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IRISH DAUPHIN HELICOPTER S.A.R. SYSTEM FLIGHT TESTS

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INTRODUCTION

This paper successively deals with :

- system description
- comments on development tests performed and associated difficulties

1 – SYSTEM DESCRIPTION

1.1 – GENERAL

The S.A.R. (Search and Rescue) system developed for the IRISH AIR CORPS' DAUPHINS is especially intended to allow search and rescue missions in Instrument Meteorological Conditions (IMC) over maritime zones in a quasi-autonomous way.

This system is installed on five SA 365 F aircraft which is the naval version of the DAUPHIN II (4100 kg gross weight) featuring :

- a 12 m-diameter, four-blade, composite main rotor
- a 1.10 m-diameter «Fenestron» fan-in-fin tail rotor
- a retractable tricycle landing gear
- two TURBOMECA ARRIEL 1M engines, with a 522 kW/ 710 HP takeoff power rating and a 580 kW/790 HP super-contingency power rating
- fuel tanks with a total capacity of 1160 l/910 kg
- a 275 kg (600 lbs) capacity rescue hoist
- an emergency floatation gear
- a complete set of radio equipments.

The S.A.R. system incorporates three major sub-systems :

- a navigation sub-system
- a automatic flight control sub-system
- a display sub-system.

Appendix 4 shows the instrument panel of one aircraft.

1.2 – NAVIGATION

The navigation sub-system consists of sensors, two computers and links with the other two sub-systems in accordance with the flow chart in Appendix 1. All links (except those analog links from sensors) are achieved through ARINC 429 digital bus.

The CROUZET NADIR MK2 computer usually ensures the whole navigation management, with the OMEGA receiver operating as an equipment ; in crippled mode, the OMEGA receiver recovers its computer function and provides some navigation functions automatically.

The functions ensured by the NADIR computer are :

- **Generation of present position**
  - from DOPPLER navigation
  - from VOR/DME navigation (50 stations)
  - from OMEGA navigation.
- **Waypoint management**
  - 50 VOR or VOR/DME stations
  - 50 specific waypoints
  - 20 auxiliary waypoints, common to both NADIR and OMEGA, defined either in latitude / longitude or in ρ/θ with respect to another waypoint, or designated from radar
  - 20 moving waypoints defined as the auxiliary waypoints plus a speed vector.
- **Typical route management**
  - between two points (FROM - TO)
  - towards one point, either directly or by reaching a radial (DIRECT→TO)
  - homing on a moving waypoint
  - hovering over a predetermined point or a «mark» point by vertical fly-over and pattern turn and transition down
  - search pattern navigation such as creeping ladder, expanded square or cloverleaf sector
  - navigation legs

- **Generation of roll commands to the coupler associated with AFCS**

- **Air data computation work**

  (TAS and IAS, pressure-altitude, OAT).

- **Fuel management**

  Consumed fuel, remaining fuel, consumption per kilometer, range and remaining flight time, economic cruise speed, fuel to reach a waypoint, fuel alert warning.

- **Flight aids**

  Instantaneous weight, OGE hovering weight, available weight margin, maximum torque warning.

1.3 – AUTOMATIC FLIGHT CONTROL

The flight control sub-system comprises :

- A SFIM PA 155 duplex analog AFCS providing stabilization on the 3 axes as well as coordinated turn and fly through steering.
- A SFIM CDV 155 4-axis digital flight director coupler capable of numerous functions detailed in Appendix 2.

The following points should furthermore be noted :

- Simultaneous operation of T.DWN + NAV allows hovering nose into wind over a predetermined point.
- A joystick available to the hoist operator allows modifying the speed in HOV or G.SPD mode.
- An F.UP (fly up) safety mode is available
- A G/A (go-around) mode is available
- The modes engaged are also indicated by the display sub-system (EADI) with different conventions (shape, color whether they related to coupler or flight director engagement and active or armed modes ; it should finally be noted that the modes are clearly correlated with the corresponding axis.

1.4 – DISPLAY

The display sub-system provides the crew with the data required for performing the mission, in addition to the conventional aircraft instruments. Data are displayed on the NADIR display unit mounted on console (1) and on a set of five color CRT's or EFIS (Electronic Flight Instrument System) mounted on instrument panel.

(1) Characteristics of waypoints, VOR/DME stations and search patterns ; fuel management and flight aids ; specific navigation parameters, etc ...

The data displayed on the five shadow mask-type tubes issued from the navigation sub-system and BENDIX 1500 radar, are transmitted through both interface units (BATIE), processed by three symbol generator units (BGS) and are called from the EFIS control unit ; the diagram in Appendix 3 gives a schematic description of the sub-system ; it should be noted that two half-systems are operating separately and can be reconfigured in case of failure.

The EFIS allow displaying :

- **EADI** : attitude and CDV 155 modes.;
- **EHSI** : EADI in case of failure of the later and various horizontal situation modes :
  - conventional HSI
  - sector or sector + radar
  - hover
  - search and hovering patterns.
- on radar screen, primary modes :
  - Weather or weather + alert
  - Search

  and possibly the secondary modes :
  - Check list
  - Navigation (superimposed)
  - Designation.

2 – TESTS OF THE SYSTEM AND PROBLEMS ENCOUNTERED

2.1 – GENERAL

The tests were conducted :

- On SA 365 N bench aircraft S/N 6015 in aerodynamic configuration of SA 365 F («large fenestron») for test of the CDV 155 and preliminary tests of display sub-system.
- On the first customer's aircraft for the other tests.
- On a specific ground test bench.

The novelty of some of the tested systems or technologies raised some problems which were all solved and are presented hereafter.

2.2 – RADIO TESTS

Developing a radio system is a research of a compromise allowing powerful transmitters and sensitive receivers to coexist on a small size helicopter made of a large percentage of composite materials.

In addition to the well known electrical noise (chopping power supplies, radiating ground connections, etc...) a lot of new noises are generated by digital computers (Symbol Generator Units, NADIR, OMEGA). This new type of interference is featured by the impossibility to isolate either the involved element or wire.

The solution then consists in filtering all inputs/outputs with filtered connectors incorporated in the equipment or bay.

The presence of airborne computers which is now irreversible will lead to a different processing of interference problems and it is understood that a change will also occur in the standards.

2.3 – NAVIGATION TESTS

2.3.1 – DOPPLER Navigation

The Doppler navigation system is a self-contained navigation system operating through the integration of Doppler speeds. The new feature lies in the automatic computation of variation.

The VOR/DME stations and some waypoints are memorized together with their variation.

The computation principle from these data is to build a permanent triangle surrounding the present position. The variation of the present position is deduced from that of triangle apexes through bilinear interpolation.

The problem is more complex when the present position lies outside all possible triangles, e.g. when the helicopter is flown over the sea. It is then necessary to resort to extrapolation by defining certain limits regarding :

- distance from point to triangle
- triangle shape.

In fact, triangles with a very flat shape and too large distances lead to important errors. Beyond these criteria, the computer generates a warning signal informing the crew that they have to actualize the variation manually.

Though it is improved as compared to previous systems, this type of computation may still induce problems since an error in entering a point variation may result in a navigation error. The monitoring criteria allow limiting its probability, but in a few years the availability of a world-wide variation computation algorithm will probably allow to get over a new step.

2.3.2 – VOR / DME Navigation

Once the coordinates and variation of a VOR / DME station are known, the bearing and distance measured on board the aircraft allow calculating the present position coordinates.

Reception from a second VOR station should normally enable improving the computation accuracy, but it proved difficult to provide the computer with good criteria for selection of stations : in fact, knowing the distance and height is unsufficient since the relief may result in impossible reception.

An evolution in the future could be the selection of VOR's by the computer itself (the absence or presence of the flag being the data feedback). The selection of stations would then be permanently optimal.

The navigation software has not been modified but it was however necessary to redefine the gains and filters used in position computation slaving loops since those initially used resulted in fluctuating groundspeed and drift data.

Though it did not lead to accuracy errors, this was somewhat inconvenient for both manual and coupler mode flying. All these modifications have been defined by ground simulation and successfully tested in flight.

This navigation mode offers the major interest of an excellent accuracy independent of flight duration.

2.3.3 – OMEGA Navigation

Developing this mode did not involve any special difficulty. It should however be noted that the problems related to qualification of the accuracy of such a navigation system are delicate, the commercial brochure from the equipment manufacturer only calls for an average accuracy over 24 hours which is a far longer time than for a flight.

2.4 – FLIGHT DIRECTOR COUPLER CDV 155 TESTS

2.4.1 – General

The coupler fitted to IRELAND DAUPHINS is technologically and functionally the most sophisticated of those couplers installed on AEROSPATIALE helicopters.

The following couplers have so far been developed :

- **CIVIL couplers** of the analog type with cruise modes (altitude hold, preset heading hold, ...) and ground-linked radio modes (VOR, ILS, ...), the most advanced type of which is the 4-axis CDV 85 coupler which allowed certificating the SUPER PUMA for approach in Category II.
- **MILITARY couplers,** some of which are of the digital type and of course not certificated and whose highest-performance models are provided with SAR modes (radio-altimeter height hold, Doppler hover, transitions, ...).

The CDV 155 coupler integrates the features of both these types of equipment, i.e. :

- it is capable not only of cruise and approach modes but also SAR modes
- it is of an advanced technology incorporating two digital computers and coupled with CRT display units (EFIS).
- it can be certificated as a whole, i.e. with functions which are not usually envisaged within the framework of certification.

2.4.2 — Coupler Development

Due to the technical difficulties normally encountered on this type of equipment, developing this coupler took several months. Summarizing it in a few lines is impossible.

As usual, there were problems associated with the helicopter natural instability. For hover modes, a precise guidance was required at zero speed and for approach (Category II requirements), the stability had also to be correct at an average speed of 100 kt. Sufficient stability could only be obtained through a very careful uncoupling of pitch and collective axes.

But these are merely conventional problems just amplified by the fact that since the offered modes are more numerous, the flight envelope points to be optimized were also more numerous as usual.

Software has been developped step by step. Simulation computation helped us to define general laws ; then SFIM precisely defined these laws which were tested successfully in flight.

We will hereafter cover some subjects which appeared to us as new.

2.4.3 — Display Units

The interface between the pilot and the equipment is very important for a coupler.

With the «IRISH system», in addition to the conventional control units together with their associated «conventional» problems (as stupid as blocked keys or invisible lights), we had the opportunity to use the EFIS and their related flexibility to display data on the instrument panel.

This is a considerable improvement as compared to conventional annunciators.

It was possible, especially :

- to provide the pilot with data which are not normally available to him. For example, by changing the color of a marking on a screen, a degradation more or less severe of the flight control system can be indicated. On a conventional instrument panel, this would need an additional indicator light which is not installed due to lack of space.
- to centralize useful data on a single location :

  When performing radio-altimeter coupling on a conventional helicopter, the height is displayed on the centre console and the radio-altimeter indicator is generally remotely located on the instrument panel.

  With an EFIS, a scale is displayed with the reference on one side and the altitude hold on the other side. Monitoring the coupler is an easy game. Safety is enhanced.

  All this seems perfect and the pilots who saw these new display systems have all been very satisfied.

For us the final adjusters, it should be noted that if the result seems satisfactory, this technology has some pitfalls :

- Such a display system requires more precise performance and if, unfortunately, there is some deviation between what is demanded to the coupler and what is obtained from it, this error becomes obvious. The pilots become more demanding.
- Furthermore, modifications take long to be embodied on EFIS.

  So far, when the color of an annunciator light was not satisfactory, a filter had simply to be changed and everything was restored for the next flight. With the EFIS (especially when the manufacturer is thousands kilometers away, as it was the case), the situation is to be appreciated at the time of design well before flying and when flying it is often two late to change anything. Fortunatly, we had very few changes to perform.

2.4.4 — Digital computer

It was not the first time we developed a digital system and everything concerning the adaptation of test equipments to this new technology had already been proven. The test engineer shifted from the potentiometer to the keyboard to modify the gains.

To prevent the failures from having detrimental effects, the best is to detect them at an early stage, hence a great number of monitorings in the computer. Developing these monitorings was hard since they were generally too close and with digital systems there is no partial solution : when there is a failure, even a minor fault, the whole computer is blocked.

A safety system has been designed which did not raise any special problem and proved somewhat advanced. This is the monitoring of collective pitch in order not to exceed the power limits. It consisted initially in stopping the collective pitch when a collective mode was active, should the pilot command an excessive vertical speed for instance or any other parameter requiring a limit-exceeding power. Then, it was deemed necessary to associate a warning to this function. As the warning appeared very interesting, it is now displayed even if the coupler is not active ; thus, a power (engine or MGB) monitoring has been introduced as generated by the coupler computer, but having nothing to do with the coupler !

The digital display is a major asset for all those modes requiring a very precise control.

In ILS approach, the possibility of a very easy change in gains led to remarkable performance ; with the CDV 155 it is now possible to envisage a safe decelerated IFR approach.

For the SAR modes, the digital processing has been very helpful but sometimes involved somewhat embarassing counterparts : this is the case for swell filtering. In the analog system, this filter which proved so hard to our predecessors was a compromise and like all compromises, it showed shortcomings. After performing the flights over the Mediterranean Sea, the first flight tests over the Atlantic Ocean and its famous «stretched swell» were envisaged anxiously.

The use of simulation on ground and then of a swell simulator in flight allowed a quick adjustement of the KALMAN filter parameters.

This filter allows now detecting the impeding frequency in the evolution of parameters and adapting the control law to the daily case after some time. Hypothetical cases (crossed swell with two different natural frequencies) can still trap the system but generally swell does no longer involve any major problem.

However, this filter which proves miraculous on many points does not bring advantages only and sometimes it is necessary to introduce a few engagement restrictions (flying over a cliff or Doppler lockoff, for instance...).

2.4.5 – System Notion

A coupling system is a channel incorporating a sensor, a computer and a «muscle». The sensor and muscle are generally known and developing the mode is limited to developing the corresponding computer printed circuit board.

With the CDV 155, more complex coupling systems appeared such as the follow-up of NADIR navigation commands.

These black boxes both featuring the same complexity and produced by two different equipment manufacturers have been developed simultaneously.

The wrecked people waiting in the sea for being rescued should not have to know whether the target he represents has been missed due to incorrect navigation or because the coupler did not observe its instructions. During the development phase, it is indispensable to be provided with the test equipments and the means for arbitrating those conflicts that can inevitably be raised between those concerned to prevent everyone from off-loading the responsibility, which could result in delays only.

A good analysis means has been the ground test rig, made with the same components as the airborne system, which allowed us play-back of the records made in flight to perform closed loop ground tests.

2.5 – DISPLAY TESTS

The display units have been defined from a system developed by BENDIX for General Aviation.

It was adapted to the helicopter through the introduction of a symbology taking into account its control specificities and adding special HOVER and PATTERN modes adapted to the its intended mission. This new symbology was designed by Aérospatiale.

Globally, very few modifications were introduced further to the flight tests, may be because the choice and definition of symbols used were made from the very design by the test pilot in charge of this program and approved by the customer at this early stage ; these choices were confirmed by other pilots taking part in the development.

What are these minor modifications ?

- In sector mode, the TO-FROM arrow of the VOR was showing as on an O.B.S. : contrary to the OBS, in this mode, the compass card is mobile and this display became completely incomprehensible for some headings.

  The problem was simply solved by drawing inspiration from the display used on HSI's.

- Display of mode engagements and excessive deviations has been improved.

Two principle choices now raise some questions which are still unanswered and the verdict from operation is to be waited

2.5.1 – Display of Ground Speeds from Doppler

These data are usually displayed on a crossed-pointer indicator, with conventions similar to the ILS, i.e. the centre of the instrument has to be flown towards crossing of pointers.

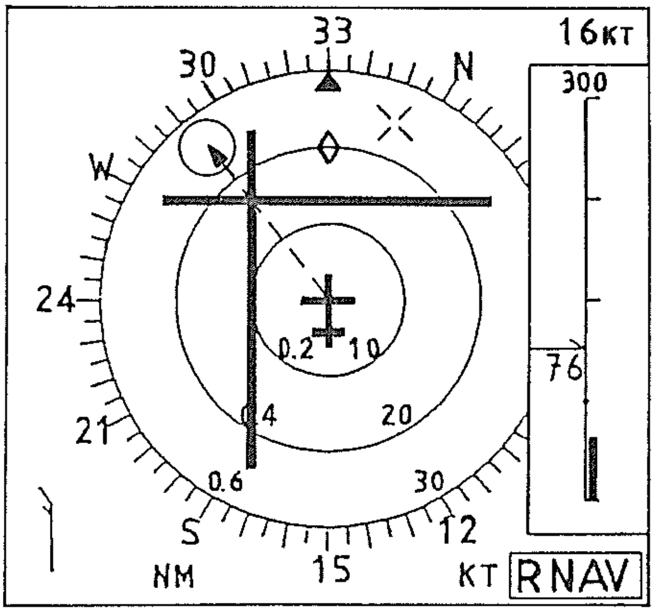
The IRISH system flight director coupler is provided with a Ground Speed mode allowing to set and trim ground speeds and the apex of the designed speed vector is displayed as a small circle in HOVER mode.

When the coupler has established the corresponding speeds, the crossed pointers move over this circle showing that stabilization is achieved.

This display is the mere «map» representation of the situation but modifies the current ground speed representation conventions and this initially raised difficulties to some «old» pilots who previously used Dopplers on other aircraft.

Taking advantage of the absence of technological constraints, we chosed to associate the roll tilt scale to the horizon and the index to the miniature aircraft. This is in fact more logical since the horizon is fixed not the miniature aircraft.

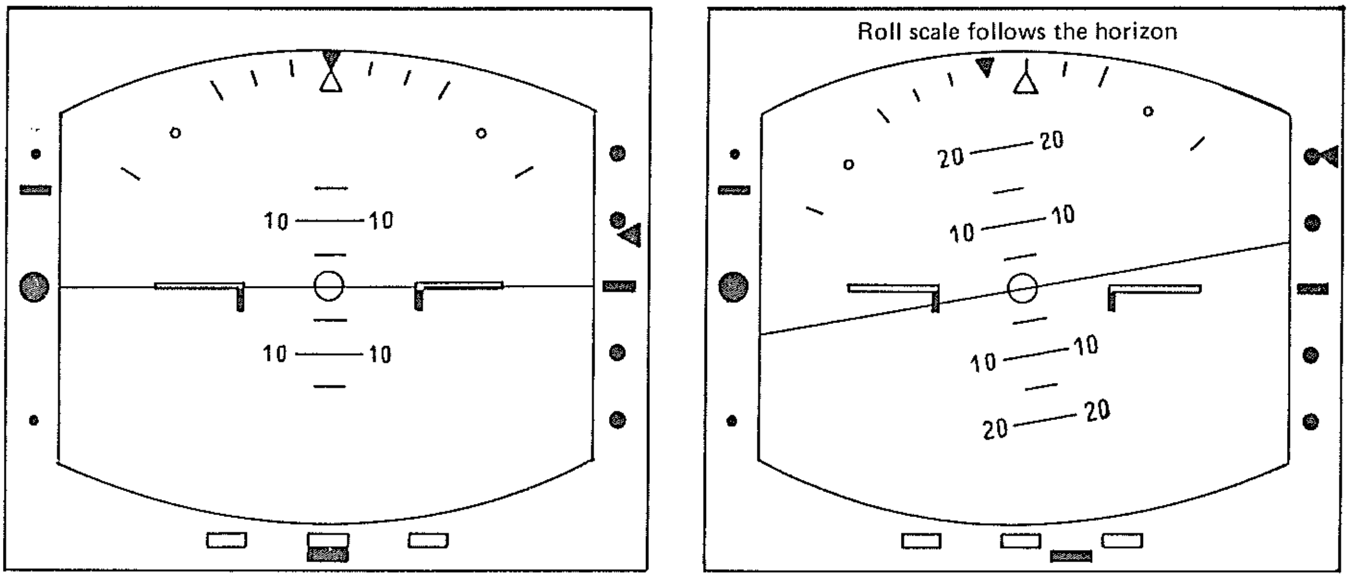
For technological reasons, this has never been done on conventional pneumatic or electromechanical horizons.



2.5.2 – Display of Roll Scale on Artificial Horizon

EFIS display

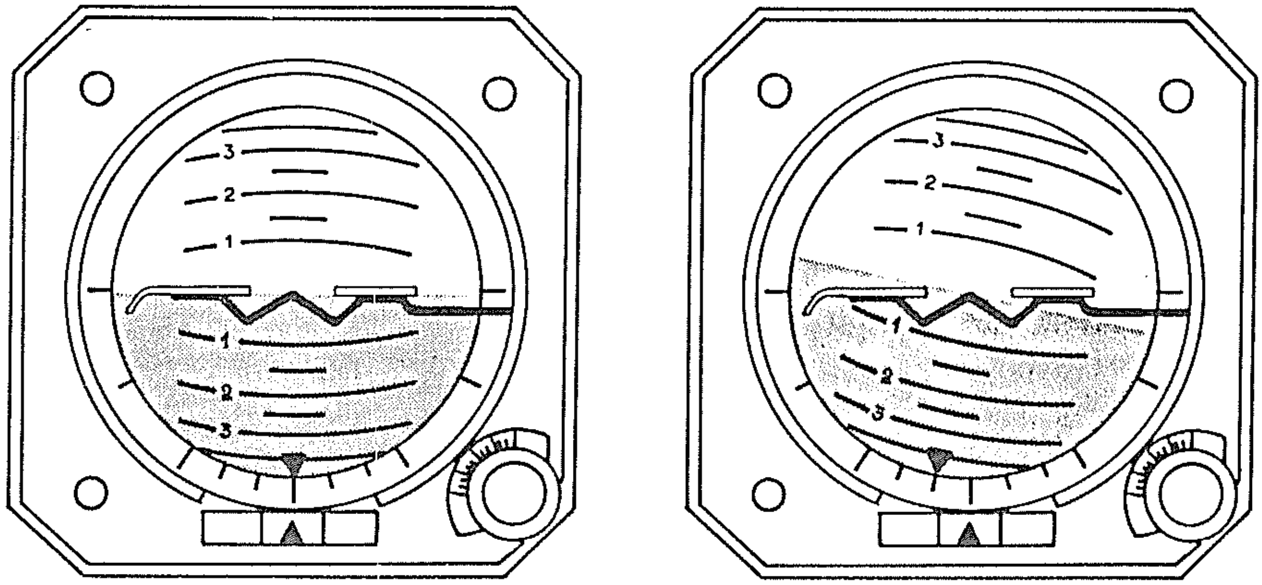
10° RH



This index can be considered as the tip of the miniature aircraft fin

Conventional display

10° LH



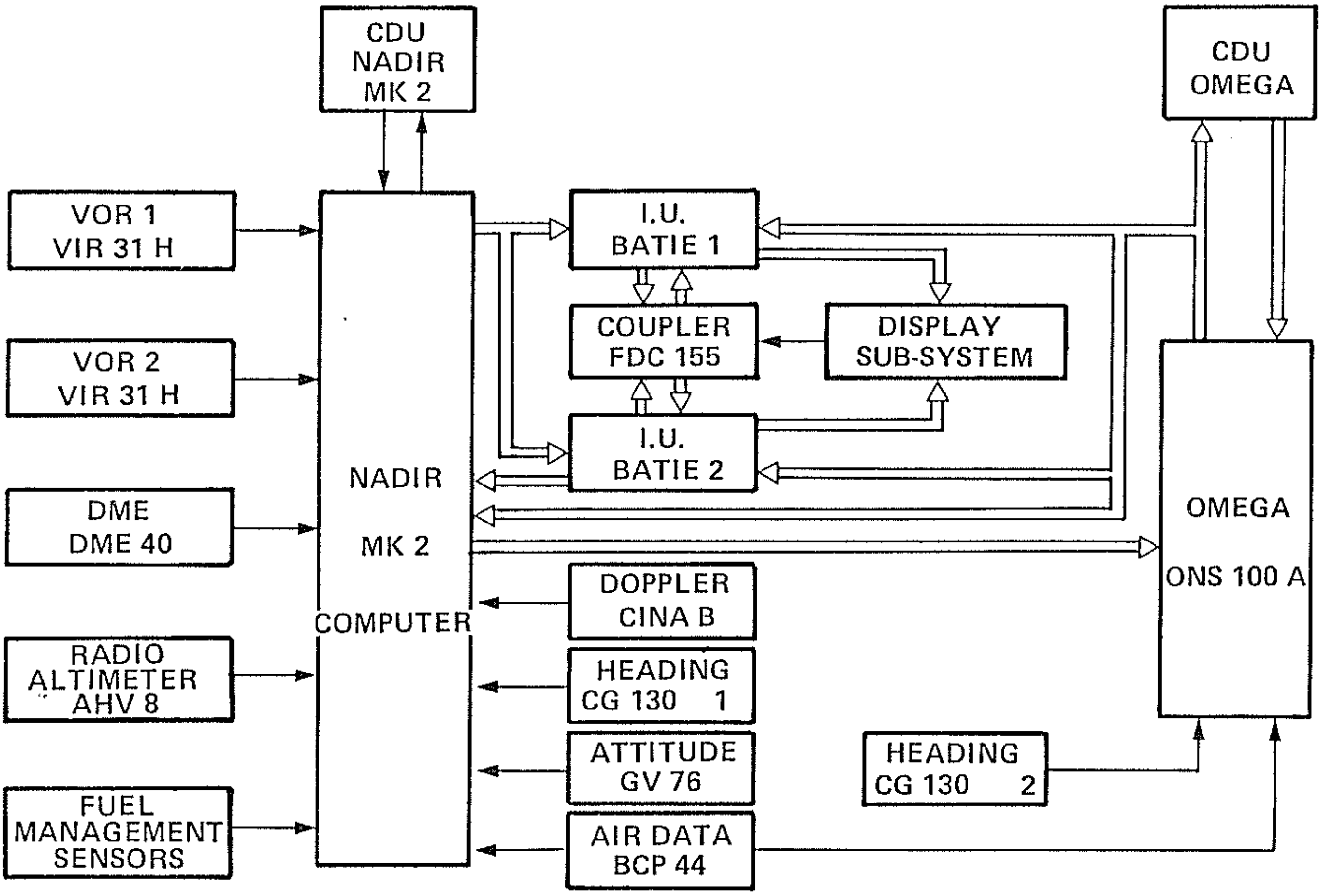
Roll scale in Roll scale is linked with aircraft

CONCLUSION

This paper describes the S.A.R. system installed on Irish SA 365 F DAUPHIN and comments on development tests performed and associated «difficulties» leading to the achievement of what is probably the most sophisticated system ever integrated on such a medium weight helicopter. Although designed for specific S.A.R. missions, the system showed during the development flights its versatility and Aérospatiale may propose it on other DAUPHIN versions as well as on the SUPER-PUMA.

APPENDIX 1

NAVIGATION SUB–SYSTEM DIAGRAM



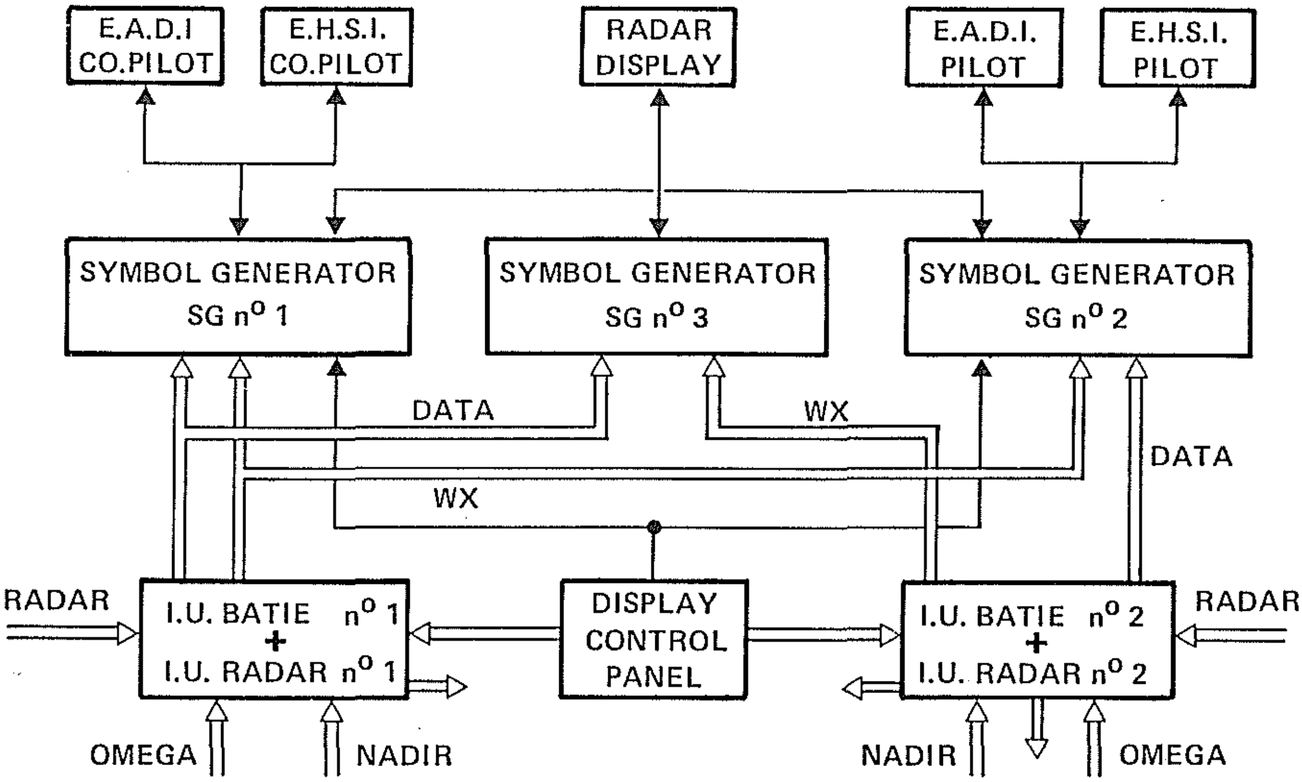
APPENDIX 2

CDV 155 FUNCTIONS

- ALT — Capture and hold of barometric altitude at engagement
- A/S — Acquisition and hold of a selected IAS
- V/S — Capture and hold of a selected vertical speed
- HDG — Capture and hold of a selected heading
- NAV — According to selection :
  - Intercept and track of a VOR radial
  - Intercept and track of a VLF Ω navigation course
  - Intercept and track of a search pattern
- LOC — Capture and track of a LOC beam } ILS
- G/S — Capture and track of a GLIDE beam } ILS
- B/C — Capture and track of a LOC back course beam
- VOR.A — Capture and track of a VOR radial in approach
- H.HT — Acquisition and hold of a preset radio-altitude in hover
- CR.HT — Acquisition and hold of a preset cruise height (radio-altitude)
- HOV — Acquisition and hold of a zero Doppler speed
- G.SPD — Acquisition and hold of V_x and V_y Doppler speeds
- T.DWN — Automatic acquisition of H.HT and HOV
- T.UP — Automatic acquisition of CR.HT and preset airspeed (75 Kt) from H.HT

APPENDIX 3

DISPLAY SUB–SYSTEM DIAGRAM



APPENDIX 4

365 F "IRELAND" INSTRUMENT PANEL