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THE WESTLAND LYNX / BERP III ROTOR MANOEUVRE TRIAL

BY
C.KEATING

PRINCIPAL FLIGHT TEST ENGINEER
WESTLAND HELICOPTERS
YEOVIL, ENGLAND

FIFTEENTH EUROPEAN ROTORCRAFT FORUM

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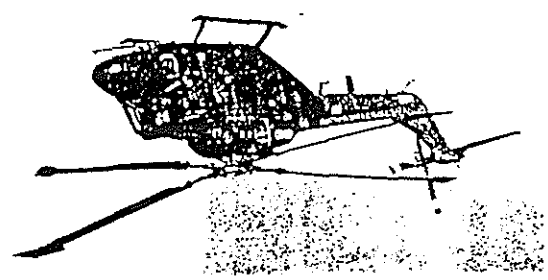
C Keating
Principal Flight Test Engineer

Flight Test Department
Westland Helicopters Limited

ABSTRACT

The flight trial undertaken to investigate the performance of the BERP rotor system in steady state and transient manoeuvring flight is described. The test method that was used to build the rotor manoeuvre data base is detailed and the general conclusions of the trial discussed.

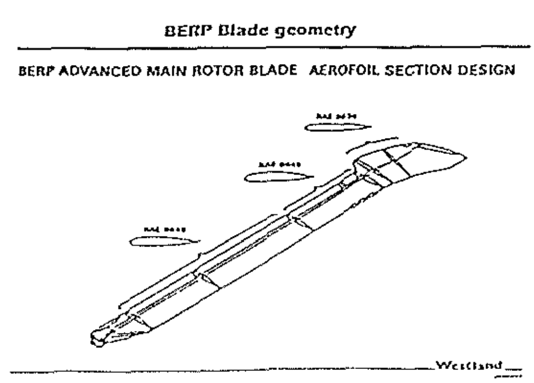


1. Introduction

The British Experimental Rotor Programme was a joint activity between Westland Helicopters and the UK Ministry of Defence to investigate the use of composite structures and advanced aerofoils. The rotor evolved from this programme has a unique aerodynamic configuration.

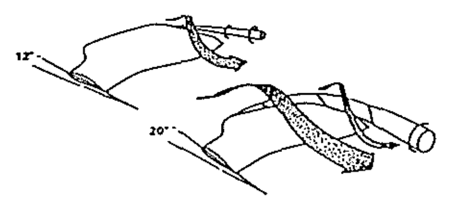
Three aerofoil sections are used in a blade of the same root chord and radius as the standard Lynx blade. The most obvious feature of this advanced blade is the distinctive tip planform.

The main lift section of the blade is of the RAE 9645 aerofoil. The nose down pitching moment of this section is balanced by the nose up pitching moment of the RAE 9648 section which extends from the blade root to 63.5% radius. (See Figure below).



The advanced tip uses the thin RAE 9634 section. The leading edge notch formed at the transition of the aerofoils at the tip acts as a low drag aerodynamic fence. This prevents flow separations initiated by stall at the inboard sections propagating into the tip region. The sharp sweepback at the outboard edge of the tip promotes vortex flow at high angles of attack and prevents the tip from stalling conventionally. (See Figure below).

BERP Tip High Angle of Attack Behaviour

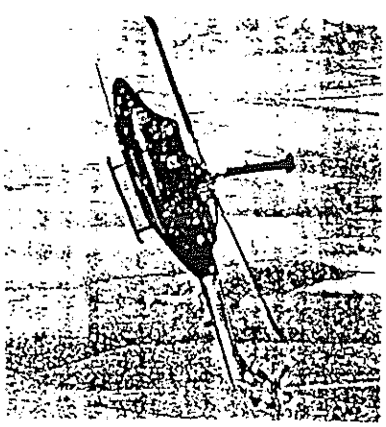


Westland

The increase in thrust over the conventional Lynx rotor equates to approximately 37%. Thus for the same ambient conditions the BERP rotored Lynx has a large margin of thrust available over the conventional rotored aircraft.

This thrust margin was demonstrated in 1985 in a level flight experiment where blade stall limited speeds were increased by margins of 45 to 70 Kts depending upon altitude and culminated in gaining the absolute world speed record for helicopters in 1986. The trial described herein was designed to investigate how the improved performance of the BERP rotor read across to manoeuvring flight.

The BERP III manoeuvre trial was undertaken to investigate the performance of this new rotor system in manoeuvres, in both steady state turning and transient conditions. The trial was undertaken as a logical development in the series of test and demonstration programmes of the BERP blade.



2. BERP Flight Development Programme

The BERP III blade first flew in August 1985 on Lynx XZ170. This initial stage of test flying concentrated on the basic handling, dynamics, vibration and performance. (Reference 1).

A sedate 30^{o} of bank was the maximum cleared at this stage. At the conclusion of these tests a series of short demonstrations were made to the UK services to show the potential of the new technology.

In April 1986 a 15 hour flight programme using a specially instrumentated blade commenced. The blade had 60 pressure transducers carefully positioned over its upper and lower surfaces together with a comprehensive strain gauge fit. The aim of this exercise was to obtain an understanding of the mechanisms of flow around the blade. (Reference 2).

From this initial flying it was apparent that the performance of the blade was such that given a suitable vehicle and rotor drive system, the rotor could set a new helicopter absolute world speed record by a handsome margin. To this end the company demonstrator aircraft G-LYNX was prepared with a Westland 30 transmission system and uprated GEM-60 engines, together with relatively minor aerodynamic modifications to the airframe.

This aircraft in the hands of then Chief Test Pilot, Trevor Egginton, set a new absolute speed record of 400.87 Km/h on 11th August 1986. (Reference 3), 1 year exactly from the first flight of the BERP rotor.

In February 1987 the blades were demonstrated to the US Army on a standard production Mk 7 Lynx. A degree of disappointment was expressed as to the limited manoeuvre envelope that could be demonstrated at that time and indeed this sowed the seeds of the trial described here.

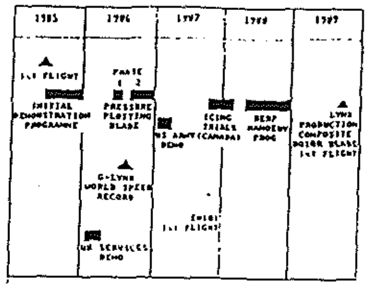
Further experience with the blade was gained during icing flying at Ottowa Canada in the winter of 1987/1988. The envelope investigated showed that the blades would enjoy an icing clearance at least as good if not better than the conventional Lynx blade.

During the time of this trial the new EH101 helicopter made it's first flight. BERP technology has been applied in the design of its rotor system. Development flying of the five prototypes continues.

The 77 flying hour trial that is the subject of this presentation commenced in July 1988 and continued until Christmas.

The final phase of the development cycle will commence when the Lynx AH Mk 9 flies in the autumn of this year with the production Lynx composite blade fitted. The blade will then be cleared for retrofit on all Lynx variants currently in service.

The philosophy of the development programme was to demonstrate the primary technology benefits with a level flight experiment and then follow up with a series of trials aimed at exploring the overall capabilities of the rotor system. These tests were spaced at a timescale that would allow analysis and assimilation of the data generated.



BERP DEVELOPMENT PROGRAMME.

3. Objective of Manoeuvre Trial

The trial objective was to conduct a scientific experimental flight trial to explore and define the improvement in manoeuvreability and controllability of a Lynx aircraft fitted with BERP blades to the limits of the demonstrator airframe and to blade loading levels well beyond the capability of the standard metal blades.

The rotor performance was to be defined by using entry conditions in terms of blade loading co-efficient (CT/S), advance ratio (μ) and to investigate the effects of pitch rate on blade performance.

The information collected during the trial would have direct applications for new tactical rotorcraft where rotor size may be set by manoeuvres requirements. The traditional means of providing manoeuvre capability by overblading leads to weight and performance penalties in the hover and cruise.

Use of BERP Technology gives performance advantages in all areas.

4. Aircraft Build Standard for the Flight Trial

The Lynx was designed as a multi role battlefield aircraft and for small ship operation. The semi-rigid rotor system provides for high control power and response rate and thus the Lynx was an ideal trials vehicle for this series of tests.

The trials vehicle used for the BERP manoeuvre trial was the first production Lynx AH Mk 1, now some fourteen years old and progressively updated to the current Mk 7 standard. The Mk7 variant differs in having an increased AUM, new reverse direction tail rotor, modified gearbox and uprated engines.

This aircraft has been used for many trials over the years and was the airframe used during the initial BERP test flying.

For the conduct of this trial increased power GEM-60 engines were installed and the passive vibration absorber, employed on the Lynx Mk7 was removed so as not to mask any vibration cues.

The main rotor blades, engines and dynamic components were previously used by the company demonstrator G-LYNX to set the world speed record.

As this airframe and dynamic components will be utilised in the Lynx Mk 9 development programme care was taken during the manoeuvre trial not to predjudice the fatigue lives of these components.

To enhance flight safety during the trial an audio 'g' warning system was fitted to the aircraft. This was set at the relevant maximum level less ten percent to cater for any overshoots that may have been caused by the rapid onset of 'g' during the manoeuvres. A rate warning system and a visual display within the direct vision of the pilot aided the precision flying of the manoeuvres necessary for the conduct of the trial. To assist accurate flying a digital angle of bank display was also fitted.

The aircraft was fitted with a comprehensive instrumentation system for the trial. The main rotor blades and head, tail rotor and fuselage were extensively strain gauged.

In addition atmospheric data, acceleration at various airframe stations, rates and attitudes were recorded. In all the instrumentation system measured 120 parameters. These were recorded on the aircraft mounted MODAS (Modular Data Acquisition System). Selected parameters could be telemetered down to a ground station manned by up to seven technical specialists monitoring the trial in real time.

Also fitted within what was by now a very cramped cabin was a video monitor camera and an oxygen life support system necessary for use by the crew when operating at the high altitudes reached during this trial.

In order to rapidly adjust flight conditions and to accurately set up the correct blade loadings as fuel burnoff occurred a small Casio personal computer was carried programmed with the relevant performance parameters.

5. Flight Trials Structure

5.1 Trials Programme

The flight trial was split into three distinct phases.

Phase 1 was to investigate sustained manoeuvres.

Phase 2 investigated transient manoeuvres.

Phase 3 combined the elements of phases 1 and 2 into what was termed the demonstration sequence.

The trial was structured in this way so in order to separate out the individual elements of each manoeuvre.

Phase 1 investigated sustained turns to the Port and Starboard at increasing angles of bank. Phase 2 looked at manoeuvres in the pitching plane followed by manoeuvres in the rolling plane and then manoeuvres in the combined pitching and rolling planes.

Datum measurements using the standard Lynx "metal" blade were performed during the first two phases allowing for a direct back to back comparison.

Phase 1 involved flying at various angles of bank at different blade loadings and advance ratios. The aircraft weight for the trial was maintained at the lowest practical value without ballast. In practice due to the considerable amount of instrumentation fitted this was well above the aircraft's minimum operating weight. This allowed the aircraft it's maximum 'g' capability which would not have been possible if ballast was used to increase blade loading. It was also desirable to maintain pitch and roll inertias constant throughout the trial for handling assessment. To increase blade loading the aircraft was flown at a high altitude. In practice this meant flying at constant $W/\sigma n^2$ for each test point at a constant TAS/n. For each test point a constant $n/\sqrt{\theta}$ was maintained in order that power consumption in steady state manoeuvring flight may be measured. The $n/\sqrt{\theta}$ was chosen for each test point such that it would result in a rotor speed close to the normal governed value.

Phase 2 was performed at the same test points flown during Phase 1 with the exception of the lowest IAS. This was so that the entry conditions for each manoeuvre were of a known blade loading. The transient manoeuvres investigated were Symmetric pull ups, Symmetric push overs, Rolling pull ups, loaded/unloaded roll reversals, and wind up turns.

Phase 3, the "demonstration sequence", built on the manoeuvres investigated during Phases 1 and 2 by combining them into the set piece manoeuvres. These manoeuvres included loops, axial rolls, barrel rolls, wing overs, torque turns, hammer heads, split 's' and a number of other representative tactical manoeuvres.

5.2 Phase 1
Sustained Manoeuvres

The sustained manoeuvres consisted of stabilised turns to both port and starboard. Three values of $W/\sigma n^2$ were achieved by performing the tests at successively higher altitudes.

$W/\sigma n^2$ values of 9000, 11000 and 13000 lb were flown at $n/\sqrt{\theta}$ s of 1.03, 1.05 and 1.07 respectively. Each condition was repeated for TAS/n of 60, 100 and 140 kt.

The technique adopted to attain the correct $W/\sigma n^2$ for the manoeuvres was to estimate the aircraft weight at the nominal test altitude and to calculate a W/δ and hence pressure altitude that gave the correct $W/\sigma n^2$ for the $n/\sqrt{\theta}$ to be tested. The aircraft was then climbed to that altitude and the W/δ calculation repeated for the actual on "condition" weight of the aircraft, adjusting pressure altitude to suit. Once the OAT had stabilised the rotor speed was adjusted to give the correct $n/\sqrt{\theta}$ and the IAS to achieve the correct TAS/n calculated and set. Using the digital angle of bank indicator a 30^o sustained turn was set up and the condition recorded.

The bank angle was increased to 45^o and conditions then allowed to stabilise. Bank angle was further increased in 5^o increments until a 'g', torque or handling limit interceded.

This technique enabled the effect of pitch rate on the sustained manoeuvre boundary to be assessed.

The sustained turn envelopes demonstrated showed significant increases in performance of the BERP over the Metal blade.

The BERP blade did not exhibit the sharp vibration rise characteristic of the metal blade which warned the pilot of the onset of stall. Indeed the limits reached on the BERP blade were mostly power and gearbox torque limits. In cases where the flight envelope limits were approached the main cue was a reduction in control response to lateral cyclic inputs.

To achieve a sustained level turn at the test point at bank angles of over 50^o proved to be a very difficult and high workload task for the pilot, it being very easy to build up a rate of descent or climb and a degree of practice was needed before a good performance point could be flown. In addition the precision of the flying necessary meant that after turning 360^o the aircraft hit its own wake and could drop up to 50 ft so the time on condition for performance measurements was minimal at the lower TAS/n's. Note that at 60 Kts TAS a full 360^o turn could be executed in less than ten seconds.

5.3 Phase 2
Transient Manoeuvres

The same test points as Phase 1 were repeated but differing techniques to achieve the correct entry parameters for each of the manoeuvres were adopted.

Symmetric Pull Ups

The aircraft was stabilised at approximately 200 ft above and 20 kts below the desired speed and altitude. A gentle dive to the correct speed and altitude was commenced, applying aft cyclic on passing through the test point. The rate and magnitude of cyclic application was controlled by the visual 'g' meter, each successive pull up increasing by 0.25 'g' increments from 1.25'g' up to the maximum normal 'g'.

A good deal of practice was again necessary before it was possible to hit the altitude, speed and rotor speed targets. As the normal 'g' meter was within the pilots scan the cyclic and collective inputs could be coordinated precisely to achieve the 0.25 'g' steps. Once practice had been gained remarkably consistent test results were achieved justifying the technique adopted.

Initial attempts at pull-ups from level flight resulted in high nose up attitudes from which the pushover to recover gave some large transient rotor speed excursions.

Symmetric Push Overs

In order to facilitate the push-overs these manoeuvres were separated from the maximum +ve 'g' pull-ups and the pilot was allowed to determine his own starting conditions.

This allowed the pilot to concentrate on one part of the manoeuvre only to ease his workload.

To achieve -ve 'g' a pull up/push over manoeuvre was used. Starting slightly below the test level, and about 10 kt fast, a pull up through the test altitude was initiated followed by a push over to -ve 'g'. This was repeated, decreasing the 'g' level at each attempt by 0.25 'g' increments until -0.5'g' was reached. This was an aircraft limitation constrained by it's current systems release.

In order to achieve stabilised conditions in negative 'g' the pull up followed by a push over technique proved to give an unexpected limitation.

The control system software of the GEM-60 engine was configured for the Westland 30 transport helicopter. The rapid pull-push-pull to recover technique allowed the aircraft to get out of phase with the acceleration rate of the engine control system and large transient rotor speeds of ±10% around the normal governed limit resulted which constrained the tests.

However, it was possible to demonstrate the -0.5 'g' capability of the airframe and rotor system but the recoveries did provide for some excitement in the cockpit and showed the capability of the BERP rotor system at reduced rotor speed.

The bank and push to an outside turn technique was also attempted but in attempting to maintain -0.5 'g' for 5 seconds resulted in some unusual attitudes from which to recover. It was felt that any requirement for a helicopter to sustain this normal acceleration for this length of time was perhaps a little too severe.

Rolling Pull Outs

A procedure similar to the Symmetric pull up technique was adopted but as the aircraft reached level attitude, lateral cyclic was progressively applied to maintain the 'g' level.

Again once practice had been gained in hitting the test points it proved relatively easy to repeat the conditions in the 0.25 'g' increments.

Loaded and Unloaded Roll Reversals

Loaded roll reversals were carried out by stabilising the aircraft at the maximum bank angle attained for each of the speed/altitude combinations and rapidly applying lateral cyclic at a series of increasing rates to achieve a maximum rate turn in the opposite direction. This was repeated for both port to starboard and starboard to port turns.

Once the entry conditions were achieved this proved to be a consistently repeatable exercise.

With practice a range of lateral cyclic input rates from slow, medium to fast also proved to be repeatable.

The major problem encountered was that after a series of these manoeuvres it was necessary to maintain sedate level flight for a period in order that the crews disoreientation could subside!

Unloaded roll reversals for each of the test points were carried out by stabilising the aircraft in level flight at the test speed and altitude and rapidly applying a lateral cyclic reversal without pulling the aircraft into the turn. This was carried out at increasing transient bank angles and rates of control application for each of the test points, again both to Port and Starboard.

The entry conditions were of course easy to set up as these were level flight cases. These were repeated twice, once with the Lynx attitude stabilised FCS engaged and once with the roll channel disengaged, as this reduced damping providing for a still faster roll rate.

Examination of the traces post flight showed a step input of rate at up to 120^{o}/second, higher rates were later achieved during manoeuvres. Roll acceleration felt in the cockpit was violent and it was found necessary to adopt a braced position if the limbs and head were not to contact the cockpit.

Wind Up Turns

For each of the test points wind up turns were carried out. These were carried out by overbanking the aircraft to a set 'g' level and increasing bank angle to hold 'g' constant as the speed decreased, keeping altitude and torque constant. These were repeated increasing the 'g' level by 0.25 'g' increments to both Port and Starboard until the maximum allowable 'g' loading was reached.

While it was possible to demonstrate a clear advantage of the BERP over the metal rotor in response and turn rate the number of variables dictated that a consistent, repeatable manoeuvre would be very difficult to achieve. Whilst it remained easy to achieve a repeatable 'g' level the combined overbank and pitch were a high workload task for the Pilot.

Phase 3
The Demonstration Sequence

This was carried out in order that a sequence of manoeuvres from phase 1 and 2 could be in·investigated and to evolve a manoeuvre sequence for demonstration to outside agencies.

This comprised a maximum power acceleration and cyclic climb, followed by the maximum sustained rate of climb up to 8000 ft. The max speed, manoeuvrability and negative 'g' capability at this altitude was demonstrated followed by a rapid entry to autorotation down to approximately 2000 ft, where an acceleration to 200 Kts was shown. The 360^{o} capability of the aircraft in pitch then demonstrated at this altitude.

The manoeuvrability sequence was built up by using the elements of Phase 1 and 2 as building blocks to examine the 360^{o} capability of the rotor system.

Flight Envelope: High Speed Dash

The test aircraft did not have the benefit of the aerodynamic smoothing of G-LYNX. Neither did it have the engine water methanol injection system, modified tail fins and re rated gearbox of that aircraft. Pulling to the torque limit a level flight speed of 180 kt was obtainable and acceleration to 200 kt achieved in a slight dive. At these speeds a similar level of 4R vibration to that of the standard metal bladed Lynx at 120 kt was measured. At the lowest blade loading tested a 45 Kt increase in the 1'g' flight envelope over the metal blades was demonstrated.

At the highest blade loading tested this equated to a 70 kt rise. As a further demonstration at rotor power and controllability the aircraft was flown to 70 kt plus rearwards and 55 kt sideways.

Barrel Rolls

A series of wing overs of increasing bank were flown from an entry speed of approximately 140 kt, gradually increasing the recovery attitude until a full barrel roll was achieved.

The Lynx attitude stabilised FCS was never designed for a 360^o capability.

The stabilisation system on reaching its attitude limits would inject unwanted inputs in other channels as the gyros snubbed and precessed. Therefore the roll channels were disengaged for these tests.

The confidence generated in the Lynx's controllability demonstrated in the rest of the trial allowed the crew to feel confident that no matter what speed and attitude may have resulted in the manoeuvre that the aircraft could be safely recovered.

The integrity of the aircraft was proved on the second barrel roll in which a combination of a little too much speed and power in the entry resulted in an excessive speed on the pull out and more 'g' than the preset limit. As the margin for error was not great, it was therefore decided to perfect the rapid axial or twinkle roll.

Axial Rolls

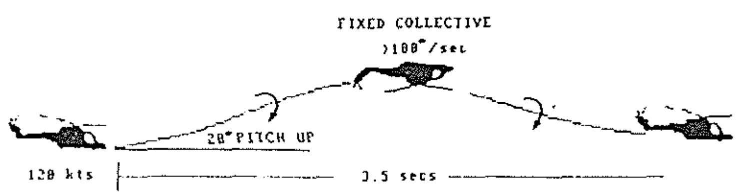
From an entry speed of 140 kt the aircraft was pitched 20^o Nose up and full lateral cyclic rapidly applied to achieve the roll. The manoeuvre was worked up by a series of rapid roll rate applications. In the roll fore and aft cyclic and collective were held constant. Lateral cyclic was backed off to keep the roll rate down to about 100^o/Sec.

The axial roll technique adopted led to minimal loss in height as the pitch up before the roll allowed the aircraft to follow a ballistic trajectory whilst the rotor system was inverted and intent on pulling it earthwards.

During the axial roll the aircraft yawed appreciably resulting in a large transient side slip and high tail rotor loads. This was a dynamic rather than an aerodynamic phenomena. The yaw rate stabilisation system was left engaged in an attempt to ameliorate this effect.

A full roll could be executed in 3½ seconds, the acceleration rate into and recovery from the roll being almost instantaneous.

The minimal time available at this stage in the trial only allowed for demonstration of rolls at one speed.



RAPID AXIAL ROLL.

The Loop

The elements of the loop were practiced by a combination of torque turns and hammerheads for the entry condition. The exit condition was practiced using a split 's' technique where the aircraft was rolled inverted at low speed and recovered in the pitching plane.

This allowed investigation of rotor and aircraft behaviour in the first two and last quadrants.

A computer simulation using the WHL flight path analysis programme was undertaken, the results giving confidence in the energy available.

When satisfied with both the entry and exit parameters full loops were attempted.

From an entry speed of 125 kt a 2 g pitchup was initiated until the aircraft reached 90^{o} attitude. Pitch rate was then increased rapidly and any roll or yaw corrected when the horizon came into view. High pitch rate was maintained until 90^{o} nose down and a 2.2 'g' pullout carried out. Exit speed was approximately 125 kt with a height loss of 400 ft.

The achievement of a tidy loop made more difficult by limitations imposed by the trials vehicle.

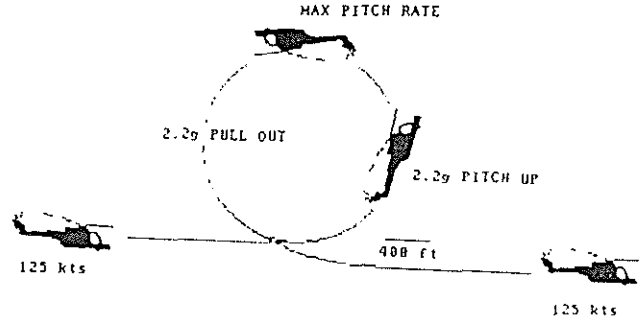
XZ170 was built to the Lynx Mk 7 standard before conversion and consequently was equipped with the mounting for the TOW sight over the co-pilot. Although the sight was removed for this trial the blanking plate completely obstructed visibility upwards to port for the pilot.

The attitude gyros were not designed for a 360^{o} capability and would therefore topple. The only attitude reference for the pilot was two horizontal lines drawn across the cockpit door windows.

These factors combined to make it difficult to produce a perfectly aligned loop.

Once the technique had been perfected the loop proved to be a remarkably comfortable and stress free manoeuvre but careful execution was necessary to avoid the danger of too much speed and not enough 'g' capability on the recovery.

If insufficient 'g' could be generated to curve the aircraft flight path the resulting speed could lead to a totally stalled rotor and hence control would be lost and recovery be impossible.



LOOP

Autorotations

Entries of increasing rapidity to autorotation from the edge of the flight envelope were carried out. In addition turns at up to 60^{o} of bank in autorotation and recoveries to level flight at increasing rates were carried out.

Rapid entry to autorotation was achieved at a rate as fast as the collective could be lowered. No handling problems were experienced and it was possible to achieve steep turns in autorotation without high transient rotor speeds.

The BERP blade proving less lively to RPM excursions than the metal blade.

6. General Points

In devising a manoeuvre test programme several points have come to light as a result of this trial.

The trials vehicle used and limitations imposed on it meant that in some areas a vehicle limit was reached before we could fully investigate the limitations of the rotor system.

The technique of flying to a 'g' meter in the pilots scan proved to be ideal, with excellent repeatability of results.

The high altitudes (up to 16000 ft) flown to obtain the highest blade loadings necessitated using oxygen. With parachutes, oxygen masks and clothing suitable for conducting the trial in winter the cockpit was cramped and uncomfortable during long sorties.

The trial proved to be very demanding on the aircrew. Repetitive extreme manoeuvres (for a helicopter) resulted in fatigue and in some cases nausea. A sortie rate of more than two hours per day is about the physical limit for one crew.

It should be noted that this flight trial involved a large number of short duration flight conditions. Cockpit workload for both crew was extremely high. The setting up of up to sixty flight conditions per flying hour whilst operating at high altitude at extreme attitudes requires careful planning if the flight crew are to be used to the best of their ability. Punctuating a series of the more violent manoeuvres with steady state conditions that allow the crew to regain their faculties provided a more efficient use of flying time.

7. Conclusions

Full analysis of the vast amount of data generated by this trial is still continuing.

Preliminary results suggest that the BERP rotor/semi-rigid hub technology is capable of giving of performance necessary for an advanced combat rotorcraft to survive in the battlefield.

The high speeds, sustained turn rates and agility proved in this trial, and demonstrated to several international agencies, confirm the belief that this rotor system fitted to a Lynx incorporating relatively simple modifications would provide a capable air to air combat vehicle.

In addition the aircraft and rotor system have been demonstrated to have a 360^{o} capability in pitch and roll should an operational need be expressed for this ability.

The semi-rigid rotor system gives a freedom from the danger of main rotor blade strike irrespective of the aircraft normal acceleration and magnitude of control input.

In conducting these tests we now understand the practical requirements for an Air to Air vehicle, and have an excellent database from which to determine the effect of manoeuvres on rotor stall behaviour or performance.

The future battlefield is a complex scenario and success or survival will depend on not just the rotorcraft performance but weapons and tactics. Westland Systems Assessment have been using a sophisicated computer model the simulate the helicopter in the battlefield environment and the tactics of helicopter air to air combat. The programme uses digitised terrain and currently allows for various scenarios and tactics to be evaluated. Further enhancements to the database will allow the effect of the increased manoeuvrability of the BERP rotor system together with manoeuvres and tactics possible only with rigid hub to be assessed.

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Symbols

W	Aircraft Weight
σ	Relative density
θ	Relative temperature
δ	Relative pressure
TAS	True airspeed
n	Fraction of normal rotor speed

Note: Some of the opinions expressed in this paper are the Authors own and are not necessarily shared by Westland Helicopters Limited.

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