**The DOLPHIN 6075: An helicopter Dedicated to Flight Test Research**

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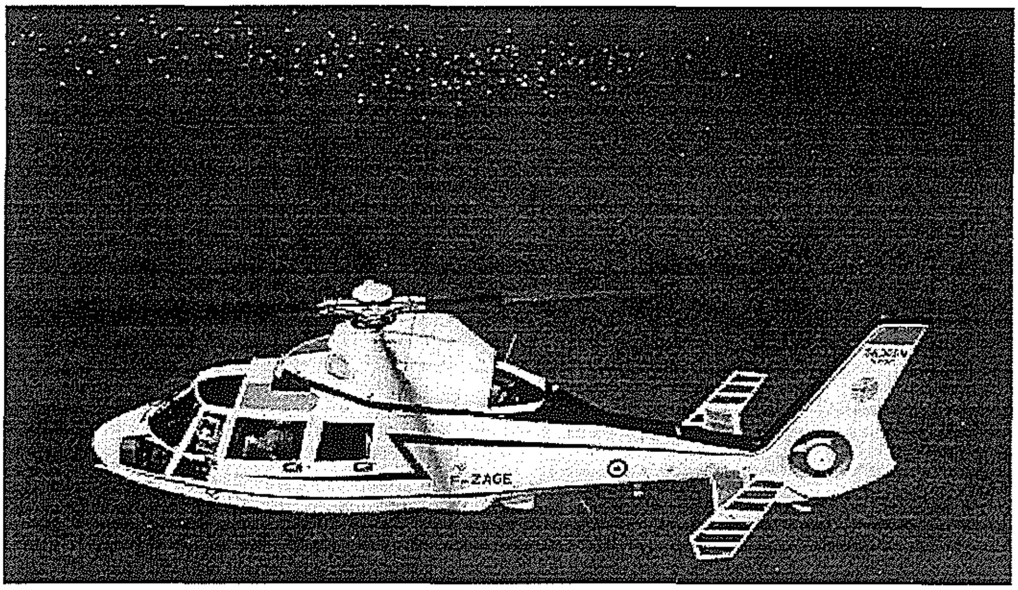

Fig.1 : DOLPHIN 6075 Research Helicopter

## SUMMARY

The DOLPHIN 6075 (Fig 1) in service in the French Flight Test Centre (CEV) supports flight test research under government contract.

This paper describes this highly instrumented rotorcraft and presents the flight test campaigns in progress and in preparation. As presented, the DOLPHIN 6075 is able to fulfil the requirements to various type of flight test research such as flight mechanics modelling, rotorcraft system identification, performance, internal or external noise measurement, low speed system calibration.

Some results obtained from the different flight tests already achieved are also presented.

## INTRODUCTION

The SA 365N DOLPHIN 6075 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 DOLPHIN 6075 has been used in a variety of research programmes to the benefit of ONERA and EUROCOPTER.

In a first part, this paper describes the flight test installation and the flight test activities. In a second part, some results obtained during these flight test campaigns are revealed.

## FLIGHT TEST INSTALLATION DESCRIPTION

This chapter describes the relevant components operating on the F.T.I (Flight Test Installation) of the DOLPHIN 6075.

### INSTRUMENTATION DESCRIPTION

To ensure his mission of research oriented aircraft, the SA 365N n°6075 Dolphin has an extensive array of sensors which, through a certain redundancy, provides a measurement reliability confidence and good data quality capacity. The Dolphin sensors can be classified in two families :

- STANDARD SENSORS
- PRESSURE SENSORS: providing engines pressure and aircraft height and airspeed parameters,
- TEMPERATURE SENSORS: measuring external, cockpit and engines temperatures parameters,
- POTENTIOMETERS: supplying shifting measurements as control command and servo-control shifts,
- GYROMETERS AND ACCELEROMETERS,
- STRAIN GAUGES: acquiring stresses parameters such as main rotor shaft flexion moment and torque, pitch link loads and blade flapping (Fig. 2).

- SPECIFIC SENSORS
- INERTIAL UNIT

The inertial unit is an ULISS 45 system produced by SAGEM. It provides navigation elements such as position, heading, track, desired track , wind speed and direction, ground speed, air speed and also delivers attitude, angular speed and acceleration parameters. All these information are acquired through an ARINC 429 line.

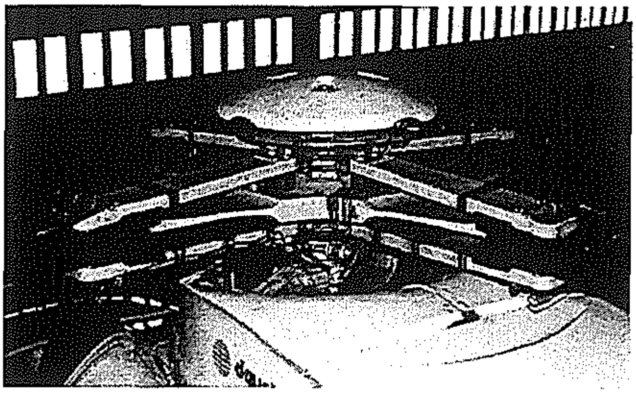

Fig.2 : Main rotor equipment

- GPS SYSTEM

The GPS system used on this aircraft is used as a basic navigation system. The data coming from the GPS are, for the moment, not acquired by the FTI. For special flight tests the PPS output had been used to synchronise aircraft and ground information data.

- DOPPLER RADAR SYSTEM

The Doppler radar is an RDN80 B one, produced by DASSAULT ELECTRONIC. It provides ground speed and vertical speed information with a global precision of 1 kt.

- RADIO HEIGHT SYSTEM

The radio height information is provided by an AHV8 system produced by THOMSON-TRT. This information is acquired by the FTI in the domain of 0 ft to 1000 ft with a precision of 1 ft.

- LOW AIRSPEED SYSTEM

The low airspeed measurement is ensured by a particular system called VIMI, developed by the CEV. This system permits to easily reach the Out of Ground Effect hovering, and to have reliable measure of airspeed between -40 kt and + 40 kt on longitudinal and lateral axis.

- TAIL ROTOR TORQUE

The tail rotor torque measurement is ensured by a specifically mean developed by the CEV. It is based on an optic measurement of the tail drive shaft torsion deformation, which provides, knowing the material characteristics of the shaft, the tail rotor torque.

## DATA ACQUISITION SYSTEM DESCRIPTION

### GENERAL CONCEPTS

The Flight Test Installation has a data acquisition system designed around one kind of sample unit which is the DAMIEN V.

Two families of parameters are distinguished :

- *parameters whose evolution is not considered to be rapid* (CG's motion for example), called 'QUASI-STATIC' parameters and
- parameters whose evolution is rapid. These constitute the 'DYNAMIC' parameters which involve on the Dolphin *stresses measurements on rotating part.*

Furthermore, the F.T.I. includes facilities which are: Magnetic Recorder, Safety Recorder, EDITH clock, Telemetry, Video Recorder, and control facilities on the Pilot and Flight Engineers stations.

### SYSTEM DESCRIPTION

*QUASI-STATIC SYSTEM*

**Inputs:** Organised around two DAMIEN V sample units, this system is able to acquire simultaneously about 200 parameters sampled up to 256 p/s These parameters can be analogic (temperature, pressure, pulses ...), or numeric (ARINC 429 lines) parameters.

**Outputs:** The system generates three IRIG Standard Pulse Coded Modulations (PCM). Each of them is rated to 8 Kwords/s in BOM code. The first message is recorded on magnetic tape, the second is transmitted by telemetry, the third is used by on board computers to provide real time control to Flight Engineers during test flights.

DYNAMIC SYSTEM

**Inputs :** This system uses one DAMIEN V sample unit. It acquires simultaneously 16 parameters sampled up to 2048 p/s. These parameters are mainly constituted of analogic voltages coming from strain gauges stuck on the moving parts of the main rotor.

**Outputs:** Similar to the quasi-static system but rated to 16 Kwords/s in BOM code.

DATATION SYSTEM

One single EDITH clock generates the time in IRIG-B standard for both acquisition systems. This clock can be synchronised via radio link on Universal Time.

MAGNETIC RECORDER

The Magnetic Recorder is a SCHLUMBERGER A4111 type in LBG2 mode. At 38 cm/s (15 IPS) speed, there is approximately 1 hour of autonomous operation.

TELEMETRY

The telemetry system includes:

- *a multiplex mounting plate which receives the three* signals to be transmitted:
  - one PCM message elaborated by QUASI STATIC system rated to 8 Kwords/s with 13 bits/word,
  - one PCM message elaborated by DYNAMIC system rated to 16 Kwords/s with 13 bits/word,
  - the voice transmission.

- the FM modulation and filtering of signals which are ensured by modules located on the mounting plate.

This capability is mainly used during special flight tests to ensure safety by controlling in real time the aircraft main limitations in terms of stresses and vibrations.

SAFETY RECORDER

The safety recorder is a SCHLUMBERGER PE 6015 recorder. It records a PCM signal sent from a R1500 data acquisition system . These two equipment are completely independent from the other data acquisition system. This means that they are supplied by the aircraft electrical generation and they have also dedicated sensors to elaborate the safety PCM message. The recorder permits to always have the last hour of flight test for data recording and the last 1/2 hour for cockpit voice recording.

ON-BOARD COMPUTERS

The SA 365N n° 6075 FTI integrates two inboard computers type IBM PC based on INTEL 486 DX processor. Each computer has the same hardware configuration including ARINC 429 I/O card, ANALOG I/O card and two channels PCM input card developed by the CEV.

The two inboard computers are positioned in spy on the PCM issued from both QUASI STATIC and DYNAMIC acquisition systems. These two computers are completely independent and provides real time flight test managing and data recording to the flight test engineers (Fig. 3), thanks to special software tools pool developed by the CEV. They can simultaneously display the information in real time under several forms: alphanumeric, graphic scales and Y = f(t) or f(X) diagrams (Fig 4).

The information displayed by both computers can be printed by screen hard-copy on an inboard HEWLETT PACKARD thermal graphic printer. The computers have also the capability to present, using ARINC 429 lines, elaborated data to the pilot on standard instruments like Horizontal Situation Indicator or Hovering Indicator and specific displays (Fig. 5).

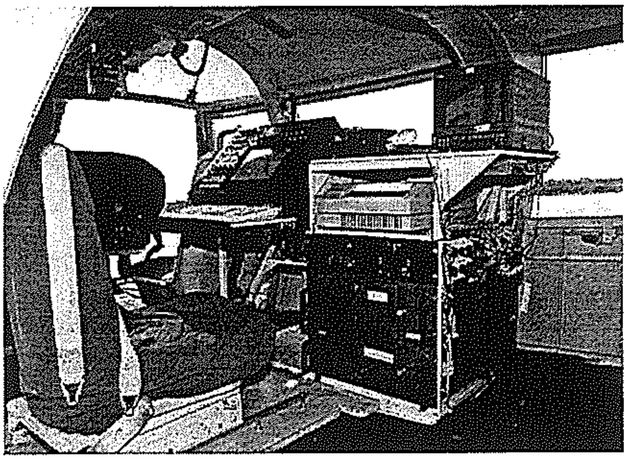

Fig 3: Flight test engineers station

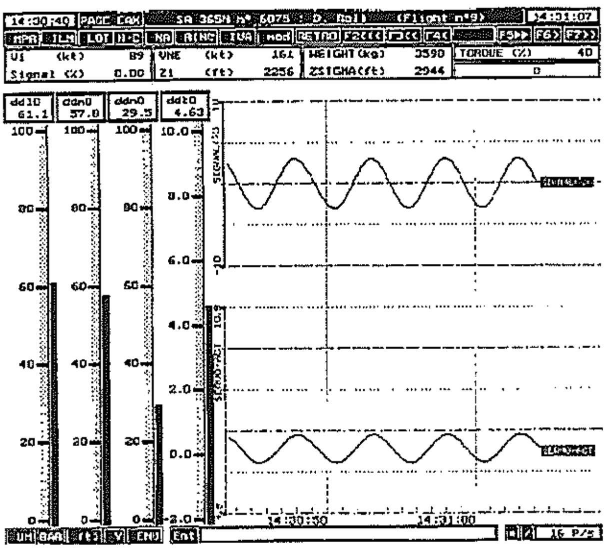

Fig 4: Example of a possible information display

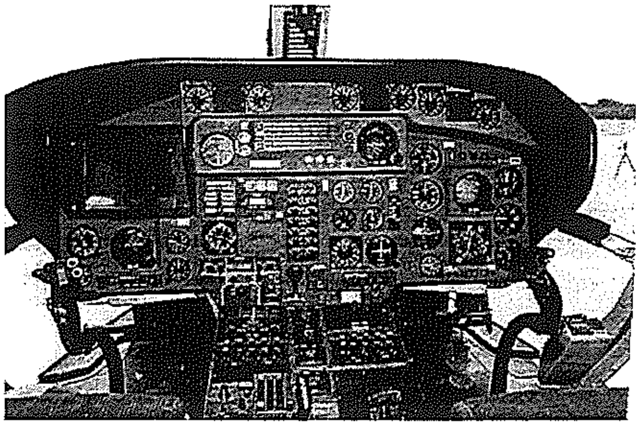

Fig.5 : Flight instrument panel

## SPECIAL INSTRUMENTATION

If necessary, the DOLPHIN can be fitted with equipment that fulfil particular requirements:

- VERTICALITY VIDEO CAMERA

A verticality camera equipment developed by the CEV can be mounted on the DOLPHIN for special tests requiring accurate helicopter position measurement in relation to ground axes. The image supplied by the camera can be directly displayed to the crew and also recorded.

- ANALOGIC ACQUISITION SYSTEM

A specific analogic signal acquisition system developed by the ONERA Structure Department can be installed in the helicopter for special tests with acoustic, accelerometer or pressure measurements. This compact system is able to format, acquire, synchronise and record about 100 parameters.

- BLADE VIDEO CAMERA

For special tests, requiring the visualisation of the blade, a video camera is fitted on the cabin. A specific computer synchronises the camera on any lateral position desired. The image can be displayed to the crew and recorded on tape recorder or in the computer memory for further analysis .

- BAVE

Calibrated control inputs can be produced by an electronic device called BAVE (« Boîtier Amplificateur de Vérins d'Essais »). The BAVE, which is connected to the on-board computer (all types of signal can be generated), commands the rotorcraft actuators. This device is used for the flight mechanics and rotorcraft identification tests.

## OFF-LINE DATA PROCESSING

Two sorts of off-line data processing are used depending mainly on the volume of the data:

**- Up to 100 Mega bits**

The data recorded on the in-board computer memory are transferred on a light ground station. Thus the flight can be immediately "re-played", interesting phases selected and results printed or directly supplied to the customer under desired format.

**- Over 100 Mega bits**

In this case, the data transmitted by telemetry or recorded on the magnetic tape on-board the aircraft are processed by the CEV data computing centre (CIGALE).

## TEST CAMPAIGN ORGANISATION

Generally and once the test research has been selected by the working group, the Flight Test Centre (CEV) undertakes the whole operation development:

- DESIGN ENGINEERING

If necessary, the technical design department elaborates with the customer (ONERA, EUROCOPTER or else) the new installation drawing.

- AIRCRAFT MODIFICATION WORK

The modifications of the aircraft installation are achieved by the CEV. Manifold works can be undertaken, up to airframe modifications.

- SAFETY CHECK

The CEV is able to deliver the flight clearance always required after an aircraft modification.

- FLIGHT TEST

Flight tests are flown in a large area closed to Istres under the CEV air traffic radar assistance. Many facilities are available (trajectography).

- DATA DELIVERY

The data processing center delivers the flight data under the format the customer needs.

## FLIGHT TESTS ACTIVITIES

This chapter presents various flight tests performed since the procurement of the DOLPHIN 6075 in 1995:

- flight mechanics modelling and rotorcraft system identification ;
- helicopter performance modelling ;
- internal noise identification ;
- visualisation of the boundary layer transition on the blade ;
- external noise sources location ;
- algorithm evaluation for low speed system calibration.

This flight test program was defined by Eurocopter, CEV and ONERA.

The main objective of this paper is not to describe each research in detail, but to present how flight tests were performed and some results obtained.

## FLIGHT TESTS PERFORMED

- FLIGHT MECHANICS MODELLING AND ROTORCRAFT SYSTEM IDENTIFICATION

The main objectives of these flight tests are:

-rotorcraft system identification;

- to get a data base to validate helicopter flight mechanics code.

FLIGHT TEST CONFIGURATIONS:

Flight test program includes the following test conditions :

- hover at $M \approx 3700$Kg ;
- forward flight at different speeds :
  - V = 0, 40, 60, 100, 140kt ; $M \approx 3700$Kg ;
- climbing and descending flight :
  - V = 100 kt ; Vz = +/- 1000 ft/mn, $M \approx 3700$Kg.

Two types of control inputs were used :

- 3/2/1/1 multi-step applied on collective, longitudinal cyclic, lateral cyclic and pedal. On collective, the 3/2/1/1 multi-steps were delivered manually by the pilot. On the other axis, control inputs were delivered automatically with the BAVE device ;
- PRBS : Pseudo-Random Binary Sequence, applied on longitudinal cyclic, lateral cyclic and pedal.

Before delivering control input on a chosen axis, the helicopter must be stabilised under the specific flight conditions and the chosen axis must be disconnected from the automatic pilot. During the control inputs sequence, the pilot had to keep the helicopter in the safety flight domain and for identification he has to keep it in the linear domain. To do that, the pilot applies pulse commands on sticks and pedal, so the pilot commands are not correlated with control inputs. During the flight, the wind must be as low as possible.

In order to identify and better understand the "Dutch roll" phenomena on rotorcraft, specific flight tests defined by Eurocopter were also conducted.

MEASUREMENTS

The parameters measured are :

- controls : ddm, ddl, ddt, ddn ;
- roll, pitch, yaw :
  - attitudes : $\Phi$, $\Theta$, $\Psi$ ;
  - rates : p, q, r ;
- linear accelerations : ax, ay, az ;
- ground speed components in helicopter axis : u, v, w ;
- static pressure and temperature : Ps, Ts ;
- differential pressure : $\Delta p$ ;
- total temperature : Ti ;
- blade root flapping angle for the 4 blades ;
- cyclic actuators motion ;
- main rotor shaft flexion moment and torque ;
- right and left engine power ;
- tail rotor torque.

The linear accelerations and angular rates are given by different sensors which permit to have redundancy for these measurements :

- inertial unit, ULISS 45 : pl, ql, rl, acxl, acyl, aczl ;
- gyrometer device : p, q, r ;
- accelerometer device : Jx, Jy, Jz.

The air speed is obtained using Ps and $\Delta p$ in forward flight above 40 kt and with the VIMI system below 40 kt. The wind components are evaluated in geographic co-ordinates and the hypothesis of low speed wind is validated.

DATA PROCESSING

The first task in flight measurements is the data analysis for detection and correction of deficiency data. Pre-processing consists in :

- preliminary checking ;
- consistency checking ;
- kalman filter/smoother ;
- specific computations.

*Preliminary checking* :

It consists in checking :

- data acquisition time evolution ;
- synchronisation of the data delivered by the two different devices which have not the same acquisition frequency ;
- detection and removal of non-valid data ;
- transfer of the different measurements in the same axis system .

*Consistency checking* :

It consists in :

- checking the measurements performed before take off for sensors verification, determination of accelerometer and gyrometer bias ... ;
- consistency checking of the inertial data by simplified Kalman filter

*Kalman filter/smoother* :

The objectives here are to estimate the helicopter trajectory , the airspeed and wind components (with the hypothesis of a constant horizontal wind), the helicopter initial state and the accelerometers and gyrometers bias.

*Specific computations :*

The following parameters are evaluated :

- collective and pitch angles from the measurements of the three cyclic actuators position ;
- conicity and rotor disk attitude ($\beta_{1C}$, $\beta_{1S}$) from the 4 blades flapping measurements ;
- main and tail rotor powers from main and tail rotor torque measurements ;
- total power from the two engines torque measurements.

RESULTS FOR IDENTIFICATION

Fig 6 shows the control inputs and Fig 7 compares the corresponding measured longitudinal axis helicopter responses with the ones obtained with an identified model (order of this model : 8 ; identification technics : output error)

- HELICOPTER PERFORMANCE MODELLING

The main objective of these flight tests is to have a data base for helicopter performance code validation.

FLIGHT TEST CONFIGURATIONS

Flight tests program includes the following test conditions :

- level flight ;
- lateral flight ;
- climb and descent flight ;
- left and right turn at different roll angles ;
- pull-up manoeuvres with specific initial conditions.

These flight configurations were performed for different speeds and weights.

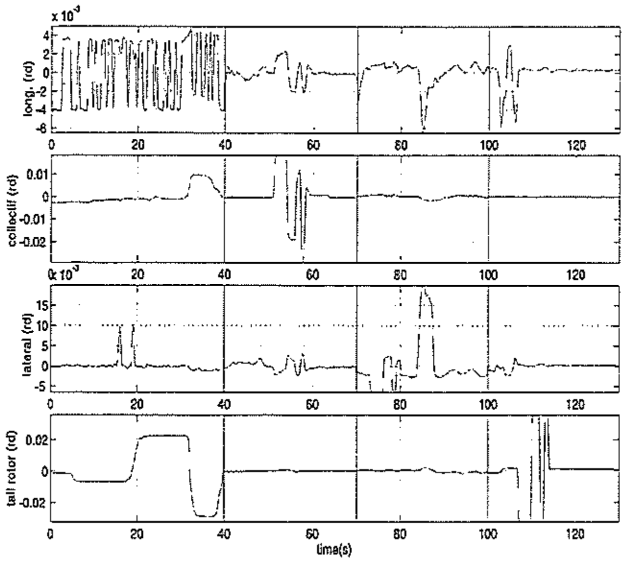


Fig 6: Control inputs

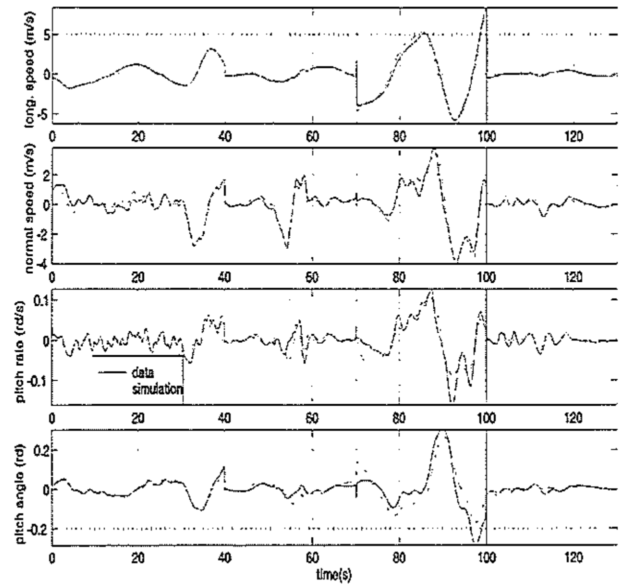


Fig 7: Helicopter longitudinal response

MEASUREMENTS

Identical to the ones for flight mechanics modelling and rotorcraft system identification.

DATA PROCESSING

In addition to the data processing defined for flight mechanics modelling and rotorcraft system identification tests, a « mean value » has to be computed for the different parameters over a part of the flight run. Standard deviations are also computed for further data analysis

RESULTS

Fig 8 shows the total power and the main and tail rotor power obtained in climb and descent for an horizontal speed of 60 kt.

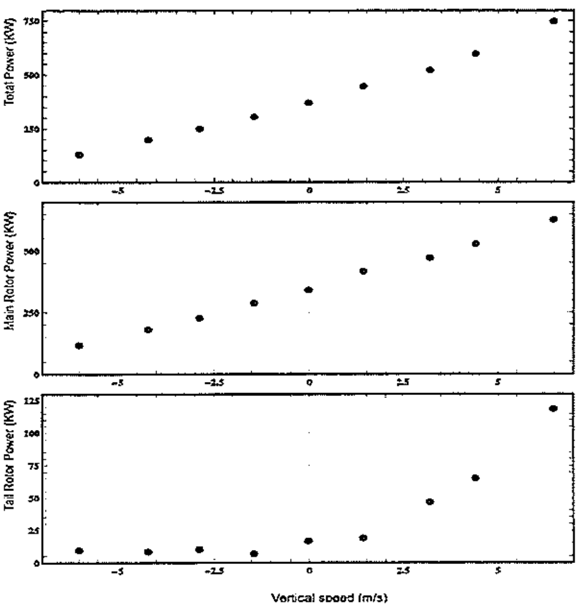


Fig 8: Climb and descent

- INTERNAL NOISE IDENTIFICATION

A flight test campaign has been performed in order to characterise the potential sources of noise in an helicopter cabin and to validate a cabin noise model based on a statistic analysis method (SEA :Statistical Energy Analysis).

Flight tests objective was to obtain an experimental data base on the noise sources inside the cabin and on the vibro-acoustic response of the helicopter.

MEASUREMENTS

For this study, a part of the CEV Dolphin instrumentation and acquisition system has to be removed and a specific instrumentation and acquisition system developed at the ONERA Structure Department was installed (Fig. 9 ; Fig. 10) :

- 60 accelerometers (fig : 9) ;
- 12 microphones (fig : 10) ;
- 6 pressure sensors (fig : 10) ;
- strain gauges bridge on each gear box bars.

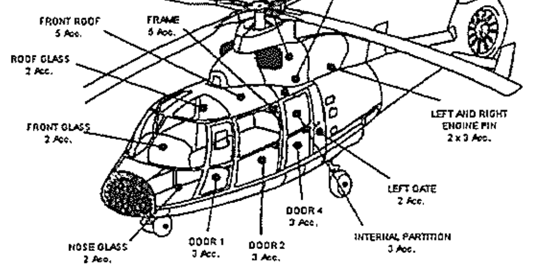


Fig 9 : Vibration measurements

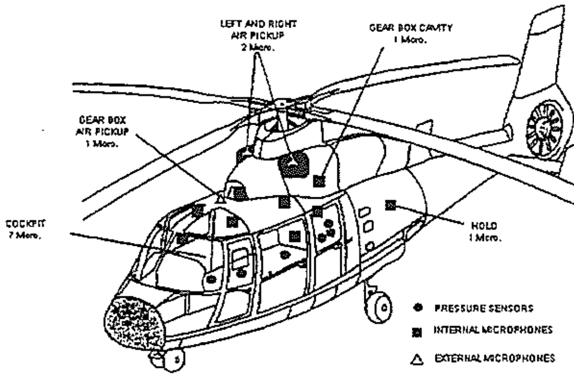


Fig 10 : acoustic measurements

Some helicopter parameters were also acquired on the safety recorder :

- main and tail rotor torques ;
- engines rating and torque ;
- pilot commands ;
- attitude angles ;
- time base.

After each flight, the CEV delivered the data recorded on the safety recorder, in f(t) graph form. Data acquired by the ONERA acquisition system were immediately processed to check sensors and records quality.

FLIGHT TEST CONFIGURATIONS

Flight tests have been performed in low noise environmental conditions and with and without top panel cabin for two helicopter masses ($M_1 \approx 3350$ Kg, $M_2 \approx 3950$ Kg) :

- in hover out of ground effect for $M_1$ and $M_2$ ;
- in level flight at V = 70 kt and 150 kt for $M_1$ (the same power ≈ 80% Pmax is required in hover and for level flight at 150 kt).

Data analysis is in progress at the ONERA Structure Department.

- VISUALISATION OF THE BOUNDARY LAYER TRANSITION ON A BLADE

Flight tests were performed to study the location of the boundary layer transition on both the upper and lower surfaces of a rotor blade in hover.

VISUALISATION TECHNICS

For these flight tests, a chemical product (mixture of acetone and naphthalene) was sprayed on a blade. During the flight, the sublimation of the product in presence of a turbulent boundary layer provides the visualisation of the boundary layer transition.

RESULTS

Fig 11 shows the location of the transition on the upper surface and Fig 12 shows the location of the transition on the lower surface.

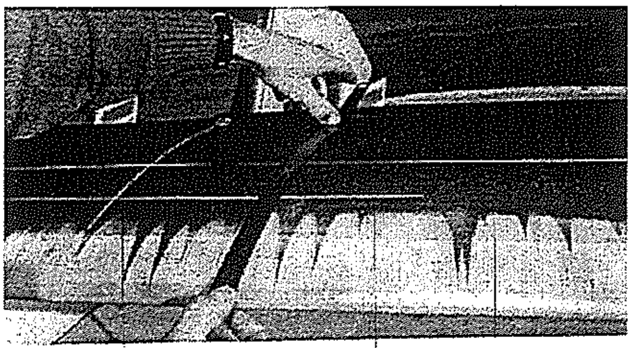


Fig 11 : Upper surface

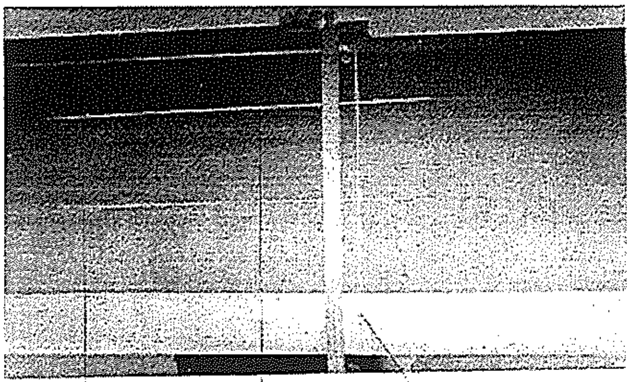


Fig 12 : Lower surface

- ALGORITHM EVALUATION FOR LOW SPEED SYSTEM CALIBRATION

Thanks to the high accuracy of the measurements provided by the DOLPHIN 6075, this helicopter is used also for different tests on airspeed measurement system or test methods (LASS of the TIGER).

## FLIGHT TESTS IN PREPARATION

Different flight tests are scheduled in the near future :

- EXTERNAL NOISE IDENTIFICATION

The purpose of these flight tests is to develop a test methodology in order to locate and characterise the different helicopter noise sources (for example : blade vortex interaction).

For these tests, an antenna composed of different microphones will be used on the ground. Tests with and without an inboard calibrated sources will be performed. These tests are conducted for the ONERA Physics Department.

- ELECTRONIC TRIM MOTOR EVALUATION

A novel electronic trim actuator will be tested at the end of 1997. In particular, variable force feels (depending on the airspeed) and carefree handling protection will be evaluated.

- ROTORCRAFT VIBRATION MODELLING

During the first months of 1998, the DOLPHIN will be fitted with vibrators in order to identify the in-flight dynamic vibrating response of the helicopter.

- LOW AIRSPEED SYSTEM EVALUATION

Tests of a low airspeed measurement system based on multiple differential pressure sensors analysis are also planned.

Other flight tests involving instrumented blade or instrumented fuselage are also under consideration for rotor blade flow studies or main rotor/fuselage interaction. These tests request the improvement of the present data acquisition system.

## CONCLUSION

The highly instrumented SA 365N DOLPHIN 6075 is in service in the French Flight Centre (CEV) in support of flight test research since 1995.

This paper describes the inboard instrumentation and acquisition system and presents some of the flight test campaigns in progress and in preparation to the benefit of ONERA and EUROCOPTER.