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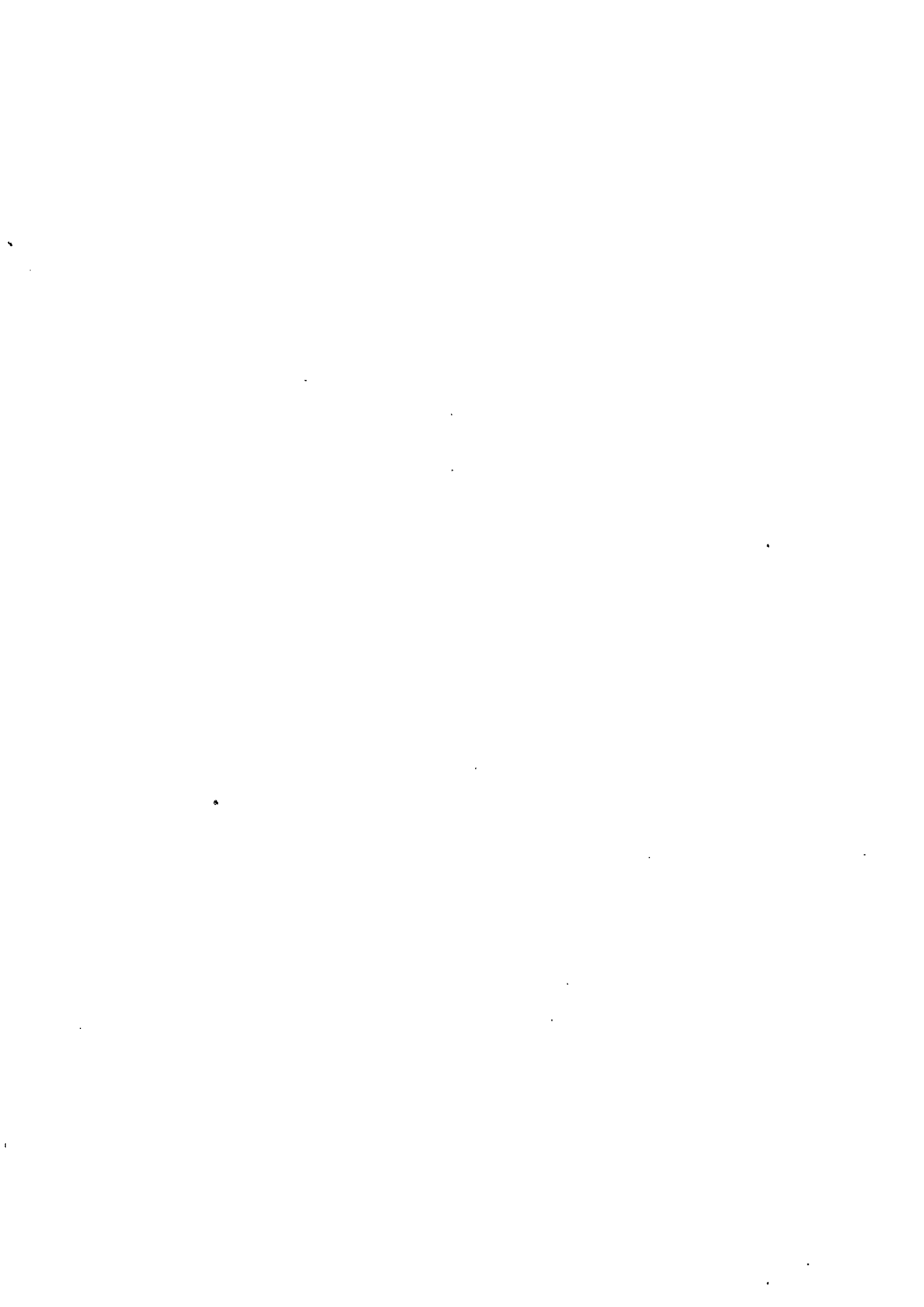
THE DEVELOPMENT OF THE WG.13 (LYNX)

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## 1. Introduction

The origin of Lynx stems from an agreement between British and French Governments to jointly fund the development of three helicopter types for the Armed Services of both Nations. This agreement has become popularly known as the "helicopter package deal".

Within the package was a requirement for a helicopter in the weight range 8,000 to 10,000 lb. A.U.W. to fulfil the needs of the British Army for a Multi-Role helicopter and the needs of Royal and French Navies for a small ship helicopter. This project was initially identified as WG.13 and subsequently designated "Lynx".

This paper is intended to briefly review some of the more interesting aspects of the design and development of Lynx and its recent entry into service.

## 2. Lynx Design

### 2.1. Basic Philosophy

A careful review was made of the desirable features to be incorporated in Lynx, particularly bearing in mind its multi-service, multi-role application. Recognising the need of the modern operator, high reliability, robustness and ease of maintenance were immediately seen as essential features. At the same time both Army and Naval roles required a compact low profile vehicle while certain Army roles dictated high agility and performance. In the small ship role clearly good engine out performance was essential and the requirements for landing and deck handling required special consideration.

### 2.2. Reliability and Maintainability

At the conceptual stage an overall reliability and maintenance plan was evolved covering all aspects of design, with the objective of achieving the targets set out in Fig. 1. It was this desire for high reliability and ease of maintenance which has above all else led to most of the novel design solutions incorporated in Lynx. A few of these are discussed in succeeding paragraphs.

### 2.3. Hingeless Rotor

It became clear in the early stages of the Lynx design study that departure from the articulated rotor principle could yield great advantages in simplification. However, it was considered prudent not to depart too dramatically from the fundamental dynamics of an articulated rotor, recognising the difficulties being experienced by others in the "rigid" rotor field.

The final design solution is the soft in-plane rotor shown in Fig. 2 in which the main flapwise flexibility is provided by a planform tapered titanium element of elliptical cross-section, designed to give maximum flexibility consistent with the required fatigue strength.

The feathering hinge is placed immediately outboard of the major flapwise flexibility thus minimising misalignment between the feathering axis and the deflected blade axis when the helicopter is in flight. This results in a reduction in the steady and vibratory bending moments across the feathering hinge and minimises unwanted feedback of loads to the controls. The centrifugal loads are taken across the feathering hinge by a simple wire wound tie-bar.

The major lag flexibility is provided by a circular cross section outboard titanium element. The choice of stiffness was dictated of course by ground/air resonance characteristics on the one hand and the amplification of lag plane loading on the other hand. Ultimately a lag plane frequency of  $.64 \text{ rad/sec}$  was chosen as a reasonable compromise between these conflicting criteria.

There can be no doubt that this design solution has produced a remarkable simplification when compared to traditional articulated systems. This is illustrated in Fig 3 where the Lynx rotor is compared with the traditional Wessex/S58 rotor. The potential impact on reliability and maintainability is self evident.

### 2.4. Main Gearbox

In addition to the general requirements for reliability and ease of maintenance, there was a requirement that the aircraft should have a low profile. This, dictated that the gearbox and rotor assembly should be as shallow as possible. Various design solutions were considered, but it became clear that a number of advantages could be achieved by the use of conformal gears.

The Westland Company have been experimenting with conformal gears since 1959 and apart from their superior load carrying capabilities, the ability to use this tooth form with lower pinion tooth numbers than are normally acceptable with traditional involute form, allows high reduction ratios across a single stage.

The final design solution is shown in Fig. 4.

The reduction from engine input shaft to main rotor is achieved through a simple spiral bevel stage and then a straight 7.6 to 1 reduction through a single conformal stage.

Once again comparison of this design solution with the traditional epicyclic solution shows a dramatic reduction in the numbers of gears and bearings employed with a consequential increase in reliability. This is illustrated in Fig. 5 where the Lynx main gear train is compared with that of the Sea King.

## 2.5. Modular Hydraulics

The principle of simplification has been extended to many of the Lynx systems. In particular, the hydraulic system has been rationalised by the adoption of a manifolded arrangement. In this arrangement all the accessories of the main hydraulic system have been collected together on two identical manifolds with all the interconnections made by drillings and galleries within the manifold. This is shown in Fig. 6 and has the advantage of eliminating the majority of pipe runs and places all critical components of the system in a readily accessible location. In the event of any major defect which proves difficult to locate by normal diagnosis, the whole manifold together with its accessories can be replaced with a complete checked out module from store - a task which can be completed by one man in about 2 hours.

## 2.6. Special Design Features associated with the Small Ship Role

### (a) Undercarriage

In a small ship application, stability on deck is a major consideration in the design of the undercarriage geometry. The most obvious solutions are quadruple units such as the Wasp, but the relatively high speeds required of the Lynx made this less desirable and finally a tricycle unit was adopted as the design solution. In respect of the undercarriage oleo itself, the major requirement is a high energy absorption capability to ensure that under the specified landing conditions, undercarriage design loads are not exceeded. However, there are a number of other considerations which govern the choice of oleo characteristics, including fatigue loading, ride height, etc.

These considerations have led to an oleo which has the characteristics shown in Fig. 7. It can be seen that the initial compression of the oleo is at a relatively low spring rate, giving high energy absorption with only modest reactions.

After some 12 inches closure, the oleo reaction rises sharply with virtually no closure for a significant range of load. The static reactions of the helicopter standing on the deck lie in this band and hence this feature ensures that ride height is virtually unchanged over the range of weights from helicopter empty to helicopter fully fuelled and armed.

The Lynx undercarriage arrangement permits Lynx to remain stable on the deck, neither toppling or sliding at deck angles up to 25 degrees.

Moreover the design criteria for the oleo recognise realistic combinations of vertical descent rate, deck motion, deck angle and relative drift over the deck for worldwide operation.

(b) Negative Pitch

The hingeless rotor of Lynx has permitted the superfine pitch philosophy of the Wasp to be developed further to provide a downward thrust of some 3000 lb. immediately after touch-down, augmenting the basic stability of the vehicle on the deck at touch-down.

(c) Brakes

On small ships, there is little use for progressive braking. For this reason on both the Lynx and the Wasp before it, we have adopted "sprag brakes." The brake is released by application of hydraulic pressure from an engine driven 3rd hydraulic system and in that sense is "fail safe". This principle is illustrated in Fig. 8.

(d) Deck Lock System (Harpoon)

A deck lock system has been devised for the Lynx, to obviate the need for the ground crew to apply temporary lashings immediately after touch-down, in severe sea states.

The deck lock comprises a self-locking "beak" carried on a hydraulically extending ram. When engaged by the pilot, the ram extends and the "beak" engages and locks in a grid located on the ship's deck. After engagement, the ram tensions to produce a downward thrust of some 3000 lb. on the vehicle, thus augmenting the inherent stability of the Lynx on the rolling deck.

This is illustrated in Fig. 9.

It is possible to rotate the aircraft around the deck lock whilst remaining firmly attached to the ship's grid and to facilitate this, the main wheels toe-out at 27° whilst the nose wheel can be selected and locked athwartships by the pilot.

### 3. Development

Lynx has been subjected to a comprehensive development programme over a period of some 6 years. This programme has encompassed 4500 flying hours and the high time development aircraft has now reached 750 hours.

Much of the activity has followed traditional lines and space permits only a brief mention of some of the more interesting aspects.

#### 3.1. Fatigue Substantiation of Major Dynamic Components

At the commencement of the programme, the areas of greatest technical risk related to the main rotor head, gearbox and main rotor blades. The main rotor head posed particular problems, in that little or no fatigue data existed on Titanium forgings. The initial design was based on a comprehensive series of coupon tests and ultimately refined around data obtained from tests on small model forgings. The final fatigue substantiation has been based on full scale programme load tests of some six specimens in which torque, CF, lift, flap and drag have all been simultaneously applied.

In most respects, the initial design criteria have been borne out by the data accumulated during substantiation but our initial views on the relationship of vibratory endurance limit with mean stress were slightly optimistic. (This has fortunately been offset by some initial pessimism of flight loads).

The results of the programme of work are summarised in Fig. 10 and in Fig. 11 they have been converted into a "no damage" boundary for comparison with flight loads.

#### 3.2. Development of "Small Ship" Features

All initial development of the Lynx undercarriage arrangement was carried out on a "drop test vehicle" shown in Fig. 12.

This vehicle was dropped in a controlled manner onto a Rolling Platform at RAE, Bedford, to check the dynamic behaviour of the undercarriage over a wide range of descent velocities and rolling platform angles simulating conditions at the instant of touch down. The vehicle was also used to examine basic stability after touch down, in respect of toppling and sliding, and to make an initial assessment of deck handling. This particular activity went off extremely smoothly and the stability on deck exceeded our expectations, making the deck-lock an "insurance" rather than a necessity in high sea states.

On completion of this phase, a Naval development aircraft was committed to the rig and performed a comprehensive series of landings and take-offs over a range of simulated sea states wider than one could ever expect to get in a single ship trial.

One aspect caused a little concern at the time and that was the effect of a high gain autostabiliser combined with high control power on rotor stresses during landings at extremes of ship movement. In this situation of course, the helicopter is trying to stabilise the ship and requires recognition in the overall fatigue spectrum, particularly during the period when negative pitch is being applied.

Since the rolling platform trials in 1972, Lynx has been operated from a number of ships of the Royal and French Navies on proving trials carried out by A & AEE, CEV, (see Fig. 13) and also most recently operational trials completed by the first RN Squadron. As one would be entitled to expect from the long association of Westland with small ship helicopters and the comprehensive step-by-step development, all ship trials have been unqualified successes.

Particularly impressive is the trial in the Spring this year carried out by A & AEE from RFA Engadine. In two periods totalling 26 days some 700 landings and take-offs were accomplished in winds up to 50 knots and sea states up to 8. The only hitch in the trial came when flying had to be curtailed at sea state 9/10 (wind speed 60/65 knots) for a while because the normal surface and air safety services in the test zone were unable to remain on station because of the prevailing conditions despite the fact that the Lynx was considered to be capable of continued operation.

### 3.3. Reliability and Maintainability

It was realised that the targets shown in Fig. 1 would not be easy to meet and would be quite impossible without:

- (a) Recognition of these targets at the conceptual design phase.
- (b) Extraordinary action in development phase to identify and rectify potential sources of unreliability.
- (c) Monitoring of all development flying to ensure that that mission reliability target was being approached.

To this end, the aircraft was divided into some 29 sub-systems and mission failure and defect rates were allocated to each. These became targets for designers and as the design evolved, checks were made inserting known reliability statistics for standard components and evolving targets for new design elements. All bought-out equipments were procured against detailed Schedules of Requirements which placed mandatory requirements on the supplier to demonstrate achievement of the requisite standard of reliability.

Similarly, from the maintenance aspect, the requisite 2.7 man hours per flying hour for the Naval Lynx was broken down into:

Flight Servicing	-	0.6 man hours per flying hour.
Scheduled Servicing	-	1.2 man hours per flying hour.
Unscheduled Servicing	-	0.9 man hours per flying hour.



It was clear to us, however, that the real problem in proving that reliability targets can be achieved is the difficulty of accumulating sufficient representative system hours at the earliest possible date - much of the early flying has to be carried out in a step-by-step manner associated with the particular technical objectives of each trial. This is not conducive to amassing large numbers of flying hours at an early date.

We were also aware of the shortcomings of formal qualification tests of individual components in respect of their ultimate reliability in aircraft systems. We therefore elected to produce the Reliability Rig, shown in Fig 14, in which all major systems of the Lynx are represented and functioned by artificial stimuli whilst the whole rig is capable of being simultaneously exposed to representative vibration, and varying climatic conditions. (In effect, we have what is known in the United States as a "hot mock-up" with its own vibration capabilities mounted within an environmental chamber).

With the aid of this device, we were able to accumulate very rapidly 1000 hours simulated operation and feed back that experience into the productionising phase. It would seem to us that this approach is an essential tool in any programme which claims reliability as a major aim and we certainly will continue to use it.

Also during the Development phase, all flying statistics were monitored in blocks of approximately 50 hours to establish what improvements were being made in the fleet as a whole by feed back and incorporation of improvements from other parts of the programme.

Assessing progress of the maintainability targets was rather more difficult, since it is difficult to separate in a development programme true maintenance from development activity and we elected instead to demonstrate the achievement of planned times for those items which have the greatest impact on the "Flight Servicing" and "Scheduled Maintenance" activity. Some typical achievements are shown in Fig. 15.

Thus at the point in time when Lynx entered service with the RN, there was a real basis for confidence that the reliability target would be met.

#### 3.4. Engine Failure in the Hover

A particularly interesting aspect of flight development was the evolution of new piloting techniques to optimise recovery from engine failure situations in the hover at low altitude. (Particularly relevant to Naval ASW operations)

The design requirements for high speed and altitude capability have produced a situation in the Lynx rotor where it has greater blade area than is required for low speed sea level operation. This means that Lynx can operate quite happily in this regime at reduced rotor speed. This led us to conclude that we should be able to exploit rotor kinetic energy during a failure situation to aid recovery by allowing rotor RPM to fall.

A complex computer model was evolved to justify this proposal. The model is in effect a low speed performance programme which calculates response subsequent to a disturbance using a simple step integration with a fixed time interval. The failed engine is represented by an exponential decay from its initial power. The live engine has a first order lag with limits on the rate of growth of power and on the maximum power.

Sub-routines are used to calculate fuselage aerodynamic forces, disc efficiency, induced velocity tail rotor power and thrust as they are required.

Finally, vertical acceleration and height are calculated from the vertical force equation.

From the model it became quite clear that significant benefits could be expected from a technique which allows the rotor speed to drop to 85%. This is illustrated in Fig. 16.

Good correlation has been achieved between flight tests and the computer model, giving confidence to its use in more complex operational situations.

This recovery technique has been utilised successfully by pilots of the UK and French Test Agencies in addition to Westland pilots and although there are optima, minor variations in technique are not critical and the sequence of pilot actions is considered natural and logical.

#### 3.5. Icing Trials

It was accepted during the conceptual stage of Lynx, that no active rotor de-icing system would be provided. However, a great deal of work was done to provide a high order of engine protection and to ensure that the basic design was optimised against accumulation of airframe ice. The validation of these aspects of the design took place in three stages:

- (a) Engine protection: Engine intake protection is provided in the form of electric heater mats applied to the engine air intakes utilising some 5.8 KVA per engine. This is supplemented by hot air bleeds at the engine front frame.

This protection system was optimised in an environmental wind tunnel early in the development programme.

- (b) Airframe icing: The sensitivity of the basic airframe design to ice build up and breakaway was examined in the first instance in the large environmental wind tunnel at NGTE. In this a complete fuselage and intake installation was mounted in a representative manner in the tunnel and airflow through the intakes simulated at realistic mass flows. It was possible in this facility to explore a range of airspeeds up to 140 knots, temperatures down to  $-20^{\circ}\text{C}$ ., and liquid water contents corresponding to maximum continuous water concentrations as given in Av.P.970, with selected tests at increased water concentrations. This activity is illustrated in Fig. 17.

This particular programme highlighted a number of potential hazards, and permitted their elimination before flight trials.

- (c) Flight Trials in Icing Environment: Two series of trials were carried out during the Winters of 1975/1976. The first trials were carried out in Denmark and the second trials in Norway and Denmark. During these trials, 59 flights in icing conditions were made, amounting to some 50 flying hours.

The aircraft was equipped with full instrumentation including 4 TV cameras viewing critical areas and displayed continuously to the pilot in the cockpit. See Fig. 18.

The results of these trials were most encouraging. In particular:

1. The shedding properties of the rotor were shown to be good.
2. No effect on handling was detected.
3. With the exception of a few minor areas requiring design changes during the trial, ice accretion on the airframe was low and shedding when it occurred was shown not to be hazardous.

4. Torque rises due to rotor ice accretion were modest and only on three occasions throughout the two trials did they justify vacating the icing environment.

From these trials it has been shown that there is a high probability of Lynx operating satisfactorily in an icing environment without active rotor de-icing. This has permitted a form of operational release to be evolved which permits such operations whilst recognising that on rare occasions the environment may have to be vacated.

This is a very significant achievement particularly in relation to a vehicle only just entering service.

#### 4. Operational Capabilities

Lynx has been conceived as a multi-role vehicle and it is therefore difficult to simply summarize its operational capabilities. A 'feel' can be gained from the following data:-

##### (a) Multi-Role Variant

This Variant has a maximum normal operating speed of 160 knots, a range with normal fuel of 360 n miles and with ferry tanks 700 n miles.

It is capable of carrying up to 10 fully armed troops in addition to the pilot and its high speed gives better "productivity" than many larger helicopters.

Lynx is extremely agile and fully capable of "nap of the earth" flying. It is capable of carrying up to 8 HOT or TOW anti-tank missiles and a wide range of podded armament (machine guns, cannons, rockets etc.)

In addition to these more conventional roles new capabilities are being evolved such as command post role and electronic counter measures.

##### (b) Naval Variant

The Naval Variant has a normal operating speed of 145 knots, a normal range of 330 n miles and with ferry tanks 600 n miles.

Two primary roles have been developed to date. An Anti Submarine role which currently utilizes the Alcatel DUAV-4 dunking sonar as a sensor (but for which role other alternatives ranging from the Bendix AQS 31D sonar to light weight sonabuoy processors are being developed) and an Anti-Surface Vessel role. For the latter role the AS 12 Missile and the U.K. Sea Skua Missile are available and other air to surface missiles are under consideration.

## 5. Entry into Service

Lynx is now in full production and the first aircraft entered service with the Royal Navy Intensive Flight Trials Squadron in September, 1976. Subsequently this Squadron was build up to 8 aircraft (6 Royal Navy and 2 Royal Netherlands Navy).

The primary task of this Squadron is the operational evaluation of Lynx in all its roles, with particular emphasis on reliability and maintainability aspects in a Service environment.

To date this Squadron has accumulated some 3060 flying hours and the "high time" aircraft has achieved 780 flying hours. See Fig. 19. This is a remarkable achievement and has frequently involved flying rates of 100 hours per month - a tribute to the basic reliability and availability of Lynx.

During this period mission reliability has been monitored and is summarized in Fig. 20. From this it can be seen that the target of 95.5% has been consistantly bettered.

Maintenance activity has also been analysed and although the target of 2.7 man hours per flying hour is not yet being achieved the predicted figure at entry into service has been bettered. From this we have every confidence that the target will ultimately be achieved through the normal "learning curve" process. See Fig. 21.

## Conclusions

The most significant conclusion relates to Reliability and Ease of Maintenance.

With the present world financial climate the achievement of high reliability and ease of maintenance will continue to increase in importance. However their achievement requires imagination at the conceptual stage backed by a vigorous campaign during detail design and development to identify and remove weaknesses. Talking about reliability is certainly not the same thing as achieving it.

Lynx can justifiably claim to be the first of the new generation of helicopters in which a significant step has been taken to recognise these requirements at concept and ultimately demonstrate their achievement in the field.

## Acknowledgement

The author wishes to acknowledge the valuable contribution of Aerospatiale as a co-operant in the Lynx design and development activity.



	RELIABILITY		MAINTAINABILITY
	M T B F	MISSION RELIABILITY	MAINTENANCE MH/FH
WASP	47.0	98.25%	4.05
SEA KING	16.0	88.0%	4.91
NAVAL LYNX	33.0	95.5%	2.7
UTILITY LYNX	37.0	96.0%	2.1

FIG. 1. MAINTAINABILITY AND RELIABILITY TARGETS

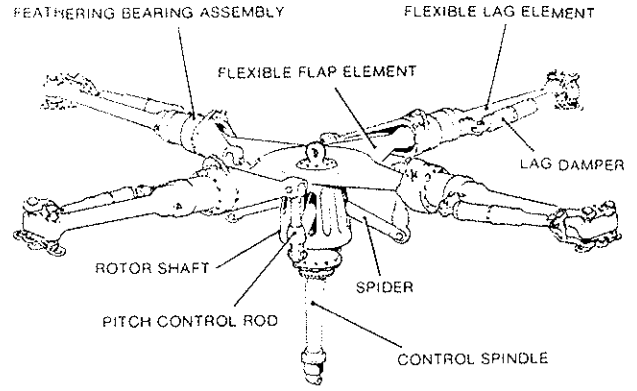
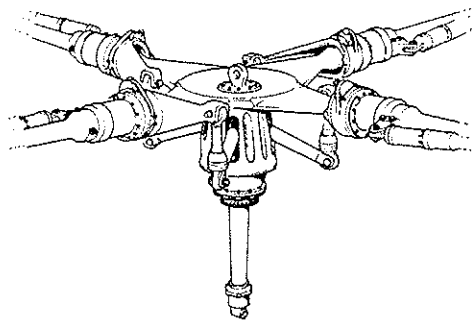
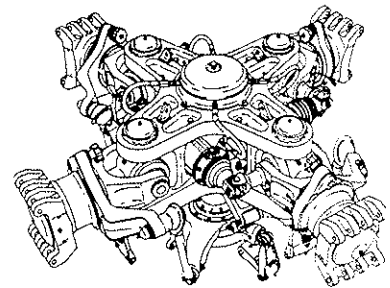


FIG. 2. LYNX MAIN ROTOR HEAD ASSEMBLY



LYNX



WESSEX

NUMBER OF SERVICING POINTS	LYNX	WESSEX
OIL	4	8
GREASE	NIL	52

FIG. 3. ROTOR HEAD COMPARISON

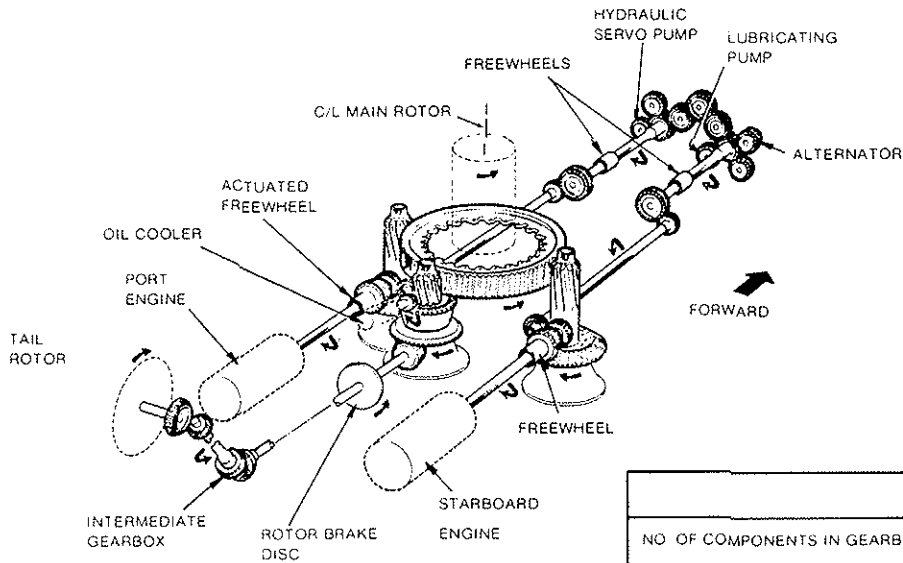


FIG. 4. TRANSMISSION LAYOUT

	LYNX	SEA KING
NO OF COMPONENTS IN GEARBOX ASSEMBLY (LESS ACCESSORIES)	26	44
NO OF GEARS	7	16
NO OF BEARINGS	19	28

FIG. 5. SEA KING GEARBOX COMPARISON

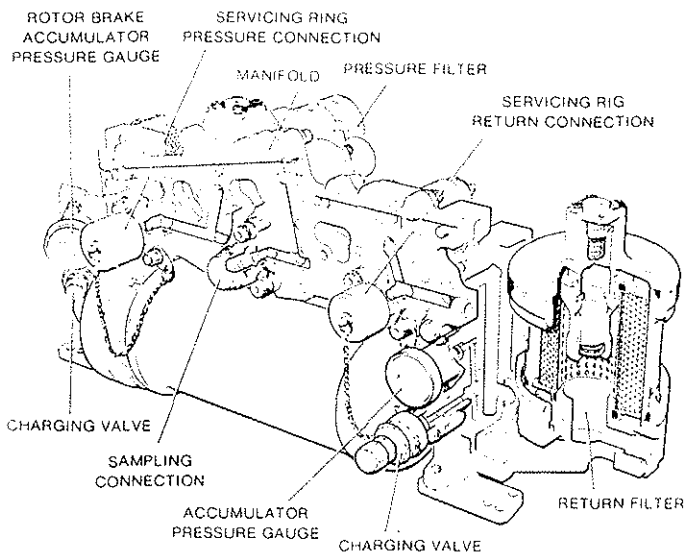


FIG. 6. HYDRAULIC MANIFOLD

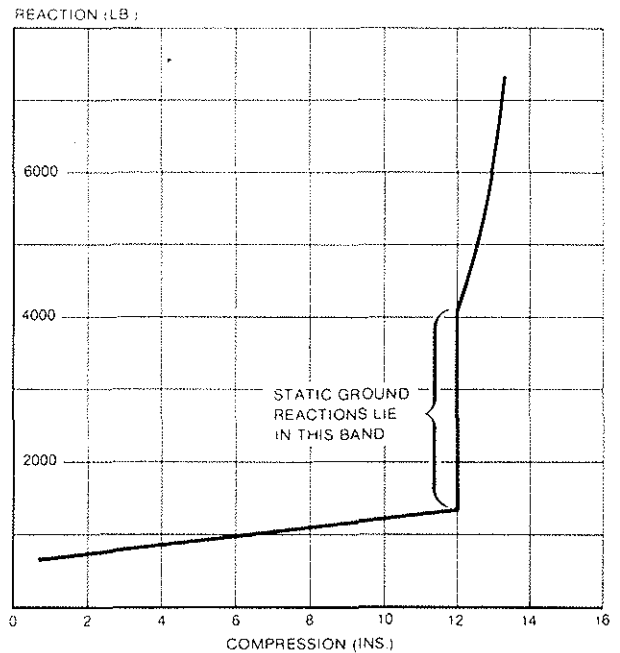


FIG. 7. OLEO REACTION CHARACTERISTICS

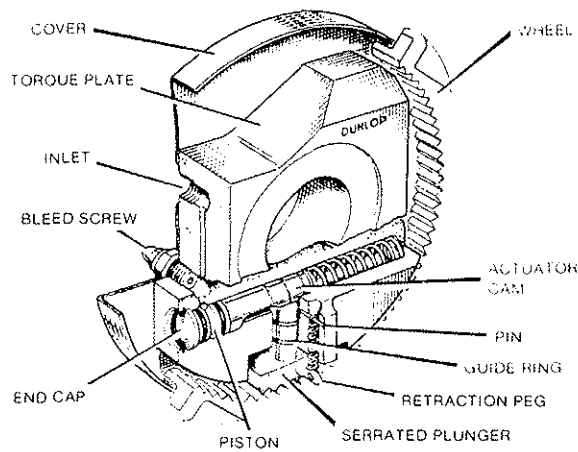


FIG. 8. SPRAG BRAKE

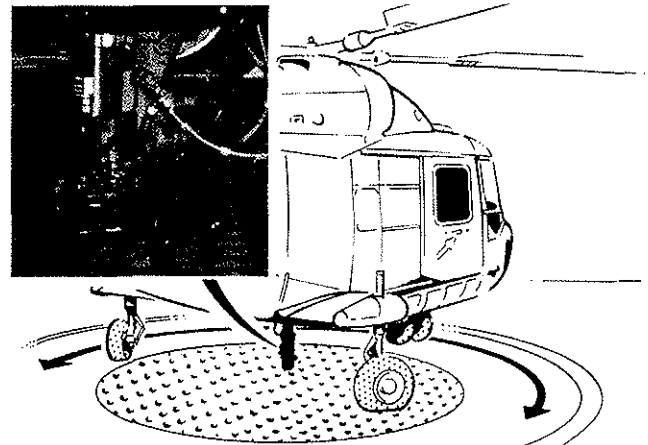


FIG. 9. HARPOON

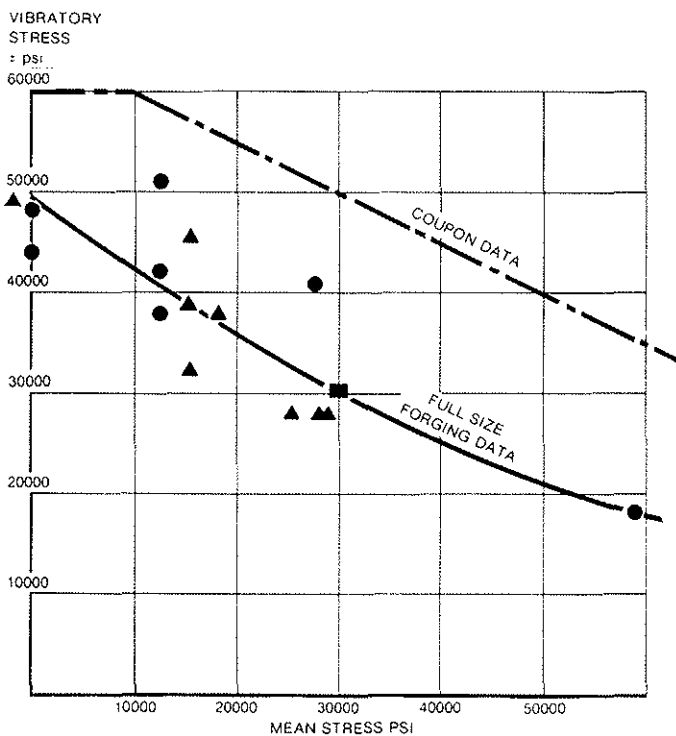


FIG. 10. LYNX MAIN ROTOR HUB FATIGUE STRENGTH

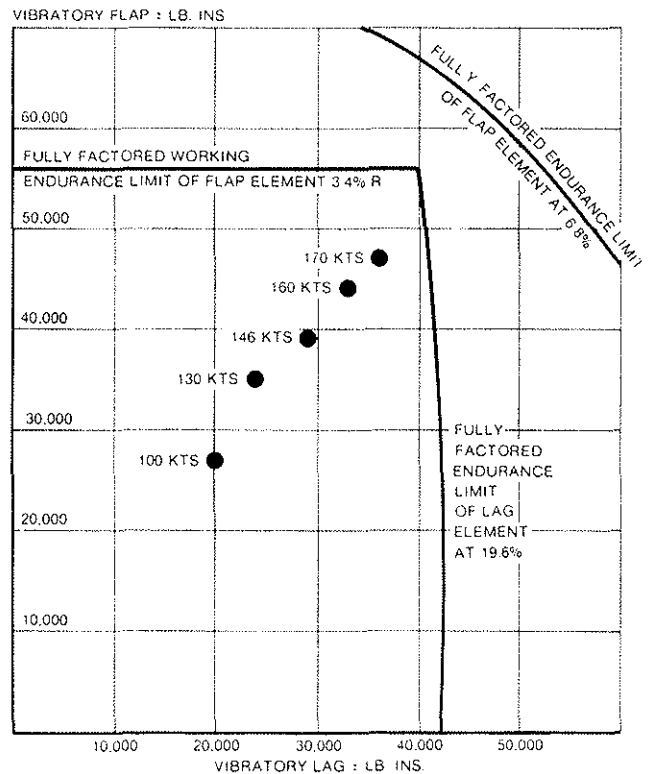


FIG. 11. LYNX MAIN ROTOR HUB FATIGUE STRENGTH RELATIVE TO FLIGHT MEASURED LOADS





FIG. 12. ROLLING PLATFORM TRIALS WITH DROP TEST VEHICLE



FIG. 13. LYNX DECK LANDING

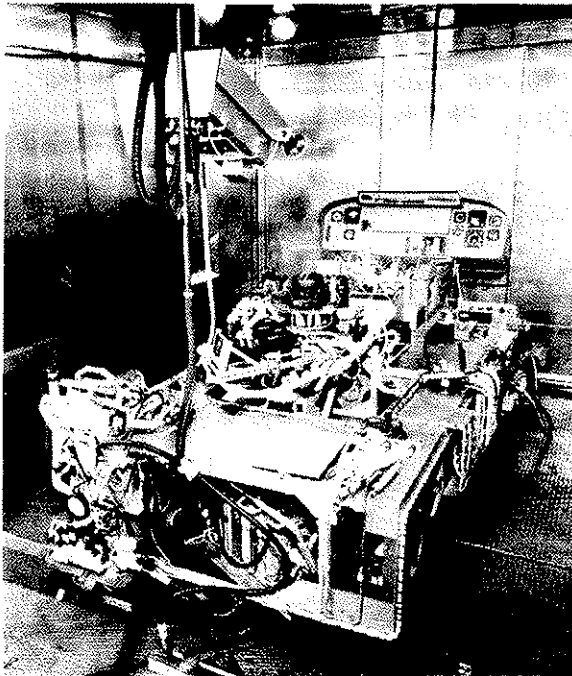


FIG. 14. RELIABILITY RIG

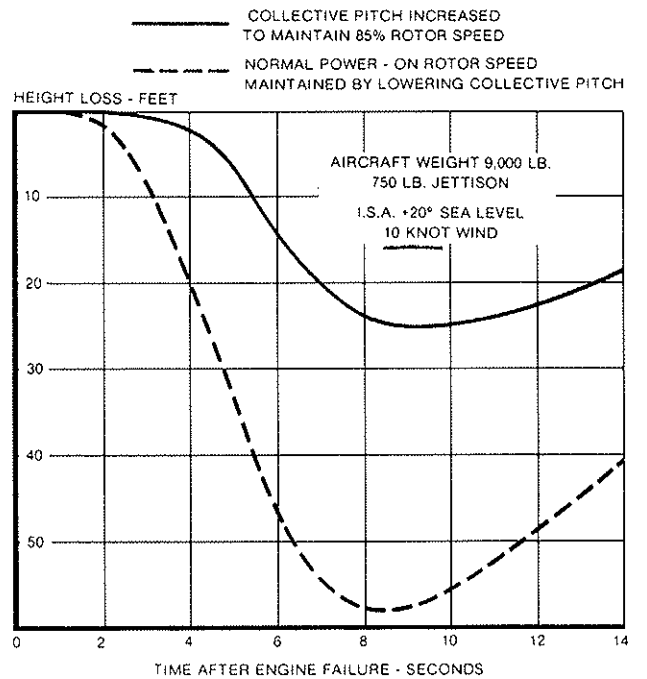


FIG. 16. HEIGHT - TIME PROFILE FOLLOWING ENGINE FAILURE IN HOVER

Component	Man hours	Elapsed time
Undercarriage	3.2	1.6
Engine Change Unit	6	3
Main Rotor Head Assembly	7.5	2.5
Main Gearbox Assembly	12	3
Intermediate Gearbox	1	1
ANY LINE REPLACEABLE UNIT	<1	<1

FIG. 15. LYNX - EXAMPLES OF TOTAL TIME TO REMOVE AND REPLACE MAJOR ITEMS

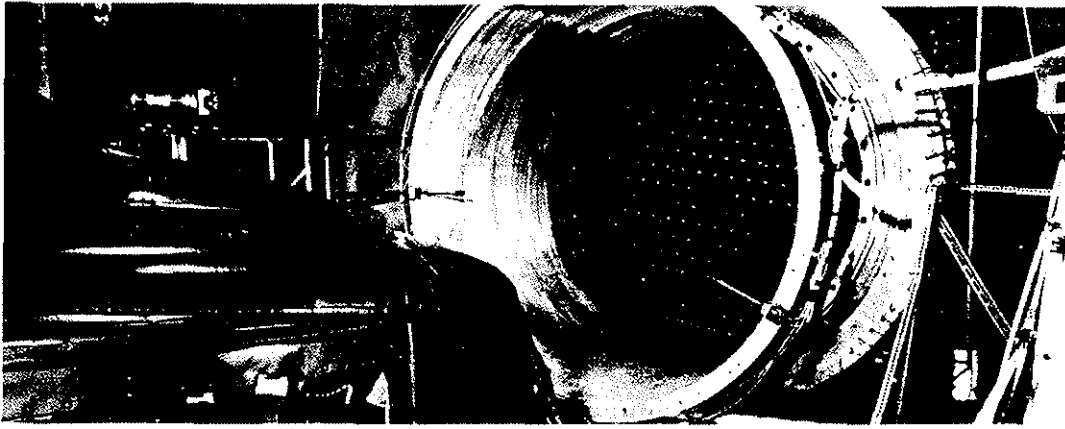


FIG. 17. LYNX IN ICING TUNNEL



FIG. 18. LYNX XW837 ICING TRIALS IN DENMARK

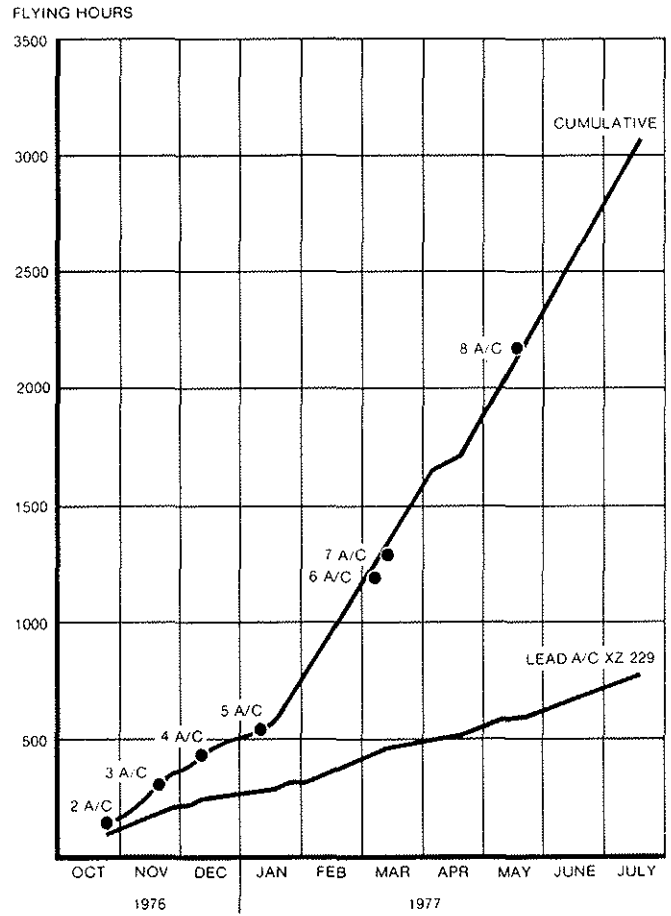


FIG. 19. NAVAL LYNX FLYING RATES ON ENTRY INTO SERVICE

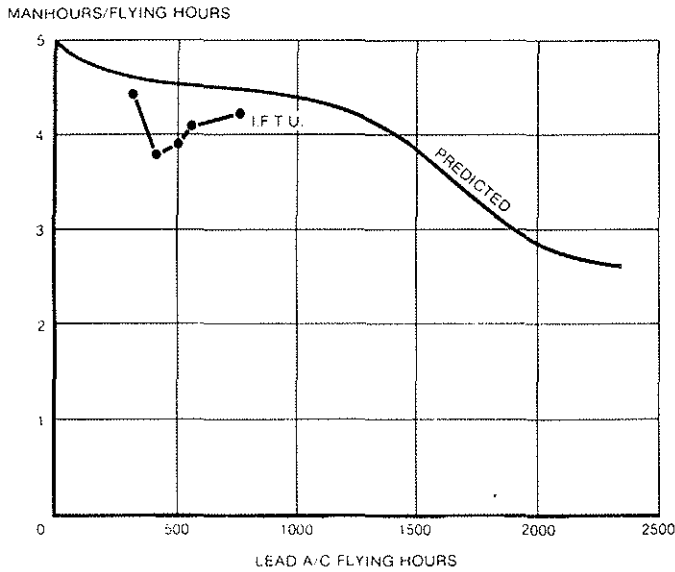


FIG. 21. NAVAL LYNX MAINTAINABILITY ON ENTRY INTO SERVICE

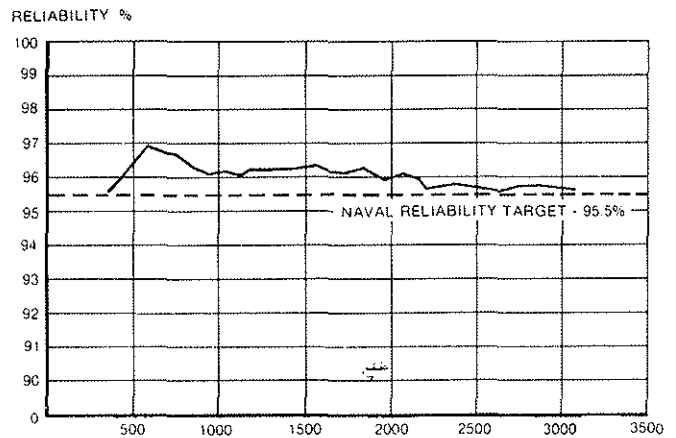


FIG. 20. NAVAL LYNX ACHIEVED MISSION RELIABILITY ON ENTRY INTO SERVICE