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ANALYSIS OF TRANSIENT DYNAMIC BEHAVIOUR OF A FIRE FIGHTING AIRCRAFT AFTER THE WATER BOMB DROPPING

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Abstract

Paper presents an analysis of the water bomb dropping from firefighting aircraft. The major objective is to select the most important parameters, being responsible for effectiveness of water drop and aircraft safety. Also, to establish a simple, computational - effective, numerical code, being able to solve simultaneously the flight dynamics equation of motion and to determine aerodynamic forces and moments, which are functions of flight parameters and time history of the motion. Unsteady incompressible potential flow over the whole aircraft dropping the water bomb is sequentially solved using low order panel methods. Constant strength source and doublet panels distributed over aircraft surface, constant strength doublet panels over flat wake and constant strength source together with linear strength doublet panels distributed over the vertical water column, being able to properly imitate the downward water outflow of growing velocity, are used to solve the Dirichlet's boundary condition. A comparison between results of classical flight dynamics model (linearization around steady, before-water-drop flight plus stability derivatives used to represent disturbed forces and moments) and results of an unsteady model (current forces and moments computed by unsteady panel method; stability derivatives are not used in this model) was performed. Paper discuses advantages and weak points of both approaches - classical, based on stability derivatives concept and a modern, based on unsteady aerodynamics.

Introduction

The payload of fire fighting aircraft may be equal up to 40% of its total weight. A sudden drop of the payload puts the aircraft out of balance by changing its mass, and sometimes the c.g. position. It can be particularly dangerous for a light aircraft, which, during this transient process may achieve high angles of attack, beyond the stall limit. To ensure the fire fighting is highly effective in operation one has to form the water bomb as almost vertical, concentrated liquid column without excessive dissipation. From the experience gained in PZL-Okęcie (Producer of small agriculture aircraft in Poland) it follows that some parameters are especially important for water drop efficiency, i.e. water drop should be completed within one or two seconds, the water capacity should be greater than a minimum critical value, the height the hopper should be as great as possible (to make the water pressure at bottom of hopper sufficiently large) and the aspect ratio of the outlet of the hopper (ratio of the outlet length parallel to flight direction to the outlet length parallel to the wing span direction) should have an appropriate value. To be able to optimize the design of the airplane and the process of water dropping one need the simple and reliable mathematical model. The important role in such model play aerodynamic characteristics which have been calculated by means of unsteady panel methods. It is assumed that the water bomb's surface is impermeable, i.e. that there is no flow through the surface, and that the water bomb behaves like a compact, and plastic body. It can not be split into smaller fragments, but it can change its shape as a result of the aerodynamic and mass forces acting on its surface and the volume. The water bomb's surface is divided into quadrilateral and triangular panels in a manner similar to that applied on the aircraft's surface. In each time step a new row of panels representing the water bomb's surface appears at the hopper outlet. The panels leaving the hopper are aligned with the direction of the resultant force acting on each panel's surface. An iterative procedure determines the position and the shape of the panels, which have already left the tank so that the water bomb's surface remains continuous during the subsequent time steps. Effects of liquid column on the aircraft lift, pitching moment and rolling moment coefficients, are investigated.

There are two areas of importance. The first is the investigation of the interaction between the air flowing around the aircraft and the water column as it emerges from and leaves the hopper. The second concerns the dynamic behavior of the aircraft during and immediately following the water release.

The techniques employed in attacking the conflagration depend upon the characteristics of each individual fire. The most common method is to instantaneously drop the entire contents of the hopper into the fire zone in the form of a „water bomb”. In addition to the quenching effect the impact has dynamic effect which helps to blow out the flame. Practical experience and theoretical considerations indicate that the effectiveness is improved as the quantity of water delivered by the aircraft is increased. Very often, agricultural aircraft are adapted for fire control operations. These have a capacity of between 1 and 1.5

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tons, which is the minimum for effective operation. Civil or military transport aircraft adapted for fire control duties have capacities of 10 tons or more. Their effectiveness is greater but they are much more expensive. Selected firefighting aircraft during water drop action are shown in Fig.1-3. Heavy firefighting bomber IL-76 MD is presented in Fig.1. It is very well seen that water bomb structure is destroyed. The air flow velocity seems to be to large and has a decisive effect upon the coherence of the liquid column, which is dispersed into fine droplets.

Fig.1 Heavy firefighting bomber IL-76 MD (hopper of 40 000 kg capacity)

Fig.2 PZL M -18 agricultural aircraft (hopper of 1850 kg capacity)

In this case the quenching effect on the fire will be negligible. An adjustment of the shape of the discharge orifice to give the column a reduced dimension transverse to the flow and an increased length parallel to the flow would reduce the tendency for the column to dispense by reducing drag. The same problem of water column dispersion can be observed in Fig.2, where M18 aircraft drops the water bomb. Another factor which accelerates the dispersion of water column is too small pressure of the water at the hopper outlet, hence too small velocity of water outflow. The only way to increase pressure at the bottom of hopper is to design it as high and slim as possible. However, because the hopper height is limited by the fuselage vertical dimension, so it is a matter of a compromise how to design the whole aircraft. A good example of such compromise is presented in Fig.3 where the whole hopper capacity can be drained in about 2 s and about 90 % of water capacity is concentrated in narrow, almost vertical column of liquid.

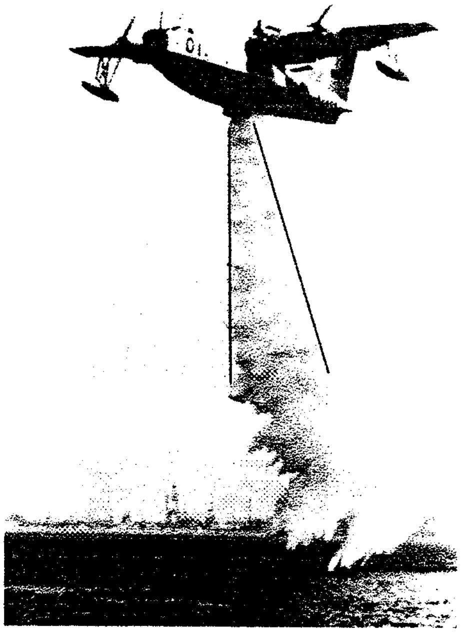

Fig.3 Shin-Meiva SS-2A amphibious aircraft (hopper of 14 000 kg capacity)

The water leaving the hopper induces two kinds of velocities. The first one, induced in a horizontal plane, resembles the flow around a cylinder, where the streamlines are deflected sideways while passing the water stream. The second one, due to entraining by the water stream of the air particles surrounding it, is similar to the flow induced by a jet blowing in a vertical direction, deflecting the streamlines downwards.

In the present analysis, the post-stall characteristics are assumed to be known from wind tunnel or in-flight experiments. The main aim of analysis is to investigate the dynamic behavior below the stall - if simulation show that aircraft go into the post-stall region then these results will be of small confidence and only the information then a limit was broken is of great value.

Some preliminary results of aerodynamic and dynamic investigation of firefighting aircraft dropping the water bomb were partially presented in paper[1], which was devoted mainly to the analysis of quasi-steady case. The panel method technique was adapted to divide the

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surface of aircraft, water column and wake into small boxes and determine the set of singularities which fulfill the boundary conditions. Also the classical approach was applied to formulate dynamic equations of motion with classical stability derivatives. In this paper a new approach is applied which consists in synchronous solving of the dynamic equations of motion and fulfilling the unsteady boundary conditions to find aerodynamic forces, moments and downwashes.

Unsteady outflow from separated body

It was assumed that pressure and gravity are only forces acting on an element of water falling down from the hopper. Water column is usually deformed because of relation between pressure and gravity. Formation of the pressure is the result of singularity distribution, both on surface of body and water column. The phenomenon of water outflow was modeled using the additional doublets, which create vertical components of flow velocity on the surface of water column, Fig.4. Linear doublet distribution, defined by values $\mu_{i,1}$, $\mu_{i,2}$, can be found from the following relations:

$$\mu_{i,2} - \mu_{i,1} = 2\,\mathrm{Vw}\,s_i \ , \ \mu_{i,1} = \mu_{i-1,2} \ .$$

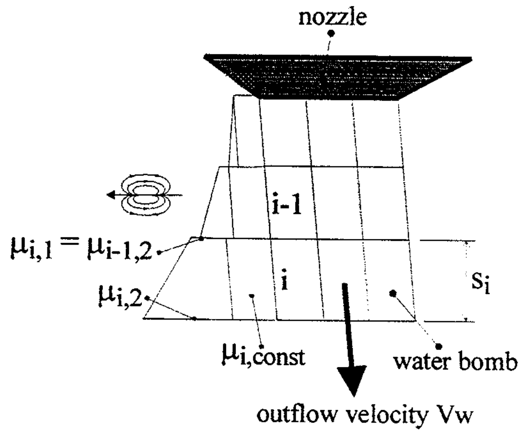

Fig.4 Linear doublet, creating linear velocity

Different velocities of water outflow were considered, starting from 0 up to 50 m/s. Influence coefficients were computed using numerical procedure described in[2]. In the first step of outflow analysis a separated fuselage (Fig.5) with hopper and water column were investigated. The length of water column corresponds to the hopper release time equal to 2s . It was assumed that after 2 s the outflow is over and that the continuity of water column is suddenly broken. Fig.6-7 show pressure distribution along body strips and its change with time. The values of pressure were computed using unsteady panel method[3] and unsteady Bernoulli equation. Lifting force and pitching moment coefficients are related to wing lifting surface, pitching moment coefficient is related to wing MAC and is fixed with the centre of hopper outflow. The significant increase of lift (Fig.8) for the ratio $A_h = 0.2$ with comparison to the case of ratio $A_h = 5$ is involved by strong deceleration of flow in the vicinity of water column and by an increase of pressure under body (it can be concluded from Bernoulli equation).

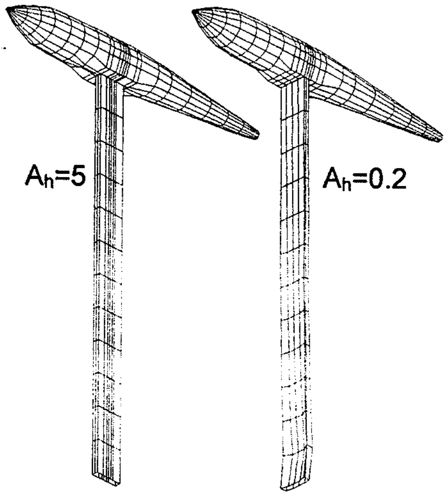

Fig.5 Water column of different aspect ratio

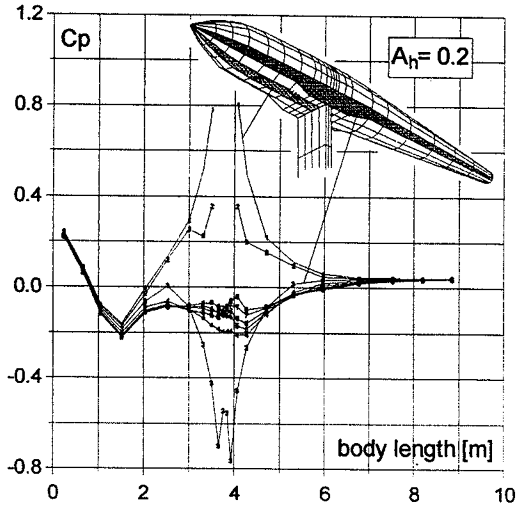

Fig.6 Pressure distribution along body strip

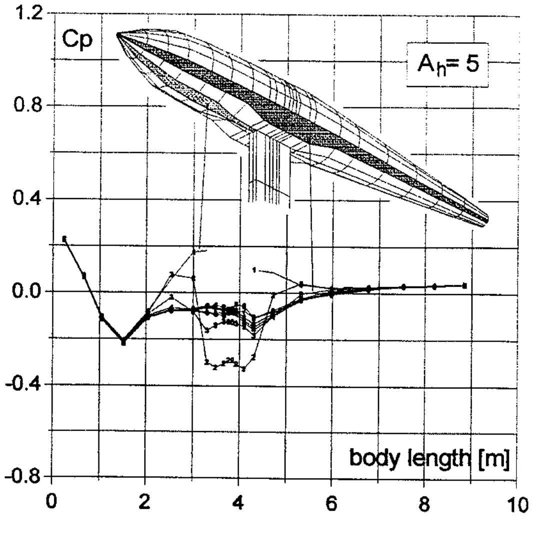

Fig.7 Pressure distribution along body strip

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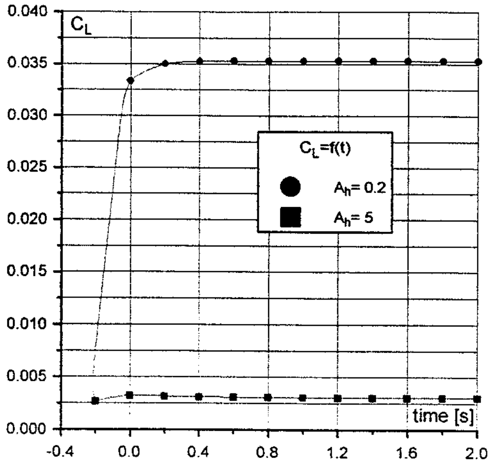

Fig.8 Lifting force coefficient

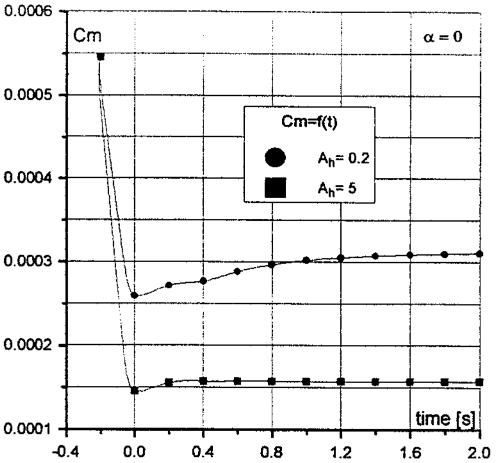

Fig.9 Pitching moment coefficient

The same can be observed in Fig.9 - an increase of pressure before the water column increases the positive value of pitching moment. However, this phenomenon is almost without any practical importance with respect to longitudinal equilibrium. It is due to fact that the change both the lift and pitching moment are quantitatively negligible and are over-dominated by an opposite effect in the presence of wing. As it will be shown in further analysis the lift on wing decreases and the pitching moment is kept almost constant.

Modeling of unsteady flow over the whole configuration

Development of the water column induces velocities of two kinds. Velocities of the first kind are induced in horizontal plane by the cross-section shape of the column. Velocities of the second kind are induced in vertical plane, parallel to the water column and are developed by the entraining of the air particles by the water stream. In order to account for the both families of the induced velocities, a computational model, based on panel methods, was proposed. Flow[3] singularities were distributed on the water column's surface. The velocities induced in the horizontal plane are modeled by the constant strength sources and doublets, distributed on the panels of the water column. The same type of singularities are distributed over the aircraft's surface. Over the water column's surface, Fig.10, in addition to the constant-strength singularities, a doublet distribution of second type is introduced. It consists of doublets, varying linearly in the direction of water flow, what is equivalent to a constant strength vortex distribution, according to the following relation:

$$\gamma = \frac{d\mu}{dz},$$

where "z" is measured in a direction parallel to the water stream, and the vortex strength γ is related to the water stream velocity V_{WS} by the equation $\gamma = 2 \cdot v_{WS}$.

This doublet distribution of predetermined strength, was introduced to model the vertical velocities of the air particles, neighboring to water column surface, which are induced in the vertical plane by the downward movement of the water.

The unknown strengths of constant doublets are determined through the Dirichlet boundary condition:

$$\sum_{k=1}^{N_{AS}} \frac{1}{4\pi}\mu \int_{AS} \vec{n} \circ \nabla \frac{1}{r}\, dS + \sum_{k=1}^{N_{WS}} \frac{1}{4\pi} \int_{WS} \mu(z) \vec{n} \circ \nabla \frac{1}{r} dS +$$

$$\sum_{k=1}^{N_{VW}} \frac{1}{4\pi}\mu \int_{VW} \vec{n} \circ \nabla \frac{1}{r} dS - \sum_{k=1}^{N_{AS}} \frac{1}{4\pi}\sigma \int_{AS} \left(\frac{1}{r}\right) dS = 0$$

where: μ - constant strength doublet distribution, μ(z)- strength of a linear doublet distribution (predetermined), σ - constant strength source distribution, N_{AS} - number of panels over aircraft's surface, N_{WS} - number of panels over water's surface, N_{VW} - number of panels of vortex-wake.

Having the constant strength doublet distribution determined, it is possible to calculate the induced flow velocities over the aircraft's surface, then surface pressures, and forces and moments acting on the aircraft[4].

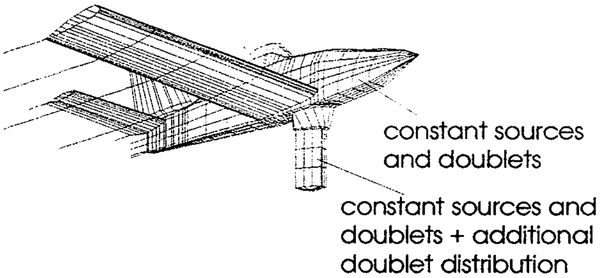

Fig. 10 Various types of singularities applied

It is assumed, that the aircraft is in steady flight before the water drop, what allows to determine the steady-state aerodynamic forces acting on the aircraft. Unsteady process starts to develop with the appearance of first strip of panels, representing the water column. At this point, the aircraft's vortex wake is divided into two parts.

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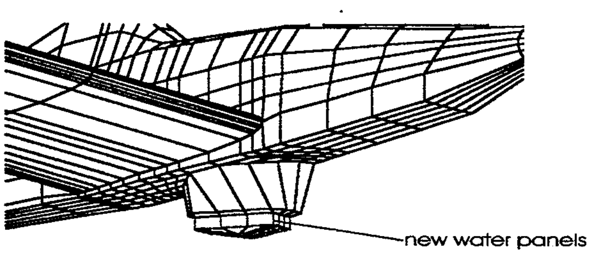

Fig.11 Development of the water column

The first part consists of semi-infinite panels, of strength determined from the steady flight condition. During each of the succeeding time steps, the wake panels created in previous steps are to be added to the initial, semi-infinite panel wake of constant strength vortex. The second part consists of panels created in a new time step, of strength determined by the Kutta condition. In each time step the length of the water column is increased, either by the lengthening of the existing ''water'' panels in the first row of the water column (in order to avoid the rapid increase of the total number of panels), or by adding new panels, when the length of the existing panels exceeds a predetermined value (Fig. 11).

Unsteady aerodynamic characteristics

Aerodynamic forces, moments, different gradients and downwash have been computed by means of the unsteady panel method. These forces and moments are functions of various flight parameters, i.e. angle of attack, pitch angle, trim parameters and time history. It would be difficult to present such forces in a graphical form as the multivariable function of all independent parameters, so these functions will be shown as functions of time (only) under the assumption that other variables (for example, angle of attack, pitch rate, flight speed etc.) are fixed and equal to that of from steady state flight condition.

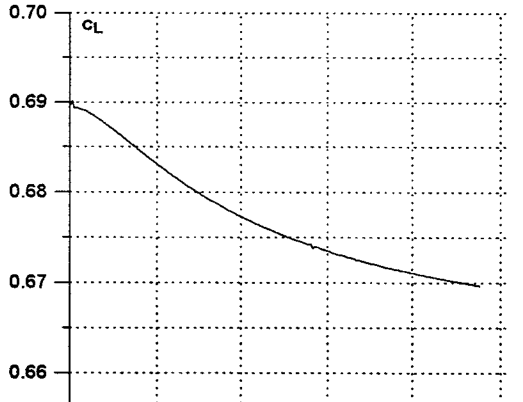

Fig.12 Lift coefficient versus time (α=6°, wing + body only)

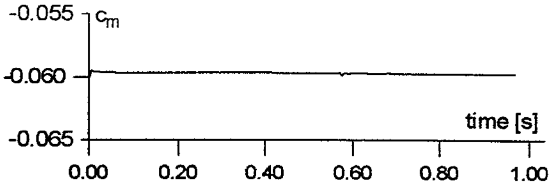

Fig.13 Moment coefficient versus time (α=6°, wing + body only)

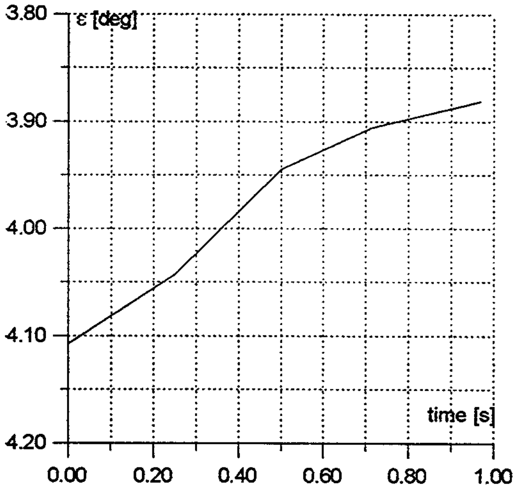

Fig. 14 Average downwash versus time (α=6°)

Fig.12-13 show lifting force and pitching moment coefficients for wing and body configuration (excluding horizontal tail), respectively. Fig.14-15 show an average downwash in the vicinity of horizontal tail and its slope with respect to angle of attack. All figures show aerodynamic characteristics over the time interval equal to 1 s - the whole time of hopper release. During this 1 s time the water column length is equal to about 5m. The variations of presented parameters are very weak, almost negligible and they tend to vanish in a new state of equilibrium, corresponding to a steady water outflow from the hopper. Scarcely perceptible decrease in lift coefficient (from 0.69 to 0.67), almost constant pitching moment of wing and body and a slight decrease in downwash (from 4.1° up to 3.9°) do not have the practical influence on the state of equilibrium.

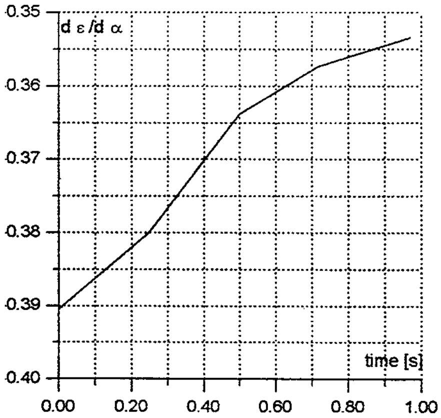

Fig. 15 Downwash slope curve versus time (α=6°)

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Dynamic model and selected results

Some assumptions have been taken to establish so-called physical model of aircraft dynamics. These are listed below:

- aircraft is considered as rigid body having three degrees of freedom: two linear displacements (x_0, y_o) in vertical plane of symmetry and pitch angle Θ, Fig.16
- horizontal elevator is movable and can be used for control, but it is weightless and can not vibrate
- two models of aerodynamics are considered: quasi-steady and unsteady
- water, being released from the hopper, influences the change of mass and moments of inertia. Also, it does influence directly aerodynamic characteristics of the aircraft, especially on lift, drag, pitching moment and downwash. So, aerodynamic characteristics can be changed due to change of the angle of attack, pitch rate, downwash and history of motion.

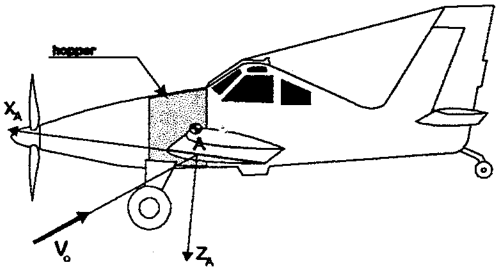

Fig.16 Side view of fire fighting aircraft PZL-106

Dynamic equations of motion have been written in the body axis system. The origin of the axis system coincides with the mean quarter-chord point, Ax_A axis is directed forward of the aircraft along the mean aerodynamic chord, Az_A axis is perpendicular to Ax_A and is directed downward. Equations of motion have the following form

$$m(\dot{U}+QW)-mz_c\,\dot{Q}+mx_cQ^2=X-mg\sin\theta$$

$$m(\dot{W}+QU)+mx_c\,\dot{Q}+mz_c\,Q^2=Z+mg\cos\theta$$

$$J_y\,\dot{Q}+mx_c\,\dot{W}-mx_cUQ-mz_c\dot{U}-mz_c\,QW=$$

$$M+mgz_c\sin\theta+mgx_c\cos\theta$$

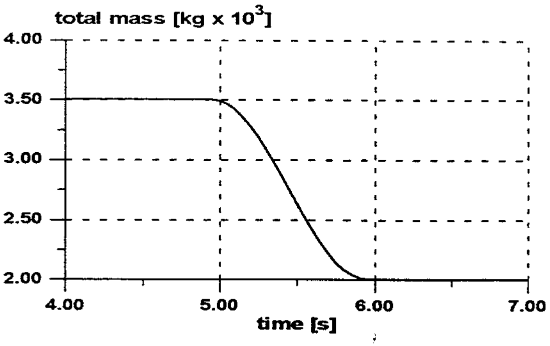

Fig.17 Change of aircraft mass versus time during water release

Numerical simulations have been performed for the following initial conditions: speed V_0 = 40 m/s and flight altitude H = 100 m. For such initial conditions the state of equilibrium has been found: angle of attack α, angle of elevator deflection δ_H and required thrust T have been computed. It was assumed that water release lasted 1 s according to the time-dependent function given at Fig.17. Dynamic equations of motion have been integrated using different two models of aerodynamics:

- quasi-steady model. Aerodynamic forces and moments depend on steady flight parameters: angle of attack, pitch rate, lift coefficient etc. It is assumed that deviations from steady flight conditions are small and that increments of forces and moments from steady state can be computed by use of stability derivatives[5]. All calculations are based on initial, steady state values.
- unsteady model. Aerodynamic forces and moments are computed by means of unsteady panel method and include time history of motion. Because in any instance of time these forces and moments depend on current flight parameters (angle of attack, pitch angle, speed etc.) and because they depend on previous time step history, so the stability derivatives are not used in this model. However, employing the unsteady model of aerodynamics one has simultaneously to integrate the dynamic equations of motion and solve the Dirichlet boundary condition[6]. In this case the unsteady Bernoulli equation has to be used to find pressure distribution and then to compute forces and moments.

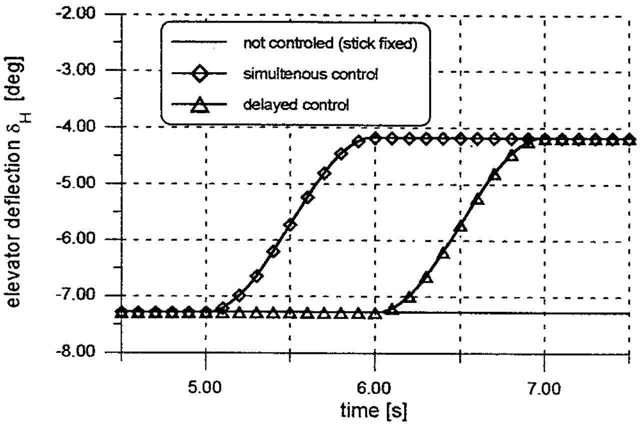

Fig.18 Control functions

Fig.19-21present selected aerodynamic characteristics, used in computer simulation. These characteristics were obtained under the assumption that angle of attack is constant, so it is rather unrealistic case. However, in real case the aerodynamics and flight dynamics are strongly coupled and depend one on another. Curves in Fig.19-21 were obtained from panel method and are presented here to show the influence of time history on lift-curve-slope (Fig.19), on downwash gradient (Fig.20) and on

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moment-curve-slope of wing and body configuration (Fig.21).

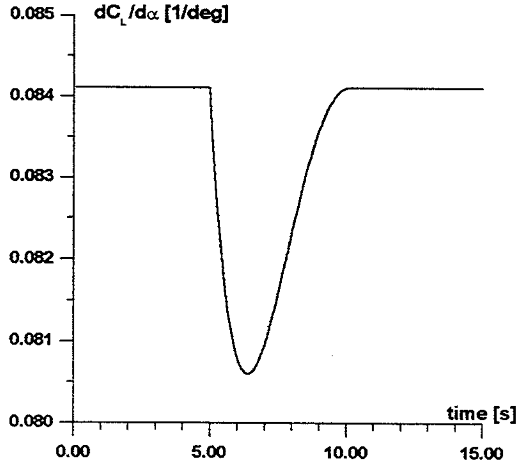

Fig.19 Change of the lift slope curve versus time

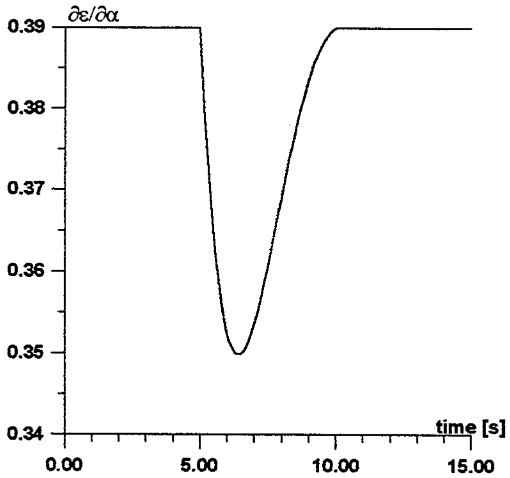

Fig.20 Change of downwash gradient

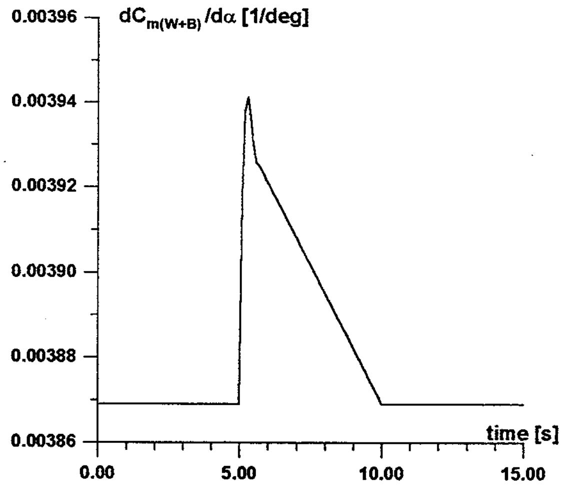

Fig.21Change of pitching moment

Fig.22-26 show results of simulation for steady aerodynamics model. Three curves shown in all these figures correspond to three different cases of aircraft control:

- solid line - aircraft is not controlled. Elevator is fixed at an angle of deflection, corresponding to the initial state of equilibrium.
- rhombic line - aircraft is synchronously controlled according to the function shown in Fig.18. Elevator is deflected from a value corresponding to initial state of equilibrium to another value, corresponding to the other state of equilibrium (after the whole hopper is drained). Elevator deflects synchronously with water releasing and according to a harmonic, time-dependent function, shown in Fig.18.
- triangular line - aircraft is controlled but with a time lag, Fig.18. Pilot starts to react just in the moment when the whole hopper is drained.

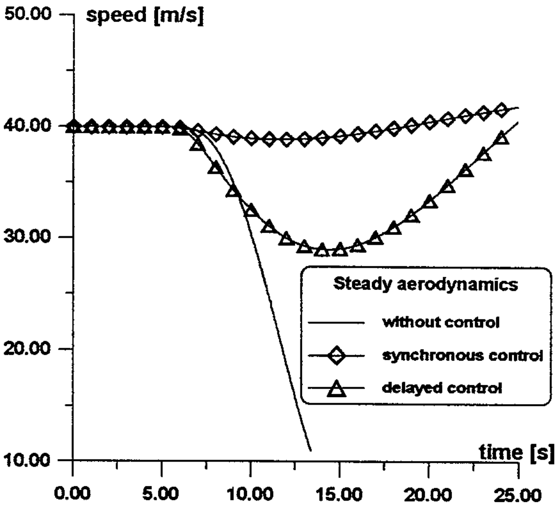

Fig.22 Flight speed versus time

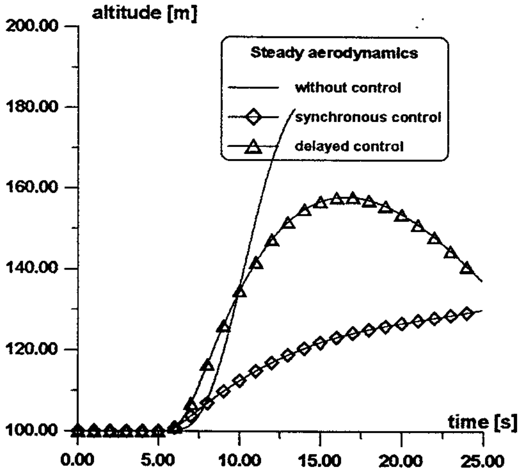

Fig.23 Altitude versus time

Fig.22 shows the change of speed versus time. One can observe the speed is rapidly reduced after water release if the aircraft is not controlled. Synchronously controlled aircraft keeps the speed practically constant, however in the case of delayed control one can observe that aircraft

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speed falls at the beginning, after that it grows-up to attain its previous value in a periodic motion.

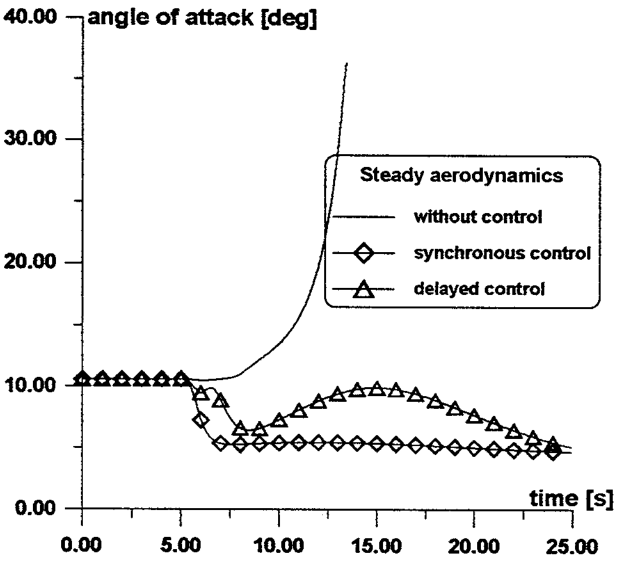

Fig.24 Angle of attack versus time

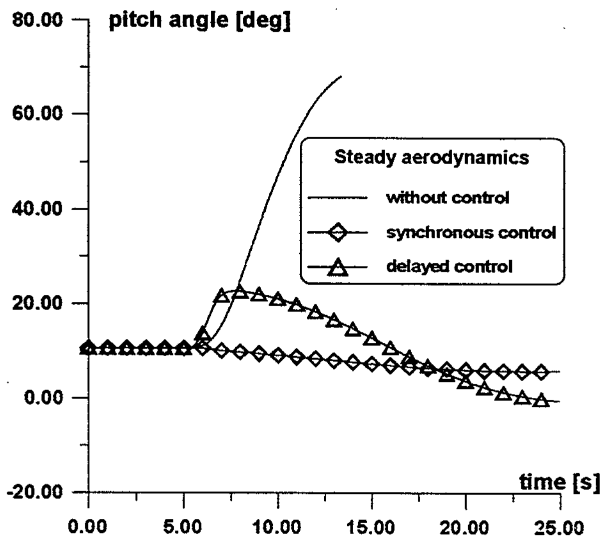

Fig.25 Pitch angle versus time

Fig.23 presents flight altitude after water release. If the aircraft is not controlled, the altitude rapidly grows-up. Also, if aircraft is controlled synchronously with the water release, then height of flight grows-up monotonically. Time-lag in elevator deflection with respect to water release results in a heavy altitude oscillation.

Fig.24 shows angle of attack versus time of water release. If aircraft is not controlled, than the angle of attack rapidly increases and reaches post stall region very fast. Such phenomenon is extremely dangerous and should be counter-measured by pilot action. If aircraft is controlled than angle of attack decreases and stabilizes very quickly. Synchronously controlled aircraft can reach the new state of equilibrium faster.

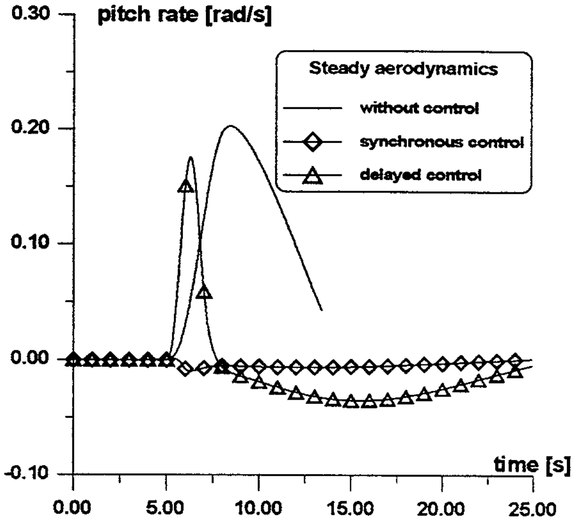

Fig.26 Pitch rate versus time

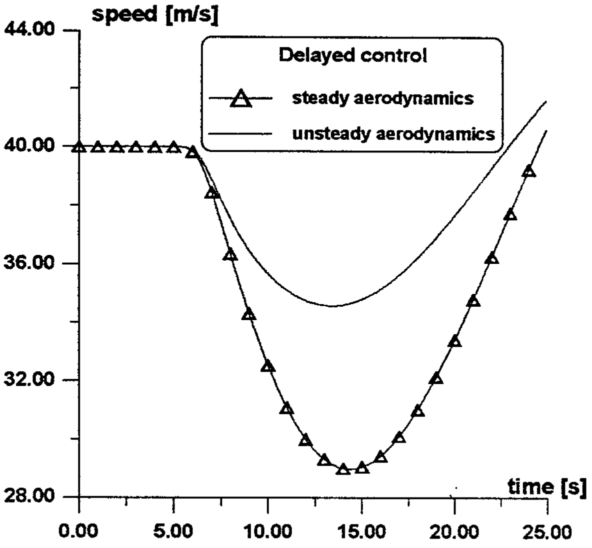

Fig.27 Comparison between responses obtained from quasi-steady and unsteady models

Curves given in Fig.25 are similar to the corresponding curves in Fig.24. It is a consequence of the fact that pitch angle is an integral of pitch rate function. For uncontrolled aircraft the pitch angle after water release increases rapidly and reaches extremely high values. If aircraft is controlled synchronously with the water release than pitch angle is slightly going down and aircraft stabilizes. Time-lag control induces dumped oscillations around the new, a little bit lower, steady state value of pitch angle.

Fig.26 presents pitch rate versus time. For either not controlled or delayed controlled case the pitch rate changes very abruptly. Synchronously controlled aircraft does not practically have pitch rate what is extremely advantageous from the flight safety and pilot comfort point of view.

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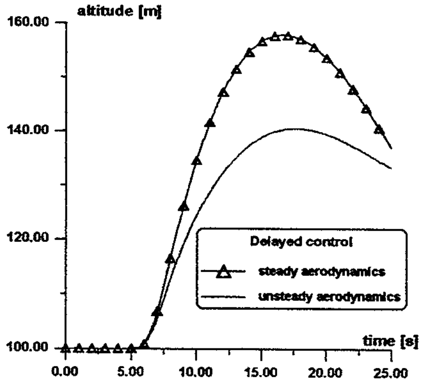

Fig.28 Comparison between responses obtained from quasi-steady and unsteady models

Fig.27-31 present a comparison between results obtained from quasi-steady and unsteady aerodynamic models, both in the case of delayed elevator control. A general conclusion is that unsteady aerodynamic model „smoothes" the transient responses, sometimes very strongly changeable in the steady case. Maximums of many curves are limited and slopes in their vicinity are bounded. One can say that unsteady forces and moments, which include time history, suppress and dump many flight parameters, not allowing them to grow-up excessively.

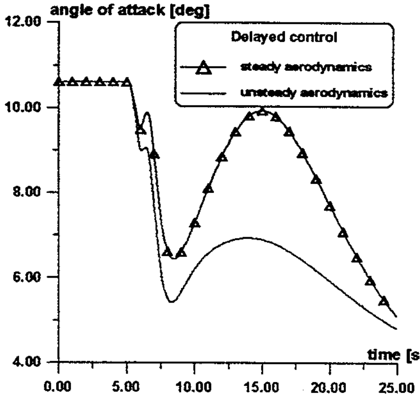

Fig.29 Comparison between responses obtained from quasi-steady and unsteady models

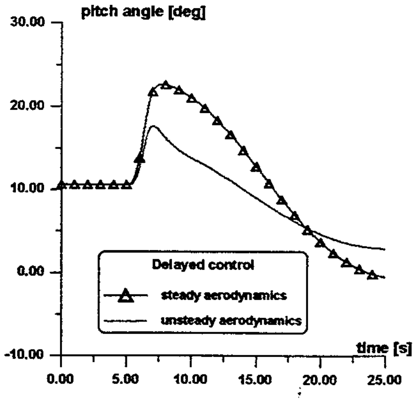

Fig.30 Comparison between responses obtained from quasi-steady and unsteady models

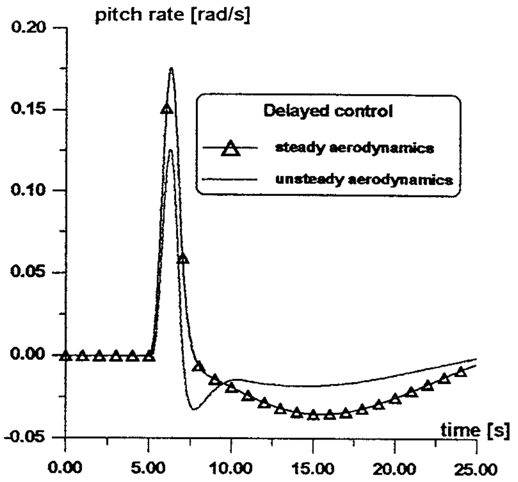

Fig.31 Comparison between responses obtained from quasi-steady and unsteady models

Flight speed (Fig.27) decreases from 40 m/s either to 29 m/s (in the case of quasi-steady model) or to 37 m/s only (in the case of unsteady model). Similarly, altitude (Fig.28) grows-up from 100 m to 158 m (in the case of quasi-steady model, or from 100 m to 140 m only (in the case of unsteady model). Angle of attack (Fig.29) and pitch angle (Fig.30) change much more gently in the case of unsteady aerodynamic model than that of quasi-steady one.

Also, the top value of pitch rate, computed by means of unsteady aerodynamic model, shown in Fig.31 is smaller than that of corresponding value computed by means of steady aerodynamic model. The reason that unsteady aerodynamic model „smoothes" the transient responses and suppresses their maximums is that in this computational model in each time instance the aerodynamic forces and moments are computed as the current functions of flight parameters, i.e. angle of attack, pitch rate, speed etc. On the contrary, in classical flight dynamic model, the forces, moments and stability derivatives are based on values in steady state flight and are valid as long as deviations from steady state flight are small. When we look at selected parameters, say at angle of attack (Fig.29), we can see that the change from initial value of 10° up to a transient value of 6° can not be considered as the small change. So, results of simulations suggest univocally that the unsteady aerodynamic model has to be employed to obtain reliable, credible results in the simulation process after water release from aircraft hopper.

Influence of selected design parameters on aerodynamics and flight dynamics

As it was established in[1] the water bomb will be formed as almost vertical, concentrated liquid column if aspect ratio of the outlet of the hopper has an appropriate value. Three different outlets (Fig.32) of aspect ratio A_h equal to 2.5, 1 and 0.4 were investigated. However, all obtained

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results clearly show that the aspect ratio has negligible influence on aerodynamic coefficients. It is true independently on the speed of water release, angle of attack and other parameters. For example, Fig.33 show lift coefficient versus time for two opposite values of the aspect ratio: $A_h = 2.5$ and $A_h = 0.4$. The difference is very small (the value equal to 0.01 is practically unimportant).

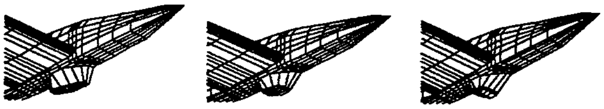

Fig.32 Outlet of the hopper of various aspect ratio

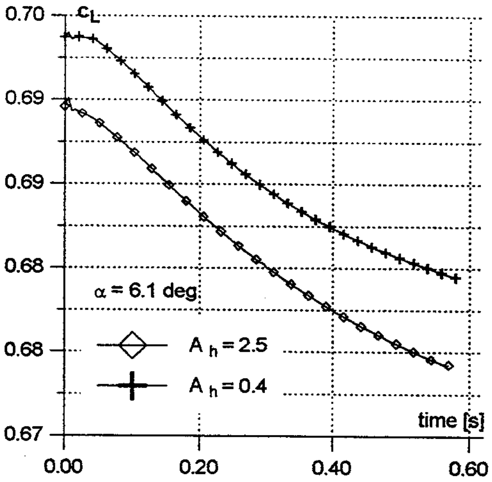

Fig.33 Influence of the hopper aspect ratio on lift

Fig.34 shows downwash distribution versus span of horizontal tail. The maximum difference between local downwashes for steady and unsteady aerodynamic model is less than 0.2°, what means that local downwash slope, $\partial\varepsilon/\partial\alpha$, is less than 0.03 (so, it does not have the strong, direct influence on static stability, neutral point position etc.). However, during rapid change of aircraft altitude following the water release from the hopper, most of aircraft flight parameters change very abruptly and in this case the influence of unsteady aerodynamic model and the time history on computed forces and moments is relevant and can give the results different from that of obtained by use of quasi-steady aerodynamics and using the classical stability derivatives.

Distance of the hopper center gravity from center gravity of the whole aircraft has strong influence on transient response after water release. This response depends on two opposite phenomena:

- immediately after water release the aircraft goes up, so there is an additional flow velocity directed down what decreases angle of attack;
- pitching moment (due to empty hopper) acts nose-up what means that angle of attack increases.

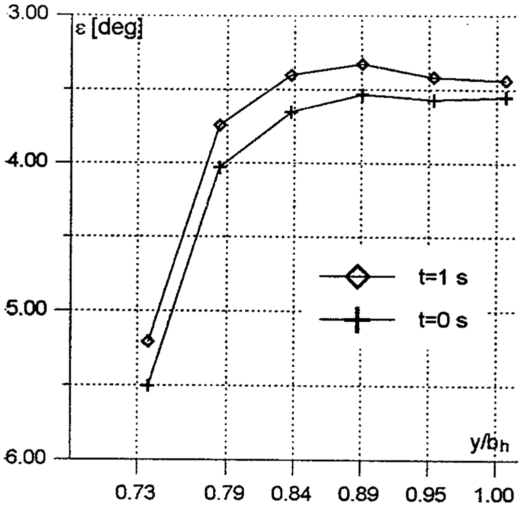

Fig.34 Downwash distribution along tail span

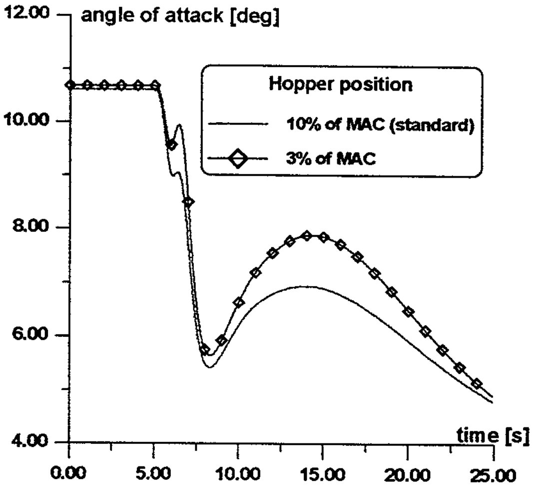

Fig.35 Influence of the hopper center gravity position on transient response

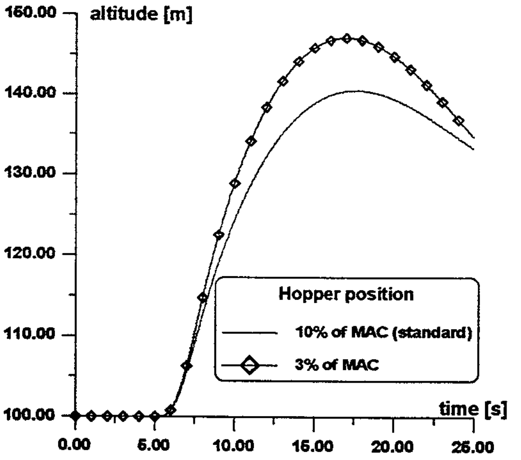

Fig.36 Influence of the hopper center gravity position on transient response

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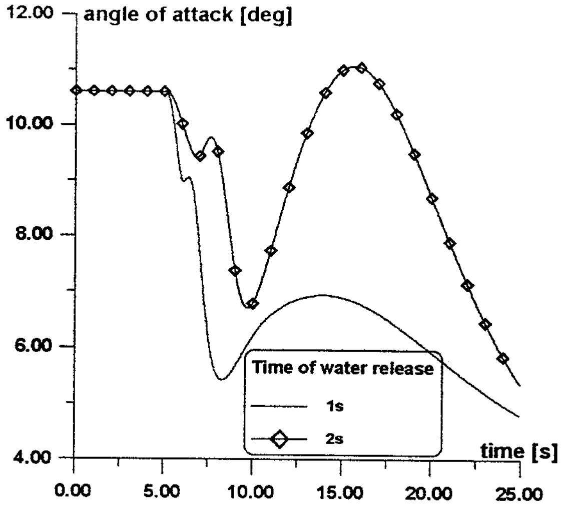

Fig.37 Influence of the water release speed on transient angle of attack

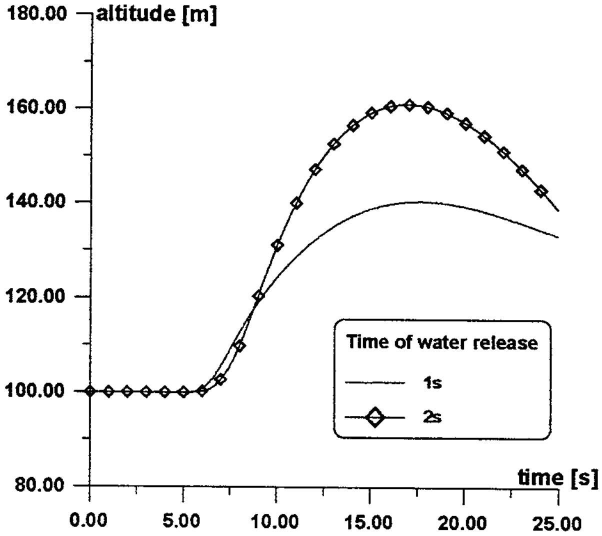

Fig.38 Influence of the water release speed on altitude

So, angle of attack can increase or decrease, depending on relations between these two, above-mentioned countering components. Fig.35-36 show variations of angle of attack and altitudes after water release in two cases (both with delayed control), when: (1) gravity center of the hopper is placed in 10 % of aircraft MAC (standard position) and (2) gravity center is moved forward to the point of 3 % of MAC. From these figures it can be concluded that the closer to the whole aircraft center of gravity is from the center gravity of the hopper the smoother is transient response. If pilot increases the time of water release (Fig.37-38) and simultaneously delays his reaction than transient response is more violent.

Conclusions

Two important areas of research are addressed in this paper. The first one is the interaction between the air flowing around the aircraft and the water column as it emerges from and leaves the hopper. The second concerns the dynamic behavior of the aircraft during and immediately following the water release. Unsteady panel method, used for analysis has shown that the interaction between the air and water and its influence on the aircraft aerodynamic characteristics is very weak for typical aircraft configurations. On the contrary, the dynamic behavior of the aircraft during, and immediately following the water release, is very strongly influenced by the change of total mass of the aircraft, redistribution of the moment of inertia and pilot control. Classical approach to simulation of aircraft motion, using steady state aerodynamic forces and moments and stability derivatives to represent small disturbances of forces and moments, gives very crude approximation of motion. On the other hand, employing the unsteady panel method to compute forces and moments and then to integrate the dynamic equations of motion permit to take into account the dependence of current loads on current flight parameters (i.e. angle of attack, pitch rate etc.) and time history. Included computational results show that unsteady aerodynamic model „smoothes" the flight parameters curves versus time and suppresses their maximum values. It can be concluded that if steady aerodynamic model give results which are acceptable from dynamic point of view, than unsteady model will give smoother and also acceptable results.

Acknowledgement

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