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ANALYSIS OF ARMY FIXED-WING CARGO RERAINT DESIGN CRITERIA

By

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A requirement to determine analytically the acceleration-time relationships for the cargo compartments of CV-2 and CV-7 aircraft, when subjected to various crash conditions, and to determine the effect of these relationships on a load-limited restraint system provides the basis for this report. The techniques used in this report represent a logical extension of previous, similar programs; in the absence of test-crash data, the results contained herein may be used with a high degree of confidence.

The excessive load-limiter displacements (2 to 16 feet) indicated for certain crash conditions considered in this report are judged to be operationally unacceptable by this activity. However, the load-limiter concept represents a significant safety and operational improvement over the conventional restraint devices for most of the crash conditions considered. This activity suggests that a trade-off study be conducted to determine the maximum safety that can be achieved by load-limited restraints commensurate with acceptable operational factors.

Since the Army no longer has operational responsibility for the CV-2 and the CV-7 aircraft, this activity has not planned further effort in the area of this report. However, results of this contract will be forwarded to the appropriate Air Force agency for consideration.
ANALYSIS OF ARMY FIXED-WING CARGO RESTRAINT DESIGN CRITERIA

Final Report
AvSER 66-21

By
James P. Avery
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This report presents the findings of an investigation into the crash pulse of fixed-wing cargo aircraft and the resulting behavior of cargo restrained by load limiters.

A crash pulse simulator computer program was developed that obtains acceleration-time histories at selected stations in the cargo compartment and under various crash conditions. This simulator was employed to obtain crash pulses for a wide range of input parameters, both for the CV-2 and the CV-7 Army aircraft. The resulting acceleration pulses were studied to determine a suitable spectrum of realistic pulses.

The crash pulse program was subsequently modified to include a routine that would simulate cargo dynamic behavior during the crash sequence, employing the floor acceleration data as it is developed. This latter program was applied to CV-2 and CV-7 aircraft, under significant crash conditions, to obtain the dynamic response of cargo to the crash pulse.
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SYMBOLS

Figure 1. Sketch Illustrating Symbols.

\( a_C \)  Longitudinal acceleration of cargo (ft/sec^2)

\( a_{FL}, a_{FN} \)  Longitudinal and normal accelerations respectively of cargo compartment floor (ft/sec^2)

\( \ddot{a}_i, \dot{a}_i \)  Rigid body acceleration components (transverse and longitudinal) at \( i^{th} \) station (ft/sec^2)

\( a_{REL} \)  Relative cargo acceleration (ft/sec^2)

\( a_{Ti} \)  Total longitudinal acceleration at \( i^{th} \) station (ft/sec^2)

\( a_{Vi} \)  Contribution to acceleration due to transverse vibration at \( i^{th} \) station (ft/sec^2)

\( A_{jk} \)  Coefficients in polynomial expressions for functions of the angle \( \theta \)
Symbol for algebraic expression

Longitudinal component of ground reaction (lb)

Soil parameters

Algebraic expressions involving coordinates of points (ft)

Flexural rigidity of fuselage (lb-ft²)

Coefficient of friction between aircraft and ground

Coefficient of friction between cargo and cargo compartment floor

Normal and tangential components of ground reaction force (lb)

Components of $F_N$ (lb)

Components of $F_T$ (lb)

Forward load-limiter limit acceleration (ft/sec²)

Symbol for algebraic expression

Algebraic expressions
Symbols for unit of acceleration equivalent to 32.2 feet per second per second

Symbol for expression, function of time

Input parameters expressed as functions of the angle \( \theta \)

Mass moment of inertia of aircraft (slug ft\(^2\))

Mass moment of inertia of forward and of aft sections of aircraft

Reduction factor

Structural parameter

Length of fuselage (ft)

Mass of aircraft (slugs)

Mass of forward and of rear sections of aircraft (slugs)

Generalized masses (for Lagrange's equations) (slugs)

Computed fuselage bending moment (ft-lb)

Yield hinge moment (ft-lb)

Transverse component of soil reaction force (lb)

Generalized coordinates (for Lagrange's equations) (ft)

Generalized forces (for Lagrange's equations) (lb)

Magnitude of space vector (ft)

Rear load limiter limit acceleration (ft/\textsec^2)

Distance from nose as an independent variable (ft)

Distance from nose to \( i \) station (ft)
\( s_B \) Distance from nose to center of gravity (ft)

\( s_{BF} \) Distance from nose to center of gravity of forward and rear sections (ft)

\( s_{BR} \)

\( s_J \) Distance from nose to \( J^{th} \) station (ft)

\( S_C \) Scoop factor

\( t \) Time (sec)

\( v_{REL} \) Relative cargo velocity (ft/sec)

\( x, y \) Coordinates of aircraft center of gravity from \( x, y \) axis system (ft)

\( X, Y \) Coordinates of aircraft center of gravity from original point of contact (ft)

\( X_F', Y_F \) Coordinates of centers of gravity of forward and rear sections, respectively (ft)

\( X_R', Y_R \)

\( X_H', Y_H \) Coordinates of yield hinge (ft)

\( Z \) Interference of aircraft original contour with soil (ft)

\( Z_G \) Actual penetration of ground by aircraft (ft)

\( \dot{X}, \dot{Y}, \dot{Z} \ldots \) Time derivatives of quantities \( X, Y, Z \ldots \)

\( \ddot{X}, \ddot{Y} \ldots \) Second time derivatives of quantities \( X, Y \ldots \)

\( \delta \) Damping coefficient for longitudinal vibration

\( \theta \) Angle of impact of aircraft (rad)

\( \theta_F, \theta_R \) Attitude angle for forward and rear sections of aircraft, respectively (rad)

\( \Delta t \) Time increment (sec)

\( \Delta () \) Change in quantity () during time increment \( \Delta t \)
\( \mu_i \) \hspace{1cm} \text{Mass of } i^{\text{th}} \text{ discrete segment of fuselage (slugs)}

\( \mu \) \hspace{1cm} \text{Mass per unit length of fuselage (slugs/ft)}

\( \phi_1 \cdots \phi_4 \) \hspace{1cm} \text{Normal mode shapes for free vibrations}

\( \omega_1 \cdots \omega_4 \) \hspace{1cm} \text{Natural angular frequencies (rad/sec)}

\( \tilde{\omega}_1 \cdots \tilde{\omega}_4 \) \hspace{1cm} \text{Resonant frequencies with damping (rad/sec)}

\textbf{SUBSCRIPTS}

\( i \) \hspace{1cm} \text{Associated with } i^{\text{th}} \text{ station or fuselage segment}

\( n \) \hspace{1cm} \text{Associated with } n^{\text{th}} \text{ generalized coordinate in Lagrange's equations}

\( F \) \hspace{1cm} \text{Associated with forward section of aircraft}

\( R \) \hspace{1cm} \text{Associated with rear section of aircraft}

\( H \) \hspace{1cm} \text{Associated with yield hinge}

\( J \) \hspace{1cm} \text{Associated with } J^{\text{th}} \text{ station}
INTRODUCTION

This report represents a continuation of the analytical investigation of acceleration-time pulses for the CV-2 and CV-7 aircraft as described in USAAVLABS Technical Report 65-30, "Cargo Restraint Systems for Crash Resistance". The crash impact parameters and limits thereof used in this program were felt to represent the conditions most likely to be encountered in an accident for the aircraft involved. In addition, it was felt that all of these conditions represented a survivable accident.
CRASH PULSE SIMULATOR

DESCRIPTION

The computer program to simulate dynamic behavior of a fixed-wing aircraft accepts as input (1) accident configuration variables, (2) structural data for the specific aircraft, and (3) soil behavior parameters. The accident configuration variables consist of velocity, sink rate, impact angle, and angular velocity (if present). The structural input data include flexural and axial stiffness properties, mass distribution data, buckling, yield and failure criteria, and various geometric data. The soil reaction parameters relate the interaction forces between aircraft and ground to the depth of penetration, the rate of penetration, and the horizontal velocity.

The simulator output is in the form of computer-plotted acceleration-time curves for three stations in the cargo compartment. Additionally, the simulator displays the maximum plowing depth, the groove length, the maximum values of generalized coordinates for vibration modes excited by crash forces, the maximum stresses in the fuselage, and the kinematic data at the completion of rebound (or slide-out).

ANALYTICAL BASIS

The simulator operates in either of two general modes: the elastic mode or the plastic-hinge mode.

The elastic mode is assumed if fuselage (longitudinal) stresses are below buckling or plastic limits. In this mode the dynamic behavior of the aircraft is divided into two parts: First, the rigid body behavior is obtained from the soil-structure interaction forces and rigid body equations of motion. Second, the vibration modes excited both by the soil reaction forces and by the rigid body motion inertial forces are evaluated.

The vibration amplitudes are found by means of a normal mode analysis in which the first and second transverse and the first and second longitudinal modes of fuselage vibration are considered. The amplitudes of these four vibrational modes are taken as generalized coordinates in Lagrange's equations of motion for the aircraft. For the assumption that the damping coefficient is proportional to mass distribution along the
fuselage (an assumption which introduces little error), the Lagrange's equations reduce to a set of independent one-degree-of-freedom equations:

\[ \ddot{q}_n + \beta \dot{q}_n + \omega_n^2 q_n = \frac{Q_n}{m_n} \]

where

- \( q_n, \dot{q}_n, \ddot{q}_n \) = generalized coordinates and time derivatives
- \( \beta \) = damping coefficient
- \( \omega_n \) = natural angular frequency
- \( Q_n \) = generalized force
- \( m_n \) = generalized mass

\[ Q_n(t) = \int_0^L p(x,t) \phi_n(x) \, dx + \sum P_i(t) \phi_n(x_i) \]

\[ m_n = \int_0^L \phi_n^2 \, dx \]

A solution satisfying initial conditions is found in the convolution integral:

\[ q_n(x,t) = \frac{1}{m_n \omega_n} \int_0^L Q_n(\tau) \exp \left[ -\frac{\beta}{2} (t-\tau) \right] \sin \omega_n (t-\tau) \, d\tau \]

which is evaluated numerically in the simulator program (reference Appendix I). With the generalized coordinates evaluated, the vibrational kinematics are determined and may be superimposed on the rigid body kinematics to obtain resultant accelerations. The maximum bending stresses are determined from the bending moments associated with the transverse vibrational modes of the fuselage.

The plastic-hinge mode of aircraft behavior is followed by the simulator, if at some fuselage station the effective buckling or the yield stress has been exceeded (when operating in the elastic mode). In the plastic-hinge mode, the aircraft is treated as two rigid bodies joined by a plastic "yield hinge" which may transmit hinge reactions as well as a plastic-hinge bending moment. In this mode, elastic vibrations are ignored, as they are con-
sidered to be negligible when compared with the large plastic deformations.
Again, the equations of motion are solved by numerical integration.

The simulation is terminated by any of the following conditions:

1. The rebound has been completed; that is, the soil penetration has returned to zero.
2. The horizontal component of velocity has been reduced to zero.
3. The deflection angle at the plastic hinge has reached a critical value, implying a fuselage break.
4. The aircraft rotates outside a specified angular limit (implying an overturning).

A flow chart and an outline of computational operations of the simulator program are provided in Appendix I.
DEVELOPMENT OF INPUT DATA

The input data for crash simulation of the CV-2 and CV-7 Army aircraft are divided into three categories: accident configuration variables, structural data, and soil reaction parameters. An example of input data for a simulation run as developed for the CV-7 aircraft appears in Appendix IV.

ACCIDENT CONFIGURATION DATA

The accident configuration variables used were those specified in the contract statement of work.

STRUCTURAL DATA

The mass distribution data have been obtained from weight analyses made by the manufacturer. These data were adjusted in accordance with various cargo and fuel level conditions for several simulator runs.

The structural stiffness data may be conveniently separated into two groups: that which deals with the vibrational behavior of the aircraft, and that which relates imposed forces to structural deformation.

Consider, first, the vibrational behavior. The mode shapes and natural frequencies (for both longitudinal and transverse vibrations) have been obtained by means of a separate computer program employing standard techniques (see Appendix VI, Program VIBRAT). Flexural rigidities, longitudinal stiffness, and mass distribution are the input to this auxiliary program; these input data have been obtained from analyses performed by the manufacturer. The output of the auxiliary program becomes input for the simulator program and consists of normal mode shapes, natural frequencies, generalized masses, and, for the transverse vibration, normalized bending stresses.

Next, consider the load deformation input parameters for the structure. A double modulus relationship has been postulated between crushing force and structural deformation in the local area of contact between the ground and the aircraft. The crushing force moduli have been obtained by computing average local plastic buckling loads for those structural members that fail by local instability and by adding an appropriate percentage for the resistance offered by bending of longitudinal members. Based upon observed behavior of a plastically deformed structure, an estimate has
been made of plausible "springback" deformation associated with unloading. A range of 10- to 20-percent springback was postulated for a 2- to 3-foot depth of structural crushing in the region of the underside of the nose. The springback is obtained in the simulator program by employing a greater modulus for unloading as well as for initial loading below a critical force (marking the onset of plastic crushing).

![Diagram of springback and residual crushing](image)

Figure 2. Plot of Normal Force Versus Structural Deformation

The onset of plastic crushing is signaled by a critical value of applied normal force (see Figure 2). This critical value is estimated considering those members that would first undergo general buckling; however, this value must also be consistent with the elastic modulus for deformation, the plastic modulus, and the assumed points through which the curves must pass.

The simulator program computes compressive bending stresses along the top of the fuselage for each time increment. When a critical effective buckling stress is reached at a given station, a "yield hinge" is considered to be formed in the fuselage and the mode of simulation changes. The critical fuselage buckling stress has been computed on the basis of the critical stress for a longitudinally stiffened curved panel. The computed value has been increased by an estimated factor to account for the dynamic overload capability associated with short-duration pulses and redistribution of stress as a plastic hinge is formed.

Once a yield hinge forms, a plastic-hinge moment offers substantially constant resistance to further bending at the hinge. This plastic-hinge moment has been computed on the basis of resistance offered to continuation of buckling and crushing of skin and longitudinal members.
In addition to the structural data described above, geometric input defining the longitudinal contour of the underside of the fuselage is required. These data were obtained from scale drawings provided by the manufacturer.

**GROUND PARAMETERS**

It should be noted that an accident can occur in a wide variety of soils whose properties may vary considerably. Consequently, the ground parameters were varied over practical ranges for a number of simulator runs.

The normal soil reaction force, $F_N$, was considered to be composed of several components. First, the essentially elastic behavior provides a contribution that increases with penetration. However, as both surface contact area and ground resistance per unit area are roughly proportional to depth of penetration, the assumed relationship is:

$$F_{N1} = C_1 Z_G^2$$

where

- $Z_G$ = ground penetration
- $C_1$ = soil elastic modulus

The constant $C_1$ has been estimated for a typical soil.

A second contribution to normal force is associated with the phenomenon of planing (hydroplaning) is associated both with horizontal velocity and depth of soil penetration. The relationship is:

$$F_{N2} = C_2 Z_G X$$

where

- $X$ = horizontal component of aircraft velocity
- $C_2$ = planing parameter

The planing coefficient $C_2$ has been roughly estimated for various soils, based upon momentum exchange and soil compressive resistance. The degree to which the nose of the aircraft remains a "plane" as opposed to
a "scoop" would further affect this parameter. In the computer simulation runs, a range of practical values was used for this parameter.

The third contribution to the normal force component is that of the direct momentum exchange effect. As the aircraft penetrates the ground, it accelerates soil mass to its velocity. A momentum exchange relationship leads to

\[ F_{N3} = C_3 Z_G^2 Z_G^2 \]

where

\[ Z_G = \text{time rate of soil penetration} \]
\[ C_3 = \text{soil impact parameter} \]

The parameter \( C_3 \) is approximately equal to the mass density of the soil multiplied by the contact area and divided by the penetration \( Z_G \).

The total normal component is the sum of the three separate contributions:

\[ F_N = F_{N1} + F_{N2} + F_{N3} \]

The tangential component of the soil reaction force is similarly composed of separate contributions. The first of these is simple friction.

\[ F_{T1} = f F_N \]

where

\[ f = \text{coefficient of friction} \]

To the extent that the soil has been penetrated and some manner of scoop has been formed at the nose of the aircraft, two additional contributions to the tangential force would exist. The first of these is associated with soil "drag" or "plowing" action and is proportional to the horizontal velocity and ground penetration:

\[ F_{T2} = C_4 X Z_G \]

The plowing coefficient for a given soil can only be determined experimentally. For this purpose a simple experiment was designed and conducted to provide a rough separation of the plowing and friction phenomena with two extremes of scoop conditions. The results of this
experiment were employed to provide order-of-magnitude values for the soil reaction parameters \( f, C_2, \) and \( C_4. \) The experiment is described in Appendix III. The other contribution associated directly with the scoop effect is the horizontal momentum exchange. It would thus vary with soil penetration and with the velocity squared; that is,

\[
F_{T3} = C_5 x^2 z_G
\]

The coefficient \( C_5 \) would depend upon effective scoop area and soil density and has been roughly computed. In simulation runs, this parameter will be varied considerably to simulate conditions ranging from a definite scoop in a freshly plowed field to the other extreme of planing over hardpan soil or a concrete ramp. The total tangential force is then the sum of the individual contributions:

\[
F_T = F_{T1} + F_{T2} + F_{T3}
\]
APPLICATION OF CRASH PULSE SIMULATOR

The CV-2 and CV-7 aircraft crash pulses were developed by the simulator program for combinations of the following parameters: velocity, sink rate, attitude angle at impact, soil conditions, and aircraft weight conditions.

1. Velocity was varied from 80 to 120 feet per second.
2. Sink rate was varied from 10 to 30 feet per second.
3. Attitude angle was varied from 3 to 15 degrees.
4. Two basic soil conditions were considered: hardpan, and a soft soil equivalent to a cultivated field.
5. For each aircraft, two weight conditions were considered: operational light and operational heavy.

A summary of significant results is contained in the following tables, which relate maximum cargo compartment acceleration (excluding short-duration peaks), time duration of pulse, and velocity change to the various input parameters.

An example input to the simulator program and developed output is contained in Appendix IV.

<table>
<thead>
<tr>
<th>Velocity (ft/sec)</th>
<th>Soil Condition</th>
<th>Maximum Acceleration (G)</th>
<th>Pulse Duration (sec)</th>
<th>Velocity Change (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Hardpan</td>
<td>6.1</td>
<td>0.138</td>
<td>12</td>
</tr>
<tr>
<td>100</td>
<td>Hardpan</td>
<td>6.4</td>
<td>0.140</td>
<td>12</td>
</tr>
<tr>
<td>120</td>
<td>Hardpan</td>
<td>7.0</td>
<td>0.144</td>
<td>13</td>
</tr>
<tr>
<td>80</td>
<td>Soft Soil</td>
<td>9.4</td>
<td>0.188</td>
<td>26</td>
</tr>
<tr>
<td>100</td>
<td>Soft Soil</td>
<td>11.4</td>
<td>0.200</td>
<td>33</td>
</tr>
<tr>
<td>120</td>
<td>Soft Soil</td>
<td>12.7</td>
<td>0.220</td>
<td>42</td>
</tr>
</tbody>
</table>

CV-7 Aircraft, operational light.
Sink rate = 20 fps; impact angle = 12 degrees
**TABLE II**  
RESPONSE TO SINK RATE

<table>
<thead>
<tr>
<th>Sink Rate (ft/sec)</th>
<th>Soil Condition</th>
<th>Maximum Acceleration (G)</th>
<th>Pulse Duration (sec)</th>
<th>Velocity Change (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Hardpan</td>
<td>3.5</td>
<td>.126</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>Hardpan</td>
<td>6.4</td>
<td>.140</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>Hardpan</td>
<td>9.1</td>
<td>.266</td>
<td>26</td>
</tr>
<tr>
<td>10</td>
<td>Soft Soil</td>
<td>6.9</td>
<td>.248</td>
<td>26</td>
</tr>
<tr>
<td>20</td>
<td>Soft Soil</td>
<td>11.4</td>
<td>.200</td>
<td>33</td>
</tr>
<tr>
<td>30</td>
<td>Soft Soil</td>
<td>14.4</td>
<td>.268</td>
<td>54</td>
</tr>
</tbody>
</table>

CV-7 Aircraft, operational light.  
Velocity = 100 fps; impact angle = 12 degrees

**TABLE III**  
RESPONSE TO IMPACT ANGLE

<table>
<thead>
<tr>
<th>Impact Angle (deg)</th>
<th>Soil Condition</th>
<th>Maximum Acceleration (G)</th>
<th>Pulse Duration (sec)</th>
<th>Velocity Change (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Hardpan</td>
<td>6.1</td>
<td>.126</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Hardpan</td>
<td>6.2</td>
<td>.124</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>Hardpan</td>
<td>6.4</td>
<td>.140</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>Hardpan</td>
<td>7.2</td>
<td>.150</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>Soft Soil</td>
<td>9.0</td>
<td>.144</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>Soft Soil</td>
<td>10.6</td>
<td>.70</td>
<td>26</td>
</tr>
<tr>
<td>12</td>
<td>Soft Soil</td>
<td>11.4</td>
<td>.200</td>
<td>33</td>
</tr>
<tr>
<td>15</td>
<td>Soft Soil</td>
<td>12.2</td>
<td>.244</td>
<td>41</td>
</tr>
</tbody>
</table>

CV-7 Aircraft, operational light.  
Velocity = 100 fps; sink rate = 20 fps
CARGO SIMULATOR

DESCRIPTION

The computer program to simulate cargo restraint systems is designed to obtain the dynamic response of a cargo retention system (employing load limiters) to an applied acceleration pulse. The cargo simulation is accomplished not as a separate computer program but rather as a subroutine appended to the crash pulse simulator program. As the specific crash pulse is generated, it becomes input (internally) to the cargo simulation subroutine.

MATHEMATICAL MODEL

The cargo is assumed to rest on the cabin floor (with a suitable friction coefficient between cargo and floor), restrained fore and aft by load limiters as illustrated in Figure 3.

![Figure 3. Cargo Restraint by Load Limiters](image)

Each load limiter provides unidirectional restraint; the aft load limiter, for example, offers restraint to forward displacement of the cargo relative to the floor (when slack is taken up).
The longitudinal force applied to the cargo is transmitted from the aircraft through either the aft or the forward load limiter, as well as through the cargo floor by means of friction. The maximum value that this force may assume is the load-limiter limit force plus the coefficient of friction times the normal force between floor and cargo. (The normal floor force, in turn, depends upon the normal component of floor acceleration.)

At each time increment, the subroutine accepts as input the generated acceleration components (longitudinal and normal) of the floor at the cargo location. For the case of zero relative velocity (of cargo to floor), the cargo mass times the longitudinal acceleration is compared with the computed maximum possible longitudinal force. If the former is less than the computed limiting value, no relative acceleration occurs. Otherwise, the cargo acceleration is the computed limiting longitudinal force divided by cargo mass. The resulting relative acceleration is then the difference between the floor acceleration and the absolute cargo acceleration.

For the case in which the cargo has a relative velocity, the applied cargo force becomes the load-limiter load plus the computed friction force (assuming tie-down slack is not present). Again, the applied cargo force determines the absolute cargo acceleration and in turn the relative acceleration.

Numerical integration of the kinematic relationships is used to obtain relative cargo velocity and displacement (at each time increment) from the above-computed relative acceleration. The load-limiter stroke is finally obtained as the maximum cargo displacement.

A flow chart and computational relationships for the cargo simulation subroutine are given in Appendix II.
APPLICATION OF CARGO SIMULATION PROGRAM

The cargo simulation program was employed for ten representative crash pulses (as shown in Table IV). For each pulse, the load-limiter stroke was computed for five different load-limiter limit forces, corresponding to 2G, 4G, 6G, 8G, and 10G limiting accelerations. The resulting limiter strokes are tabulated in Table IV along with the input conditions for each simulation run. (The center of the cargo compartment was selected as a representative location.)

A family of curves showing load-limiting force versus cargo displacement appears in Figure 4.

Appendix V shows typical output sheets from the cargo simulation program.
## TABLE IV
**RESULTS OF CARGO SIMULATION**

<table>
<thead>
<tr>
<th>Aircraft Configuration and Soil Condition</th>
<th>Velocity (ft/sec)</th>
<th>Sink Rate (ft/sec)</th>
<th>Impact Angle (deg)</th>
<th>Max. Pulse Duration (sec)</th>
<th>Load Limiter Change (ft/sec)</th>
<th>Cargo Limiter Displ. (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-2 Operational Light Soft Soil</td>
<td>120</td>
<td>30</td>
<td>15</td>
<td>2.14</td>
<td>60</td>
<td>2</td>
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<td></td>
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<tr>
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<td>9</td>
<td>11.6</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>10</td>
<td>6</td>
<td>5.67</td>
<td>128</td>
<td>12</td>
</tr>
<tr>
<td>CV-1 Operational Heavy Hardpan</td>
<td>100</td>
<td>30</td>
<td>15</td>
<td>7.4</td>
<td>300</td>
<td>25</td>
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<td>CV-2 Operational Heavy Soft Soil</td>
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<td>30</td>
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15
<table>
<thead>
<tr>
<th>Legend</th>
<th>Weight Condition</th>
<th>Soil Condition</th>
<th>Velocity (ft/sec)</th>
<th>Sink Rate (ft/sec)</th>
<th>Impact Angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Heavy</td>
<td>Soft Soil</td>
<td>120</td>
<td>30</td>
<td>12</td>
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<tr>
<td>(2)</td>
<td>Heavy</td>
<td>Soft Soil</td>
<td>120</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>(3)</td>
<td>Heavy</td>
<td>Soft Soil</td>
<td>120</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>(4)</td>
<td>Heavy</td>
<td>Hardpan</td>
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<td>30</td>
<td>15</td>
</tr>
<tr>
<td>(5)</td>
<td>Heavy</td>
<td>Hardpan</td>
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<td>30</td>
<td>6</td>
</tr>
<tr>
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<td>Light</td>
<td>Soft Soil</td>
<td>120</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>(7)</td>
<td>Light</td>
<td>Soft Soil</td>
<td>90</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>(8)</td>
<td>Heavy</td>
<td>Hardpan</td>
<td>80</td>
<td>30</td>
<td>3</td>
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</tbody>
</table>

**Figure 4. Plots of Load-Limiter Force Versus Cargo Displacement**
RESULTS

The investigation has led to the development of a crash pulse computer simulator (Appendix IV) providing an analytical tool for the study of crash pulse time histories of fixed-wing aircraft. This tool was applied to the CV-7 aircraft to obtain tabulated acceleration data (Tables I, II, III) for variations of pertinent input parameters, including soil conditions and accident configurations.

In addition, the investigation has led to the development of a cargo simulator program (Appendix V) to serve as an analytical tool to study cargo acceleration levels and displacements during a crash sequence. This simulator was applied to obtain tabular data and plots (Table IV and Figure 4) relating cargo displacements to load-limiter values for various crash conditions.

It should be pointed out that all of the acceleration-time pulses generated in this program fall within the human tolerance limits.
APPENDIX I
CRASH PULSE SIMULATOR

FLOW CHART

READ INPUT
INITIALIZE QUANTITIES
COMPUTE CONSTANTS

INCREMENT TIME BY \( \Delta t \)

INCREMENT VELOCITIES
AND DISPLACEMENTS
FOR TIME INCREMENT, \( \Delta t \)

TEST FOR COMPLETION

RUN COMPLETE

PRINT SUMMARY DATA
FOR SIMULATION RUN

RUN NOT COMPLETE

PRINT AND PLOT
ACCELERATIONS
AT TIME = \( t \)

COMPUTE GROUND
REACTION FORCES

SELECT MODE
OF BEHAVIOR

YIELD-HINGE

COMPUTE RIGID
BODY ACCELERATIONS
(TWO CONNECTED BODIES)

ELASTIC

COMPUTE RIGID BODY
ACCELERATIONS

INITIALIZE FOR
YIELD-HINGE
MODE

BUCKLE STARTS

TEST FOR
STABILITY LIMITS

STABLE

REFER TO APPENDIX II
COMPUTATIONAL OPERATIONS (Refer to List of Symbols)

1. Geometric, structural, and soil parameters that depend upon the angle \( \theta \) are computed as polynomials:

\[
H_n = A_{n1} + A_{n2} \theta + A_{n3} \theta^2 + A_{n4} \theta^3
\]

2. The coordinates \( x \) and \( y \) are found:

\[
x = H_2 \sin \theta - (s_B - \frac{1}{H_1}) \cos \theta
\]

\[
y = (s_B - \frac{1}{H_1}) \sin \theta + H_2 \cos \theta
\]

3. The interference, \( Z \), and its time derivative, \( \dot{Z} \), are found:

\[
Z = Y - y, \quad \dot{Z} = \frac{\Delta Z}{\Delta t}
\]

4. The normal force, \( F_N \), is computed:

a. For positive \( Z \) and \( F_N \), less than critical \( F_{N \text{ critical}} \),

\[
F_N = K_1 (Z - Z_G)
\]

where

\[
Z_G = \sqrt{\frac{K_1}{g}} Z + B^2 - B
\]

\[
g = C_1 + (Z_G)^2 C_2
\]

\[
Z_G = \frac{\Delta Z_G}{\Delta t}
\]

\[
B = \frac{(1 - S_C) H_8 X + K_1}{\dot{Z} g}
\]

and

\[
F_{N \text{ critical}} = \frac{1 + 8 \theta^2}{H_6}
\]

\[
K_1 = \frac{1 + 4 \theta^2}{H_3}
\]

\[
C_1 = \frac{1 + 4 \theta^2}{H_4}
\]
\[ C_2 = \frac{1}{H_5} \]

\[ S_C = \text{scoop factor (varying from 0 to 1)} \]

b. For \( F_N > F_N \text{critical} \), \( Z \) positive,

\[ \Delta F_N = k K_1 (\Delta Z - \Delta Z_G) \]

where

\[ \Delta Z_G = \frac{\Delta Z}{[Z_G + (1 - S_C) H_8 X] k K_1 + 1} \]

\[ k = \text{reduction factor for modulus } K_1 \]

c. For \( Z \) negative,

\[ \Delta F_N = K_1 (\Delta Z - \Delta Z_G) \]

where

\[ \Delta Z_G = \Delta Z \frac{Z_G}{Z} \]

5. The tangential force is computed:

\[ F_T = f F_N + S_C [H_8 \dot{X} + H_9 \dot{X}^2] Z_G \]

where

\[ f = \text{effective coefficient of friction} \]

6. Accelerations are computed:

\[ \ddot{X} = \frac{F_N}{m_A}, \quad \ddot{Y} = \frac{F_T}{m_A} \]

\[ \ddot{\theta} = \left[ \frac{F_N x + F_T (y + \frac{Z_G}{2})}{I_A} \right] \]

where

\[ m_A = \text{aircraft mass} \]

\[ I_A = \text{aircraft mass moment of inertia} \]
7. Generalized forces for vibration modes are computed:

\[ Q_1 = P \phi_1(s_j) + M \frac{d \phi_1}{ds}(s_j) - \sum a_i \phi_1(s_i) \]

\[ Q_2 = P \phi_2(s_j) + M \frac{d \phi_2}{ds}(s_j) - \sum a_i \phi_2(s_i) \]

\[ Q_3 = C \phi_3(s_j) - \sum a_i \phi_3(s_i) \]

\[ Q_4 = C \phi_4(s_j) - \sum a_i \phi_4(s_i) \]

where

\[ P = F_N \cos \theta - F_T \sin \theta \]

\[ C = F_T \cos \theta + F_N \sin \theta \]

\[ M = C \left[ \left( y + \frac{ZG}{2} \right) \sin \theta + x \cos \theta \right] \]

\( \phi_1 \ldots \phi_4 \) = normalized vibration modes as functions of \( s \)

\( s_j \) = distance along fuselage axis to center of force application (from nose)

\( a_i, a_i \) = rigid body acceleration components (transverse and longitudinal at station \( s_i \))

\( \mu_i \) = mass associated with \( i^{th} \) finite subdivision of fuselage

8. Generalized coordinates are evaluated:

\[ q_n(t + \Delta t) = \exp \left( -\frac{\zeta}{2} \Delta t \right) \left\{ q_n(t) \cos \omega_n \Delta t + \left[ h_n(t) + \frac{Q_n(t) \Delta t}{m_n \omega_n} \right] \sin \omega_n \Delta t \right\} \]

where

\( n \) = varies from 1 to 4

\( \zeta \) = damping coefficient

\( m_n \) = generalized mass = \( \int_0^L \mu_n x^2 \, dx \)
\[
\omega_n = \sqrt{\frac{2}{\xi_n} - \frac{3}{4}}
\]

\(\omega_n\) = natural frequency

and \(h_n(t)\) is found from:

\[
h_n(t + \Delta t) = \exp\left(-\frac{\xi_n}{2}\Delta t\right) \left\{ h_n(t) + \frac{Q_n(t) \Delta t}{m_n \omega_n} \left[ \cos \omega_n \Delta t - q_n(t) \sin \omega_n \Delta t \right] \right\}
\]

9. The bending moment is computed:

\[
M_B(s_i) = EI(s_i) \left[ \frac{d^2 \phi_1}{ds^2}(s_i) + \frac{d^2 \phi_2}{ds^2}(s_i) \right]
\]

where

\(EI(s_i)\) = Flexural rigidity at \(s = s_i\)

10. The longitudinal acceleration is computed

\[
a_{Ti} = a_i + a_{Vi}
\]

where

\(a_{Ti}\) = total longitudinal acceleration at \(s = s_i\)

\(a_i\) = rigid body acceleration at \(s = s_i\)

\(a_{Vi}\) = relative acceleration from longitudinal vibration

\[
a_{Vi} = q_3 \frac{d^2 \phi_3}{dt^2}(s_i) + q_4 \frac{d^2 \phi_4}{dt^2}(s_i)
\]

11. Components of velocity and displacements are computed from kinematic relationships:

\[
\Delta X = (X - \frac{\Delta X}{2}) \Delta t
\]

where

\(X\) = updated acceleration (that is, acceleration at end of time interval, \(\Delta t\))

\(\Delta Y, \Delta \theta\) are found similarly.
\[ \Delta X = (X - \frac{\Delta X}{2}) \Delta t \]

where \( X = \) updated velocity

\( \Delta Y, \Delta \theta \) are found similarly.

12. For the "yield-hinge" mode of aircraft deformation, rigid body accelerations are computed as follows: The angular acceleration, \( \theta_F \), of the forward portion of the aircraft and the angular acceleration, \( \theta_R \), of the rear portion (aft of the yield hinge) are each computed:

\[
\begin{align*}
\theta_F &= \frac{G_3 \cdot G_5 - G_2 \cdot G_6}{\text{Den}} \\
\theta_R &= \frac{G_1 \cdot G_6 - G_3 \cdot G_4}{\text{Den}}
\end{align*}
\]

where

\[
G_1 = \left( \frac{l_F}{m_F} + \frac{m_R}{m_A} r_F^2 \right) \frac{m_A}{m_F}
\]

\[
G_2 = \frac{m_R}{4m_F}
\]

\[
G_3 = \frac{M_h m_A}{m_R m_F} + F_n \left( \frac{X_h m_A}{m_F^2} + \frac{D_{XF}}{m_F} \right) + F_T \left[ \frac{\left( \frac{Y_h}{m_F^2} + \frac{Z}{2} \right) m_A}{m_F^2} - \frac{D_{YF}}{m_F} \right] + \frac{m_R}{m_F} G_D
\]

\[
G_4 = D_{XF} \cdot D_{XR} + D_{YF} \cdot D_{YR}
\]

\[
G_5 = \left( \frac{l_R}{m_R} + \frac{m_F}{m_A} r_R^2 \right) \frac{m_F}{m_A}
\]

\[
G_6 = -\frac{M_h m_A}{m_R m_F} - F_n \frac{D_{XF}}{m_F} + F_T \frac{D_{YR}}{m_H} + G_D
\]

\[
\text{Den} = G_1 \cdot G_5 - G_4 \cdot G_2
\]
\[ G_D = D_{XR}(D_{YF} \cdot \theta_F^2 + D_{YR} \cdot \theta_R^2) - D_{YR}(D_{XF} \cdot \theta_F^2 + D_{YF} \cdot \theta_R^2) \]

\[ I_F, I_R = \text{mass moments of inertia} \]

\[ m_A, m_F, m_R = \text{masses} \]

\[ X_H', Y_H = \text{coordinates of yield hinge} \]

\[ M_H = \text{yield-hinge moment} \]

\[ D_{XF} = X_F - X_H \]

\[ X_F', Y_F = \text{coordinates of forward center of gravity} \]

\[ D_{YF}, D_{XR}, D_{YR} = \text{similar to } D_{XF} \]

\[ r_F^2 = D_{XF}^2 + D_{YF}^2 \]

\[ r_R^2 = \text{similar to } r_F^2 \]

13. Acceleration components, \[ X_F', Y_F', X_R', Y_R' \], of forward and aft section center of gravity are computed:

\[ X_F = \frac{-F_T + m_R G_7}{m_A} - \frac{m_R}{m_A G_9} \]

\[ Y_F = \frac{F_N - m_R G_8}{m_A} - \frac{m_R}{m_A G_{10}} \]

\[ X_R = \frac{F_T - m_F G_7}{m_A} + \frac{m_F}{m_A G_9} \]

\[ Y_R = \frac{F_n - m_F G_8}{m_A} + \frac{m_F}{m_A G_{10}} \]

where

\[ G_7 = \theta_F^2 D_{XF} + \theta_R^2 D_{XR} \]
\[ G_8 = \theta_F^2 D_{YF} + \theta_R^2 D_{YR} \]
\[ G_9 = D_{YF} \cdot \theta_F + D_{YR} \cdot \theta_R \]
\[ G_{10} = D_{YF} \cdot \theta_F + D_{YR} \cdot \theta_R \]

14. Velocity and displacement components are updated from kinematic relationships:

\[ X_F^* = (X_F - \frac{\Delta X_F}{2}) \Delta t \]

where

\[ X_F^* = \text{updated acceleration} \]

\[ \Delta Y_F^*, \Delta \theta_F^*, \Delta X_R^*, \Delta Y_R^*, \Delta \theta_R^* \] are found similarly.

\[ \Delta X_F = (X_F - \frac{\Delta X_F}{2}) \Delta t \]

where

\[ X_F = \text{updated velocity} \]

\[ \Delta Y_F, \Delta \theta_F, \Delta X_R, \Delta Y_R, \Delta \theta_R \] are found similarly.
APPENDIX II
CARGO SIMULATOR

CARGO SUBROUTINE
FLOW CHART

ENTER

COMPUTE ACCELERATIONS
\( a_{FL} \)
\( a_{FN} \) (normal)

\( v_{REL} < 0 \)

NO

NEG. SLACK > 0 ?

YES

\( v_{REL} < 0 \)

\( v_{REL} = 0 \)

\( v_{REL} > 0 \)

\( v_{REL} = 0 \)

POS. SLACK > 0?

YES

\( a_F > 0 \) ?

NO

NEG. SLACK > 0 ?

YES

\( a_F > F_{LL} \) ?

YES

\( a_C = -F_{LL} \)

NO

\( a_C = 0 \)

YES

\( a_C = R_{LL} \)

\( a_{REL} = a_F - a_C \) (\( \perp \) FRICITION COMPONENT)

UPDATE \( v_{REL} \)

UPDATE CARGO DISPLACEMENT

EXIT
COMPUTATIONAL OPERATIONS FOR CARGO SUBROUTINE

1. Longitudinal acceleration is computed by crash pulse program.

2. Normal acceleration (augmented by an equivalent acceleration for weight) is computed:

   \[ a_{FN} = X \sin \theta + Y \cos \theta - \beta s_J + 32.2 \cos \theta \]

   where

   \[ s_J = \text{Distance from center of gravity to the cargo location} \]

3. If cargo relative velocity (relative to the floor) is zero at beginning of time interval \( \Delta t \), cargo acceleration is computed as follows:

   \[ a_C = a_F \quad \text{for } (-F_{LL} - f_C a_{FN}) < a_F < (R_{LL} + f_C a_{FN}) \]

   \[ a_C = -F_{LL} - f_C a_{FN} \quad \text{for } a_F < (-F_{LL} - f_C a_{FN}) \]

   \[ a_C = R_{LL} + f_C a_{FN} \quad \text{for } a_F > (R_{LL} + f_C a_{FN}) \]

   where

   \[ a_C = \text{cargo acceleration} \]

   \[ a_F = \text{floor acceleration (longitudinal)} \]

   \[ a_{FN} = \text{floor acceleration (normal)} \]

   \[ f_C = \text{coefficient of friction between floor and cargo} \]

   \[ R_{LL} = \text{rear load-limiter limit load (in the form of equivalent cargo acceleration)} \]

   \[ F_{LL} = \text{forward load-limiter limit load (equivalent acceleration)} \]

4. If the cargo has a relative velocity, cargo acceleration is computed as follows:

   \[ a_C = R_{LL} + f_C a_{FN} \quad \text{for } v_{REL} > 0 \text{ and no slack} \]
5. If slack is present in system, the cargo acceleration is:

\[ a_C = -F_L - f_C a_{FN} \text{ for } v_{REL} < 0 \text{ and no slack} \]

6. The relative cargo acceleration is computed as:

\[ a_{REL} = a_F - a_C \text{ with } a_{REL} \text{ taken positive in the forward direction but } a_F \text{ and } a_C \text{ positive in the aft direction.} \]

7. Relative velocity and relative displacement are computed by numerical integration:

\[ \Delta v_{REL} = (v_{REL} - \frac{\Delta a_{REL}}{2}) \Delta t \]

\[ \Delta s_{REL} = (v_{REL} - \frac{\Delta v_{REL}}{2}) \Delta t \]

where

- \( s_{REL} = \) relative (forward) displacement of cargo
- \( v_{REL} = \) relative (forward) velocity of cargo
APPENDIX III

SOIL DRAG EXPERIMENT

An experiment designed to separate phenomena involved in the longitudinal resistance offered by the soil (during a crash) and to establish relative magnitudes of significant parameters was conducted using a typical clay-sand soil.

DESCRIPTION

An instrumented "shoe" was attached to the underside of a heavy cart. The cart was towed at various speeds over a trough of prepared soil, with the shoe set at a level for a given penetration of the soil. (See Figure 5.)

Instrumentation provided a history of normal and tangential forces for each run. Six runs were accomplished (and duplicated); they consisted of three velocities with the shoe orientated in each direction, i.e., with the sloped edge forward and the blunt edge forward.
The results are tabulated as follows:

<table>
<thead>
<tr>
<th>Velocity (fps)</th>
<th>Shoe Orientation</th>
<th>Tangential Force (lb)</th>
<th>Normal Force (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Slope Forward</td>
<td>550</td>
<td>800</td>
</tr>
<tr>
<td>22</td>
<td>Slope Forward</td>
<td>520</td>
<td>700</td>
</tr>
<tr>
<td>38</td>
<td>Slope Forward</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>4</td>
<td>Blunt Forward</td>
<td>500</td>
<td>550</td>
</tr>
<tr>
<td>22</td>
<td>Blunt Forward</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>38</td>
<td>Blunt Forward</td>
<td>450</td>
<td>350</td>
</tr>
</tbody>
</table>

If a mathematical model for the tangential force is postulated as

$$F_T = fF_N + vA_s x,$$

ranges for the coefficients \(f\) and \(v\) may be computed consistent with the above data. These ranges are found to be:

- \(f\) varies from 0.3 to 0.9
- \(v\) varies from 10 to 46 (lb-sec/ft)

where

- \(A_s\) is the total contact surface (ft^2)
**INPUT NOTATION FOR COMPUTER PROGRAMS**

<table>
<thead>
<tr>
<th>INPUT NOTATION</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(I, J)</td>
<td>(I=1, 3; J=1, 4) Coefficients describing contour coordinates (ft)</td>
</tr>
<tr>
<td>A(I, J)</td>
<td>(I=3, 9; J=1, 4) Coefficients describing ground-aircraft interaction</td>
</tr>
<tr>
<td>AS(J)</td>
<td>Area of structural cross section (ft²)</td>
</tr>
<tr>
<td>BETA</td>
<td>Longitudinal vibration damping factor</td>
</tr>
<tr>
<td>CDTH</td>
<td>Critical angle of plastic hinge rotation (rad)</td>
</tr>
<tr>
<td>CIA</td>
<td>Mass moment of inertia of aircraft about &quot;Y&quot; axis (slug ft²)</td>
</tr>
<tr>
<td>CIM(J)</td>
<td>Mass moment of inertia per section (slug ft²)</td>
</tr>
<tr>
<td>CLN</td>
<td>Station for cargo attachment</td>
</tr>
<tr>
<td>CMA</td>
<td>Total mass of aircraft (ft-lb)</td>
</tr>
<tr>
<td>CMU(J)</td>
<td>Mass per section (lb sec²/ft)</td>
</tr>
<tr>
<td>CM(I)</td>
<td>(I=1, 4) Generalized masses (lb sec²/ft)</td>
</tr>
<tr>
<td>CNS, NS</td>
<td>Number of fuselage sections</td>
</tr>
<tr>
<td>DF(J)</td>
<td>Fuselage depth from longitudinal axis (ft)</td>
</tr>
<tr>
<td>DS</td>
<td>Length of a section (ft)</td>
</tr>
<tr>
<td>DT</td>
<td>Time increment (sec)</td>
</tr>
<tr>
<td>ECA(J)</td>
<td>Normalized stresses for first and second bending vibration modes (lb/ft²)</td>
</tr>
<tr>
<td>ECB(J)</td>
<td>Structural parameter (lb/ft)</td>
</tr>
<tr>
<td>EI(J)</td>
<td>Flexural rigidity of fuselage (lb ft²)</td>
</tr>
</tbody>
</table>
EPS - Error factor
FLL - Forward load-limiter limit acceleration (G)
FMU - Friction coefficient
MSW - Program switch code
OM(J) - Frequencies of vibrations (rad/sec)
PH1(J) PH2(J) PH3(J) PH4(J) - Normalized deflections of first and second vibration modes
RLL - Rear load-limiter limit acceleration (G)
RPM - Reduction factor to plastic-hinge moment
SB - Location of center of gravity (ft)
SNK - Sink velocity of aircraft (ft/sec)
STRB - Buckling stress (lb/ft²)
THT - Angle of impact (rad)
THTD - Angular velocity (rad/sec)
VEL - Velocity at aircraft (ft/sec)
ZM(J) - Section moduli (ft³)
APPENDIX IV
CRASH PULSE SIMULATOR FORTRAN LISTING

PROGRAM CRASH
DIMENSION V(10),PV(10),A(10,4),H(9),WDFN(30),Q(20)
1PO(30),PH(32),PH2(32),PH3(32),PH4(32),CMU(32),ECA(32),ECH(32)
1DE(32),CM(32),AC(32),U(21),Pu(21)
10M(4),CM(4),SNDF(4),C5DF(4),CMOM(4),PLUT(7),RT(4),QMX(4),ZM(32)
10 FORMAT(8F10.6)
READ 10*,VFL,SNK,THT,THTN
READ 10*,((A(I,J),J=1,4),I=1,9)
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
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READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
READ 10*,CMU,CMU,CMU,CMU,CMU,CMU,
NS=NS
OM(1) = OM(1) - RTA * RTA/4 * 0
OM(4) = OM(4) - RTA * RTA/4 * 0
DO 15 1 = 1*4
OMX(1) = 0
CMOM(1) = SQRTF(OM(1)) * CM(1)
SND(1) = SINF(SQRTF(OM(1)) * NT)
15 CSN(1) = COSF(SQRTF(OM(1)) * NT)
SWCH = -1.0
DO 20 J = 1*NS
101 &T(J) = 0.
DO 16 J = 1*4
SND(1) = FXPF(-RTA/2 * NT) * SND(1)
16 CSN(1) = FXPF(-RTA/2 * NT) * CSN(1)
PT(1) = 0
PT(2) = 0
PT(4) = RTA
ZK = 0.
FC = 0.0
FU = 2.0
SH = 0.0
ZKG = 0.
ZKM = 0.
STRM = 0.
PRINT 200*MINT+NDAY+NYR+RUN
200 FORMAT(1X,20X,ASAVG,NALF+20X,SH RUN *15//)
PRINT 201
201 FORMAT(1X,48H TIME STA. A STA. D STA. C (ACCFL. G UNITS)*)
MSW = 1
STRL = 0.
DO 112 I = 1*3
112 V(I) = V(I) + NT + V(I)
110 PFN = FN
DO 111 I = 1*10
111 DV(I) = V(I)
THT = V(3)
DO 113 I = 1*9
113 H(I) = A(1) + THT*(A(I) + THT*(A(I) + THT* A(I)))
IF (THT < 117) = 118*118
117 H(I) = 5H
118 T = SB - 1.0/H(1)
H(4) = 1.0/H(4)
T2 = T1 - SINF(THT) - T1 * COSF(THT)
H(2) = H(2) * COSF(THT) + T1 * SINF(THT)
H(1) = T2
V1(1) = H(2) - V(2)
ZH = (V1(1) - V(1))/D1
Z = V1(1)
127 IF(Y=7) 130,700,700
130 IF(V(4)) 134*114*181
181 IF(Z) 114*114*182
182 IF(V(9)=A) 115,700*700
114 PRINT 116
116 FORMAT(1AH,RFHOUND,COMPLETE)
GO TO 700
116 SWCH = -1.0 * SWCH
117 IF (SWCH) 918*321*322
321 STOP
322 GA = AC(R)/32.2
N = GA + 7.8
326 IF (N) 307,307,307
327 IF (N-71) 106*304*307
328 PLOT (N) = AST
3.2 GA = AC(18)/32.2
K = GR + 26.5
306 IF (K) 305*305*306
307 IF (K-71) 307*307*307
308 PLOT (K) = ED
309 GC = AC(18)/32.2
L = GC + 7.8
309 IF (L) 310*308*309
310 IF (L-71) 310*310*308
310 PLOT (L) = PLS
310 PLOT (26) = PRD
310 PLOT (31) = PRD
310 PRINT 311*1*3G*GR*GC*PLOT
311 FORMAT (5X,F5.1,3F15.2,71A1)
312 IF (N) 312,312,312
313 IF (N-71) 314*314*312
314 PLOT (N) = BLNK
315 IF (K) 316*316*315
316 IF (K-71) 317*317*315
317 PLOT (K) = BLNK
318 IF (L) 318*318*318
319 IF (L-71) 320*320*318
320 PLOT (L) = RLNK
318 CONTINUE
30 NZ = ZD ; NT
COF = 1.4*THT*THT
H(3) = H(3)/COF
H(4) = H(4)*COF
W(A) = H(A)/[2.*COF-1.*]
1F1ZG = -ZGM + 411*411*412
412 ZGM = ZG
412 1ZG = ZG
411 ZG = ZG
411 IF (NZ) 119*120*120
170 GO TO (R00 + R01) * MSW
820 FUH = H(4) + ZG * ZG/8(H(4))
CK = (1.0 - SC)*H(R) * V(4) + 1.0/H(9))/(2.0 * FUH)
ZG = SQRTFIZ/(H(3) * FUH) * CK * CK - CK
ZS = Z - ZG
FN = ZS/H(4)
IF (FN - 1.0/H(4)) < 0.0 < FN + 0.0
802 MSW = 2
801 FUH = H(4) + ZG * ZG/8(H(4))
IF (FN - 1.0/H(4)) < 0.0 < FN + 0.0
804 FCH = H(3)
GO TO 806
805 FCH = FC * H(3)
800 ZG = ZG + ZG
ZS = Z - ZG
807 FN = ZS/FCH
FN = FN + 8FN
GO TO 803
119 N2S = NZ + ZG/(Z - DZ)
809 FNS = (1.0 - SC)*H(R) * V(4) + 7.0
IF (FN - FNSC) < 0.0 < FN + 1.0
808 FN = FNSC
121 FT = FMU * FN + (H(8) * V(4) + H(9) * V(4) + V(4)) * ZG * SC
ZG = (2G - FZG)/8T
CTH = COSF(V(3))
STH = SINF(V(3))
P = FN - CTH - FT * STH
C = FT + CTH + FN + STH
120 GO TO (126 + 1.0) * MRTN
126 V(7) = FT/CMA
PNCR = NCR
V(8) = FN/CMA
V(9) = (FN * H(1) + FT * (V(2) + ZG/2.0)) / CIA
123 GO TO 126
130 V(7) = V(7) + (V(6) + PV(6) + 1.0) * DT/2.
134 SJ = NS/2.
DO 131 J = 1 * NS
WND(J) = V(7) * STH + V(R) * CTH - V(9) * (SB - SJ)
131 SJ = SJ + DS
DO 132 I = 1 * 20
132 POJ(J) = O(11)
SP = Z - (V(7) + ZG/2.0) * STH + H(1) * CTH
CMM = CT((V(2) + ZG/2.0) * CTH + H(1) * STH)
J = SP/NS + 1.0
O(11) = P * PH1(J) + CMM * (PH1(J + 1) - PH1(J))/NS
O(2) = P + PH2(J) + CMM * (PH2(J + 1) - PH2(J))/DS
\[ \begin{align*}
\text{CIF} &= \text{CIF} + \text{CIM}(N) + \text{CMU}(N) + \text{SJ} + \text{S}\text{J} \\
\text{153} \quad \text{SJ} &= \text{SJ} + \text{DS} \\
\text{CIF} &= \text{CIF} - \text{CMF} + \text{SRA} + \text{SFR} \\
\text{CIR} &= \{ \text{CIF} - \text{CIF} - \text{CMF} \} \times (\text{SR} - \text{SRA}) - (\text{SR} - \text{SFR}) \\
\text{G1} &= (\text{CIF}/\text{CMF} + \text{CMR} + \text{MF} + \text{MR}) / \text{TM} \\
\text{C8} &= (\text{CIR}/\text{CMR} + \text{TM} + \text{RR}) / \text{TM} \\
\text{MXF} &= \text{U}(11) - \text{U}(10) \\
\text{MYF} &= \text{U}(20) - \text{U}(2) \\
\text{MRTN} &= 2 \\
\text{NTH} &= 0 \\
\text{NO} &= 160 \\
\text{PNTW} &= \text{NTH} \\
\text{PEN} &= \text{FN} \\
\text{NO} &= 161 \\
\text{I} &= 1 + 21 \\
\text{PUI}(1) &= \text{U}(1) \\
\text{NO} &= 162 \\
\text{I} &= 1 + 6 \\
\text{U}(4 + 1) &= \text{U}(6 + 1) + \text{U}(12 + 1) + \text{PU}(12 + 1) + \text{DT}/2 \\
\text{U}(11) &= \text{U}(1) + \text{U}(6 + 1) + \text{P}(12 + 1) + \text{DT}/2 \\
\text{TH} &= \text{U}(3) \\
\text{NO} &= 163 \\
\text{I} &= 1 + 9 \\
\text{H}(11) &= \text{A}(11) + \text{THT} \times \text{A}(1 + 2) + \text{THT} \times (\text{A}(1 + 3) + \text{THT} \times \text{A}(1 + 4)) \\
\text{STH} &= \text{SINF} (\text{THT}) \\
\text{CLTH} &= \text{OSF} (\text{THT}) \\
\text{IF} (\text{THT}) &= 147 + 168 + 18 \\
\text{W}(11) &= \text{SH} \\
\text{R1} &= \text{SR} - 1 + \text{H}(1) \\
\text{H}(4) &= 1 + \text{H}(4) \\
\text{T2} &= \text{H}(2) \times \text{STH} - \text{T2} \times \text{STH} \\
\text{W}(2) &= \text{H}(2) \times \text{STH} + \text{T2} \times \text{STH} \\
\text{H}(1) &= \text{T2} \\
\text{SINF} &= \text{SINF} (\text{U}(A)) \\
\text{CTH} &= \text{OSF} (\text{U}(A)) \\
\text{U}(21) &= \text{H}(2) - \text{NSF} \times \text{STH} - \text{U}(2) \\
\text{Z} &= \text{U}(21) \\
\text{ZD} &= (\text{U}(21) + \text{PU}(21)) / \text{DT} \\
\text{DO} &= 164 \\
\text{I} &= 1 + 2 \\
\text{U}(10) &= \text{PUI}(10) + \text{U}(7) + \text{PU}(7) + \text{U}(0) + \text{PU}(9) + \text{NYF} \times \text{DT}/2 \\
\text{U}(30) &= \text{PUI}(20) + \text{U}(8) + \text{PU}(8) + \text{U}(0) + \text{PU}(9) + \text{NM} \times \text{DT}/2 \\
\text{MXF} &= \text{U}(11) - \text{U}(10) \\
\text{MYF} &= \text{U}(20) - \text{U}(2) \\
\text{NXR} &= \text{U}(19) - \text{U}(4) \\
\text{NO} &= 164 \\
\text{DYR} &= \text{U}(5) - \text{U}(20) \\
\text{V}(1) &= \text{U}(11) \\
\text{V}(2) &= \text{U}(2) \\
\text{V}(3) &= \text{U}(3) \\
\text{V}(4) &= \text{U}(7) \\
\text{V}(5) &= \text{U}(8) \\
\text{V}(6) &= \text{U}(9) \\
\text{T} &= \text{T} + \text{DT} \\
\text{GO TO} &= 127 \\
\text{NO} &= 165 \\
\text{DTH} &= \text{U}(6) - \text{U}(3) \\
\end{align*} \]
147 PRINT 14A
14A FORMAT (1H FUSFLAG, ARRASK)
GO TO 7OG
150 PWM=STR*2*(MTH*(.5-1)*NTH*NTH)
1F(NTH-PNTH)1 1AO,17)17)
160 PWM=RRM*PWM
170 GA=(DXF*DXR+DYF*DYR)
   G0=G0*RM
   F1=U(Q) U(U)
   F2=U(J) U(U)
   F3=DXR*DF*DYR-DR*RF*YF+DYF*F2*DXR
   GA=PM/(CMF*TM)+FN*U(J) /CMF+DF+FT*(U(20)+.5*2.)/(CMF+RM*F2)
   FA=-PM/((CMF*TM)-FN*DXR/CMF+FT*DFR*CMF+DF)
   DFN=(G1-G5-G6*G2)
   U(I)=((G1-G5-G6*G4)/DFN
   U(I)=((G1-G5-G4)*DFN
   F3=F1*DXR+F2*DFR
   FA=NYF*U(I)
   FA-NYR+U(14)
   FR=NYF*U(I)
   FO=NXR*U(14)
   U(1)=(-F1+CMR*F4)/CMC-LUMF(F4+F7)
   U(1)=(-F1-CMF*F4)/CMC+TM*(F6+F7)
   U(14)=((FN+CMR*SP)/CMC-LUMF(F8+F9)
   U(17)=((FN-CMF*F1)/CMC+TM*(F8+F9)
   SJ=NS/2.
   J=1+NS
   IF (J-JH)174*174*175
   AC(J)=U(I)1*CTH+U(U)1*STH-U(U)1*(SRF-SJ)
   GO TO 173
   J=1+NS
   AC(J)=U(I)1*CTHR+U(U)1*STHR-U(U)1*(SRF-SJ)
   SJ=JS*DS
   GO TO 160

700 PRINT 203, NRUN
203 FORMAT (1H1*20X, 15H INPUT DATA RUN,15//)
   PRINT 204+VFL*SNK*THPlFMTI
   PRINT 204+VFL*F7.2+6X*4H SNK*FA,2,
   1AX*6H THT+FX*6X*11H FRTCT COFF+F5.7//
   PRINT 205+STRB*CDTH+BETA

205 FORMAT (1H CR STRESS F10.3*6X*7H CR ANG*F6.3*6X*7H DAMP FACTOR+F7.3//)
   PRINT 206+MF*H4P+HSP

206 FORMAT (1H FN1=ZS*E10.4+10X*11H FN2=ZG*ZG*F10.4+10X*11H FN3=ZG*ZD*ZG/F10.4//)
   PRINT 207+NP*H7P+HBP

207 FORMAT (1H FN=F10.4+10X*11H FT=F10.4+10X*11H FT2*XD*XZ*ZG*ZG*E10.4//)

40
PRINT 208
208 FORMAT(20X,15H DEVELOPED DATA//)
PRINT 209, V(I), I=1,6
Z5=Z5P
GL=V(1)-H1P
PRINT 410, ZG*ZS*ZGM*GL*STRM
410 FORMAT(12H GRND DEFORM,F5,2.5X,F7,2.5X)
11H MAX GRND DEFORM,F6.2*5X*7H GROOVE,F7.2*5X*10H MAX STRESS,F9.2*)
PRINT 409, IQMX(I), I=1,4*NST
409 FORMAT(29H GENERALISED COORDINATES Q1=F10.5*3X*4H Q2=F10.5*3X*
14H Q3=F10.5*3X*4H Q4=F10.5*3X*12H MAX STR LOC+15)
STRL=ARSF(STRL)
PRINT 192, STRL, JSTL
192 FORMAT(10X,16H MAX TENS STRESS, F9.2*3X*16H LOCATION NUMBER, 15)
PRINT 40
40 FORMAT(1H1,11H INPUT DATA)
PRINT 145, ((A(I), J), I=1,4), J=1,9)
PRINT 145, FC*SC
PRINT 145, CMA*CIA*SP*STRA*CDTH*RPM*CNS*DS*FMU*DT
NRUN=NRUN+1
READ 10, VEL, SNK, THT
IF(EOF(60),999,11)
990 STOP
END
INPUT DATA FOR CRASH PULSE SIMULATOR

**Aircraft - CV-7 (Operational Light)**

<table>
<thead>
<tr>
<th>A(I, J)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.03704</td>
<td>3.1196</td>
<td>-8.557</td>
<td>11.005</td>
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<tr>
<td>2</td>
<td>4.64</td>
<td>-1.672</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>3</td>
<td>8.0 x 10^{-7}</td>
<td>0.0</td>
<td>8.0 x 10^{-6}</td>
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<tr>
<td>4</td>
<td>1.924 x 10^{-7}</td>
<td>0.0</td>
<td>33.6 x 10^{-6}</td>
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<tr>
<td>5</td>
<td>8.0 x 10^{-4}</td>
<td>0.0</td>
<td>135.0 x 10^{-4}</td>
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<tr>
<td>6</td>
<td>2.0 x 10^{-5}</td>
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<td>42.2 x 10^{-5}</td>
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<tr>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>8</td>
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<td>-2400.</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>9</td>
<td>20.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**CMA** = 900.0            **CDTH** = 0.30

**CIA** = 1.53 x 10^5        **RPM** = 50

**SB** = 27.0            **CNS** = 26.0

**STRB** = 7.0 x 10^7        **BETA** = 40.0
DS = 26.
FMU = 0.75
DT = 0.001

OUTPUT OF PROGRAM VIBRAT (REFER TO APPENDIX VI)

CMU, CIM, AS, DF:

<table>
<thead>
<tr>
<th>CMU</th>
<th>CIM</th>
<th>ZM</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.0</td>
<td>200</td>
<td>0.050</td>
</tr>
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Developed Data For Crash Pulse Simulator

Final coordinates: (at rebound)

\[ \begin{align*}
X &= -2.37 \text{ ft} \\
Y &= 7.45 \text{ ft} \\
\theta &= 0.13 \text{ rad}
\end{align*} \]

Final velocities and accelerations:

\[ \begin{align*}
X &= 78.59 \text{ ft/sec} \\
Y &= -2.17 \text{ ft/sec} \\
\dot{\theta} &= -0.50 \text{ rad/sec}
\end{align*} \]

\begin{align*}
\text{Fuselage deflection} &= 0.78 \text{ ft} \\
\text{Maximum ground deformation} &= 0.45 \text{ ft} \\
\text{Length of groove formed between contact and rebound} &= 20.8 \text{ ft}
\end{align*}
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REBOUND COMPLETE
APPENDIX V
CARGO SIMULATOR FORTRAN LISTING

PROGRAM CRASH
DIMENSION V(10), PV(10), A(4*6), H(9), W0N(30), 0(20)*
1DQ(70), PH(92), PH(92), PH(92), PH(92), PH(92), CMU(92), ECA(32), ECR(32)
1LH(92), LTH(92), AC(92), U(21), PU(21), OM(4), CM(4), SDN(4), CSN(4)*
1RFMP(4), PLOT(71), ST(4), DMX(41), ZM(92)
10 FORMAT (8F10.6)
READ 10* V(1): SNK: THI: THDP
READ 10* ((A(I,J)+J=1,J=1+1)*I=1)*I=1)
READ 10* CMA, CIA, SR, STRB, CDTH, RPM, CNS, DS, FNU, DT
READ 10*CMA, CMF, PH6, PH6, PH6, PH6, ECA, ECP, ZM
READ 10*CM: CM: RTA
READ 300, (PLOT(J), J=1,71) RLNK, PRN, AST, F0, PLS
300 FORMAT (71A, 5A1)
READ 10* CLN: RLL, FLL
READ 9* MNTH, NDAY, NYR, NUN
9 FORMAT (415)

SN = 1.5
SC = 7.5
11 DO 12 J=1,10
11 V(1) = 0,
12 RLL = RLL, S2
FLL = FLL, S2
LN = CLN
V(i) = THI
V(i) = SQRTF (VEL*V6L - SNK*SNK)
V(5) = SNK
V(6) = THDI
DO 14, 1, 2
14 V(1) = A(1:11) + T1*T1(A(1:1) + THI*A(1:3) + THI*A(1:4))
FN = 9
IF (THI) 70, 71, 71
70 V(1) = V(1) + A(1:11) * 600. * THI
71 THI = SB=1 + V(1)
12 = V(2) + SINF (THI) - T1*COSF (THI)
2 = V(2) * COSF (THI) + T1*SINF (THI)
V(1) = T1
FT = FN
XT = 1
NCR = 1
MRTN = 1
THDP = THI
DO 17 1 = 39
17 (1) = A(1:11) + THI*(A(1:11) + THI*(A(1:9) + THI*A(1:4))
HP = H(3) / (1.4 + 2.4 * THI)
H = H(5)
HP = H(5) / (1.4 + 2.4 * THI)
HP = HPV(5)
47
NO 13 J = 1+20
19 O(J)=0.
T=0.
NS=NS
OM(J)=OM(3) - RFTA * RFTA/4.0
OM(J)=OM(4) - RFTA * RFTA/4.0
NO 15 I = 1+4
OMX(I)=0.
CMOM(I)=SRTF(OM(I)) * CM(I)
SN(I)=SRTF(OM(I)) * NT
15 CSN(I)=SRTF(CS(I)) * NT
CHM=-1.0
NO 401 J = 1+NS
201 ACC(J) = 0.
NO 16 I = 7+4
SND(I) = EXPF(-RFTA/2. * DT) * SND(I)
16 CSN(I) = EXPF(-RFTA/2. * DT) * SND(I)
BT(I)=0.
RT(2)=0.
RT(3)=RFTA
ZG = 0.
FNC = 0.0
FC=5.0
FU = 2.0
SH=60.
ZDG = 0.
7GM = 0.
STRM = 0.
PRINT 200 * MNTH * NDAY * NYR * NRUN
200 FORMAT(1H1, 2X, 5H TIME, 2X, 6H RATE, 2X, 5H RUN, 1S//)
PRINT 21
201 FORMAT (5H* TIME, CARGO, AC, FLOOR, ACEL, 3X, 12H(*) FLOOR, (= CARGO)
MSW = 1
PVR = 0.
VR = 0.
PAR = 0.
SR = 0.
SRM = 0.
SRL = 0.
STR = 0.
AR=0.
MCR=1.
NO 112 I=1+3
112 VI(I)=VI(I+3) * NT + VI(I)
110 PFIN
DO 111 I=1,10
111 VI(I)=VI(I)
TH=V(3)
DO 113 I=1,9
113 H(I)=A(I)+THT* (A(I)*2)+THT* (A(I)*3)+THT* (A(I)*4))
   IF (THT) 117,118,118
   H(I)=SH
118 T1=SB-1./H(I)
   WR(I)=1./H(I)
   T2=H(I)*SINF(THT)-T1*COSF(THT)
   W(1)=H(I)*COSF(THT)+T1*SINF(THT)
   H(I)=T2
   V(10)=H(2)-V(2)
   Z=V(10)-PVI(10)/DT
   Z=V(10)
127 IF(T<.3) 180,700,700
180 IF(V(4)) 114,114,181
181 IF(Z) 114,114,182
182 IF(V(4)<-R) 114,700,700
114 PRINT 116
116 FORMAT(18H REBOUND COMPLETE )
   GO TO 700
115 SWCH = -1.*O * SWCH
   IF(ACLN) 570,571,571
570 ACLN=0.
571 IF(VR) 500,501,502
501 IF (ACL(N)) 502,502,504
504 IF (SRM - SR) 505,505,506
505 IF (ACL(N) - RLL) 600,600,507
507 AR = ACL(N) - RLL
508 IF (VRM) 517,518,519
517 AR = AR + SMU * ACLN
   GO TO 520
518 AR = AR - SMU * ACLN
   GO TO 520
518 IF (ARSF(A)) - SMU * ACLN) 521,521,522
521 AR = 0
   GO TO 514
522 AR = AR + (L - SMU * ACLN/ABS(A))
520 VR = PVR + (AR + PAR) * DT/2.
   IF (VRM PVR) 509,510,510
509 VR = 0.
   AR=0.
   GO TO 514
510 SR = SR + (VR + PVR) * DT/2.
   IF (SR - SR) 511,511,512
512 SRM = SR
511 IF (SR - CRL) 411,411,514
513 SRL = SR
514 PVR = VR
   PAR = AR
   GO TO 600
506 AR = ACL(N)
GO TO 508
509 IF (SR - SRL) 515,515,50A
510 IF (AC(LN) - FLL) 600,600,61A
511 AR = AC(LN) + FLL
GO TO 508
520 IF (SR - SR1) 507,507,506
500 IF (SR - SRL) 51A,51A,506
600 IF (SWCH) 31A,31A,43
530 STOP
531 GA = (AC(LN) - AR)/12.5

K = GA + 24.5
IF (K) 305,305,396
306 IF (K-7) 307,307,305
307 PLOT (K) = EQ
305 GC = AC(LN)/32.2
L = GC + 26.5
IF (L) 3CA,308,309
300 IF (L-7) 310,310,30R
310 PLOT (L) = AST
308 PLOT (26) = PDL
311 FORMAT (5X.F5.3,2F12.2,7141)
312 IF (K) 315,315,316
316 IF (K-7) 317,317,315
317 PLOT (K) = RLINK
315 IF (L) 31A,31A,319
319 IF (L-7) 320,320,318
320 PLOT (L) = BLNK
318 GO TO (523,524) * MCR
523 DZ = DT
COF=1,4*THI*THI
H(3) = H(3)/COF
H(4) = H(4)*COF
M(1) = H(1)/2*COF + 1
1F(ZG - ZGM) 411,411,412
412 ZGM = ZG
ZSP = Z * ZG
411 PZG = ZG
1F (DZ) 119,120,120
120 GO TO (800,801), MSW
800 FUH = H(4) + ZND + ZND/H(5)
CK = (1,0-SC)*H(8) + V(4)+1.0/H(3))/(2,0 + FUH)
ZG = SQRTF(Z/(H(3)*FUH+CK+CK)) - CK
ZS = Z - ZG
1F (FN - 1)/H(61) 803,803,805
802 MSW = 2
801 FUH = H(4) + ZNG * ZNG / H(5)
1F (FN - 1)/H(61) 804,804,805
804 FCH = H(3)
GO TO 806
A04 FCH = FC  + H(3)
A06 NZG=NZ/(Z*FUM+ZG+1)=5C1*H(8)*V(4)*FCH+1*0
B09 ZG=ZG+NZG
N2S = NZ - NZG
DFN = DZS/FCH
FN=PFN+DFN
GO TO 803
119 NZG=NZ*ZG/(Z-DZ)
FCH = H(3)
GO TO 899
A04 FN5c=(1馨=Sc)*H(8)*V(4)*ZG
IF (FN-FNSC) 809+12; 171
A08 FN=FN5C
121 FT = FMU + FN + (H(8)  + V(4)  + H(9)  + V(4)  + V(4))  + ZG  + Sc
ZGc = (ZG  - PZG)/OT
CTH=COSF(V(3))
STH=SINF(V(3))
P = FN*CTH-FT*STH
C = FT * CTH + FN * STH
129 GO TO (196+19)*V(1)
12A V(7)=FT/CMA
FNCR = NCR
V(A)= FN/CMA
V(0)= FNS*H(1) + FT*V(12) + ZG/2.1/CIA
NO 130 J=1; 3
V(3+1)=V(3+1)+V(A+1)+PV(3+11)*NT/2.
12C V(11)=V(11)+V(3+1)+PV(3+11)*NT/2.
KJS=S/P.
NO 131 J=1; NS
WNH(J)=V(7)*STH+V(A)*CTH-V(9)*(SA-SJ)
131 SJ+JS+DS
NO 132 I = 1; 20
132 PQ(0)=Q(1)
J=SP7=SUB-(V(7)+ZG/2.1)*STH+H(11)*CTH
CMM=C*[(V(12)+ZG/2.1)*CTH+H(11)*STH]
J=SP7=NS+1; 0
Q(1) = P * PH1(J) + CMM * (PH1(J+1)-PH1(J1))/NS
Q(2) = P * PH2(J) + CMM * (PH2(J+1)-PH2(J))/DS
Q(3)=C*PH3(J)
Q(4)=C*PH4(J)
ACFL = V(8) - STH - V(7) - CTH
SJ = SA - NS/2.
THSO=V(14)*V(A)
NO 133 J=1; NS
Q(1) = Q(1)-CMU(J)*WDD(J)-PH1(J)
Q(2) = Q(2)-CMU(J)*WDD(J)-PH2(J)
Q(3) = Q(3)-CMU(J) + (ACFL + THSO + SJ) - PH3(J)
Q(4) = Q(4) - CMU(J) + (ACFL + THSO + SJ) - PH4(J)
133 SJ = SJ-DS
DO 217 I = 1; 4
IF(T-DT/2) 210*210*211
210 Q(4 + 1) = Q(1) * DT * NT/(16. * CM(1))
Q(14 + 1) = Q(14 + 1) + 9. + (SORTF(OM(1)) * DT)
GO TO 213
213 QT = PQ(14 + 1) + PQ(1)/CMOM(1)*DT
Q(4 + 1) = PQ(4 + 1) * CSP(1) + QT * SND(1)
Q(14 + 1) = QT * CSD(1) - PQ(4 + 1) * SND(1)
219 Q(17) = Q(1) + AT(1) + AT(1)/4. + Q(4 + 1) - AT(1) * PQ(8 + 1)
IF (ABSQ0(4+1) - QMX(1)) 212 + 212 + 214
214 QMX(1) = ABSQ0(4 + 1)
212 Q(17) = PQ(8 + 1) - (Q(12 + 1) * PQ(12 + 1) * DT/2) * 0
PSTB = 0
PSTR = 0
CMNT = CMA - CMU(1)/2. * 0
SJR = SA - NS/2.
PShR = 0
RMM = CMM
NPP = 1
NO 400 J = 1,NS
AC(J) = ACFL + THSO * SJ + Q(15) * PH3(J) + Q(15) * PH4(J)
GO TO (147.144), MXT
147 ACN = V(17) * STH + V(19) * TH - V(19) + SJ
IF (J = LN) 146, 147 + 146
147 ACLN = ACN + 32.2 * CTM
146 ShR = PShR * CMU(J) * ACN
GO TO (401 * 407) + NPP
401 IF (SP = SR + SJ - DS/2.) 403, 403, 402
403 NPP = 2
SHR = ShR - P
409 MM = RMM - (PShR * ShR) * NS/2., + CM(J) + V(9)
PShR = ShR
STR = ECA(J) + Q(15) + ECA(J) * Q(6)
IF (STRL = STRN) 191, 191, 190
190 STRL = STRN
JSTL = J
191 IF (STRL = STRN) 419, 414, 414
414 STRL = STRN
JST = J
415 IF (STRL = STRR) 140 + 41 + 41
410 PStr = PSTR
PSTR = PStr
GO TO 146
141 JH = J + 1
SH = SA - SJ - DS/2. * 0
PRINT 147, JH
142 FORMAT (21H YIELD HINGE AT STA., J3)
MXT = 2
146 CMNT = CMNT + CMU(J) + CMU(J + 1) / 2. * 0
400 SJ = SJ - NS
145 FORMAT (1X, 10E11.4)
DO 161 I = 1, 2

161 PU(I) = U(I)
DO 162 I = 1, 16

162 U(I) = PU(I) + (U(I+1) + PU(I+1)) * DT/2

TH = U(I)
DO 163 I = 1, 9

163 H(I) = A(I+1) + TH * (A(I+1) + TH * A(I+1))
STH = SINF(IH(I))
CTh = COSF(IH(I))
IF (IH(I)) 157, 158, 158

157 H(I) = SH
158 TH = SH - 17 H(I)

H(4) = IH(4)
TH = R(IH(2) + IH(4))
H(2) = H(IH(2) + IH(4))
H(1) = T2
STHR = SINF(U(IH(2)))
CHHR = COSF(U(IH(2)))
U(21) = H(2) - DSF * STH - U(2)
Z = U(21)
Z = (U(21) - PU(21)) / DT
DO 164 I = 1, 2

164 U(I) = PU(I) + TH * (U(1) + PU(1)) * NYF + DT/2

DXF = U(I) - U(1)
DYF = U(1) - U(2)
DXR = U(1) - U(3)
DYR = U(1) - U(4)

166 NYR = U(IH(5)) - U(19)
V(1) = U(1)
V(2) = U(2)
V(3) = U(3)
V(4) = U(4)
V(5) = U(5)
V(6) = U(6)

T = T + DT
GO TO 127

165 TH = U(IH(6)) - U(13)
IF (TH <= CDTH) 166, 167, 167

167 PRINT *, 168
168 FORMAT (15H FUSELAGE BREAK)
GO TO 700

166 PHM = STRP % ZM(JH) *(5-11) * TH * DTH
IF (DTH <= PDTH) 169, 171, 171

169 PHM = RPM * PHM

171 G4 = (DXF * DXR + DYF * DYR)
G2 = G4 * RM
F2 = U(IH(2)) - U(IH(1))
F = DXF * DXR + DYF * DYR
G3 = PHM / (CMF * TM) + FN * (U(IH(1)) / (CMF * TM) + DXF / CMF) * FT * (U(IH(2)) * 5 + Z) /
1(CMF*TM)-DF/YF/CMF+RH*F3
G6=PHM/(CMR*TM)-FN*DXF/CMF+FT*DYR/CMF+F3
DEN=61*G5=G4=62
U(15)=63*G5=G2*G61/DEN
U(18)=64*G6=L3*G4)/DEN
F4=1*DXF+F2*DXR
F5=FL*DYF+F2*DYR
F6=DF*U(15)
F7=DF*U(18)
F8=DXF*U(15)
F9=DF*U(18)
U13;=(FT*CMF*F4)/CMA-CLM*(F6+F7)
U16 =-(FT-CMF*F4)/CMA*TM*(F6+F7)
U14=(FN*CMR*F5)/CMA-CLM*(F8+F9)
U17=(FN-CMF*F5)/CMA+TM*(F8+F9)
SJ=NS/2.0

DO 173 J=1:NS
IF(J-JH) 174 174*175
174 AC(J)=-U(13)*CTH+U(14)*STH+U(9)*U(9)*(SRF-SJ)
GO TO 173
175 AC(J)=U(16)*CTH+U(17)*STH+U(12)*U(12)*(SRF-SJ)
173 SJ=SJ+DS
IF(CLN*3.>SH) 572*573*573
572 AC(LN)=U(13)*STH+U(14)+32*2)*CTH-U(15)*(SRF-CLN*3.)
GO TO 160
573 AC(LN)=U(16)*STH+U(17)+32*2)*CTH-U(18)*(SRF-CLN*3.)
GO TO 160
700 AC(LN)=U
710 T=T+DT
MCR=2
GO TO 115
624 T=T+DT
IF(VKH) 525*525*115
525 PRINT 203*NRT
203 FORMAT(1H1*20X+15H INPUT DATA RUN.15//)
PRINT 204*VEL*SNK*THTP*FMU
204 FORMAT(4H VEL,F7.2,6X+4H,SNK,F6.2,20X,THT,F7.2,6X+4H,PCT,COF,F5.2,20X)
PRINT 205*STRA+CSTH*FTA
205 FORMAT(1H CR STRESS +F10.3*6X+7H CR ANG.F6.3*6X+6H DAMP FACTOR+F7.3//)
PRINT 206*H3P*H6P*H9P
206 FORMAT(4H FN=10.4*10X+7H CR ANG.F6.3*10X+11H FN2=ZG*ZG*E10.4*10X+11H FN3=ZG*ZGZG/EC6*E10.4//)
PRINT 207*H6P*H7P*H9P
207 FORMAT(7H FN=10.4*10X+11H FT=FMT/ZG*ZG*E10.4*10X+11H FT2=ZG*ZG*E10.4//)
PRINT 208
208 FORMAT(20X+15H DFVELOPFD DATA.//)
PRINT 209*TV1(11)=1.6
209 FORMAT(3H X=F7.2*5X+3H Y=F6.2*5X+F6.2*5X+F6.2*5X+F7.2*)
INPUT DATA FOR CARGO SIMULATOR

Aircraft - CV-7 (Operational Light)

The input data is the same as that for the crash simulator, (refer to Appendix IV) plus the following:

CLN = 13.
RLL = 8.
FLL = 4.

Developed Data For Cargo Simulator

Same as for crash simulator, plus:

Maximum forward displacement of cargo relative to floor = 0.33 ft
SIMULATOR PLOT OF CARGO AND FLOOR ACCELERATIONS

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APPENDIX VI
PROGRAM VIBRAT FORTRAN LISTING

PROGRAM VIBRAT

DIMENSION PH(32),ET(32),EC(32),PHA(32),PLOT(71),CUI(32),V(32),
1 RM(32),CF(32),AS(32)

5 FORMAT (AT10,4)
6 FORMAT (2F10,4,2F10)
7 FORMAT (7A1,3A1)

E = 1D000.00000

CN=NS

CN = 4.26 / (CN#NS)

SJ = NS/2

MO = 0

SJ = NS/2

SJ = SJ + NS

F1 = CU(J) + SJ/4

F2 = (F1 + CUU(J) - CUI(21))/4

F3 = F1 - NS/4

F4 = F2 + NS/4

F5 = F3 - 2, NS

DEF = CUI(J - 1) * SJ

DEF = SJ + NS

DEF = (DEF + CUI(J)) * SJ/2

F1 = F1 + DEF

F2 = F2 + DEF

F3 = F3 + (F1 - DEF/2) * NS/2

F4 = F4 + (F2 - DEF/2) * NS/2

F5 = F5 + (F3 - DEF/2) * NS/2

V(M) = V(1) = V(1) + NS/4

NO CM = J = 2, NS

NVE(CUI(J-1) + PH(J-1) + CUI(J) + PH(J))/2

V(J) = V(J - 1) + NV

GO TO (P32*1018, 1)*XT

P32 NVE = E*CUU(NS) + PH(NS) - CUI(NS - 1) + PH(NS - 1)/8

VF = V(NS) + NV

"V = PH(NS) + IV(NS) + NV/2) * NS/2

DEF = F1 + F4 - F2 + F3

V1 = (F2 * RMF - F4 * VF)/DEF
C2 = (C3 + VE + 1) * BME1/DEF
S3 = S3/N7
N4 = (PH(1) + C1 + SJ + C2)
N5 = + J = 1;NS
PH(J) = PH(J) + C1 + SJ + C2
0.1E SJ = SJ + NS
MST = 2
GO TO (OS1,919)*MSW
0.1H P4U = (O4U(11/E1(11)) * NS/4
PH(1) = PHP * NS/4
NC OUT J = 2;FC
DMPHP = (PM(J - 1)/E1(J - 1) + PM(J)/E1(J)) * NS/2
PDP = PHP + DMPHP
9.2H PH(J) = PH(J - 1) + (PHP - DMPHP/2) * NS
PRINT 09,H4
GO TO OUT
0.04 DCM=ABPC(OU-DOY)
DOY = OM
MST = 1
IF (DOX = EPS) 09R,098,J11
0.0D DO OUT J = 1;NS
PLLOT(94)=NDN
IF(ARGV(PH(J),-1,1) =0,0,END,END
8.0H DMP=2H*PH(J)+2
N = PHP + 1;E
PLLOT(N) = STAR
5.3 PRINT 10+J,PH(J)+PLLOT
10 FORMAT (11,F4*PS4+12X,71A1//)
9.0H PLLOT(N) = BLNK
PRINT 11,OM
11 FORMAT(11H1,10X,F12,3//)
0.09 OUT J = 1;NS
ECFU = RM(J) * EC(J)/E1(J) * OM
0.1H PRINT 12,ECFU,J
12 FORMAT (2X,F12,3//)
GO TO (021,927)*MSW
0.2H MSW = 2
0.2H EPS=1.0
CM1 = 0
NC 016 J = 1;NS
CM1 = CM1 + (CMU(J) + PH(J)) * PH(J)
0.14 PH(J) = PH(J)
PRINT 14,CM1
PRINT 12
13 FORMAT(1H1,12H SECOND MODE)
S8=NS/2
COF=9.42 / (CNS*NS)
NC 015 J=2;NS
PH(J) = COSF(COF*CH(J))

010 CJ = SJ + NS
015 CM = 0

DO 019A J = 1, NS
016 CJ = CM + CMU(J) * PH(J) = PH(J)
A = CMU(J) / PH(J)
DO 017 J = 1, NS

017 PH(J) = PH(J) - A * PH(J)
GO TO (021, 018, 031, MXT)

019 FACT = 1. * PH(J)
DO 020 J = 1, NS

020 PH(J) = PH(J) * FACT

025 FORMAT (5X, 10F11.4)

GO TO 001

027 CMU(J) =

030 CMU(J) + CMU(J) * PH(J) * PH(J)
PRINT 14, CM

NS(J) = 1

034 CJ = CMU(J)

DO 030 J = 1, NS

030 PH(J) = COSF(COF*CH(J))

035 CJ = SJ + NS

PRINT 05, PH

037 CMU(J) = (E4 * CMU(J) + PH(J) * PH(J) - E4 * CMU(J) * PH(J)) / 8.

DO 032 J = 1, NS

032 CMU(J) = CMU(J) + CMU(J) * PH(J) * PH(J)

036 CMU(J) = CMU(J) + CMU(J)

PRINT 05, CMU(J)

040 CJ = CMU(J)

PRINT 05, PH

044 CF(J) = CMU(J) / AS(J) + CMU(J) / AS(J)

045 CM = CMU(J)

PRINT 05, CF

049 CF(J) = CF(J) + CMU(J) / AS(J)

PRINT 05, CF

058 PH(J) = CF(J) * PH(J) / AS(J) * AS(J)

059 J = 1, NS

060 PH = (CF(1) / AS(J-1) + CF(J) / AS(J)) * NS / (2 * F)

63
000 PRINT (J-1) + PHI
  PRINT PHI
  GO TO 020

020 PHI=1
  GO TO 040

040 PHI=PHI-1
  PHI=PHI*PHI
  GO TO 040

041 PHI=PHI+1
  PHI=PHI*PHI
  GO TO 040

042 PHI=PHI-1
  PHI=PHI*PHI
  GO TO 040

043 PHI=PHI-1
  PHI=PHI*PHI
  GO TO 040

044 PHI=PHI+1
  PHI=PHI*PHI
  GO TO 040

045 PHI=PHI-1
  PHI=PHI*PHI
  GO TO 040

046 PHI=PHI+1
  PHI=PHI*PHI
  GO TO 040

047 PHI=PHI-1
  PHI=PHI*PHI
  GO TO 040

048 PHI=PHI+1
  PHI=PHI*PHI
  GO TO 040

END
INPUT FOR PROGRAM VIBRAT

DS = 3.0
EPS = 0.10
NS = 26.
MSW = 1
CMU = refer to Appendix IV

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1. REPORT TITLE
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2. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

3. AUTHOR(S) (Last name, first name, initial)
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11. SPONSORING MILITARY ACTIVITY
US Army Aviation Materiel Laboratories
Fort Eustis, Virginia

12. ABSTRACT
This report presents the findings of an investigation into the crash pulse of fixed-wing cargo aircraft and the resulting behavior of cargo restrained by load limiters.

A crash pulse simulator computer program was developed that obtains acceleration-time histories at selected stations in the cargo compartment and under various crash conditions. This simulator was employed to obtain crash pulses for a wide range of input parameters, both for the CV-2 and the CV-7 Army aircraft. The resulting acceleration pulses were studied to determine a suitable spectrum of realistic pulses.

The crash pulse program was subsequently modified to include a routine that would simulate cargo dynamic behavior during the crash sequence, employing the floor acceleration data as it is developed. This latter program was applied to CV-2 and CV-7 aircraft, under significant crash conditions, to obtain the dynamic response of cargo to the crash pulse.
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