Back to Session Subjects

THE COMPOUND HELICOPTER VERSUS TILT ROTOR

- EUROPE'S SHORTCUT TO THE FUTURE

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Abstract

A revaluation of the compound helicopter in comparison to the tilt rotor aircraft was performed for civil transport and Search and Rescue missions at a pre-design study level using the expertise in compound helicopter optimisation developed at the University of Southampton. The iterative analysis for set missions was conducted using statistical and analytical mass and drag component models, combined with a blade element rotor/prop-rotor code incorporating interference effects to calculate the aerodynamic performance. The comparison based on economic indices showed the compound helicopter, whilst not matching the tilt rotor in optimum cruising speed, to be competitive with the tilt rotor for the civil transport missions, due to the compound helicopter's higher payload fraction. For the Search and Rescue mission the compound helicopter design was found to have greater viability due to its high hover efficiency. The reason for the contrast of these results in relation to previous studies can be found in the careful minimisation of the compound helicopter wing area to reduce the structural weight and hover blockage penalties. The use of BERP type rotor blade technology to allow advancing-blade penetration to higher Mach numbers before the onset of critical drag rise was also of significant benefit.

1 Introduction

With the recent contraction in the military and civil rotorcraft market, there has been a renewed effort to significantly expand the performance and the potential roles of rotorcraft to develop their market segment. This is best illustrated through the development of the Bell-Boeing V-22 and the Bell-Agusta 609 tilt rotor aircraft, with their large leap in performance over conventional helicopter types. In the euphoria of the tilt rotor's apparent success, however, it seems that the potential of other advanced configurations to achieve similar performance levels and fill other niches will be neglected. This paper is intended to demonstrate that the compound helicopter, while not matching the tilt rotor in all areas, is competitive for most missions and has other attributes that make it a competitive and in some ways a complementary design.

Several comparisons between the compound helicopter and the tilt rotor were performed throughout the eighties, most of which came down heavily in favour of the tilt rotor, an example being that by Wernicke and Fischer [1]. A few studies could be interpreted as favouring the compound helicopter, such as that by Unger [2]. For the purposes of this investigation, however, it was decided to perform a new comparison using the results of a study unfavourable towards the compound helicopter by Esculier, *et al* [3] as a basis. Esculier, *et al's*, study looked at the relative merits of the compound helicopter and tilt rotor aircraft for three pre-defined civil missions, long range transport, offshore transport and search and rescue. It came down strongly in favour of the tilt rotor for all of these missions, except for very short-range missions.

In many ways the compound helicopter is a more complex aircraft than the tilt rotor to design, due to the many layers of redundancy possible with an aircraft that has two forms of propulsion and two sources of lift. Mutual rotor-wing interference makes the optimisation process more intricate. For this reason it was felt that based on the expertise gained at the University of Southampton in the optimisation of the compound helicopter configuration, Orchard and Newman [4, 5], improvements could be made over the suggested performance levels in Esculier, *et al's* paper. Given that the compound helicopter is more heavily based on conventional helicopter technology, if comparable improvements in productivity and velocity could be made with this configuration then its lower technical risk and cost should make it an effective competitor to the tilt rotor for mid-level manufacturers. In addition if this configuration could be shown to be competitive in the primary performance parameters, then its benefits in other areas, such as manoeuvrability could make it a complementary if not preferable aircraft.

To make a valid comparison, both the tilt rotor and compound helicopter were modelled anew based on the methodology of Esculier *et al's* paper, with modifications only being made where the data used was unclear. The same mission descriptions, ranges and productivity indices were used for the comparison. From this it was hoped to see whether the optimised configuration could make any impression on the tilt rotor aircraft

2 Mission Description

The generic missions developed by Esculier, *et al.*, are based on that of a long-range civil transport aircraft and a long range Search and Rescue (SAR) vehicle, Figures 1 and 2. The missions themselves are broken down into separate flight phases of:

- Take-off phase from hover
- Climb phase
- Forward flight (cruise or search)
- Hover phase (landing or rescue)

The descent portion of the flight was not considered, as with Esculier, *et al.*, and a fuel reserve of 45 minutes at best endurance speed was included.

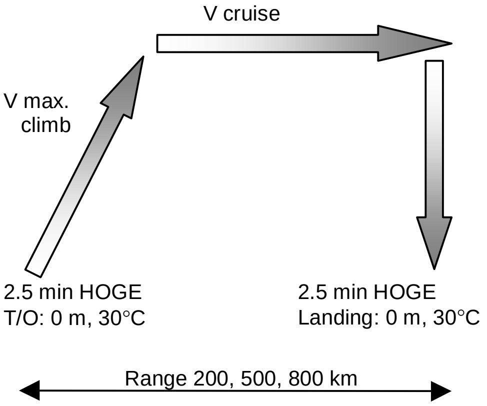
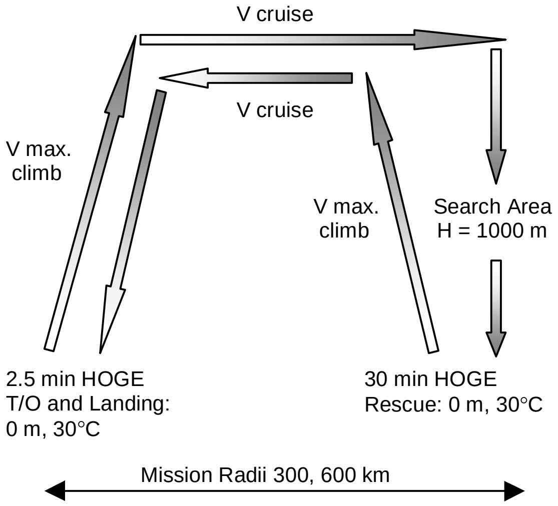


Figure 1: Generic Mission Profile for Civil Transport



Search: 2hrs at the higher - 100kts or Best Endurance Speed

Figure 2: Generic SAR Mission Profile

The SAR mission is based on a four-man crew, picking up eight survivors at the extremity of the mission.

3 Aircraft Modelling Methodology

3.1 Tilt Rotor

The aircraft is of the tilt-rotor configuration promoted by Bell and Boeing with two rotating engines and three bladed prop-rotors mounted on the ends of a constant-chord wing. The wing has a 23% section thickness and has simple flaps of 30 percent wing chord that can be deflected to large angles to minimise the hover download penalty. Where sufficient statistical data has not been available then the design features of the Bell-Boeing V22 and Bell-Agusta BA-609 have been utilised. For instance the prop-rotors are directly based on the design of those of the V-22. A 15% prop-rotor speed increase is employed for the aircraft when in helicopter mode. The aircraft sizing methodology is as follows:

1. An initial estimate of the gross weight of the aircraft is made based on the payload and range to be flown.
2. The prop-rotor diameter is determined by a specified maximum disc loading.
3. The fuselage is sized using a passenger number based on the payload and likely cross-section/seating arrangement.
4. The wing span is chosen to provide sufficient prop-rotor-fuselage clearance.
5. The wing chord is determined by requiring a suitable stalling speed in aeroplane mode, typically about 120 knots with flaps deployed.
6. Airframe drag is computed from a sub-element model.
7. Prop-rotor blade area is determined from a specified solidity coefficient.
8. The power plant and transmission is then sized to meet the requirement to hover OEI at 5000ft on a 90°F day and ensure a maximum velocity 10% above the cruise velocity.
9. The fuel requirements for the set mission are calculated.
10. The all-up-mass of the aircraft is recomputed using the sub-element mass model.
11. Steps 2 – 10 are repeated until the all-up-mass converges.

3.2 Compound Helicopter

The sizing of the compound helicopter is far more complex than the tilt-rotor due to the inherent redundancy of lift and thrust with the configuration. From experience in optimising many performance parameters of the compound helicopter at the University of Southampton, many benefits have been shown by operating the compound helicopter with the supplementary thrust equal to horizontal drag, hence this has been used throughout, Orchard and Newman [4]. Another consistent finding was the benefit of a low wing position in terms of minimising the rotor-wing interference and also for structural reasons, such as the benefits of undercarriage attachment to the wing. The choice of wing size is such that retreating blade stall can be avoided throughout the envelope, allowing for a 30° bank angle. The wing has a 75% taper and 18% thick section.

A fixed rotor speed is chosen such as to avoid critical drag rise at a velocity 10% above the design cruise speed. The use of a variable speed rotor was avoided to reduce the likelihood of fuselage dynamic response, although the inclusion of this feature could have significant performance advantages. The rotor system uses a 6% thickness blade section at the tip with a notch a distance inboard, as with the BERP blade, to take advantage of its ability to penetrate to high Mach numbers before critical drag rise occurs. A twist of 8% has been used since no suitable design criterion is available. The blades are of approximately 50% greater inertia than those of a comparative conventional helicopter to minimise the potential high-speed autorotation entry problem. The configuration and size is found using the following method:

1. The rotor tip speed is set to allow a forward velocity increase 10% over the design cruise speed before the advancing-blade critical Mach number is reached.
2. An initial estimate of the aircraft’s weight is made from the payload weight and the range to be flown.
3. An initial estimate of the aircraft’s rotor radius is made using an inputted disc loading.
4. The blade number is chosen in relation to aircraft all up mass to minimise likely vibration difficulties.
5. The wing is sized to avoid retreating-blade stall throughout the envelope allowing a 30° bank angle manoeuvre margin - intermediate velocities must be evaluated.
6. The fuselage is sized in relation to the rotor radius, the necessary payload and the likely seating arrangement / fuselage cross-section.
7. The tail rotor is designed to be able to oppose twice the level of the main rotor torque in hovering flight.

8. The component drag is estimated using the sub-element model.
9. The supplementary propulsor size and power requirements are determined.
10. The power requirements are determined from the OEI requirements (500ft/min climb at 5000ft, 90°F) and maximum velocity requirements (the latter predominates).
11. The power plants and transmission are sized to meet the performance requirements.
12. The fuel requirements for the set mission are calculated.
13. The component masses are evaluated using the sub-element model and the all-up-mass is recomputed.
14. The rotor radius is designed to meet the following requirements:

- Ability to perform a 1500ft/min vertical climb at 5000ft on a 90°F day.
- Ability to achieve a 30° bank angle in the hover at 5000ft on a 90°F day.
- Maximum vertical autorotative descent rate of 3000ft/min.
- Hover power less than half of the maximum velocity power requirements.

15. Steps 4 – 14 are repeated until the all-up-mass converges.

It should be noted that the OEI requirements for the compound helicopter were made more stringent than for the tilt rotor aircraft. It is expected that this will disadvantage the compound helicopter in relation somewhat, yet resources have not allowed this discrepancy to be corrected as yet. The requirement for the hover power to be less than the maximum velocity requirements is also redundant, since the aircraft is inevitably limited by the needs at maximum velocity. It was also of note that the autorotation requirements were not the limiting design factor for the rotor in most cases, although it is felt that more research is necessary to investigate the difficulties and modelling of high-speed autorotation entry. Whilst a tail rotor has been specified, it is realised that other anti-torque devices may offer greater benefits to the compound helicopter through drag reduction, due to this configuration’s low anti-torque requirements in cruise and high-speed in relation to the conventional helicopter. Both aircraft types are assumed to be twin engined.

3.3 Modelling the Aircraft Characteristics

As with any preliminary design study, the lack of knowledge of the design requires an iterative approach and reliance on statistical data from past designs. While there is a vast array of data for conventional helicopters and fixed-wing aircraft, the data available for both the tilt rotor and compound helicopter is very sparse. For this reason the former data was adapted along with common analytical techniques to estimate component weights of the aircraft, references [6 - 9]. Whilst not expected to be perfectly accurate, this technique should, with a degree of conservatism, allow the correct trends to be exposed. Identical mass, drag and rotor performance models have been used wherever reasonably possible to ensure the validity of the comparison.

The component level mass analysis broke the aircraft design down into the fuselage, wing, rotor/prop-rotor hubs, blades, drive train, tail rotor, empennage, installed equipment, flight controls, fuel system, undercarriage, auxiliary thrust propeller(s) and the power plants of the aircraft. The model was validated by analysing existing helicopters and tilt rotor aircraft, the helicopter in particular giving good agreement. The all up weight for the V-22 was underestimated to a degree, although this is probably due to the wing folding mechanism and equipment levels of this aircraft.

The estimation of the aircraft drag was also determined on a component basis with appropriate fixed-wing or helicopter empirical correction factors being applied to estimate the interference drag. The rotor-wing interference was modelled using the technique of reference [5] as a basis. The rotor hub of the compound helicopter was assumed to be of the semi-rigid type, with no concentrated effort being made to reduce its drag levels. It is felt that this is one area where large gains could made in reducing the compound helicopter drag level, enabling increases its performance. The wing is modelled using basic lifting line theory, to calculate the lift and induced drag, combined with tabulated profile drag coefficients. The model takes into account the aspect ratio, chord, aerofoil section and taper. Download in the hover is calculated using strip theory from the drag of a modified cylinder, appropriately dimensioned, for the compound helicopter fuselage and a flat plate for the wings of both aircraft. The latter's lift coefficient and area is modified to account for the beneficial effects of suitable flap deflections. The influence of the fountain effect and optimal flap deflection has been incorporated empirically using the experimental results of Felker and Light, references [10 - 12].

In contrast to the work by Esculier, *et al.*, the current modelling approach uses blade element theory for the performance analysis of the rotors, prop-rotors and propellers. This approach was preferred over the momentum theory methodology used by Esculier, *et al.*, as it enables incorporation of compressibility effects, retreating-blade stall effects and improved rotor design features to a level not possible using the momentum method. This is particularly important since both aircraft types operate near the extremes of rotor performance. This technique has also enabled some of the features of the advanced BERP blade design to be utilised on the compound helicopter design, although more can be done in this area.

The performance limitations such as the OEI requirements at 5000ft are calculated directly using the blade element model, a standard contingency engine rating being applied. To model the engine performance, the analysis is based around the existing data for the Pratt and Whitney CT7 engine characteristics. Temperature, altitude, engine rating and installation losses are accounted for.

3.4 Limitations

As noted one of the big difficulties with a project study of this nature is the dearth of data relating to the new aircraft types that are being designed. For this reason existing data for has been extrapolated into new regions from existing designs which were usually intended for different tasks, which has necessitated a conservative approach regarding the state of technology advances. To this end the mass and drag models can be assumed to be on the conservative side, but are expected to produce the correct if not exact trends for these configurations. Supporting this conclusion is the closeness with which the V-22 could be modelled, taking its most severe mission as a starting point and accounting for the extra weight of its folding mechanisms. The current work has focussed more on the aerodynamics of the two configurations and it is thought that techniques employed give a robustness and sufficient detail to make a fair comparison at this level, without the need for additional statistical data. A word of caution on this point, however, as although much experience has been gained at the University of Southampton regarding the optimisation of the compound helicopter configuration, there is still a lot about the design of the rotor for this configuration to be learned. It is expected that the design of the rotor for this configuration will be subtly different in many ways to the conventional helicopter's if the optimum performance is to be obtained. In this regard the current study can be viewed as one of the first steps of this process. The same could be held true for the prop-rotor of the tilt rotor aircraft, although a far greater level of effort has been applied to the design of the V-22 rotor design used as the basis in this analysis.

4 Comparison of the Configurations

The comparison of the different aircraft configurations is directly based on the performance and technical parameters suggested by Esculier, *et al*. The technical parameters consist of the aircraft's all-up-mission mass and the empty weight of the aircraft, which can be compared to the AUM as a indicator of the '*mass efficiency*' of aircraft. Also to be considered are the mission time, which is largely dependent on the design cruise speed and the fuel requirements.

To put the technical parameters into perspective, Esculier, *et al.*, developed a second set of criteria to assess the economic efficiency of the various aircraft and missions. The first of these, equation 1, is a measure of the mission costs of the aircraft, which is derived from the observation that the direct operating costs are roughly proportional to the empty mass of the aircraft and fuel flow.

$$\begin{aligned}Mission\_Cost = K_1 \times Empty\_Mass \times \\ Mission\_Time + K_2 \times Fuel\_Mass\end{aligned} \qquad [1]$$

Where the initial cost of the aircraft is reflected by K_1 and the influence of the fuel cost is represented by K_2. The values used for these coefficients are 1 and 2 respectively, unless noted, as was suggested by Esculier, *et. al*.

To assess the relative ecconomic efficiency of the different aircraft, it was noted that the cost to the customer utilising the aircraft is proportional to the range and payload to be delivered. From this, the customer's cost, and the mission cost, paid by the operator, a relative *'productivity index'* can be defined as:

$$PI = \frac{Payload \times Range}{Mission\_Cost} \qquad [2]$$

The advantage of operating a faster aircraft was developed into a *'rentability index'* by Esculier, *et al.*, equation 3, based on the hypothesis that a customer would be willing to pay 30% more to fly twice as fast.

$$RI = PI \times \left(\frac{Range}{Mission\_Time} \right)^{0.4} \qquad [3]$$

5 Civil Transport Mission Comparison

Using the same *productivity* and *rentability* indices as in Esculier, *et al's* study the new results show the compound helicopter to be more competitive as a whole, Figures 3 and 4, than predicted by Esculier, *et al*. The analysis also indicated that the best design speeds, in terms of the economic indices, for the tilt rotor was 300 knots, slightly lower than the 310 knots suggested by Esculier, *et al.*, and 250 knots for the compound helicopter, which is higher than the 230 knots suggested in the previous paper. There are several reasons for the differences between the current results and those of the former work.

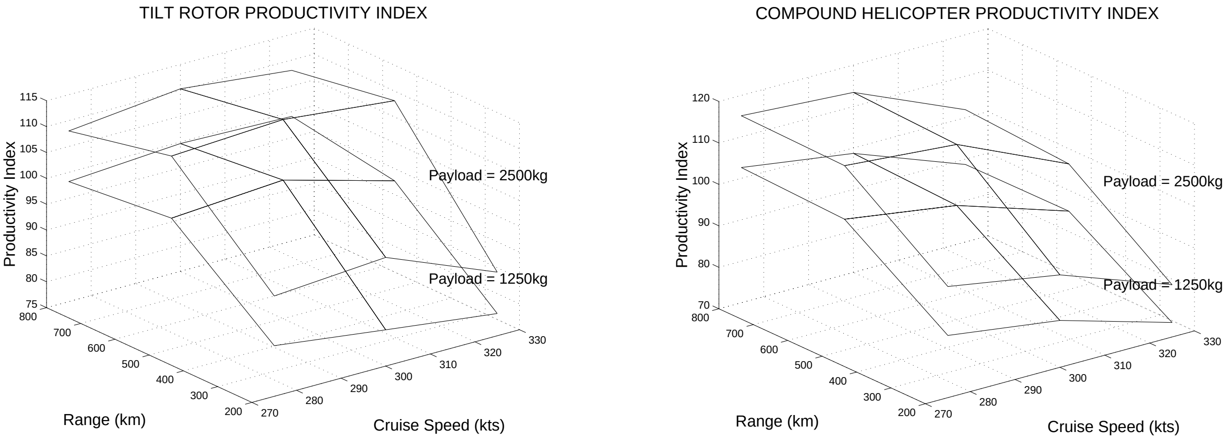


Figure 3: Productivity Index – Civil Transport Mission

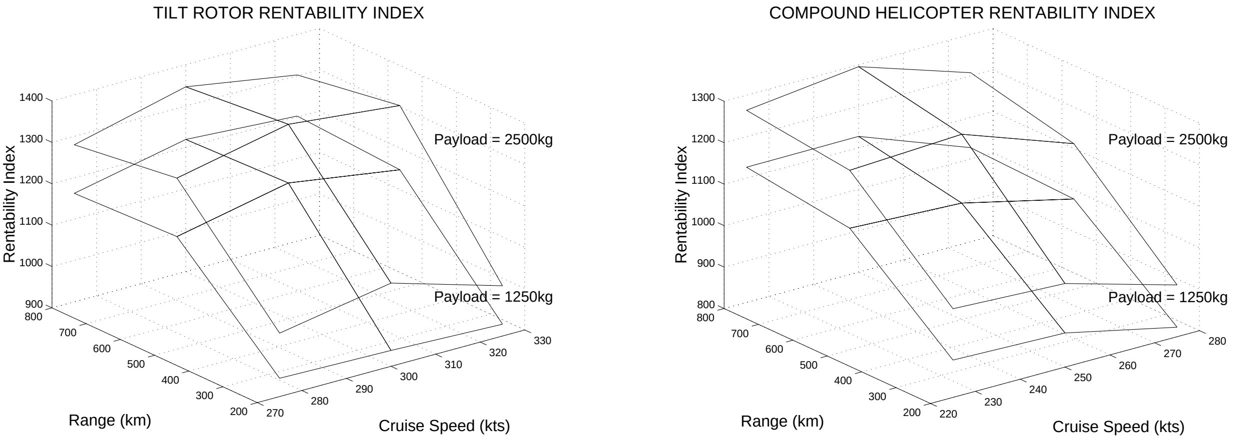


Figure 4: Rentability Index – Civil Transport Mission

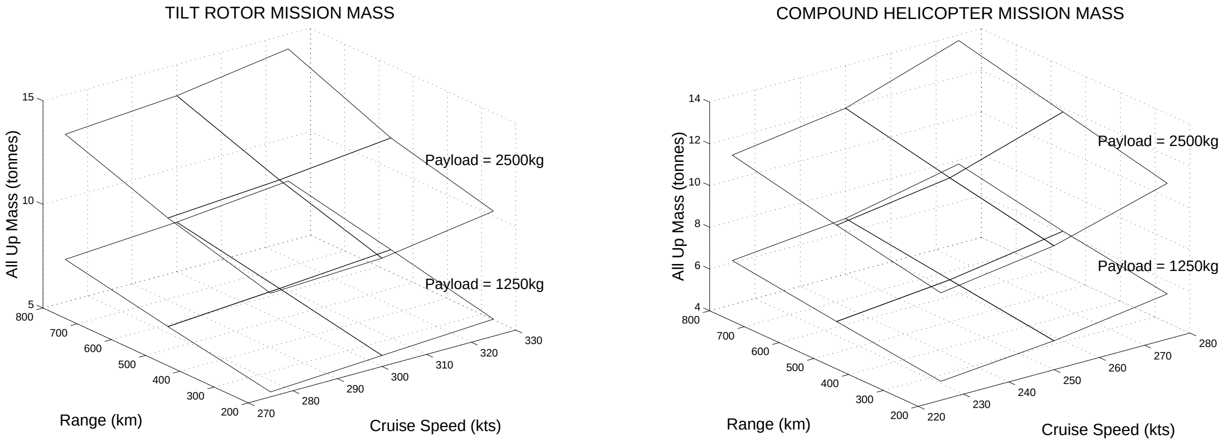


Figure 5: Mission Mass – Civil Transport Mission

Looking at the AUM for both configurations, Figure 5, the compound helicopter benefits for at all ranges, thanks to its lower disc loading in the hover and the lower cruise velocities used giving it a higher payload fraction. The increase in AUM with increasing velocity is proportionally higher for the compound helicopter, however, due to the ever-present limitations of the main rotor at high forward velocities, in particular the penalties of the rotor profile power and hub drag. Combining this with its lower cruise velocities in relation to the tilt rotor designs, the compound helicopter shows a greater economic sensitivity to changes in design velocity. The productivity and rentability indices drop away at a much sharper rate for the compound helicopter above its optimum velocity, Figures 3 and 4. Interestingly the productivity of both designs begins to plateau off above a range of 500km, the compound helicopter's higher payload fraction enabling it to compete with the faster tilt rotor.

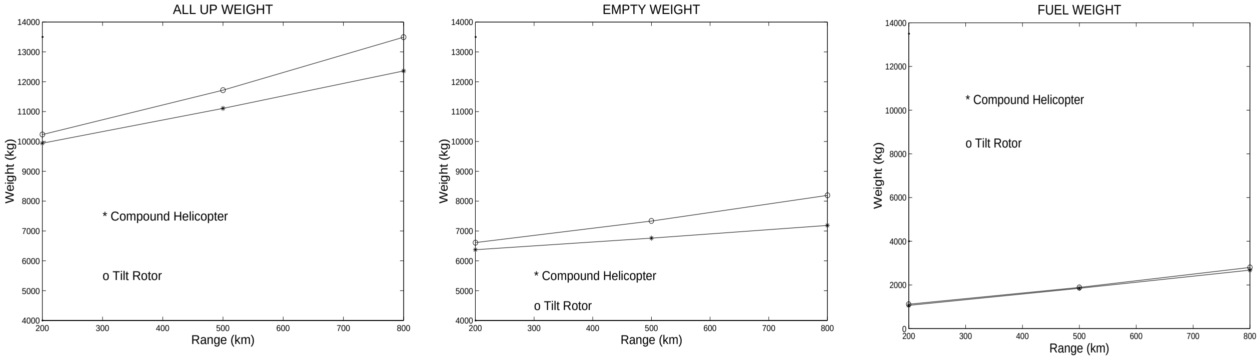


Figure 6: AUM, EM, Fuel Mass – Civil Transport with 2500kg Payload

If the optimum velocities of the previous figures are taken and the individual weight components are investigated, it can be seen that not much separates the two aircraft types in terms of fuel burn, Figure 6. The compound helicopter benefits in terms of lower installed power, but the additional mission time translates to the requirement for a proportionally larger fuel load. The configuration has a relatively small wing, however, of the order of 5% of the rotor disc area hence the additional power requirements in hover are minimal, enabling its high payload fraction. The tilt rotor in comparison hand is penalised by both the hover download and the structural weight of a large wing, which gives it a significantly lower payload fraction.

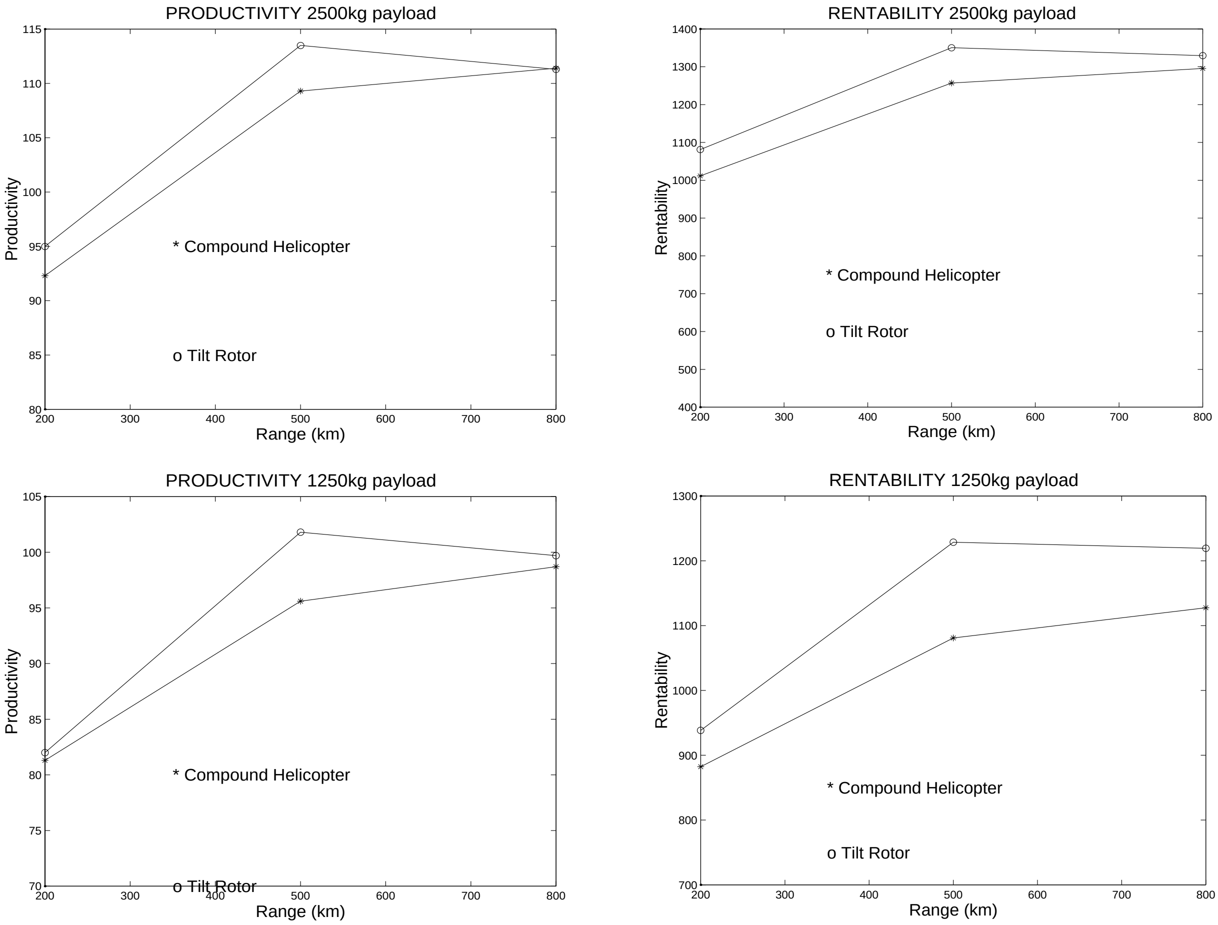


Figure 7: Productivity and Rentability – Civil Transport Mission

Comparing the two configurations economically on a one-to-one basis, again at the previously noted best design velocities, Figure 7, the compound helicopter is surprisingly competitive productivity-wise against the tilt rotor for both payload weights. This comes down, as mentioned before, to the lower empty weight of the former aircraft. Unexpectedly the tilt rotor productivity diminished above a range of 500km relative to the compound helicopter and this was found to be driven by the hover limitations. As the range is extended the configuration not only required larger engines but also increased the aircraft size to meet the OEI requirements, hence driving the mission fuel consumption rates up at a higher rate. The compound helicopter on the other hand is not driven by the OEI hover condition, the maximum velocity power being the primary driving factor.

The sum of the changes between these results and Esculier, *et al's* analysis may be partly the result of overly conservative data for the compound helicopter in the previous analysis. Throughout the current work a determined effort has been made to use identical models for the two aircraft types if reasonably possible. In defence of the original paper, little was done in it to optimise the compound helicopter configuration and the wing – rotor interactions could only be modelled at their most rudimentary level. Experience has shown that the sizing of the wing can be critical, Orchard and Newman [4, 5], hence the design criterion to size the wing to a minimum size to avoid retreating-blade stall. Also benefiting the compound helicopter in the current study is the use of the BERP-like rotor with a thin tip aerofoil section and notch allowing higher tip speeds than otherwise possible, although the benefits available in this area have by no means been fully explored

6 SAR Operation Comparison

The results in terms of mission cost and fuel consumption were most surprising for the SAR missions, Figures 8 to 10. Figure shows the compound helicopter to be the most cost effective for the SAR mission at both mission radii. Conventional thinking is that the increased cruise efficiency of the tilt rotor will outweigh any benefits the compound helicopter gains from its improved hover efficiency. With the optimisation of the configuration however, there is little relative cruise penalty when operating at the lower compound helicopter cruise speeds and it therefore gains substantially from its improved hover efficiency. As a result both the mission mass, Figure 9, and the fuel mass, Figure 10, of the compound helicopter are significantly lowered, resulting in the lower mission cost for this configuration. It must be pointed out that the analysis takes no account of the benefits gained from quicker response times possible with the tilt rotor, which will influence the survivability rate of those rescued.

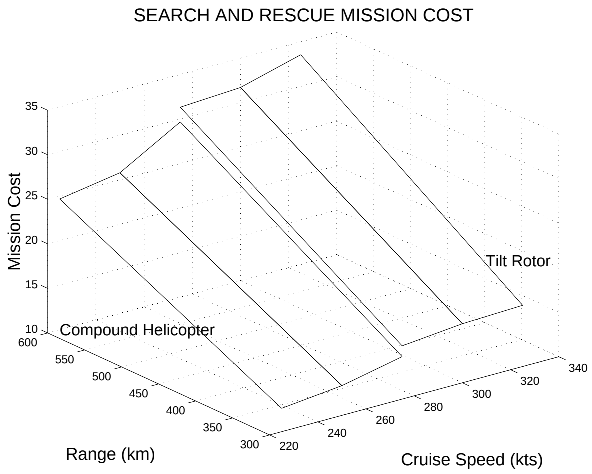


Figure 8: Mission Cost - SAR

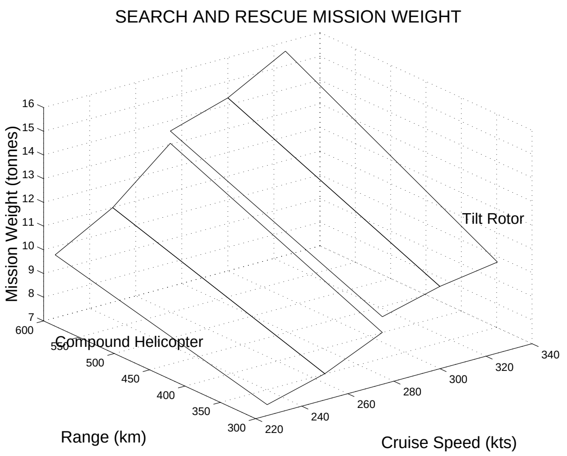


Figure 9: Mission Mass – SAR Mission

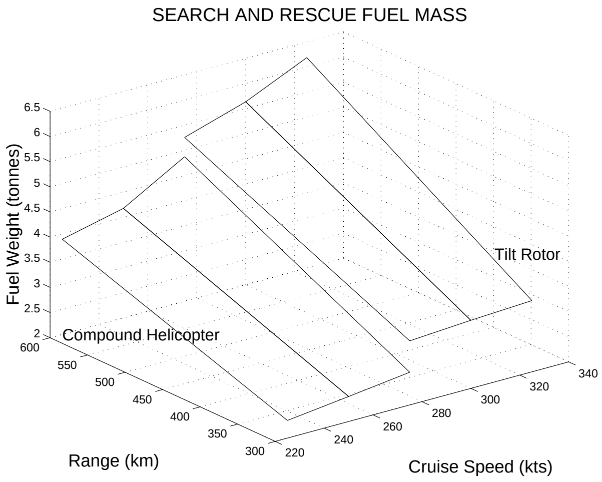


Figure 10: Fuel Mass – SAR Mission

7 Discussion

The size of improvement in the comparison of the compound helicopter against the tilt rotor using the new analysis and optimised compound helicopter design surprised even the authors. This initially resulted in a detailed revaluation of the code, until it was realised that the optimisation and choice of rotor system lent the redesigned compound helicopter some significant advantages over the aircraft used in Esculier, *et al's* work. The first and highly significant feature is the ability to minimise the wing size to only that necessary to avoid retreating-blade stall and facilitate the required speed. This is necessary to minimise both the structural weight and blockage penalty of the wing, both of which can severely limit the economics of the compound helicopter. The second feature is the inclusion of some of the features of the BERP rotor blade, particularly the notch, which truncates the propagation of the shock wave on to the tip of the blade, and the use of a thin aerofoil section at the tip extremity. Both of these features enable better advancing-blade Mach number penetration than more conventional designs and hence allow a reasonable tip speed to be utilised that does not unduly affect the hover portion of the envelope. These advancing-blade benefits are inherently aided by the unloading of the rotor that occurs with the compound helicopter resulting in lower blade incidences as higher Mach numbers are approached, adding further compressibility relief. The model has, however, only incorporated the rudiments of the BERP design and it is felt that further improvements could be made to the compound helicopter performance by further customisation of the rotor to meet the compound helicopter's particular needs. The addition of a small rotor speed variation for the hover portion of the envelope also offers the potential for further compound helicopter performance improvements.

It is of the Author's opinion that more needs to be done with regard to developing a suitable design criterion for the compound helicopter rotor. Previous work by the Authors [4, 5] has utilised a conventional helicopter rotor as a design starting point. The current analysis, however, has again highlighted the desirability to reduce the blade area to minimise the profile power penalty in the cruise, since the high installed power levels necessary to achieve the maximum speed make this possible without compromising the OEI requirements. It was found in many cases that the limiting influence on the rotor size became the avoidance of rotor stall at high altitudes/low air densities. Also of concern is the high-speed autorotation entry of the aircraft, in that although the autorotation limitation did applied did not inhibit the design, this is a known potential problem area for the compound helicopter, hence further discussion on a suitable rotor design criterion for the compound helicopter is desired.

Moving back to the tilt rotor, apart from the SAR mission, the tilt rotor generally held a small advantage over the compound helicopter for all the civil missions. Whether this advantage is pared back further by compound helicopter improvements will be the subject of future research, but it was obvious from the analysis that the hover ability and transition between helicopter and aeroplane modes were the limiting factors for the tilt rotor design. That the optimum design speed of 300-knots is slightly in excess of the cruise speeds used by the V-22 and BA-609, suggests that the aircraft design was pitched at a reasonable level.

The sensitivity of the two configurations to changes in the economic coefficients K_1 and K_2 can be done through simple inspection of the relavent empty weights and fuel loads. As the compound helicopter usually excells in terms of empty weight, its increased mission times have little influence. Similarly the fuel load of the two configurations are normally of sufficiently similar order that the two aircraft types can be expected to have similar sensitivities to changes in these parameters.

Further consideration must be made regarding appropriate missions for the two configurations, as they have different strengths and weaknesses. The missions chosen by Esculier, *et al.* should favour the tilt rotor, particularly the civil mission with little hover requirements, as borne out by the results, although they do not favour the tilt rotor to the degree that might be expected. For missions such as the SAR mission with a higher proportion of the mission spent in hover, it is suggested that the compound helicopter could be expected to excel to a greater extent. Another example may be an ASW mission, which requires high dash speeds followed by long periods spent in hover. Whether the conventional helicopter's performance can be exceeded in this case is still a matter for debate. Other missions where the compound helicopter may be more appropriate include those where manoeuvrability is important, such as an attack mission, as the redundancy of lift inherent in the configuration can be used to advantage, Orchard and Newman [5]. To fully utilise this advantage, either the wing will have to be resized in relation to the minimal wing area used in the current analysis or the deployment of flaps as a manoeuvre-enhancing device should be considered.

A further significant point in the compound helicopter's favour is its closeness to the conventional helicopter in design. For this reason there is the potential for a current conventional helicopter manufacturer to rapidly develop an effective competitor to challenge the American's hold on the advanced rotorcraft market, currently dominated by the tilt rotor. The natural evolution of the conventional helicopter design should allow this to be done at a reduced level of technical and financial risk. The compound helicopter should also benefit from the ability to be developed following current helicopter flight or airworthiness constraints, without the difficulties of developing new rules and procedures.

8 Conclusions

So, is the compound helicopter a viable alternative to the tilt rotor? On the basis of the current results the answer must be affirmative. The analysis shows the compound helicopter to only be at a small disadvantage when performing the civil transport missions with long periods of cruising flight, and that it excels at missions, such as the SAR mission, that require significant periods of hover. The compound helicopter gains due to its higher payload fraction.

In comparison to the previous compound helicopter results obtained by Esculier, *et al.*, the compound helicopter was shown to be much more economically viable. This can be attributed to the higher level of optimisation attempted within the current study, particularly with regards to minimising the wing size, which reduces the structural weight and hover blockage penalties of the compound helicopter. The use of the features of the BERP blade was also felt to have improved the capabilities of the compound helicopter aircraft in the current study, due to the advancing-blade's ability to penetrate to higher Mach numbers than more conventional designs. It is felt that more can be done to optimise the rotor system for the compound helicopter to extract an even greater level of performance.

While the tilt rotor may have greater maximum speed potential, the compound helicopter has been shown to be competitive. Probably its biggest advantage, however, is its lower development costs, since it is a natural expansion of existing helicopter technology. The compound helicopter could be Europe's bridge over the American industry's technological lead - it could be Europe's shortcut to the future.

Glossary

OEI	- One Engine Inoperative
AUM	- All Up Mass (Mission Take-off Weight)
ASW	- Anti-Submarine Warfare
BERP	- British Experimental Rotor Programme
PI	- Productivity Index
RI	- Rentability Index

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