200 \text{ lb/ft}^2$

$c = 0$

$a = 7.96 \times 10^{-4}$

$n = .283$

Thus

$$p = \frac{\int_0^t p^{.283}\,dt + 1.227 \times 10^{-6} \int_0^t p w_s \,dt + .0756}{-1.51 \times 10^{-6} Z_s + 1.05 \times 10^{-5} + 6.24 \times 10^{-8} \int_0^t p^{.283}\,dt}$$

Computed Trajectories

The combined catapult/rocket/man/ejection seat model program is listed in the appendix. A continuous system modelling program (CSMP) representation was used which employs a digital simulation of an analog circuit. This system is extremely simple to program, run and modify. The results of these cases are shown in figures 3, 4, and 5.

The catapult used in all of these cases was based on a solid propellant stroking device used by L. A. DeStefano of Frankford Arsenal in his program F003E. The performance of this catapult when driving a 350 lb rigid mass is shown as curve A in figure 3. Some minor differences in the magnitude of the mass in the burning rate representation and the absence of the air drag term in DeStefano's calculation account for the relatively small differences between this curve A and curves B and C which were obtained using the CSMP program. The catapult force rises smoothly to a peak after about .17 seconds and falls off as the piston velocity increases. When the catapult strokes out at 7.34 feet, the propulsive force falls to zero and picks up again as the rocket ignites. The sharp separation between the catapult and rocket forces is rather artificial but was left in this form to differentiate clearly between the two modes. As the seat leaves the rails, it picks up extra degrees of freedom in the fore and aft plane and in pitch.

Comparison of Rigid Mass and Dynamically Loaded Seat

Figure 3 compares the time histories of the ejection of the eleven degree of freedom man/seat model with that of a rigid mass of the same total weight. The catapult force is very slightly higher for the case of the rigid mass and the spinal force, in the dynamic case, oscillates about the rigid case curve. The difference in dynamic reaction to the smoothly increasing catapult force and the abruptly rising rocket force is very marked. In the case of the rocket force, the buttock and spinal forces both osciliate severely so that maxima well above the mean values are obtained.

Effect of "Zero Weight" Seat

In figure 4, an hypothetical zero mass seat was used to determine whether the absence of the large seat mass of cases B and C would cause any larger difference between the rigid and dynamic cases. Again the difference between the two cases is remarkably small for the catapult phase.

Effect of Initial Velocity Impulse

Figure 5 depicts a case in which an initial velocity impulse was applied to the rigidly and dynamically loaded seats. A very slightly more rapid ejection is achieved in this way without loading the spine more than in the previous cases, although the spinal load curve has three pronounced peaks rather than the single peak of case B.

SECTION III

CONCLUSIONS

The simple set of cases run in this study show that, in effect, there is very little difference between the performance of "live" and rigidly loaded catapult ejection seats. There are, of course, differences in the internal forces of the system such as in the spine and the buttocks but for loads which are as smoothly applied as those of the catapult used in this study, even these differences are not very significant. The absence of the seat itself does not alter the situation appreciably.

The use of an initial velocity impulse which could be applied by allowing the catapult to acquire velocity prior to striking the seat, may cause a slightly more rapid ejection without overloading the spine beyond the loads attained in the no-impulse case.

The combined model assembled in this study represents the eleven-degree-of-freedom man/seat system with its propulsion and stabilization system during the catapult, rocket-powered and free-flight phases of an ejection sequence. The utility of this model is clearly established, even by its application to the relatively simple cases described here. It is believed to be a tool that will be of increasing value to the study of the ejection seat problem.

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APPENDIX

LIST OF CATAPULT/ROCKET DYNAMIC PROGRAM

Program BAND 25 (Case C)
Developed For Tymshare CSMP System
(Continuous System Modelling Program)

```
BLØCK TYPE INPUT1  INPUT2  INPUT3
   56   K      0       0       0
  166   K      0       0       0
    3   X      5       2       0
    4   P    153       0       0
    5   I    199       0       0
   24   -      5       0       0
    1   X     24       4       0
   23   X     28      24       0
   27   X     25       5       0
   33   X     36      24       0
   35   X     34       5       0
   38   G    199       0       0
   39   X     42      24       0
   41   X     40       5       0
   48   G    199       0       0
   50   X     53      24       0
   52   X     51       5       0
   54   G    199       0       0
   55   ATR    4       2       0
   57   W     55      56       0
   58   S     57       0       0
   59   W     58      56       0
   60   X      4       4       0
   61   X      2       2       0
   62   W     60      61       0
   63   X     59      62       0
   64   W     55      56       0
   65   S     64       0       0
   66   G     65       0       0
   67   X     62      66       0
   68   W     55      56       0
   69   C     68       0       0
   70   W     69      56      55
   71   X     70      62       0
   72   W     28       4       0
   73   I    166      72       0
   82   W     42      28       0
   83   I    166      82       0
   84   M     83       0       0
   85   X     84      83       0
   87   X     83      83       0
   88   X     83      87       0
   86   W     83      85      88
   89   B     83       0       0
   90   W     83      89       0
   91   Ø     84       0       0
   92   R     91      90      86
   93   +     92      82       0
   94   W     42      36       0
   95   I    166      94       0
   97   W     36      28       0
   98   I    166      97       0
  100   W     53      42       0
  101   I    166     100       0
  103   B     73       0       0
  104   M     73       0       0
   74   X    104      73       0
   75   X     74      73       0
   76   G     75       0       0
   77   Ø    104       0       0
   78   W     77      56       0
   79   R     77      78      76
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```
  81   X    103    79     0
  80   +     81    72     0
 105   W      2    25     0
 106   I    166   105     0
 108   W     25    34     0
 109   I    166   108     0
 111   W      2    40     0
 112   I    166   111     0
 114   W      2    51     0
 115   I    166   114     0
 117   I      5     0     0
 118   C    117     0     0
 119   S    117     0     0
 120   G    106     0     0
 107   +    120   105     0
 121   G    109     0     0
 110   +    121   108     0
  22   +    107  -110     0
  25   I     23    22   119
  34   I     33   119   110
 122   G    112     0     0
 113   +    122   111     0
  40   I     39   119   113
 123   G    115     0     0
 116   +    123   114     0
   6   +   -107  -113  -116
  51   I     50   119   116
 124   G     95     0     0
  96   +     94   124     0
 125   G     98     0     0
  99   +    125    97     0
  26   +     93    99   -80
  28   I     27    26   118
  37   +     96   -99     0
  36   I     35    37   118
 126   G    101     0     0
 102   +    126   100     0
  43   +    102   -96   -93
  42   I     41   118    43
  53   I     52   118   102
 127   W     56   106     0
 128   W     56   106   109
 129   W     56   112     0
 130   W     56   115     0
 131   W     56   127   128
 132   W    131   129   130
 133   W    127   128     0
  30   X     99   133     0
 134   W    127   129     0
  45   X     93   134     0
 135   W    128   129     0
  44   X     96   135     0
 136   W    130   129     0
  46   X    102   136     0
  47   +     44    45   -46
  49   +     47    48     0
 137   W    132   127     0
  14   X     80   137     0
 138   W     56   132     0
 139   0     73     0     0
 140   W     56    73    98
 141   W     56    73    83
 142   W    141    56   101
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 143   W     139     56    140
 144   W     143    141    142
 145   W      56    144      0
 146   W     139    144      0
  11   X     107    146      0
 147   W     144    141      0
  12   X     113    147      0
 148   W     144    142      0
  13   X     116    148      0
  19   +      11     12     13
 149   W     139    140      0
  29   X     110    149      0
  31   W      29     30    199
 154   S1    117      2      4
 155   S2    117      2      4
 156   I     154      0      0
 157   I     155      0      0
 159   0     201      0      0
 160   W     201     56      0
 161   W      56    159      0
 162   R     159    161    160
 163   L     162      0      0
 164   G     163      0      0
  16   X     164    138      0
 165   G     163      0      0
  15   X     165    145      0
 172   S      55      0      0
 173   C      55      0      0
 174   X     172     67      0
   7   +     165      6    174
 175   X     172     63      0
 176   X     173     67      0
   9   +      80   -176    175
 177   X     173     63      0
   8   +       7   -177      0
 180   W       4      5      0
 181   ATR   180      2      0
 182   S     181      0      0
 183   C     181      0      0
 184   X     180    180      0
 185   W      61    184      0
 178   X     182    185      0
 179   W      71    178      0
  17   +     179     31     38
  18   +      17     49     54
  20   +      15     16     18
  21   +      19     14     20
 186   X     183    185      0
 187   G      56      0      0
 192   +     190    191      0
 193   W     190     56    157
 194   /     192    193      0
 188   **    194    187      0
 189   X     194      4      0
 190   I     188      0      0
 191   I     166    189      0
 195   W     194     56      0
 196   0     157      0      0
 150   R     196    166      8
 151   R     196    166     21
  32   G     151      0      0
 152   R     196    166    119
   2   I       1    150    152
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  197    R     196     195     164
   10    +       9    -197    -178
  153    I       3      10     118
  199    U      32       0       0

BLØCK    IC/PAR1          PAR2           PAR3
   56     1.000E  0     .000E  0      .000E  0
   38   -1.956E- 2      .000E  0      .000E  0
   48   -1.140E- 1      .000E  0      .000E  0
   54   -2.590E- 2      .000E  0      .000E  0
   57    2.590E  0   -2.255E- 1       .000E  0
   59   -2.500E  0    7.600E  0       .000E  0
   62    1.190E- 3    1.190E- 3       .000E  0
   64    1.880E  0    4.930E- 1       .000E  0
   66   -2.000E  0      .000E  0      .000E  0
   68    2.120E  0   -1.846E- 1       .000E  0
   70   -4.600E  0    5.704E- 1     1.490E  0
   72    4.720E  1   -4.720E  1       .000E  0
   73    9.260E- 2    2.115E- 2       .000E  0
   82    1.940E  1   -1.940E  1       .000E  0
   83    1.570E- 2    5.150E- 2       .000E  0
   86    2.590E  3    1.138E  5    -5.700E  5
   90    5.278E  3    3.312E  2       .000E  0
   91   -1.200E- 1      .000E  0      .000E  0
   94    4.750E  0   -4.750E  0       .000E  0
   95   -7.620E- 2    2.100E- 1       .000E  0
   97    4.750E  0   -4.750E  0       .000E  0
   98    7.620E- 2    2.100E- 1       .000E  0
  100    1.075E  1   -1.075E  1       .000E  0
  101    8.440E- 4    9.300E- 2       .000E  0
   76    1.720E  5      .000E  0      .000E  0
   77   -1.066E- 1      .000E  0      .000E  0
   78    5.090E  4    2.084E  2       .000E  0
  105    1.678E  2   -1.678E  2       .000E  0
  106    4.440E- 4    5.960E- 3       .000E  0
  108    9.500E  0   -9.500E  0       .000E  0
  109    1.364E- 2    1.050E- 1       .000E  0
  111    1.020E  2   -1.020E  2       .000E  0
  112    4.440E- 4    9.800E- 3       .000E  0
  114    2.550E  1   -2.550E  1       .000E  0
  115    4.440E- 4    3.920E- 2       .000E  0
  117    1.744E- 1      .000E  0      .000E  0
  120    3.145E  4      .000E  0      .000E  0
  121    1.940E  2      .000E  0      .000E  0
   25     .000E  0    5.030E- 1    -3.217E  1
   34     .000E  0   -3.217E  1     2.140E  0
  122    1.910E  4      .000E  0      .000E  0
   40     .000E  0   -3.217E  1     6.700E- 1
  123    4.780E  3      .000E  0      .000E  0
   51     .000E  0   -3.217E  1     2.680E  0
  124    9.700E  1      .000E  0      .000E  0
  125    9.700E  1      .000E  0      .000E  0
   28     .000E  0    5.030E- 1     3.217E  1
   36     .000E  0    2.140E  0     3.217E  1
  126    1.400E  4      .000E  0      .000E  0
   42     .000E  0    3.217E  1     6.700E- 1
   53     .000E  0    3.217E  1    -2.680E  0
  127    9.100E- 1   -1.000E  0       .000E  0
  128    5.000E- 1   -1.000E  0    -1.000E  0
  129    3.083E- 1   -1.000E  0       .000E  0
  130    3.330E- 1   -1.000E  0       .000E  0
  131   -4.270E- 3    1.950E- 1     4.560E- 2
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   132      1.000E  0    1.461E- 1    3.650E- 2
   133      1.000E  0   -1.000E  0     .000E  0
   134      1.000E  0   -1.000E  0     .000E  0
   135      1.000E  0   -1.000E  0     .000E  0
   136      1.000E  0   -1.000E  0     .000E  0
   137      1.000E  0   -1.000E  0     .000E  0
   138      2.530E- 1   -1.000E  0     .000E  0
   139     -2.720E- 1     .000E  0     .000E  0
   140     -6.250E- 1    1.000E  0    1.000E  0
   141     -1.546E  0    1.000E  0    1.000E  0
   142      1.000E  0   -1.037E  0    1.000E  0
   143      1.950E- 1   -5.720E- 1    4.560E- 2
   144      1.000E  0    1.461E- 1    3.650E- 2
   145     -8.000E- 1   -1.000E  0     .000E  0
   147      1.000E  0   -1.000E  0     .000E  0
   148      1.000E  0   -1.000E  0     .000E  0
   149      1.000E  0   -1.000E  0     .000E  0
    31      1.000E  0    1.000E  0   -6.400E- 1
   159     -4.400E- 1     .000E  0     .000E  0
   160      3.612E  5   -8.996E  4     .000E  0
   161      3.940E  3   -3.940E  5     .000E  0
   163      3.940E  3     .000E  0     .000E  0
   164      8.660E- 1     .000E  0     .000E  0
   165      5.000E- 1     .000E  0     .000E  0
   180      1.000E  0    1.000E  1     .000E  0
   185      5.950E- 3    5.950E- 3     .000E  0
   179      1.000E  0     .000E  0     .000E  0
   187      2.830E- 1     .000E  0     .000E  0
   193      6.240E- 8    1.050E- 5   -1.570E- 6
   191      7.560E- 2    1.227E- 6     .000E  0
   195      1.875E- 2   -3.975E  1     .000E  0
   196      7.250E  0     .000E  0     .000E  0
    32      8.970E- 2     .000E  0     .000E  0
     2       .000E  0    1.700E- 1   -3.217E  1
   153       .000E  0    1.700E- 1    3.217E  1
   199       .000E  0    4.260E  0     .000E  0

FUNCTION GENERATORS NOT SPECIFIED


INTEGRATION INTERVAL =    2.000E- 3

OUTPUT START TIME =     .000E  0
  OUTPUT INTERVAL =    4.000E- 3
         END TIME =    5.000E- 1


PRINT OUTPUT BLOCKS:  156    2   83  100  194
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REFERENCES

1. Payne, Peter R., and Edward G. U. Band, *A Four-Degree-of-Freedom Lumped Parameter Model of the Seated Human Body*, AMRL TR-70-35, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, January 1971.

2. Band, Edward G. U., *Calculation of Rocket Powered Trajectories on a 'Plane of Symmetry' Model of a Human Subject and Ejection Seat*, AMRL TR-71-7, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, January 1971.

3. DeStefano, Leonard A., and 1st Lt. John E. Holvoet, *An Analysis and Simulation of Breech-Launched Rockets, Part I: Analysis*, Frankford Arsenal, Department of the Army Memorandum Report M69-14-1, May 1969.

*U.S.Government Printing Office: 1971 — 759-077/082