EIGHTEENTH EUROPEAN ROTORCRAFT FORUM

C - 07

Paper No. 133

THE CABRI
Two seat helicopter - Design and first flights

by

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September 15-18, 1992

Avignon, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

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Abstract

The G2 "CABRI" (french for a baby mountain-goat) is a totally new light piston engine helicopter.

Powered by a 150 hp, four cylinder aircraft engine, with a design gross weight of 550 kg, it is a good performance training and personal transportation two seater.

Its structure is mainly of carbon/fiberglass/Nomex shell construction, specially designed to be simple and minimize cost penalty associated to composites.

Its main rotor is a state-of-the-art, but extremely simplified three-bladed composite Spheriflex. It has a high inertia to allow safe full autorotation training.

Personnally developped by the author, the G2 "CABRI" started ground testing late 91 and made a successful first flight beginning of April 92, with EUROCOPTER. It may serve as a flying demonstrator for a new, production light piston engine helicopter to come.

INTRODUCTION

The CABRI development started as a personal project with an ambitious, but reasonable goal : to design and fly a totally new two-seat, piston engine helicopter, and demonstrate that modern technology can offer some advantages over well proven, old technology currently in use in this range of aircraft.

Of course, the author's job with (late) Aerospatiale Helicopters, his deep involvment in recent tail and main rotors developments, and also in light aviation, helped determine the definition of "modern technology"...

No particular mission was sought, because of the demonstrator nature of the aircraft, and mainly because a good two-seater would fulfill most expectable missions :
- training,
- personnal transportation,
- *surveillance*,
- photography, etc...

Basically, little compromise was to be made for production cost. However, a main goal was to keep the helicopter extremely simple, with small parts inventory. This approach proved itself an efficient way to find low-cost solutions.

On the other hand, maximum compromise is made for safety and fail-safe design, due to the demanding demonstrator mission and the very limited resource available for fatigue and ground testings. This is a useful long term effort, because safety is all what progress is about.

Following is a technical description of the CABRI demonstrator and its first flights.

Roughly, the G2 CABRI is comparable, in size and power, to the admirable and successful ROBINSON R22, though as different in detail technology as could be.

Three main features make the CABRI different from other helicopters of its class :

- a 100 % composite, monocoque fuselage,
- a three bladed, Spheriflex main rotor,
- a shrouded "Fenestron" tail rotor.

As a compensation to this frustrating situation, two goals were set :

1. To stay in a situation where maximum and immediate benefit would result easily, should a new generation engine be successfully developped (turbine or any)

2. To take full advantage of extremely quiet rotors, by designing an efficient exhaust and muffler system.

TECHNICAL DESCRIPTION

Powerplant

It's evident to say that powerplant selection is fundamental in any aircraft project, but it is even more critical with a piston-engined helicopter, where powerplant accounts for about 40 % of empty weight (44 % for CABRI).

CABRI engine type and installation are the results of a conservative and modest approach : the LYCOMING O-320, horizontal flat-four was selected as a well proven, reliable and certificated engine, in accordance with the old principle that "the more experimental the aircraft is, the less the engine should be".

To better illustrate the "piston penalty", one can compare two engines of some weight :

	CABRI'S 150HP 0.320	LHTEC T-800
Max. cruise power	97 kW	770 kW
Max. T.O. power	112 kW	1030 kW
Weight	145 kg (equipped)	145 kg

Architecture

General layout is rather conventional as shown fig. 2 dictated by the use of heavy and bulky engine, with belt primary transmission.

It is strongly influenced, however, by the composite construction of the fuselage : the fight to reduce number of "hard points", to minimize access doors and non-structural components, while keeping good access and good firewall separation, resulted in this layout where the engine is hung below the rear fuselage, but 80 % faired by two cowlings.

The same effort resulted in the original concept of a central load-carrying box (fig 3), instead of the EUROCOPTER so-called "hull" structure, where all the controls, wiring and tubing are routed under a flat floor.

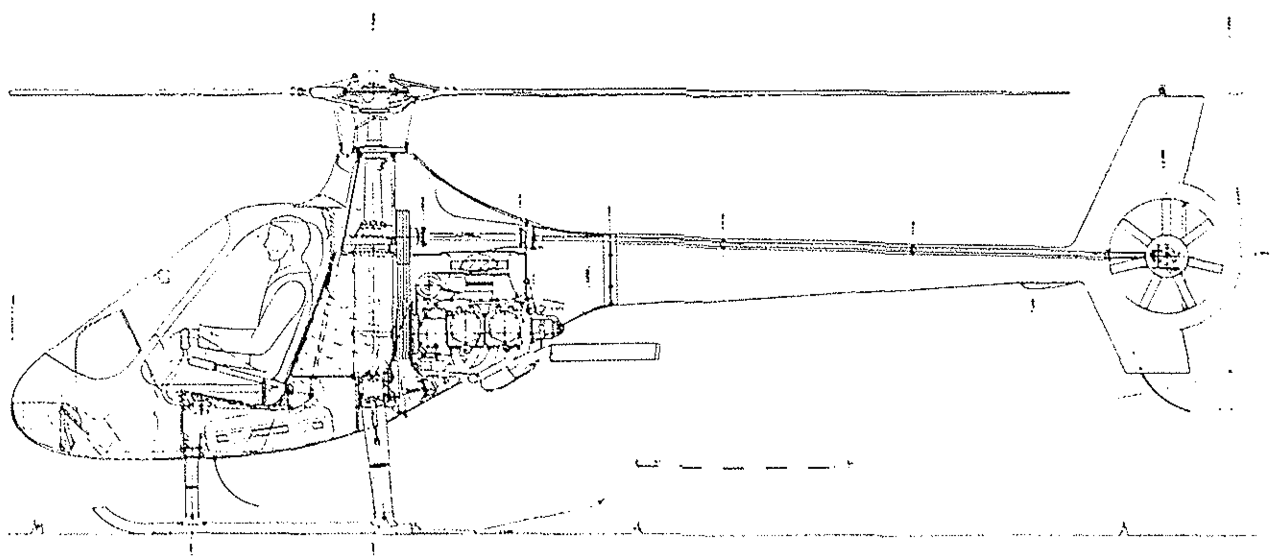


Figure 2 - General layout

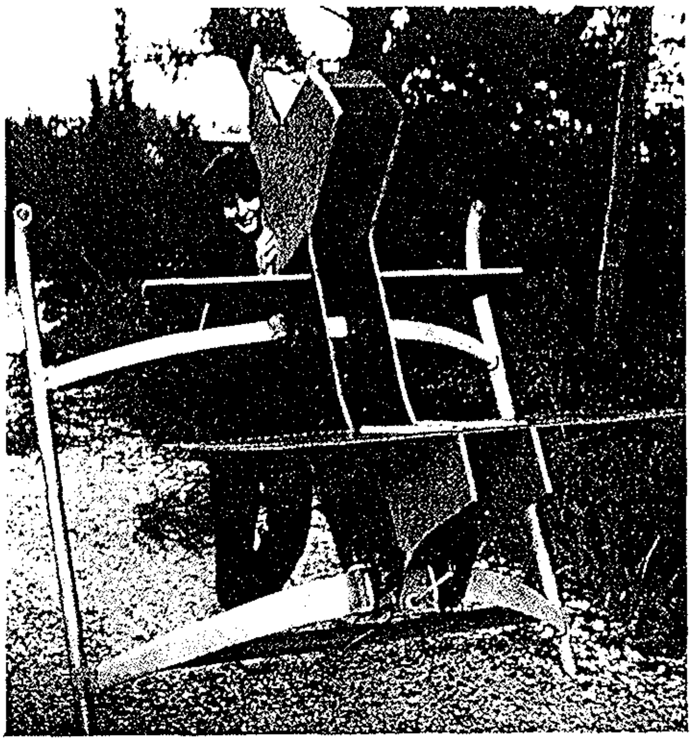


Figure 3 - Central structure

The engine is positioned nose-forward, with the driven pulley immediately on the main gearbox drive shaft.

This compact and light arrangement is made possible since the belt tensioning is achieved by rotating the engine slightly.

Engine cooling is achieved by a very light, vertical axis fan mounted on the belt-driven alternator. A forward air intake provides the fan with ram air in cruise, at a minimum drag penalty. It thus saves cruise power, and allows safe flight, should the fan fail.

Two integral fuel tanks, with single-point filler, take place between the cabin bulkhead and engine compartment, right on the rotor axis. Their 154 l capacity allows a high endurance : more than 5 hours (at partial payload).

Structure and landing gear

Main structure essentially consists in two composite sandwich shells, surrounding a central skeleton made of flat composite sandwich panels as shown fig. 3.

Its design tends to minimize hard points and maximize overlapping joints to allow the minimum use of fasteners.

Tail structure is of composite construction and includes in one piece, tail boom, fenestron shroud and vertical fin. Six bolts and an aluminium ring, attach it to center fuselage and allow easy disassembly.

Full landing spot visibility during the flare was considered an absolute requirement, and is fully provided by two chin windows. As a compromise to keep transparencie cost and weight reasonable, the single piece windshield is relatively small, with single curvature.

Due to this feature, the CABRI bears an unquestionable family resemblance to EUROCOPTER AS 350 ECUREUIL.

Landing gear is conventional, with two aluminium skids, and two carry-through struts. Design goal was a 4 m/s, zero-lift crash resistance, more than twice the energy required by FAR 27. It was achieved using filament-wound *R-fiberglass bows, resulting in a low drag and rather* flexible gear, eventually making the project named after the jumping, baby mountain goat...

Composite shell construction allows a 70 kg structural *weight (illustrated fig. 4) or 22 % of empty weight,* with an unmatchable smooth and clean surface.

Figure 4 - Structure

Main transmission

Primary transmission is a conventional 4 sheave V-belt drive, of 1 to 0.91 ratio.

A large ball bearing located inside the engine-mounted pulley carries the belt tension. This bearing is attached to an excentric lever to allow belt tensioning as shown fig. 5. A small electric jackscrew actuator applies the tension at startup.

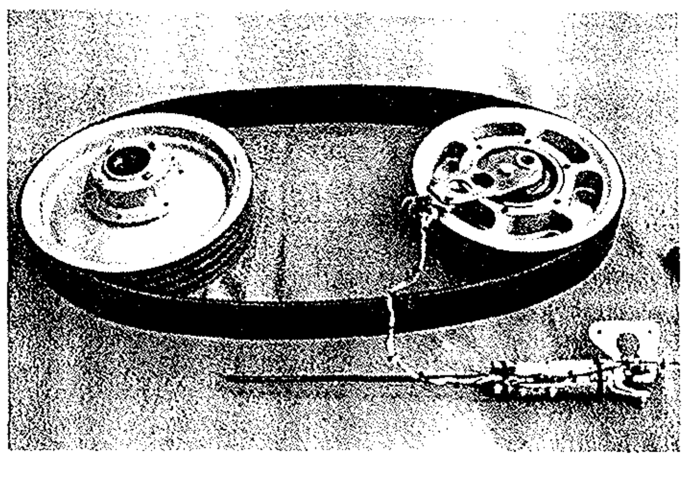


Figure 5 - Primary transmission

The use of a lower diameter/higher revving, shrouded tail rotor calls for a tough compromise between main and tail gearbox ratio, the product of the two being 10.

Choice was for a moderate 4 to 1 ratio for main gearbox, and thus a pretty high 1 to 2.5 ratio for tail gearbox, both of conventional simple spiral bevel gear construction.

Main gearbox uses a simple ram oil scoop for lubricating, and has a finned bottom for cooling.

Rotor mast is a non-rotating one, *à la* Mc Donnel Douglas, and rotor hub includes a pair of conical bearings. Driving torque is carried through a splined central shaft.

Main rotor

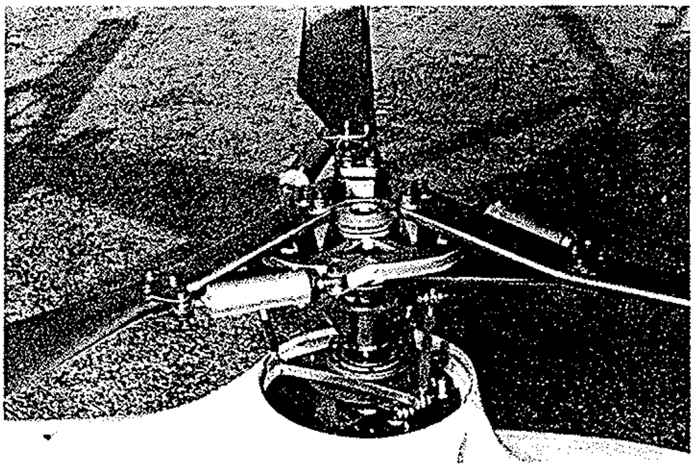


Figure 6 - Main rotor

Listening to some piston engine helicopters users, it seems that the main rotor is the very part where spending technology and money could give a sure competitive advantage.

CABRI rotor is pictured fig. 6. It can be described in three propositions :

1. High inertia
2. Mild control power
3. Fail-safe design

1. High inertia

Comfort in Autorotation Belongs to Rotor Inertia...

Figure 7 compares autorotation margin of different helicopters, using the approximative, but widely accepted t/k criteria.

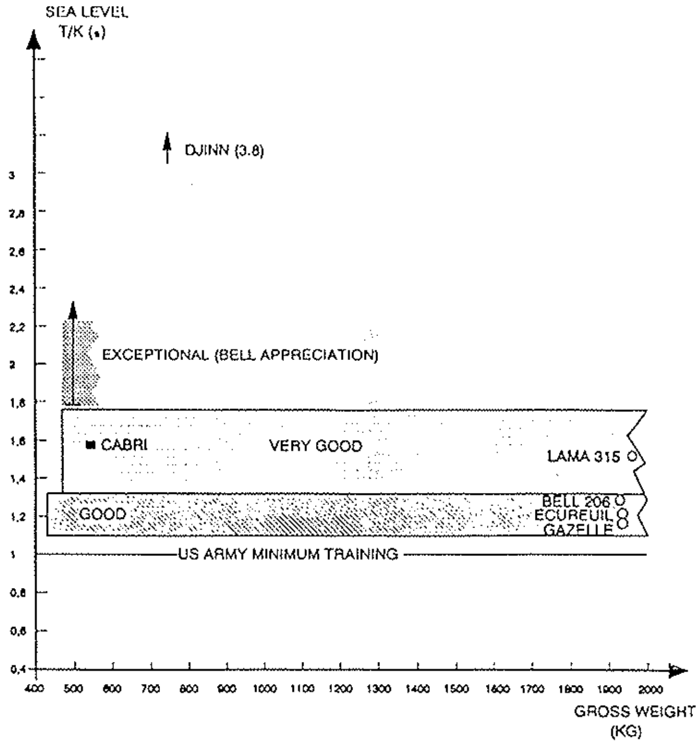


Figure 7 - Autorotation criteria

The CABRI is in good standing (though not exceptional like its great-grandfather the tip-jet driven DJINN) thanks to its designed-to-inertia rotor.

Inertia is very difficult to achieve, particularly with a three bladed rotor. When shifting the same rotor from two blades to three blades :

- chord is divided by 1.5
- thickness by 1.5,
- individual inertia requirement by 1.5,
- average density is multiplied by 1.5,
- bending resistance is divided by 3.4
- critical load factor by 2.25,
- bending stiffness by 5.1,
- static deflection is increased by 3.4.

With 20.3 aspect ratio and tip + span weight, the CABRI blade design was looking very challenging. It was only made possible using a simple, but massive composite construction, and thanks to the exceptional centrifugal capacity offered by elastomeric spherical bearings.

2. Good control power

With an equivalent hinge offset of 4.8 %, the CABRI rotor stands in the medium range, compromise between agility, vibration and weight, proven by a majority of modern helicopters. It does away with mast bumping, minimizes dynamic roll-over or overcontrol, and allows a large C.G. range.

3. Fail-safe design

The elastomeric spherical bearing, with a two-bolt attachment, as used in the nearly 3.000 Ecureuil and Dauphin Starflex rotors, has a virtually unmatchable safety

record, particularly in poor to deficient maintenance conditions.
Associated with simple fork attachment, it leads to an all-condition, all mission, fail safe rotor.

As to compensate for blade stringent requirements, the very low coning and lag angles of a CABRI-sized rotor make design of spherical bearing, and simple elastomeric lead-lag damper a comparably easy and low-risk task.

The design and fabrication of the main rotor represent a significant part of CABRI development. The very valuable experience gained is immediately applicable to full scale development of a low cost, low maintenance, high safety rotor.

<u>Tail rotor</u>

The shrouded rotor "Fenestron" concept is all but an endangered species. However, despite the increasing number of project developments, the smallest specimen was still the 1967's GAZELLE one.

It has since been proven that the shrouded tail rotor stands kW-to-kW comparison with its conventional competitor. The concept then brings a definitive safety advantage with little or no penalty, specially to a small *piston driven helicopter where :*

- tail boom is relatively low and long,
- average landing surfaces are rough and hostile (tall grass being a very hostile environment to those micro conventional rotors),
- average pilot experience and skill are extremely low.

Maximum effort was made in designing the CABRI minimum fenestron, to make it simple and light (fig. 8)

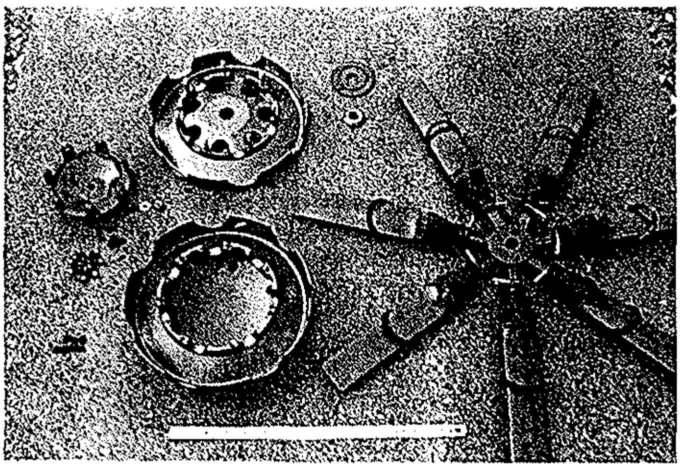


Figure 8 - Tail rotor

Its patented, single drive shaft runs in an oblique groove as shown figure 9, at exactly the cost and weight of a conventional rotor's one.

Figure 9 -Tail rotor drive shaft

Its patented rotor hub combines well proven, Kevlar torsion strap, with single piece, single molding blades.

Its gearbox is fairly simple, including pitch control mecanism, *and stands the comparison with a* conventional, equivalent one, for weight and parts inventory, as shown fig. 10.

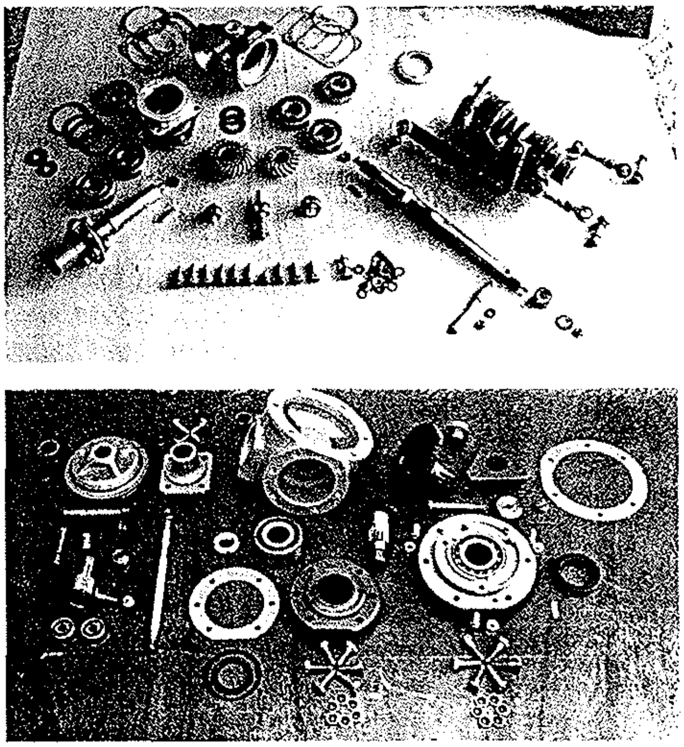


Fig. 10 - Gearboxes : conventional Compared to Fenestron

Vertical fins are set with an angle of attack, calculated to release rotor thrust in cruise, thus giving high chance of safe landing, should the rotor be destroyed in flight.

Lower vertical fin is tall and crushable, providing extra safety in very hard landing, when the already high, 12° tail skid clearance is exceeded

Cockpit and flight controls

Dual flight controls with conventional sticks are directly connected to the swashplate by long pushrods, in the simplest, yet conventional manner.

A single wheel adjusts an omnidirectional, stick-free friction, provided in an original and patented mixer.

Collective control includes a throttle correlation. Provision is made for its adjustment during flight testing.

All the controls parts are shown in fig. 11.

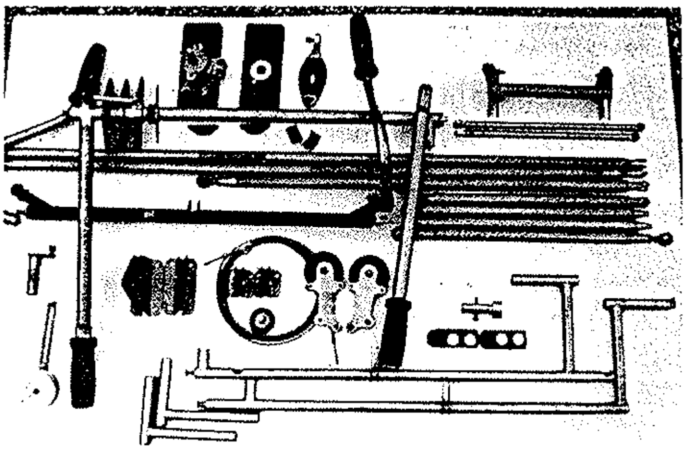


Figure 11 - Controls breakdown

The cockpit is conventional, side-by-side, with a comfortable 1.18 m inside width.

Cockpit, control and instrument panel is a design dictated by the convenient central structure, where everything is routed (fig. 12). Its width makes it accomodate standart avionic stack.

Two bagage compartments allow a, comparably high, 180 liter capacity under/behind the seats.

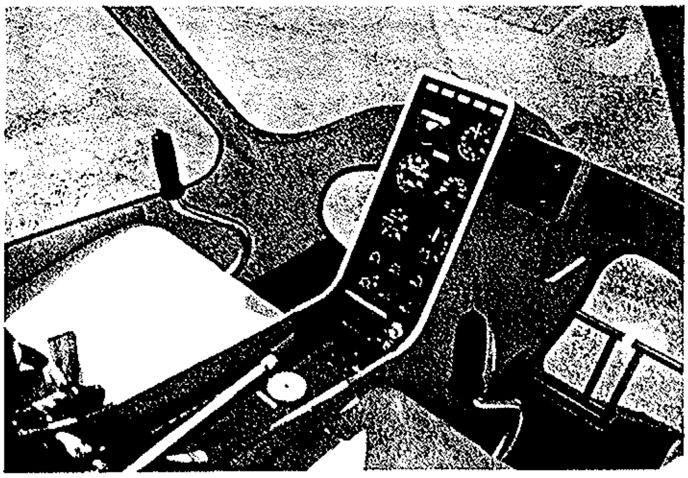


Figure 12 - Cockpit

GROUND AND FLIGHT TESTING

Instrumentation

A minimum, but decent instrumentation is installed on board. Compromise was needed to meet both security and analysis needs, while installing all the orange boxes in the baggage compartments (fig. 13). This was a condition to a two-pilot flight testing, considered a top-requirement by the non-licensed author...

20 parameters are on-board recorded, and 12 are transmitted to a table-sized ground station.

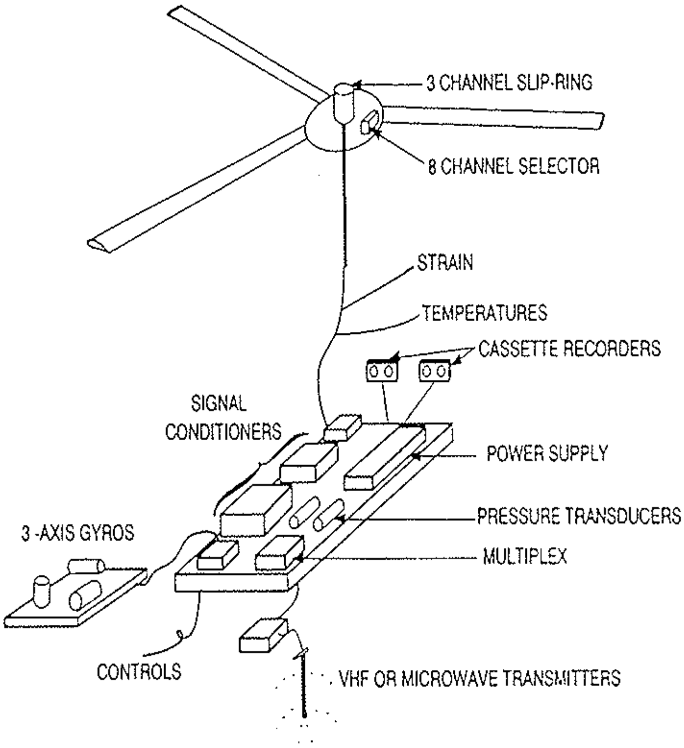


Figure 13 - Telemetry instrumentation

Ground testing

A very simple shake-test was conducted using an electric actuator, to better predict the ground resonance margin (fig. 14).

This phenomena is considered critical to safety, because calculations showed that a comparably much higher rotor -inertia/fuselage-inertia ratio makes ground resonance very explosive for small helicopters.

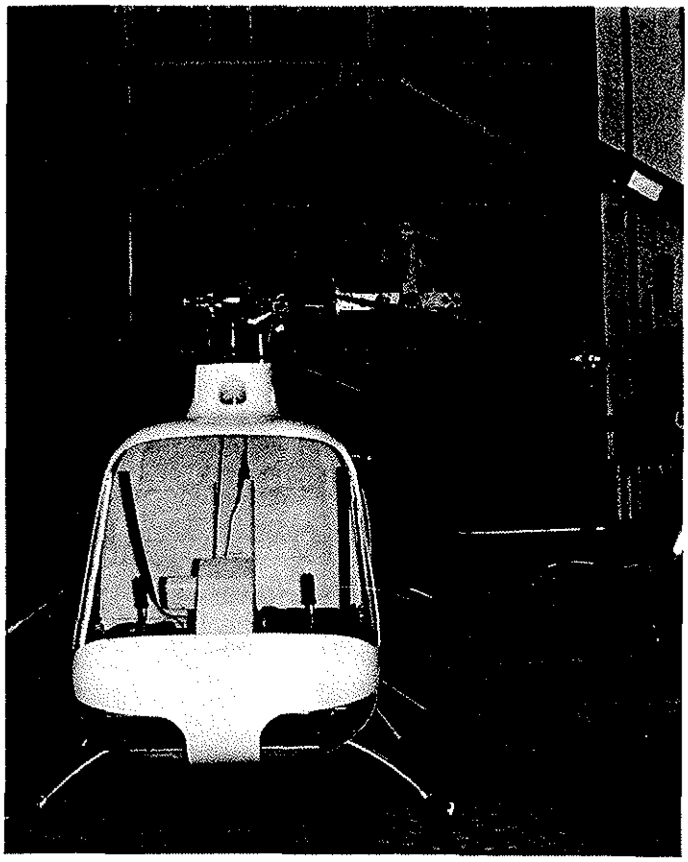


Figure 14 - Shake-test

Most ground testing time was spent repairing minor problems with the engine's accessories, and some radio interferences.

More significant is the resource needed to solve drive belts instability, because it revealed a well known and feared problem : vendor's product liability concern.

This problem seems more dangerous to light helicopter than ground resonance...

FLIGHT TESTING

The flight testing program is in its very early phases, and few conclusions can be drawn.

However, first flights released several critical uncertainties caused by down-sizing of existing concepts :

Tail rotor

Unusually low tip-speed, extremely low disk loading and Reynolds number were uncertainty factors on Fenestron performance. Fortunately, it proved itself stable and efficient, demonstrating a stop-to-stop, 360° spot-turn in 4 seconds, in both directions.

Main rotor

The main satisfaction comes from the control forces, which are both very low and direct. This demonstration is fundamental to the rotor concept, as it is the first time a fully elastomeric rotor is flown without controls boost.

External noise

Several of CABRI's features should make it a very quiet helicopter :
- three bladed rotor,
- moderate tip speed,
- thin tip airfoil,
- low disk loading Fenestron tail rotor,
- four-in-one, tuned, in-line exhaust,
- and, of course, its small size...

First flights confirmed expectation with a low noise, including a hardly noticeable tail rotor one.

It seems reasonable to take the challenge to say that the CABRI, could eventually be the quietest helicopter flying, of any class.

Dynamics

Testing confirmed analysis showing an unsatisfactory ground resonance margin and explosive behaviour.

The soft landing gear gives possibility of both stiffening or softening, however, and experience gained is very valuable.

Performance

Flight envelope is partly open, including :
- Speed of 80 kts at 95 % gross weight
- Sideward flights
- Engine shutdown at low altitude

CONCLUSION

The future of CABRI project, its evolution into an industrial program, depends on two issues : technical and industrial.

From a technical standpoint, along with the concepts validation, a decision is ahead : stay with the two-seat helicopter, or increase the capability to a three-seater.

The industrial challenge is to find the right structure that offers sufficients power, high manoeuvrability, and still is slim enough to match the unit-cost target, about one-fifth that of the smallest EUROCOPTER product.

Developped from a totally white sheet of paper, with marginal resource, the CABRI is the absolute technical demonstrator. It just started its toughest job : to convince people, validate technical concepts, help find improvements, and most of all, help some engineers, technicians and pilots learn a job : piston-driven light helicopter manufacturer

CABRI MAIN CHARACTERISTICS

Empty weight .... 320 kg
Max. gross weight .... 550 kg
Fuel capacity .... 154 l

Main rotor diameter .... 6.5 m
Chord .... 3 x 160 mm
Rotational speed .... 597 RPM

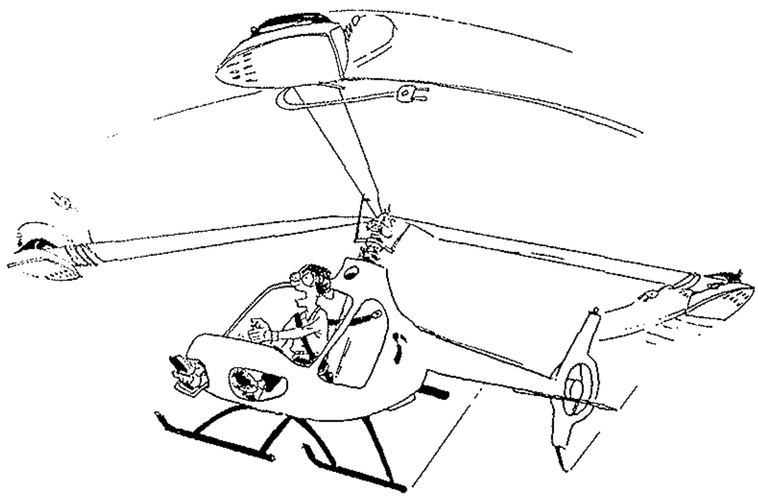
Tail rotor diameter .... 0.54 m
Chord .... 7 x 38 mm
Rotational speed .... 5734 RPM

Rotor height .... 2.1 m
Overall fuselage length .... 5.75 m
Cabin width .... 1.18 m
Baggage capacity .... 2 x 90 l

Powerplant .... LYCOMING 0-320 E2A
.... 150 hp at 2700 t/mn

Disk loading .... 16.6 kg/m^2
Power loading .... 3.7 kg/hp

Gross weight lift coef. (Czm) 0.41
Autorotation critera (t/k) .... > 1.5 s
First lag mode 0.55
Equivalent hinge offset .... 4.8 %



CALCULATED PERFORMANCE at G.W.

Max level speed .... 200 km/h
Cruise speed .... 180 km/h
Max. distance .... ≃ 1000 km
Hover ceiling OGE ISA .... 2200 m