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Perturbed Motion of Airplane and Safe Store Separation

S. C. Raisinghani & S. Rao
Department of Aeronautical Engineering, Indian Institute of Technology, Kanpur-208016

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Abstract. A method is presented to predict the perturbed motion of an airplane following stores jettisoning. The mass, moment of inertia, forces, and moments acting on the airplane are suitably split into contributions from the stores and the rest of the airplane parts. The separation of stores is assumed to result in a step change of mass, moment of inertia, forces, and moments contributed by stores. The resulting set of perturbed state equations of motion are solved for two illustrative airplane-stores combination. A criterion is evolved to qualitatively indicate locations for safe store separation. It is suggested that the present method be used to predict airplane perturbed motion following stores separation for a given airplane-store combination and results be used in conjunction with store trajectory analysis for finally declaring a store location as safe or unsafe.

1. Introduction

Strike airplanes are required to carry a variety of external stores, to be jettisoned when desired. It is important that the dropped stores of any kind must clear the carrier airplane safely. During the designing of such carrier airplanes, lot of attention has to be paid to predict safe locations for mounting external stores. This involves accurate prediction of aerodynamic characteristics of stores in the presence of the interference flow field of the carrier airplane[1,2,3&4]. The stores trajectory after separation is determined to predict whether stores[5,6&7] will clear the airplane safely or not. However, in all such studies of predicting the stores trajectory, it is assumed that the airplane stays in its prejettisoning steady state flight condition.

It seems reasonable to expect that an airplane will be perturbed from its steady state flight when the stores are jettisoned. The magnitude and direction of perturbations will be a function of the airplane's dynamic characteristics, type of stores, location of stores and the jettisoning mechanism. It is suggested that the predicted trajectories of separated stores be analysed in conjunction with the predicted perturbed motion of the airplane. This will further indicate how a given location of stores increases or decreases chances of store-airplane collision depending on the kind of airplane perturbations induced by stores jettisoning.

The governing perturbed equations of motion are formulated to predict the airplane response following stores separation. Two test cases are solved to show the effect of stores location on resulting airplane response. A criterion is evolved to qualitatively interpret the perturbed motion vis-a-vis safe separation of the dropped stores.

2. Notation

A_x, A_z, A_m	elements of vector in Eqn. (8), defined by Eqn. (9)
C_{D_I}	drag coefficient of the loaded airplane at steady state
C_{D_s}	drag coefficient of the store based on S_s
C_s	mean aerodynamic chord of the store's wing
C_{L_s}	lift coefficient of the store based on S_s
$C_{m_{o_s}}$	zero lift pitching moment coefficient of the store based on S_s and C_s
d_T	vertical shift of aircraft C. G. following stores dropping (Fig. 1, positive downward)
F_x, F_z	aerodynamic force components along x-and z-axes for loaded airplane
F_{x_a}, F_{z_a}	aerodynamic force components along x-and z-axes for airplane
F_{x_s}, F_{z_s}	aerodynamic force components along x-and z-axes for stores
f_x, f_z, f_{T_x}, f_{T_z}	corresponding perturbed quantities of F_x, F_z, T_x and T_z
g	acceleration due to gravity
H_T	vertical distance between airplane $C. G.$ and thrust line (Fig. 1)
h_s	height of stores from airplane $C. G.$ (Fig. 1, positive downward)
I_{yy}, I_{yy_a}	moment of inertia about y-axis for loaded airplane and airplane (without stores).
I_{yy_S}	contribution of stores to pitching moment of inertia about the airplane y-axis
M, M_a	aerodynamic pitching moment of loaded airplane and airplane
M_T, M_{T_a}	thrust moment of loaded airplane and airplane
M_{T_s}	contribution to thrust moment of airplane due to shift in vertical $C. G.$ location following stores jettisoning
m_a, m_T	corresponding perturbed quantities for M_a and M_{T_a}
$\overline{m}$, $\overline{m}_a$, $\overline{m}_s$	mass of loaded airplane, airplane and stores
Q	total pitch rate
q	perturbed pitch rate for airplane

$\bar{q}$, q_s	dynamic pressure at free stream and at the stores
S	wing area
S_s	wing area of the stores
T_1	steady state thrust required for loaded airplane
T_x, T_z	thrust force component along x-and z-axes
U, W	forward (along x) and downward (along z-) velocity
u, w	perturbed U and W
x_s	stores aerodynamic centre along x-axis
$X_{C.G.}$	airplane centre of gravity
α	angle of attack
Θ	total pitch angle
θ	perturbed pitch angle
ρ	atmospheric air density
Subscript	
a	airplane (without stores configuration)
s	stores
T	thrust
x, y, z	axes direction
1	steady state value
Superscript	
$\cdot$	derivative with respect to time

3. Formulation

For convenience, we shall refer to the airplane with external stores as 'loaded airplane' and the same airplane minus the jettisoned stores as 'airplane'. The loaded airplane is assumed to be rigid and in a steady state, rectilinear, winglevel flight. The external stores are assumed to be installed under the wing and these are gravity dropped at some chosen time. The stores jettisoning will, in general, result in the following changes for the loaded airplane :

(a) Gross weight and moment of inertia change. (b) The forces and moments contributions due to stores cease to act on the airplane. (c) The *C. G.* of the airplane will shift, changing the trim condition of the airplane. (d) The wing area from where the stores are dropped, will get aerodynamically cleaner following stores separation. This will modify the wing contribution of aerodynamic forces and moments to the airplane. (e) As long as the stores remain in the immediate vicinity of the wing (after separation), the interference effects between the stores and the wing will result in variation of forces and moments acting on the wing.

At the outset, we recognize that the last two considerations (d) and (e) above are very complex and difficult to estimate with any degree of confidence. Eventhough the interference effects are important when predicting the store trajectory after separation, it is hopefully assumed that the contributions to airplane response due to (d) and (e) considerations will be smaller as compared to other contributors listed above and we will, therefore, exclude them from our formulation.

Since we will be interested in a very short time period following the stores separation, it is reasonable to assume that the resulting perturbed response of the airplane will be small. Thus we assume the usual decoupled set of equations of motion for longitudinal and lateral-directional motions of the airplane. Considering the case of symmetric load dropping only, the resulting airplane perturbations are assumed to be only in the plane of symmetry; the perturbed motion being governed by the set of longitudinal equations of motion.

The constitutive longitudinal equations of motion[8] in the stability axes system for the loaded airplane are as follows :

$$\left.\begin{aligned} \bar{m}\dot{U} &= -\bar{m}g\,\mathrm{Sin}\,\Theta + F_x + T_x \\ \bar{m}\,(\dot{W} - UQ) &= \bar{m}g\,\mathrm{Cos}\,\Theta + F_z + T_z \\ I_{yy}\,\dot{Q} &= M + M_T \end{aligned}\right\} \tag{1}$$

Let the stores be symmetrically jettisoned at time $t = 0$. The mass, moment of inertia, forces and moments for the loaded airplane are expressed as the sum of the corresponding values for the airplane and the stores,

$$\bar{m} = \bar{m}_a + \bar{m}_s - \bar{m}_s\,H(t)$$

$$I_{yy} = I_{yy_a} + I_{yy_s} - I_{yy_s}\,H(t) \tag{2}$$

$$F_x = F_{x_a} + F_{x_s} - F_{x_s}\,H(t)$$

$$F_z = F_{z_a} + F_{z_s} - F_{z_s}\,H(t) \tag{3}$$

$$M = M_a + M_s - M_s\,H(t)$$

$$M_T = M_{T_a} + M_{T_s} - M_{T_s}\,H(t)$$

where M_{T_s} represents the indirect contribution that may arise due to change in the vertical location of centre of gravity of the airplane following store jettisoning and thus changing the thrust contribution to pitching moment. $H(t)$ is the unit step function defined by,

$$H(t) = 1 \text{ for } t \geqslant 0$$

$$= 0 \text{ for } t < 0$$

One way to interpret the above splitting of forces and moments is as follows: suppose the airplane model was tested at the given steady state flight condition in two configurations; *A*-with external stores mounted (loaded airplane); *B*-without external stores. Then forces and moments at cofiguration *A* will represent LHS of Eqn. (3) and configuration *B* will represent the first terms on RHS of Eqn. (3). The difference between *A* and *B* will give the force and moment terms denoted by F_{x_s}, F_{z_s} and M_{A_s} for the stores.

3.1 *Steady State Equations of Motion*

To obtain steady state equations of motion, Eqns. (2) and (3) are substituted in Eqn. (1) and $H(t)$ is set equal to zero. This yields,

$$-(\bar{m}_a + \bar{m}_s)\, g \,\mathrm{Sin}\, \Theta_1 + F_{x_{a_1}} + F_{x_s} + T_{x_1} = 0$$

$$(\bar{m}_a + \bar{m}_s)\, g \,\mathrm{Cos}\, \Theta_1 + F_{z_{a_1}} + F_{z_s} + T_{z_1} = 0$$

$$M_{a_1} + M_s + M_{T_{a_1}} + M_{T_s} = 0 \tag{4}$$

where subscript 1 denotes steady state values. For the sake of simplicity, subscript 1 has been omitted from the terms representing stores contribution at steady state flight condition, without creating any ambiguity of notations in the perturbed equations of motion to be derived next.

3.2 *Perturbed State Equations of Motion*

To derive the perturbed state equations of motion following stores jettisoning, all motion variables, force, and moment terms in Eqn. (1) are expressed as sum of steady state quantity and perturbed state quantity. For force and moment terms, Eqn. (3) are first substituted into Eqn. (1) and then the terms F_{x_a}, F_{z_a}, M_a and M_{T_a} for the airplane (without stores) are expressed as sum of corresponding steady state and perturbed quantity. Thus, we write,

$$F_x = F_{x_{a_1}} + f_x + F_{x_s} - F_{x_s} H(t)$$

$$F_z = F_{z_{a_1}} + f_z + F_{z_s} - F_{z_s} H(t)$$

$$M = M_{a_1} + m_a + M_s - M_s H(t)$$

$$M_T = M_{T_a} + m_T + M_{T_s} - M_{T_s} H(t)$$

$$F_{T_x} = F_{T_{x_1}} + f_{T_x}$$

$$F_{T_z} = F_{T_{z_1}} + f_{T_z}$$

$$U = U_1 + u;\ W = W_1 + w;\ Q = Q_1 + q$$

$$\Theta = \Theta_1 + \theta \tag{5}$$

where all lower case letters denote the corresponding perturbed state quantity.

Equations (2) and (5) are substituted into Eqn. (1) and the steady state equations of motion (4) are substracted from it. After the usual simplifications for small perturbation quantities are made i.e. neglecting the terms with product of perturbation quantities, approximating $\sin \theta \doteq 0$ and $\cos \theta \doteq 1$, we obtain

$$\bar{m}_a \dot{u} = \bar{m}_s g \operatorname{Sin} \Theta_1 H(t) - \bar{m}_a g \theta \operatorname{Cos} \Theta_1 + f_x + f_{T_x} - F_{x_s} H(t)$$

$$\bar{m}_a (\dot{w} - U_1 q) = - \bar{m}_s g \operatorname{Cos} \Theta_1 H(t) - \bar{m}_a g \theta \operatorname{Sin} \Theta_1 + f_z + f_{T_z} - F_{z_s} H(t) \quad (6)$$

$$I_{yy} \dot{q} = m_a + m_{T_a} - M_s H(t) - M_{T_s} H(t)$$

The force and moment terms due to stores are rewritten as follows :

$$F_{x_s} = - D_s = - C_{D_s} q_s S_s$$

$$F_{z_s} = - L_s = - C_{L_s} q_s S_s \quad (7)$$

$$M_s = C_{m_{o_s}} q_s S_s C_s + (X_{C.G} - x_s) q_s S_s C_{L_s} - h_s q_s S_s C_{D_s}$$

$$M_{T_s} = T_1 d_T = C_{D_1} \bar{q} S d_T$$

The perturbed force and moment terms for airplane in eqn. (6) are expanded in terms of corresponding total force and moment terms' derivatives with respect to motion variables and each derivative being evaluated at the steady state condition. This leads to the usual form of perturbed state equations of motion in terms of stability and control derivatives. However, since stick fixed condition is assumed while the stores are being jettisoned, all the control derivative terms are dropped. These stability derivatives are suitably regrouped into dimensional stability derivatives; for dimensional derivatives, notations of Roskam[5] are followed. Substituting Eqn. (7) in Eqn. (6) for stores force and moment terms, we finally obtain the following perturbed state equations of motion for the airplane for $t \geqslant 0$ (after the separation of stores at $t = 0$).

$$\begin{bmatrix} D - X_u - X_{T_u} & -X_\alpha - X_{\dot{\alpha}} & g \cos \Theta_1 - X_q D \\ -Z_u - Z_{T_u} & U_1 D - Z_\alpha - Z_{\dot{\alpha}} D & g \sin \Theta_1 - U_1 D - Z_q D \\ -M_u + M_{T_u} & -M_\alpha - M_{T_\alpha} - M_{\dot{\alpha}} D & D^2 - M_q D \end{bmatrix} \begin{bmatrix} u(t) \\ \alpha(t) \\ \theta(t) \end{bmatrix} = \begin{bmatrix} A_x \\ A_z \\ A_M \end{bmatrix} \quad (8)$$

where $D \equiv \dfrac{d}{dt}$

$$A_x = (C_{D_s} q_s S_s + \bar{m}_s g \operatorname{Sin} \Theta_1) / \bar{m}_a$$

$$A_z = (C_{L_s} q_s S_s - \bar{m}_s g \operatorname{Cos} \Theta_1) / \bar{m}_a$$

$$A_M = [\{C_{m_{o_s}} C_s - (X_{C.G.} - x_s) C_{L_s} + h_s C_{D_s}\} q_s S_s - C_{D_1} \bar{q} S d_T] / I_{yy_a} \quad (9)$$

X_u, X_{T_u} ... M_q represent the dimensional stability derivatives for the airplane in standard notations as defined in Roskam[8]

4. Application of the method

To predict the perturbed response of the airplane following stores separation, the following information is required to solve Eqn. (8).

(a) The steady state flight condition of the loaded airplane. (b) Mass, moment of inertia and geometric details of the airplane and stores. (c) Stability derivatives of the airplane. (d) Total drag coefficient (C_{D_1}) of the loaded airplane at the steady state flight condition. (e) Aerodynamic characteristics of the stores in the form of lift, drag, and pitching moment coefficient along with the average dynamic pressure (q_s) seen at the stores.

It is the last named quantities which are most complex and difficult to estimate. For a given store and airplane combination, these are strong functions of chordwise, spanwise, and vertical location of the stores on the wing. The complexity of such evaluations is well documented by Marsden and Haines[1], Goodwin et al[5] and Cooper et al[9].

It was not possible to obtain a complete set of data required (as listed above, a to e) for any real airplane-stores combination. It was therefore, decided to choose fictitious airplane and store data which approximately resembled some real configurations. It is in this context that we will name our carrier airplanes as FIAT (resembling Fiat-G-91) and F-100 (resembiling North American F-100). The chosen stores configuration was dictated more by the available literature which could be used directly to predict the aerodynamic characteristics of it as needed for the analysis. Table 1 gives the characteristics features of carrier airplanes FIAT and F-100 used for illustration. Figure 1 shows the geometry of the stores considered. The mass of the stores was assumed to be one per cent of the airplane mass. The location of the stores under the wing was varied in the following manner.

Spanwise location : Kept fixed at half semi-span

Vertical location : Below the lower surface of the wing, at two locations $V1 = 0.135\ \bar{C}$ and $V2 = 0.372\ \bar{C}$, where $\bar{C}$ is the mean aerodynamic chord of the wing.

Chordwise location : Centre of gravity of the store was located at five chordwise points, $C1 = -0.5\bar{C}$; $C2 = -0.25\bar{C}$; $C3 = 0.0C$; $C4 = 0.25C$; $C5 = 0.5\bar{C}$.

where negative sign indicates chordwise location having store *C. G.* ahead of airplane *C.G.* and positive sign indicates opposite of it. For each vertical location $V1$ and $V2$, all five chordwise locations $C1$ to $C5$ are used for analysis.

Table 1. Physical characteristics, steady state flight condition and stability derivatives for FIAT and F-100 airplanes used as test cases.

Quantity	Airplane : FIAT	Airplane : F-100
Mass, $\overline{m}_a$	5000 Kgs	12,272 Kgs
U_1	137.5 m/sec	196.43 m/sec
Wing area, S	16.42 m^2	37.18 m^2
MAC, $\overline{C}$	2.05 m	3.41 m
Air density, ρ	0.685 kg/m^3	0.9075 Kg/m^3
Mach No.	0.44	0.6
I_{yy_a}	30,400 Kg/m^2	89,153 Kg/m^2
Θ_1	0.0	0.0
g	9.81 m/sec^2	9.81 m/sec^2
C_{D_1}	0.0375	0.0186
C_{L_1}	0.47	0.184
C_{D_u}	0.048	0.0041
$C_{T_{x_1}}$	0.0375	0.018
$C_{D\alpha}$	0.41	0.153
C_{L_u}	0.0286	0.103
$C_{L\alpha}$	3.9	3.889
$C_{L\dot{\alpha}}$	0.8	0.65
C_{L_q}	3.6	3.854
$C_{m\alpha}$	-1.8	-1.527
C_{m_q}	-4.4	-3.673
C_{m_u}	0.0	0.0
$C_{m\dot{\alpha}}$	$-.487$	-0.400
$X_{C.G.}$	.25 $\overline{C}$	0.3 $\overline{C}$
H_T	0.48 m	0.383 m

All nondimensional stability derivatives are for the airplane (without stores). The notation used is standard and conforms to Roskam[8].

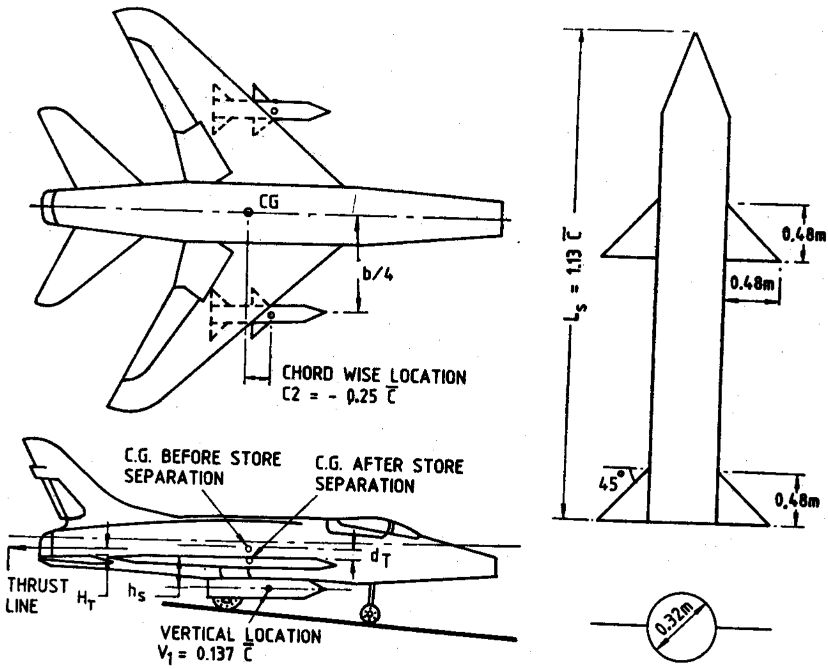

Figure 1. One airplane-store configuration and store geometry used as a test case.

The aerodynamic characteristics of stores at various locations under the wing for chosen steady state flight condition are estimated based on results of Marsden and Haines[1]. To illustrate the procedure used and various assumptions made, a sample calculation to estimate A_x, A_z and A_m for one store location for one airplane is given in Appendix *A*. Once the elements of vector on the RHS of Eqn. (8) are so estimated, the Laplace transform techniques are used to solve Eqn. (8) for each location of the stores for both the airplanes. The solutions of the required motion variables following stores jettisoning are plotted against time; the plots have been drawn using the computer graphics of *DEC*-1090 Computer system at IIT Kanpur.

5. Results and Discussion

To arrive at any conclusion regarding the effect of airplane perturbation motion on the probability of collision between the airplane and the separated stores, it is necessary to evolve a criterion for it. Let us consider a case where the store is located in the vicinity of the wing's leading edge portion and the *C.G.* of the airplane is behind this part of the wing (Fig. 1). If the store separation from such configuration were to result in nose-down pitching moment, it will enhance the probability of collision between the store and the wing. Further, if the perturbed velocity component of the airplane were also negative (deceleration of airplane), it will add to the danger of collision. This combination of pitch-down motion and deceleration tends to move the wing leading edge portion towards the just jettisoned store and thus present potential hazard of collision. To put the argument other way around, the most forward location of the stores will be considered safe, if the resulting airplane response had pitch-up motion coupled with deceleration. It may be pointed out that mixed response such as pitch-up motion with acceleration or pitch-down motion with deceleration has to be analysed in terms of relative magnitudes of θ and u variations to arrive at safety criterion. Similar arguments are used for stores located near the trailing edge of the wing and *C.G.* of the airplane lying ahead of it. Here the safe jettisoning will require nose-down pitching motion with acceleration and the opposite combination indicating increased chances of collision.

The third motion variable, angle of attack, α, will also affect the above considerations. However, it was observed that for all the locations considered, α was always positive and of small magnitude. Thus it will result in small downward motion of airplane and is not favourable to safe jettisoning from any stores location. Since it affects all locations in a similar manner, it was not considered separately and no modifications are made in the above laid down criterion. Finally, it may be noted that the nature of only the initial response for first few seconds following the store separation need be considered while applying the above criterion.

The perturbed responses following stores separation for FIAT and F-100 airplane. will now be discussed in the light of the above criterion for safe jettisoning of stores Perturbed dimensionless velocity, (u/U_1) and pitch angle, θ for vertical location $V1$ and all five chordwise locations $C1$ to $C5$ are shown in Fig. 2 for FIAT airplane.

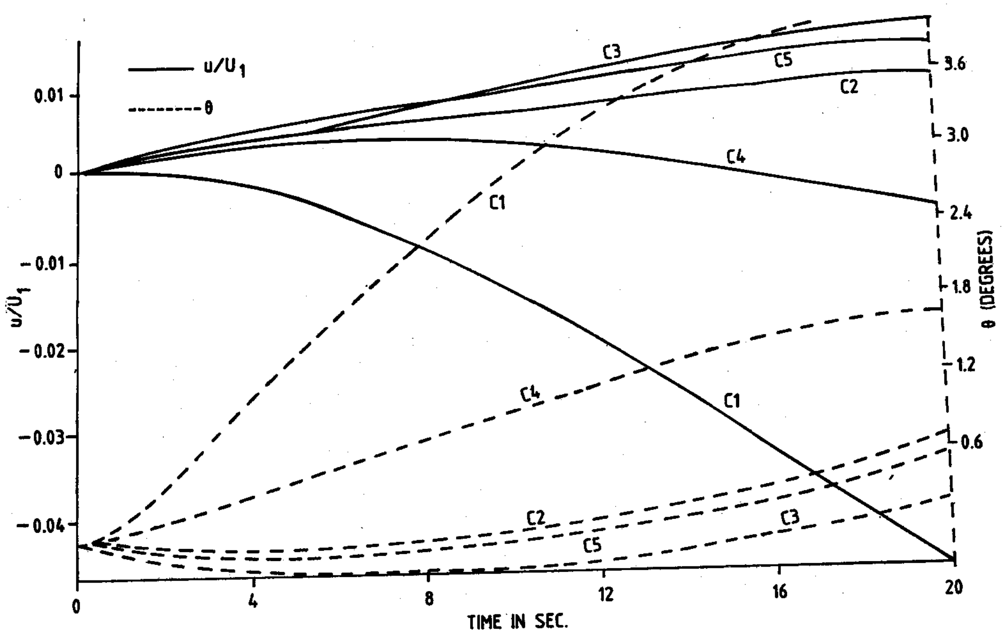

Figure 2. FIAT airplane response following stores jettisoning from vertical location $V1$.

Figure 2 shows that the airplane pitches down and accelerates for all chord wise locations except for, pitch-up motion for *C*1 and *C*4 and deceleration for *C*1 location. This suggests that location *C*1 (most forward) has the right combination of pitch-up and deceleration for safe separation. All other locations have a mild variations of θ and u; the aft most location *C*5 having the desirable nose-down motion and acceleration but of much smaller magnitudes; so we conclude that most forward location seems to recommend itself most, followed by aft most location.

Figure 3 shows u/U_1 and θ plots for the second vertical location of the stores, i.e. *V*2 location. It shows that for about first five seconds, airplane accelerates for all chordwise locations; maximum for most aft location *C*5 and minimum for most forward location *C*1. This is accompained by pitch-down motion for *C*3 and *C*5 locations and pitch-up for the rest of three chordwise locations. In this case, therefore, most aft location *C*5 has the desirable u and θ perturbations to qualify as the most safe stores location. Most forward location *C*1 does have right θ perturbation but it is spoiled by wrong u, albeit small in magnitude.

Now we shall discuss the results for F-100 airplane. First we study the results for *V*1 location. Fig. 4 shows u and θ plots for all chordwise locations. It is seen that the variations of both u and θ are similar to that observed for FIAT airplane and hence, the identical conclusions regarding safe locations can be drawn. For the other vertical location *V*2, Fig. 5 shows u and θ variations with time. Again the results are similar to the corresponding results for FIAT airplane, except for θ showing pitch-up instead of pitch-down tendency for *C*3 location. We can again conclude

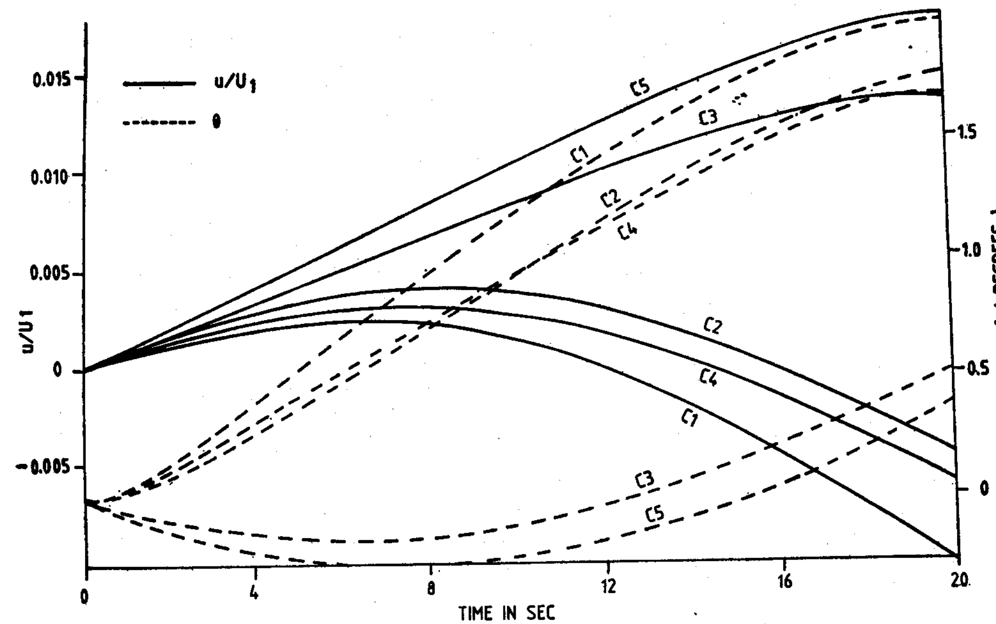

Figure 3. FIAT airplane response following stores jettisoning from vertical location *V*2.

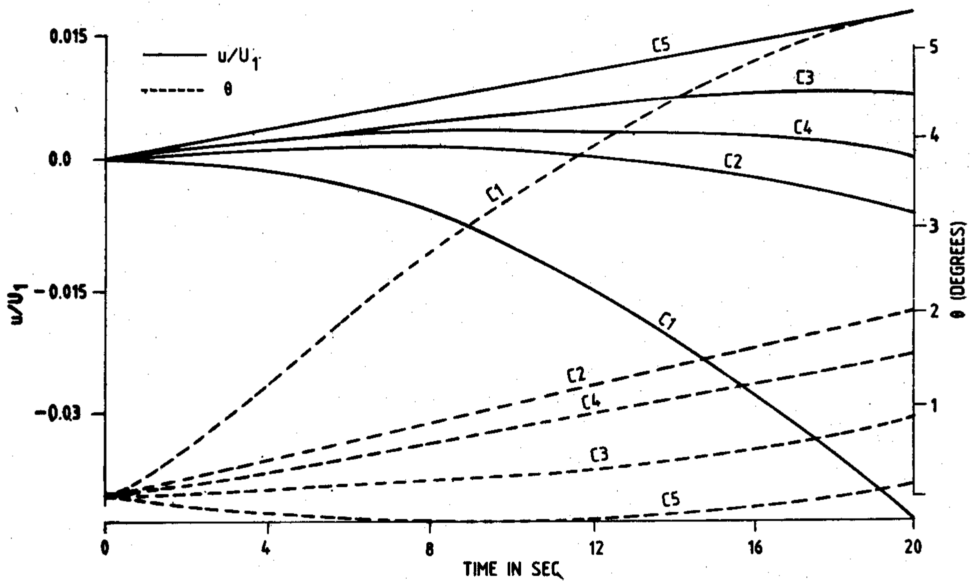

Figure 4. F-100 airplane response following stores jettisoning from vertical location *V*1.

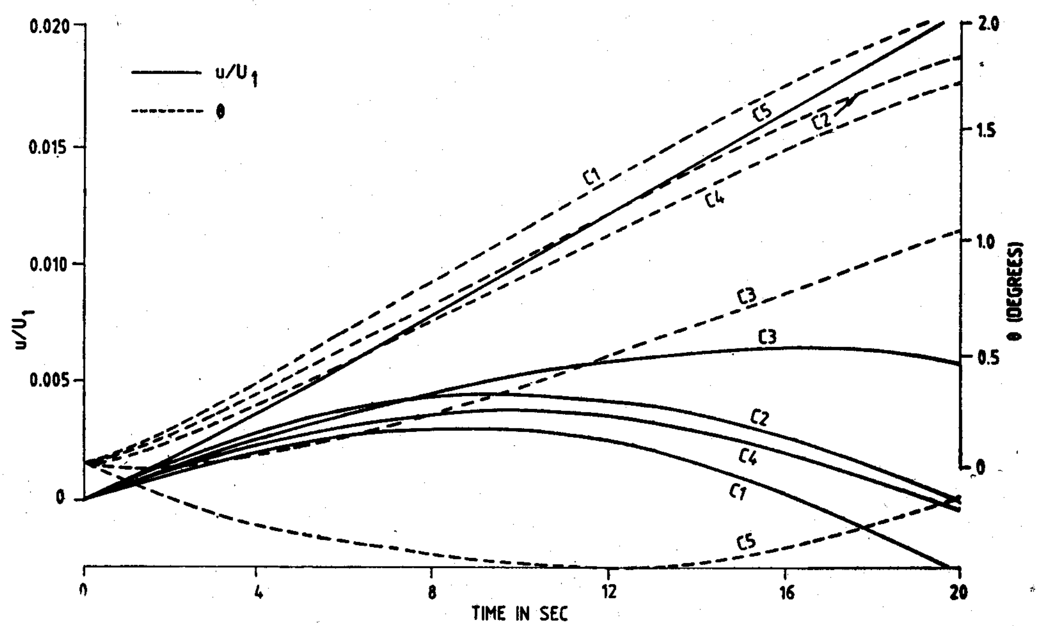

Figure 5. F-100 airplane response following stores jettisoning from vertical location *V*2.

that forward locations are safer as compared to aft locations of stores. Thus we observe that for stores nearer to wing surface $V1$, the most safe location is most forward while for stores at locations lower down from wing $V2$, the aft most location becomes safer.

Based on the two airplanes studied above, it may be suggested that a study of airplane response following stores jettisoning should be undertaken to indicate whether the initial tendency of perturbed airplane is to go towards the stores or away from it. This information combined with trajectory of the stores after separation should be used to finally declare a store location being safe or not. It may be again emphasized that no general conclusions should be drawn from the case studies reported here; separate study has to be carried out for each specific airplane-store combination.

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Appendix A

A sample calculation and steps followed to estimate A_x, A_z and A_M terms appearing in Eqn. (8) for FIAT airplane at Mach No. 0.44 are presented below. The store position used is,

$$C1 = -0.5\,\bar{C};\ V1 = 0.133\,\bar{C};\ \text{Spanwise location} = \text{half semi-span}$$

Estimation of A_x

$$A_x = (C_{D_s}\, q_s\, S_s + \bar{m}_s\, g \,\text{Sin}\, \Theta_1)\, \bar{m}_a \tag{A1}$$

The drag coefficient for the stores C_{D_s} is assumed equal to 0.2 for low mach numbers[2].

q_s is estimated from the following expression,

$$q_s = SCF.\,\bar{q} \tag{A2}$$

where SCF is the scale factor estimated from Marsden and Haines[1] for the chosen stores configuration and its location under the wing. The free stream dynamic pressure being known for the selected steady state flight condition (Table 1), we calculate q_s from A2.

The characteristic area S_s for stores is taken as its wing are and equal to 0.23 m^2.

Mass of the stores $\bar{m}_s = 0.01\ \bar{m}_a\ N_s$, where N_s is the number of stores.

Thus for two stores configuration, we obtain,

$$A_x = 0.121 \text{ m/sec}^2.$$

Estimation of A_z

$$A_z = (C_{L_s} q_s S_s - \bar{m}_s g \cos \Theta_1)/\bar{m}_a \tag{A3}$$

The stores lift coefficient, C_{L_s} was again estimated from Marsden and Haines[1] and necessary mach number correction was accounted for. Other quantities in A3 are same as were estimated for A_x, thus we get,

$$A_z = 0.467 \text{ m/sec}^2$$

Estimation of A_M

$$A_M = [\{- C_{m_{o_s}} C_s - (X_{C.G.} - x_s)\ C_{L_s} + h_s C_{D_s}\}\ q_s S_s - C_{D_1} \bar{q}\ S\ d_T]/I_{yy_a}$$

Zero lift pitching moment coefficient for store $C_{m_{o_s}}$ was again estimated from charts given in Marsden and Haines[1]. The mean aerodynamic chord of the wing of the store, C_s was calculated to be $= 0.29$ m., $X_{C.G.} - X_s = -0.5\ \bar{\bar{C}}$ for the chosen location of the store. It was assumed for convenience that store *C. G.* and aerodynamic centre are coincident.

h_s = vertical distance from *C.G.* of airplane to lower surface of wing at store location $+ V1$ (where $V1 = 0.135\ \bar{C}$ for present case).

$d_T = -h_s \left(\frac{\bar{m}_s}{\bar{\bar{m}}_a}\right)$ will yield the vertical shift of *C.G.* due to store dropping. Since stores are located below the airplane *C. G.*, the *C. G.* shift will be upward, hence d_T is taken negative. The other required terms in expression of A_M like C_{D_1}, I_{yy_a} are taken from Table 1. Finally the value of A_M so calculated is,

$$A_M = 0.0485/\text{sec}^2$$

Similar procedure was used to calculate A_x, A_z and A_M for all chosen airplane-store configurations analysed for illustration.