Aircraft Dynamic Response to Variable Wing Sweep Geometry

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A numerical method to obtain a complete solution of the dynamic response of a variable swept wing aircraft in the course of changing the sweep angle is presented. Both aerodynamic and trajectory computations are included. A method for calculating the unsteady aerodynamic characteristics of wing/tail combinations at subsonic speeds under varying sweep backs is developed. The method uses a potential flow model consisting of discrete unsteady vortex rings distributed over the wing and tail surfaces. A set of complete equations for flight dynamics in the main body axes is formed with a deformable system dynamics. The time history method is used to calculate the aerodynamic characteristics and the aircraft responses. All aerodynamic and flight dynamic parameters during the whole course of varying the sweep back have been obtained and such influences as various control rules, flight Mach number, etc., on aircraft response during that vaiation have been satisfactorily analyzed. Some computation examples and response analyses are presented that are useful for studying the flight stability, maneuverability, and safety of wing sweep change at low altitudes.

Nomenclature

A = area, m^2
a = speed of sound, m/s
b = length, m
C = unsteady fundamental solution, Ref. 4
$\tilde{C}(\beta_0)$ = steady aerodynamic coefficient corresponding to the initial swept-back angle β_0 at initial time step t_0
D = drag, N
F = force acting on an aircraft, N
g = gravity acceleration, m/s^2
H = flight altitude, m
I = inertia moment of an aircraft about origin 0, $N \cdot m \cdot s^2/deg$
$I_i (i=1,2)$ = inertia moment of the right and left variable wings about their own center of gravity
L = unsteady aerodynamic lift, N
M = moment acting on an aircraft, N·m, or flight Mach number
m = mass, kg, $= \sum_{i=0}^{2} M_i$
n = increment of normal load factor, $[L + T \cdot \sin(\alpha+\phi)]/mg - 1.0$
O,X,Y,Z = main body coordinates, OX is aligned to the axis of aircraft, Figs. 1 and 2
O_e,X_e,Y_e,Z_e = ground coordinates, Figs. 1 and 2
q = dynamic pressure, N/m^2
R = flight range, m
S = static moment of an aircraft about the origin O, $N \cdot s^2$
T = thrust, N
t = time, s
V = flight velocity, m/s
α = angle of attack, deg
β = sweep angle of wing leading edge, deg
γ = flight path elevation angle, deg
Δ = increment
δ = elevator deflection angle, deg
θ = pitch angle, deg
κ = index of time step
ϕ = angle of thrust, deg
ω = rotational angular velocity, deg/s, Fig. 1
$\omega_i (i=1,2)$ = rotational angular velocity of the right and left variable wings about their own rotating shaft, respectively, deg/s, Fig. 1

Superscripts

$\alpha,\delta,\kappa,\omega$ = as defined above
$(\dot{\ })$ = first derivative with respect to time, d/dt
$(\ddot{\ })$ = second derivative with respect to time, d^2/dt^2
$(\bar{\ })$ = vector
$(\bar{\bar{\ }})$ = tensor

Subscripts

a = aerodynamic
g = center of gravity
$i=0,1,2$ = fuselage and right and left wings of variable sweep angle, respectively
ib = fundamental solution for dynamic step variation
L = lift
M = moment
ob = fundamental solution for pure swept change
ref = reference
t = thrust
x,y,z = components of respective variable in the main body coordinates
∞ = freestream

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Introduction

VARIABLE swept wing aircrafts have attracted the attention of specialist, scholars, and engineers because they have good aerodynamic qualities when flying at various speeds. During flight, the aerodynamic configuration and aerodynamic characteristic undergo great change, an important factor in enabling the aircraft to fly unsteadily. The wing rotation about rotating shafts can cause a shift in the mass center of the aircraft and a variation in the moment of inertia. The variation in the momentum and angular momentum of the wings can also influence the motion of the aircraft.

Dzygadlo and Maruszkiewiez[1,2] analyzed the peculiarities of the longitudinal motion of an aircraft with varying sweep backs. Bulekov and Teryev[3] derived a moment equation that takes the aircraft center of gravity as the origin in the main body axes and made use of the transfer function to compute aircraft response characteristics to a pulse function in the changing geometry. These works described how to simplify and solve the motion equations, but did not involve the essence of the unsteady aerodynamic variations.

Since rotation of the wings will cause a shift of the aircraft center of gravity, to make the calculation easier, in this paper a set of motion equations in the main body axes has been derived, which takes a certain point on the symmetry axis of aircraft as the origin. In the same way, to show more exactly the variation in the unsteady aerodynamic characteristics of the wing during varying sweep backs, the conventional computation method for the quasisteady aerodynamic characteristics of an aircraft is used and a computation method for unsteady aerodynamic characteristics of the aircraft during varying sweep backs is introduced. This method is used to compute the transient unsteady response of an aircraft.

The purpose of this paper is to take into account the factors mentioned above and to give the parameters of longitudinal motion, flight attitude, and trajectory of the aircraft in the course of varying sweep backs—that is, the longitudinal dynamic response of an aircraft. It is suitable to assume various rules for varying sweep backs, thrust change, and elevator deflection (including open- and closed-loop controls). The influences of flight altitude and Mach number are also taken into account.

Equations of Motion of Aircraft

To make the computation easier, the aircraft can be treated as a combination of a fuselage (including the tail) and right and left wings of variable swept angles.

During flight, because of the swept angle variation of the wings, the aircraft cannot be regarded as a rigid body—its mass center is shifting along the fuselage. In this paper, the system of main body coordinates (O,X,Y,Z), the origin of which is located at a certain fixed point on the symmetry axis (X axis) of the aircraft, is chosen as a computing coordinate system and the system of ground coordinates (O_e,X_e,Y_e,Z_e) as an inertia reference coordinate system (see Fig. 1).

In the main body coordinates (O,X,Y,Z), the dynamic equation for an aircraft with variable swept wings can be expressed in vector form as

$$\bar{F}=m(\dot{\bar{V}}+\bar{\omega}\times\bar{V})+\dot{\bar{\omega}}\times\bar{S}+2\bar{\omega}\times\dot{\bar{S}}+\bar{\omega}\times(\bar{\omega}\times\bar{S})+\ddot{\bar{S}}$$

$$\bar{M}=\bar{I}\cdot\dot{\bar{\omega}}+\dot{\bar{I}}\cdot\bar{\omega}+\bar{\omega}\times(\bar{I}\cdot\bar{\omega})+\bar{S}\times\dot{\bar{V}}+\bar{S}\times(\bar{\omega}\times\bar{V})$$
$$+\sum_{i=1}^{2}\{\bar{I}\omega_i\cdot\dot{\bar{\omega}}_i+\dot{\bar{I}}_i\cdot\bar{\omega}_i+\bar{\omega}\times(\bar{I}_i\cdot\bar{\omega}_i)$$
$$+\frac{1}{m_i}[\bar{S}_i\times\ddot{\bar{S}}_i+\bar{\omega}\times(\bar{S}_i\times\dot{\bar{S}}_i)]\}\tag{1}$$

The longitudinal dynamic response of an aircraft with variable swept wings is discussed in this paper. If the sweep change and mass distribution of the right and left variable wings are assumed to be symmetric, then Eq. (1) can be reduced into the form of the component,

$$F_x=m\dot{V}_x-S_y\dot{\omega}_z-mV_y\omega_z-S_x\omega_z^2-2\dot{S}_y\omega_z+\ddot{S}_x$$

$$F_y=m\dot{V}_y-S_x\dot{\omega}_z-mV_x\omega_z-S_y\omega_z^2+2\dot{S}_x\omega_z+\ddot{S}_y$$

$$M_z=-S_y\dot{V}_x+S_x\dot{V}_y+I_z\dot{\omega}_z+S_xV_x\omega_z+S_yV_y\omega_z$$
$$+\dot{I}_z\omega_z+2[-I_{1xz}\dot{\omega}_{1x}-I_1y_z\dot{\omega}_{1y}+I_{1z}\dot{\omega}_{1z}$$
$$-\dot{I}_{1xy}\omega_{1x}-\dot{I}_{1yz}\omega_{1y}+\dot{I}_{1z}\omega_{1z}$$
$$+\frac{1}{m_1}(S_{1x}\ddot{S}_{1y}-S_{1y}\ddot{S}_{1x})]\tag{2}$$

If only the longitudinal motion of an aircraft is discussed, the components of each force and moment should be (see Fig. 2),

$$F_x=-D\cdot\cos\alpha+L\cdot\sin\alpha+T\cdot\cos\phi-mg\cdot\sin\theta$$

$$F_y=D\cdot\sin\alpha+L\cdot\cos\alpha+T\cdot\sin\phi-mg\cdot\cos\theta$$

$$M_z=M_{za}-M_{zt}+(-S_x\cdot\cos\theta+S_y\cdot\sin\theta)\cdot g\tag{3}$$

To solve Eqs. (2) and (3), the following geometric and kinematic relations must be added:

$$\alpha=\mathrm{arctg}(-V_y/V_x),\quad \theta=\gamma+\alpha$$

$$V=(V_x^2+V_y^2)^{1/2},\qquad M=V/a$$

$$\dot{\theta}=\omega_z,\quad \dot{R}=V\cdot\cos\gamma,\quad \dot{H}=V\cdot\sin\gamma\tag{4}$$

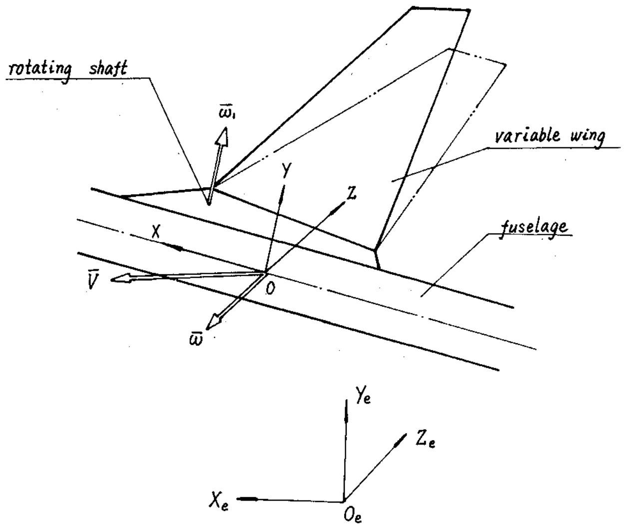

Fig. 1 Main body coordinates and ground coordinates.

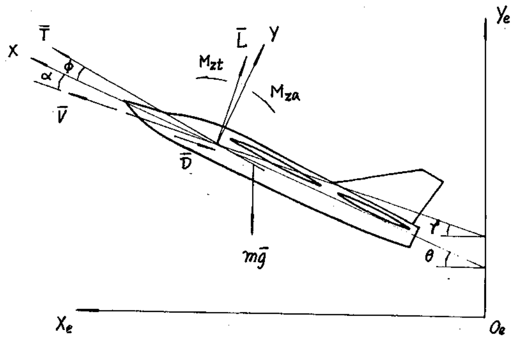

Fig. 2 Angles, forces, and moments used in this paper.

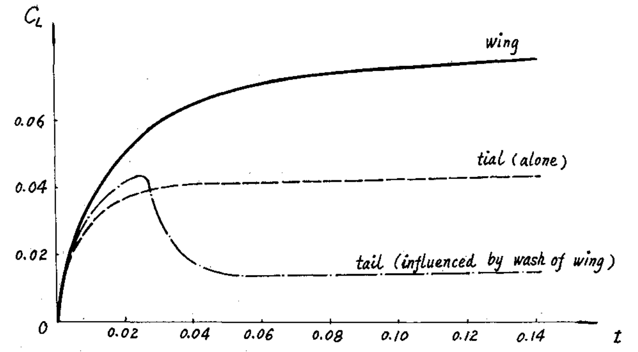

Fig. 3 Fundamental solutions of wing (alone), tail (alone), and tail (influenced by wing wash).

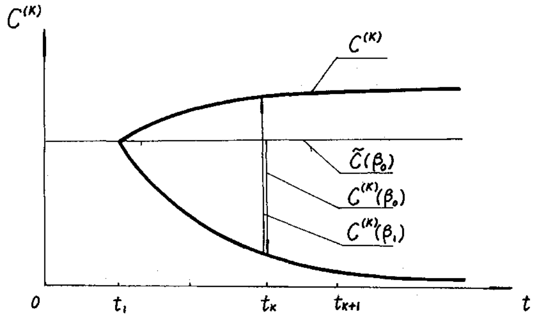

Fig. 4 Unsteady fundamental solution of variable-sweep wing in the course of changing geometry.

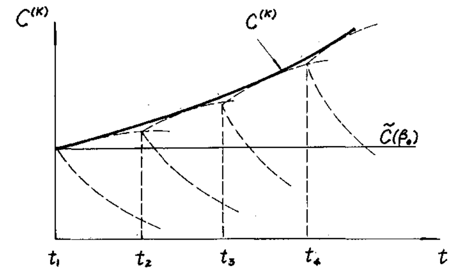

Fig. 5 Unsteady fundamental solution of variable swep wing in the course of pure swept change.

If the rules for sweep angle change $\beta = \beta(t)$, elevator deflection $\delta = \delta(t)$, and engine thrust $T = T(t)$, as well as the rules for dependence of atmospheric density and sound speed on flight altitude of an aircraft $\rho = \rho(H)$ and $a = a(H)$ are given, Eqs. (2–4) can be solved. During flight of varying sweepbacks, each static moment, inertia moment, and their derivatives with respect to time in Eqs. (2) and (3) will vary continually with the sweep angle of the wing. The method of transferring matrix is adopted to determine these values.

Unsteady Aerodynamic Calculation

When an aircraft is flying under the condition of varying sweptbacks, the sweptback angle of the wings will change over a considerable range, as will the aspect ratio and aerodynamic configuration of the wings. Consequently, a remarkable variation in the aerodynamic characteristics of the aircraft will occur. The dynamic response of the aircraft caused by this variation changes the aerodynamic characteristics of the aircraft. These are two factors that can cause the unsteady motion of the aircraft.

According to the computation model proposed in Refs. 4 and 5, the computed unsteady aerodynamic characteristics of wing and horizontal tail are as shown in Fig. 3, the tail being in the wake vortices shedding continually downward from the wing trailing edges. It is evident that the tail receives first an upwash and then a downwash of the vortex wake.

The principle of the computation of unsteady aerodynamic characteristics of the wing described in Refs. 4 and 5 can also be used to compute unsteady aerodynamic characteristics of variable sweep wings. During varying sweep backs, the wing configuration changes continually. Therefore, the shapes of the vortex rings on the wings and in the wake will also change continually. This not only causes complications in the computation, but also requires a large computer.

The method of perturbation transfer is adopted to compute the unsteady aerodynamic characteristics caused by varying sweep backs. A perturbation caused by a change in the wing configuration in the course of varying sweep backs is transferred into a series of composite "dynamic" perturbations that vary continually.

This is explained by an example of the pure swept change of the unit angle of attack. First, the continuous variation of the sweep angle is discretized into its step variation $\Delta\beta_K$ at each time step $t_K (k = 0, 1, 2, \ldots)$. Suppose the real perturbation at the time step t_1 is

$$\alpha = 1\ \text{deg}, \qquad \beta = \beta_0 \to \beta_1 \tag{5}$$

Transfer this perturbatrion into

$$\begin{aligned} &\beta = \beta_0, && \alpha = 1\ \text{deg} \to 0\ \text{deg} \\ &\alpha = 0\ \text{deg}, && \beta = \beta_0 \to \beta_1 \\ &\beta = \beta_1, && \alpha = 0\ \text{deg} \to 1\ \text{deg} \end{aligned} \tag{6}$$

This divides a perturbation indicated by Eq. (5) into the three perturbations indicated by Eq. (6) that are taking place simultaneously. The first perturbation in Eq. (6) corresponds to the wing with a sweep angle β_0 whose angle of attack suddenly decreases 1 deg. According to the computation method described in Refs. 4 and 5, the unsteady fundamental solution in this case can be calculated. The second perturbation cannot cause aerodynamic variation because the angle of attack is zero. The third perturbation corresponds to the wing with a sweep angle β_1 whose angle of attack increases 1 deg. In the same way, the unsteady fundamental solution in this case can also be calculated. After the two unsteady fundamental solution are superimposed, the unsteady fundamental solution of the wing in the course of varying sweep backs indicated by Eq. (5) can be obtained. The superimposed course is shown in Fig. 4. If the wing continuously changes its sweep angle after time step t_1, a series of superimposition for the perturbation transfer may be made in the same way as above at each corresponding time step of varying sweep backs. This is shown in Fig. 5. Thus, the superimposition formula for the unsteady fundamental solution of the unit angle of attack in the course of varying sweep backs can be obtained as

$$C^{(k)} = \tilde{C}(\beta_0) + \sum_{j=0}^{k-1} [C^{(k-j)}(\beta_{j+1}) - C^{(k-j)}(\beta_j)] \tag{7}$$

In the same way, the method of computing the unsteady fundamental solution in the case where there are sweep angle changes after a dynamic step variation of the aircraft can be obtained by superimposing a series of the fundamental solutions mentioned above at each corresponding time step caused by the sweep change to the dynamic unsteady fundamental solution of the initial wing configuration (see Fig. 6). There is a similar computation formula,

$$C^{(k)} = C^{(k-i+1)}(\beta_i) + \sum_{j=i}^{k-1} [C^{(k-j)}(\beta_{j+1}) - C^{(k-j)}(\beta_j)] \tag{8}$$

where subscript i is the index of the initial time step of the dynamic step variation of the aircraft.

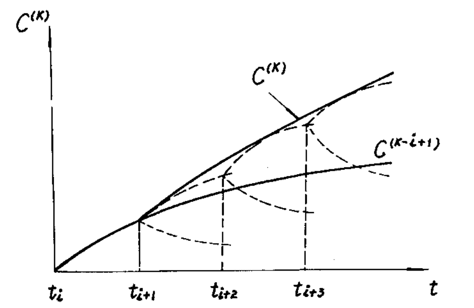

Fig. 6 Unsteady fundamental solution of variable-sweep wing in the course of varying sweep backs after a dynamic step variation.

Suppose the flight attitude and motion parameters of an aircraft at any time step t are

$$\alpha^{(\kappa)}=\alpha^{(0)}+\sum_{i=1}^{\kappa}\Delta\alpha_i$$

$$\omega^{(\kappa)}=\omega^{(0)}+\sum_{i=1}^{\kappa}\Delta\omega_i$$

$$\delta^{(\kappa)}=\delta^{(0)}+\sum_{i=1}^{\kappa}\Delta\delta_i \tag{9}$$

then the unsteady aerodynamic force and moment acting on the aircraft at the time step t are

$$L(K)=q_\infty S_{\text{ref}}\Big[\alpha^{(0)}C_{L_{ob}}^{\alpha(\kappa)}+\omega^{(0)}C_{L_{ob}}^{\omega(\kappa)}+\delta^{(0)}C_{L_{ob}}^{\delta(\kappa)}+\sum_{i=1}^{k}\big(\Delta\alpha_i C_{L_{ib}}^{\alpha(\kappa)}+\Delta\omega_i C_{L_{ib}}^{\omega(\kappa)}+\Delta\delta_i C_{L_{ib}}^{\delta(\kappa)}\big)\Big]$$

$$M_{za}(K)=q_\infty S_{\text{ref}}b_{\text{ref}}\Big[\alpha^{(0)}C_{M_{ob}}^{\kappa(\kappa)}+\omega^{(0)}C_{M_{ob}}^{\omega(\kappa)}+\delta^{(0)}C_{M_{ob}}^{\delta(\kappa)}+\sum_{i=1}^{k}\big(\Delta\alpha_i C_{M_{ib}}^{\alpha(\kappa)}+\Delta\omega_i C_{M_{ib}}^{\omega(\kappa)}+\Delta\delta_i C_{M_{ib}}^{\delta(\kappa)}\big)\Big] \tag{10}$$

Computation Method

Equations (2) are nonlinear and have variable coefficients. L and M_{za} in Eq. (3) can be obtained from Eq. (10) and depend not only on the sweep angle and motion attitude at that time step, but also on their course of historical development. So it is extremely difficult to get an analytical solution for the set of Eqs. (2).

In this paper, the time history method is adopted to compute the aerodynamic characteristics and aircraft responses. First, divide the course of varying sweepbacks into 1000 or thousands of time steps and then make the computations from time step t_0 one by one. At any time step t_κ, the variations of the sweep angle and elevator deflection angle may be introduced. Having computed the unsteady aerodynamic characteristics, compute all the magnitudes of the aircraft response according to Eqs. (2-4) at the same time step. The results computed at time step t_κ are used as the input not only of the next time step $t_{\kappa+1}$, but also of any following time step.

In Eqs. (2), $\dot V_x$, $\dot V_y$, and $\dot\omega_z$ are implicit functions; thus, it is very complicated to write their explicit functions. So, the method to solve linear algebra equations is chosen to compute $\dot V_x^{(\kappa)}$, $\dot V_y^{(\kappa)}$, and $\dot\omega_z^{(\rho)}$ at any time step.

In this way, the computation is cycled over and over. Through the cross computations in turn at each time step, the numerical solutions over the whole course of varying sweep backs can be achieved.

Computational Examples and Response Analyses

To study the influence of the varying sweep angle on aircraft motion, a hypothetic variable sweep aircraft in horizontal steady flight at the initial time step t_0 is computed. Its parameters such as thrust, balance angle of attack, and balance angle of elevator deflection can be computed by iteration.

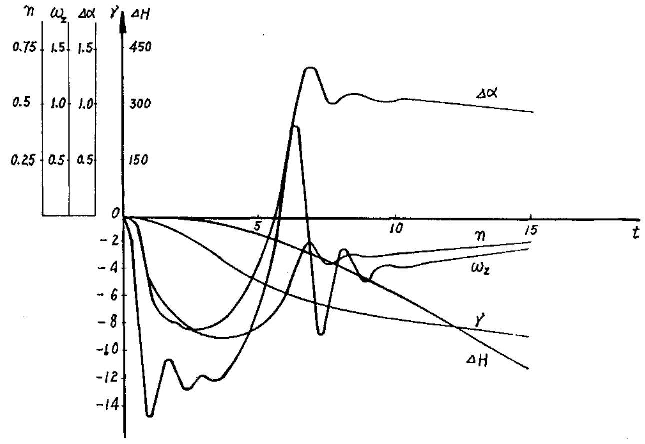

Fig. 7 Variations of increment of normal load factors, pitching angular velocity, angle of attack, flight path elevation angle, and flight altitude vs time.

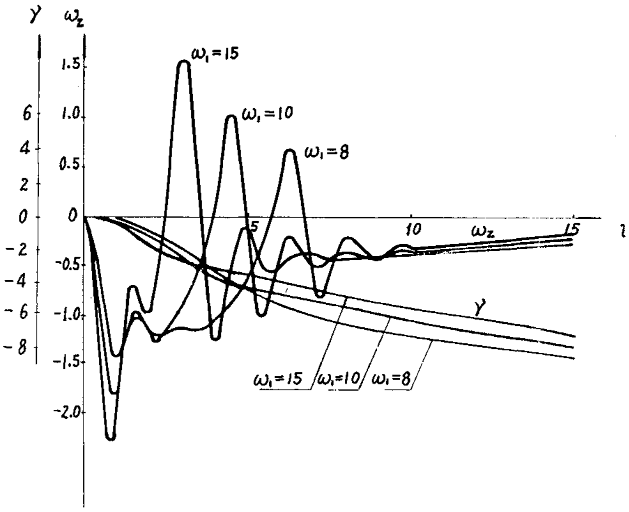

Fig. 8 Variations of flight path elevation angle and pitching angular velocity vs time at different rotational angular velocities of wings about their own rotating shift.

From time step t_1, the aircraft begins to change its sweep angle. The sweep angle varies 30–70 deg at a constant angular speed $\omega_1=8$, 10, or 15 deg/s and vice versa. In all computation examples, $M=0.65$ and $H=6000$ m are taken to be the typical state. To make comparisons in a few cases, different altitudes H and Mach numbers M are used.

A longer time interval cannot be used to compute the unsteady dynamic response. The time interval usually used in the computations is 0.005 s. For longer periods, the Runge-Kutta method is used and the time interval is 0.05 s. Four computations examples were computed and analyzed, as described below.

Response to Sweep Change without Control

The responses to sweep change without control (that is, the thrust and elevator deflection angle keep their initial balance values) are computed first. Figure 7 shows a group of response curves to sweep change when $M=0.65$, $H=6000$ m, $\omega_1=8$ deg/s and $\beta=30$–70 deg.

For different rotational angular speeds of wing ω_1, response variation is the key to determining the sweep change rate. Figure 8 compares curves of ω_z and γ in relation to different

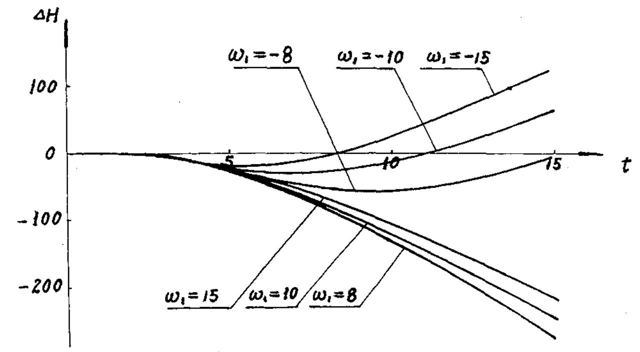

Fig. 9 Variation of flight altitudes vs time at different rotational angular velocity of wings about their own rotating shift.

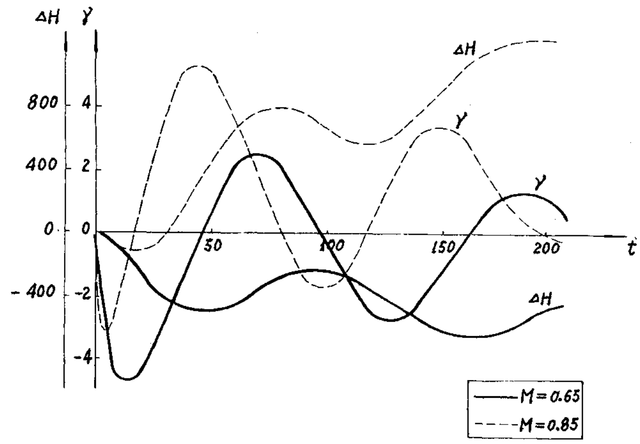

Fig. 10 Variations of flight altitude and flight path elevation angle vs time at different Mach numbers.

values of ω_1. The computation results show that a faster ω_1 does not degrate the response characteristics. The influence of different ω_1 on ΔH is shown in Fig. 9.

The influence of different Mach numbers M on ΔH are shown in Fig. 10. It can be seen that the variation tendencies are the same at the beginning of sweep change. However, because of the difference between the variations in the aerodynamic characteristics caused by different Mach numbers M, there are large differences in the long-duration responses. Two points are obvious in Fig. 10:

1) It is dangerous to make sweep changes at low altitude if the aircraft is flying without control.

2) The response is sensitive to the rate of variation in the aerodynamic characteristics with β. So, to keep good response characteristics in the sweep change at different Mach numbers and altitudes, an autopilot is required.

Response to Sweep Change with an Autopilot

The above computational examples denote the inherent characteristics of response to sweep change without control of the heaving motion. Two types of the control are usually used in autopilots; the automatic trimming for steady and level-off states are analyzed numerically in this section.

Figure 11 shows the steady trim response to sweep change when $\beta = 30 \rightarrow 70$ deg. It can be seen that both γ and ΔH received some restraint. However, since the balance angles of attack of the whole aircraft will vary with the sweep angles, the trim of the pitching angle introduces an error in flight path elevation angle γ. The trim effect is far from ideal.

Figure 12 shows the level-off trim response to sweep change when $\beta = 30 \rightarrow 70$ deg. Because the signal $K_H \cdot \Delta H + K_{\dot{H}} \cdot \dot{H}$ is connected when $-3 < \theta < 10$ deg, the altitude is stabilized automatically. Therefore, the effect is better.

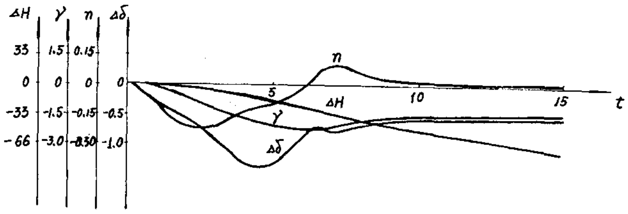

Fig. 11 Variations of flight altitude, flight path elevation angle, increment of normal load factor, and elevator deflection angle vs time for steady trim rule when $\omega_1 = 8$ deg/s.

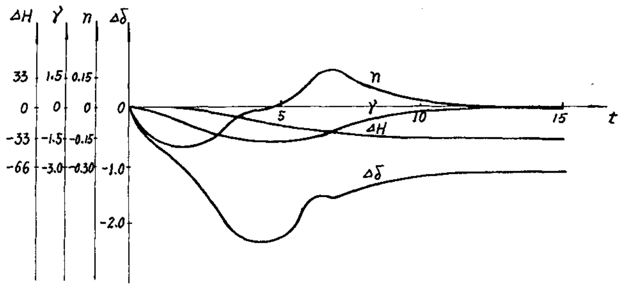

Fig. 12 Variations of flight altitude-flight path elevation angle, increment of normal load factor, and elevator deflection angle vs time for level-off trim rule when $\omega_1 = 8$ deg/s.

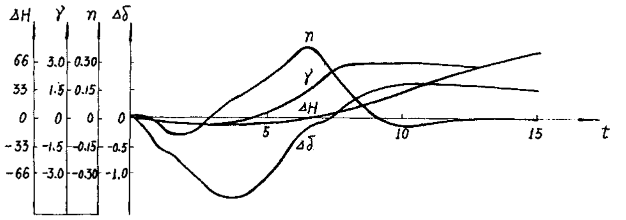

Fig. 13 Variations of flight altitude, flight path elevation angle, increment of normal load factor, and elevator deflection angle vs time for steady trim rule when $\omega_1 = -8$ deg/s.

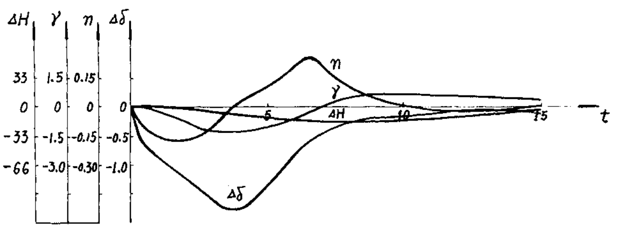

Fig. 14 Variations of flight altitude, flight path elevation angle, increment of normal load factors, and elevator deflection angle vs time for level-off trim rule when $\omega_1 = -8$ deg/s.

Figures 13 and 14 show the response curves of the steady, and level-off trim controls of an autopilot when $\beta = 70$ to 30 deg.

For steady trim, the balance angle of attack decreases when $\beta = 70 \rightarrow 30$ deg and the trim of pitch angle θ leads to the positive flight path elevation angle γ. The trim effect is getting worse. Thus, level-off trim control is more suitable for improving the response quality of varying sweep backs.

These computation results should be considered when choosing an autopilot control method.

Influence of Gravity Center Shift and Inertia Moment Variation

Figure 15 shows the influence of backward shift in the center of gravity when β increases from 30 to 70 deg during which Δx_g is the total shift magnitude (m). The curves indicate that the proper backward shift in the c.g. improves the

Table 1 Influence of unsteady aerodynamic characteristics on response

ω_1		$\dot{\alpha}_{max}$	$\dot{\omega}_{zmax}$	$\Delta\alpha_{max}$	ω_{zmax}	n_{max}	ΔH_e
8	Quasisteady	−0.9307	−2.6845	−0.8332	−1.4699	−0.4452	−60.7751
	Unsteady	−0.8587	−2.4457	−0.8261	−1.3774	−0.4452	−60.3454
	p.d. %	8.4	9.3	0.8	6.7	0.0	0.7
10	Quasisteady	−1.2095	−3.6705	−0.8490	−1.8611	−0.4534	−29.7935
	Unsteady	−1.1098	−3.3389	−0.8314	−1.7280	−0.4527	−29.5033
	p.d. %	9.0	9.9	2.1	7.7	0.15	1.0
15	Quasisteady	−1.5619	−5.0807	−0.9547	−2.3384	−0.4556	−13.9910
	Unsteady	−1.4311	−4.6660	−0.9118	−2.1587	−0.4547	−13.8034
	p.d. %	9.0	8.9	4.7	8.3	0.2	1.4
20	Quasisteady	−1.8128	−6.3159	−1.0073	−2.6742	−0.5014	−8.3004
	Unsteady	−1.6578	−5.7219	−0.9494	−2.4587	−0.4858	−8.1694
	p.d. %	9.3	10.4	6.1	8.8	3.2	1.6

Note: The maximum is in the negative direction. ΔH_e is the altitude loss at the time step when the variation in the sweep angle is complete.

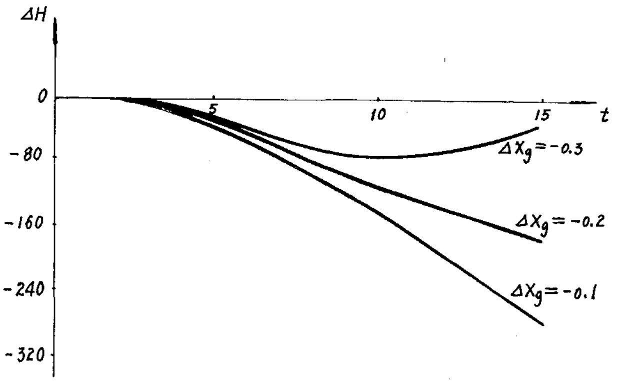

Fig. 15 Varations of flight altitude vs time under the conditions of backward shift in the center of gravity.

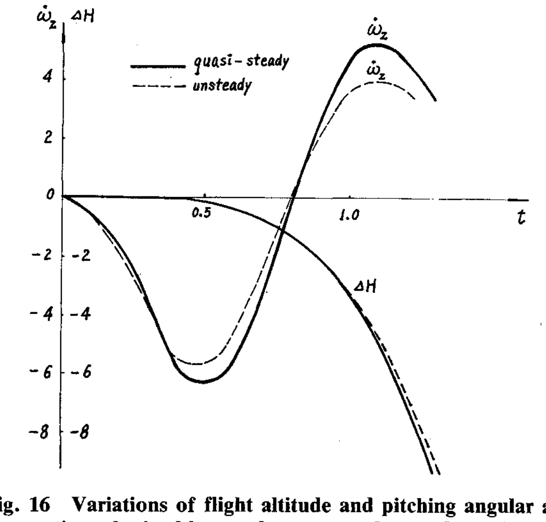

Fig. 16 Variations of flight altitude and pitching angular acceleration vs time obtained by steady or unsteady aerodynamic method.

aerodynamic characteristics of an aircraft with varying sweep backs. This is because the backward shift in the c.g. can partially cancel the influence of the backward shift in the pressure center on the aerodynamic moment and decrease the initial nose-downward moment, as well as decrease the nose-downward angular velocity of rotation, flight path elevation angle γ, and loss of altitude ΔH.

The inertia moment of variable wings is about 10% relative to that of the whole aircraft and its variation has little influence on γ and ΔH.

In the same way, the influence of the variations of γ and ΔH with the static moment can also be neglected.

Influence of Unsteady Aerodynamic Characteristics on the Response to Varying Sweepbacks

In the above examples, two computation methods for quasisteady and unsteady characteristics are used. The results are rather similar (see Table 1).

Figure 16 shows response curves for $\dot{\omega}_z$ and ΔH obtained by the two methods described above. There exist some phase shifts in the curves for $\dot{\omega}_z$ and the amplitudes are different. The unsteady response tends to outstrip the other; but, for the response curves of ΔH, they are nearly coincident.

Conclusion

This paper has described the equations of motion of an aircraft with variable swept wings during changes of the sweep angle and presented a computational method of solving these equations. Through computation and analysis, the following preliminary conclusions can be made:

1) The dynamic response to varying sweep backs depends primarily on variations in the aerodynamic characteristics. The computational results indicate that it is dangerous to make sweep change at low altitudes without an autopilot and that the response is very sensitive to the aerodynamic variations. So, it is necessary to have an autopilot.

2) A great speed of sweep change does not seriously deteriorate the response quality in a practical speed range. It is thus acceptable to raise the speed of sweep change.

3) The computational examples show that, in the practical speed range, the unsteady effect influences the short-period parameters more obviously than the long-period ones, such as the loss of altitude ΔH, the flight path elevation angle γ, and speed variation ΔV.

4) By means of the method and computational program in this paper, the influence of each design parameter on the response to sweep change can be quantitatively checked and the influence of autopilot parameters can also quantitatively given. In this way, it will be helpful in aerodynamic design and in the choice of parameters of an autopilot of a variable sweep aircraft.

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