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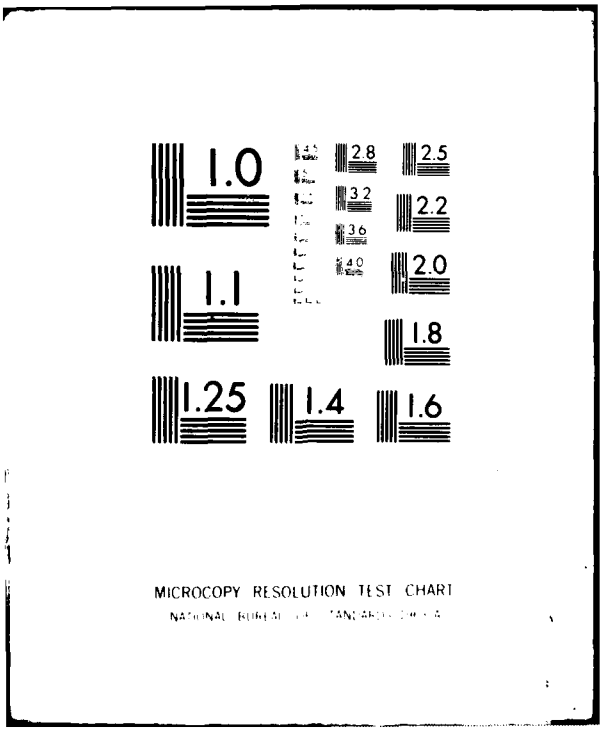
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C.A. MARTIN

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A DISCUSSION OF THE FLYING QUALITY REQUIREMENTS OF A BASIC TRAINING AIRCRAFT

C.A. MARTIN

SUMMARY

This Memo is a slightly amplified version of a draft paper which was prepared in 1980 at A.R.L. as a focus for discussion on the desirable flying qualities of a basic training aircraft. The Memo aims to identify flying qualities of importance in a basic training aircraft and also to suggest interpretations of particular Military Specifications. The proposition is developed that flying qualities which are considered "good" for an operational aircraft are not necessarily desirable for a training aircraft.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

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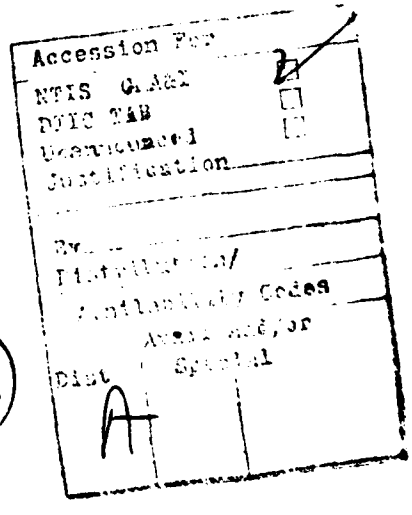

1. INTRODUCTION

In recent years there has been increasing local interest in basic training aircraft prompted by the R.A.A.F. requirement to replace the CT4A. With an Australian development under way to meet this requirement it seemed worthwhile to promote discussion of the flying quality requirements. A draft paper was prepared in Aerodynamics Division A.R.L. and given limited circulation in 1980. There was little positive reaction, the tendency being to suggest reliance on existing Military Specifications such as MIL-F-8785C. This specification is used widely in three ways: Firstly as a design guide, secondly as a firm specification and thirdly as a source of test and evaluation criteria. However, comprehensive though the specification may be, there is still a need for interpretation, particularly in its use as a design guide.

The present Memo is a slightly amplified version of the earlier draft. It aims to identify the flying qualities of importance in a basic training aircraft, to suggest interpretations of particular Military Specifications, and to provide a focus for discussions of the most desirable flying qualities.

Section 2 discusses flying qualities requirements in a general way and develops the proposition that qualities considered "good" for an operational military aircraft or for a comparable general aviation aircraft are not necessarily desirable for a basic training aircraft. Sections 3 to 8 discuss particular flying qualities. The implications of conventional "static stability" requirements including the effects of power and configuration, are emphasised. The influence of aerobatic requirements on the flying qualities of a basic training aircraft is also discussed.

2. GENERAL CONSIDERATIONS

In general terms, the flying qualities of a basic training aircraft should be such that:

a) The flying skills required for advancement to high performance trainers or operational aircraft are developed.

b) All training manoeuvres can be carried out safely by the student when flying solo.

Although improvements have been made in the flying qualities of military operational aircraft there is little evidence to suggest that the levels of pilot skill required have diminished. Firstly, the workload associated with high speeds and complex aircraft systems has increased so that the effort available for aircraft control is less.

Secondly the performance of combat aircraft has increased to a point where the flight envelope is frequently limited by stability and control deficiencies. Highly developed flying skills are required to enable aircraft to be flown to these flight envelope boundaries.

Hence, it is unlikely that a basic training aircraft with flying qualities rated as "good" in the context of operational military aircraft and comparable general aviation aircraft will meet objective a) above. For example, an aircraft with docile stalling characteristics would not be very useful for tuition in stall recovery. Furthermore, the characteristics should be reasonably representative of advanced operational aircraft. Thus the control strategy required for spin recovery should not be peculiar to the training aircraft, but should be more generally typical.

Clearly the flying qualities of the basic training aircraft are an important part of the design requirement. It is not sufficient to rely literally on the relevant Military Specifications such as MIL-F-8785C (Ref.1) and AVP970. These specifications have been substantiated against a wide range of aircraft, few of which are basic training aircraft. Some interpretation is necessary to arrive at flying qualities criteria appropriate for basic training aircraft.

In connection with objective b) above, there is a direct relationship between flying qualities and flight safety. "Good" flying qualities imply a matching of control tasks to human pilot capabilities. While maximum safety is aimed for in aircraft design, compromises are made in favour of performance and cost. It is usually acceptable to compromise safety further for military aircraft than for civil aircraft. Hence it should be possible to arrive at a compromise on flying qualities which adequately meets objectives a) and b) without recourse to variable stability control systems; such an approach would be uneconomic for a basic training aircraft.

In practice it is difficult to predict handling quality parameters sufficiently accurately at the design stage to be sure of achieving the required compromise on flying qualities. One possible approach would be to maintain the aerodynamic stiffness and damping, and hence stability, at an acceptable constant level. The control power could then be raised during prototype development to achieve the required level of responsiveness. Since manual controls are envisaged, such an approach would necessitate careful design of control surface hinge moments.

3. LONGITUDINAL FLYING QUALITIES

Longitudinal flying qualities will be considered under the following headings:

(1) Longitudinal static stability.

(2) Phugoid stability.

(3) Short period response.

(4) Control forces in manoeuvring flight.

(5) Longitudinal trim.

3.1 Longitudinal 'Static Stability'

For conventional low speed aircraft, many of the longitudinal flying qualities have proved to be satisfactory if the condition termed positive 'static stability' is maintained. Static stability is strongly dependent on the variation of pitching moment with incidence (Cm_α) called the pitch stiffness which in turn depends strongly on aircraft C.G. position. When the effects of power and structural distortion are included additional speed dependent terms are introduced which modify the C.G. position for zero 'static stability'. This position is called the static stability limit (hs) in Ref.2. For aircraft with manual controls, the pitch stiffness can change when the elevator is allowed to float freely, resulting in a modification to (hs). The 'static stability' with controls fixed and 'static stability' with controls free are related respectively to the elevator control position and control force required for trimmed flight throughout the aircraft speed range. Therefore, 'static stability' requirements are specified in Ref.1 in terms of the gradients of elevator control deflection and control force with speed. These requirements determine an aft limit for the aircraft C.G. and hence a minimum level of 'static stability'. The requirements have been applied successfully to a wide range of aircraft and are applicable to a basic trainer. The forward C.G. limit is generally determined for low speed aircraft by the control power available for manoeuvring at take-off and landing with large pitch stiffness. One feature of highly powered single engine propeller driven aircraft is the sensitivity of pitch stiffness and hence static stability to lift coefficient, engine power, and configuration. Measurements on a number of single engine aircraft show variations of up to $7\%\bar{c}$ for (hs) for the conditions listed. Consequently careful design is required to achieve an adequate C.G. range, since the aft C.G. limit is determined by the condition with least 'static stability' and the forward C.G. limit is determined by the condition with greatest 'static stability'. Therefore, although the 'static stability' requirements are seen to be applicable to the basic training aircraft, design problems could arise in ensuring an adequate C.G. range for all flight conditions and configurations.

3.2 Phugiod Stability

For conventional low speed aircraft, providing that the 'static

stability' requirements are met then the phugoid stability should be satisfactory.

3.3 Short Period Response

For conventional low speed aircraft, which are not required to fly at high altitude, a tailplane sized to give an adequate C.G. range will generally provide satisfactory short period damping. Therefore the pitch damping requirements of Ref.1 do not usually pose a design problem.

The flying quality requirements of Ref.1 recognise that for many aircraft, satisfactory longitudinal response cannot be assured by defining short period frequency and damping values alone. Ref. 1 includes additional requirements in terms of the parameters n/α and $\omega n^2_{sp}/n/\alpha$. The former represents the change in normal acceleration for a given change in incidence; the latter is equivalent to the ratio of initial pitch rate acceleration to steady state normal acceleration for an idealised step input. The parameter $\omega n^2_{sp}/n/\alpha$ is called the 'Control Anticipation Parameter' (C.A.P.) When C.A.P. is low, a pilot rates the pitch response sluggish and overcontrols flight path corrections. When C.A.P. is high, a pilot rates the aircraft as too abrupt and sensitive and undershoots flight path corrections. The inclusion of the short period response parameters discussed above, in Ref.1 is supported by in-flight and ground simulation of a range of aircraft types, covering high performance and large transport aircraft. However, it is doubtful if the characteristics of light aircraft have had much influence on the specification. Although the requirements are likely to be appropriate, there is little information on their application to basic training aircraft, and it is considered that the following points should be noted. Firstly, as a general aim, a training aircraft which is sensitive in pitch would be preferred as this would be more typical of higher speed operational aircraft. These characteristics would result from an aircraft with low pitch inertia and/or large pitch stiffness. The latter implies maintaining the normal operating C.G. substantially ahead of the neutral point. Secondly, Ref. 3 has questioned the relevance of the short period response requirements at low forward speed. For the basic training aircraft flying at low speeds, only small normal accelerations can be generated but these are accompanied by large changes in flight path. In this situation, the response requirements based on normal acceleration may not be suitable. However, little flight research has been carried out in this area for small low speed aircraft.

3.4 Control Forces in Manoeuvring Flight

The flying qualities specifications for steady stick force per 'g' in manoeuvring flight are based on a large body of data, for

a wide range of aircraft and so should be appropriate for the trainer. One problem associated with the design of suitable manoeuvring characteristics is that of ensuring satisfactory stick force per 'g' over a large range of c.g. positions. Control angle and control force per 'g' are determined by the moments due to pitch stiffness and pitch damping. At aft C.G.s, where pitch stiffness is almost zero, the pitch damping for conventional low speed aircraft is usually large enough to ensure an acceptable minimum stick force per 'g'. Considerable design effort was carried out on single engined aircraft in the late 1940s to minimise the increase in control force with forward C.G. movement. It is reported in Ref.4 that closely balanced elevators were used in conjunction with bob-weights or with types of balance that gave the elevators a tendency to float against the relative wind. Although the desired stick forces in steady turns were obtained, the control characteristics were often considered unsatisfactory because of the lightness of the forces required in rapid pull-ups. In addition, the increased hinge moment floating characteristics led to poor handling in turbulence. These manoeuvre considerations put extra constraints on the available C.G. range when the pitch stiffness is strongly influenced by power, flap setting and lift coefficient as discussed in Section 3.1.

A further consideration which has important influence on control forces is the control circuit gearing. Aircraft which are required to perform aerobatic manoeuvres generally possess large control surface deflections to provide control authority at low forward speeds as discussed in Section 7. This requirement increases the control circuit gearing and consequently the problems of providing satisfactory control forces characteristics throughout the aircraft speed and C.G. range.

3.5 Longitudinal Trim

For the trainer aircraft, the trim changes associated with power, flaps and undercarriage should not be so large that they cause handling problems but should be sufficiently identifiable to permit the pilot to recognise and learn to cope with normal trim change effects. This is an area in which, ideal flying qualities, i.e. zero change in trim, would have no training value. Existing methods for predicting power and configuration changes on the flow at the tail and hence on trim changes are not comprehensive and reliable. Great care is needed to meet either the usual objective of small trim change effects or of nominated levels of trim change as suggested here.

3.6 Summary of Longitudinal Flying Qualities

In summary, it is expected that most of the longitudinal flying quality requirements will be met if the Ref.1 requirements for 'static stability' and for control authority at forward C.G. are

satisfied. One area which is difficult to define is the requirement for short period response at low speeds. The most difficult design problems are expected to be the provision of a useful C.G. range, of acceptable stick force per 'g' characteristics and of suitable trim change characteristics throughout the aircrafts range of power, flap configurations and lift coefficients. Finally, as a general aim, the pitch response of the aircraft, which is the net effect of short period response, elevator power and control force characteristics, should appear crisp rather than docile. Designing the aircraft to have sensitive pitch response is one method of increasing the control skill level required of the pilot without reducing aircraft stability.

4. LATERAL AND DIRECTIONAL FLYING QUALITIES

The lateral and directional flying qualities will be considered under the following headings:

(1) Conditions in steady sideslips.

(2) Spiral stability.

(3) Dutch Roll stability.

(4) Roll response.

(5) Directional control and trim.

4.1 Conditions in Steady Sideslips

A number of flying qualities requirements are specified in Ref.1 to ensure satisfactory lateral and directional characteristics in steady sideslips. These characteristics depend upon the variation of yawing moment with sideslip, called yaw stiffness, and on the variation of rolling moment with sideslip, called roll stiffness, and also on the effectiveness of the rudder and aileron. An important aim of the requirements is to avoid the possibility of fin stall and/or rudder overbalance. The requirements also aim to ensure that sufficient yaw stiffness is provided to minimise sideslip excursions. These requirements are equally important for both training and operational aircraft. However, other important design requirements such as Dutch Roll frequency and roll-sideslip ratio and spiral stability also determine the yaw and roll stiffness characteristics. In particular, for a training aircraft, the spin recovery characteristics are a major consideration.

4.2 Spiral Stability

The spiral stability requirements in Ref.1 are very similar for all classes of aircraft. However, some discussion of their implications for a basic training aircraft is considered worthwhile. For a significant portion of the training flight time, the pilot will

be exercising strong control over the aircraft and the flight conditions will be altering such that changes in roll trim will frequently occur. Even with the provision of an aileron trimmer, it is difficult for pilots to differentiate spiral divergence from out of trim rolling. In Ref.5, the opinions of several pilots are reported in which they state that they are unable to identify positively, the spiral mode from gradual roll-offs caused by other factors. Unless spiral instability is very large, it is regarded more as a nuisance than a control problem. However, as reported in Ref.6 it can lead to higher workload in certain precision tasks.

In summary, the spiral mode requirements of Ref.1 which permit a small degree of spiral instability appear suitable for the training aircraft. Although a stable or neutrally stable spiral would be preferred, the consequences of an unstable spiral are not expected to be significant.

4.3 Dutch Roll Mode

A prime requirement of the Dutch Roll Oscillation is that adequate damping should exist. Current requirements in Ref.1 also include the effects of frequency and roll-sideslip ratio, such that a low or very high frequency oscillation with high roll-sideslip ratio requires higher damping. As with longitudinal motion, it is usual for low speed conventional aircraft that the requirements for sizing the tail (for the fin and rudder, these are the directional stiffness requirements listed in Section 4.1) generally ensure satisfactory dutch roll damping. The dutch roll frequency is directly related to directional stiffness and satisfactory values are not usually difficult to achieve. However, the interaction of adverse aileron yaw, with the dutch roll oscillation can lead to difficulties in precision tracking and turn co-ordination. Poor tracking performance can result unless skilful co-ordination of aileron and rudder is applied. For the training aircraft the achievement of perfect turn co-ordination by suitably designing the aileron yaw characteristics would not be desirable: an appreciation of the use of rudder and turn indicator for correct turn co-ordination and the development of appropriate control skills is a training objective.

The training aircraft role raises other considerations regarding adverse aileron yaw and wing dihedral. The aerobatic requirements to perform stall turns from vertical flight and to perform inverted flight make further requirements on the above handling parameters. During inverted flight both the dihedral and the methods used to overcome adverse aileron yaw have the reverse effect. The wing dihedral acts as anhedral, and the aileron features used to reduce aileron yaw act to oppose the commanded direction of turn. Similarly, in vertical flight, the aileron control characteristics can become very prominent. Depending upon the emphasis given to the

aerobatic requirements of the trainer, some compromise in the choice of wing dihedral and aileron yaw characteristics for the level flight case will be required.

In summary, the dutch roll requirements of Ref.1 appear suitable for the trainer. However, some modification to the choice of the most desirable values for wing dihedral and aileron yaw characteristics may be required because of the trainer's aerobatic requirements.

4.4 Roll Response

Flying qualities for roll response are concerned with achieving satisfactory roll performance and with avoiding large sideslip excursions and bank angle oscillations. Sideslip excursions are caused firstly by the yawing moments due to aileron and secondly by yawing moments due to roll rate. The former effect was discussed in Section 4.3 and the latter, which depends on the aircraft configuration, is difficult to alter. The roll rate and bank angle oscillations are caused by excitation of the dutch roll mode, primarily via sideslip excursions. Because of the expected satisfactory dutch roll characteristics of the trainer, as discussed in Section 4.3, this aspect should not be very significant.

In line with the arguments used in Section 3.7 for advocating crisp pitch response, it is considered that designing the aircraft with lively roll response is a method of setting the level of skill required from the pilot without diminishing aircraft stability. One consequence of good roll response is the need for careful design of aileron hinge moments. Considerable ingenuity is required to achieve satisfactory roll rates at high speed within the maximum pilot effort (usually around 20 lb.) and also retain sensible control forces at low speed. With good roll response, particular emphasis is also placed on good control harmony.

4.5 Directional Control and Trim

A major consideration concerning the trainer flying qualities will be the effect of power on directional control. The direct forces acting on a highly powered propeller at the nose of an aircraft act like a destabilising fin to reduce directional stiffness. In addition, for single propellers, considerable sidewash occurs at the fin due to the propeller slipstream rotation. Against these disadvantages, the increase in dynamic head at the tail due to propeller slipstream generally results in increased fin and rudder effectiveness. One important result of these power effects is that during take-off, considerable angles of rudder and sideslip are required to balance the power induced yawing moments and side forces.

Although the rudder design will be influenced greatly by the spin recovery requirements, the effect of power and the relative effectiveness of the fin and rudder will have an important influence on rudder balancing. The rudder has to prevent swing during take-off and has to trim out the yawing moment during climb due to full power. At one extreme, the rudder trim loads should not require exceptional pilot effort to maintain straight flight and yet the rudder should not be so light and powerful that large sideslips can be generated inadvertently during instrument flight. It is stated in Ref.7 that 'judicious manipulation of rudder hinge moment characteristics b_1 and b_2 may result in marked reduction of directional trim problems and that thorough development work on this point is well worth while'.

In summary the requirements for a basic training aircraft are that the rudder balance should be such that the pilot gets a proper appreciation of the effects of power through the rudder pedals, without having to apply excessive loads, and yet without the risk of inadvertently generating large sideslip angles.

5. STALL CHARACTERISTICS

While complying with the requirements of Ref.1, the stall characteristics of the trainer should represent standard stall behaviour and should be sufficiently demanding for the student pilot to develop standard stall recovery skills. It is also highly desirable for the stall warning to be generated naturally via aerodynamic buffeting of the controls and the airframe and that the intensity should increase with increasing incidence.

At the stall the nose down pitch, wing drop and height lost should be of sufficient magnitude to require positive control action for recovery and for demonstrating appropriate pull-out procedures. Similar requirements should apply for stalls with power and flaps and different stall warning and stall speeds should be recognisable.

6. SPINNING

The trainer is required to be able to demonstrate spinning which includes spin initiation, incipient and steady spin and spin recovery, both erect and inverted. The aircraft should not be susceptible to spins although the development of reliable and repeatable procedures for spin initiation should be possible. Recognisable incipient and steady spin conditions should be reached within a short time of spin initiation and the spin recovery technique should be efficient and typical of standard procedures. The requirement for some wing drop at the stall is compatible with the need to have reliable procedures for spin initiation.

7. AEROBATICS

Since the requirements for aerobatics and inverted flight are major design considerations in the selection of the aircraft engine, they should have similar prominance in the design of the aircraft flying qualities. Two aspects concerning wing dihedral and adverse yaw were discussed in Section 4.3. Many aerobatic manoeuvres are carried out at low speeds or involve low speed portions. In consequence, aircraft designed for aerobatics tend to have large control surface deflections to obtain maximum control authority at low speeds. To avoid excessively large control forces at high speed and to help the pilot judge control inputs during manoeuvres when control forces are low, the control column deflection tends to be larger than for a general aviation aircraft. Clearly these considerations have to be balanced against the requirements of the aircraft's other important roles.

8. TURBULENCE

The main considerations regarding the effect of turbulence are to ensure that the stiffness derivatives in pitch, roll and yaw are not excessively large, since this would lead to large aircraft moments due to gust velocities. However, for the trainer, these requirements would be secondary to the smooth air design requirements for the stiffness derivatives. Similarly, the hinge moments characteristics which determine control float, should not be excessively large, since this would lead to control force changes and poorer control during turbulence.

9. CONCLUDING REMARKS

The paper discusses aircraft flying qualities which are considered to be important for a basic training aircraft. The proposition is made that there is scope for adjusting certain flying quality parameters to suit the training role, without contravening flying quality specifications or noticeably affecting aircraft safety. Within the discussion, interpretations of particular Military Specifications are given and design aspects, which are considered to pose particular problems, are highlighted.

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16.Abstract

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