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THE EH101 DEVELOPMENT PROGRAMME

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SUMMARY

This paper describes the EH101 helicopter flight development programme from initial conception to the present day. Lessons learnt during the testing phase are highlighted and significant milestones achieved are detailed. In particular the early development testing is described in some detail.

1 THE REQUIREMENT

In the early 1980's it was becoming apparent to the Royal Navy (RN) that a replacement needed to be sought for the Sea King helicopter, the new aircraft to enter service in the early years of the 1990's. Similarly the Italian Navy (Marina Militaria Italiano or MMI) had reached a similar conclusion independently. Each service had approached their native helicopter manufacturing companies (Westland Helicopters (WHL) as was and Agusta Helicopter respectively) to initiate feasibility studies of the replacement aircraft. With a similar specification drawn by both services it became obvious that a collaborative venture to fulfill both requirements was a good idea, hence an independent company called E H Industries (EHI) was set up to manage the programme. This company, based in London, would be a joint WHL and Agusta holding. EHI realised that the payload, range, reliability and overall aircraft performance required by the two Navies would provide a potential world beating civilian aircraft to replace the many Sikorsky S61 type aircraft operating offshore, similarly the internal dimensions required could be used to produce a long range medium size tactical transport and Utility aircraft.

The bold decision was made to develop 3 core variants of the same airframe to meet Civil and Military rules and to fulfill Naval, Civil passenger and civil/military utility and Search and Rescue roles simultaneously, the EH101 project was born in 1981 with the signing of Memorandum of understanding (MOU) 2, Project Definition.

It was realised that with such an ambitious programme a large amount of testing, both on the ground and in flight would be required. It was therefore decided to construct 9 pre production flight vehicles, PP1 - PP9 inclusive and several non flight complete airframes or powered rigs. The most significant of which are the Avionics airframe for lightning/EMC testing and the 'GTV' (Ground Test Vehicle or 'Iron Bird'). The GTV is a ground based transmission, electrical system and rotor rig powered by the requisite engines. It is fully representative of the transmission system and its use to support the flight development programme will be described later.

The initial workshare and allocation of the 9 aircraft is described below.

A/C	Type	Location	Task
PP1	Basic Naval	WHL	Basic Vehicle Development
PP2	Basic Naval	Agusta	Basic Vehicle Development
PP3	Basic Civil	WHL	Basic Civil Development and AFCS
PP4	RN	WHL	Basic Naval Systems/EIS Development

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PP5	RN	WHL	RN Mission Systems Development
PP6	MMI	Agusta	MMI Mission Systems Development
PP7	Military Utility	Agusta	Basic Utility Vehicle Development
PP8	Civil PAX	WHL	Civil Specific Development
PP9	Civil Utility	Agusta	Civil Specific Development

In addition the GTV was based at Agusta.

The initial allocation of development tasks has remained fairly constant, primarily due to the inherent build standards defined at initial build and to the complexity of the instrumentation required, the most significant alteration to the allocation of tasks was that PP4 undertook installation tests of the RN selected RTM322 engine, more of which later.

At this point a few salient features of the aircraft as initially flown are pertinent.

AUW (kg)	13000
Nr (%)	100
Vne (kias)	120
Transmission	4640 SHP

The aircraft has a fully articulated rotor head fitted with advanced planform blades derived from the British Experimental Research Programme (BERP) that gained WHL the absolute helicopter speed record in 1986.

2 THE EARLY DAYS

The flight programme was initiated on 9 October 1987 when WHL Chief Test Pilot Trevor Egginton applied collective and PP1 became airborne at Yeovil, England watched by most of the factory staff, the programme soon gathered momentum when PP2 joined the flying programme in November 1987.

After 50 hours cumulative flying the aircraft was presented to the Test Centres of the UK and Italy for the first Official Test Centre (OTC) review involving UK and Italian military personnel. Vibration levels of both 1R and 5R were higher than expected, some handling problems, especially during low speed manoeuvring were apparent, aircraft performance figures were disappointing, and at high speed a lateral shake, christened 'shuffle' was noted. As development testing progressed, the inefficiency of operating the two instrumented basic development aircraft (PP1 and PP2) at different sites in two countries was noted. It was decided that the most beneficial way to improve the situation would be to base the aircraft at the same location; Cascina Costa in Italy, the home base of Agusta Helicopters was the logical choice. The weather being better for testing and with Agusta facilities on site to provide support to the transmission and rotor systems which were regarded as the critical components at this phase of the programme. PP1 left the UK in October 1988 and joined PP2 to inaugurate the 'Single Site Operation' (SSO).

3 SINGLE SITE

The Single Site Operation was a major undertaking for both companies but justified the effort put into the operation, as the aircraft successfully completed basic vehicle development. With hindsight the operation should have been planned from the beginning, A few details of the techniques used and results obtained are described below.

3.1 Prioritisation

Prior to the start of the operation the issues requiring development were prioritised in order to allocate technical expertise to providing a solution.

3.2 Specialisation

Due to the workshare between Agusta and Westland agreed at the contract signature it was obvious that either one company or other 'owned' the solution and could allocate the appropriate technical expertise, however this did not apply to the assets used on the operation, PP1, PP2 or the GTV could be (and were) used to data gather on any task as the programme dictated. Within the resident team 'specialists' were allocated from within the Flight Test or Technical teams as being individually responsible for ensuing testing was achieving the required results, this is a philosophy we still use in GKN Westland.

3.3 Flexibility

One of the advantages of having a small dedicated team in one location was the knowledge that all members of the team had of the overall programme activities, this allowed cross fertilisation of ideas between specialists which was also true of the different national outlooks and experiences, Italian expertise aided British and vice versa, the greatest problem being the cultural differences of the two countries.

4. DEVELOPMENT TECHNIQUES USED AT SSO

4.1 Cures for Pitch Up

One of the characteristics requiring investigation was a "pitch up" during transition to forward flight, this manifested itself as a forward cyclic stick movement input at approximately 17 kts which was unacceptable from a pilots handling view. Early flights with the original symmetric tailplane removed showed that rotor wake impingement onto the original symmetric low set tailplane was the source of the problem (Fig1).

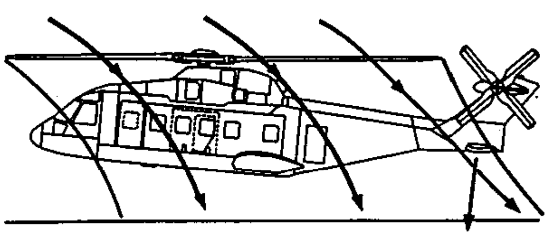

FIG 1) THE SOURCE OF PITCH UP

With that knowledge a range of tailplanes were tried, eventually leading to two solutions; a 'traditional' high set tailplane and a low set asymmetric tail plane which used the fin to blank the rotor wash and reduce wake impact effects (Fig 2). The results of which can be seen in Figure 3. Both of the latter were deemed acceptable during a 'Fly off' competition held by the respective government test agencies on an Italian Navy Frigate .

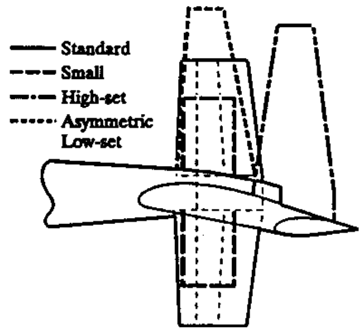

FIG 2) TAILPLANE CONFIGURATIONS ASSESSED

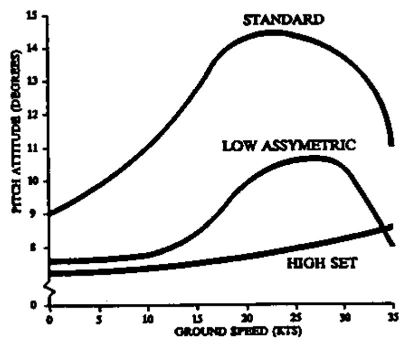

FIG 3) PITCH UP DATA

The final decision coming down in favour of the low asymmetric tailplane for strength, weight and ease of incorporation into the existing design reasons, also it could be folded.

4.2 Aerodynamic Improvements

4.2.1

As mentioned previously the 'shuffle' phenomenon was a lateral tail shake, which has been seen before on other helicopters. Wind Tunnel tests and 'tufting' on the cowlings of PP2 showed that rotor head vortices were exciting the lateral natural frequency of the tail unit structure (Fig 4), (it was apparent on both Naval and Utility variants proving that rear fuselage shape had no or little effect). The obvious thing to do was to divert the vortices away from the tail area and/or to reduce them.

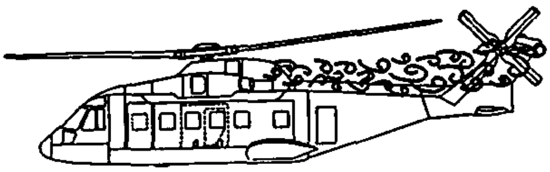

FIG 4) THE SOURCE OF SHUFFLE

Many helicopters are fitted with a domed rotor head fairing colloquially known as a "Beanie". Numerous Beanie designs were tried known by such names as the Teeny Beanie, Fried Egg Beanie, Chinese hat beanie, Big Beanie or Frisbee Beanie, all with varying degrees of success. In addition a fairing around the top of the centre engine cowling known as the 'horse collar' was fitted that produced down swept vortices which entrained the rotor head vortices away from the tail (Fig 5). Shuffle was gradually being reduced.

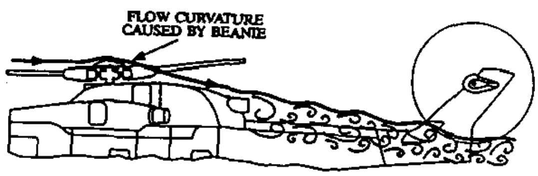

FIG 5) BEANIE EFFECT

4.2.2

A further development activity was drag reduction, This involved the wind tunnel at Yeovil spending many hours producing designs that could be easily built and test flown, again a product of a dedicated team that allowed a fast turnaround of design to hardware to test. Large fairings on the rotor head to smooth the articulation areas of the head were built and flown, broadly based on the WHL design used on the speed record Lynx they produced very significant drag reductions and helped cure shuffle as a by-product.

4.2.3

Other performance losses were obvious in the hover, a notoriously difficult regime to ensure clean airflow within. The EH101 suffered in its early days from excessive exhaust gas reingestion (a problem only associated with Vertical Take-off aircraft). To determine the shape and magnitude of the gas patterns a smoke generation system was installed into each exhaust comprising a small electric driven pump, nozzle and a cabin mounted diesel fuel tank. The fuel was sprayed into the exhaust to produce a visible gas wake from each engine in turn. Infra Red cameras had been used but the volume of gas produced in the hover negated their effectiveness. Normal video equipment was used to record the gas flows associated with different experimental exhaust pipes. Each was also assessed quantitatively by measuring intake temperatures in the engine intakes with a matrix of pressure and temperature probes. The results of the development can be seen in Figure 6.

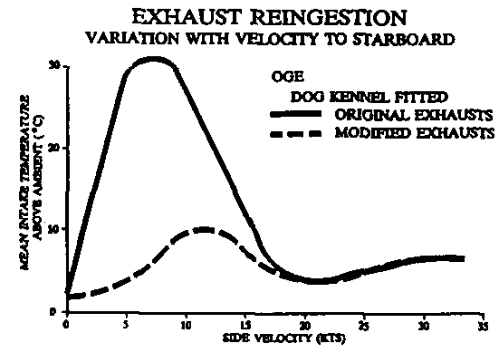

FIG 6) REINGESTION DATA

The wind tunnel had also been improving the BERP blade design with the production versions of the Lynx Composite Main Rotor Blade (CMRB), these improvements were read across into the EH101 blade and retrofitted, most noticeably the tip section was given a degree of anhedral to improve wake interaction in the hover.

Tail rotor power was also investigated, apart from fitting a strengthened 'teetering' tail rotor design, aerodynamic improvements made to the rear fuselage included a reduced area fin with a tailored rear section and addition of a horizontal strake to which reduced circulation induced side thrust. Luckily the area at Cascina Costa is located in a low windspeed environment and many of the above fixes were easy to quantify in the calm air in Italy, the testing would have been impossible in the UK, again justifying the effort put into the SSO.

As with all testing there are tradeoffs and compromises to be made, however the aerodynamic issues discussed above seemed to interact well and a benefit in one area would manifest itself in another so the entire aerodynamic improvement task was effectively one package that was retrofittable to the entire EH101 fleet, this is summarised in Figures 7 and 8. At the end of SSO solutions existed to:

a) Shuffle
b) Level flight power consumption
c) Hover power consumption
d) Tail rotor authority
e) Exhaust gas reingestion and installed power losses.

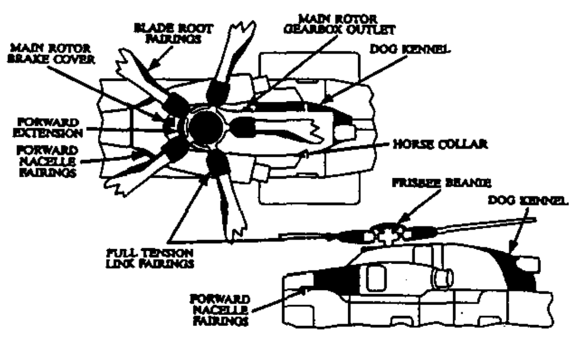

FIG 7) AERODYNAMIC IMPROVEMENTS 1

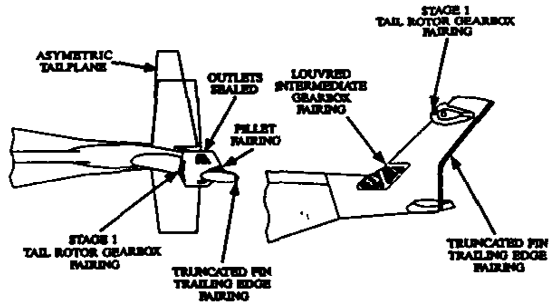

FIG 8) AERODYNAMIC IMPROVEMENTS 2

4.3 5R Vibration Improvements

Levels of airframe vibration were higher than expected at blade passing frequency (5R). Structural modifications were incorporated to stiffen the fuselage as well as passive vibration absorber devices which are traditionally used to cure vibration problems in rotary wing aircraft . Both a double stacked Lynx helicopter main rotor head mounted vibration absorber and a trial installation of cabin mounted vibration absorbers were assessed and showed noticeable reductions in some 5R levels within the cabin but with a large weight penalty. Meanwhile back in Yeovil a new system of active vibration absorbtion using compliant gearbox mountings hydraulically actuated had been developed. Known as ACSR (Active Control of Structural Response) this revolutionary system uses the inherent dynamic response of a fuselage to counteract blade induced vibrations. The EH101 installation is the first practical active vibration absorbtion system in use and was developed on PP3 in the UK. This system at a stroke massively reduced the 5R vibration levels (in some cases by 90%) and is fitted as standard to all EH101 Aircraft. See Figure 9.

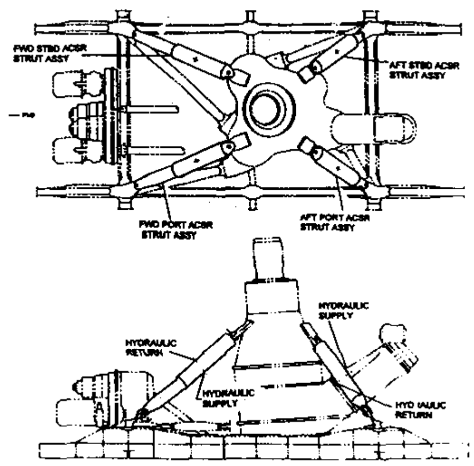

FIG 9) ACSR INSTALLATION

4.4 SSO Achievements

In summary after the Single Site Operation completed its remit there existed or were in design improvements in all areas under development. In the final months a further OTC assessment was carried out to verify the SSO findings, The conclusions matched the comr 'nies. Many of the solutions were not flight tested as the GTV and ground rigs were used to quantify the improvements to transmissions and structural components but being under the control of the SO itself helped to integrate this aspect of the development task into the whole aim of the operation, to cure the problems.

By comparison the improvement in aircraft characteristics before and after single site are as follows;

	Before SSO	Post SSO
AUW (kg)	13000 kg	14290 kg
Nr (%)	100	100/102
Vne (kias)	120	167
Transmission	4640 SHP	5200 SHP
Altitude	10000 Ft	15000 Ft
Low Spd Env	20 kts	50 kts

The aircraft was now able to be used throughout its envelope to increase its mission performance and to serve as a basis for specific systems development.

5 SIGNIFICANT TRIALS POST SSO

Post Single Site all 9 aircraft were flying with new priorities, predominately with respect to PP1 - PP4. Basic vehicle envelope expansion continued with the aim of achieving a limited civil variant release in 1994, an icing clearance and with the awarding of the Royal Navy Merlin contract, integrating of the RTM322 engine into the EH101 airframe (more of which later). The tragic loss of PP2 in January 1992 had a major impact on the programme and milestones slipped approximately a year.

PP5 had a successful first flight with all mission systems and 'glass cockpit' working including a night landing. This boded well for an intensive mission system and naval specific test programme which included Ship Interface trials with the Royal Navy Type 23 frigates HMS Norfolk, HMS Iron Duke and HMS Northumberland (Fig 10). This series of tests proved the maintainability of the aircraft in the naval environment and its operability of frigate sized vessels, including cross winds of 40 kts and ship deck motions in all axes. The hydraulic deck lock and deck handling system was tested and gave confidence that longer duration tests will not be a problem.

FIG 10) PP5 ON HMS IRON DUKE

PP3 carried out trials in Denmark and Canada and returned with an icing release down to -10°C, it proved flight in snow (both precipitating and recirculating) was feasible and that cold soaking overnight still allowed starting and flight. The heated blades were exercised which provided valuable data to be read across to the production heated blade and the forthcoming cold trial in Sweden, again on PP3. The instrumentation fit on PP3 was extensive and included fixed and rotated cameras, ice and snow detector system and comprehensive strain gauging and temperature monitoring including transparencies and main and tail rotor hubs and blades (FIG 11)

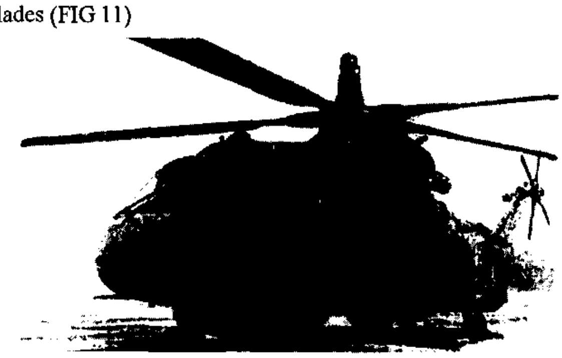

FIG 11) PP3 IN SNOW

PP7 and PP1 carried out the major load data gathering task required to substantiate the 10000 hr structural fatigue life required by the customers and proved the CT7-6 engine was exceptionally reliable.

The major drive during 1993 and 1994 was achievement of the Civil Airworthiness Authority Type Certification (TC) of the EH101, in both Passenger and Utility Variants. by CAA, RAI and FAA simultaneously. Most of the development fleet participated in this task with the exception of the dedicated naval variants. The target certification was for an aircraft as previously described as the baseline post SSO. All the labour paid off with issue of 6 Type certificates on 24 Sept 1994, 3 Authorities approval for 2 variants of 1 aircraft.

6 MERLIN

As a result of the selection of (then) IBM ASIC in September 1991 as the prime contractor for the Royal Navy Merlin programme, significant build standard changes were introduced to the basic naval variant baseline standard including a dipping sonar, colour tactical displays and a more comprehensive tactical system. New engines were also specified, the testing of which was carried out on PP4. The additional equipment further increasing the basic weight of the aircraft thus giving more work for the basic vehicle test aircraft to carry out. The selection of IBM as prime contractor required a change in approach to development and qualification flight testing for both Westland and Agusta as several new layers of procedure and monitoring were introduced to manage the qualification programme.

Merlin as a separate entity within the overall EH101 programme has a noticeably different emphasis on the type of testing required. The Merlin test fleet comprises PP5 and the first 4 production aircraft. These will be used to validate and prove that the Merlin system meets the targets set within the specification. A further significant change is that the aircraft are controlled by the prime contractor (now Lockheed Martin ASIC) rather than EHI itself which provides the aircrew and technical backup to meet the test requirements. The final steps in the qualification process are the Operational Performance and Acceptance Procedures trials, which involve Royal Navy crews using the aircraft to show compliance with the requirements of specific role and tactical scenarios. Two production aircraft are to be used for this very intensive series of trials, with PP5 avaiulable as the backup if required.

Meanwhile the first production aircraft RN01, has been returned to temporary EHI control to complete the qualification processes that require production standard items to be evaluated. When these tests are finished the aircraft will be handed back to Lockheed Martin ASIC control.

As part of the 'Merlinisation' of the Naval EH101 PP4 carried out the integration work involving the Rolls Royce - Turbomeca RTM 322 turboshaft engine, the earlier aircraft and GTV not being suitable due to the digital control configuration of the engine itself, this mandating a 'Glass' cockpit aircraft. The engine integration work progressed smoothly despite the installation requiring significant changes to the engine bay and cowling structure, these giving valuable advanced knowledge prior to building the production aircraft. Significant lessons were learnt during the engine integration work , the limited experience WHL had gained when fitting the T800 engine experimentally to the Lynx in 1992 proving invaluable. PP4 was lost during a high altitude test flight on April 7th 1995, the crew of four establishing a world first by successfully parachuting from the aircraft and surviving. This required changes to the test plans that mainly involved a far greater involvement of the first production aircraft.

7 THE PRESENT AND FUTURE

The EH101 programme is now leaving development behind and is winding up for production with the Integrated development program being fully completed by the end of 1996. We now have the first production aircraft flying in Yeovil generating final qualification data for the productionised components which have arrived from the development testing. RN01 as it is known is currently carrying out engine installed performance and structural load survey data gathering as part of the production standard qualification process, RN02 will join the Merlin Team trials fleet very shortly and complete the naval systems integration with the Royal Navy standard of Dipping sonar and tactical systems. CIVIL 01 flies early in 1997 and will be used to increase the envelope as initially cleared in 1994 to the final design standard. A major change in the civil aircraft approach is that the certification basis for all future civil EH101 aircraft will be to the new JAR29 rules.

The aircraft enhancement during development is summarised below and shows the improvements in the aircraft over the years.

	Initial	Post SSO	Production
AUW (kg)	13000	14290	14600
Nr (%)	100	100/102	102
Vne (kias)	120	167	167
Transmission	4640 SHP	5200 SHP	5200 SHP
Altitude	10000 ft	15000 ft	15000 ft
Low Spd Env	20 kts	50 kts	50 kts
Bank Angle	30 degs	45 Degs	60 degs

Two significant events in the last 18 months are worthy of note. The first of which has been the award of the RAF Support Helicopter contract to Westland to supply 22 EH101 SH, now known as Merlin HC3, to the Royal Air Force beginning in 1998. This contract introduces a whole new range of capabilities to this already capable aircraft including an Air-Air refuelling facility and a full Night Vision goggle environment. Planning is well underway for testing these aircraft.

The Intensive Operations Flying Programme has commenced using PP8 and PP9, this programme uses both aircraft flying representative sortie profiles of naval and civil variants to show systems maturity and to provide real data for maintenance calculations. In total 4000 hours of flying data will be gathered on these two aircraft at Brindisi and Aberdeen over the next 3 years.

As regards the other development aircraft PP3 is going cold again in 1997, probably to Sweden and will provide full cold release data for all variants, this will be the end of its useful life and it will join PP1 (now also retired) as a ground test rig. PP6 and PP5 are carrying out the completion of the common AFCS and naval avionics qualification prior to being allocated to the National specific naval avionic qualification exercises. PP7 on completion of its current flying block, gathering the final confirmatory load data with the production civil main rotor head, will enter a major lay up before being shipped to the USA to carry out hot and high tests at Leadville Colorado and Edwards Airforce base California. Thereby with PP3 completing the climatic release for the production civil and naval variants.

So far orders have been received for a total of 82 aircraft, 44 Merlin HM1 for the Royal Navy, 22 Merlin HC3 for the Royal Air Force, 16 EH101 for the MMI. The first civil order , for a far east customer is imminent. which is expected to be the first of many such orders. Following the disappointment of the cancellation in 1993 of the Canadian Order for 50 aircraft EHI are confident that the Cormorant SAR variant of the EH101 will be selected to replace the Labrador aircraft currently in service.

Th EH101 programme has been both exciting and challenging to all parties involved over the last few years, the end result of the effort put into the project is the most advanced rotorcraft now in production and one that will be seen around the world for many years to come.