THE COMPOUND HELICOPTER - A CONCEPT REVISITED

by

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Summary

This paper describes various forms of lift and thrust compounding and indicates the benefits and conclusions that have arisen from early collaborative studies between WHL and RR. The principal features of a thrust only and thrust and lift compounded helicopter are presented and the advantages which occur (eg increased speed, high speed agility, reduced vibration, improved L/D, ratio, horizontal fuselage attitude and reduced cost of maintenance) are presented in some detail.

Some applications of the compound helicopter concept to both new designs and existing helicopters via retrofit are presented. In addition suggestions are made regarding the way forward, in terms of research topics, and a possible proof of concept demonstrator vehicle.

1.0 Introduction

As the title of the paper suggests the idea of compounding a helicopter is not new. However, with advancements in technology and design capability the concept is worth considering again and as this paper illustrates it is the logical extension for a vehicle using the edgewise rotor. The compound helicopter offers considerable benefits with a minimum increase in complexity.

At first though it is important to define what a compound helicopter is. The definition is as follows (figure 1):-

i) Thrust compounded helicopter:
 - employs a second source of propulsive thrust in addition to the main rotor

ii) - employs
 - a second source of propulsive thrust in addition to the main rotor
 plus
 - a second source of lift in addition to the main rotor.

To understand why the concept has been revisited one must consider the position and limitations of the conventional helicopter in the market place. Since reaching operational service in the early 1940's the helicopter through its vertical take-off capability has established itself in various specialised sections of the market (eg. attack helicopter, anti submarine warfare, the off shore oil industry, air-sea rescue, tactical transport, etc).

However universal acceptance of the conventional helicopter has not been achieved because it suffers from a number of disadvantages (figure 2) when compared to other forms of aerial transport. These can be summarised as follows:

i) limited maximum speed and productivity
ii) poor high speed agility
iii) unattractive operating economics
iv) indifferent ride quality

A comparison of the flight envelopes for the pure helicopter, thrust compounded and thrust and lift compounded helicopters and can be seen in figure 3. This figure illustrates that the thrust compounded helicopter offers a small increase in forward speed and 'g' capability whilst the thrust and lift compounded helicopter offers a significant increase in the flight envelope with no low speed penalty.

As mentioned before the concept is not new. Several experimental and potential production compound helicopters have been flight tested, but none have achieved production status in the west. However, lift compounded helicopters are in service in the Soviet Union. Figure 4 shows a selection of the experimental and production vehicles.

2.0 Background Studies

Activity continued throughout the early 1970's but the underlying conclusions from the studies were that the increase in weight and complexity outweighed the potential benefits. The concept though did not die and with advances in technology and performance prediction methods the concept once more began to attract attention at Westlands.

The privately funded studies which began at Westland Helicopters (WHL) in 1981 led to collaborative work with Rolls Royce (RR) which began in 1982, see figure 5. The results from early studies (figure 6) led to a Unitied Kingdom Ministry of Defence (MoD) sponsored programme of work called the 'Advanced Compound Helicopter Study' which began in 1985. The objectives of the MoD study were as follows (figure 7):-

Vehicle - to investigate the application of advanced compound helicopters to a range of missions - battlefield, transport, ASW and AEW using the most promising engine and wing concepts.

Engine - to carry out parametric studies of variable cycle engines covering performance, weight and installation, and to identify promising engine candidates for different missions.

It is important to note that the MoD study options (figure 8) were not limited in their scope. The underlying aim of the study was to identify what effect various options had on vehicle configuration and performance.

Therefore within the scope of the study a number of characteristic missions were considered. The emphasis though was on the battlefield anti-tank and civil/military transport missions. Westland and Rolls Royce investigated many integrated airframe engine configurations with a basic desire to minimise the complexity of the compound concept.

This led to the evolution of the variable cycle engine which retained any increase in complexity within the confines of the engine (eg: a variable area exhaust nozzle or engine driven fan can be used as a means of providing auxiliary thrust). The essential elements of the variable cycle engine can be seen in figure 9. Manipulation of the exhaust nozzle area is a relatively simple way of providing controllable auxiliary thrust and does not constitute a major mass or complexity penalty.

An example of a variable cycle engine with a compressor stage ahead of the gas generator to provide the wing blowing supply and a variable area exhaust nozzle can be seen in figure 10.

However as part of the study it was recognised that for certain missions enhanced propulsive efficiency eg as provided by a ducted fan or propellor, was beneficial, although at the expense of increased complexity.

Various wing options were investigated, see figure 11. These consisted of the simple mechanically flapped, augmentor and circulation control wings. The influence of location, size and shape of the wing were all considered. Again there was a desire to reduce complexity but there was an additional requirement to reduce the down load on the wing in the hover.

The augmentor and circulation control wings, which were considered in order to provide a reduced area surface (to minimise download in the hover and low speed regimes) operating at a high value of lift coefficent were discounted because of their high induced drag and complexity. The simple mechanically flapped wing has the additional advantages of reducing the problems associated with retrofit.

In addition to the MoD studies Westland contributed to collaborative studies in Europe under GARTEUR. The compound helicopter was considered along with the tilt rotor and tilt wing configurations as a vehicle which could assist in the solution of air transportation problems which are currently manifesting themselves.

The conclusions from the MoD study can be seen in figure 12, and the conclusions from both studies can be summarised as follows:

i) Advanced compound helicopter configurations can be defined which offer increased productivity, speed, range, and agility whilst reducing vibration, fatigue and power transmission at high speed.

ii) Configurations can be achieved with a minimum increase in complexity, mass and minimal low speed penalty.

iii) The variable cycle engine with a controllable area exhaust nozzle and the ducted fan are the preferred methods of providing horizontal propulsion.

iv) The concept is applicable to a wide range of missions.

3.0 Discussion of results

Private venture studies have continued at Westlands and Rolls Royce principally to define the vehicle's optimum configuration and flight envelope through performance estimation and operational analysis.

Where quantified data is presented, it refers to a thrust and lift compounded version of the battlefield Lynx which is being considered as the datum aircraft in a number of roles. Thrust and lift compounding is achieved through the addition of a simple mechanical flapped wing to off-load the rotor and two Rolls Royce RTM 322 engines fitted with variable area exhaust nozzles replacing the existing Gem engines.

The basic performance targets of a thrust and lift compounded helicopter can be summarised as follows (figure 13):

i) Maximum speed of 250 knots
ii) Lift/drag ratio increased by approximately 25%
iii) Enhanced 'g' capability at high forward speeds (eg. 4'g' at 200 knots).

The benefits deriving from the performance targets can be realised in the following important characteristics (figure 14).

- improved time on station
- quicker reaction time
- enhanced survivability
- superior productivity

Additional benefits also follow from the adoption of compounding as follows:-

The increased agility benefits can be seen in figure 15. The increased 'g' capability enables the good low speed manoeuvrability of the helicopter to be preserved to high forward speeds. The implications for obstacle avoidance, see figure 16, and potential 'one to one' air combat superiority, see figure 17, against a range of opponents both fixed wing and rotary wing are very good.

The provision of the auxiliary source of thrust, for example the variable cycle engine, brings with it the considerable benefits resulting from the ability to accelerate, see figure 18 and decelerate, see figure 19, with essentially a level fuselage attitude. These benefits can be summarised as follows (figure 20).

- enhanced battlefield survivability/safety due to reduced obstruction of vision
- superior target acquisition, tracking and weapons release capability
- improved passenger comfort
- improved cruise efficiency due to reduced drag and download.

In addition the use of compounding leads to a reduction in the main gearbox power requirements at high forward speeds, see figure 21. This in turn leads to a lower main gearbox torque and hence (figure 22):-

- improved time between overhauls
- increased safety
- lower cabin noise

An important further benefit which accrues from thrust and lift compounding in the reduction in vibration at source (figure 23). When combined with techniques for active vibration suppression, the dream of a 'jet smooth ride' for a rotorcraft should become a reality. This results in (figure 24):-

- increased crew efficiency
- reduced unscheduled maintenance of airframe and equipment leading to
  - reduced operating costs
  - improved availability

4.0 Applications

A stength of the compound helicopter concept is that can be applied to existing helicopters through retrofit, and to new designs.

4.1 New Design

The full benefits of compounding are only achieved by a new vehicle design, see figure 25. Here the vehicle configuration will be dependent upon the role envisaged. Thrust compounding alone using a variable cycle engine is very attractive, particularly in those battlefield applications where a sustained high forward speed is not important but a high dash speed is required and the vehicle spends significant periods of time in the hover. The lack of a wing removes any penalties associated with download in the hover whilst the variable cycle engine provides a means of rapid acceleration/deceleration, if reverse thrust is used, whilst maintaining an essentially horizontal fuselage attitude throughout the mission.

For sustained high forward speeds, as required by a civil transport, a wing and engine driven aft mounted ducted fan prove to be very attractive. In this case, for example, if the blade area is sized to take account of the contribution of the wing and auxiliary source of thrust in forward flight then the blade weight could be reduced. The effect would then be cumulative. Reduced blade weight will lead to a reduction in the hub and gearbox size and weight and therefore possibly lead to a vehicle no heavier than the conventional helicopter undertaking its appropriate mission.

In the military sphere it is the emergence of the air to air combat and air escort roles which provide the applications that exploit the attributes of the thrust and lift compounded helicopter.

In the escort role a speed differential in excess of 30% would be provided whilst for air to air combat enhanced agility leads to better turn rates and reduced turn radii. Finally the level vehicle fuselage attitude will increase safety in nap of the earth flight and improve target acquisition, tracking and weapons release.

4.2 Retro Fit

As mentioned before a strength of the compound helicopter concept is that it can be retro-fitted to existing helicopters and significant improvements in performance are possible. The potential improvements can be broadly categorised into performance enhancements and superior crew/passenger appeal.

The simplicity of the retrofit compound helicopter concept can be illustrated by considering a thrust compounded helicopter using the variable cycle engine employing a variable area exhaust nozzle. The increase in complexity in this example is small and contained with the engine.

Performance studies based on a thrust and lift compounded *EH101*, see figure 26, using simple mechanically flapped wing and engine aft mounted ducted fans have indicated the following improvements (figure 27):-

- reduced cruise fuel burn (typically 5%) for a given helicopter cruise speed
- increased cruise speed by 25 - 40 knots (*depending on the installed power*)
- increased productivity of typically 10 - 15%
- increased range by approximately 5%

In addition the reduction in vibration will reduce operating cost by reducing non-scheduled maintenance. The quality of ride will be significantly improved which will lead to much greater passenger appeal.

5.0 The Way Ahead

In order to capitalise on the advantages of a compound helicopter and optimise the configuration for a specific requirement, further research work is required.

The research should address the following areas (figure 28):

- operational analysis of applications
- propulsion matching of variable cycle engine options
- variable cycle engine technology + infra red suppressors
- reduced rotor rpm operation at high forward speeds
- drag reduction
- wing download
- rotor/wing interference
- intake design
- stability and control
- advanced control implementation
- integrated flight and engine controls
- yaw control
- flight demonstration

In parallel with the research work a proof of concept demonstrator vehicle is required. To this end Westlands have been working with Rolls Royce on the definition of a proof of concept demonstrator vehicle based on a battlefield version of the Lynx helicopter, see figure 29. The basic features of the demonstrator aircraft are (figure 30):-

- battlefield Lynx with BERP (British Experimental Rotor Programme) rotor and
  - Phase 1: RTM322 engines with variable area exhaust nozzles
  - Phase 2: RTM322 engines with variable area exhaust nozzles and a simple mechanically flapped wing
- providing
  - estimated maximum speed of 235 knots
  - estimated maximum normal acceleration of 4 'g' at 200 knots (equated to an angular rate of 21 degrees/second)
  - operational exposure to potential customers

The demonstration vehicle would be used to explore the performance boundaries against the demands of present and emerging roles of the helicopter.

6.0 Concluding Remarks

The paper illustrates that the compound helicopter extends the capabilities and applications of the conventional helicopter thus maximising the market for rotorcraft utilising the edgewise rotor. This involves a low-risk progression from the conventional helicopter.

The possibility of providing thrust compounded, and thrust and lift compounded versions of a particular helicopter design means that a solution to the provision of vehicles meeting a wide variety of roles is possible in a very cost effective manner.

In particular the use of the variable cycle engine employing a controllable area a exhaust nozzle and the simple mechanically flapped wing minimises the additional complexity and is especially suited to the case of retrofit.

When the concept is combined with emerging technologies such as active control of vibration, and active flight control including integration of engine controls, the overall performance of the vehicle in terms of economics, quality of ride and safety will be substantial.

7.0 Acknowledgements

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COMPOUND DEFINITION

- THRUST COMPOUNDED HELICOPTER
  - EMPLOYS A SECOND SOURCE OF PROPULSIVE THRUST IN ADDITION TO THE MAIN ROTOR
- THRUST & LIFT COMPOUNDED HELICOPTER
  - EMPLOYS
    - (i) A SECOND SOURCE OF PROPULSIVE THRUST IN ADDITION TO THE MAIN ROTOR
    - PLUS
    - (ii) *A SECOND SOURCE OF LIFT IN ADDITION TO THE MAIN ROTOR*

Figure 1

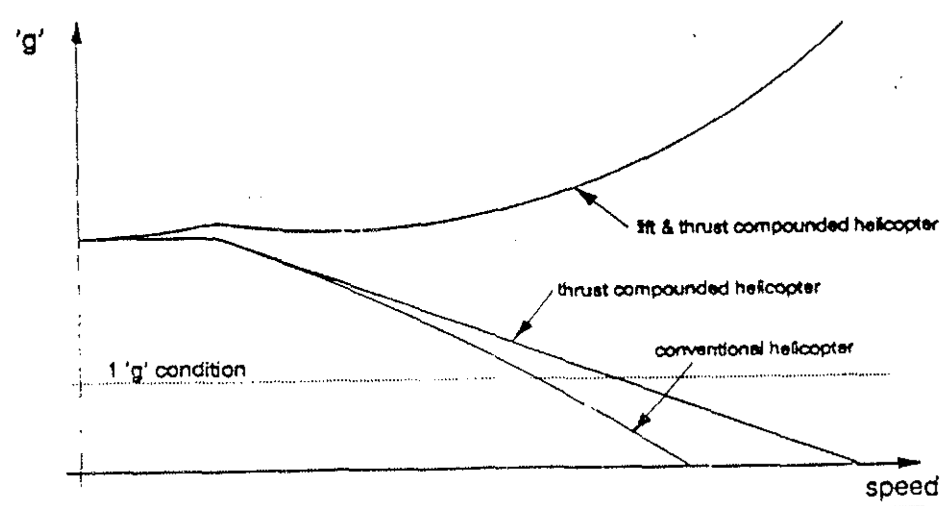
CONVENTIONAL HELICOPTER

OK
- FIRMLY ESTABLISHED PRODUCT
- LARGE AND DIVERSE MARKET

BUT
- LIMITED SPEED & PRODUCTIVITY
- POOR HIGH SPEED AGILITY
- VIBRATION

Figure 2

COMPARISON OF FLIGHT ENVELOPES



PREVIOUS COMPOUND HELICOPTERS

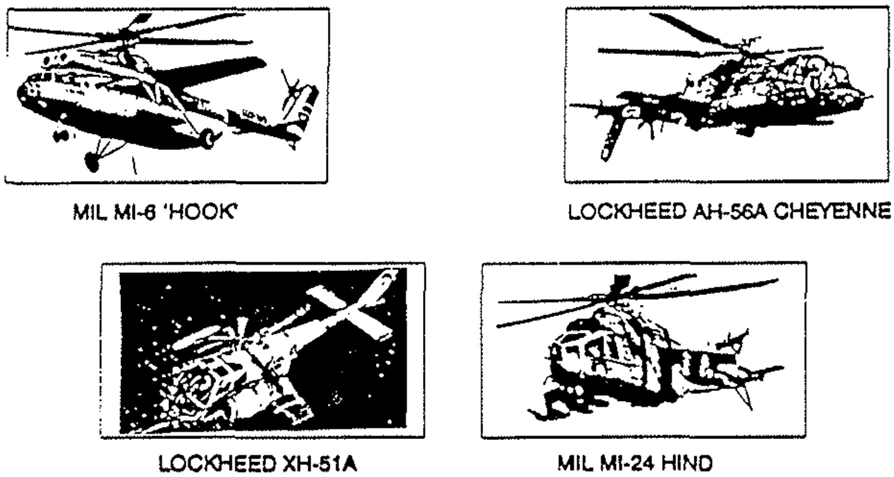


Figure 4

PROGRAMMES ADDRESSING COMPOUND ISSUES

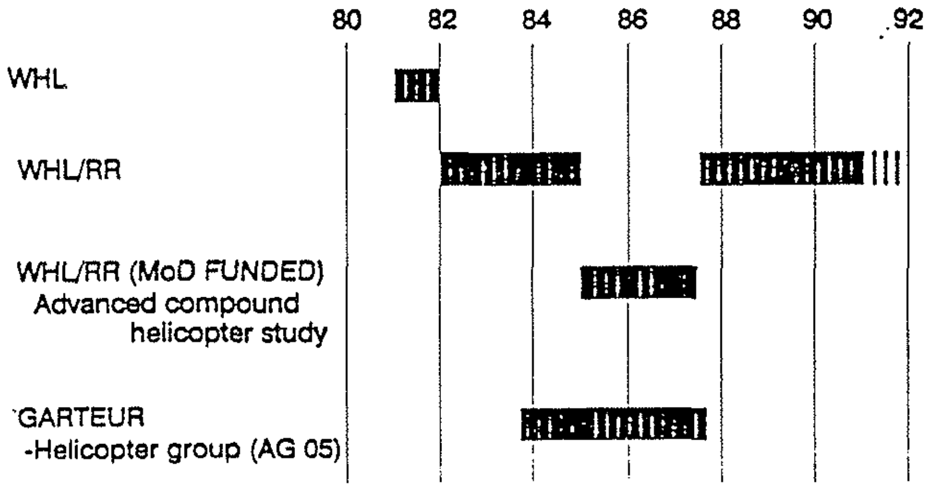


Figure 5

CONCLUSIONS FROM EARLY STUDIES

- Advanced compound configurations can be defined which offer increased productivity, speed, range and performance compared with conventional helicopters.

- The variable cycle engine is an attractive solution to compound helicopter propulsion requirements.

- The advanced compound concept merits further investigation.

Figure 6

OBJECTIVES OF MoD STUDY

VEHICLE : INVESTIGATE THE APPLICATION OF ADVANCED COMPOUND HELICOPTERS TO A RANGE OF MISSIONS - BATTLEFIELD, TRANSPORT, ASW AND AEW USING THE MOST PROMISING ENGINE AND WING CONCEPTS.

ENGINE : CARRY OUT PARAMETRIC STUDY OF VARIABLE CYCLE ENGINES COVERING PERFORMANCE, WEIGHT AND INSTALLATION.

IDENTIFY PROMISING ENGINE CANDIDATES FOR DIFFERENT MISSIONS.

Figure 7

MoD STUDY OPTIONS

MISSION	POWERPLANT	WING
CIVIL/ BATTLEFIELD TRANSPORT ATTACK	TURBOSHAFT ENGINE INCORPORATING EITHER VARIABLE NOZZLE	CONVENTIONAL ie MECHANICALLY FLAPPED
ANTI-SUBMARINE WARFARE	OR ENGINE DRIVEN FAN	AUGMENTOR
AIRBORNE EARLY WARNING	OR TRANSMISSION DRIVEN PROPELLOR OR DUCTED FAN	CIRCULATION CONTROL

Figure 8

ELEMENTS OF A VARIABLE CYCLE ENGINE

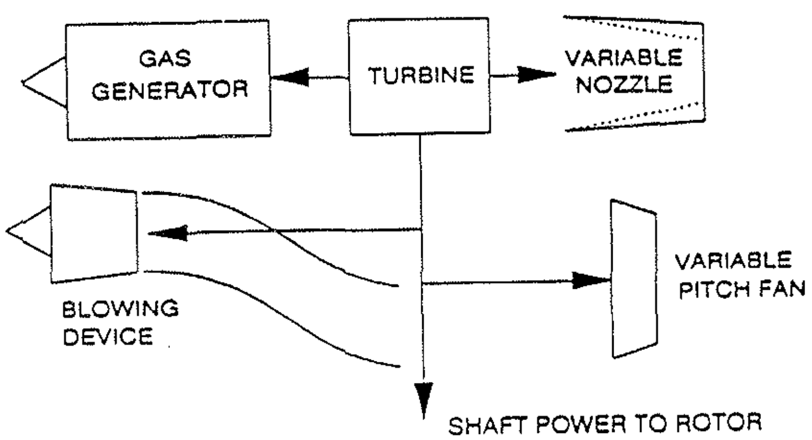


Figure 9

EXAMPLE VARIABLE CYCLE POWER PLANT

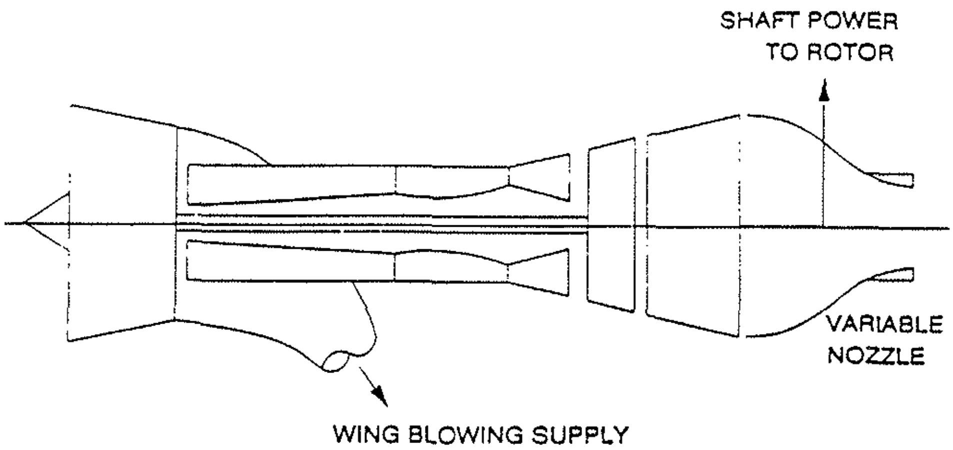


Figure 10

MoD STUDY WING OPTIONS

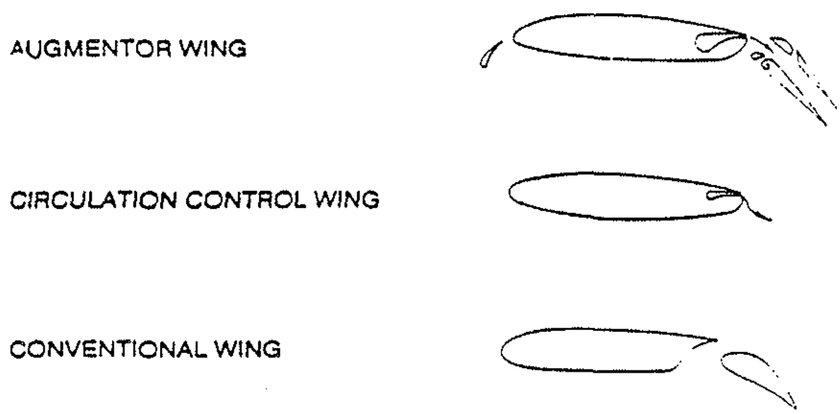


Figure 11

MoD STUDY CONCLUSIONS

WHL/RR study for MoD concluded that the Advanced Compound Helicopter Concept provides:-

- High speed
- High agility
- Horizontal fuselage attitude throughout flight envelope
- Reduced vibration
- Reduced power through main transmission

WITH:-

- Minimum increase in complexity
- Small mass penalty
- Minimal low speed penalty

AND:-

- The concept is applicable to a wide range of missions

Figure 12

PERFORMANCE TARGETS

- MAXIMUM SPEED OF 250 KNOTS
- LIFT/ DRAG RATIO INCREASED BY APPROXIMATELY 25%
- ENHANCED 'g' CAPABILITY AT HIGH SPEED
  e.g. 4'g' AT 200 KNOTS

Figure 13

LONGER RANGE/ HIGHER SPEED BENEFITS

- **Improved time on station**
- **Quicker reaction**
- **Enhanced survivability**
- ***Superior productivity***

Figure 14

INCREASED AGILITY BENEFITS

- Traditional good low speed manoeuvrability preserved to high forward speed
- Potential 'one to one' combat superiority against a range of opponents both fixed wing and rotary wing

Figure 15

AGILITY - OBSTACLE AVOIDANCE

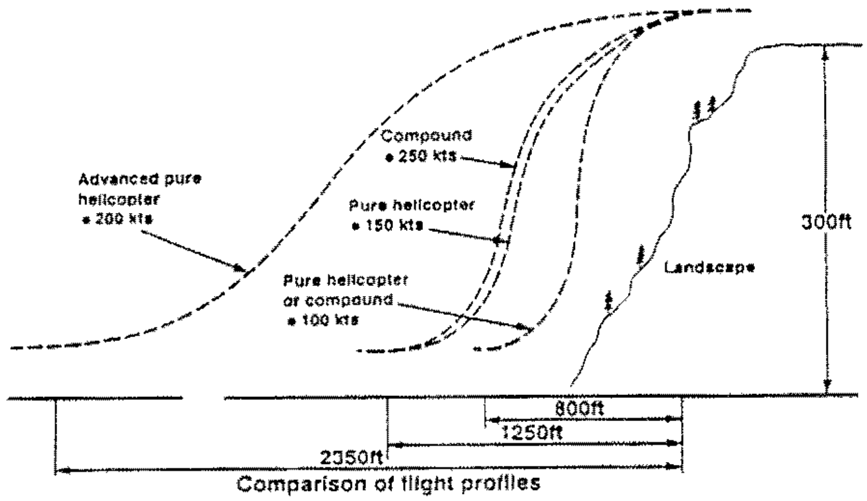


Figure 16

AGILITY

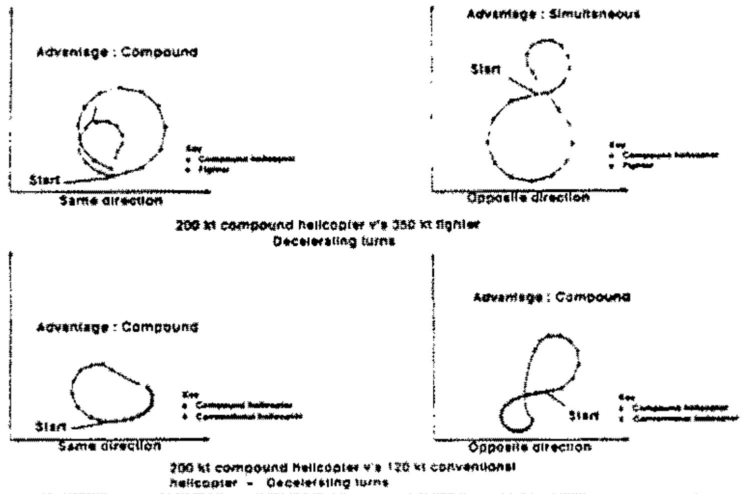


Figure 17

AGILITY - ACCELERATION

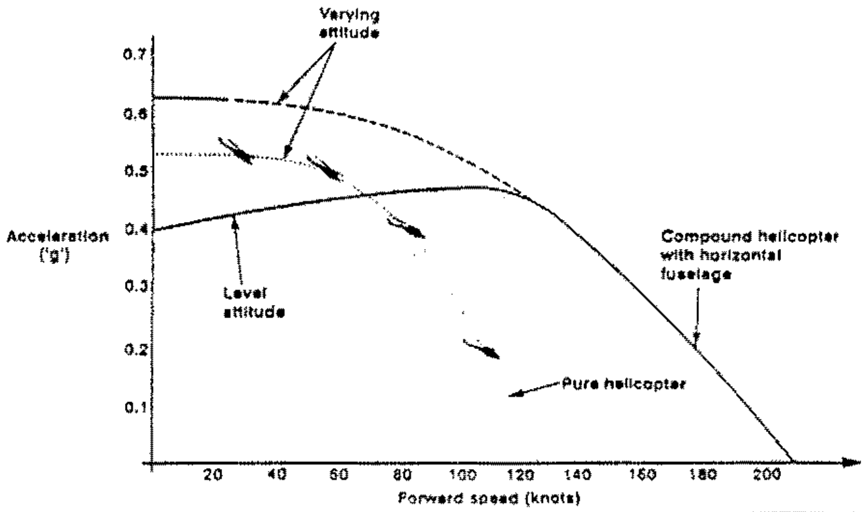


Figure 18

AGILITY - DECELERATION

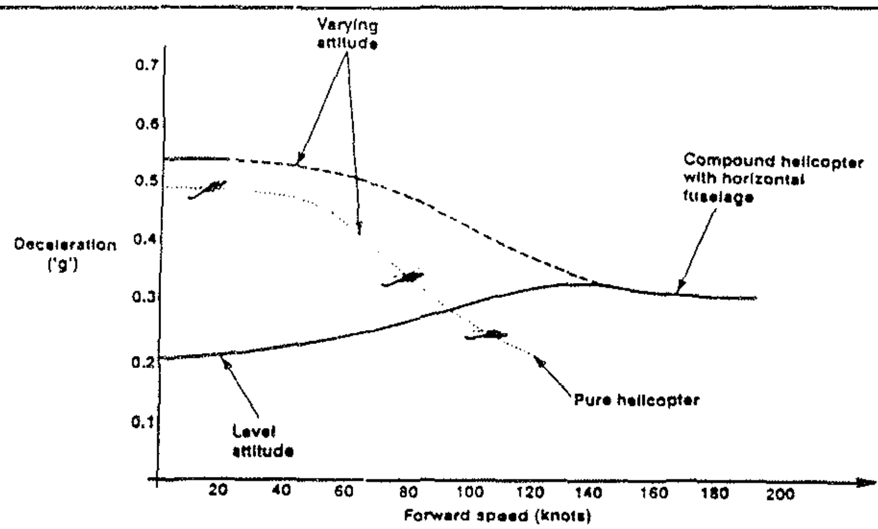


Figure 19

LEVEL FUSELAGE ATTITUDE BENEFITS

- Enhanced battlefield survivability due to reduced obstruction of vision
- Superior target acquisition, tracking and weapons release capability
- Improved passenger comfort
- Improved cruise efficiency due to reduced drag and download

Figure 20

MAIN GEARBOX POWER REQUIREMENTS

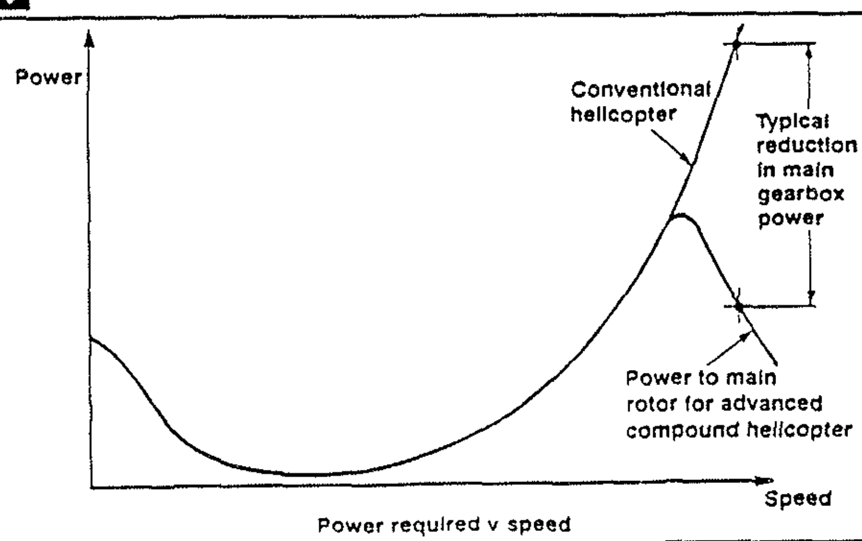


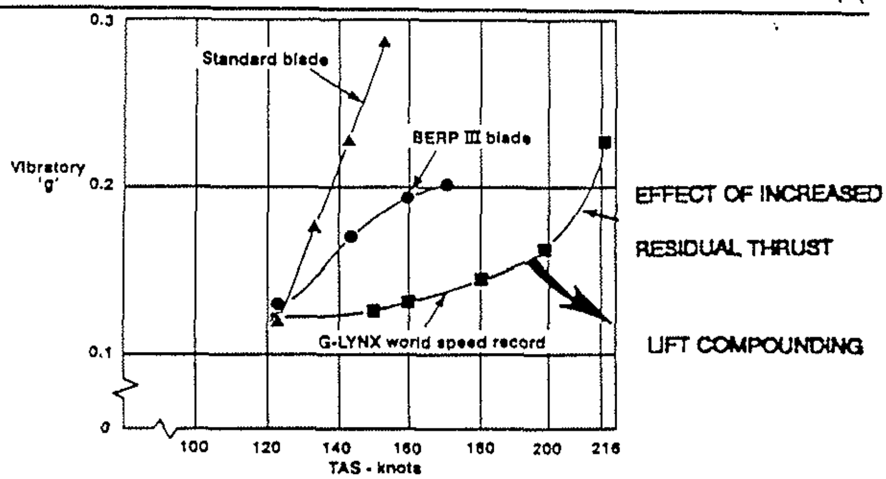
Figure 21

GEARBOX BENEFITS

- Reduced rotor power at high forward speed
- Lower main gearbox torque leading to :
  - Improved TBO's
  - Increased safety
  - *lower internal cabin noise*

Figure 22

VIBRATION



4R vibration levels (LYNX)
Test data is average of 4 stations

Figure 23

REDUCED VIBRATION BENEFITS

- Improved passenger comfort
  - potential for 'jet smooth ride'
- Increased crew efficiency
- Reduced unscheduled maintenance of airframe and equipment leading to
  - reduced operating costs
  - Improved availability

ADVANCED COMPOUND HELICOPTER

Figure 25

COMPOUND EH101

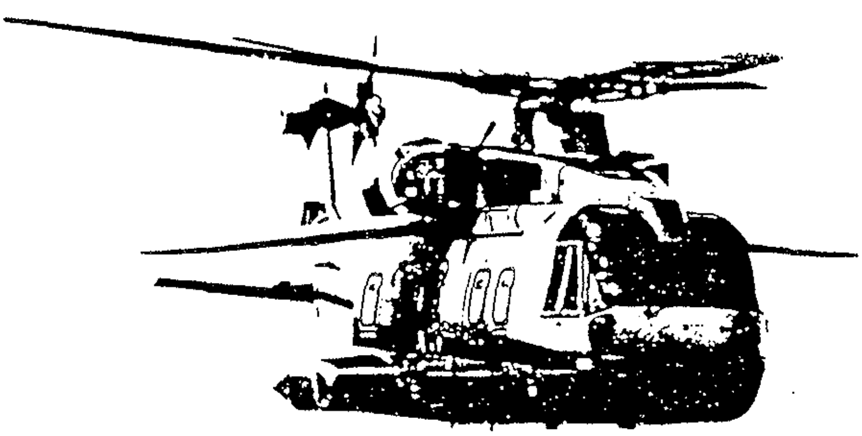


Figure 26

COMPOUND EH101 PERFORMANCE

PRELIMINARY INDICATIONS

- REDUCED CRUISE FUEL BURN (TYPICALLY 5%) FOR A GIVEN HELICOPTER CRUISE SPEED
- INCREASED CRUISE SPEED BY 25 - 40 KNOTS DEPENDING ON INSTALLED POWER

LEADING TO

- INCREASED PRODUCTIVITY OF TYPICALLY 10 - 15%
- INCREASED RANGE BY APPROXIMATELY 5%

Figure 27

THE WAY AHEAD

- Operational analysis of applications
- Propulsion matching of variable cycle engine options
- Variable area nozzle design + Infra Red suppressors
- Research topics
    - Reduced rotor r.p.m. at high speeds
    - Drag reduction
    - Wing download
    - Rotor/wing interference
    - Intake design
    - Stability and control
    - Advanced control implementation
    - Integrated Flight and Engine Controls
    - Yaw control
- Flight demonstration

Figure 28

LYNX COMPOUND DEMONSTRATOR

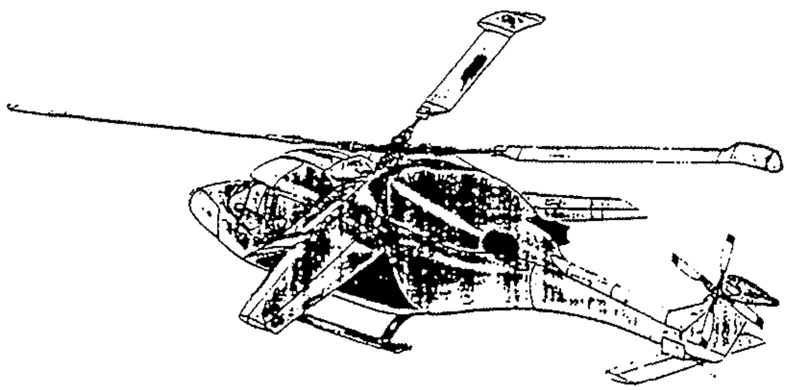


Figure 29

LYNX COMPOUND DEMONSTRATOR

- *Lynx airframe with BERP (British Experimntal Rotor Programme) rotor and*
    - Phase 1 :- RTM322 engines with variable area exhaust nozzles
    - Phase 2 :- modified RTM322 engines with variable area exhaust nozzles and mechanically flapped wing

- Features
    - Estimated maximum speed of 235 knots
    - Estimated maximum normal acceleration 4'g' at 200 knots (equates to an angular rate of 21 degrees/sec)
    - *Provides operational exposure to potential operators*

Figure 30

COMPOUND HELICOPTER TECHNOLOGY

- WILL INCREASE THE MARKET AND NUMBER OF ROLES SERVICED BY A VEHICLE USING THE EDGEWISE ROTOR
- IS APPLICABLE TO A WIDE RANGE OF MISSIONS
- CAN BE A RETRO - FIT TECHNOLOGY
- CAN BE ACHIEVED WITH A SMALL TECHNOLOGY STEP
- IS A LOW RISK PROGRESSION FROM THE CONVENTIONAL HELICOPTER

Figure 31