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HIGH SPEED DAUPHIN (DGV)
200 KNOTS TOWARD THE FUTURE

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ABSTRACT

The Dauphin Grande Vitesse (DGV) is an upgraded version of the X380 experimental helicopter designed to gather aerodynamical data on conventional helicopter rotor behaviour at high cruise speed.

X380''s new rotor and upper fairings had proved successful and had allowed this helicopter to be flown with ease and increased controllability at the boundaries of the production Dauphin N1 flight envelope with standard engines. The vibratory level was also found to be lower than that of the standard Dauphin although the suspension system had been locked.

The Dauphin Grande Vitesse is equipped with 2 ARRIEL 1X power plants, each developing up to 660 kW (884 shp) at standard sea level, a reinforced (1200 kW; 1607 shp) main gear box, new servo controls and hydraulic system and a reinforced structure.

Special care has been devoted to streamlining, with particular attention to protuberances.

The fin is equipped with an electrically trimmable rudder to reduce the power needed in cruise flight and oblique climb as well as to improve yaw control in autorotation.

The Dauphin Grande Vitesse started its successful evaluation trials at the beginning of March 1991 and eventually broke the 200 kt barrier while beating the world speed record in the E1 class on 3 km distance with 372 km/hr (200.86 kt).

This paper covers the aircraft description, developmental and flight envelope extension tests, test results and interpretation and, finally, the lessons learned from this programme.

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1. INTRODUCTION

Although the press essentially focussed its attention on the speed record, the Dauphin Grande Vitesse (or DGV for High Speed Dauphin) was not set up as a record breaker.

DGV is, basically, a research aircraft intended to gather aerodynamical data at high speeds, taking advantage of its predecessor's architecture to ease the design of the next helicopter generation.

This task is part of Eurocopter policy as regards the general enhancement of helicopter technology and design.

Being a fundamental research task, the DGV programme has been partly funded by the French Official Services (Direction Generale de l'Aviation Civile (DGAC) and Services Techniques des Programmes Aéronautiques (STPA)) which then had the opportunity to have the helicopter tested by their own pilots from Centre d'Essais en Vol (C.E.V.).

2. AIRCRAFT DESCRIPTION

DGV can, at first glance, be identified by its 5-blade rotor with parabolic tips fully integrated within the global upper deck fairing. It is not different, up to then, from its Dauphin X380 predecessor (Fig. 1)

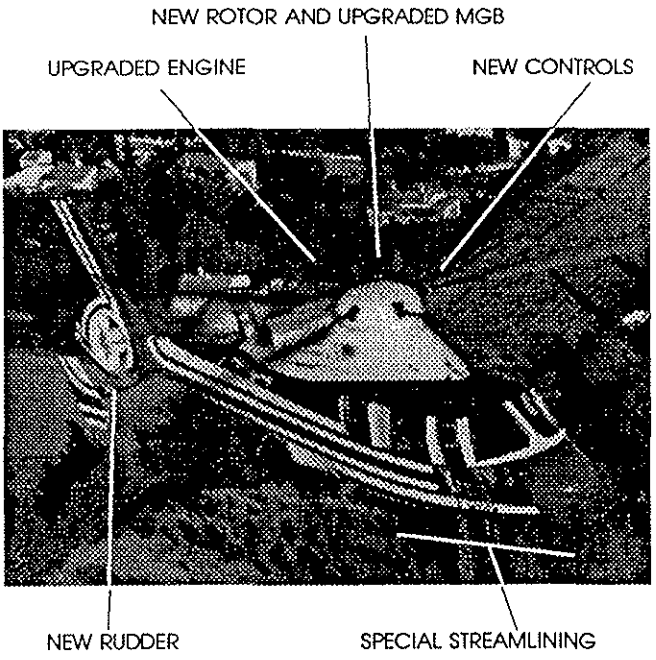

Figure 1: General View

Looking more carefully, one can notice some changes in the tail (Fig. 2) which now bears a rudder and smaller empennage endplates; considerable efforts were also devoted to fuselage and fairings streamlining.

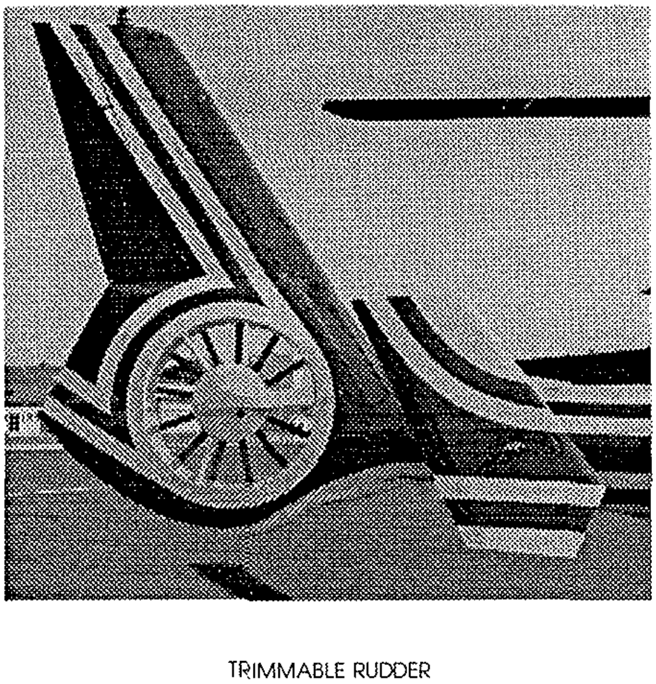

Figure 2: Yaw Control System

The latter characteristic is not usually noticed since a clean *aircraft looks natural,as it should always be, but with a* considerable amount of work!

The most significant evolution, however, is not visible.

In order to reach the objectives assigned, the installed power was increased by nearly 20% with the new ARRIEL 1X engine while the main gear box permissible torque was increased by 30% by uprating the last epicyclic stage. A full set of modifications was thus introduced including for the main part :

- Structural reinforcements
- A full hydraulic system change

the latter because it was impossible to cover single hydraulic failures at the boundaries of the scheduled flight envelope with the existing system.

However significant these modifications may appear, they were conducted with minimum costs and delays because they had been scheduled from the very early X380 stages. Space reservations, minor modifications in X380 definition and even flight testing instrumentation could then be introduced at the most favourable time.

When summarizing the evolutions introduced during the X380 or High Speed Dauphin programme, one ends with a virtually new MGB/rotor/control system, including 3 patented helicopter technology improvements (Fig. 3)

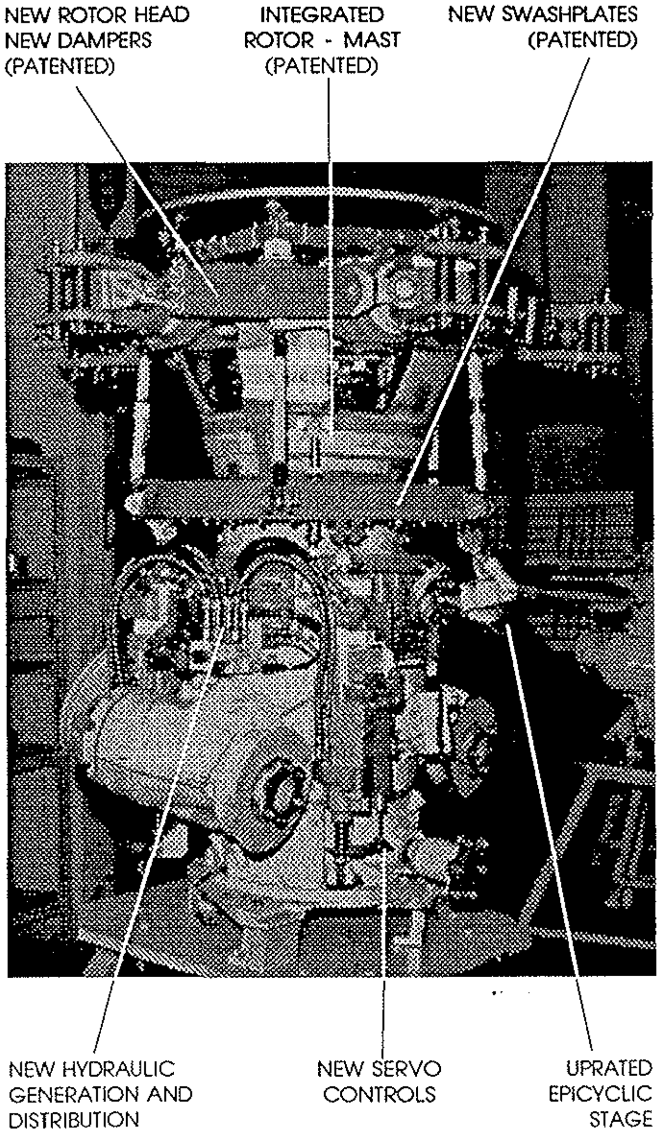

Figure 3: Rotor and MGB

The X380 programme was technology oriented; DGV was its logical performance-oriented follow-on.

3. FLIGHT TESTING

During its 25 hours of flight testing, the aircraft covered an envelope that had not previously been explored (Fig. 4) and gathered considerable data which allowed the analysis of various phenomena to be conducted successfully. The most interesting of these were related to:

- The influence of rudder in various flight phases
- The influence of rotor RPM on performances
- The influence of Mach number on performances
- The accuracy of the performance and vibration models

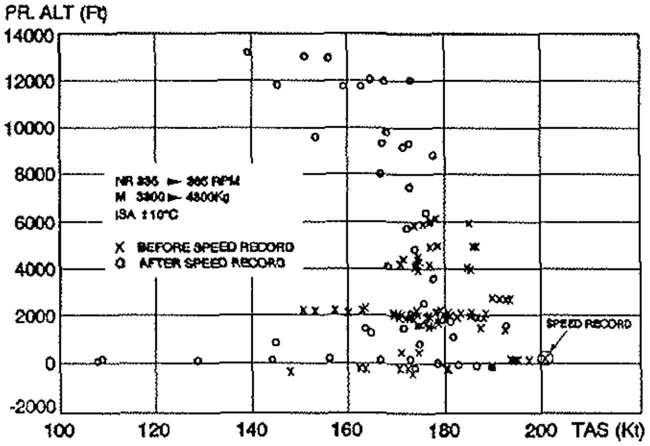

Figure 4: Flight envelope

3.1 Influence of rudder in various flight phases

Every conventional helicopter needs to unload its tail rotor system in cruise flight to save power, generally via the vertical surfaces supporting the tail rotor. The fenestron system itself includes a real aircraft-type tail.

On the one hand, these vertical surfaces allow satisfactory power saving at their dimensioning speed and help unload the tail rotor/fan at intermediate speeds but they tend, on the other hand, to create a parasite momentum when autorotating with substantial forward speed.

A triple advantage can be expected when fitting a rudder:

1. Optimizing the rudder's setting in forward flight can either increase (below fin dimensioning speed) or decrease (above fin dimensioning speed) the fin's lateral lift to minimize the power required at the tail rotor. Performance is then improved in two ways:

a. The total aircraft drag is reduced because the rudder's drag is far below that generated by the tail rotor system

b. The power saved can be re-routed to the main rotor, thus enhancing performance.

Optimizing the rudder's cruise setting has allowed gains up to 5 kt at iso-1000 kW reduced power or a 75 kW saving at iso-175 kt (Fig. 5).

2. The same reasoning applies in climb, where the rudder, when correctly set, allows a 7% increase in the maximum rate of climb with all engines operating compared to a configuration equivalent to an absence of rudder (Fig. 6a)

Gains are also to be expected in One Engine Inoperative (OEI) conditions. Saving being proportional to speed, there is a marginal interest in Category A's first segment where speed is low. However, a substantial increase in Category A's take-off weight can be expected when the second segment is the limiting factor (Fig. 6b).

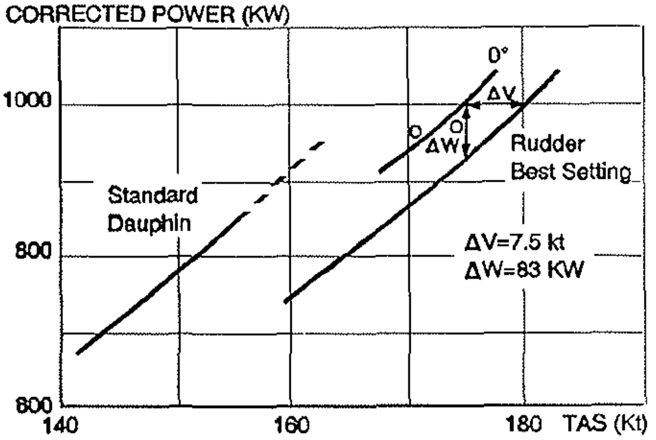

Figure 5: Cruise Advantage

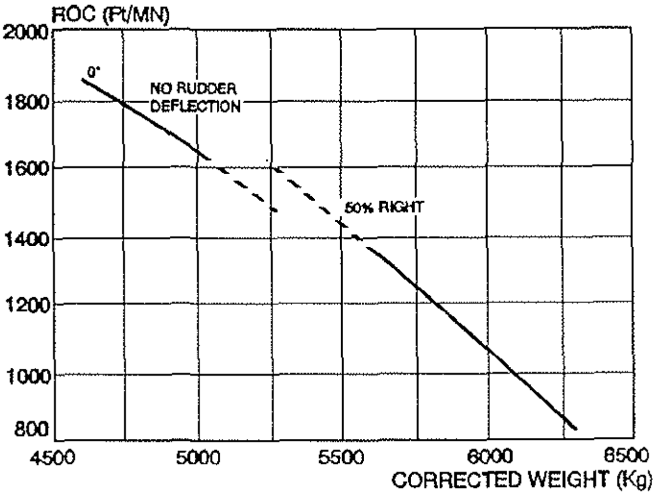

Figure 6a: R.O.C. advantage

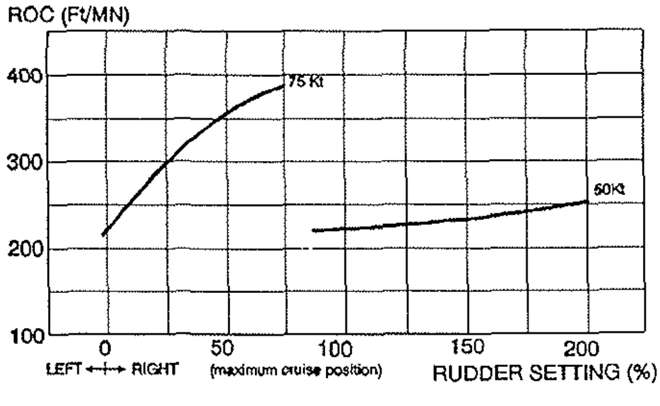

Figure 6b: R.O.C. advantage

3. Using the rudder to cancel the lateral lift while autorotating allows for a considerable increase in yaw authority whatever the forward speed may be. The VNE limit existing in autorotation can then be cancelled (Fig. 7).

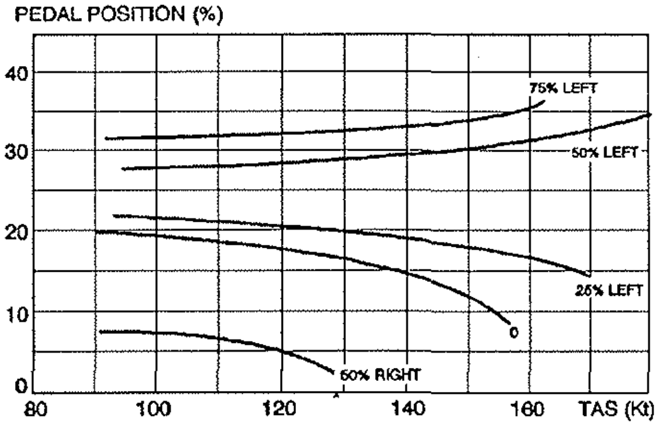

Figure 7: Autorotation advantage

3.2 Influence of rotor RPM on performances

The optimization criterion that was selected was «Minimum Power Required».

A number of flight tests were undertaken at various rotor speeds ranging from 335 to 365 RPM to evaluate the effects of this criterion. The general trend that was established was that DGV's optimum rotor RPM increases with speed but it is not yet clear by how much, because of couplings with other aerodynamic effects. This point is still being studied.

Indeed, numerous problems prevented using in very high speed flight what was believed to be the optimum RPM. These problems were chiefly related to:

1. Control margins and mainly collective pitch travel, although this had been increased
2. Stress on engine/gearbox couplings. Should the experiment be continued, these standard ARRIEL parts could easily be replaced since they were considered disposable in this experiment because of their simplicity and relatively low cost.
3. Maximum main gear box torque. Higher RPMs were used to increase the power transmitted without overreducing the MGB's fatigue life
4. Engine regulation margins

Despite those limitations, DGV objectives were reached as evidenced during the speed record. The rotor speed for this flight had been set to 357 RPM.

3.3 Influence of Mach number on performances

All things being equal, the effect of temperature on performances via the Mach number is one of the significant lessons learned during the DGV trials.
Indeed, tests did prove that the sole application of $\rho/\rho O$ deparametering was no longer sufficient for performance calculations at high speeds. In fact, the Mach number influence is to be taken into account from 120 kt.

This phenomenon can be summarized as follows:

1. drag is diverging to a specific Mach value in each airfoil composing a blade (Fig. 8)
2. The rotor zones where the airfoils are exceeding this value are influenced by flight conditions (speed and rotor RPM) as well as temperature via the Mach number, $V/\sqrt{\gamma rT}$ by definition.

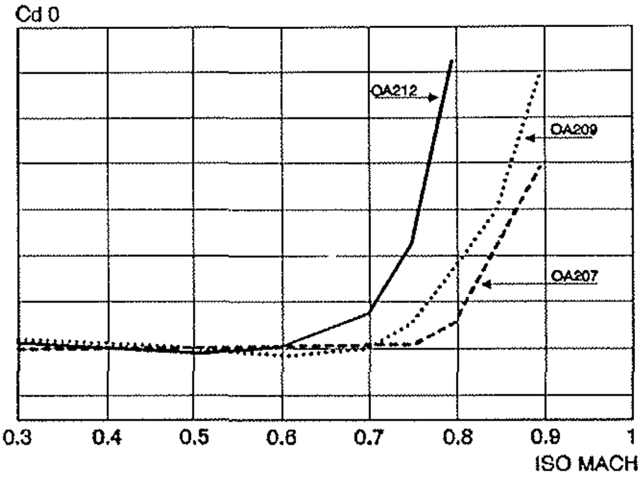

Figure 8: Zero-lift drag of Dauphin blade airfoils

The temperature's variation has little effect while the speed remains low because the evolution of the related Mach number changes the airfoil Cd0 only slightly. Beyond 120 kt however, the Cd0 divergence value is exceeded in some rotor zones because of temperature variation and this leads to excessive power consumption.

3. The rotor disk zones affected by drag divergence are presented in Fig. 9 at 90, 150 and 200 kt speed as well as 0° and 20°C temperature. It can be noted that the deviation is significant!

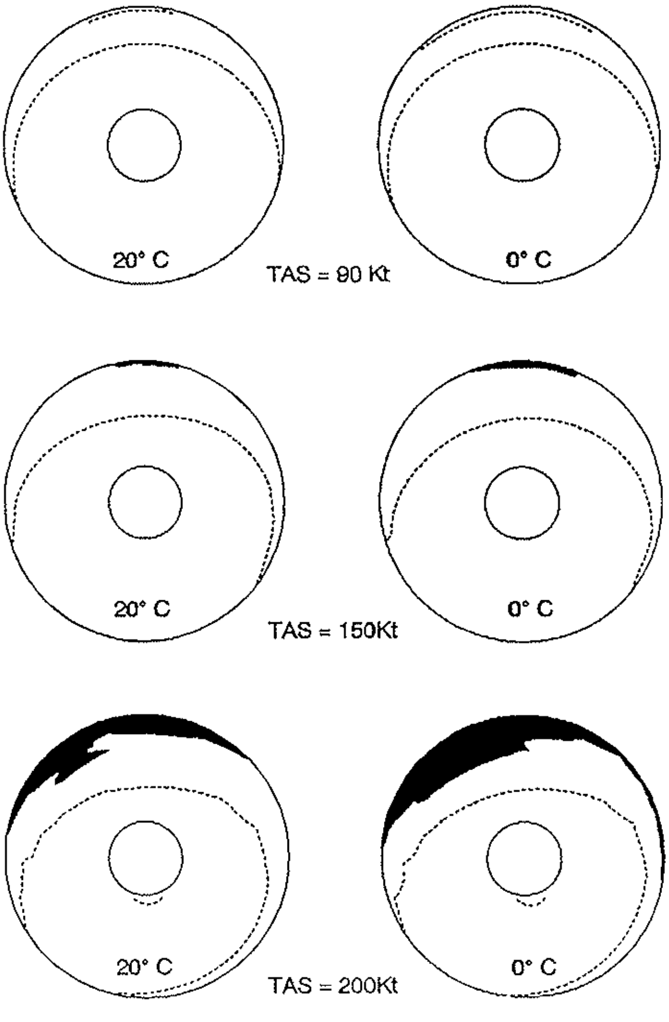

Figure 9: Rotor disk zones with diverging Cd0 (iso CxM^3)

Those same zones are presented at iso-Mach in Fig. 10 in a DGV flight configuration at 4150 kg corrected weight, 20°C outside temperature and 90/200 kt speed.

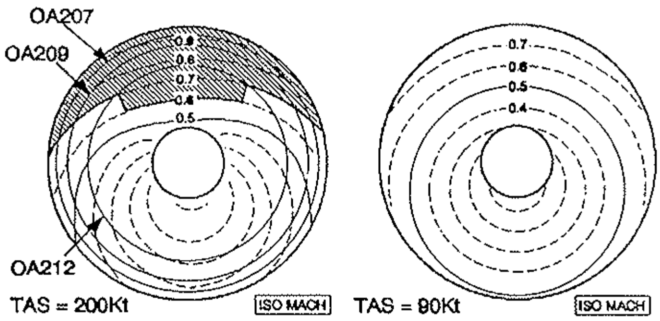

Figure 10: Rotor disk zones with diverging CdO (iso-Mach)

4. Finally, the necessary power curve calculated in two DGV flight configurations at 4150 kg corrected weight and 0/20°C outside temperature are presented in Fig. 11.

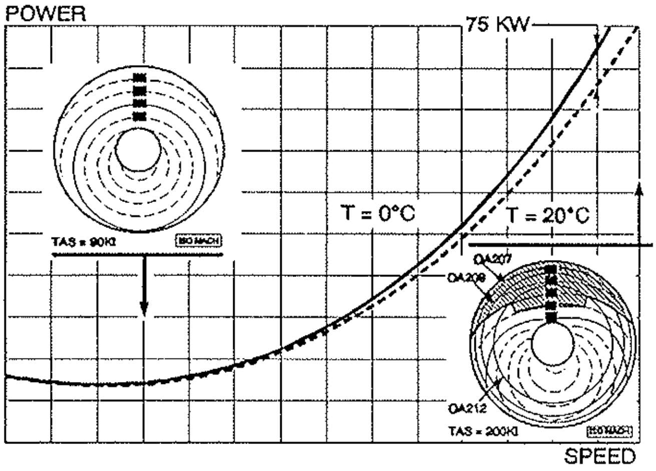

Figure 11: Influence of Mach number

The deviation plotted amounts to 75 kW at iso-190 kt speed or somewhat more that 4 kt at iso-1200 kW power

The integrality of the DGV flight tests at high speed was naturally processed with due consideration for these facts

3.4 Accuracy of performance and vibration models

The calculation models were permanently readjusted throughout the test trials.

1. by modification of the calculation modes whenever a new phenomenon could be explained
2. by adapatation of the equations' coefficients as a function of the test results

As a consequence, the current models offer satisfactory calculation/flight measurement correlations. They are considered usable at the speed ranges being explored, with all the more confidence since they are close to the measured weight, altitude, temperature etc.

Model accuracy is thus better than 2% as regards DGV performance calculations and it is estimated that it should remain within ±5% for the calculations of those weight envelopes different from that of DGV.

The most spectacular, in that it probably was the least expected, result is the quality of the vibration measurements correlation.

Vibrations are generally more difficult to predict because to the complexity of the rotor head exciting forces and moments' prediction model (R85 with flexible blade) must be added the complexity of the fuselage's finite element model and the extreme delicacy of the transmissibilities' evaluation in amplitude and, mainly, phase.

Fig. 12 gives an idea of the results obtained. However, it must be noted that the latter are slightly readjusted in amplitude by the flight measurement points.

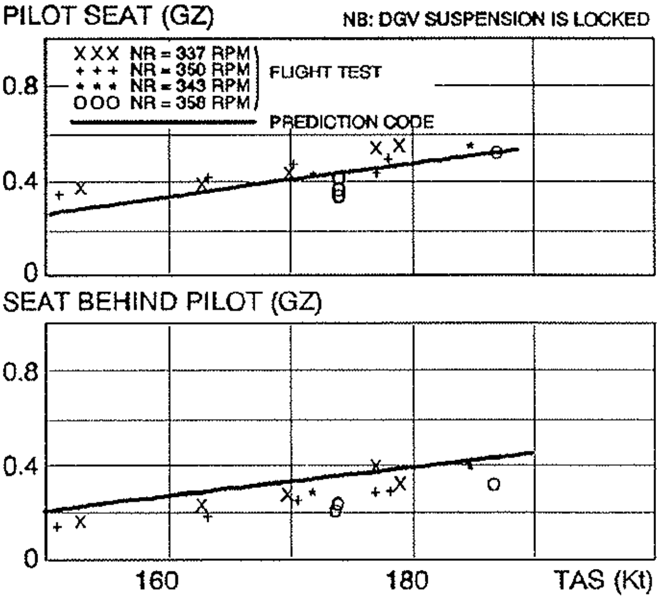

Figure 12: Vibration model accuracy

4. THE WAY AHEAD

DGV demonstrated that the performance and technology necessary to design a new civil high speed helicopter are now familiar.

Indeed, performance and stress estimation proved quite correct and the essential new parts suffered very little damage as shown in Fig. 13.

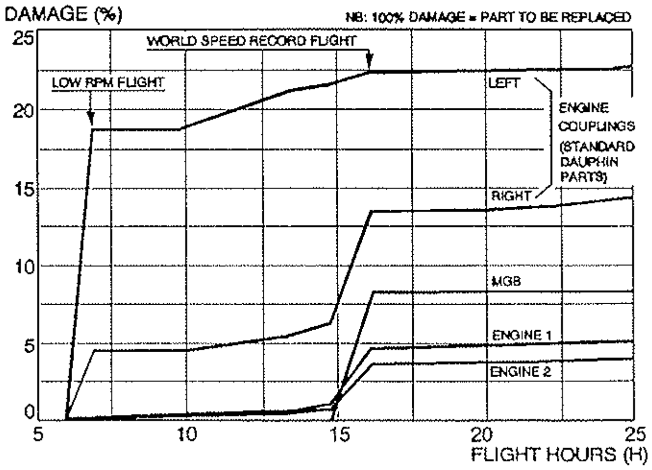

Figure 13. DGV damage

However, some fields still need to be improved and, in particular:

1. Noise, either internal or external, is an important concern: DGV recently completed flight test trials intended to measure external noise (ICAO) at various airspeeds and rotor speeds (as low as 325 RPM).

2. Vibrations, a prime characteristic as far as comfort is concerned: DGV2 has been tasked to flight test an active suspension system at high speeds by 1994.

3. Integration of new concepts: These, including new blades, a damage tolerant main gear box with new materials and rudder control laws shall be flight tested in a new demonstrator. The latter will gather every concept validated separately and is also aimed at exploring high manoeuvrability at high speed and maximum take-off weight.

This Demonstrateur Tres Grande Vitesse (or DTGV for very high speed demonstrator) shall be the ultimate follow-on of the X380-DGV family. It is scheduled before the end of the century.

No decision is in sight regarding a commercial high speed offspring of DGV although it can be certain, as speed history shows (Fig. 14), that the next generation helicopters will cruise faster than the current ones.

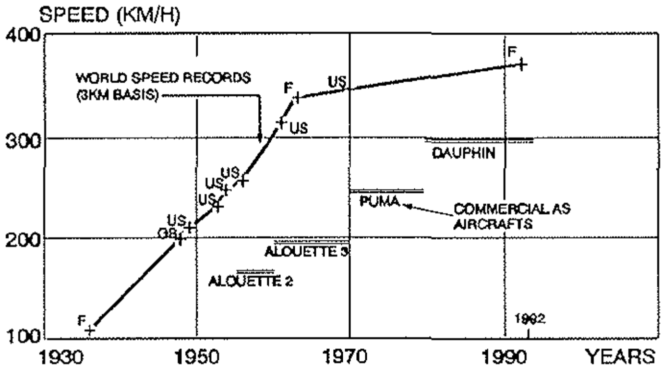

Figure 14: Speed history

The future of fast cruising helicopters is, in any case, related to a commercial interest in speed .But that is another story!