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DAUPHIN 6075 FLIGHT TEST ON PERFORMANCE DATA ANALYSIS AND CODE VALIDATION

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The Dauphin 6075 in service in the French Flight Test Centre (CEV) supports flight test research under government contract. This highly instrumented rotorcraft is able to fulfill the requirements of different flight test researches such as flight mechanics, system identification, rotorcraft performance, internal or external noise, blade boundary layer transition visualisation, vibrations. This paper concerns flight tests on "performance" and presents the data analysis procedure, the data base obtained and some comparisons with the results of a flight mechanic code developed by EUROCOPTER (HOST : "Helicopter Overall Simulation Tool").

The main flight tests performed for performance study include the following configurations :

- level flight for a sweep in airspeed at different M/σ ;
- climb and descent flight for a sweep in vertical speed at different airspeeds ;
- left and right turns for a sweep in roll angles at different airspeeds ;
- lateral left and right flights for a sweep in lateral speed ;
- pull-up manoeuvres with specific initial conditions.

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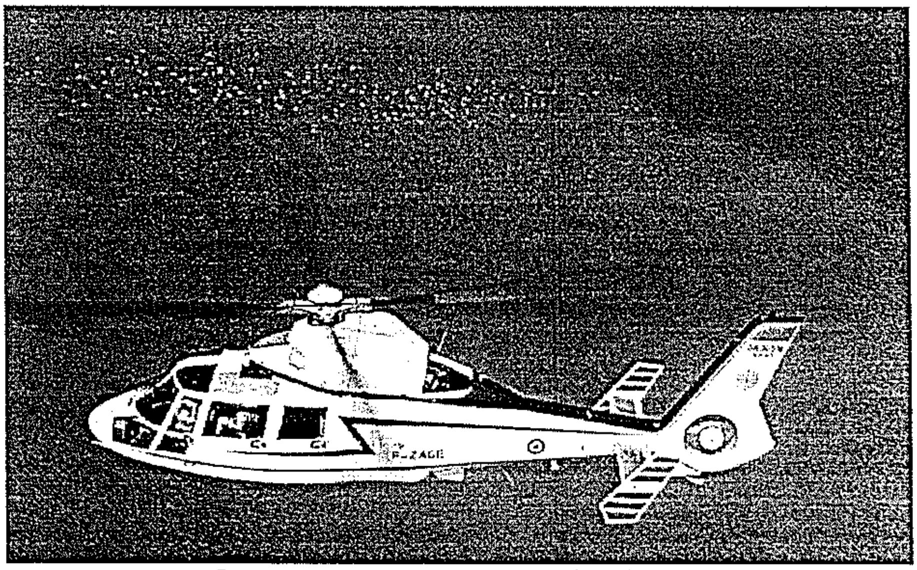

Fig. 1 : DAUPHIN 6075 Research Helicopter

1. OBJECTIVES

The SA 365N DAUPHIN 6075 (Fig. 1) is a multipurpose instrumented rotorcraft operated by the French Flight Test Centre based in ISTRES in the South of France.

The flight test researches are selected in a Working Group, managed by the French Official Service (SPAé), and including the CEV, ONERA and EUROCOPTER.

Since its procurement in 1995, the DAUPHIN 6075 has been used in a variety of research programmes to the benefit of ONERA and EUROCOPTER.

This paper concerns the flight tests on helicopter performance. The instrumentation, the data processing, the procedure to select the configurations and the data base obtained illustrated by some comparisons with EUROCOPTER code HOST are presented.

2. HELICOPTER INSTRUMENTATION

The Dauphin 6075 has an extensive array of sensors with a certain redundancy providing a measurement reliability confidence and a good data quality capacity.

Two acquisition systems are used, one for the non-rotating parameters with a sampling rate of 64 Hz and one for the main rotor parameters (in rotating frame) with a sampling rate of 1024 Hz.

One single EDITH clock generates the time for both acquisition systems and is used with the rotor blade azimuth and the number of rotor revolutions to provide synchronization between the two systems.

The main sensors are :

- Inertial Unit (ULISS 45 from SAGEM Company) : It provides helicopter accelerations, angular speeds, attitude angles, ground speed, wind speed (2 components and for air speed above 40 kts).
- DOPPLER radar system (RDN80B from DASSAULT ELECTRONIC Company) for ground speed and vertical speed informations.
- Pressure sensors for engines pressure, static and differential pressure.
- Temperature sensors for external total and engines temperatures.
- Gyrometers and accelerometers for aircraft accelerations and angular rates.
- Attitude Unit for helicopter attitudes.
- Potentiometers for servo-control displacements allowing the determination of the blade pitch angles.
- Strain gauges for main rotor shaft flexion moment and torque, pitch link loads and blade flapping for the 4 blades.
- Tail rotor torque by a specific optical mean developed by CEV.

Engine parameters measurements allow to get the engine power (total power) and as mentioned before reference time and blade azimuth are also available.

Detailed installation and data acquisition system descriptions are presented in [1].

3. DATA PROCESSING

Data processing includes preliminary checking, consistency checking, Kalman filter/smother, specific computations and selection of the best stabilized part of each flight run for parameters "mean value" computations.

3.1. Preliminary checking

This concerns :

- checking of the data acquisition time evolution ;
- checking of the synchronisation of the data delivered by the two acquisition systems ;
- detection and removal of non-valid data ;
- transfer of the different measurements in the same axis system.

3.2 Consistency checking

This concerns :

- checking the measurements performed before take off for sensors verification and first determination of sensors bias (in particular accelerometers and gyrometers) ;
- consistency checking of the inertial data by simplified Kalman filter (at first on the attitudes and then on ground speed components).

3.3 Kalman filter/smoother

The objective is to estimate the helicopter state in particular its trajectory and attitudes, the airspeed and wind components (with the hypothesis of a constant horizontal wind), the helicopter initial state and the accelerometers and gyrometers bias.

For low airspeed configurations for which airspeed measurements are non-valid, a preliminary test at larger airspeed has to be performed in order to estimate the wind components. For this preliminary test the helicopter has to follow a specific trajectory ("hippodrome shape" in a horizontal plane). Once the wind components are estimated they are considered constant during the following test runs.

3.4. Specific computations

Main rotor blade pitch angles :

No direct measurements being available, they are computed from the swash-plate servo-controls displacements (DTA : displacement of the forward servo-control, DTG : displacement of the left servo-control, DTD : displacement of the right servo-control). A calibration performed before the tests has given the matrices A and B of the transfer function between DTA, DTG, DTD and the main rotor collective (θ_0), longitudinal cyclics (θ_{1s}) and lateral cyclics (θ_{1c}) :

$$\begin{vmatrix}\theta_0\\ \theta_{1c}\\ \theta_{1s}\end{vmatrix} = [A]^* \begin{vmatrix}\dfrac{DTD+DTG}{2}\\ \dfrac{DTD-DTG}{2}\\ \dfrac{DTD+DTG}{2}-DTA\end{vmatrix} + [B]$$

Main rotor flapping :

The conicity, lateral and longitudinal flapping angles are computed from the instantaneous blades flapping and azimuth by :

$$\beta_0 = \frac{1}{4}\sum_{i=1}^{4}\beta_i$$
$$\beta_{1s} = \frac{1}{2}\sum_{i=1}^{4}\beta_i \sin(\psi - \frac{i\pi}{2})$$
$$\beta_{1c} = \frac{1}{2}\sum_{i=1}^{4}\beta_i \cos(\psi - \frac{i\pi}{2})$$

where β_i is the flapping of blade i (the number of blades is 4) and ψ is the azimuth of one of the blades considered as the reference blade.

If $\overline{\beta}_i$ and σ_i are the mean value and the root mean square of the flapping of blade i for a trimmed configuration, each blade instantaneous flapping β_i is corrected by :

$$\beta_{i\ \text{corrigé}} = (\beta_i - \overline{\beta}_i)\frac{\sigma_{ref}}{\sigma_i} + \overline{\beta}_{ref}$$

in order to have the same mean value and root mean square than the reference blade for trimmed configurations.

Power calculations :

The total power is computed from the engine power and the main and tail rotor powers from the main and tail rotor torque measurements.

Airspeed components and helicopter accelerations in an horizontal/vertical axis system :

In hover and low speed it is difficult for a pilot to stabilize perfectly an helicopter in a specific configuration (level flight, climb/descent or turn). In order to be able to judge the flight configuration really tested, airspeed components and helicopter accelerations have been computed in a horizontal/vertical axis system by :

$$\begin{bmatrix} Uh \\ Vh \\ Wh \end{bmatrix} = \left[AVT(0,\Theta,\Phi\right]^* \begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

and

$$\begin{bmatrix} axh \\ ayh \\ azh \end{bmatrix} = \left[AVT(0,\Theta,\Phi\right]^* \begin{bmatrix} ax \\ ay \\ az \end{bmatrix}$$

where :

- U, V, W are the airspeed components and a_x, a_y, a_z the accelerations in the helicopter axis system and U_h, V_h, W_h and ax_h, ay_h, az_h in the vertical/horizontal axis system.
- AVT (0, θ, φ) a rotation matrix of angles 0, θ and φ around helicopter axis z, y and x.

Angular accelerations have been also computed by numerical differentiation of the angular rates. They are used also to check the configuration really tested.

3.5. Calculations of the trimmed parameters value :

In order to have the trimmed value of the different parameters for a specific configuration a mean value has to be computed over a part of the flight run. An automatic process has been developed to select the best time period (a "window" of about 5 to 10 seconds) over which this mean value is computed.

4. SELECTION OF THE CONFIGURATIONS

As it is very difficult to stabilize perfectly an helicopter in a specific low speed configurations (level flight, climb/descent, turn) a procedure to select the configurations to be kept in a data base has been defined. This procedure is based on the analysis of the airspeed components and of the linear and angular helicopter accelerations.

A code developed by EUROCOPTER [2] (code HOST : "Helicopter Overall Simulation Tool") has been used to study the effects of lateral and vertical airspeed components and the ones of linear accelerations on the main helicopter parameters (attitudes, control angles and powers). For example figures 2 and 3 demonstrate the influence of .5 m/s² longitudinal and lateral accelerations on the helicopter attitude and control angles in level flight. Figure 4 shows the effect of a vertical acceleration (.5m/s²) on the total power and figure 5 the effect of a lateral velocity (1 m/s) on the bank angle. These results show that :

- a .5 m/s² longitudinal acceleration has an effect of about 3° on the helicopter pitch angle (Fig. 2) ;
- a .5 m/s² lateral acceleration has an effect of about 3° on the bank angle (Fig. 3) ;
- the vertical acceleration has an effect on the power (Fig. 4) ;
- the lateral velocity has an effect on the bank angle (Fig. 5).

These effects can explain a good part of the scattering of the flight test data that can be encountered (in particular at low speed or for the bank angle).

A selection of the flight test configurations to be retained in the data base has been defined based on limits allowed for lateral and vertical airspeed components for angular rates and for linear and angular accelerations. The « ideal » limits to consider are :

- .1 m/s² on the linear horizontal accelerations ;
- .5 m/s for the lateral horizontal velocity (or longitudinal horizontal velocity for lateral flights) ;
- .25 m/s for the vertical velocity (for level flights) ;
- .15°/s for the angular rates (except for turn) ;
- .1°/s² for the angular accelerations.

5. DATA BASE OBTAINED

All the flight test runs have been analysed with the procedure defined in 3 and 4 and the data base constituted with the selected runs contains :

- level flight for a sweep in airspeed at different M/σ ;
- climb and descent flight for a sweep in vertical speed at different airspeeds and different M/σ ;
- left and right turns for a sweep in roll angles at different airspeeds ;
- lateral left and right flights for a sweep in lateral speed.

Some pull-up manoeuvres with specific initial conditions have also been performed.

Some of the results are presented on figures 6 to 14 :

- figures 6 to 8 concern level flight configurations at M/σ=3800kg ;
- figures 9 to 11 concern climb and descent flights at V=100kt ;
- figures 12 to 14 concern turning flights at V=80kt.

The complete data base can be used for codes validation and improvements. Some comparisons between flight test results and computed results are presented on figures 15 to 18. The calculations have been performed with EUROCOPTER HOST code [2].

Figures 15 and 16 concern level flight with a sweep in airspeed between -50km/h and 250km/h for M/σ=3700kg. Calculations with and without interaction between the main rotor wake and the horizontal stabilizer have been performed. The pitch up effect quite visible on the evolution of the pitch (fig.15), longitudinal flapping (fig.15) and longitudinal cyclic (fig.16) angles is relatively well predicted by the model.

Figures 17 and 18 concern climb and descent flights at 40kt. The comparisons for the evolution of the parameters with the rate of climb are relatively good even if some differences occur.

This data base is going to be used to validate some model improvements studied at ONERA concerning, in particular, the interactions between the main rotor wake and the rear parts of the helicopter. Some flight tests are still needed to complete this data base.

6. CONCLUSION

Flight test results are needed both to understand specific phenomena and to obtain useful data basis for codes validation. The SA365N DAUPHIN 6075 operated by the French Flight Test Centre is devoted to flight test research programmes to the benefit of ONERA and EUROCOPTER since 1995.

This paper shows some of the results obtained for helicopter performance and presents the data analysis procedure used, the data base obtained and some comparisons with the results of EUROCOPTER flight mechanic code HOST.

References :

[1] D.Papillier, P.Large, P.Bonnet, B.Gimonet, D.Heuzé
The Dolphin 6075 : An Helicopter Dedicated to Flight Test Research.
23rd European Rotorcraft Forum, Dresden, Germany, September 1997.

[2] P.Eglin
Aerodynamic Design of the NH 90 Helicopter Stabilizer
23rd European Rotorcraft Forum, Dresden, Germany, September 1997.

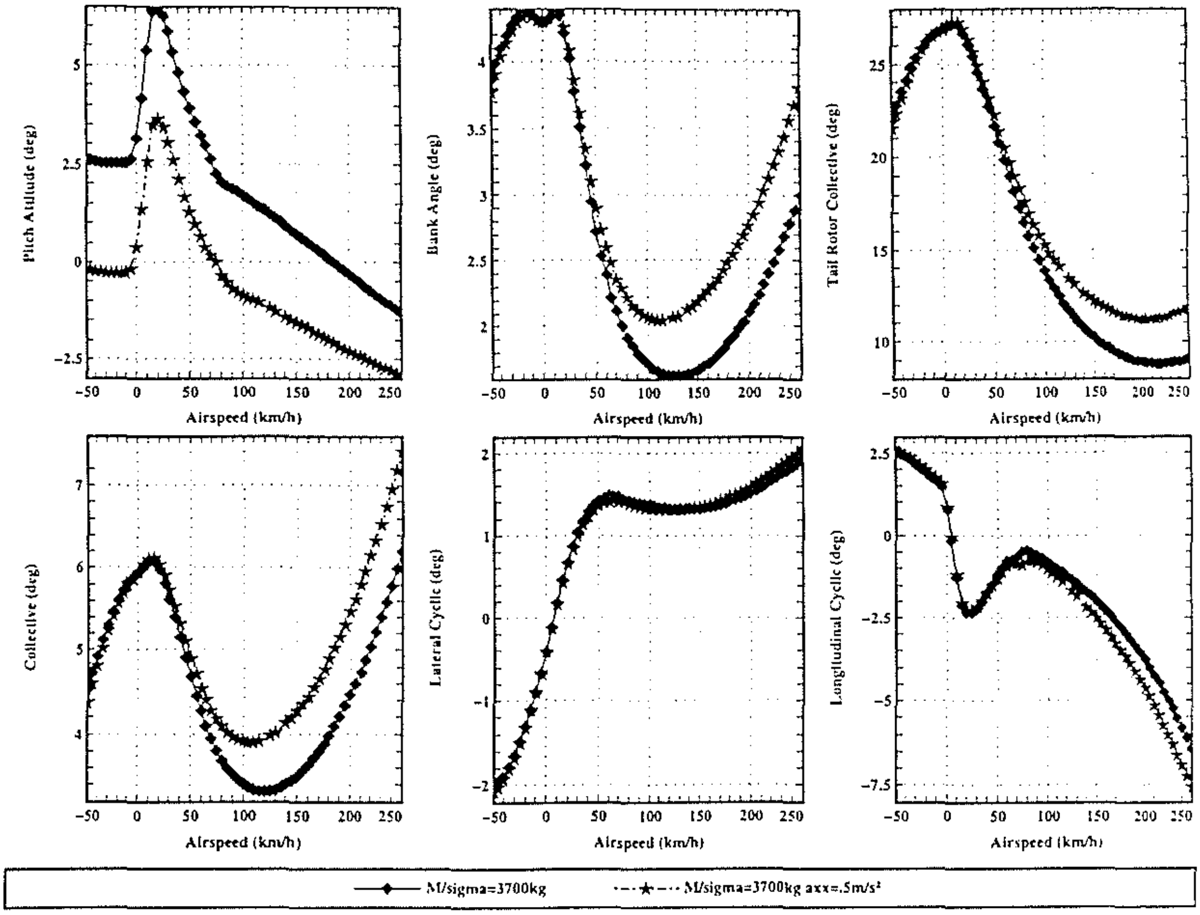

Fig.2 Effect of a longitudinal acceleration (HOST calculation)

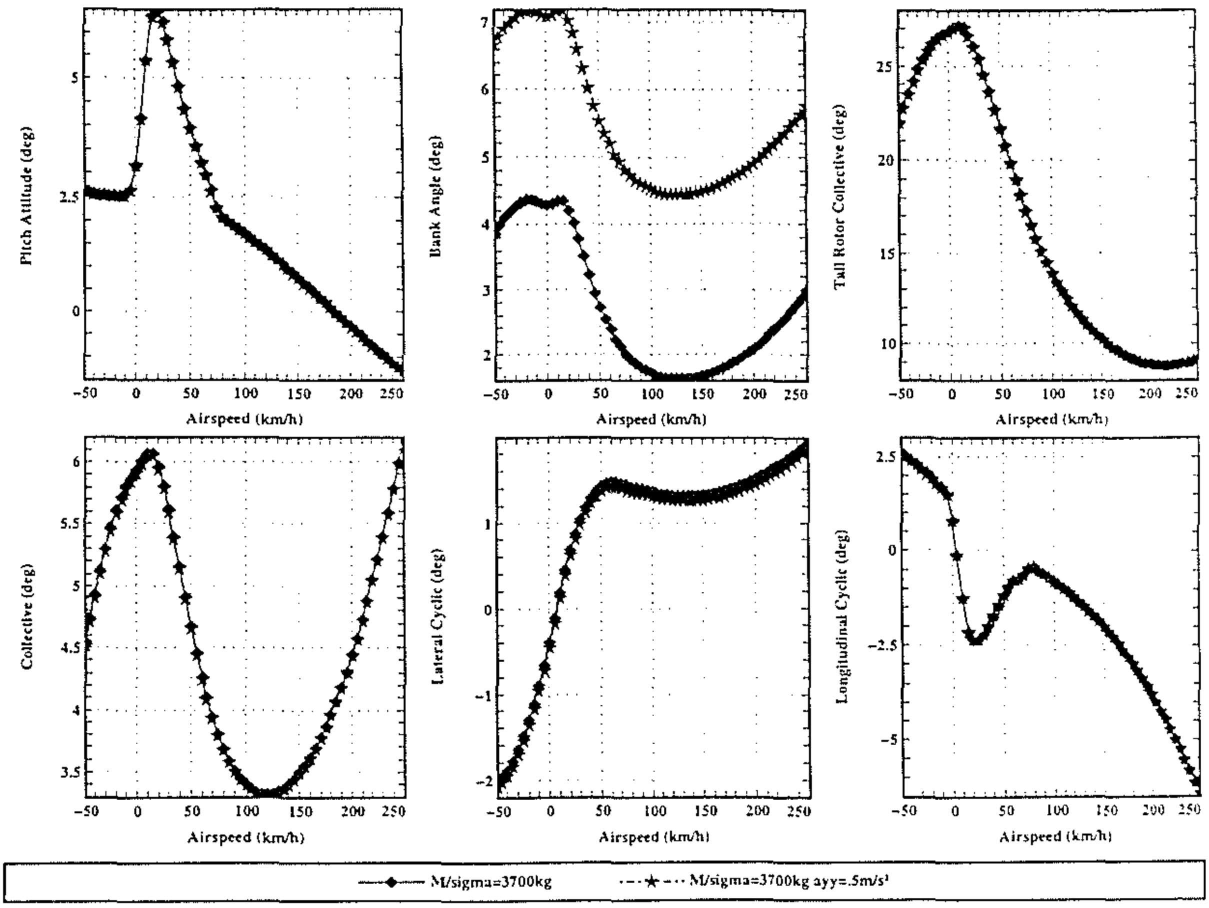

Fig.3 Effect of a lateral acceleration (HOST calculation)

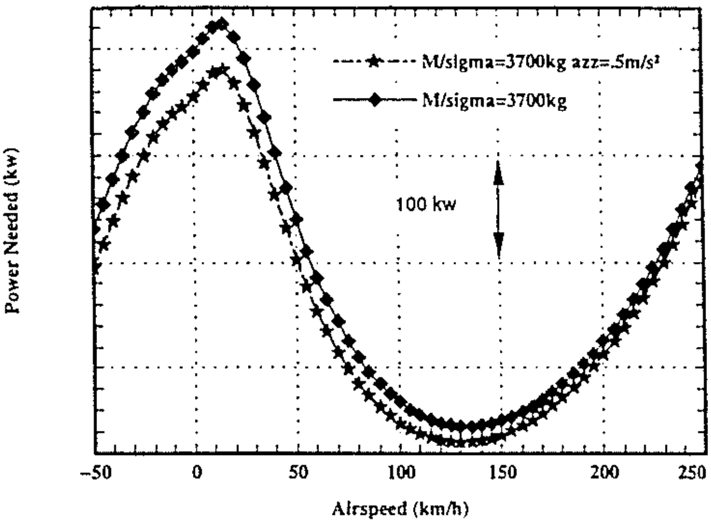

Fig.4 Effect of a vertical acceleration -HOST Calculation

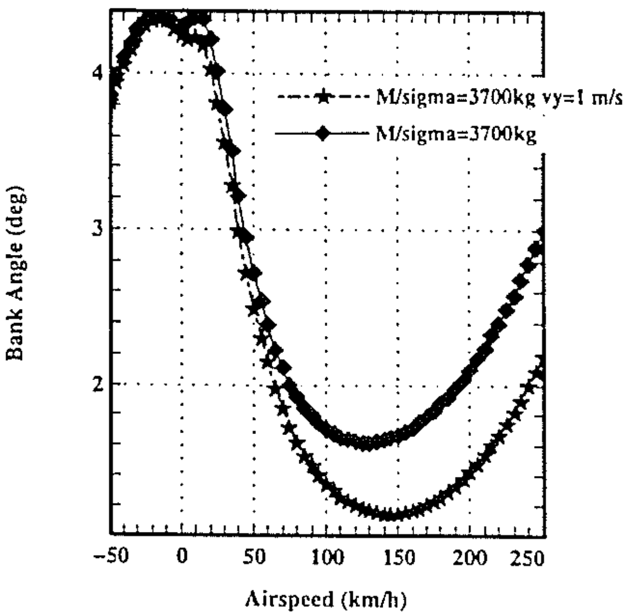

Fig.5 Effect of a lateral velocity -HOST Calculation

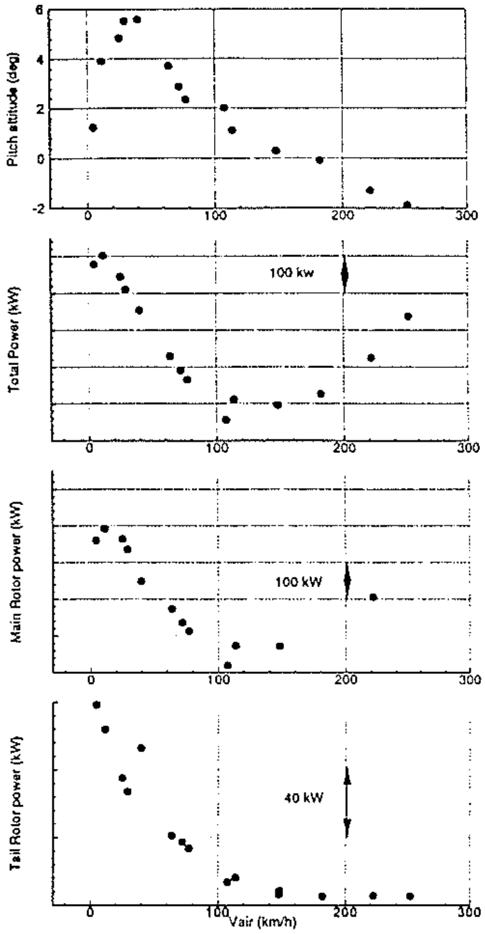

Fig.6 Level Flight (M/σ=3800Kg)

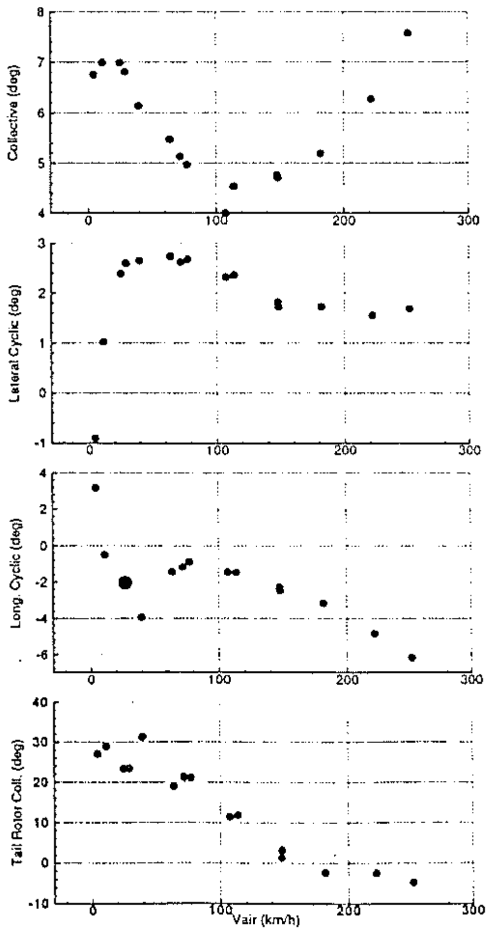

Fig.7 Level Flight (M/σ=3800Kg)

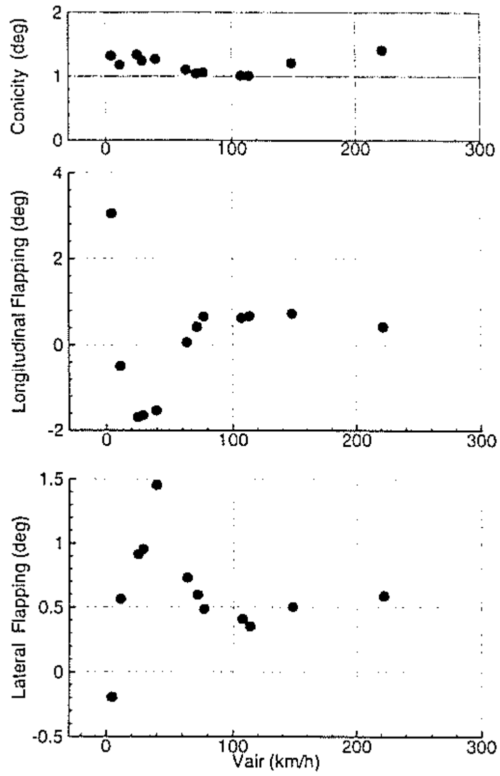

Fig.8 Level Flight (M/σ=3800Kg)

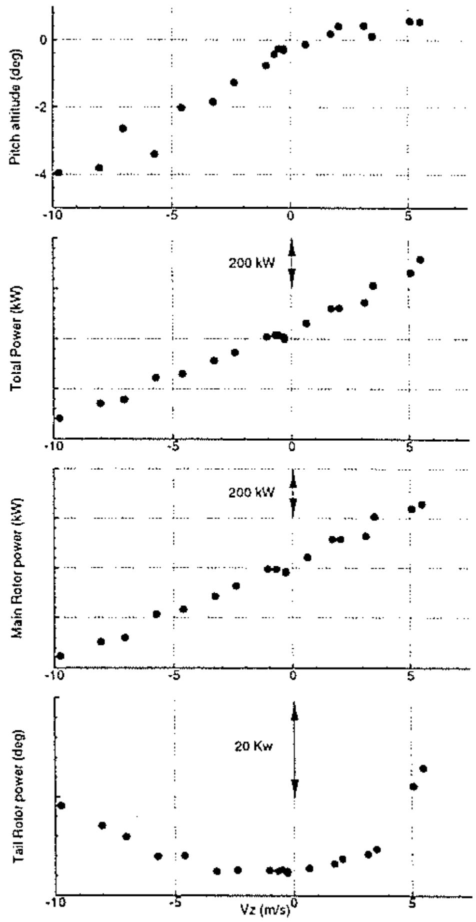

Fig.9 Climb/descent Flight (V=100kt)

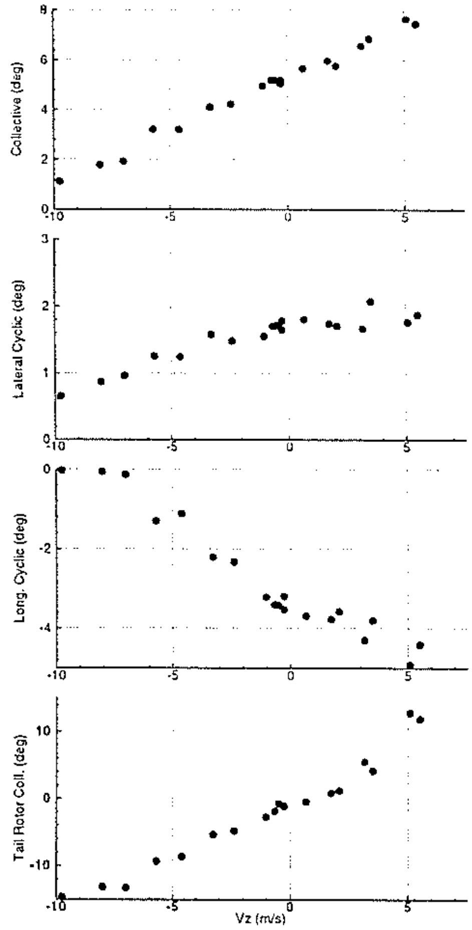

Fig.10 Climb/descent Flight (V=100kt)

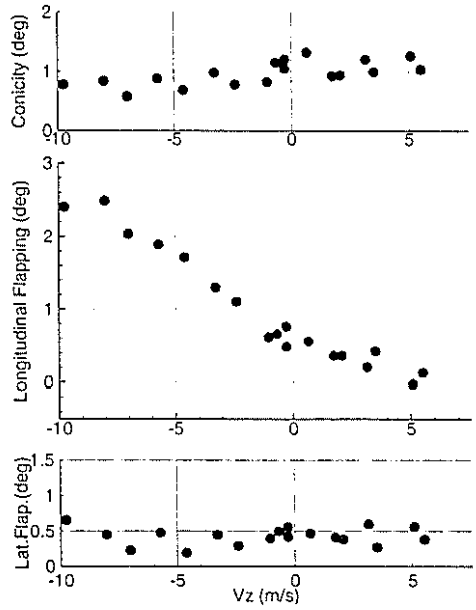

Fig.11 Climb/descent Flight (V=100kt)

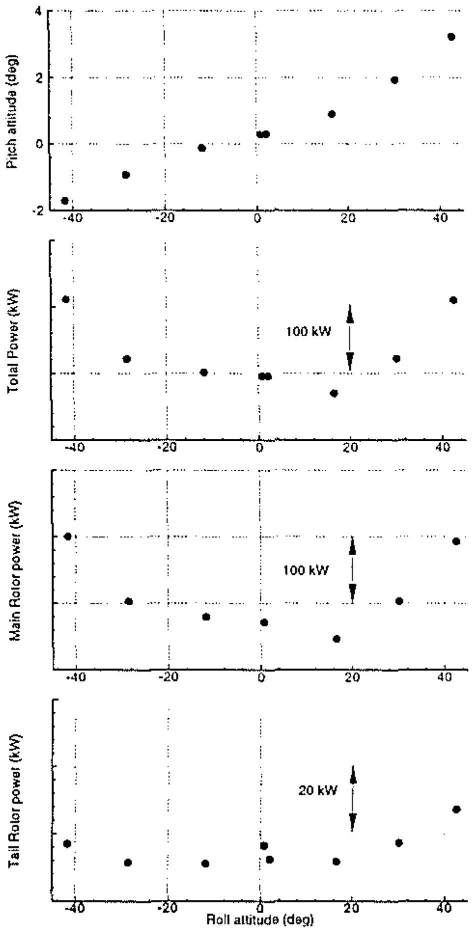

Fig.12 Turn Flight (V=80kt)

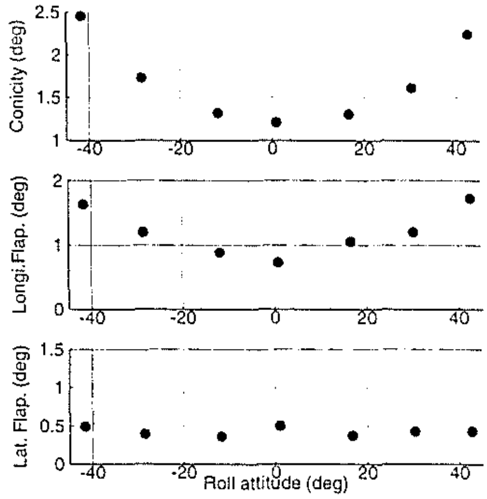

Fig.14 Turn Flight (V=80kt)

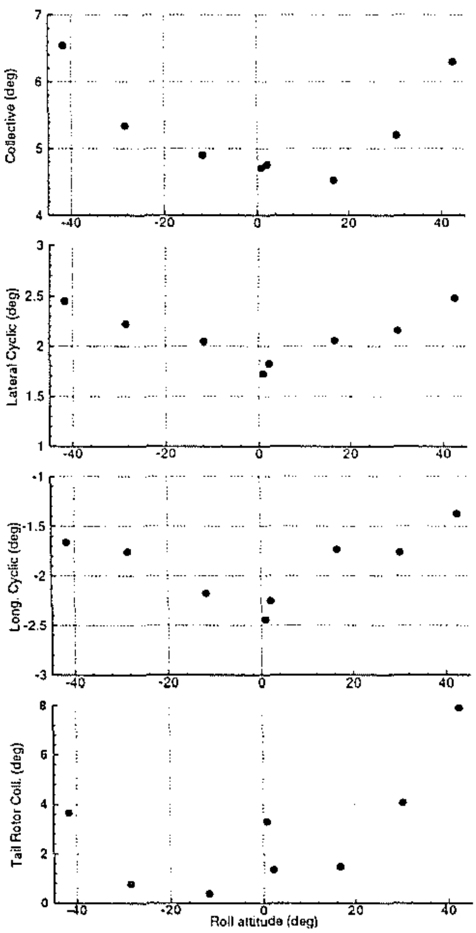

Fig.13 Turn Flight (V=80kt)

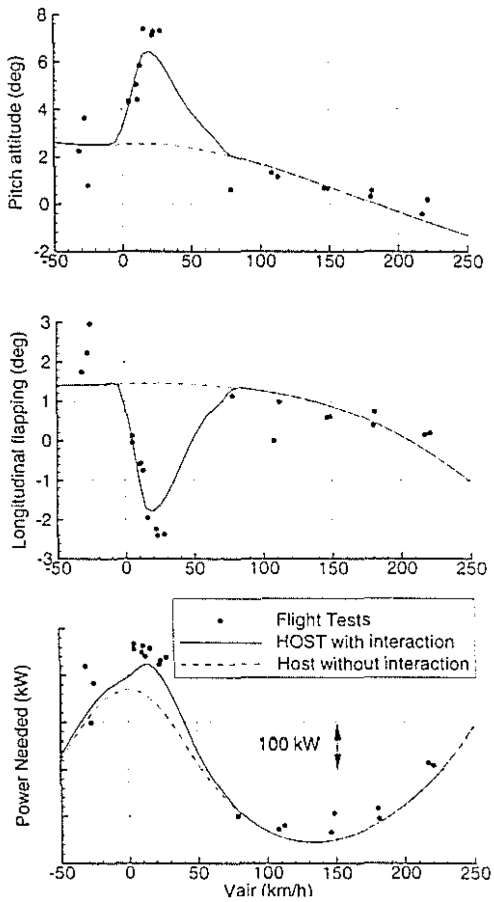

Fig. 15 Level Flight (M/σ=3700kg)

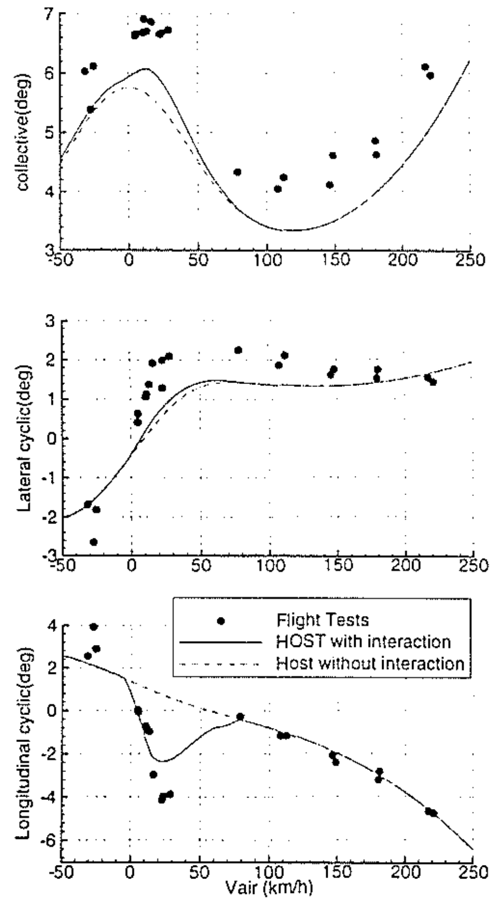

Fig.16 Level Flight (M/σ=3700kg)

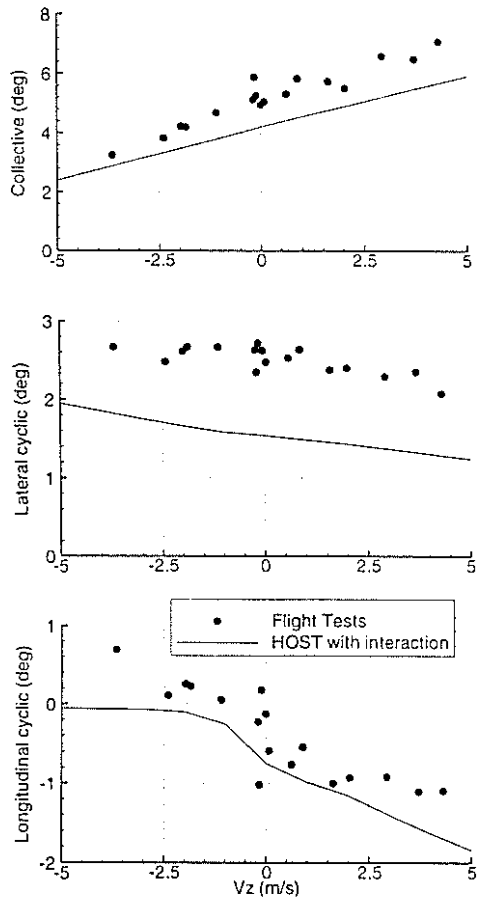

Fig.18 Climb/descent Flight (V=40kt)

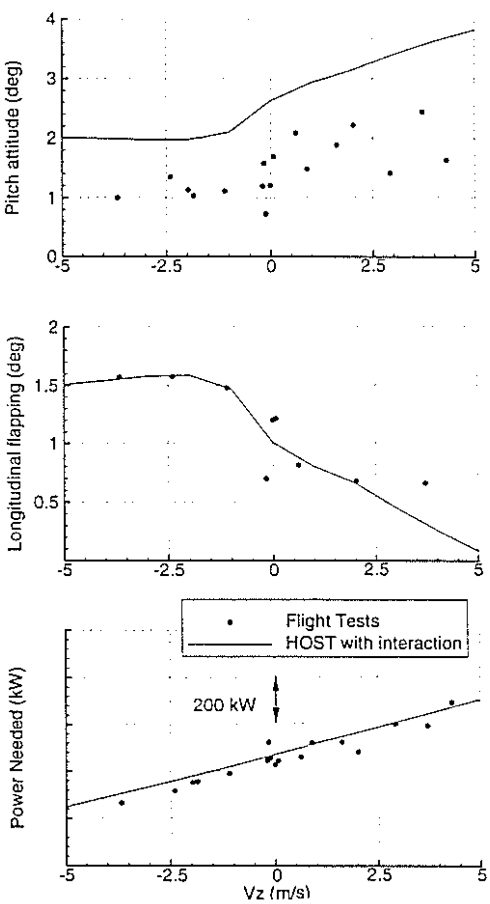

Fig.17 Climb/descent Flight (V=40kt)