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# A MODIFIED OUTPUT ERROR METHOD AND ITS APPLICATION ON AN AIR ACCIDENT

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Abstracts : A modified output error method developed by the authors are presented, and an example of its application on an air accident is shown. In order to obtain the aerodynamic coefficients of an aircraft, the maximum likelihhood method and the output error method are often employed. However, in the case of an air accident, there is only one flight data available. The newly devised modified output error method by authors seems to have shown fine performance. By employing this method and processing the flight data, unstational aerodynamic coefficients are obtained. The contradiction between the recorded flight data and the circumstantial evidence was reasonably explained.

Keywords : Aircraft, Flight Control, Estimation, Identification, Simulation

## 1.INTRODUCTION

In order to obtain aerodynamic coefficients and their derivatives from flight data, maximum likelihood method and output error method have been successfully employed until now. In cases where we can obtain enough amount of flight data under indicated conditions, above methods can estimate those coefficients with fine accuracy. However in cases of air accidents, we can obtain only one flight data from DFDR (Digital flight data recorder) under very abnormal flight conditions. Therefore in order to estimate the aircraft aerodynamic coefficients and flight states depending on the DFDR data, we will require some different algorithm from those of above methods. In our experience, when we estimate the force and torque worked on the aircraft by maximum likelihood method, and simulate the aircraft behavior by giving those force and torque, the aircraft trajectory becomes considerably different from that of obtained by the DFDR data. The reason is suposed to be caused by the quantizing error of Kalman filter etc. Motivating by the fact that we have developed an algorithm which dose not result in any time delay and perfectly can reproduce the original flight data with simultaneously satisfying the aircraft six degree-of-freedom dynamics. An example of the application of the algorithm to an actual aircraft accident shows the fine performance, and we could estimate the aircraft condition under the accident without time delay and a large noise. The algorithm we have developed is in principle depending on the output error method, therefore we nominated it as the modified output error method. In the following sections, we will explain the algorithm and show some results processed by this algorithm.

## 2.THE MODIFIED OUTPUT ERROR METHOD ALGORITHM

In the accident, the obtained data from DFDR are, acceleration components of the aircraft three axes $a_{td}$ (X axis), $a_{nd}$ (-Z axis), $a_{ld}$(Y axis), the Euler angles $\phi_d$ (roll angle), $\theta_d$ (pitch angle) and $\psi_d$ (yaw angle), and the angle-of-attack $\alpha$ ,the hight $h$ which is obtained from both an aneroid altimeter and radio altimeter, TAS(True air speed) $V_d$ etc., where the suffix " $d$ " shows the values are abtained from DFDR. The aneroid altimeter data has an unknnown offset, while the radio altimeter data is very noisy as it reflects structures on the surface such as buildings and trees etc. and geographical roughness, therefore the employed altitude data is based on the aneroid altimeter data compensated its offset by the radio altimeter. The TAS data is reliable unless the aircraft is not in stall. The aircraft two axes acceleration components $a_t, a_n$ and three axes torque components $M_u, M_v$ and $M_w$ are selected as control variables, which are determined to coincide with the integrated output of the aircraft six degree-of-freedom dynamics $h_d, V_d, \theta_d, \phi_d$ and $\psi_d$ . As for the lateral acceleration $a_l$ , there is no data available directly connecting with it, therefore the data is treated as a true value, and other five cntrol variables are determined through five observed data. These five control variables are not determined simultaneously, but at first $a_t, a_n$ and $M_v$ are determined to satisfy the aircraft longitudinal equations, next $M_u$ is determined to satisfy the roll equation, and finally $M_w$ is determined to satisfy the yaw equation. These process is repeated again by employing the updated state and control variables. The flow chart is shown in Fig.1. The following are the employed equations.

$$\dot{u} = F_u/m - qw + rv \qquad (1)$$
$$\dot{v} = F_v/m - ru + pw \qquad (2)$$
$$\dot{w} = F_w/m - pv + qu \qquad (3)$$
$$\dot{p} = (I_z M'_u - I_{xz} M'_w)/(I_x I_z - I_{xz}^2) \qquad (4)$$
$$\dot{q} = M'_v / I_y \qquad (5)$$
$$\dot{r} = (I_x M'_w - I_{xz} M'_u)/(I_x I_z - I_{xz}^2) \qquad (6)$$
$$\dot{\phi} = p + (qs\phi + rc\phi)\tan\theta \qquad (7)$$
$$\dot{\theta} = qc\phi - rs\phi \qquad (8)$$
$$\dot{\psi} = (qs\phi + rc\phi)\sec\theta \qquad (9)$$
$$\dot{x} = c\theta c\psi u + (-c\phi s\psi + s\phi s\theta c\psi)v + (s\phi s\psi + c\phi s\theta c\psi)w \qquad (10)$$
$$\dot{y} = c\theta s\psi u + (c\phi c\psi + s\phi s\theta s\psi)v + (-s\phi c\psi + c\phi s\theta s\psi)w \qquad (11)$$
$$\dot{z} = -s\theta u + s\phi c\theta v + c\phi c\theta w \qquad (12)$$
$$M'_u = M_u - qH_w + rH_v \qquad (13)$$
$$M'_v = M_v - rH_u + pH_w \qquad (14)$$
$$M'_w = M_w - pH_v + qH_u \qquad (15)$$
$$H_u = I_x p + I_{xz} r \qquad (16)$$
$$H_v = I_y q \qquad (17)$$
$$H_w = I_{xz} p + I_z r \qquad (18)$$

where $s\phi$, $c\phi$ etc. show the abreviation of $\sin\phi, \cos\phi$ etc. $a_t, a_l$ and $a_n$ are corresponding to the output of the aircraft three axes accelerometer, which are obtained by subtracting gravitational terms from $F_u/m, F_v/m$ and $F_w/m$, respectively. The transformation from the inertial coordinates to the body coodinates are implimented by successive rotation about Z,Y and X axes with $\psi$ (yaw), $\theta$ (pitch) and $\phi$ (roll), respectively. The first step of the algorithm shown in Fig.1 is explained in detail.

(a) Let calculate following to the initial process the values of $\phi, \psi, p, r, F_u^*, F_w^*$ and $M_v^*$, where $\theta(t)$ and $q(t)$ are current states.

(b) Integrate eqs (1),(3),(5),(8) and (12) $t_L$ seconds, and let the obtained values of $V, h$ and $\theta$ at $t + t_L$ as

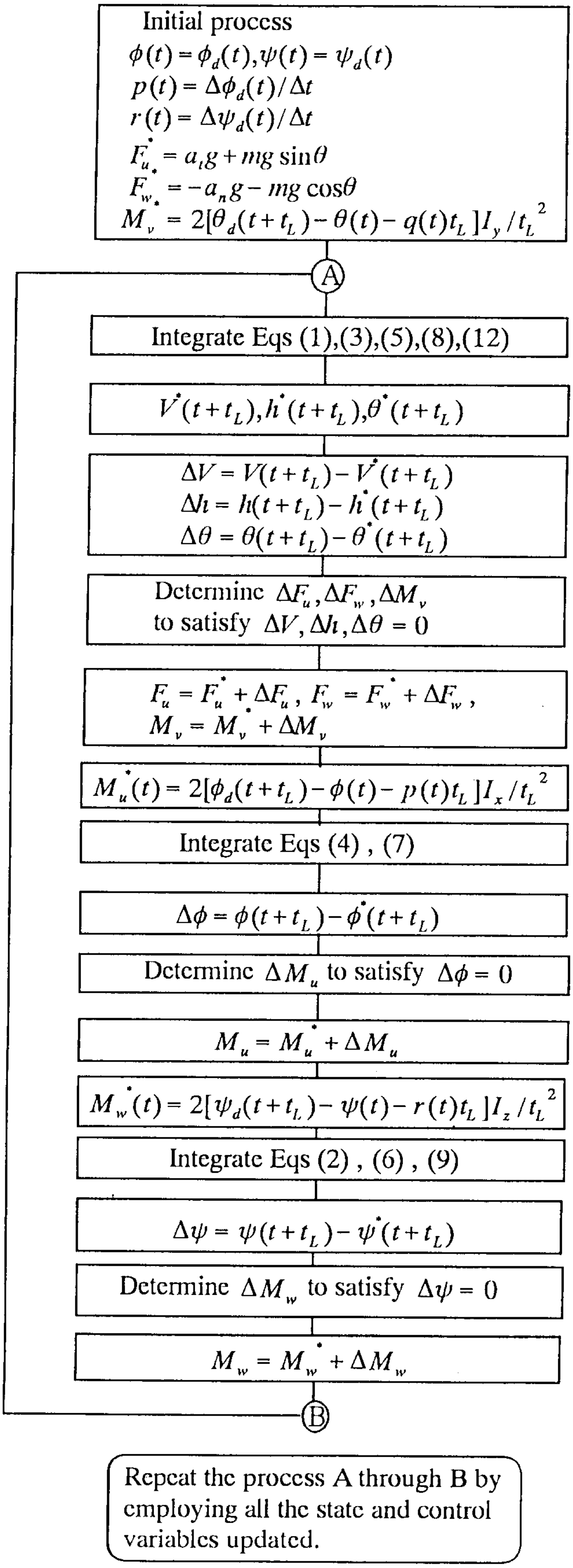

Fig.1 Flow chart of the algorithm

$V^*(t + t_L)$, $h^*(t + t_L)$ and $\theta^*(t + t_L)$ respectively.

(c) Let change the $F_u^*$ value very small amount $\Delta F_u$, and implement the same process as (b). This time we note the obtained values as $V_1(t + t_L), h_1(t + t_L)$ and $\theta_1(t + t_L)$.

(d) Let change the $F_w^*$ and $M_v^*$ values in the same way as (c), and note obtained state values at $t + t_L$ as $V_2(t + t_L), h_2(t + t_L), \theta_2(t + t_L)$ and $V_3(t + t_L)$, $h_3(t + t_L), \theta_3(t + t_L)$ respectively.

(e) Now we have obtained all the effect coefficients of $\Delta F_u(t), \Delta F_w(t), \Delta M_v(t)$ to $V(t + t_L), h(t + t_L)$ and $\theta(t + t_L)$, therefore we can calculate the exact values of $\Delta F_u(t), \Delta F_w(t)$ and $\Delta M_v(t)$ so that the values of $V, h$ and $\theta$ at $t + t_L$ are coincide with those of DFDR data $V_d(t + t_L), h_d(t + t_L)$ and $\theta_d(t + t_L)$ by solving the simultaneous equations.

(f) Update the $F_u, F_w$ and $M_v$ values by

$$F_u = F_u^* + \Delta F_u$$
$$F_w = F_w^* + \Delta F_w$$
$$M_v = M_v^* + \Delta M_v$$

In the same way, we determine the control variables $M_u$ and $M_w$ as are shown in Fig.1. The whole process from A through B is repeated again by employing the updated state and control variables.

## 3. RESULTS AND DISCUSSION

Figures 2 through 7 show the original data and estimated values for some variables. The obtained values are smoothly tracking the original data without a time delay, still satisfying differential equations (1) through (18) perfectly. From about 30 seconds before up to the drop and crash, the DFDR data about altitude, velocity, and $\alpha$ (angle-of-attack) are not believable, but we could estimate fairly reasonable values even in the situation. Because of the lack of the DFDR data we could not estimate the aircraft states, immediately before the drop. The ground traces data of the aircraft debris are processed and supplimented to estimate the states, which is beyond the scope of this paper and is not stated here. Figures 8 and 9 shows the views of the aircraft just before the drop.

## 4.CONCLUSION

A modified output error method is developed by anthors, and an example of its application on an air accident is shown. The method can reproduce the aircraft states without a time delay, and can estimate the input forces and torques worked on the aircraft. Although the method requies a fairly large computer time, it is very useful as it can compensate for the lack of the flight data.

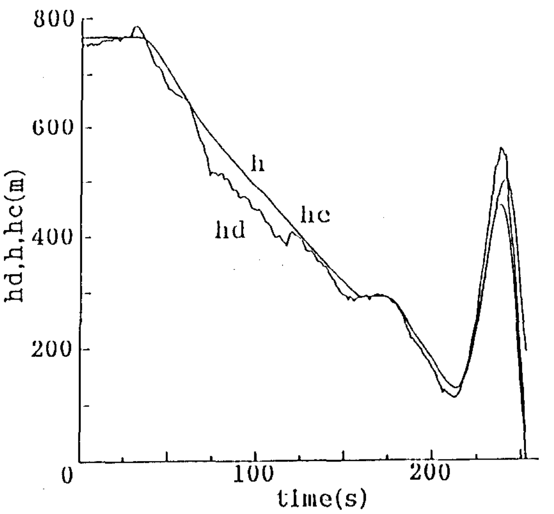

Fig.2 Altitude estimation

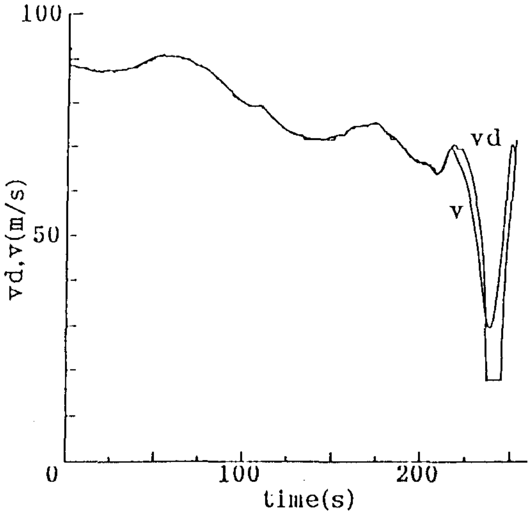

Fig.3 Velocity estimation

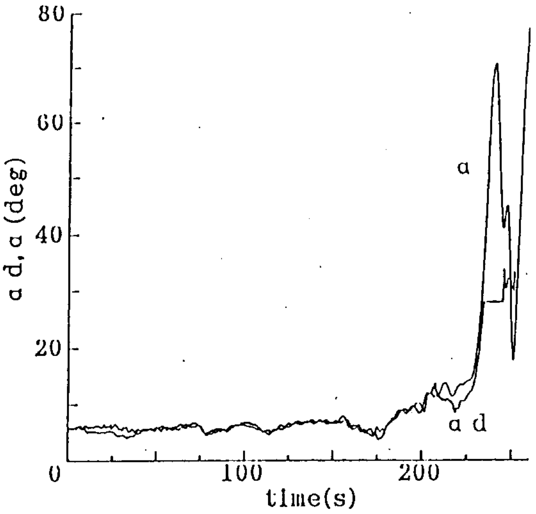

Fig.4 Angle-of-attack estimation

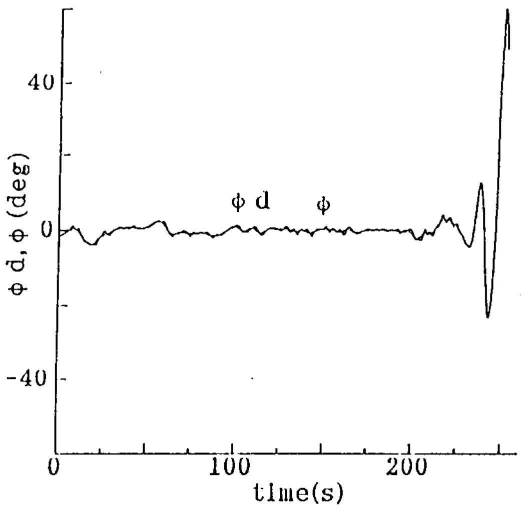

Fig.5 Roll angle estimation

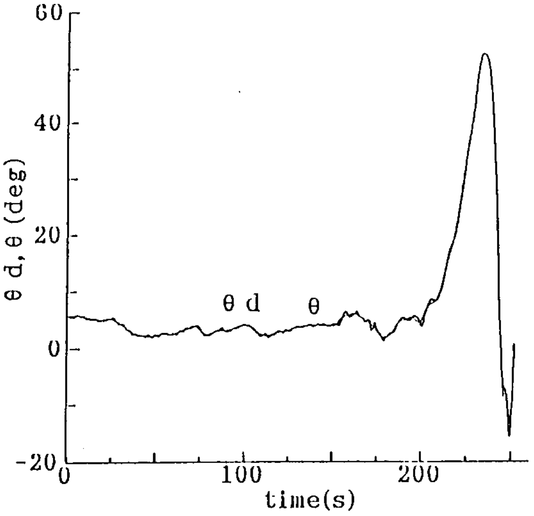

Fig.6 Pitch angle estimation

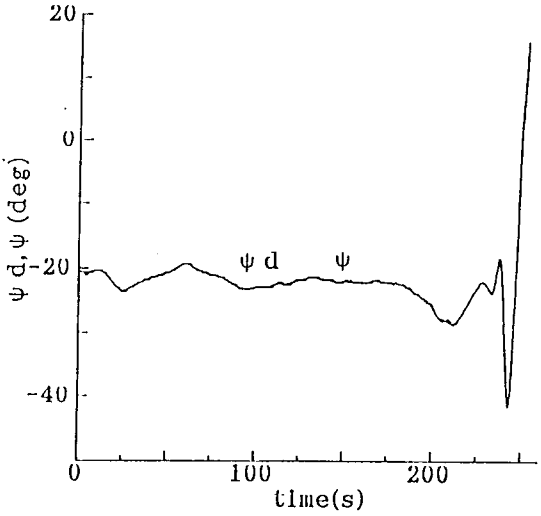

Fig.7 Yaw angle estimation

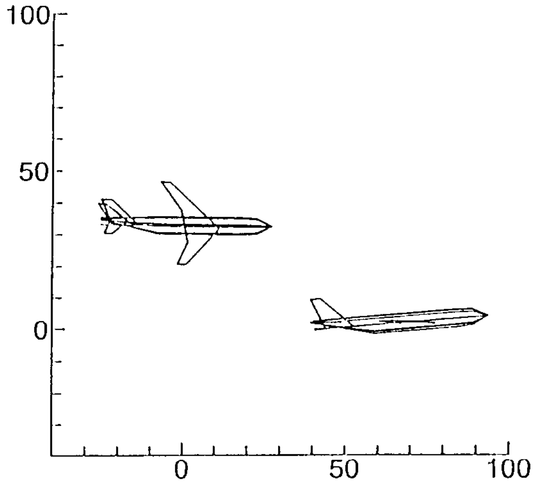

Fig.8 Side view just before the drop

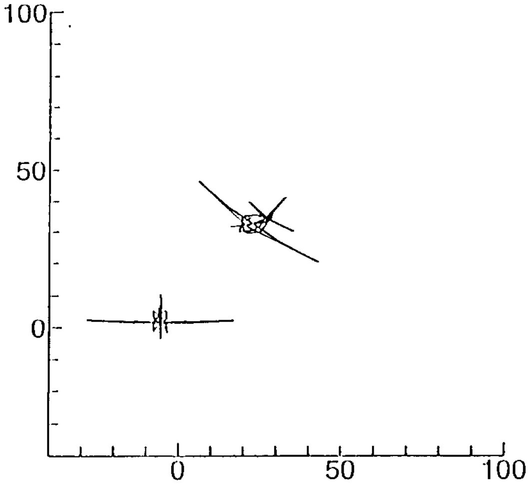

Fig.9 Behind view just before the drop