EIGHTEENTH EUROPEAN ROTORCRAFT FORUM

I - 02

PAPER N° 87

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SEPTEMBER 15-18, 1992
AVIGNON, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

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Abstract

In October 1988 the first BO 108 prototype equipped with two Allison 250 C20R engines made its maiden flight. The second prototype (V2), equipped with two TURBOMECA ARRIUS 1B engines and Digital Engine Control Unit (DECU) has provided successful flight test results since June 1991. A brief description of the engine and engine control will be given together with information about the different DECU functions and mode of operation. The ground and flight test program together with the aircraft test equipment and instrumentation will be presented. Results will focus on the most important tests related to the use of a digital engine control system and the main advantages of those systems over conventional (hydro-mechanic/pneumatic) engine control systems.
Finally the definition and initial flight testing of a variable rotorspeed adapted to the flight conditions will be presented.

Introduction

The BO 108 was the first ECD-rotorcraft to be equipped with a Digital Engine Control system (DEC). The BO 108 which will be marketed under a new type designation will be enlarged as compared to the present two prototypes, providing seven seats at a max. take-off weight of 2500Kg. One of the two engine solutions available with the BO108 was chosen to be the TURBOMECA ARRIUS (previous TM 319) engine which is already installed on ECF-AS 355. The ARRIUS engine family is part of the latest TURBOMECA engine generation and covers the 450 to 750 shp range. This new engine generation was started in 1980 and has led to four new engines: ARRIUS, TM333, MTR390 and RTM322. The lower part of the power range offered by TURBOMECA engines, is covered by the ARRIUS family. Several versions of this engine are already either in production or in development

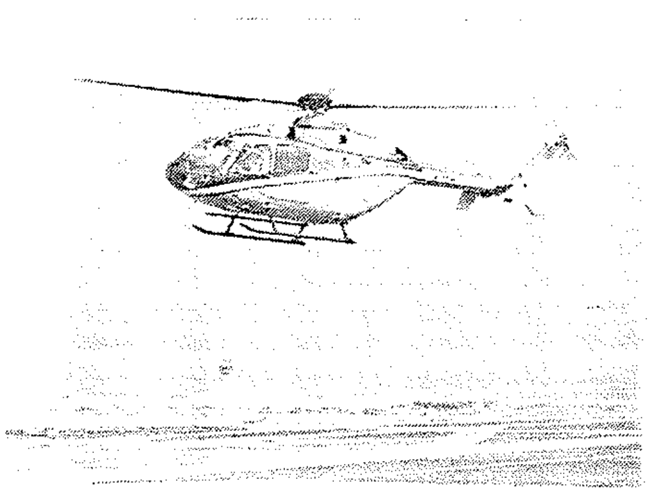

Fig. 1 BO 108 V2 with ARRIUS 1B engines

as shown on table 1. The ARRIUS 1B version used on BO 108 is the version which has a power shaft with 28° bevel gear.

Table 1

Version	Aircraft	Status
ARRIUS 1M	ECF AS 355 N (Military)	Production
ARRIUS 1A	ECF AS 355 N (Commercial)	Production
ARRIUS 1B	ECD BO 108	Development
ARRIUS 2C	MDHC MDX (MD901)	Development
ARRIUS 1E	AS 355 (Elec. de France)	Prototype
ARRIUS 1D	SOCATA OMEGA	Development

Description of the ARRIUS 1B engine

ARRIUS architecture
The engine is devided into two modules: power section module and gearbox module.
The power section module has the simplest possible design for a free turbine engine:
A high pressure ratio centrifugal compressor, a high expansion ratio uncooled single stage gas generator turbine and a high expansion ratio

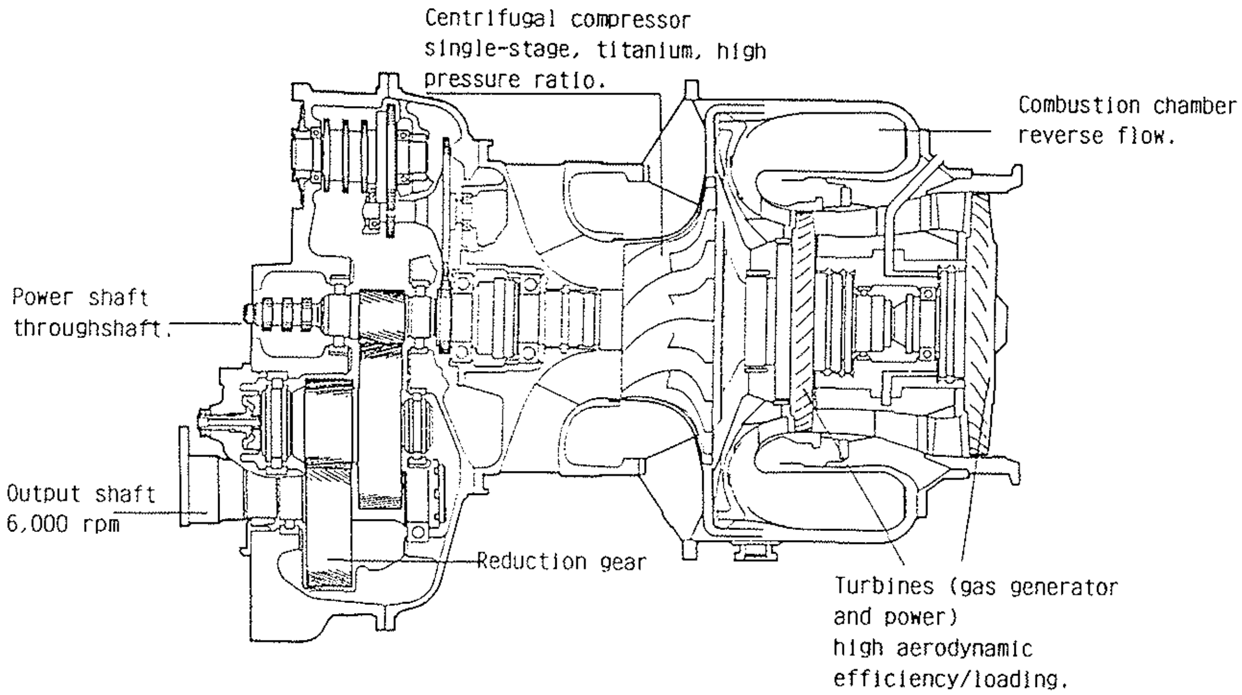

Fig. 2

single stage power turbine.
The gearbox module is adapted to the specific need of the different aircraft powered by the ARRIUS: the ARRIUS 1B has a power shaft with a 28° bevel gear.

ARRIUS performance

Based on the high efficiency of new components, the operating cycle was optimized according to the size of engines in order to have on one hand a high specific power and a low specific weight, on the other hand, a low specific fuel consumption at partial power.
Table 2 shows performance data of the ARRIUS family for twin engine helicopters.
The overall performance of ARRIUS is enhanced by its digital engine control unit (DECU)

ARRIUS control system

The whole ARRIUS family is controlled by the same fuel control system, which consists in a single channel Digital Electronic Control Unit (DECU) associated with a fuel metering device and a manual backup.
The DECU (see figure (3), fitted in the helicopter, receives pilot commands and information from engine sensors, then sends commands to the engine fuel system. Electrical power supply is ensured by an alternator fitted in the engine.

Table 2

		ARRIUS 1	ARRIUS 2
Ratings (SHP) ISA / SL	Maximum continuous	472	567
	Maximum take off	499	634
	Intermediate contigency	499	634
	Maximum contigency	531	680
	SFC lb/SHP/hr	0.55/520SHP	0.51/680SHP
	Compression ratio	8.5	INCREASED
	Maximum flow rate	BASIC	+17%

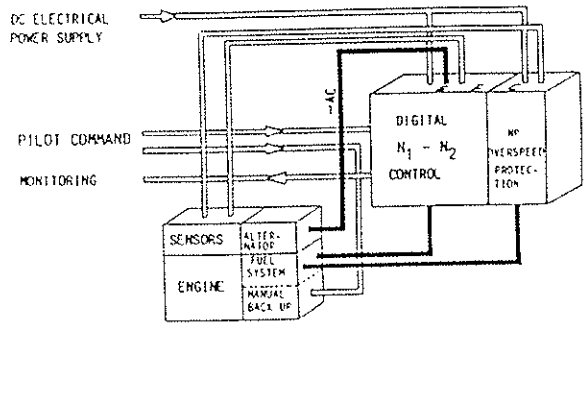

Fig. 3

The use of the electronic numerical control system is the result of more than 12-year in-house development at TURBOMECA. It is a standard equipment on ARRIUS (turboshaft and turboprop versions), TM 333, RTM 322, MTR 390, MAKILA 1A2 and ARRIEL 2. TURBOMECA was among the first to control helicopter engines with an electronic control system, and to accumulate operational flight hours.

Software functions
Figure (4) shows the basis diagram of the engine control. Some details are given hereafter about the main sequences.

Start-up sequences
After selecting "IDLE" or "FLIGHT", the startup is controlled through T1 (ignition fuel flow) and N1 (acceleration fuel flow). The fuel flow is limited by T45.
The start-up is finished when N1 reaches 50%.
Then the following sequences are depending on the status of the selectors:

"NORMAL" or "TRAINING"

"FLIGHT" or "IDLE"

Figure (5) shows the position of the corresponding points.

Stabilized operation

Idle

K1: proportional gain of the idle droop law,
A : engine 2 stopped and engine 1 on "IDLE". It is a theoretical point, which corresponds to the max N1 on the integral part of the IDLE law.
B : engine 2 stopped and engine 1 on "IDLE" (OEI operation, flat pitch),
C : the both engines (AEO operation) are on "IDLE" N2 demand is 75%,
D : engine 1 on "IDLE" and engine 2 on "FLIGHT". The engine 1 is unloaded; so the point D is on the "NO LOAD" curve.

Training idle
E : the training is a integral law (N2 demand = 92,5%)

Flight

K2: proportional gain of the flight droop law,
F : AEO flight operation, the position on this curve depends on the pitch value,
G : OEI flight operation, the position on curve depends on the pitch value.

Transient

Acceleration control
The engine control is optimized to give the best accelerations taking into account the following protections:
engine surge: the fuel flow law is a function of P3, P0 and T1; it allows a electric power extraction of 200 A without surge problem,
MGB overtorque: N1 acceleration is also controlled to avoid an overtorque.

Deceleration control
The fuel flow is limited to prevent engine flame-out.

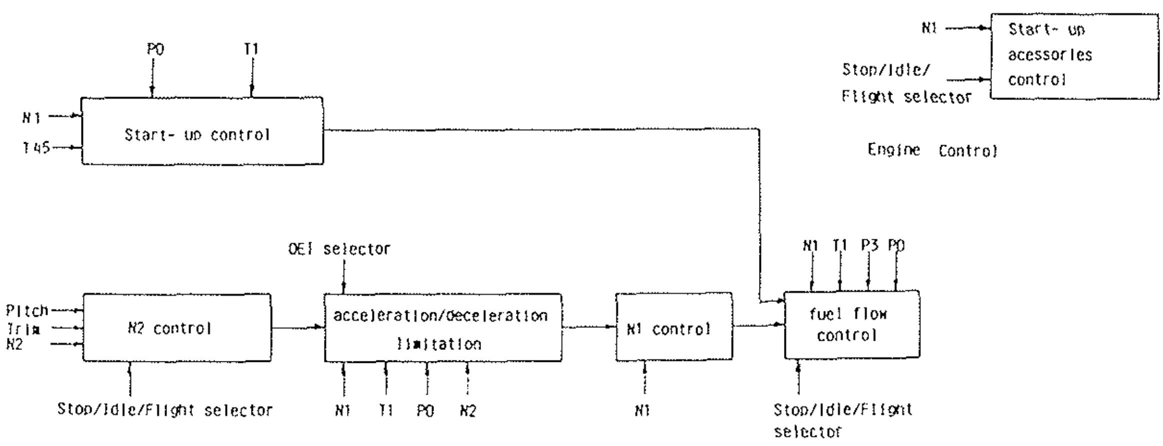

Fig. 4

Software description ARRIUS 1B
Control law Idle and Flight

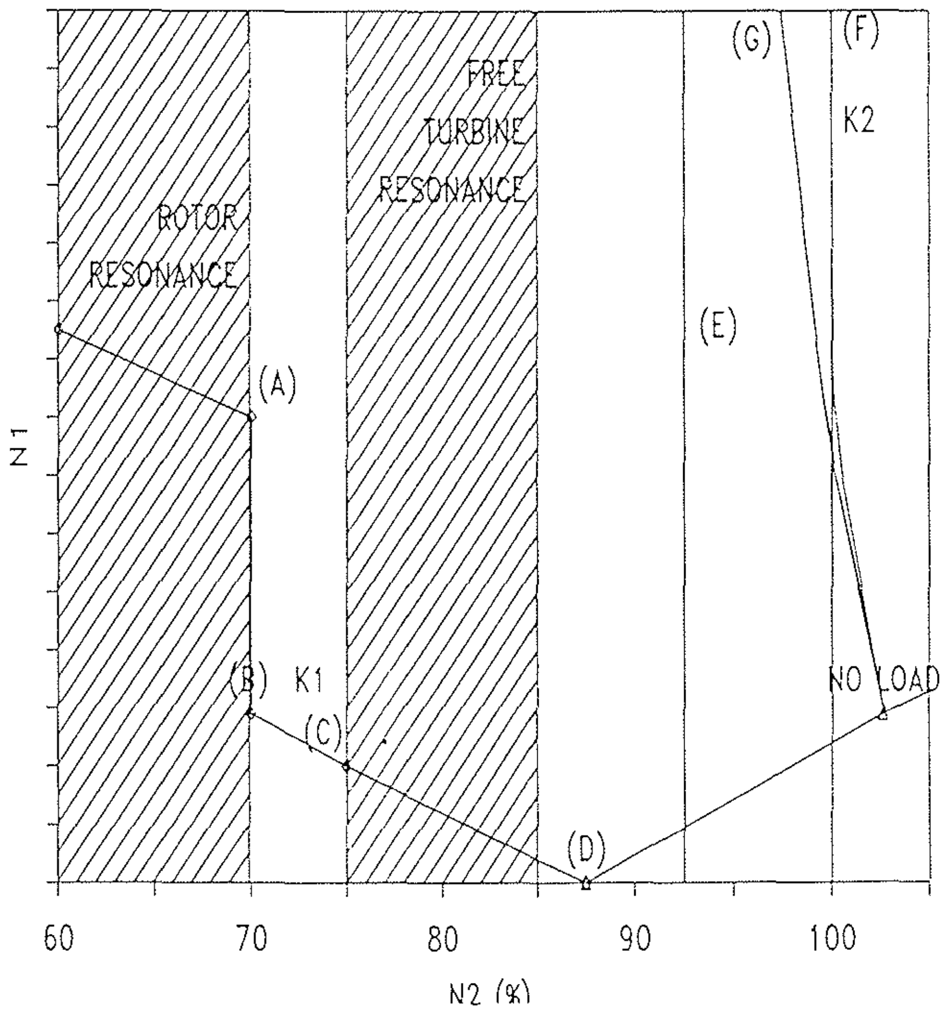

Fig. 5

Operation of the ARRIUS 1B Engine

When the helicopter is energized, the DECU will self test and give information if anything is wrong.

To start the engine "IDLE" or "FLIGHT" have to be selected and the DECU will start the engine. This start is very consistent, temperature T4 is controlled and the risk of overheating is nearly nil.

If "IDLE" is selected, the rotor will accelerate to (C) or (B).

If "FLIGHT" is selected, the rotor will accelerate to (F) or (G). This is automatic giving a smooth and constant acceleration, acceptable both in high wind and iced ground conditions.

For instance, on the BO 108, starting the two engines up to 100% NR (rotor speed), takes exactly one minute.

Furthermore engine limitations are presented on one instrument since the TURBOMECA engines have a single limiting parameter, which is N1 (gas generator speed).

It is possible by trimming the engines differentially to match N1 or torque. These settings remain constant and are independent from each other.

Failure case operation

DECU failure

There are three types of DECU failure:

- Redundancy: If one of the redundant transducers or circuits fails, the DECU switches automatically to the alternate. The pilot does not know it and has nothing special to do. The failure will be signalled at the end of the flight for the maintenance crew.

- Minor failure: Such a failure has no effect on the performance level of the engine, but may have an effect on handling possibilities. The pilot has to use the engine with care. The signalled code numbers are listed in the Flight Manual with corresponding eventual procedure

- Major failure: In this case the fuel metering system is frozen in the position it was in just before the failure. Immediate pilot action is nil or minimal. This failure is signalled and the pilot can go on flying, while controlling the engine manually:

- the failed engine's manual lever is lit,

- the manual control has full authority to give maximum power, to idle or to shut off the engine, regardless of the fuel flow before the failure. It is also possible to relight the engine on manual control.

- some care is necessary when controlling manually. But in case of twin-engine helicopter, the other engine is still controlled automatically.

Engine failure

All Engines Operative (AEO) ratings (take-off, maximum continuous) are pilot controlled. In the case of One Engine Inoperative (OEI) operation the DECU controls the engine, which delivers its maximum contingency power and no more. Thus the pilot focuses on piloting the helicopter, controlling rotor speed slightly below normal flight value.

Maximum contingency is set by the DECU and the pilot switches to intermediate contingency in due time (time limit is signalled by the DECU) or when maximum contingency is no longer necessary.

Restarting an engine in flight

This requires only a simple pilot action: switch the flamed out engine's selector from "FLIGHT" to stop and then to "FLIGHT" again.

The automatic sequence will restart the engine much better than a pilot under stress.

Pilot training

Training for OEI operation

Life of the engines and main gear box limits the use of OEI ratings to real cases of OEI flight.

As OEI training is essential for pilot proficiency, the OEI ratings can be lowered. Associated with lower grossweight, it is a representative training: same rotor speed (NR) piloting technique, same instrument indication.

In case of "trained pilot" error, if NR drops too low, the idled engine will automatically restore its power up to maximum OEI rating, if necessary.

Training for simulated DECU failure

The DECU can be frozen by selecting "MANUAL" to simulate its failure at any time. The engine can then be controlled manually to simulate for instance a landing with one engine in manual mode.

At any time, by switching the engine back to NORMAL position, the pilot can restore normal operation.

Flight safety

Decreasing the pilot work load, having a sound reaction to possible failure, with simple and fool-proof action, making possible a realistic pilot training as frequent as necessary without consuming high power life, all of those concur to improve flight safety.

Advantages for the operator

Some of them have been already stated:

• the automatic starting, with no overheating improves the real life of the engine,

• the training mode, while allowing very efficient pilot training, is very thrifty on high power hours. It is a real engine life time saver.

• OEI ratings, being DECU limited, are never exceeded.

Moreover the DECU being a powerful computer can give additional precious help:

• Engine power check: The DECU can calculate the torque and turbine temperature that the minimum guaranteed engine should deliver in those flight conditions, and compare them with the actual values.

• Health monitoring system: the DECU can log hours, starts, cycles, to calculate crack and creek elapsed life.

• Help to maintenance: at the end of each the DECU displays any control system defect, so the maintenance crew can fix it without losing a precious time trouble shooting.

Increasing the life of the engine and saving time for maintenance have direct financial advantages for the operator.

Advantages for the aircraft manufacturer

The DECU is also beneficial to the manufacturer by improving the adaption of the engine to the airframe:

• the engine, being controlled with more precision can be used at the best of its possibilities: for instance, for a given engine, better response to a collective increase can be obtained, without transient overtorque,

• the control system can be isolated from torsional unstability frequencies,

• helicopter limitations can be approached precisely; better engine matching; more precise and elaborate topping of the engine power in OEI operations.

• no maintenance flight time is necessary for check or adjustment of engine topping

• no maintenance flight time is necessary for check or adjustment of a bleed valve or a flow fence

• no maintenance flight time is necessary for adjustment of a mechanical pitch compensation because the respective potentiometer which is used by the DECU can be precisely adjusted on ground

• the training mode can save main gear box life,

• rotor efficiency can be improved by trimming NR, manually for aerodynamics of the main rotor, or automatically, for instance by foot pedal action, to improve lateral wind capability

• new functions can be introduced: even the control mode can be changed, for instance, the control loop can change from proportional to integral when necessary,

• in case of a generalized management system, all the engine parameters can be forwarded by the DECU through a data link,

• the improvement of precision and versatility of the control systems is such that new OEI very high power ratings (30 s OEI rating) have been made possible. Such a rating has been already certified by TURBOMECA for the MAKILA 1A2.

Ground and flight test program
gine related tests are shown)

The ground/flight test program for a new engine with a digital engine control system has to check some points which are related to the use of of electronic equipment for engine control. Safety aspects will define the sequence of tests to be performed. The test steps listed hereafter are shown in the sequence of priorities.

Configuration: Aircraft tied to ground, engine cowlings removed, EPU connected

- Engine start and acceleration to GI (OEI)
- Verification of N1 and rotorspeed for GI
- Checking for leaks, oil pressure
- Acceleration to FI
- Verification of N1 and adjustment of rotorspeed for FI
- Checking for leaks, oil pressure
- Repeat with other engines
- Torsional stability check with collective inputs up to MCP OEI,AEO (pilot input)
- Torsional stability check with collective inputs at three power settings (3 to 7Hz sine inputs OEI,AEO)

Configuration: Aircraft tied to ground, engine cowlings installed, EPU connected/disconnected

- Efficiency of ejector at GI (OEI)
- Efficiency of ejector at FI (5 Min MCP OEI)
- Voltage regulator adjustment
- Disconnect EPU / switching of battery and both 28V DC-generators and BUS TIE
- EMI tests with increased output power on VHF1, VHF2 and Transponder.
- Overspeed check with freq. doubler
- Training of manual mode (Pilot and FTE)
- Test of fuel shut off valve ENG1 and ENG2

Configuration: Aircraft ready to fly (engine cowlings installed)

- First Flight (HIGE,HOGE,manoeuvering up to 20 Kt)
- Level flight, climb/descent (60 ,80,100 Kt) 4000ft check for rotorspeed range, eng vibrations and temperatures, flight characteristics
- Ground run with simulation of FADEC failures, power check, topping check.
- Level flight, climb/descent (60 ,80,100 Kt) at high altitude
- Engine characteristics (acceleration, deceleration), simulated eng. failures.

Test aircraft instrumentation

A total of 93 parameters have been measured during the first ground and flight tests of the BO 108 V2. However only 58 parameters were related to the testing of the new engines, the other being necessary for general purpose or surveillance of the aircraft which was new and not identical to the first prototype V1. More details about the instrumentation are given hereafter

Type of sensor	Quantity
-Rotational speed (N1,N2)	4
-Temperature (TOT,air inlet eng. surface, eng. compartment, oil,fuel,tail boom)	25
-Pressure (oil,ejector,vent line, fuel, eng. compartment)	20
-Force (eng. mounts)	2
-Vibration (eng.)	2
-Fuel flow	2
-Others	3
Total (eng. related):	58

Results of ground and flight tests

Ground tests
Engine start and GI/FI rotorspeed
Engine starting of the ARRIUS 1B is initiated automatically after switching of the START/IDLE toggle switch either in the GI or FI position. The selection of the N1 for ground idle (GI) has to fulfill multiple requirements at GI OEI, GI AEO and with a combination of one engine at GI and the other eng. at FI or with one engine being in TRAINING mode

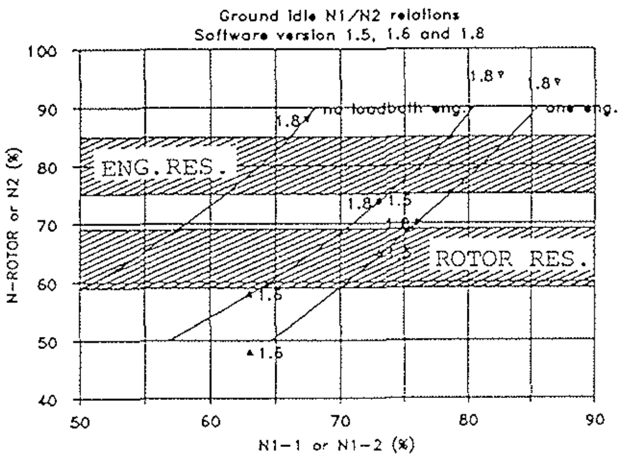

Fig. 6

The first FADEC software version had 73% N1, the second version 63% N1 for GI. Fig (6) shows the combinations of N1 and N2 which are obtained with those choices at different START/IDLE toggle switch positions and the two critical speed ranges (eng. power turbine and main rotor resonance speed) which have to be avoided. Neither the specified N1 of 73%, nor the chosen 63% N1 could fulfill the requirements listed in table 1. A more sophisticated software (1.8) with N2-control for GI was prepared by TURBOMECA and successfully tested.

Table 1
(Requirements for GI definition)

- N2 above/below critical main rotor reson. speed 65±5%
- N2 above/below critical power turbine reson. speed 80+-5%
- N1 above 60% in order to obtain adequate 28VDC generator power
- N2 below 90% in order to avoid free wheel clutching in AR
- N2 about 90% in TRAINING mode in order to assure power assistance from reduced eng.

Torsional Stability

Torsional stability was an important objective of the first ground tests. Torsional stability was tested with collective inputs from the pilot, and with a sine of 3 to 7 Hz (collective axis) injected using a stimuli system and the AFCS input of the hydraulic system. At the beginning, torsional stability was found to be marginal in OEI and poor in AEO conditions. Optimisation of the respective low pass filter in the DECU software was performed in two steps. Fig. (7) shows the eng. torque response to a sinus sweep (collective) where the resonance phenomena

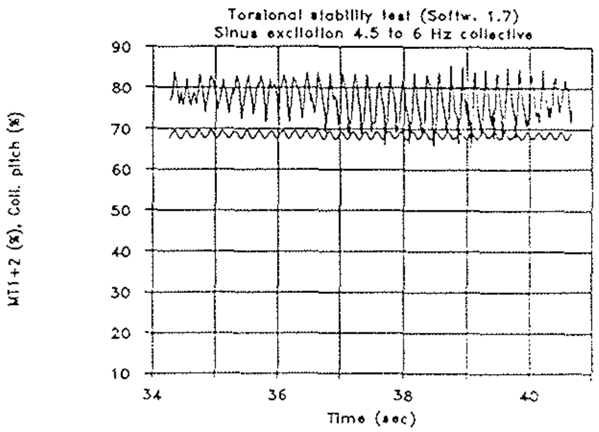

Fig. 7

could be observed. Fig. (8) shows the same configuration with slow and fast collective inputs (made by the pilot). Fig (9) shows the final result which uses a more complex filter

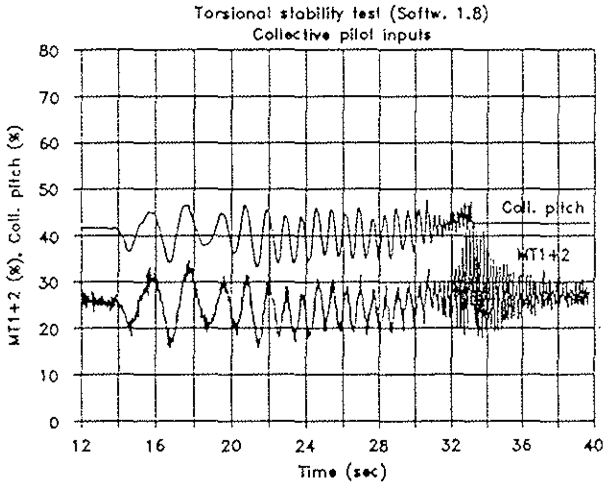

Fig. 8

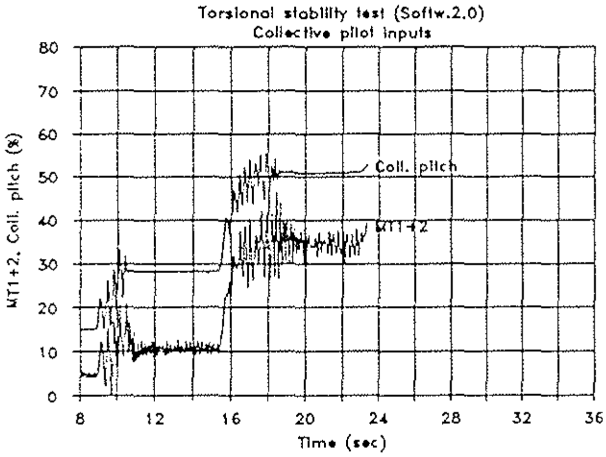

Fig. 9

Engine installation:

A good efficiency of the ejector was found with the eng. cowling installed and from there no problems whith the eng. compartment temp. were found. Engine lubrication and oil cooling worked well. Engine vibrations were found to be well below the limits.

EMI safety check

An EMI check with increased HF-power on VHF1 and VHF2 was performed prior to the first flight in order to check the correct wiring and shielding of the DECU system. For safety reasons the output power of the transmitters was increased to about 40 Watt (instead of 20) by means of an amplifier for these tests.

Flight tests
The first ground test of the BO 108 with ARRIUS engine was made on may 28 1991. The first flight was made only seven days later. The progress of the flight tests related to the engine was very fast with about 50 ground or flight tests within 3 months (70% of them for engine purpose). The test of the last software which is still in use today started on 26 September 1991

Rotorspeed range
The test and optimisation of the rotorspeed range was one of the first objective of the flight tests. The ECD decision was to use only two screwdriver-adjustable potentiometers for precise N2-adjustment and torque matching, and not to have the N2 control available to the pilot command. The requirement was to maintain the rotor speed within the limits of 98 to 102% in AEO power configuration, within the expected flight envelope, without needing any correction at the N2 control input. Fig. (10) shows the N1 versus rotorspeed variation with the aircraft trimmed to 100% N2 at 6000ft ISA and then flying at sea level. Fig (11) shows the N1 versus rotorspeed variation after climbing to 18000ft .

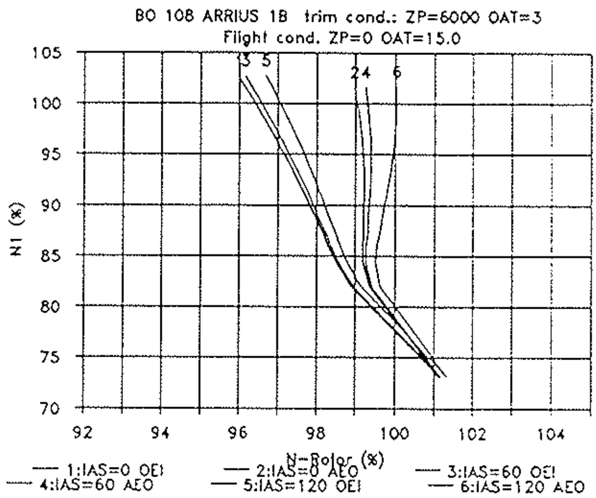

Fig. 10

The optimisation of the rotorspeed range was performed with the software versions 1.8 and 2.0 . The first version had a steeper static droop line combined with lower gains in the N1-loop. The second version had a slightly lower static droop line combined with higher gains in the N1-loop. The second version was finaly chosen due to the improved acceleration characteristics which could be demonstrated. The requirement to maintain the rotorspeed within ± 2% could be demonstrated with the exception of low power settings in high altitude (N1 below 78%), which are quite close to AR.

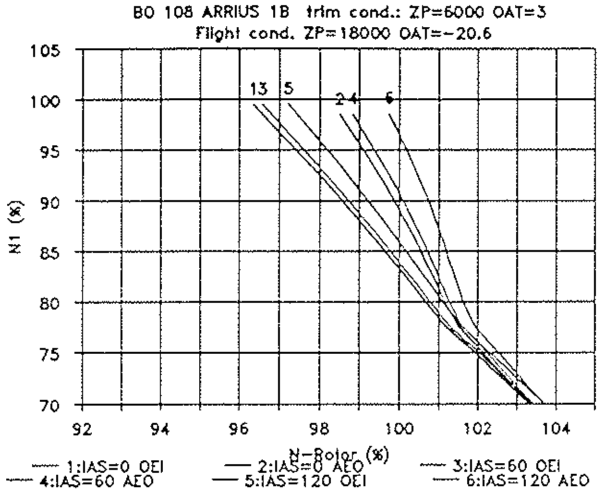

Fig. 11

Eng Acceleration/deceleration
Engine acceleration/deceleration characteristics testing was the next objective of the flight tests. Both software versions 1.8 and 2.0 had already passed extensive flight tests on the AS 355 at CGTM which was appointed by TURBOMECA to perform these tests, giving ECD the maximum confidence that the engine will work perfectly under all foreseeable conditions. The engine acceleration tests on BO 108 were performed under the most severe conditions, like maximum altitude combined with 200 A load on the 28 VDC generator and fast collective inputs from autorotation to AEO take off power or OEI max. contingency power. Of all these tests none produced a stall or surge and, the acceleration/deceleration which was already good for the 1.8 software was found to be excellent for the 2.0 software. Fig. (12) shows a fast collective input AEO from about 12% total torque to MCP with torque transients up to AEO take-off power. The collective input was activated within 0.8 sec and the rotor speed dropped down to 96%. The significant improvement between the pneumatic engine control system and a sophisticated engine control system (like ARRIUS) can be shown by the comparison of Fig. (12) and (13), showing a measurement which was made 2 years earlier on the first BO 108 prototype (V1) which used a conventional pneumatic control system. The pilot intended to perform a fast collective input from low power to MCP (92% MT1+2). However due to the delayed acceleration of the engine and the absence of a torque limiting system he decided to lower the collective pitch after some time even, for a much slower and smaller input.

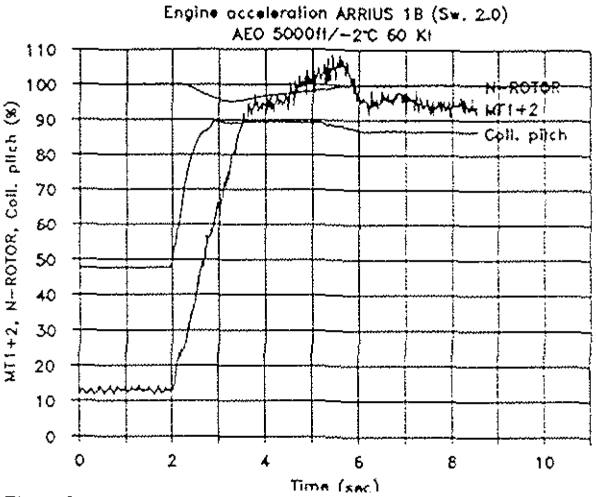

Fig. 12

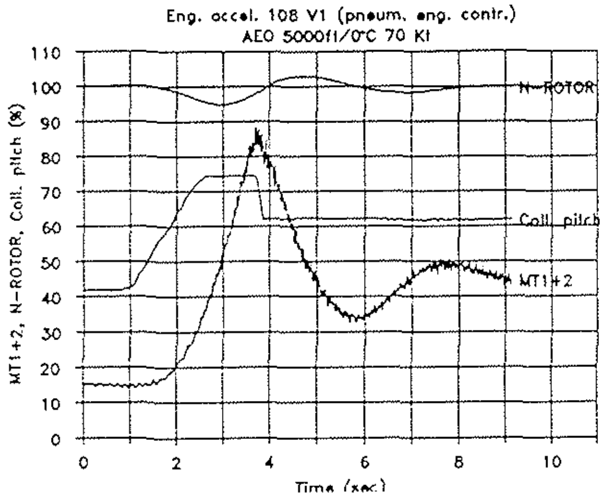

Fig. 13

Fig (14) shows a fast collective input AEO from AR to MCP. This is a more severe test because the compressor must accelerate from a very low N1. The main part of the collective input was made in about 1.7 sec. The rotor speed dropped down to 94.7% which triggering the audio "low rotor-speed" warning which starts at 95%.

Fig. (15) shows approach and landing with eng. 1 in manual mode (MT1 manually adjusted to 20% prior to the approach) and without further corrections. The rotorspeed which is controlled by engine No 2 only remains between 96 and 102%

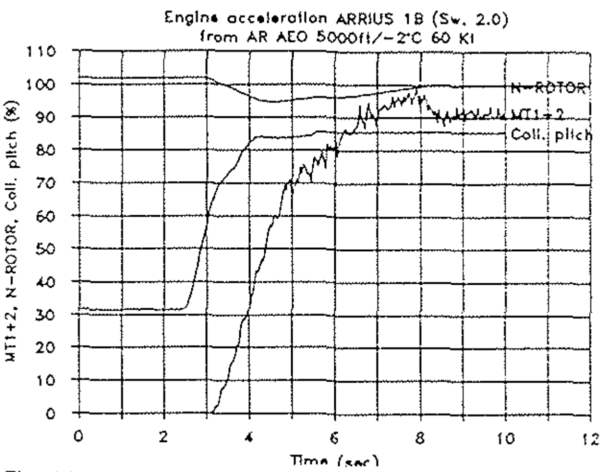

Fig. 14

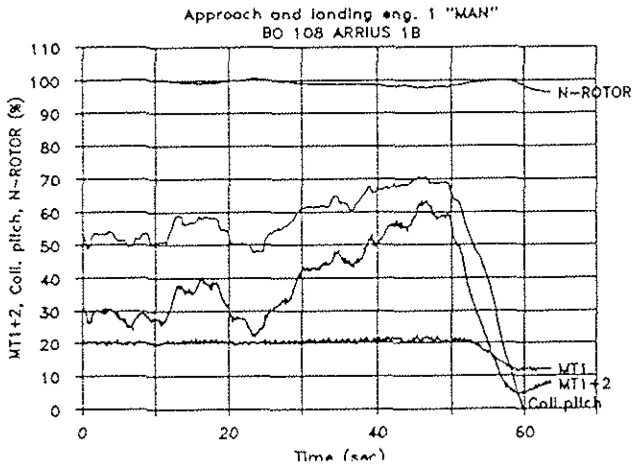

Fig. 15

Investigation of DECU failures

Ground tests were performed using a failure injection box for the simulation of failures of the multiple sensors of the DECU and using a frequency doubler in order to check the function of the N2 overspeed protection system.

The most severe failure of the DECU is the major failure wich results in a frozen fuel metering system. The failed engine has to be controlled manually. This type of failure was tested in flight and it was shown that even an approach and landing in this configuration is very easy and needs no further correction once the failed engine has been adjusted to about 20% MT.

Simulated engine failure

Simulated engine failures were performed with power settings as high as to reach the 2.5 min power of the remaining engine which is topped by the software. However most of the tests have been performed using the training mode in order to save life time of the engines since the engine is topped to 30 min power if the training mode is engaged. Fig. (16) shows a simulated engine failure (ground run, aircraft tied-down).

The failed engine was cut by switching from FLIGHT to IDLE and the rotorspeed dropped down to 96% as the N1 of engine 1 reached the topping which was 103% N1 for the actual conditions.

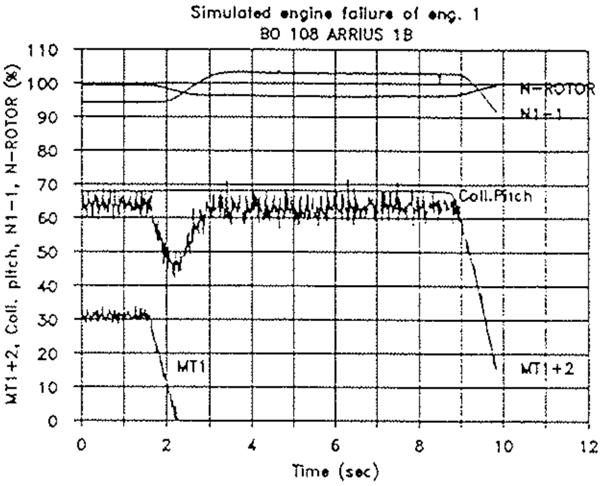

Fig. 16

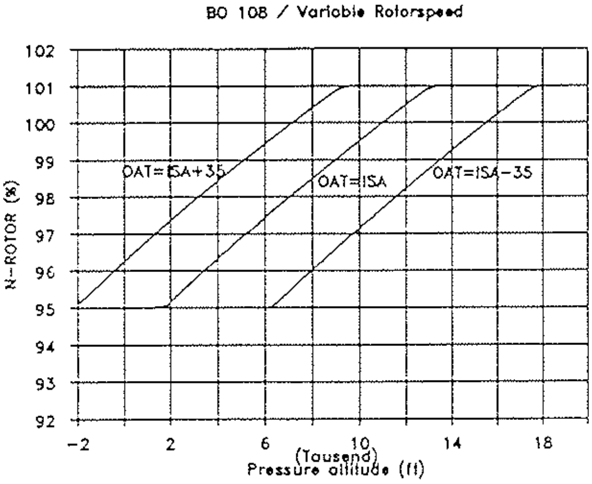

Fig. 17

Variable rotorspeed

The definition and test of a variable rotorspeed is the main objective of the actual engine-related flight tests of the BO 108 V2. Future helicopters like the BO 108 must be designed for the noise considerations of the next 10 years and therefore should be developed today to meet future requirements.
The rotorspeed is (for a given main and tail rotor) the most important parameter which influences the noise emission of a helicopter. It is therefore important to use a reasonable but low rotorspeed for the part of the flight envelope where noise emission is a concern. On the other side it will be of interest to use the maximum allowable rotorspeed for example for hover at high altitude, in in order to reduce the main rotor torque and to get maximum thrust from the tail rotor.
A variable rotorspeed which varies the rotorspeed by about 6% between low altitude/high density and high altitude/low density has been defined by ECD and the respective software is just in preparation at TURBOMECA. Flight tests of this software will start in september 1992 .
Fig. (17) shows the N2/sigma function which will be used for the first tests of a variable rotorspeed.

Conclusion

Testing of the ARRIUS 1B on BO 108 was very successful. The cooperation between ECD and TURBOMECA was excellent and the result is remarkable under many aspects.

- maximum comfort for the pilot with automatic starting, precise topping including full OEI engine and gearbox protection, and sophisticated OEI training features.
- good engine installation with large margin to the engine limitations (temperature and vibrations) and excellent access to the engine for maintenance
- Modern futuristic variable rotorspeed control reducing noise and increasing high altitude performance
- safe and reliable concept with full engine separation and no crosstalk between the two DECU

In conclusion, an engine with engine installation and optimisation all very promising for the future.