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TRECOM TECHNICAL REPORT 63-71

STUDY OF
DESIGN FACTORS IN AIR DELIVERY FOR
CV-7 CARIBOU AIRCRAFT

Task 1D643324D59806
(Formerly Task 9R87-14-007-06)

December 1963

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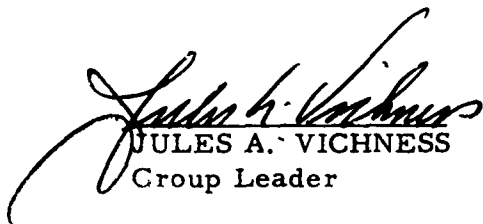
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STUDY OF
DESIGN FACTORS IN AIR DELIVERY FOR
CV-7 CARIBOU AIRCRAFT

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U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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SYMBOLS

<u>Alphabetical Character</u>	<u>FORTTRAN Character</u>	
AM	AM	length of container
β	S	$\text{Tan}^{-1} \left(\frac{2HG}{AM} \right)$
DE or DD	DE or DD	arbitrary interval of time between successive points in solution of a differential equation
g		acceleration of center of gravity
G		center of gravity
H		mid-point of platform of container
HG	HG	height of center of gravity of container above underside
HH	HH	height of container
I_G		moment of inertia of container about center of gravity, about horizontal axis perpendicular to line of flight
KE		kinetic energy
L		sill of floor
P		force of extraction of parachute on container in gravitational units
q	Q	distance of mid-point of underside of container from aft edge of floor
$\dot{q}$	QD	first derivative of Q with respect to time

<u>Alphabetical Character</u>	<u>FORTTRAN Character</u>	
t		time
V		potential energy
W		weight of container in gravitational units
x	X	distance in inches from forward bulkhead of cargo compartment to some indicated point of container
x_{st}	XST	distance from bulkhead of point on floor from which container starts from rest
$x_B y_B$		coordinates of corner B of container
$x_G y_G$		coordinates of center of gravity of container
θ	T or TH	angle through which container has turned from original horizontal position
$\dot{\theta}$	TD	first derivative of θ with respect to time
$\ddot{\theta}$	TDD	second derivative of θ with respect to time
λ	YAL	angle of inclination of parachute cord to horizontal
ϕ	F	$\theta + \lambda + \beta$
$\dot{\phi}$	FD	first derivative of ϕ with respect to time
$\ddot{\phi}$	FDD	second derivative of ϕ with respect to time

SUMMARY

A study is made of the motion of containers loaded in the cargo compartment of the Caribou CV-7 aircraft when the containers are to be extracted by parachute.* The cord of the parachute is attached to the foot of the aft side of the container (a method that gives the container a distinct path of descent) rather than to the mid-point of the aft side. None of the containers loaded in any of the positions defined in the six standard loading diagrams used in this report will strike either the ceiling or the ramp at the rear of the cargo compartment. The safe envelope for any load is a rectangle of 76 inches in height above the floor; this will have to be further reduced to allow for the height of the rollers above the floor.

The motion of the container from the instant when it is released from a stationary position on the floor of the aircraft and is allowed to move aft under the force of the extraction parachute until it is falling freely under its main chute can be divided into the following three phases:**

One-Degree-of-Freedom Motion

During this phase, the container slides down the rollers. This sliding, with the underside of the container resting horizontally on the rollers, continues for a short distance after the mid-point of AB on the container has reached point L. While the 108-, 162-, and 216-inch-long containers slide normally down the floor, the 54-inch-long container (see Figure 1) possesses a special motion of its own. Provided it is clear of the guide rail, corner A rises very slightly above the floor but returns at once to the horizontal position.

* A subsequent report will discuss the minimum height from which containers may be dropped in order to strike the ground when the parachute is located directly above the container.

** A rigid body moving in space possesses six degrees of freedom, but we consider that the fore and aft vertical sides of the container remain throughout in the same vertical planes. A fixed plane in the container is therefore constrained to pass through three arbitrary points, and in this way three of the six degrees of freedom are "ankylosed". (Reference J. H. Jeans, The Dynamical Theory of Gases, 4th Edition, Cambridge University Press, New York, New York, 1925, p. 67, par. 77.)

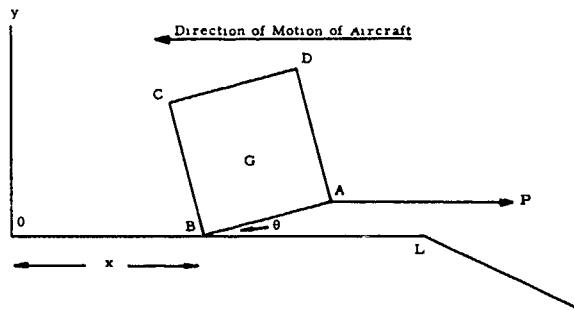


Figure 1. Movement of Container in Aircraft With One-Degree-of-Freedom Motion.

Two-Degrees-of-Freedom Motion

The container continues to move aft with its underside in contact with the aft edge of the floor, L. The initial conditions for this two-degree motion are the final conditions for the one-degree motion. The container always remains in contact with edge L. The possibility that corner C of the container might come

dangerously close to the ceiling of the cargo compartment must be watched. The ceiling is 82 inches above the floor; if a clearance of 6 inches is allowed, a safe envelope to study for a container or other load is one that can have no point that would foul a height 76 inches above floor level; here, again, it is necessary to make allowance for height of rollers.

Three-Degrees-of-Freedom Motion

This phase occurs after B has cleared L and the container is falling freely under the force of gravity and the force of its main chute. The initial conditions for this three-degree motion are provided by the final conditions for the two-degree motion.

When data were computed for this report, it was assumed that the ramp was inclined to the horizontal at an angle of 15 degrees, that there was no friction between the containers and the floor, and that the force exerted by the extraction parachute is 1.5 times that of gravity at all stages of the process of extraction.

The analytical mechanics approach to the trajectories of the containers is described. The work was performed on an IBM 1620 computer, and the more important FORTRAN programs used to obtain the data are presented in the appendix.

CONCLUSIONS

It is concluded that:

1. None of the containers loaded in any of the positions shown in the six loading plans will hit the ceiling or the ramp when the latter is inclined at 15 degrees to the horizontal.
2. The safe envelope parallel to the axis of the aircraft is a rectangle of 75 inches in height above the floor.
3. Small variations in the angle of inclination of the parachute cord to the horizontal do not affect these results.
4. Since the containers slide horizontally down the floor, the length of the guide rail has no effect on the motion.

INTRODUCTION

This report is written to supplement "A Study of Air Delivery Supply Systems for the CV-7 Caribou Aircraft", published by the Quartermaster Research and Engineering Center, Aerial Delivery Systems Office, Natick, Massachusetts, in June 1960.

A report prepared in May 1963 by the U. S. Army Transportation Research Command (USATRECOM) showed an approximate method for calculating the trajectories of containers to be extracted by parachute from various stationary positions on the aircraft floor when the parachute cord was attached to the mid-point of the aft side of the container. Attaching the cord to the mid-point gives a distinctly different motion to the container. (The higher the point of attachment, the greater will be the tendency of the container to tip and strike the ceiling.) Generalized equations of motion were not employed in the report, and the trajectories obtained were not exact. The results indicated that containers starting from positions 300 inches or more from the forward bulkhead would strike the ramp.

The present report deals with the trajectory of the container when the cord is attached to the foot of the aft side; attachment at this point gives the container a totally distinct path.

NOTE: Attaching the cord at an intermediate point between the foot and mid-point of the aft side could also be considered.

Information was required regarding the effect of the length of the guide rail on the container trajectory. Theoretically, a container extracted by a cord attached to the foot of the aft side remains virtually horizontal until it reaches the aft end of the floor of the cargo compartment. Hence, on the model considered for this report, the length of the guide rail has little or no effect on the container path. However, to load containers into the aircraft, the top of the guide rail must stop short of the end of the platform by a distance approximately equal to half the length of the longest container. The longest container is 216 inches, so the horizontal flange of the rail must stop around 108 inches short of the rear end of the floor.

Since the container remains horizontal while sliding down the floor whether there is a guide rail or not, the possibility of the roof's being struck by the container during this first phase of the motion need not be envisaged. A FORTRAN program has been developed to find the maximum safe envelope, but the absence of appreciable tipping means that a container 76 inches in height above the floor will not strike the ceiling; allowance must be made for the height of the rollers.

Six loading plans for containers of four different lengths in the cargo compartment were considered in this study and are shown in Figure 2; the shaded areas represent containers of the lengths indicated, loaded horizontally.

ASSUMPTIONS

It has been assumed that:

1. If the tail ramp is inclined at 15 degrees to the horizontal, no container considered in the six loading plans will strike the ramp.
2. Unless otherwise stated, the cord of the extraction parachute remains horizontal. Two of the four FORTRAN programs presented in the appendix include as a parameter the angle of inclination of the cord, and in these programs a non-zero value can be given to this angle without difficulty.*
3. The force exerted by the extraction parachute is 1.5 times that of gravity at all stages of the process of extraction. This is the sort of practical factor regarding which experimental data would be valuable.
4. There is no friction between the container and the floor. (It is natural to wonder what effect the presence of some friction would make. Friction would reduce the effective force of the chute cord below 1.5 times that of gravity; by so doing, it would decrease the horizontal velocity acquired by the container while sliding down the floor and thus increase the chance of the ramp's being struck. However, if the cord

* Since four principal FORTRAN programs have been included in this report, agencies with computing facilities will be able to extend the calculations to further ranges of the parameters. However, USATRECOM will be glad to amplify any of the calculations for those who cannot obtain the use of a computer.

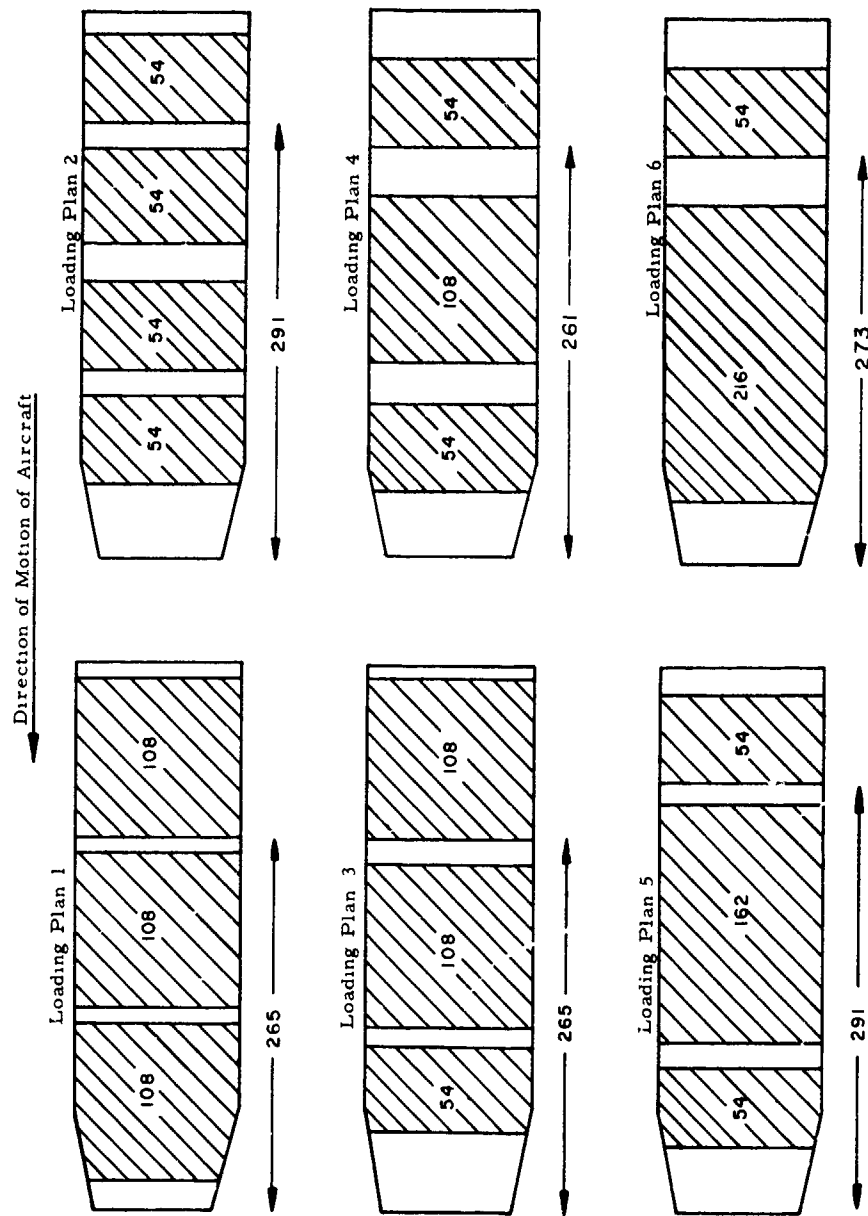


Figure 2. Loading Plans for Cargo Compartment of Caribou CV-7 Aircraft.

remained attached to the foot of the aft side of the container, there would be no tendency to tip, and thus the possibility of the ceilings's being hit would not be increased.)

ONE-DEGREE-OF-FREEDOM MOTION

Although the first phase of the motion has been referred to as having one degree of freedom, the configuration of the container in Figure 1 is described in terms of the two coordinates x and θ . It will be shown that θ departs from zero value for a short time only. In effect, therefore, this phase is one of a single degree of freedom. Let x_G and y_G be the coordinates of G , the center of gravity, with respect to the axes shown; note that the y axis has positive direction upward in this case.

If

$$x_G = x + \frac{AM}{2} \cos \theta - HG \sin \theta$$

and

$$y_G = \frac{AM}{2} \sin \theta + HG \cos \theta,$$

then

$$\dot{x}_G = \dot{x} - \dot{\theta} \left(\frac{AM}{2} \sin \theta + HG \cos \theta \right)$$

and

$$\dot{y}_G = \dot{\theta} \left(\frac{AM}{2} \cos \theta - HG \sin \theta \right).$$

The kinetic energy of the container is equal to that of its total mass moving with its center of gravity plus the kinetic energy of rotation about the center of gravity. If it is assumed that the container is symmetrical in its loading and construction, then the height equals twice HG , and the radius of gyration about a horizontal axis through G perpendicular to the plane of the paper is

$$\frac{AM^2 + 4HG^2}{12}.$$

If KE is the kinetic energy, then

$$2KEg = W[\dot{x}_G^2 + \dot{y}_G^2 + \dot{\theta}^2 \left(\frac{AM^2 + 4HG^2}{12} \right)].$$

Substituting for $\dot{x}$ and $\dot{y}$, this becomes

$$2KEg = W[\dot{x}^2 - 2\dot{x}\dot{\theta} \left(\frac{AM}{2} \sin \theta + HG \cos \theta \right) + \dot{\theta}^2 \left(\frac{AM^2 + 4HG^2}{3} \right)].$$

As there is no friction between the container and the floor, the container has a potential energy function under the action of the forces of gravity and the pull of the chute. This potential function is

$$V = \text{constant} + W\left(\frac{AM}{2} \sin \theta + HG \cos \theta\right) - P(x + AM \cos \theta).$$

LAGRANGE EQUATION OF MOTION FOR GENERALIZED COORDINATES x AND θ

The Lagrange equation of motion for θ is

$$\begin{aligned} \frac{W}{g} \frac{d}{dt} \left[-\dot{x} \left(\frac{AM}{2} \right) \sin \theta - \dot{x} HG \cos \theta + \dot{\theta} \left(\frac{AM^2}{3} + 4HG^2 \right) \right] - \frac{W}{g} \left[-\ddot{x} \left(\frac{AM}{2} \right) \cos \theta - HG \sin \theta \right] \\ = -W \left(\frac{AM}{2} \cos \theta - HG \sin \theta \right) - P AM \sin \theta. \end{aligned}$$

When the differentiation is performed, this equation is reduced to

$$-\ddot{x} \left(\frac{AM}{2} \right) \sin \theta + HG \cos \theta - \ddot{x} \theta \left(\frac{AM}{2} \right) \cos \theta - HG \sin \theta + \ddot{\theta} \left(\frac{AM^2}{3} + 4HG^2 \right)$$

$$+ \ddot{x} \theta \left(\frac{AM}{2} \right) \cos \theta - HG \sin \theta = g \left(-\frac{AM}{2} \cos \theta + HG \sin \theta - 1.5 AM \sin \theta \right)$$

on dividing through by W and setting $\frac{P}{W}$ equal to 1.5 in the last term.

The product term in $\ddot{x} \theta$ cancels out, and the equation becomes

$$\begin{aligned} -\ddot{x} \left(\frac{AM}{2} \right) \sin \theta + HG \cos \theta + \ddot{\theta} \left(\frac{AM^2}{3} + 4HG^2 \right) \\ = g \left(HG \sin \theta - \frac{AM}{2} \cos \theta - 1.5 AM \sin \theta \right). \end{aligned} \quad (1)$$

The Lagrange equation of motion corresponding to the coordinate x is

$$\frac{W}{g} \frac{d}{dt} \left[\dot{x} \left(\frac{AM}{2} \right) \sin \theta + HG \cos \theta \right] = P.$$

When the differentiation is performed and $\frac{P}{W}$ is set equal to 1.5, the equation becomes

$$\ddot{x} - \ddot{\theta} \left(\frac{AM}{2} \right) \sin \theta + HG \cos \theta - \dot{\theta}^2 \left(\frac{AM}{2} \right) \cos \theta - HG \sin \theta = 1.5g. \quad (2)$$

Whether the initial value of $\ddot{\theta}$ is positive or negative must be determined. When this phase of the motion starts, whether the container is held horizontal by the the guide rail or not, both θ and $\dot{\theta}$ are zero. If θ and $\dot{\theta}$ are set equal to zero in Lagrange equations (1) and (2), then

$$-\ddot{x}HG + \ddot{\theta}\left(\frac{AM^2 + 4HG^2}{3}\right) = -g\left(\frac{AM}{2}\right)$$

and

$$\ddot{x} - \ddot{\theta}HG = 1.5g.$$

Hence,

$$\frac{\ddot{\theta}}{\ddot{x} - \ddot{\theta}HG} = \frac{-g\left(\frac{AM}{2}\right)}{1.5g - HG\ddot{\theta}}$$

$$\begin{vmatrix} -HG & -\frac{AM}{2} \\ 1 & 1.5 \end{vmatrix} = \begin{vmatrix} -HG & \frac{AM^2 + 4HG^2}{3} \\ 1 & -HG \end{vmatrix}$$

The denominator of the right-hand member is always negative. Therefore, if $3HG$ is greater than AM , $\ddot{\theta}$ is initially positive. $AM = 54$ inches for the small container, and this condition is always satisfied. Hence, $\ddot{\theta}$ is initially positive for the small container; that is, it tips backward as in Figure 1. However, when the two Lagrange equations are solved numerically, θ at once returns to zero value. For the other three sizes of the container, AM is greater than $3HG$; as a result, no tipping occurs, and the container pursues a true one-degree-of-freedom motion until it reaches L , the end of the platform, and begins to tip as explained in the section on two-degrees-of-freedom motion. In the latter case, the tipping is in the opposite direction; that is, corner A of the container is not above corner B as shown in Figure 1 but is below B .

FORTTRAN NUMERICAL SOLUTION OF EQUATIONS (1) AND (2)

Since the initial value of $\ddot{\theta}$ has been discussed and the criterion for its being positive has been observed, the solving of equations (1) and (2) can be continued in order to determine x and θ for subsequent values of time. FORTRAN Program Number Two (see appendix) provides an approximate numerical solution of the two ordinary nonlinear differential equations in x and θ .

The values of the parameters AM and HG are read into the computer. On the same line of the program, DE is also read in. (This is an arbitrary interval of time which was taken as .01 second between successive configurations of the system at which solutions of the equations were sought.) In the next line of the program, the initial value of x, called X(1), is read in; this is the starting station of the forward side of the container. In the same line of the program, the following is read in:

XD(1) the first derivative of x with respect to time at the initial instant;

T(1) the initial value of θ ; and

TD(1) the initial value of $\frac{d\theta}{dt}$.

XD(1), T(1), and TD(1) all have the value of zero in the case of a small container starting from the rearmost station. If, however, the container were released under the guide rail, X(1) would be the length of the guide rail, and XD(1) would be the velocity the container acquires in traveling down the guide rail--that is, from whatever station under the guide rail it started from rest.

Lines 5 through 12 of FORTRAN Program Number Two give the second differential coefficients of x and of θ , that is, XDD(1) and TDD(1). Lines 14 through 17 are short Taylor-series equations to find the values of X and T and of their first derivatives at the close of the next time interval. Lines 18 through 26 form and solve two ordinary simultaneous linear algebraic equations for TDD and XDD, which in turn are substituted in the Taylor series of lines 14 through 17; the whole process is repeated as often as desired.

If AM = 54 inches, HG = 30 inches, DD = .01 second, and X(1) = 291 inches, the successive values for T, or θ , are as follows:

T(1) = .000000 radian

T(3) = .000367 radian

T(2) = .000273 radian

T(4) = -.000444 radian

A negative value of θ is, of course, impossible as it is constrained to be non-negative by the platform. In physical terms, this means that the small container makes an initial jerk with positive θ as shown above for T(1) to T(3) but returns to the horizontal position and slides down the floor.

If the length of the container were reduced so that AM became, say, 1 inch only, then the force P would tip it over completely. Somewhere

between the 54-inch and the 1-inch containers, there must be some value of AM_0 which divides small containers into those that tip slightly and return to the horizontal and those that fall completely over. Such a value for AM_0 would mark what Loupounoff called a "point of dynamical bifurcation".

Thus, for all four types of containers, the first phase of the motion is, in effect, a sliding down the floor until the end, L, is reached. For this reason, the first phase is referred to as the one-degree-of-freedom phase.

TWO-DEGREES-OF-FREEDOM MOTION

For this phase of the motion, θ (the angle of inclination of the container to the horizontal reckoned positive as shown in Figure 3) and q (the distance from L to the mid-point of the underside, AB, of the container) are selected as general coordinates.

Let x_{st} be the distance in inches between the bulkhead at the forward end of the cargo compartment and the forward end of the container when the latter starts to move at the beginning of the one-degree phase. Let $Q(1)$ be the value of q when tipping starts. Then, between release from station x_{st} and start of tipping, the container has moved

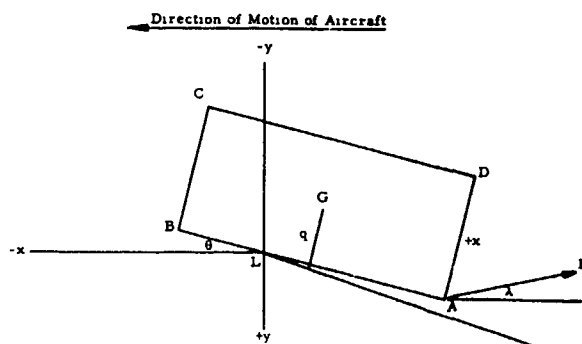


Figure 3. Sketch Illustrating Two-Degrees-of-Freedom Motion

$$(377 - x_{st} + Q(1) - 1/2 \text{ length of container}) \text{ inches}$$

under an acceleration of $1.5g$ inches per second². Hence, the final velocity of the container at the close of phase one and at the start of phase two is θ .

$$\begin{aligned} & \sqrt{3g[377 - x_{st} - \frac{AM}{2} + Q(1)]} \text{ inches per second} \\ & = \sqrt{1159.2[377 - x_{st} - \frac{AM}{2} + Q(1)]} \text{ inches per second} \quad (3) \end{aligned}$$

For phase two, this is the initial value of the first derivative of q and is called $QD(1)$. The initial values of θ and $\dot{\theta}$ are both zero; these are referred to as $T(1)$ and $TD(1)$ respectively.

Taking axes of coordinates as shown in Figure 3 (that is, with positive direction of y axis downward), the center of gravity of the container, G , has coordinates

$$x_G = q \cos \theta + HG \sin \theta \quad \text{and} \quad y_G = q \sin \theta - HG \cos \theta.$$

The kinetic energy of the container is equal to that of its total mass moving with its center of gravity together with the kinetic energy of rotation about its center of gravity. Therefore, if KE is its total kinetic energy,

$$\begin{aligned} 2KE_g &= W(\dot{x}_G^2 + \dot{y}_G^2) + I_G \dot{\theta}^2 \\ &= W\{[\dot{q} \cos \theta + \dot{\theta}(-q \sin \theta + HG \cos \theta)]^2 \\ &\quad + [\dot{q} \sin \theta + \dot{\theta}(q \cos \theta + HG \sin \theta)]^2\} + I_G \dot{\theta}^2 \\ &= W[\dot{q}^2 + \dot{\theta}^2(q^2 + HG^2) + 2HGq\dot{\theta}] + I_G \dot{\theta}^2. \end{aligned}$$

Since the motion is assumed to be frictionless, the container has a potential energy function under the force of gravity and the force of the chute; thus,

$$\begin{aligned} V &= \text{constant} + g[-W(q \sin \theta - HG \cos \theta) \\ &\quad - P \cos \lambda(q + \frac{AM}{2}) \cos \theta + P \sin \lambda(q + \frac{AM}{2}) \sin \theta] \\ &= \text{constant} + g[-W(q \sin \theta - HG \cos \theta) - P(q + \frac{AM}{2}) \cos(\theta + \lambda)]. \end{aligned}$$

THE LAGRANGE EQUATIONS OF MOTION FOR θ AND q

The Lagrange equation of motion for θ is

$$\begin{aligned} \frac{d}{dt} [I_G \dot{\theta} + W(q^2 + HG^2) \dot{\theta} + HG W \dot{q}] \\ = Wg(q \cos \theta + HG \sin \theta) - P(q + \frac{AM}{2}) g \sin(\theta + \lambda), \end{aligned}$$

and the equation for q is

$$W \frac{d}{dt} (\dot{q} + \dot{\theta} HG) - W \dot{\theta}^2 q = g[W \sin \theta + P \cos (\theta + \lambda)].$$

Divide these equations through by W , and let $\frac{P}{W} = 1.5$. Also, let

$$G = I_G + HG^2 = \frac{AM^2 + 4HG^2}{12} + HG^2,$$

using the known formula for radius of gyration of a rectangular parallelepiped about an axis perpendicular to its plane and through its center of gravity. Thus,

$$\begin{aligned} \ddot{\theta}(G + q^2) + 2q\dot{q}\dot{\theta} + HG\ddot{q} \\ = g[q \cos \theta + HG \sin \theta - 1.5(q + \frac{AM}{2}) \sin (\theta + \lambda)] \end{aligned} \quad (4)$$

and

$$HG\ddot{\theta} - \dot{\theta}^2 q + \ddot{q} = g[\sin \theta + 1.5 \cos (\theta + \lambda)]. \quad (5)$$

FORTTRAN NUMERICAL SOLUTION OF EQUATIONS (4) AND (5)

The method for solving these equations by using FORTRAN Program Number One is as follows:

First, calculate the initial values of θ , q , $\frac{d\theta}{dt}$, and $\frac{dq}{dt}$; in the program these symbols are called $T(1)$, $Q(1)$, $TD(1)$, and $QD(1)$. Substitute these values in the two differential equations, and solve them for $\ddot{\theta}$ and $\ddot{q}$ as two ordinary simultaneous linear algebraic equations in these two unknowns.

Second, by means of Taylor's theorem, find the values of θ , q , $\frac{d\theta}{dt}$, and $\frac{dq}{dt}$ at .01 second after the initial instant. Thus,

$$T(2) = T(1) + .01 TD(1) + \left(\frac{.01}{2}\right)^2 TDD(1)$$

and

$$TD(2) = TD(1) + .01 TDD(1).$$

Similarly, find the values for $Q(2)$ and $QD(2)$.

Third, substitute these values of θ , q , $\frac{d\theta}{dt}$, and $\frac{dq}{dt}$ in the two differential equations and solve them as simultaneous algebraic equations for the second derivatives of θ and q .

Repeat the same process for T(3) and Q(3), etc.

Calculation of QD(1)

Instead of reading in the value of $\frac{dq}{dt}$ at the initial instant as was done before, in certain of the FORTRAN programs the following line, which calculates QD(1) from equation (3), is inserted in the program:

$$QD(1) = \sqrt{1159.2[377 - x_{st} - \frac{AM}{2} + Q(1)]}.$$

Initial Value of q

The calculation of the initial value q [that is, Q(1)] possesses some interesting features. If it is assumed that this initial value is zero (that is, that tipping starts when the center of gravity of the container is vertically over point L at the end of the floor), then the initial value of $\frac{d^2\theta}{dt^2}$ is negative, and hence, θ starts to assume negative values. In

physical terms, this means that the container begins to tip into the floor. Thus, coordinates θ and q must be regarded as being subject to a constraint; namely, θ must be positive. If θ and $\frac{d\theta}{dt}$ are equal to zero in the differential equations,

$$\ddot{\theta}(G + q^2) + HG\ddot{q} = g[q - 1.5(q + \frac{AM}{2}) \sin \lambda]$$

and

$$\ddot{\theta}HG + \ddot{q} = 1.5g \cos \lambda.$$

Solving for $\ddot{\theta}$,

$$\frac{\ddot{\theta}}{g} = \frac{q(1 - 1.5 \sin \lambda) - 1.5(\frac{AM}{2}) \sin \lambda - 1.5HG \cos \lambda}{G + q^2 - HG^2}.$$

The denominator of the above is always positive; hence, for $\ddot{\theta}$ to be positive initially,

$$q(1 - 1.5 \sin \lambda) \text{ must be } \geq 1.5(HG \cos \lambda + \frac{AM}{2} \sin \lambda).$$

The sign of equality in the above equation gives the initial value of q and is incorporated in certain of the programs to avoid reading in Q(1) as data. It is evident that in no case can Q(1) be greater than $\frac{AM}{2}$.

Reaction of Aft End of Platform on Container

The fundamental equations for the two-degrees-of-freedom motion have been developed on the assumption that from the moment that corner A (see Figure 3) of the container reaches L, the container remains in contact with the aft edge of the cargo compartment until corner B of the container reaches L. In order to make this assumption, the force of reaction of the edge L on the container must be considered positive. Since the container has a smooth lower surface, the direction along which the reaction acts is normal to the underside of the container. Let R units of force be the magnitude of the reaction; then, if the forces are resolved vertically,

$$W - P \sin \lambda - R \cos \theta = \frac{W}{g} \frac{d^2 y_G}{dt^2}$$

where y_G is reckoned positive downward as in Figure 3. When the two differentiations are carried out,

$$R \cos \theta = W - P \sin \lambda + \frac{W}{g} (-HG \cos \theta \ddot{\theta}^2 - HG \sin \theta \ddot{\theta} - \ddot{q} \sin \theta - 2\dot{q} \cos \theta \dot{\theta} + q \dot{\theta}^2 \sin \theta - q \ddot{\theta} \cos \theta).$$

By means of this relation, the sign of R may be tested for being positive or negative by setting up a short FORTRAN subprogram which can be incorporated in the main dimensioned program which solves the two-degrees-of-freedom Lagrange equations and gives q and θ and their first two derivatives. These six quantities [Q(1), QD(1), QDD(1), T(1), TD(1), and TDD(1)] remain in core storage, since they are dimensioned and are thus available for the subprogram. The subprogram shows that R is positive in all cases.

Accuracy of Solution of Differential Equations

A subprogram has been incorporated in FORTRAN Program Number One to test the accuracy of the solutions. This subprogram transfers all the terms to the left-hand members of the equations and substitutes in them the values found for q and θ and their first two derivatives. This gives the error; expressed as a proportion of the sum of the absolute values of the terms in the differential equations, the errors are around one part in 1,000.

INCLINATION OF CONTAINER

Table 1 presents some of the numerical results of FORTRAN Program Number One (see appendix) which solves the equations of motion for the two-degree phase. The line of data following the "END" of this program relates to a 216-inch-long container placed with its center of gravity at the center of gravity of the aircraft; that is, with the forward side of the container 77.8 inches from the forward bulkhead. The height of the center of gravity of the container in this case is considered to be 20 inches--a reasonable value for a load such as a small truck.

TABLE 1
TWO-DEGREES-OF-FREEDOM MOTION FOR 216-INCH-LONG CONTAINER

Time From Start of Tipping (seconds)	Angle of Inclination to Horizontal (radians)	Value of q (inches)
.00	.000000000	37.7
.01	.000000323	42.9
.02	.0000174	48.1
.03	.0000800	53.4
.04	.000210	58.8
.05	.000423	64.2
.06	.000728	69.6
.07	.00113	75.2
.08	.00164	80.7
.09	.00225	86.4
.10	.00295	92.0
.11	.00375	97.8
.12	.00464	103.6
.13	.00562	109.4

No further entries have been made in the table because q is already greater than half the length of the container; consequently, the container has cleared the end L of the floor. The angle of inclination of the parachute cord to the horizontal has been taken as .034907 radian, that is, two degrees of arc. The table shows clearly that the inclination of the container is slight under representative conditions.

CALCULATION OF SAFE ENVELOPE

It has been shown that a container tips through so small an angle that it seems almost unnecessary to develop a FORTRAN program to find the safe envelope. It could be assumed, for example, that a 76-inch-high container would at no time during the two-degree phase have any point more than 77 inches above the floor and hence that a constant height of 76 inches would be safe in view of the 6-inch clearance provided. This is correct for all the containers considered in the six loading plans.

FORTRAN PROGRAM NUMBER FOUR

In Figure 4, let AB be the underside of the container, H the mid-point of this underside, and q the distance from H to L. Let NU be an ordinate of the container (that is, NU is perpendicular to AB). In lines 1 through 34 of FORTRAN Program Number Four (see appendix), the values of q and θ are found as previously. In lines 36 and 37, N is set at the end A and successively at 4-inch intervals along the underside, AB, of the container. The initial height of HH is read in as 60 inches, and line 42 increases HH by 1 inch for each loop of a "DO" cycle. For each value of θ , q, HH, and AN, the height of the point U above the floor is called ROOF(1), and its value is given by

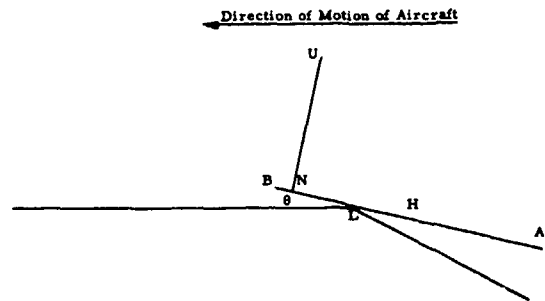


Figure 4. Sketch for Determining Safe Envelope.

$$\text{ROOF}(I) = \text{HH} \cos T(I) + [\text{AN}(K) - Q(I)] \sin T(I)$$

where HH is the value of the length of the ordinate NU.

For each location of N along AB, line 44 punches out the first value of ROOF(1) to equal or exceed 76 inches. Line 45 reduces HH to 74 inches. Next, the program moves N 4 inches closer to B and repeats the whole process until N is at the end B of the underside. Thus, with the 108-inch container considered, there are 28 different locations for N. The initial value of AN, namely, AN(1), which is read in for FORTRAN Program Number Four, is -54 inches.

In the line of data following the "END" or Program Number Four, the starting station for the forward side of the container was considered to be 265 inches from the bulkhead at the forward end of the cargo compartment; this arrangement corresponds to loading plans 1 and 3. A container starting this close to L has the greatest period of time to tip and thus to strike the ceiling. Thus, a critical case is being used in FORTRAN Program Number Four; nevertheless, it can be seen that the container can have a constant height of 76 inches without fouling the ceiling. The same applies to all other containers starting in any of the six loading plans.

NOTE: As soon as this envelope departs for any reason from the simple rectangular outline considered in this report, it may be necessary to adopt a more sophisticated expression for the moment of inertia about a horizontal axis through the center of gravity. A container with contents of nonuniform density, a small truck, or a gun might well be so asymmetric that the theory set forth in this study might require modification.

THREE-DEGREES-OF-FREEDOM MOTION

This phase occurs after the container leaves the floor. Particular attention is paid to the possibility of whether the inclined ramp at the rear of the floor could be struck. In Figure 5, axes are taken through

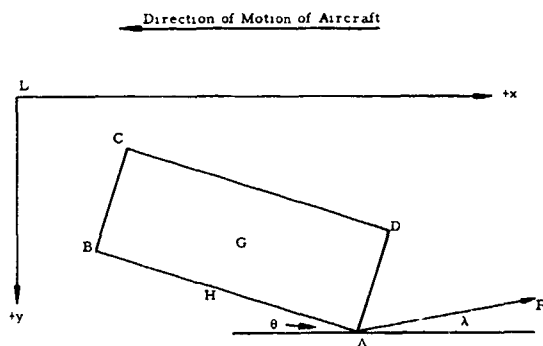


Figure 5. Sketch Illustrating Three-Degrees-of-Freedom Motion.

against the force of the parachute cord from some standard position to its present position. Thus,

the end L of the floor-- L_x positive in the aft direction and L_y positive in the downward direction. The configuration of the three-degree system is defined by the coordinates x_G and y_G of the center of gravity and by θ , the angle of inclination of the underside of the container to the horizontal.

The potential energy of the system is that of its total mass situated at the center of gravity plus the work done

$$V = \text{constant} - Wy_G - P \cos \lambda (x_G - HG \sin \theta + \frac{AM}{2} \cos \theta) \\ + P \sin \lambda (y_G + HG \cos \theta + \frac{AM}{2} \sin \theta).$$

The kinetic energy of the system is that of its total mass moving with the center of gravity and the kinetic energy of rotation about G. Thus,

$$2KEg = W(\dot{x}_G^2 + \dot{y}_G^2) + I_G \dot{\theta}^2.$$

LAGRANGE EQUATIONS OF MOTION FOR COORDINATES x AND y AND FOR ANGLE OF INCLINATION

For the coordinate x,

$$W\ddot{x}_G = Pg \cos \lambda \quad (6)$$

and for y,

$$W\ddot{y}_G = g(W - P \sin \lambda). \quad (7)$$

For the angle of inclination, θ ,

$$I_G \ddot{\theta} = g(-P HG \cos \theta \cos \lambda - P \frac{AM}{2} \cos \lambda \sin \theta \\ + P HG \sin \lambda \sin \theta - P \frac{AM}{2} \cos \theta \sin \lambda). \quad (8)$$

This last equation yields

$$\frac{I_G \ddot{\theta}}{gP} = \cos \theta (-HG \cos \lambda - \frac{AM}{2} \sin \lambda) - \sin \theta (-HG \sin \lambda + \frac{AM}{2} \cos \lambda).$$

Let β be such that $\tan \beta = \frac{2HG}{AM}$; then,

$$\frac{I_G \ddot{\theta}}{gP} = \sqrt{HG^2 + (\frac{AM}{2})^2} [-\cos \theta \sin (\lambda + \beta) - \sin \theta \cos (\lambda + \beta)] \\ = -\sqrt{HG^2 + (\frac{AM}{2})^2} \sin (\theta + \lambda + \beta).$$

The square of the radius of gyration of the container about the horizontal axis through G perpendicular to the plane of the paper is

$$\frac{AM^2 + 4HG^2}{12} .$$

Hence,

$$\ddot{\theta} = \frac{-9g \sin (\theta + \lambda + \beta)}{\sqrt{4HG^2 + AM^2}} . \quad (9)$$

FORTTRAN Numerical Solution of Equation $\ddot{\phi} = -SS \sin \phi$

Let $\phi = \theta + \lambda + \beta$. In the FORTRAN program, ϕ is recorded as F and β as S. Also in the FORTRAN program, the coefficient of $\sin (\theta + \lambda + \beta)$ in the right-hand member of equation (9) is called -SS. Therefore, in the FORTRAN program, the exact solution of $\ddot{\phi} = -SS \sin \phi$ involves elliptic integrals of the first kind, which are, in effect, published for discrete values of SS. To find ϕ for intermediate values of t and of SS would thus involve a double interpolation by t and SS and would prove to be troublesome. It is therefore more convenient to find an approximate numerical solution of equation (9) in the same way as has been done for other differential equations.

FORTTRAN Program Number Three (see appendix) is a double one: it first solves equation (9) and then uses the values of ϕ and θ to obtain the trajectory of corner B of the container in such a way that it can be readily decided whether or not the 15-degree ramp is struck. This program relates to a 108-inch-long container starting from the rear-most station in loading plans 1 or 3, and this is a critical case for striking the ramp. In this program the angle λ , or YAL, is zero; that is, the parachute cord has been assumed to be horizontal. (Nonzero angles of this inclination can also be tested without difficulty.)

Lines 1 through 17 of this program provide the solution of equation (9). HG and AM are read in as usual. T(1) and TD(1), which are the initial values of θ and its first derivative with respect to time, and DD, which is the arbitrary interval of time between successive configurations of the three-degree system and which is taken to be .005 second, are also read in.

There is a FORTRAN subroutine for ATAN so that β , whose value is $\text{ATAN} \left(\frac{2HG}{AM} \right)$, can be found with no difficulty.

The initial values of T(1) and TD(1) for the three-degree motion are the final values for the corresponding two-degree motion. In the case of the 54-inch container, the container remains horizontal until corner B reaches L and the three-degree motion starts. Thus, the small container enjoys no two-degree motion and the initial values for T(1) and TD(1) for this container are both zero.

As $\phi = \theta + \lambda + \beta$, the derivatives of ϕ and of θ with respect to time are equal. This is the explanation of line 10 of FORTRAN Program Number Three. Line 11 finds FDD(1) from the differential equation itself, while line 12 differentiates the equation and uses the result to determine FDDD(1).

Thus F(1), FD(1), FDD(1), and FDDD(1) are quantities that can be substituted in the Taylor series for F(2), FD(2), FDD(2), FDDD(2), and so on, successively, for any value of index "I" in the FORTRAN program. $\phi = \theta + \lambda + \beta$ as a function of time having been found, the corresponding values of θ can be used to find the trajectory of corner B. If equation (6) is integrated twice with respect to time,

$$x_G = (x_G)_0 + t(\dot{x}_G)_0 + t^2\left(\frac{3g}{4}\right) \cos \lambda$$

where suffix o refers to the initial conditions. Evidently, x_G initially equals

$$\frac{AM \cos \theta_0}{2},$$

and from the known formula for distance covered at constant acceleration,

$$(\dot{x}_G)_0 = \sqrt{3g(377 - x_{st})}.$$

Thus,

$$x_G = \frac{AM}{2} \cos \lambda + t\sqrt{1159.2(377 - x_{st})} + 289.2t^2 \quad (10)$$

where t is time in seconds from corner B's being at L.

Similarly, equation (7) yields

$$y_G = (y_G)_0 + t(\dot{y}_G)_0 + \frac{t^2g}{2}(1 - 1.5 \sin \lambda). \quad (11)$$

Based on these coordinates of G, those of B are as follows:

$$x_B = x_G - HG \sin \theta - \frac{AM}{2} \cos \theta,$$

which, in view of equation (10), gives

$$x_B = \frac{AM}{2} + t\sqrt{1159.2(377-x_{st})} + 289.2t^2 - HG \sin TH(I) - \frac{AM}{2} \cos TH(I)$$

and

$$y_B = y_G + HG \cos \theta - \frac{AM}{2} \sin \theta = -HG + t(\dot{y}_G)_0 + 193.2t^2 + HG \cos TH(I) - \frac{AM}{2} \sin TH(I).$$

Here TH(1) means the value of θ at configuration index "I". The symbol TH is used simply to emphasize that the three-degree phase is being considered. Either of the two following methods could be used to find the initial values of TH(1), THD(1), and QD(1): a FORTRAN subprogram (which would interpolate the values of these three quantities between the two successive values of Q, one less than and the next greater than $\frac{AM}{2}$) could be incorporated in Program Number One, or the same interpolation could be performed by hand. However, only six loading configurations of containers in the cargo compartment are being considered, and those most likely to lead to the ramp's being struck are loading plans 1 and 3 with the 108-inch containers and loading plans 2 and 5 with the 54-inch containers. Therefore, there are only two distinct loading plans of interest; $(\dot{y}_G)_0$ will be calculated by hand and the result will be read in as data.

$$y_G = q \sin \theta - HG \cos \theta.$$

Hence,

$$\dot{y}_G = \dot{q} \sin \theta + q \cos \theta \dot{\theta} + HG \sin \theta \dot{\theta},$$

and

$$(\dot{y}_G)_0 = QD(1) \sin TH(1) + \frac{AM}{2} THD(1) + HG TH(1) THD(1) \quad (12)$$

if θ is small.

To find QD(1), TH(1), and THD(1), Program Number One is run with data corresponding to a 108-inch container starting from a station 265 inches from the forward bulkhead. It is then possible to find the two successive entries in the output for Q; the first, Q(3), is less than

$\frac{108}{2} = 54$ inches, and the next, $Q(4)$, is greater than 54 inches. Following are the values of $Q(3)$ and $Q(4)$, together with the corresponding values of T and the first differential coefficients of the two coordinates, Q and T .

$Q(3) = 52.092921$	$Q(4) = 55.724500$
$QD(3) = 360.35773$	$QD(4) = 365.95819$
$T(3) = .18743423E-04$	$T(4) = .88831920E-04$
$TD(3) = .37486846E-02$	$TD(4) = .10269014E-01$

The three-degree motion starts when $Q = 54$ inches; by simple interpolation for this value, $TH(1) = .55549696E-04$, $THD(1) = .71727702E-02$, and $QD(1) = 363.29876$. If these values are substituted in equation (12),

$$(\dot{y}_G)_0 = .020181 + .387331 + .000012 = .407524$$

When this value is now substituted in equation (11), the second part of FORTRAN Program Number Three can be constructed, that is, lines 19 through 27. The expressions for x_B and y_B are built up piecemeal because of the need to keep the lines of FORTRAN down to 72 characters. The ratio $y_B : x_B$ is calculated as shown for each value of index "I"; it does not equal or exceed $\tan 15^\circ = .2679$ for any x_B less than $88 \cos 15^\circ$ inches, 88 inches being the length of the ramp. This shows that the ramp is not struck in loading plans 1 or 3.

For loading plans 2 and 5 with the 54-inch containers, the calculations are more simple. Here, $AM = 54$ inches, $x_{st} = 291$ inches, $T(1) = 0$ and $TD(1) = 0$, $Q(1) = 27$ inches, and $QD(1) = 315.739$ inches per second. Thus, $(\dot{y}_G)_0 = 0$, and the first term in line 24 of FORTRAN

Program Number Three for $YBA(1)$ drops out. Once again the ratio $y_B : x_B$ never equals or exceeds $\tan 15^\circ$ for x_B less than $88 \cos 15^\circ$ inches, so it can be concluded that the ramp is not struck.

APPENDIX

FORTRAN PROGRAMS

FORTRAN PROGRAM NUMBER ONE

		<u>Line</u>
C	SOLUTION OF TWO-DEGREES-OF-FREEDOM EQUATIONS	1
	DIMENSION T(21),TD(21),TDD(21),Q(21),QD(21),QDD(21)	2
	READ 3,T(1),TD(1),Q(1),QD(1),AM,DE,YAL,HG	3
	C=386.4*((Q(1))*COS(T(1))-1.5*(Q(1)+AM/2.)*SIN(YAL))	4
	G=((AM**2)+4.*(HG**2))/12.+(HG**2)	5
	B=HG	6
	A=G+(Q(1))**2	7
	F=386.4*(1.5)*(COS(YAL))+((TD(1))**2)*Q(1)	8
	E=1.	9
	D=HG	10
	TDD(1)=(C*E-F*B)/(A*E-D*B)	11
	QDD(1)=(A*F-D*C)/(A*E-D*B)	12
C	T AND Q HAVE NOW BEEN PREPARED AT POSITION OF SUBSCRIPT (1)	13
	DO 51 I=1,20	14
	Q(I+1)=Q(I)+DE*QD(I)+(((DE**2)/2.)*QDD(I))	15
	QD(I+1)=QD(I)+DE*QDD(I)	16
	T(I+1)=T(I)+DE*TD(I)+((DE**2)/2.)*TDD(I)	17
	TD(I+1)=TD(I)+DE*TDD(I)	18
	CAA=Q(I+1)*COS(T(I+1))+HG*SIN(T(I+1))	19
	CAB=-1.5*(Q(I+1)+AM/2.)*SIN(T(I+1)+YAL)	20
	CA=CAA+CAB	21
	CB=-2.*(TD(I+1))*(QD(I+1))*Q(I+1)	22
	CC=(386.4*CA) + CB	23
	BA=HG	24
	AA=G+(Q(I+1))**2	25
	FAA=386.4*(SIN(T(I+1))+1.5*COS(T(I+1)+YAL))	26
	FAB=((TD(I+1))**2)*(Q(I+1))	27
	FA=FAA + FAB	28
	EE=1.	29
	DD=HG	30
	TDD(I+1)=(CC*EE-FA*BA)/(AA*EE-DD*BA)	31
	QDD(I+1)=(AA*FA-DD*CC)/(AA*EE-DD*BA)	32
C	T AND Q HAVE NOW BEEN PREPARED AT ALL POSITIONS TO SUBSCRIPT 21	33
C	THERE FOLLOW TWO FUNCTIONS TO TEST THE ACCURACY OF THE DIFFL EQUATS	34
	J=I+1	35
	FAMM=AA*TDD(J)+2.*(Q(J))*(QD(J))*(TD(J))+(HG*(QDD(J)))	36
	FAMN=386.4*(Q(J)*COS(T(J))+HG*SIN(T(J)))	37
	FAMP=579.6*(Q(J)+AM/2.)*SIN(T(J)+YAL)	38

	FAM=FAMM+FAMP-FAMN	39
	FANA=HG*TDD(J)-((TD(J))**2)*Q(J)+QDD(J)	40
	FANB=386.4*(SIN(T(J))+1.5*COS(T(J)+YAL))	41
	FAN=FANA-FANB	42
	PUNCH 5,J,FAM,FAN	43
	PUNCH 4,J,Q(I+1),QD(I+1),QDD(I+1)	44
51	PUNCH 4,J,T(I+1),TD(I+1),TDD(I+1)	45
	STOP	46
4	FORMAT (I2,1X E14.8,1X E14.8,1X E14.8)	47
3	FORMAT (F3.1,F3.1,F4.1,F5.1,F5.1,F3.2,F8.6,F4.1)	48
5	FORMAT (I3,1X E14.8,1X E14.8)	49
	END	50
	0.00.037.7515.1216.0.010.03490720.0	51

FORTRAN PROGRAM NUMBER TWO

C	INCLINATION OF SMALL CONTAINER DURING FIRST PHASE	1
	DIMENSION X(50),XD(50),XDD(50),T(50),TD(50),TDD(50)	2
	READ 3,AM,HG,DE	3
	READ 6,X(1),XD(1),T(1),TD(1)	4
	A=-HG	5
	B=(AM**2 + 4.*HG**2)/3.	6
	C=-193.2*AM	7
	D=1.	8
	E=-HG	9
	F=579.6	10
	XDD(1)=(C*E-F*B)/(A*E-D*B)	11
	TDD(1)=(A*F-D*C)/(A*E-D*B)	12
	DO 55 I=1,45	13
	X(I+1)=X(I)+DE*XD(I)+((DE**2)/2.)*XDD(I)	14
	XD(I+1)=XD(I)+DE*XDD(I)	15
	T(I+1)=T(I)+DE*TD(I)+((DE**2)/2.)*TDD(I)	16
	TD(I+1)=TD(I) + DE*TDD(I)	17
	AA=-((AM/2.))*SIN(T(I+1)) + HG*COS(T(I+1))	18
	BB=(AM**2+4.*HG**2)/3.	19
	CCP=HG*SIN(T(I+1))-((AM/2.))*COS(T(I+1))-3.*((AM/2.))*SIN(T(I+1))	20
	CC=386.4*CCP	21
	DD=1.	22
	EE=-((AM/2.))*SIN(T(I+1))+HG*CCS(T(I+1)))	23
	FF=579.6+((TD(I+1))**2)*((AM/2.))*COS(T(I+1))-HG*SIN(T(I+1)))	24
	XDD(I+1)=(CC*EE-FF*BB)/(AA*EE-DD*BB)	25
	TDD(I+1)=(AA*FF-DD*CC)/(AA*EE-DD*BB)	26
	PUNCH 4,I,X(I),XD(I),XDD(I)	27
	PUNCH 4,I,T(I),TD(I),TDD(I)	28

55	CONTINUE	29
	STOP	30
4	FORMAT (I3,1X E14.8,1X E14.8,1X E14.8)	31
3	FORMAT (F4.0,F3.0,F3.2)	32
6	FORMAT (F5.1,F5.1,F3.1,F3.1)	33
	END	

054.30..01
291.0000.00.00.0

FORTRAN PROGRAM NUMBER THREE

	Configurations 1 and 3 Trajectory of Edge B	1
	Dimension F(51),FD(51),FDD(51),FDDD(51),T(1),TD(1),TH(51)	2
	Dimension TEE(51),XBA(51),XBB(51),XB(51),YBA(51),YBB(51),YB(51)	3
	Dimension RAT(51)	4
	Read 3,HG,AM,T(1),TD(1),DD	5
	Read 5,X	6
	SS=3477.6/(SQRT(AM**2+4.*HG**2))	7
	S=ATAN(2.*HG/AM)	8
	F(1)=S	9
	FD(1)=TD(1)	10
	FDD(1)=-SS*SIN(T(1)+S)	11
	FDDD(1)=-SS*COS(T(1)+S)*TD(1)	12
	DO 50 I=1,50	13
	F(I+1)=F(I)+DD*FD(I)+((DD**2)/2.)*FDD(I)+((DD**3)/6.)*FDDD(I)	14
	FD(I+1)=FD(I)+DD*FDD(I)+((DD**2)/2.)*FDDD(I)	15
	FDD(I+1)=-SS*SIN(T(I+1)+S)	16
	FDDD(I+1)=-SS*COS(F(I+1))*FD(I+1)	17
	TH(I)=F(I)-S	18
	P=I	19
	TEE(I)=P*DD	20
	XBA(I)=TEE(I)*SQRT(1159.2*(377.-X)) + 289.2*(TEE(I))**2	21
	XBB(I)=-HG*SIN(TH(I))-(AM/2.)*COS(TH(I))	22
	XB(I)=AM/2.+XBA(I) + XBB(I)	23
	YBA(I)=.4075*TEE(I) + 193.2*(TEE(I))**2	24
	YBB(I)=HG*COS(TH(I)) - (AM/2.)*SIN(TH(I))	25
	YB(I)=-HG + YBA(I) + YBB(I)	26
	RAT(I)= YB(I)/XB(I)	27
	PUNCH 4,I,XB(I),YB(I),RAT(I)	28
50	CONTINUE	
	STOP	
3	FORMAT (F4.1,F5.1,E14.8,E14.8,F4.3)	
5	FORMAT (F5.1)	
4	FORMAT (I3,1X E14.8,1X E14.8,1X E14.8)	
	END	

30.0108.0+.55549696E-04+.71727702E-02.005
265.0

FORTRAN PROGRAM NUMBER FOUR

	<u>Line</u>
CALCULATION OF SAFE ENVELOPE	1
DIMENSION T(21),TD(21),TDD(21),Q(21),QD(21),QDD(21),ROOF(21)	2
DIMENSION AN(30)	3
READ 3,T(1),TD(1),X,AM,DE,YAL,HG,HH,AN(1)	4
Q(1)=(1.5*((AM*SIN(YAL))/2.+HG*COS(YAL))/(1.-1.5*SIN(YAL)))	5
QD(1)=SQRT(1159.2*(377.-X-((AM/2.-Q(1))))	6
C=386.4*((Q(1))*COS(T(1))-1.5*(Q(1)+AM/2.)*SIN(YAL))	7
G=((AM**2)+4.*(HG**2))/12.+(HG**2)	8
B=HG	9
A=G+(Q(1))**2	10
F=386.4*(1.5*(COS(YAL)))+(TD(1))**2)*Q(1)	11
E=1.	12
D=HG	13
TDD(1)=(C*E-F*B)/(A*E-D*B)	14
QDD(1)=(A*F-D*C)/(A*E-D*B)	15
39 DO 44 I=1,20	16
Q(I+1)=Q(I)+DE*QD(I)+((DE**2)/2.)*QDD(I)	17
QD(I+1)=QD(I)+DE*QDD(I)	18
T(I+1)=T(I)+DE*TD(I)+((DE**2)/2.)*TDD(I)	19
TD(I+1)=TD(I)+DE*TDD(I)	20
CAA=Q(I+1)*COS(T(I+1))+HG*(SIN(T(I+1)))	21
CAB=-1.5*(Q(I+1)+AM/2.)*SIN(T(I+1)+YAL)	22
CA=CAA+CAB	23
CB=-2.*(TD(I+1))*(QD(I+1))*Q(I+1)	24
CC=(386.4*CA) + CB	25
BA=HG	26
AA=G+(Q(I+1))**2	27
FAA=386.4*(SIN(T(I+1))+1.5*COS(T(I+1)+YAL))	28
FAB=((TD(I+1))**2)*(Q(I+1))	29
FA=FAA+FAB	30
EE=1.	31
DD=HG	32
TDD(I+1)=(CC*EE-FA*BA)/(AA*EE-DD*BA)	33
QDD(I+1)=(AA*FA-DD*CC)/(AA*EE-DD*BA)	34
44 CONTINUE	35
DO 64 K=1,28	36
P=K	37
AN(K)=AN(1) + (P-1.)*4.	38
38 DO 54 I=1,20	39
ROOF(I)=HH*COS(T(I))+(AN(K)-Q(I))*SIN(T(I))	40
IF (ROOF(I)-76.) 54,55,55	41
54 CONTINUE	42
HH=HH+1.	43
GO TO 38	44
55 PUNCH 31,I,X,ROOF(I),HH,AN(K)	45
HH = 74.	46
64 CONTINUE	47
STOP	48
3 FORMAT (F3.1,F3.1,F5.1,F5.1,F3.2,F8.6,F4.1,F4.1,F6.1)	49
31 FORMAT (I3,1X F5.0,1X F9.4,1X F5.0,1X F5.0)	50
END	51
0.00.0265.0108.0.010.00000030.060.0-054.0	52

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extracted by parachute and the motion is restrained by the use of guide rails. None of the containers loaded in any of the positions defined in the loading diagrams used for this report will strike either the ceiling or the ramp at the rear of the cargo compartment.

Throughout this report the word "container" is used to describe the load to be extracted together with its platform. In certain instances, for example, the load may be a small truck or a 105mm howitzer, either of which possesses an outline far removed from that of a conventional container.

The analytical mechanics approach to the trajectories of the containers is described. Work for this study was performed on an IBM 1620 computer. The more important FORTRAN programs used to obtain the data are presented.

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