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HELICOPTER MANOEUVRABILITY TESTING IN PRACTICE

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ABSTRACT

The manoeuvre stability of a rotary wing aircraft has long been determined by tests devised at a time when the performance of helicopters was somewhat limited compared with that of today's aircraft.

Attempts have been made to adapt fixed wing theory to provide static and manoeuvre margins for a rotary wing aircraft, but these terms do not have the same significance for helicopters as for fixed wing aircraft. Furthermore, the military helicopter pilot is unlikely to be familiar with the theory of manoeuvre stability, much less the concept of a manoeuvre margin for his aircraft, requiring only carefree manoeuvring throughout the flight envelope defined by his mission.

To give the pilot as much information as possible about the agility of his aircraft, we must start by asking him what information is relevant. If the present generation of manoeuvre stability tests do not provide this data, then new tasks must be devised which will define the agility of an aircraft in a form which is readily comprehensible to the ordinary squadron pilot.

INTRODUCTION

1. As helicopters become more agile and structurally robust, it would seem likely that the pilot will require more information than that available at present in order to utilise the full capability of such an aircraft. The problem is, what information is required and how can we provide it?

2. Fixed wing aircraft define the manoeuvre margin as the distance of the cg from the manoeuvre point, but the longitudinal position of the cg is not as significant for a helicopter, affecting trim more than controllability. A second, more usual definition is given in terms of stick force, or stick position, per 'g'. The existing tests to describe the manoeuvre stability of a helicopter include measuring the stick position per 'g' during symmetrical pull-ups and push-overs, and the movement of the stick during steady turns. The latter test is a qualitative assessment of the manoeuvre stability, which Prouty (Reference 1) refers to as angle of attack stability: the helicopter is trimmed in straight and level flight and the stick position noted; it is then held in a steady turn and the stick position again noted. If the stick is aft of its trim position to hold the turn then the aircraft is manoeuvre stable, but if it has been moved forward of its trim position the aircraft exhibits manoeuvre instability. A further test which is no longer carried out at ETPS is the NACA 2-second test, which states that the shape of the normal acceleration time history curve must become concave downwards within two seconds of initiation of a defined pull-up manoeuvre.

3. Attempts to adequately quantify the manoeuvre stability by defining a manoeuvre margin have been made in the past, notably by Bramwell (Reference 2) and O'Hara (Reference 3), but little research has been carried out recently. In addition, unlike his fixed wing counterpart, the helicopter pilot is unlikely to be familiar with the concept of a manoeuvre margin for his helicopter, much less the theory of manoeuvre stability. To aid the ordinary squadron pilot, therefore we must look at the practical aspects of defining the agility of a helicopter, obtain the pilots' own views, and suggest tests which will describe agility in terms which they can readily assimilate.

4. Both Bramwell and O'Hara began their investigations by analysing the longitudinal motion of a single rotor helicopter and establishing how far the theory of static and manoeuvre margins of fixed wing aircraft could be applied to it. O'Hara defined a manoeuvre margin which can be determined from flight measurements of cyclic and collective pitch values to trim for a range of steady accelerations in pull-ups at the same speed, ie

$$H_m = -(1+n)\frac{h_n}{R}\left(\frac{dB_1}{dn}\right)_{C_H=0} + \left[\frac{\partial a_1}{\partial \theta}(1+n)\frac{h_e}{R} + \frac{\partial C_H}{\partial \theta}\frac{h}{R} - \frac{a_T \bar{V}_T}{C_H}\frac{\partial \alpha_p}{\partial \theta}\right]\left(\frac{d\theta}{dn}\right)_{C_H=0}.$$

which simplifies for tests at constant collective pitch to:

$$H_m = -\left[(1+n)\frac{h}{R} + \frac{C_J}{C_H}\frac{e}{R} + (1+\eta_B)\frac{a_T \bar{V}_T}{C_H}\right]\left(\frac{dB_1}{dn}\right)_{C_H=0}.$$

5. Bramwell essentially confirmed these findings, defining his manoeuvre margin as:

$$H_m = \frac{\mu z_w}{2t_c'}\left[\left\{\left(\frac{dB_1}{dn}\right)_{n1}(1+n_1) + \left(\frac{dB_1}{dn}\right)_0\right\} t_c'\left(1+\frac{\partial a_1}{\partial \alpha}\right)\right]$$

*Symbols as defined in References (1) and (2)

which can also be measured in terms of stick position to trim in pull-ups: the larger the value of H_m, the greater the manoeuvre stability. This gives us a basis for quantifying agility, but not one which the pilot will necessarily need or understand. However, correlation can be made of the quantitative data and pilots handling qualities ratings which may prove useful.

6. At ETPS, part of our continuing task is to adapt and update standard testing techniques to ensure that they keep pace with new aircraft technology. As the foregoing theory was developed and adapted from the existing fixed wing theory, perhaps we can use or adapt the test techniques of the fast jet world to define the manoeuvre performance of the new breed of agile helicopter.

7. Fixed wing manoeuvre performance is usually divided into :

a. Turning performance

b. Energy manoeuvring

Turning performance is defined in terms of speed, bank angle and 'g'loadings. Energy manoeuvring is only relevant to combat aircraft in air to air combat or air to ground attacks and involves changes in height and speed with consequent exchanges of kinetic and potential energy.

8. Factors limiting the manoeuvre performance of an aircraft include the maximum lift which the wing is capable of generating, maximum structural 'g' loading (or pilot limit), maximum engine thrust, and aerodynamic phenomena such as wing rock, nose slice etc. These characteristics are usually displayed as limitations on the two main types of manoeuvre boundary, namely the lift and thrust boundaries, which are defined as:

a. LIFT BOUNDARY This is the maximum instantaneous amount of usable lift that can be generated by the aircraft wing.

b. THRUST BOUNDARY This is the maximum g loading that can be sustained in level flight at a given speed and engine setting.

9. It would seem that such boundaries would be useful for the new generation of agile helicopter but one problem immediately springs to mind: the thrust is provided in totally different ways. Thrust provided by a jet engine for a fixed wing aircraft does not vary with angle of attack etc as does that provided by the main rotor of a conventional helicopter. The standard test techniques used for fixed wing aircraft depend largely on the fact that the engine characteristics remain constant, therefore they can not be directly applicable to the rotary wing world. Nevertheless, the techniques used may still provide us with useful information.

10. Stalling puts an absolute limit on the amount of lift available from a fixed wing aircraft but this may be a 'false' limit in practice as the aircraft may become operationally ineffective before the stall due to buffet, wing rock etc. Another boundary will therefore exist inside the stall boundary which

defines the practical flight envelope, the tracking boundary for instance. A helicopter does not suffer from the stall as such, but we may be able to define a boundary analogous to the tracking boundary. For example, any combat aircraft which is to fire weapons must do so from a stable platform, so some form of tracking task may be required and a test devised such that a combination of speeds, turn rates, g-loading etc gives the pilot a boundary beyond which his ability to successfully fire a weapon is degraded.

TRACKING TASKS

11. The major problem with any form of tracking task is the difficulty in making the test repeatable. However, new technology may help us overcome this problem and, in the meantime, we must devise tasks which will be as consistent as possible.

12. One possible method suggested is that a target aircraft fly a pre-set circular track at a specific speed while a second aircraft acquires it and attempts to track it. None of the ETPS helicopter fleet at present contains any form of sighting mehanism, but a simple circle drawn on the windscreen would be sufficient to obtain qualitative data on the ease of the task.

13. An alternative suggestion is that the target aircraft fly straight and level at a predetermined speed and, when the test aircraft has acquired it, carry out a series of bank angle changes, left and right alternately, bank angle and time being the controlling factors.

14. These manoeuvres are, or can be, role related which is more important in the military environment than in the civil field, but they are subject to human error. For this reason, their main use should be in the qualitative assessment of an aircraft's manoeuvrability rather than to obtain any quantitative assessment.

There is one method which may be of use in the future, however, which would provide a repeatable tracking task. If a computer generated and controlled target image could be superimposed on a head-up or helmet mounted display, the target's movements could be precisely controlled and repeated. This is not available to us at present but such a system means that tracking tasks may prove very useful in the future.

REPEATABLE TASKS

15. To obtain any useful and comparable quantitative data we must look to some form of repeatable test. The Royal Aircraft Establishment at Bedford have begun some work in this field and have some data on handling qualities from tests flown by different pilots which show encouraging results. Manoeuvres include:

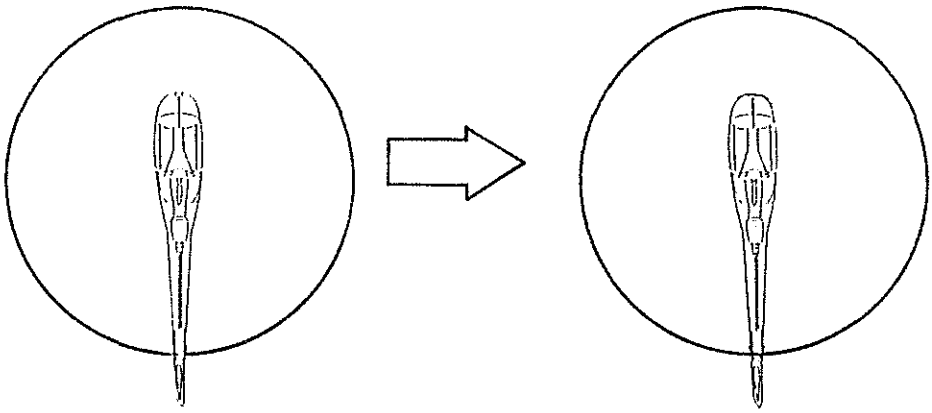
a. Sidesteps

b. Quick stops

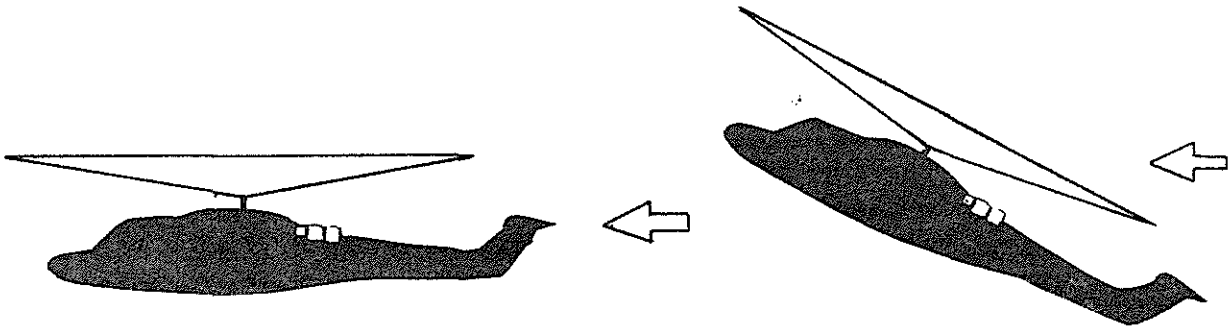
c. Bob-ups/downs

d. Figures - circles, 8's, serpent/snake

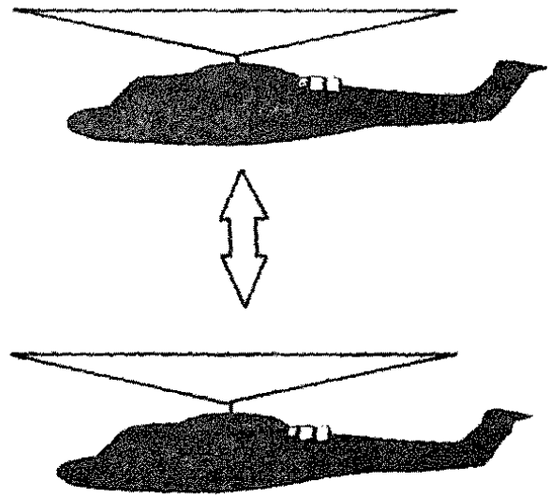
Figure 1. Manoeuvrability/Agility Tests



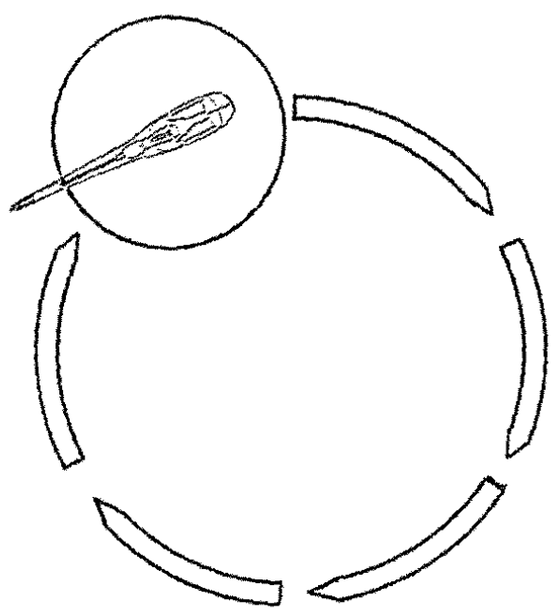
a. Sidestep



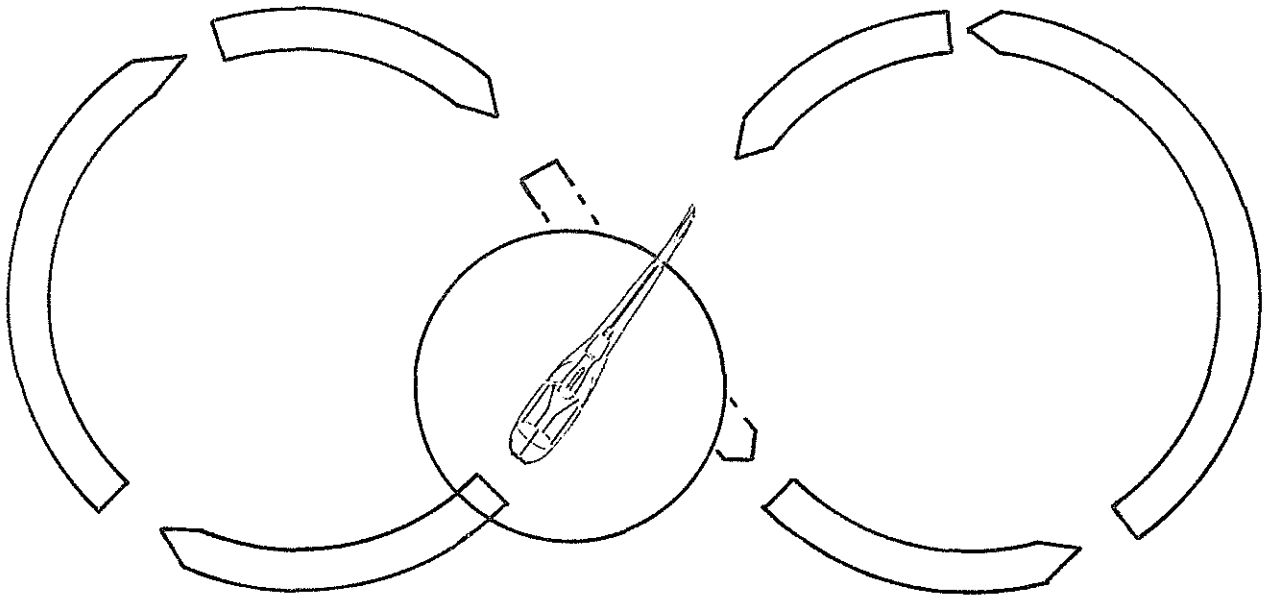
b. Quick stop



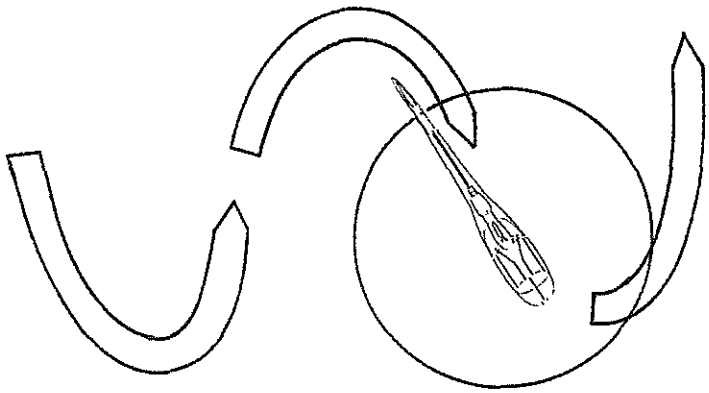
c. Bob-up/down



d. Circle



e. Figure 8



f. Serpent/Snake

16. Sidestep.

This manoeuvre involves the pilot in flying his aircraft sideways between two markers set at a known distance apart. A limiting bank angle is imposed and the manoeuvrability can be quantified by measuring the time taken to fly from a stabilised hover adjacent to one marker to a stabilised hover at the second marker and relating this to the minimum time to cover the distance which will be a function of the maximum permitted or achievable sideways velocity. This has been called the **'Agility Factor'** of the aircraft:

$$\text{Agility Factor} = \frac{\text{Actual Time to Complete Manoeuvre}}{\text{Min Possible Time to Complete Manoeuvre}}$$

17. Quick-stop.

In essence, we are here measuring the distance taken for the pilot to bring the aircraft to a stop from a specific speed. The shorter the distance the better in terms of manoeuvrability. (An analogous test to this is the 'dash', where the pilot moves from one point to another in the shortest possible time. If deceleration is quantified by the quick stop then acceleration could be measured by the dash either from point to point or from the hover to attain a set speed.)

18. Bob-up/bob-down.

Of particular relevance to the army battlefield and anti-tank role, this manoeuvre is similar to the sidestep but in the vertical plane. Agility can be quantified again by relating the time taken to establish a hover at a given height above the point where the aircraft initially hovers to the minimum time possible, as before.

19. Figures.

These tasks are more difficult to quantify but are repeatable and will provide qualitative handling qualities data.

THE PILOTS' VIEWS

20. The Rotary Wing element of this year's course at the Empire Test Pilots' School comprises 5 students and 3 tutors. All are, obviously, experienced pilots and, between them, they have flown a wide variety of types in numerous roles and environments. What, then, do they think of the established tests and what information would they like to have that is not already available?

21. There is one overriding requirement on which all were agreed: the question of engine and rotor governing. Unless the system can be designed such that there is no question of over-torqueing or overspeeding the rotor, then this will always impose a major limit on the aircraft's manoeuvrability. This, however, is a completely separate topic and is the subject of some much needed research at present. Hence, it will be assumed that this is not a limiting factor.

22. Firstly, all agreed that if they could be assured of carefree handling then all other information would be gained by 'hands-on'experience with the aircraft. There was also a measure of agreement that some form of emergency capability should be built in, ie the limits of the carefree handling control system must be within the absolute limits of the aircraft but the absolute limit should be achievable if required in the event of an emergency, via some

switching mechanism or by pulling through an artificial stop on the stick. However, one must know the limits of the aircraft before a flight control system capable of allowing carefree handling can be designed. This brings us back to the question of what information must be given to the control system.

23. Firstly, what can we learn from the tests already in use, and are they relevant or worthwhile? One of the major objectives of the pull-ups, push-overs and steady turns is to provide information about the 'g' envelope: how much force does the pilot need to apply to the stick to produce a given load factor? Flight control systems, artificial feel, bob weights etc already mean that the information is obtained and used to a large extent in terms of stick **displacement** per 'g' rather than stick **force** per 'g' and in fly-by-wire or fly-by-light systems, stick force and displacement can be tailored to meet almost any requirement.

24. With this in mind, our pilots suggested that the same tests could be used but, instead of the information on pitch, roll and yaw rates which we obtain at present, by improving the instrumentation fit we could easily obtain acceleration data in these axes. Further, a series of steady turns, including turns at full power, would provide maximum and sustained 'g' levels, turn radius and sustained angle of bank. This information would provide most of what the pilot wants to know about his aircraft. Added to this, hover performance is required and the general opinion of the team is that it is here that the sidesteps and bob-ups can provide useful information. Both tests will produce data on the ease with which the aircraft can be re-established in a hover after a quick change of position. This easily relates to the requirement for a battlefield helicopter to provide a stable platform from which to deliver weapons whilst exposing itself for the shortest possible time.

25. It is role relation which is of the greatest importance to the military pilot. However, one helicopter may be used in a wide variety of roles and this poses a problem for role-related testing. A possible solution to this is in the production of several envelopes which can be superimposed. For instance, a complete flight test on a helicopter will provide its flight envelope which, in the light of the views of the ETPS staff and students should contain such information as maximum and sustained 'g', maximum sustained bank angle, linear and angular velocities and accelerations, and turn radius. Should this aircraft now be used in the anti-tank role, then the particular requirements for this type of role must be defined and the two envelopes superimposed. testing carried out at the points of overlap.

26. This technique is not ideal, however, as we are in danger of producing a 'cliff-edge' envelope, at least in part. It must, therefore, be an essential requirement that the envelopes are blended rather than simply superimposed. To provide the blending, it is important that testing is carried out at the points of overlap but, as there can be unpredictable behaviour at any flight condition, a full test programme will probably be required.

CONCLUSION

27. If the small cross section of pilots at ETPS can be treated as representative of pilots as a whole, there seems to be a feeling that the present tests performed to describe the manoeuvre stability of a helicopter are inadequate. As technological advances remove the barriers which prevent helicopters achieving their full performance capability, new methods of quantifying their agility must be devised.

28. Military pilots require information on the accelerative and decelerative performance, together with maximum and sustained 'g' loadings, maximum sustained angle of bank and turn radius. To obtain such quantitative data, suggested tests include pull-ups and push-overs as practised now, steady turns at full power, and some form of repeatable tracking task. In addition to this, and in order to quantify hover and accelerative performance, sidesteps, bob-ups, quick stops, spot turns and dash capability would be tested.

29. Quantitative data is of more use to the designer than the pilot, who will form a qualitative opinion of the agility of his aircraft and learn its limits by experience. However, it is important that any proposed tests involve the pilot at an early stage as it is he to whom the information is of most use, and his knowledge and experience can often prevent unnecessary work.

30. It now remains to obtain data from each of the suggested tests, adapt, improve and add to them, analyse the information, and propose a set of repeatable tasks which will give the pilot the information he requires to exploit the full capability of the new breed of agile helicopter.

REFERENCES

1. R W Prouty, Practical Helicopter Aerodynamics, PJS Publications

2. F O'Hara, An Analysis of the Longitudinal Stability and Control of a Single-Rotor Helicopter, Aeronautical Research Council R & M No 2958

3. A R S Bramwell, Longitudinal Stability and Control of the Single-Rotor Helicopter, Aeronautical Research Council R&M No 3104