SIXTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 7

THE DEVELOPMENT OF THE AS 355
ECUREUIL 2 / TWIN STAR

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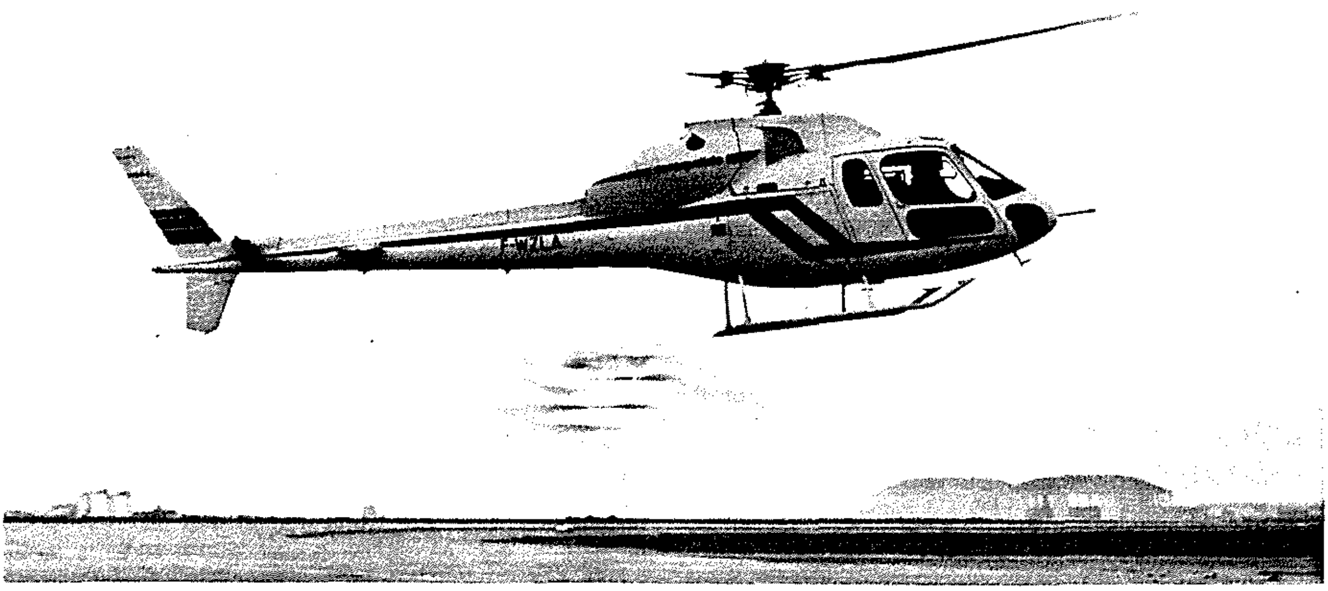


Figure 1 : AS 355 - MAIDEN FLIGHT OF PROTOTYPE

1 – INTRODUCTION

Flight over inhabited areas and over the sea has in recent years boosted demand for twin-engined helicopters on the civil market.

In 1977, we did a survey of the North American and European markets and although we were already aware of this trend, we were struck by the enthusiasm of civil operators at the prospect of a modern, economical, light twin-engined helicopter derived from the single-engined Ecureuil/Astar.

At the same time, we carried out preliminary feasibility studies which gave favourable results as regards :

- the possibility of installing 2 engines without major modifications to the airframe or to the power train, and
- the possibility of increasing the maximum weight by minor reinforcements to the airframe.

It was thus possible to develop the Ecureuil 2 by taking a large number of components from the single-engined Ecureuil, benefitting from the reliability of proven components and minimizing the cost of industrialization.

There was nothing to prevent the programme getting underway. Nothing, that is, except a problem which engineers wrongly consider minor : that of finding a source of funding. When this had been overcome, the final decision to launch the programme was taken in November 1978 and officially announced at the H.A.A. Convention in Las Vegas, February 1979.

At that same convention, the optimistic predictions of our market evaluation were confirmed and even exceeded by the fact that 107 firm orders were taken for the «Twinstar».

2 – PROGRAMME TARGETS

- USE OF ASTAR COMPONENTS
- LOW MANUFACTURE COST
- LOW OPERATION COST
- PERFORMANCE
- LOW NOISE AND VIBRATION LEVEL
- I.F.R. FLIGHT CAPABILITY
- DEVELOPMENT AND PRODUCTION SCHEDULE
- OPTIONAL EQUIPMENTS SCHEDULE

Figure 2 : MAIN TARGETS

The main targets of the programme were as follows :

– To use single-engined Astar components wherever possible.

– To maintain the economic guidelines drawn for the single-engined version :

- Low production cost thanks to value analysis.
- Low operating cost thanks to a high level of reliability and to simplified maintenance.

– To achieve at least as good performance as with the single-engined AS 350.

– To provide good comfort features :

- Low cabin noise.
- Low vibration level.

– To build a basic helicopter capable of being fitted with IFR equipment.

– To meet a very tight development and industrialization schedule.

– To have available, with the first production helicopters delivered, a large number of certificated options so that the aircraft will be operational for off-shore, corporate, ambulance and aerial work roles.

To these targets must be added that of the budget, which in this case was a serious constraint. We will not go any further into this subject, which alone usually creates more problems than all the technical aspects put together.

3 – TECHNICAL DESIGN

3.1 – Let us return to the technical aspects of the helicopter's design, starting with the components taken from the single-engined Ecureuil.

– Apart from a few minor reinforcements, the fuselage and cabin arrangement are the same.

The main dimensions, cabin space and cargo hold areas are unchanged. However, visibility has been improved by the larger lower transparencies.

– The STARFLEX composite rotor head is also the same as on the AS 350. As you know, compared to conventional rotor head design with hinge bearings and lubrication systems, the STARFLEX has many advantages in terms of weight, reliability, maintenance and production cost.

– The rear shafting, tail gearbox and tail rotor have also been kept the same. The tail rotor is of a modern design, a see-saw arrangement with no rotating bearings. The two composite blades are built onto a single fibreglass spar which is flexible in torsion.

3.2 – Power plant

Let us now look at the components which are specific to the Ecureuil 2/Twinstar, beginning with the power plant.

The preliminary performance calculations indicated that the most suitable power plant for this helicopter would be two engines of 400 to 450 h.p. There was only one gas turbine engine on the world market that met this specification : the ALLISON Model 250 C 20 B, a well-established engine with exceptionally well-proven technology, since more than 14.000 Model 250 engines have been manufactured. Other possibilities involving engines derived from existing 600 h.p. engines were examined, but these less optimized solutions would have led to penalties of weight, fuel consumption and price, and so in the end the Allison engine was selected.

The two engines are installed side by side, and drive the main gearbox via a coupling gearbox consisting of 5 cylindrical helical gears and two free wheels.

With this arrangement it was possible to use the existing AS 350 gearbox with slight modifications ; the bevel gear shank was lengthened to fit with the cylindrical coupling gear and the oil pump flow was increased so as to lubricate the new gearbox module using the existing system.

For use on the twin-engined version, the gearbox was substantiated by testing for a power increase from 400 to 440 kW at the main rotor.

Figure 3 : IMPROVED VISIBILITY

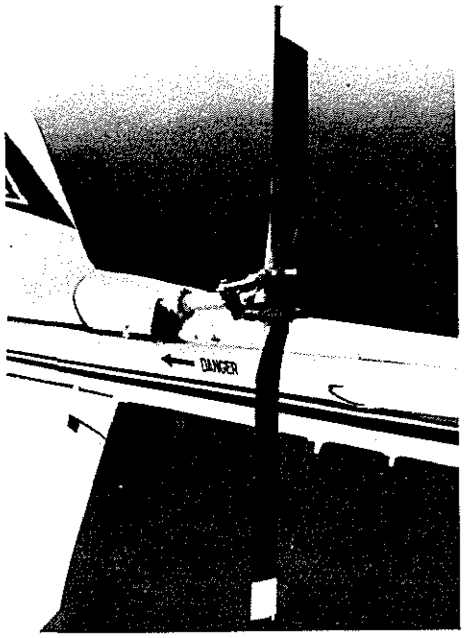


Figure 5 : TAIL ROTOR

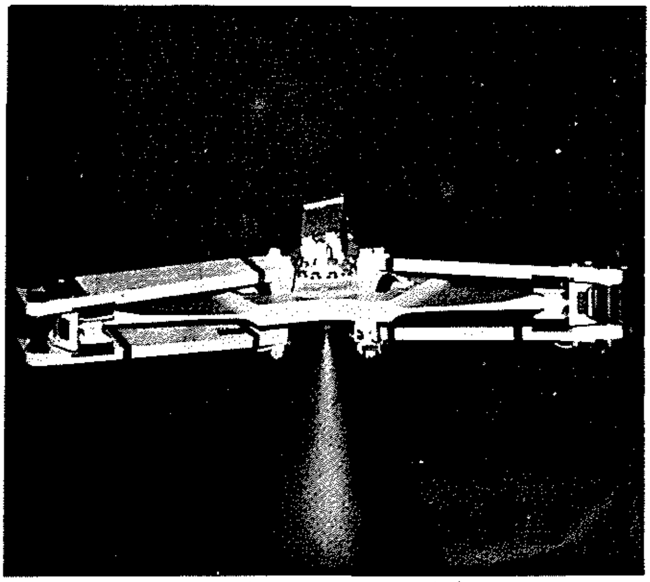


Figure 4 : GENERAL VIEW OF STARFLEX ROTOR HEAD

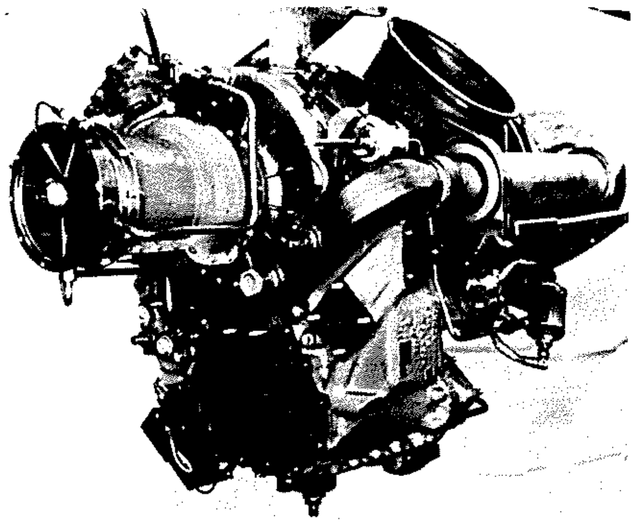
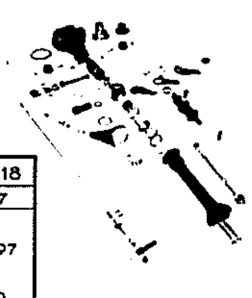


Figure 6 : MODEL 250 C 20 F ALLISON ENGINE

STARFLEX AS 350

SA 318 HINGED



NUMBER OF PARTS		AS 350		SA 318	
	TOTAL	70		377	
OF WHICH	BEARINGS	0		30	
	SEALS	0	0	45	97
	LUBRIFICATORS	0		22	
	SELF-LUB. BEARINGS	3	6	0	0
	LAMINATED BEARINGS	3		0	

Figure 4b : COMPARISON OF AS 350 STARFLEX AND SA 318 HINGED ROTOR HEADS

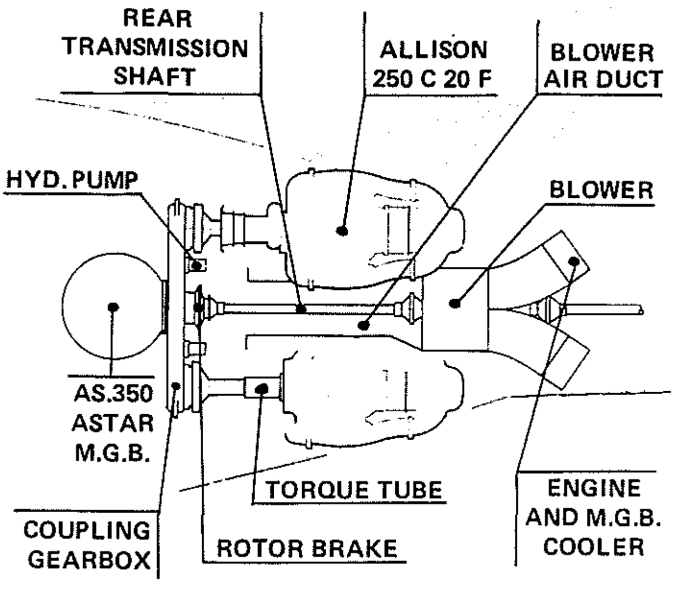


Figure 7 : POWER PLANT INSTALLATION

from the MGB compartment to pass through 2 sets of oil coolers. This system cools both the main gearbox oil and the engine oil,

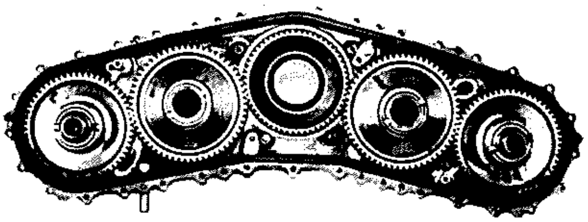


Figure 8 : COUPLING GEARBOX

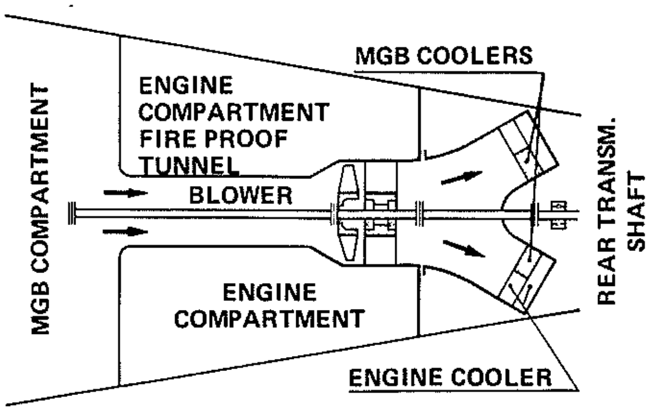


Figure 10 : COOLING SYSTEM

3.3 — Consequences of twin engines

Adaptation to twin engines involved a number of inevitable changes to :

– the upper cowlings, which were completely redesigned and optimized by wind-tunnel testing,

– the engine controls, with the levers moved from the floor to the roof,

Figure 9 : COCKPIT

– the engine monitoring instruments, which in the VFR version were adapted to fit the existing instrument panel arrangement,

– the oil cooling system, which has a plastic axial fan housed in a tunnel between the engines, driven by the tail rotor transmission drive and blowing air coming

– the fuel system, which consists of two completely separate systems. The AS 350's plastic fuel tank is replaced by two structural tanks made of press-formed panels and base sections. Fuel capacity goes up from 530 to 730 litres and the operating range without fuel reserve is over 800 km,

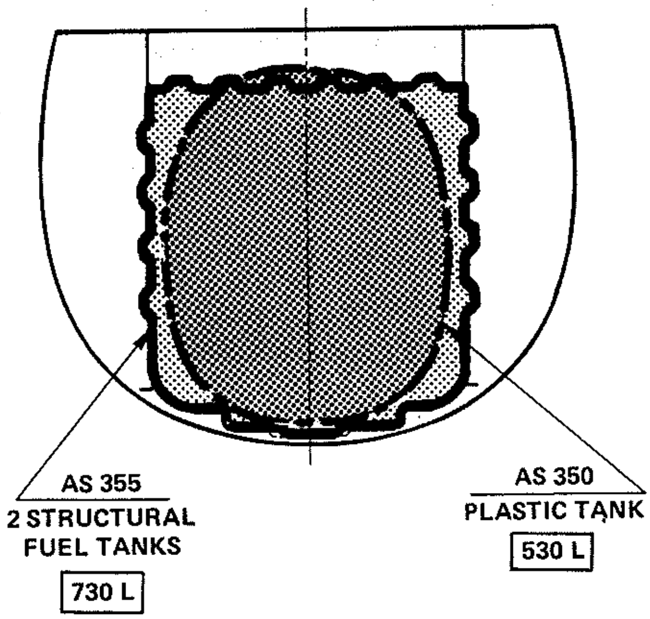


Figure 11 : AS 350 & 355 FUEL TANKS

– lastly, the use of engines with front air intakes made it relatively easy to build dynamic air intakes into the new cowlings. Their shape was optimized by wind-tunnel testing, and they have protection screens. The pressure loss is low ; more than 50 % of the dynamic air pressure remains at the input to the axial compressor, i.e. 15 mbar at 240 km/hr. Given that a typical static air intake has a pressure loss of about 15 mbar, the effective gain with the dynamic air intake is 30 mbar, which represents an increase of about 6 % in the power available at the engine.

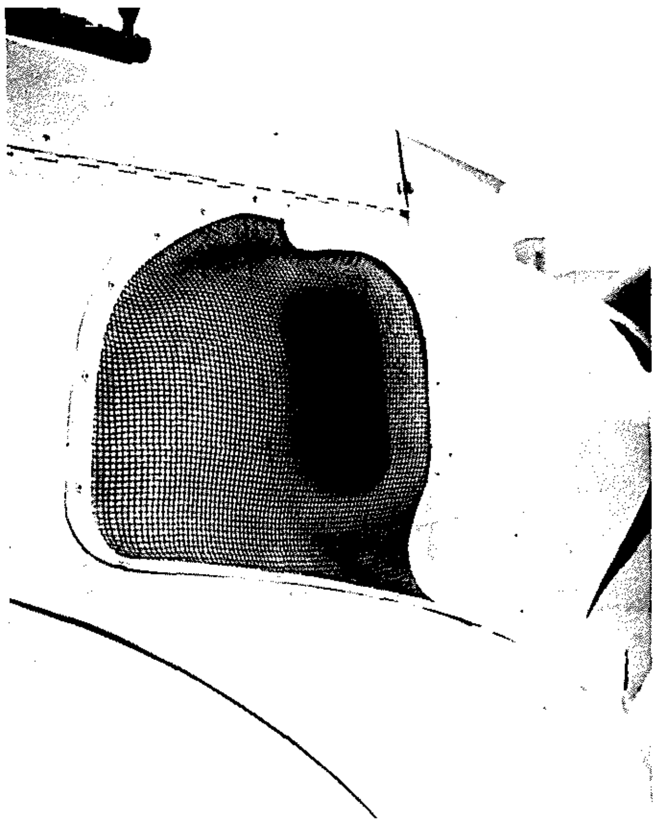


Figure 12 : DYNAMIC AIR INTAKE

3.4 - Consequences of the weight increase

To compensate for an empty weight increase of 180 kg due to the installation of two engines, the maximum weight was increased to 2100 kg for the E version and subsequently to 2300 kg for the F version.

This weight increase made a number of changes necessary :

- Strengthening of the airframe and landing gear.
- Newly-designed main rotor blades.
- Newly-designed dual servo units (F version).

- The airframe reinforcement mainly involved no more than the addition of a few rivets or of stiffeners in the critical areas. The only major modification was a 0.2 mm increase in the thickness of the transmission support deck inside the main gearbox compartment.

- Like the AS 350 rotor blades, the new main rotor blades are made of composite materials. The chord has been increased from 300 to 350 mm and the NACA 0012 blade profile has been replaced by a constant profile, OA 209. This profile was developed jointly with ONERA and is characterized by considerable improvements in maximum Cz, the drag divergence Mach number and the lift-to-drag ratio.

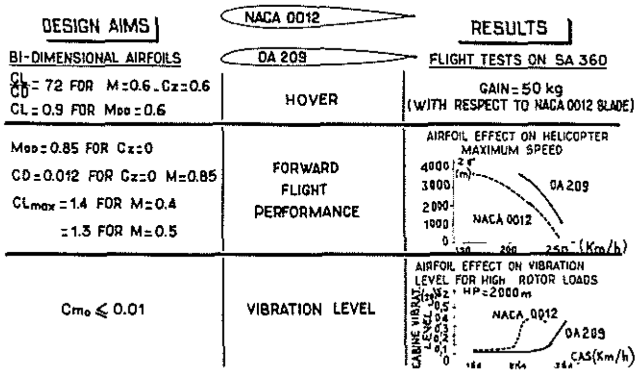


Figure 13 : OA2 MAIN ROTOR BLADE

At the start of the programme, these new blades were intended to lift the 2300 kg of the Twinstar F version. They were designed to have the closest possible dynamic behaviour to that of the AS 350 blades, to reduce the risk of development modifications, which are frequently troublesome.

In practice, this design turned out to be correct when the static vibration tests were done, and later on the rotating dynamic test stand with stress measurements. These results were confirmed when the first flights with these blades were made in October 1979, and since no adjustment was required we decided to use them on the E version as well as on the F.

These blades give an 70 kg improvement in take-off weight, and in forward flight they give a 10 km/h gain in speed with the same power, at ground level and approximately 50 km/h at 12,000 feet.

3.5 — Fire protection

Lastly in our review of the technical aspects of this helicopter's design, the Ecureuil 2/Twinstar was the first helicopter in the world to be bound by the new certification requirements brought in by FAR 27, amendment 16 (or FAR 29, amendment 17). This is an amendment concerning protection against fire, and it was enacted in October 1978.

The requirement is that, in any area where there is a possibility of a leakage of flammable fluids or vapours, there must be means to minimize the probability of ignition, and also the resultant hazards if ignition does occur.

Practically speaking, this new regulation mainly concerns the main gearbox compartment, in which there are always systems containing inflammable fluids and also possible causes of fire. Since there were no precedents in this area, we had some trouble interpreting and implementing the text of the regulation, but finally after direct contact with representatives of the European and American certification authorities, we did reach an acceptable solution.

To reduce the risk of fire, we first paid special attention to implementing a number of rules which were already part of good standard design practice ; these involved :

- keeping apart the electrical and the fluids systems,
- preventing wear to electrical insulation by shielding or clips,
- preventing friction wear on hoses,
- keeping the number of connections in systems to a minimum,
- avoiding known or possible hot areas.

Next, in order to further reduce the probability of fire, we look such precautions as :

- providing drainage for the transmission support platform,
- using explosion-proof electrical components,
- recommending the use of a new hydraulic fluid (to MIL.H.83282) which is less inflammable than the standard fluid.

It has been demonstrated by probability calculations that with these precautions taken, the remaining fire risk is approximately 10^{-9} per hour in flight.

Despite this very low fire risk, we still had to meet the second part of the certification requirement, limiting the consequences of a fire in this area.

Our philosophy for meeting this requirement was as follows : when a fire occurs in the main gearbox compartment, firstly the pilot must be warned and secondly it must be possible to fly the helicopter long enough to descend and land. After discussion, this period was established as 5 minutes.

The implementation of this philosophy ultimately lead to some cost and weight penalties in the shape of :

- a fire detection system and a means of confirming the alarm,
- modifications aimed at protecting from fire the flying controls and airframe, and at preventing the fire from spreading to the adjacent areas.

To demonstrate the fire resistence of the critical components in this compartment, there were a number of specific tests and one full-scale test, which was exceptionally spectacular because of the strong air currents in this area of the helicopter.

Fig. 14 shows the main differences between the Twinstar and the Astar.

The Twinstar described is in fact the E version, so its maximum weight is 2,100 kg.

With the F version, the increased maximum weight of 2,300 kg causes an increase in the control stresses, and so to protect against a hydraulics failure we installed tandem type dual servo units ; supplied from two separate hydraulic pressure sources.

AS 350 ASTAR

1 950 kg. (4 300 lb.)

- **TWO ALLISON 250 C 20 F ENGINE**
- **COUPLING GEAR BOX ON M.G.B.**
- **TWIN ENGINE MODIFICATIONS :**
  - **AIR INTAKES**
  - **COWLINGS**
  - **FIRE WALLS**
  - **OIL & FUEL SYSTEMS**
  - **CONTROLS**
  - **INSTRUMENTS**
- **TWO FUEL TANKS**
- **REINFORCED AIRFRAME & LANDING GEAR**
- **NEW INSTRUMENT PANEL**
- **NEW MAIN ROTOR BLADES**

AS 355E TWINSTAR

2 100 kg. (4 630 lb.)

Figure 14 : MAIN CHANGES FROM AS 350 to AS 355

4 – PERFORMANCE

The main performance data for the AS 355 are given in **figs. 15 and 16.**

AS 355 WEIGHTS

	VERSION	
	E	F
GROSS WEIGHT	2 100 kg	2 300 kg
EMPTY WEIGHT, STD AIRCRAFT	1 230 kg	1 250 kg
USEFUL LOAD	870 kg	1 050 kg
EXT. LOAD GROSS WEIGHT	2 300 kg	2 500 kg
MAX. EXTERNAL LOAD	906 kg	1 100 kg

Figure 15 : PERFORMANCE

MAIN PERFORMANCE

		E 2 100 kg	F 2 300 kg
FAST CRUISE SPEED	S.L.	239 km/h	232 km/h
BEST RANGE SPEED	S.L.	214 km/h	210 km/h
MAX. RATE OF CLIMB	S.L.	9.5 m/s	8 m/s
MAX. RANGE	S.L.	825 km	795 km
IGE HOVER CEILING		3 950 m	3 100 m
OGE HOVER CEILING		3 000 m	2 100 m
SERVICE CEILING – ONE ENGINE IN OPERATION		2 600 m	1 750 m

Figure 16 : PERFORMANCE

The top design targets for the Twinstar were low cost and operating cost effectiveness rather than performance as such. However, we believe we have achieved a good compromise and the performance data are perfectly respectable, whether you consider useful load, ceilings, speed or especially range, which is increasingly important today, now that off-shore prospecting is moving farther and farther from the shore-line.

Let us note that the distance of 800 km, with no fuel reserve, can be covered without auxiliary fuel tanks.

5 – MAINTENANCE

Like the Astar, the Twinstar was designed for simplified maintenance and a low cost per flying hour.

Pre-and post-flight checks and the daily inspection can be carried out without opening the cowlings.

Periodic maintenance operations have been reduced to a very low level.

The engines and gearbox have high TBOs and are modular in design.

The Starflex rotor head is very simple and subject only to on-condition maintenance. Its component parts can be inspected without removal or disassembly, and when there is deterioration requiring the component to be removed, this can be done very quickly and without special tools. For example, it has been demonstrated that a laminated spherical thrust bearing can be changed by 2 men in 15 minutes, this being the total time between landing and take-off.

The tail rotor is, likewise, very simple and subject to on-condition maintenance. The tail rotor and gearbox assembly is very light ; it can be removed and reinstalled by one man without lifting apparatus.

The fatigue life of most critical parts is infinite ; the few which have limits have a service life of over 2000 hours.

The Twinstar's D.O.C. has been extrapolated from Astar data, with allowance made for the differences in design and, where appropriate, for loading differences. This gives a D.O.C. 30 % greater than the Astar's, which is considered excellent for a twin-engined helicopter.

6 – VIBRATION LEVEL

The anti-vibration systems on the AS 355 are the same as on the AS 350, i.e. :

- A spring-type anti-vibration device on the rotor head, cancelling out a large part of the main rotor vibration at its source.
- A flexible two-directional suspension system between the bottom of the main gearbox and the airframe ; this method has proved its worth in years of operation on the Puma, Gazelle and Dauphin.
- Two counter-vibration weights on flexible blade stems, the effect of which is to counter the remaining 3 Ω vibration directly beneath the cabin floor.

Together, these systems give the Ecureuil/Astar an excellent vibration level ; the average 3 Ω level measured on helicopters during the acceptance inspection is 0.07 g for the pilot and copilot seats and 0.06 g for the rear seats, these measurements are taken during flight at the fast cruise speed.

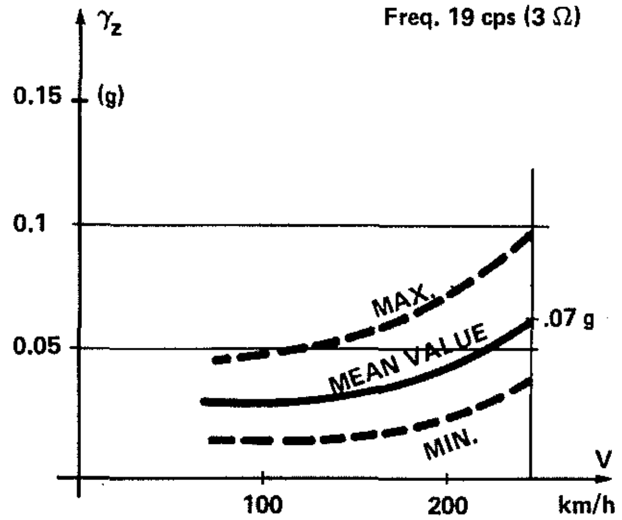


Figure 17 : VIBRATION LEVEL

The vibration adjustment work for the Twinstar is not yet finished, but laboratory and in-flight measurements show that its vibration characteristics are very similar to those of the single-engined version.

The actual levels are expected to be in line with these results.

7 – CABIN NOISE

Another factor of comfort is cabin noise. Here again, the preliminary measurements indicate that the noise level in the cabin is very comparable to that measured in the Ecureuil/Astar which, as we know, is excellent.

The measured level is 79 dB SIL at a speed of 110 Kts, with soundproofing equipment weighing less than 30 kg.

8 – OPTIONS

However, a basic helicopter, whatever its performance and comfort, cannot perform most of the roles that are required of it. To use a favourite image of our Options Department Chief, it is like a tractor sold without any farming equipment.

We have therefore planned for availability, by the delivery date of the first Twinstars, of a wide range of optional equipment, of which **fig. 18** gives the main items ; this will enable the aircraft to carry out most possible missions involving :

- personnel and corporate transportation,
- off-shore transportation,
- casualty evacuation,
- aerial work with internal or external loads,
- sea and mountain rescue.

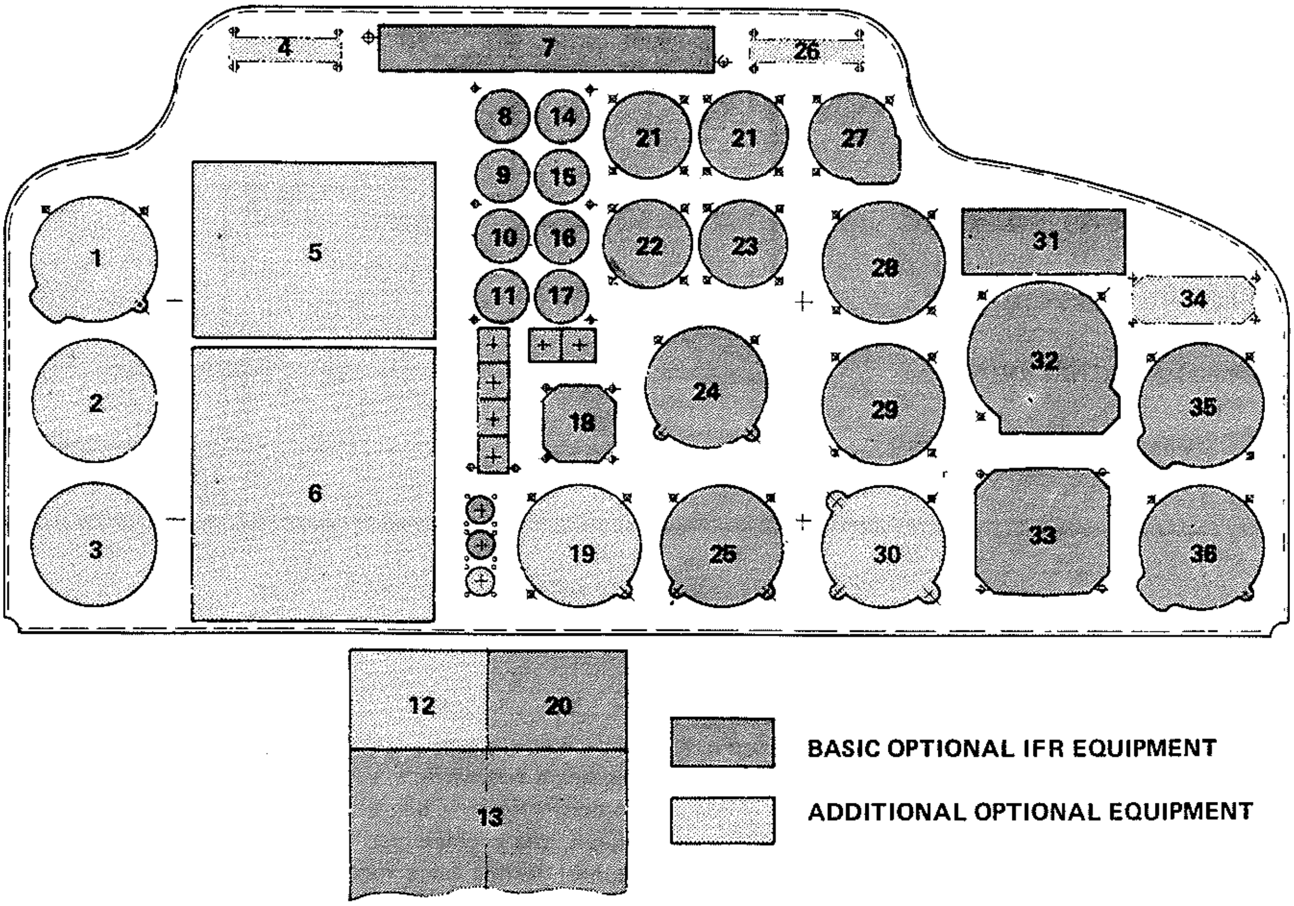
In 1981 we shall be developing and obtaining certification for a single-pilot IFR kit for which a suggested panel arrangement is shown in **Fig. 19.**

- **EMERGENCY FLOATATION GEAR**
- **FLOAT LANDING GEAR**
- **SKIS**
- **HIGH SKID LANDING GEAR**
- **CARGO SWING**
- **CASUALTY – CARRYING INSTALLATION**
- **ELECTRICAL HOIST**
- **FERRYING TANK**
- **FOLDING OF MAIN ROTOR BLADES**
- **VERY COLD WEATHER KIT**
- **«COMFORT» INSTALLATION**
- **AUTO-PILOT (SFIM 85)**
- **LARGE CHOICE COM/NAV. EQUIPMENT**

Figure 18 : OPTIONS LIST

9 – TIMESCALE

The programme targets for developing and industrializing the Ecureuil 2, E version, were most ambitious ; as can be seen in **Fig. 20**, we had 15 months from the start of design work in mid-1978 to get the first prototype ready to fly, and 12 further months to obtain French type certification. The next three months were devoted to obtaining FAA and CAA certification so that the first production helicopters could be delivered early in 1981.



1 – 2 nd ALTIMETER
2 – RESERVED
3 – RESERVED
4 – MARKER
5 – RESERVED RADIO COM/NAV
6 – WEATHER RADAR
7 – FAILURE WARNING PANEL
8 – FUEL GAUGE, ENGINE 1
9 – FUEL PRESSURE, ENGINE 1
10 – OIL PRESSURE, ENGINE 1
11 – OIL TEMPERATURE, ENGINE 1
12 – COUPLER CONTROL PANEL
13 – RADIO COM/NAV
14 – FUEL GAUGE, ENGINE 2
15 – FUEL PRESSURE, ENGINE 2
16 – OIL PRESSURE, ENGINE 2
17 – OIL TEMPERATURE, ENGINE 2
18 – GYRO COMPASS CONTROL

19 – RADIO-COMPASS OR IVG OR RMI
20 – AP CONTROL PANEL
21 – EGT
22 – ENGINE R.P.M. - L.H. - R.H.
23 – TORQUEMETER L.H. - R.H. ENGINE
24 – STAND BY HORIZON
25 – RADIO-COMPASS
26 – MARKER
27 – CLOCK
28 – FREE TURBINE R.P.M.
29 – AIRSPEED INDICATOR
30 – RADIO ALTIMETER
31 – AUTOMATIC PILOT
32 – HORIZON
33 – H.S.I.
34 – D.M.E.
35 – RATE OF CLIMB INDICATOR
36 – ALTIMETER

Figure 19 : INSTRUMENT PANEL FOR I.F.R. FLYING

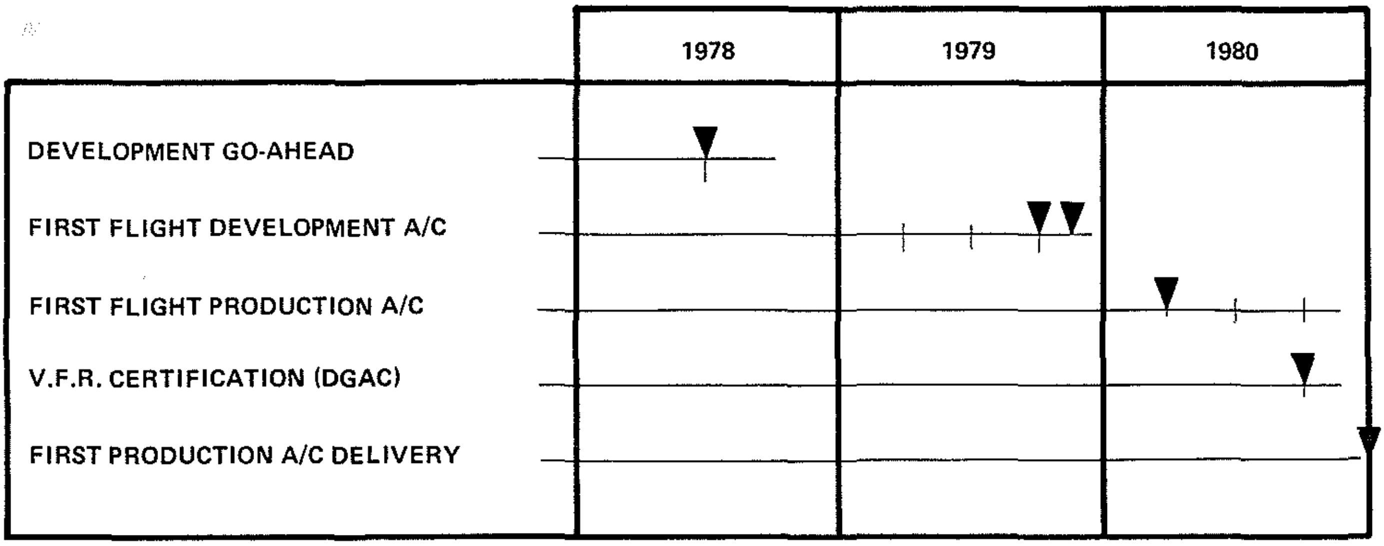


Figure 20 : GENERAL TIME SCALE

The first major stages in this programme were carried out exactly to schedule, given that :

- the 1st prototype flew in September 1979,
- the 2nd prototype flew in November 1979 and the 1st production aircraft flew in March 1980.

This achievement was possible, first, because we had adopted the principle of using as many as possible of the existing AS 350 components and, second, thanks to the «island» organization that was set up for this purpose. This involves grouping together, geographically and under a single Project Chief, all the staff involved in the programme : design, production, flight testing, inspection and budget monitoring staff.

The main problems encountered during development flight testing were excessively high gearbox oil temperatures, poor static stability in yaw and a stick displacement curve in pitch, with the slope tending to be reversed at high speed.

These are, in fact, three very classic problems, but they are not always easy to solve.

- The oil temperature problems was solved by the combined effects of three separate adjustments : a better distribution of the oil jet outputs, to avoid splashing in the high-speed stages of the gearbox, an improved airflow in the cooling unit, and the selection of higher-performance oil coolers.
- The yaw problem led to very low frequency oscillations of ± 5°, which were very hard to control. This instability was only apparent with a rear C.G. location, and it was caused by the larger engine cowlings, which obstructed the airstream to the tail fins.

The first solution to be implemented, which involved adding a vertical fin at each end of the horizontal stabilizer, proved effective. But after visualization of the airflow in flight, the problem was thoroughly investigated by wind-tunnel testing on a model, which showed that the same result could be obtained by a much simpler, lighter and less expensive method. This consisted in adding a 20 mm-wide angle flange to the left-hand trailing edge of the upper fin. To restore the fin's anti-torque efficiency, a second angle flange was added, symmetrical with the first.

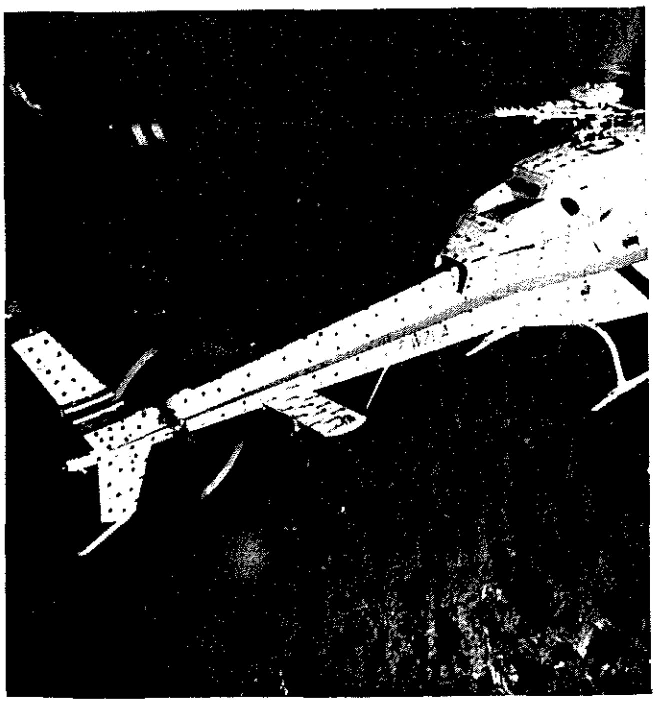


Figure 21 : PROTOTYPE DURING AERODYNAMIC FLIGHT TEST

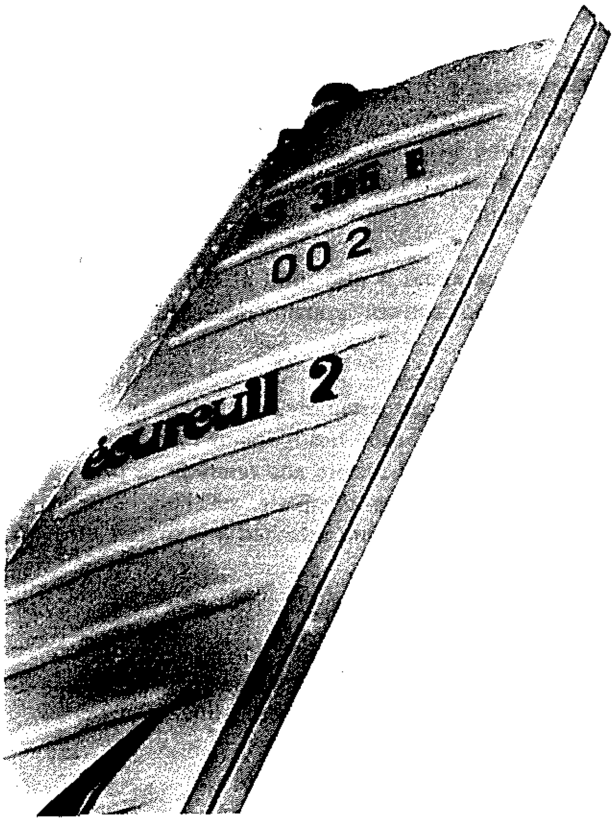


Figure 22 : *UPPER FIN*

This solution, deemed unorthodox by the aerodynamics specialists and surprising to others, was tested in flight with the same results as indicated by the wind-tunnel tests. It was finally approved after checks to make sure that the drag caused by the flanges was at an acceptable level.

The stick displacement curve problem in the pitch axis involved meeting the requirement in the regulations that, throughout the flight envelope, the curves showing the fore-and-aft position of the stick relative to the airspeed must have a positive slope. The problem was overcome by optimizing the stabilizer's angle of attack and adding a small stall flange to the upper side of its trailing edge.

Today, the helicopter's development is considered complete, and the FAA and CAA transmission assembly endurance tests are finished, as well as the gearbox fatigue testing at 1.4 times the maximum power. The special tests have also been done, with the helicopter in the refrigerated chamber, air intake icing, and impact from birds and hailstones on the air intake protection screens. Hot weather tests have also been achieved.

There remain to be done a number of component fatigue tests in the laboratory, further transmission endurance testing to substantiate the initial TBOs and the last certification flights, for which the 3 development aircraft are used.

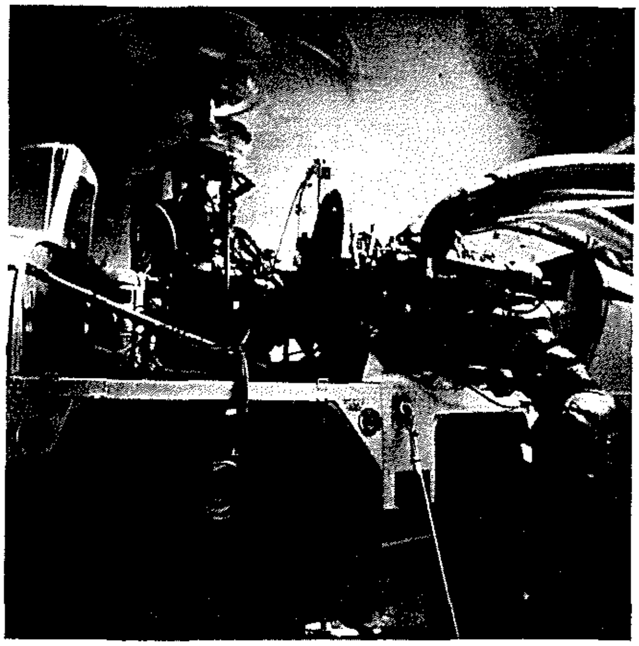


Figure 23 : *COLD ROOM TESTING*

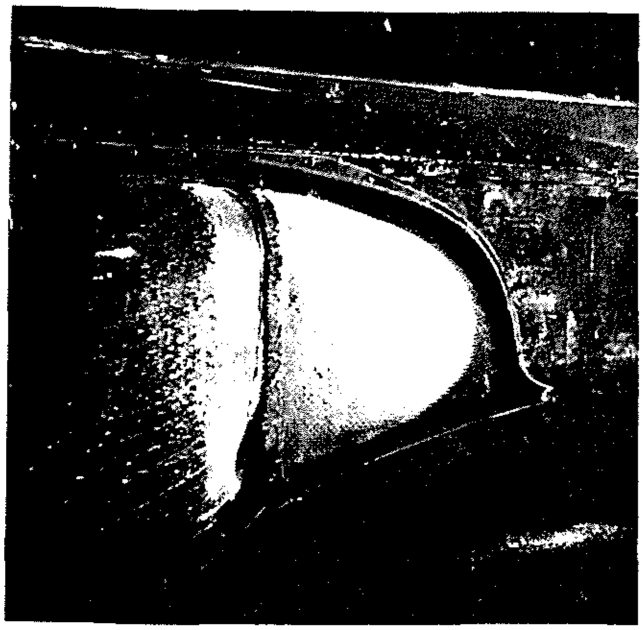


Figure 24 : *ICING TESTS ON AIR INTAKES*

Line production of the AS 355 has been merged into the existing production line in the «self-contained production unit» set up for the AS 350.

The design of this production shop was aimed at making the work operations easier and reducing both the actual manufacturing time and the total shop time for helicopters on the line.

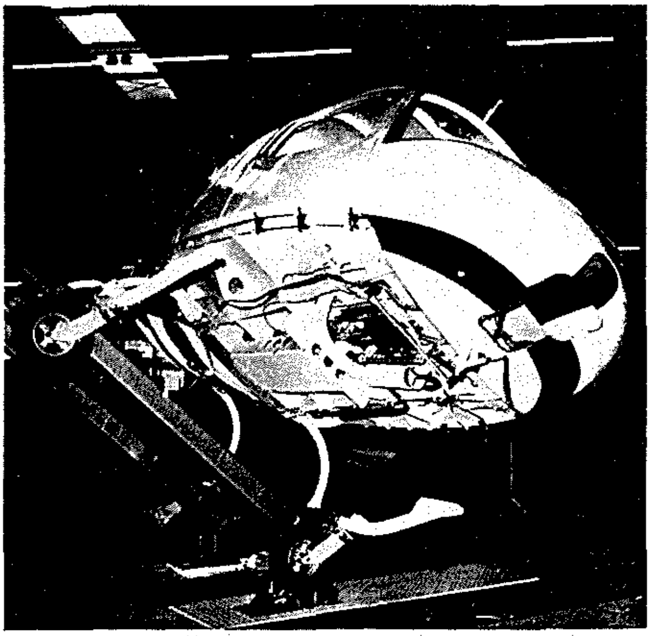


Figure 25 : FINAL ASSEMBLY IN THE SELF-CONTAINED PRODUCTION UNIT

Some very original ideas were used to achieve this :

- The airframe is assembled at the start of the line and painted before equipment is fitted. At the painting station the aircraft is turned on a circular elevator rail, like a chicken on the spit, so that the painter works standing up.

- A pivoting stand is also used at the station where the supply and control systems are fitted beneath the cabin floor.

- The power train assembly, consisting of the engines, main gearbox, rotor head, engine-to-gearbox coupling, fire walls and oil system and reservoir, is pre-assembled on a trolley. The complete assembly is then lifted onto the airframe and attached in a matter of minutes.

Thanks to these innovative methods, the helicopter can now be handed over for the acceptance flight just six days after it first starts down the assembly line.