FLYING QUALITIES CRITERIA FOR ADVANCED CONTROL TECHNOLOGY TRANSPORTS

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Abstract

The background behind expected developments concerning primary flight control systems of future Active Control Technology transports is indicated. A survey of research performed by the National Aerospace Laboratory (NLR) *) to generate the necessary information to formulate low-speed flying qualities criteria for future transport aircraft employing a certain class of active control technology is presented. As tools, research flight simulators and research aircraft have been used. All evaluations have been performed using a deflection-type side-stick controller. The acceptability of neutral stick force stability for attitude stabilized aircraft is dealt with followed by a comprehensive treatment of criteria for longitudinal and lateral-directional manoeuvring characteristics.

Introduction

The concept of future transport aircraft deviates distinctly from the concept of present-day flying machines. The flying qualities of these aircraft will depend to a high degree on the functioning of the flight control system. The criteria presently in use for aircraft development, however, are based on characteristics of the bare airframe. Because of this state of affairs, the need for comprehensive research efforts resulting in documented experience for use by control system designers of future transport aircraft has arisen.

This paper presents a review of research performed in the 1972-1979 time period concerning flying qualities of future transport aircraft.

The presence of a flight control system which provides the pilot with the necessary control capabilities, while it also performs automatic (stabilizing) functions, will play a fundamental role in the concept of the future aircraft. When the flight control system is considered a primary design variable, important improvements in the effectiveness of the whole aircraft concept can be obtained. Of particular importance for transport aircraft are the following two applications of the so-called Active Control Technology:

- alleviation of gust and manoeuvring loads
- relaxation of static stability.

The second application has a direct relationship with the controllability and stability through the application of new mechanization forms of the primary flight control system. Flying qualities criteria to be developed for use in the design of these new systems is the central theme of the research described in this paper, which only considers the required characteristics of the normal operational (non-failed) flight control system.

*) Investigations mentioned in this paper have been carried out partly under contract for the Netherlands Agency for Aerospace Programs (NIVR) and the Department of Civil Aviation (RLD) in the Netherlands.

The paper is based on information available in references 1 through 8, which are based on a total of 120 in-flight approaches and 1000 flight simulator landing approaches including touchdowns.

Relaxed static stability and advanced flight control systems

Improvements with respect to aircraft weight and aerodynamic efficiency resulting from relaxing the conventional requirement for a certain level of inherent longitudinal static stability can be considerable. The concept of augmenting the stability of an aircraft in such a way that the contemporary requirement for a certain minimum value of inherent (longitudinal) static stability can be relaxed, is called Relaxed Static Stability (RSS)*).

It is to be expected that aircraft designed according to the principle of RSS, will most likely possess a flight control system based on electrical signal transmission plus (digital) computing elements. The prime objective of such a system is to transmit, combine and shape electrically the signals from the pilot's controller and aircraft sensors in order to command the servo-actuators driving the aerodynamic control surfaces. Thus the systems to be discussed are in the category indicated as fly-by-wire (FBW) with stability augmentation, which is defined here as follows: "An electrical primary flight control system employing feedback such that the vehicle motion is the controlled parameter".

Primary flight control systems based on pitch rate and roll rate as the primary controlled vehicle motion quantities are considered by this author the prime candidates for future application. Pitch and roll attitude are the flight variables directly perceived by the pilot (horizon) during visual flight and can profitably be used as indicators for flight path changes which will result from changes made to the aircraft attitude. Moreover the aircraft attitude must be controlled accurately in the touchdown fase of the landing. Systems based on the control of pitch rate and roll rate have been well received in many in-flight and flight simulator evaluations for the low speed flight regime. An "attitude-hold" feature included in such a system is considered a natural addition and possibly indispensable for aerodynamically unstable aircraft. For a detailed discussion of the arguments leading to the conclusions that transport aircraft may very well be equipped with this type of flight control system, and therefore its selection for further evaluation here, one is referred to reference 5.

*) In the case of RSS, for which the aft c.g. limit is no longer restricted by stability considerations at least a limit on aft centre-of-gravity location defined otherwise should be postulated. A minimum nose-down pitching acceleration at the stalling speed in the landing configuration would probably be the best approach to define this limit.

When electrical commands as the sole means for a pilot to control his aircraft is accepted it becomes feasible to use a small side-stick controller in transport aircraft. It has already been shown by other researchers that a side-stick controller fitted to an armrest when combined with certain types of closed-loop flight control systems is favoured over the conventional wheel/column combination. To gain experience with this concept, the NLR started in 1972 in-flight evaluations with an in-house developed deflection-type controller, see figure 1.

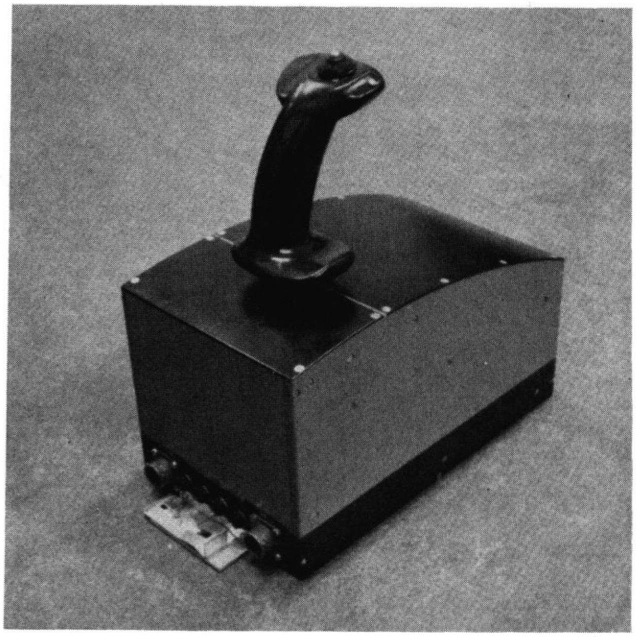

Fig. 1 NLR side-stick controller

Another important subject in relation to (aerodynamic) control in the symmetrical sense should be mentioned at this place. Especially during the final approach and landing an appreciable time lag between pitch attitude changes and ensuing flight path angle changes is detrimental especially under certain operational conditions such as low weather minima. For certain aircraft concepts, e.g. those with high wing loading, the concept of direct-lift control (DLC) can be of value to improve the dynamic relationship between flight path angle and pitch attitude (manoeuvre enhancement). A direct-lift device is capable of generating a normal force with essentially no requirement for on aircraft attitude change.

In this study only the concept of "blended" DLC, directed at the enhancement of the initial flight path response of the aircraft to commanded pitch angle changes is considered. [It is to be observed that the advantages obtainable by using direct-lift devices to provide short-term (high-frequency) lift modulation combined with the use of the tail surfaces for long-term control, hold equally well for manual as for automatic control].

Numerous flight tests have indicated that properly mechanized blended direct-lift control leads to:

- smaller pitch attitude changes when correcting the approach path,
- more precise ILS-beam following,
- suppression of initial acceleration reversal at the centre of gravity (elimination of heave cross-over time),
- improved "floating" control, resulting in better touchdown accuracy.

A study of criteria for good stability and control characteristics of future aircraft (to be fitted with advanced control systems) should therefore encompass the DLC aspect as is done in this study.

In-flight and ground-based experiments

Flight tests

An experiment with the Fokker F-28/Mk 6000 prototype aircraft, which is a short-haul twin-engined jet transport aircraft, figure 2, has been performed in relation to stick force stability criteria for attitude stabilized aircraft *). Attitude stabilized aircraft feature neutral stick force stability and therefore an investigation of the possible merits of artificially generated positive stick force stability has been undertaken.

Fig. 2 Fokker Fellowship F-28/MK6000 test aircraft

Flight control system

The F-28/Mk 6000 has been fitted with a "model-following" flight control system featuring the rate-command/attitude hold property in pitch and roll [The innerloop of the existing autopilot was used as "follower"]. In order to have the capability to generate positive stick force stability of various levels, a signal proportional to the airspeed deviation from the reference approach speed could provide the desired effect on the control force to be applied.

The NLR developed deflection-type side-stick controller was used.

The aircraft configuration and speed were selected such that the approach was performed at the speed for minimum drag (bottom of the thrust required versus airspeed curve).

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*) A pilot experiment, using the NLR Beechcraft Queen Air preceeded this experiment.

Conduct of tests

The flight task consisted of an ILS/VASIS (instrument landing system/visual approach slope indicator system) approach (no flight director) down to a height of 50 ft. The ILS to VASIS transition occurred at a height between 900 and 500 ft.

Effort ratings were given to quatify the amount of effort for specific subtasks on nod-adjectival rating scales. Pilot commentary in response to a questionnaire was recorded for further analysis. Relevant aircraft data were recorded in flight.

A detailed account of the conduct of the experiment is given in reference 1.

Simulator tests

The NLR research flight simulator (four degrees of freedom motion system, TV-terrain model visual system, figure 3, was used in experiments related to manoeuvring criteria. The cockpit was equipped with the NLR side-stick controller.

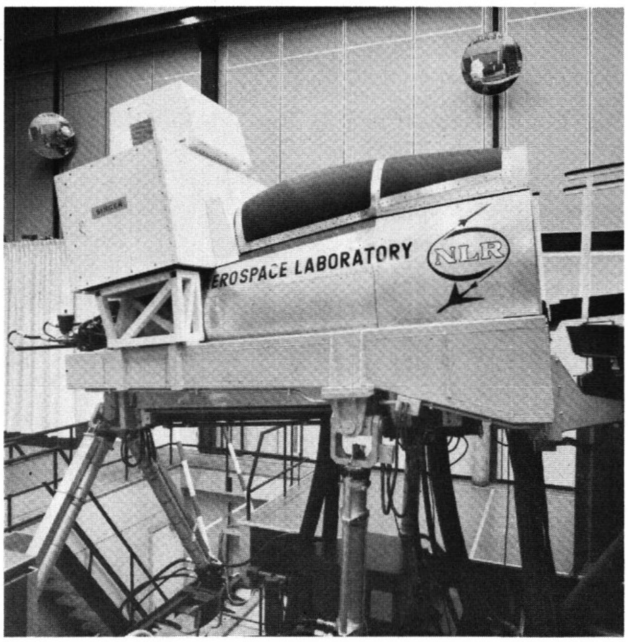

Fig. 3 NLR research flight simulator

Aircraft model

Two baseline transport aircraft have been simulated, based on the complete six degrees-of-freedom equations of motion. Both aircraft have been derived from the Fokker F-28/MK 6000 aircraft.

Baseline airplane A had a gross weight corresponding to the maximum landing weight of the F-28/MK 6000 aircraft which is called here the nominal gross weight. Baseline aircraft B had a 40 % higher gross weight, the aim of which was to investigate aircraft configurations with a lower value of the normal acceleration sensitivity parameter, n_α, and more in particular the longitudinal manoeuvre enhancement through application of direct-lift control. In connection with this weight increment, the moment and product of inertia and the maximum thrust capability have been increased also by 40 %.

For the simulation experiment the following hypothetic modifications relative to the Fokker F-28/MK 6000 have been incorporated in the model for the basic aircraft:

- Reduction of the horizontal tail surface by 40 %.
- Substitution of the stabilizer/elevator combination by an all-flying horizontal tail configuration.
- Addition of spoilers for the generation of direct-lift (for baseline aircraft B only).

Longitudinal flight control system

A functional block diagram of the flight control system is shown in figure 4. Longitudinal control is performed by means of a pitch-rate-command/attitude-hold system. A two-gradient stick-force-pitch rate command function (shaping) is used. A low-pass filter is incorporated in the command path to block high-frequency inputs. Washed-out direct-lift control is incorporated for the purpose of manoeuvre enhancement (for baseline airplane B only). A bank compensation loop is included in order to assist the pilot in maintaining vertical equilibrium when performing banking manoeuvres. Thrust variation with throttle is accomplished manually.

Lateral-directional flight control system

The concept of rate-command is used for lateral control as well (Fig. 4). When there is no roll command and the bank angle is greater than 3 degrees a bank-angle-hold mode is activated. When the bank angle is less than 3 degrees and no roll command is given, a "wing leveller" function is switched on, which drives the bank angle to zero degrees. For lateral control a three-gradient force-roll rate command function (shaping) is used. A low-pass filter is applied also in this command path. A yaw damper, consisting of washed-out yaw rate feed-back to the rudder, is included. A second-order cross-feed of aileron to rudder is incorporated for good turn-coordination characteristics. A direct link is used between the rudder-pedals and the rudder for most of the evaluation trails. A heading-rate-command/heading-hold system commanded through rudder-pedal deflection is used in the last evaluation trails.

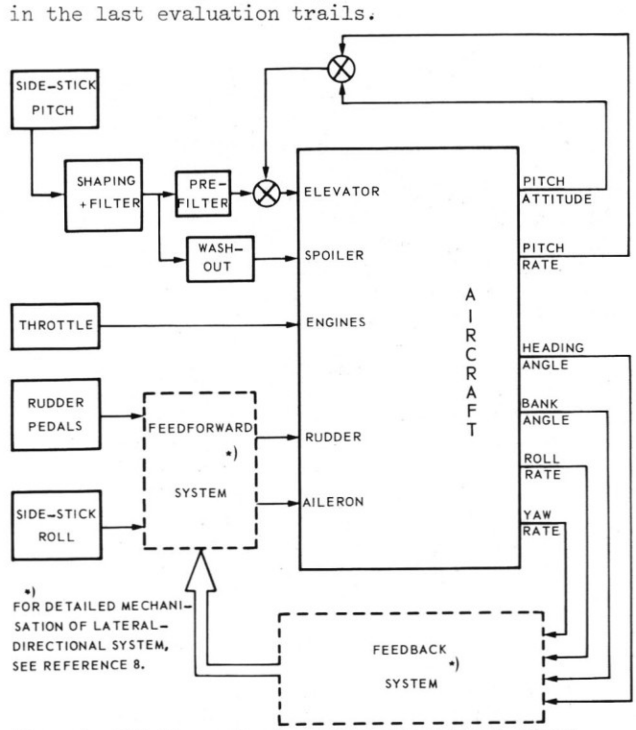

Fig. 4 Flight control system functional block diagram used during simulator tests

Simulated atmospheric and guidance environment

The mean wind model has been selected such that it incorporates the characteristics of "veering of the wind" as well as distinct shears.

The turbulence model applied featured "intermittency characteristics" which is representative for the non-gaussian distribution of velocity differences in real atmospheric turbulence. The intensity of the turbulence experienced during the approach was characterized as light-to-moderate by the participating pilots.

The ILS/visual guidance environment was characterized by a programmed off-set distortion on the ILS glide slope (one dot, at Outer Marker position) for the experiments concerning the longitudinal flying qualities only, as well as programmed mis-alignment of the ILS-localizer (one dot at the cloud break height of 400 ft) in order to require the execution of a side-step manoeuvre under visual conditions.

Conduct of tests

The flight task consisted of an ILS approach (no flight director) and landing. During the experiments related to the roll response criteria cross winds up to 15 knots were simulated.

Cooper-Harper ratings were assigned to characterize the evaluated configurations. Effort ratings were given to quantify the required effort for specific items of the task. Pilot commentary in response to a "comment card" was recorded for further analysis. Data acquisition and reduction took place using the digital equipment of the flight simulator.

A detailed account of the conduct of the experiments is given in references 5 and 8.

Flying qualities criteria

General

Although other descriptions are possible, the following description for flying qualities is given here:

> Flying Qualities of an aircraft determine the suitability of the aircraft for control by a human pilot; to be a little bit more specific, the "suitability" can be interpreted as those qualities and characteristics of an aircraft which influence the precision, ease and safety with which a pilot is able to perform designated manoeuvres and tasks to fulfil a designated role.

The use of a side-stick with electrical commands, nonlinear gains, command prefilters, response feedbacks and (associated) signal shaping gives the designer a large number of parameters to manipulate to achieve good flying qualities. These options also present the research community with a vast number of combinations of system elements to consider, especially if there are significant interactions.

In such situations economic considerations force experimenters to limit the scope of any particular investigation by selecting what are hoped to be representative values of many of the system elements, which are then hold constant while parameters of primary interest are varied in the experiment.

It should be realized that due to the very complex interrelating factors in the flying qualities of an aircraft, the universal application of boundaries defined in criteria established through research programs as described here, is not justified. Much will remain in the foreseable future which requires qualitative assessment by the certification pilot.

Research performed so far as described here has been aimed at the formulation of criteria primarily for the design of flight control systems. In the experiments the parameters were varied in such a way that the division between "satisfactory without improvement" (Cooper-Harper ratings 1-3) and "deficiencies warrant improvement" (Cooper-Harper ratings 4-6) could be defined.

The state of the art of designing good handling qualities into flying machines is fundamentally empirical. This is also the case for the background of the two pilot models generally accepted for the calculation of the system dynamics and performance of the pilot-aircraft system, the "servomechanism model" and the "optimal control model". Most of the experience with these models holds for continuous tracking tasks. It is a question if application of such models is warranted in highly non-stationary phases of flight such as the (visual) side-step manoeuvre close to the ground, the flare and the touchdown. The servomechanism model developed to parameterize pilot dynamics for a wide range of controlled elements is used here in relation to two closed-loop criteria for longitudinal control.

It should be recognized that, as long as a more universal model for pilot dynamics is not available, designing adequate handling qualities into future systems will remain an art involving "handbook" type information.

Longitudinal stability with respect to speed

Attitude stabilized aircraft do not show a tendency of speed deviation when disturbed from trim but the conventional requirement for a stable control force versus speed gradient, also called positive stick force stability is violated.

Systematic variation of the level of (artificially generated) positive stick force stability for an aircraft with a rate-command/attitude-hold flight control system has resulted in the following conclusion concerning a possible criterion related to stick force stability in the landing approach and touchdown:

> "For attitude-stabilized aircraft operating in the bottom or on the frontside of the thrust required versus airspeed curve (speed for minimum drag or faster) with manual throttle control the "inherent" condition of neutral stick force stability is satisfactory for the execution of an ILS/VASIS approach".

The conclusion is reached after close examination of the results of a dedicated in-flight experiment.

Neutral stick force stability existed in the simulator tests aimed at the study of required manoeuvring characteristics and from pilot commentary obtained it may be concluded that neutral stick force stability is satisfactory for the landing as well.

Consideration of the "phugoid" stability is not relevant for aircraft fitted with a pitch-rate-command/attitude-hold flight control system, since such aircraft do not show a lowly damped oscillatory long-period mode, which absence, as a matter of fact, is considered beneficial with regard to speed holding characteristics during the landing approach.

For aircraft with above-mentioned flight control systems the English military requirement concerning "flight path stability" (JAC 925, 1975) is phrased as follows: "The value $\partial\gamma/\partial V$ shall not be positive" *). For aircraft with pitch-rate-command/attitude-hold systems it is proposed to maintain this criterion since no expermimental evidence is available that it is advisable to modify it **).

Longitudinal manoeuvring

Systematic variation of the equivalent short-period frequency, the (pitch) overshoot parameter and the direct-lift control effectiveness of two conceptual aircraft equipped with a rate-command/attitude-hold flight control system has been performed in a piloted flight simulation program. Conclusions concerning criteria for satisfactory longitudinal manoeuvring characteristics during the landing approach and touchdown presented next are divided in "open-loop" and "closed-loop".

Open-loop criteria

1. Two characteristics of the aircraft pitch rate time response to a step-type input of the pilot's controller have been identified to be of critical importance. "Rise time", T_{rise}, which is the time to reach 90 % of the steady state and "settling time", T_{settle}, which is the time after which the response remains within a band of values which range from 90 % to 110 % of the steady state should both be within limits. The limit values are:

$$T_{rise} < 1 \text{ second and } T_{settle} < 4 \text{ seconds.}$$

An illustration of the limits is given in figure 5 together with the (US) SST time response criterion. It is indicated that the SST time response criterion is too lenient. The criterion to be discussed below is considered to be best suited to cover the area of "initial overshoot".

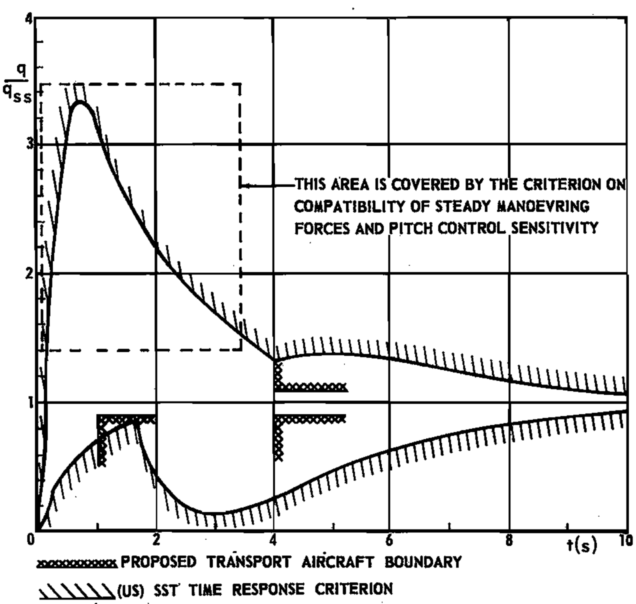

Fig. 5 Pitch rate time response criterion

*) The US Military Specification allows a slightly positive value of $\partial\gamma/\partial V$.

**) This should be considered in the light of manual throttle control; in the case of high-reliability auto-throttles the requirement should be relaxed.

2. A criterion format proposed by Chalk and others in 1973 is considered appropriate to cover the case where the pitch control sensitivity is too high relative to the "stick-force per g". This criterion on the compatibility of steady manoeuvring forces $|F_e/n_p|_{ss}$ and pitch control sensitivity $|\ddot{\theta}/F_e|_{max}$ limits the product of these terms; for the determination of $|F_e/n_p|_{ss}$ constant speed has to be assumed while $|\ddot{\theta}/F_e|_{max}$ is determined at the frequency for the highest amplitude ratio in a Bode response representation. The limit value established is:

$$|F_e/n_p|_{ss} \times |\ddot{\theta}/F_e|_{max} < 0.7 \text{ rad/s}^2\text{.g}$$

Closed-loop criteria

1. Precise control of pitch attitude is essential for fighter aircraft in the air-to-air combat phase as well as during the approach and landing phase of transport aircraft. A criterion format originally developed for fighter aircraft (Neal-Smit criterion) requiring a minimum bandwidth, $\omega_{BW-\theta}$, for the pilot-aircraft closed-loop system for up-and-away flight has been tried for application in relation to transport aircraft in the landing approach. In order to have satisfactory characteristics the resonance $|\theta/\theta_c|_{max}$ and the pilot compensation $\measuredangle pc$, resulting from the loop closure, according to preset rules, should stay within certain boundaries. Based on the experiments discussed in this paper and available literature a boundary for transport aircraft in the $|\theta/\theta_c|_{max} - \measuredangle_{pc}$ plane has been defined, see figure 6. For a "minimal bandwidth" of 1.2 rad/s the following boundary is proposed:

$$|\theta/\theta_c|_{max} < 0 \text{ dB and } \measuredangle_{pc} < 35 \text{ degrees.}$$

[More experiments are needed to validate the selected "minimum bandwidth" further and to validate/refine the boundary outside the areas investigated so far, as indicated in figure 6].

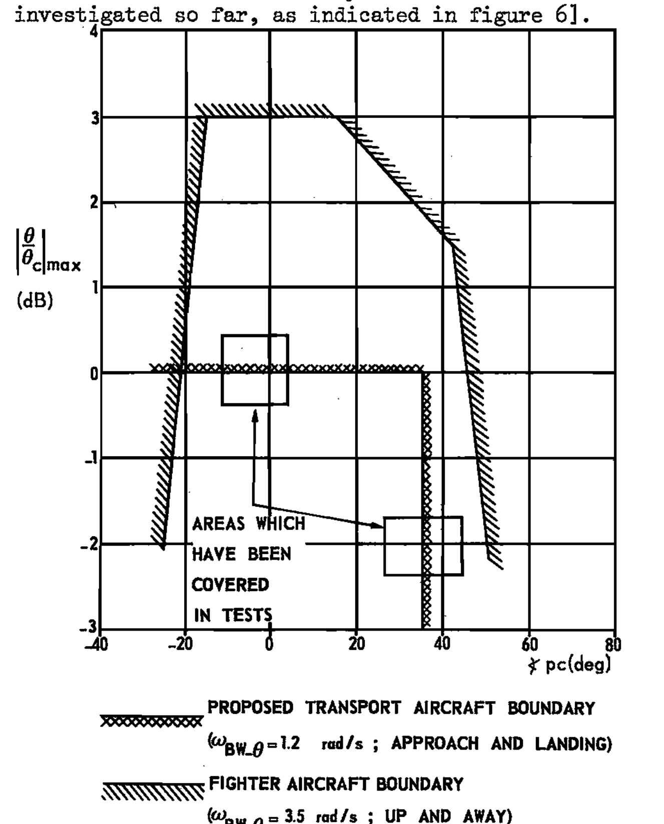

Fig. 6 Proposed boundary in the $|\theta/\theta_c|_{max} - \measuredangle_{pc}$ plane

2. Based on the experiments discussed in this paper it is concluded that it is not possible to give an "open-loop" type criterion to specify the amount of manoeuvre enhancement through blended DLC required for aircraft deficient in flight path response (n_α too low). The reason is that altitude loop performance obtained depends among others on pilot compensation used in the inner loop (attitude). As the format proposed here, a series closure structure is envisaged in which the inner-loop is closed according to the concept discussed above (minimum bandwidth 1.2 rad/s, while observing the $|\theta/\theta_c|_{max}$ and $\measuredangle_{pc}$ boundaries) and the outerloop is closed (with only a gain to represent the pilot action) in such a way that a phase margin of 30 degrees is obtained. The proposed criterion is the minimal bandwidth, ω_{BW-h}, which should exist after the loop closure.
The limit value is:

$$\omega_{BW-h} > 0.55 \text{ rad/s.}$$

Thus the minimal gain of the direct-lift system is determined by the above-mentioned criterion value of the closed-loop, see figure 7.

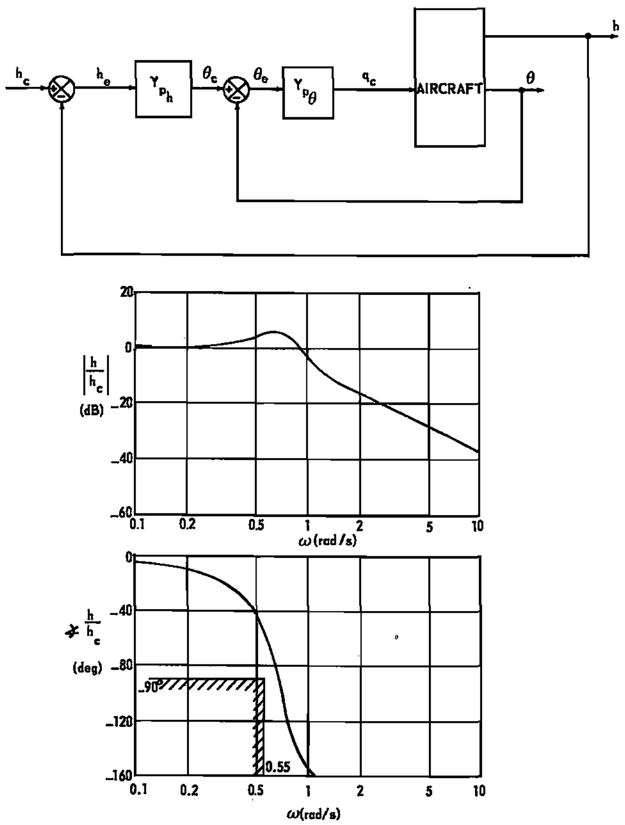

Fig. 7 NLR proposed criterion on minimum bandwidth for the (closed) altitude loop

Lateral-directional manoeuvring

Systematic variation of the effective roll mode time constant $t_{63\,\%}$ (time to 63 % of the steady state roll rate after a step input), maximum available roll rate and pure time delay of a conceptual aircraft equipped with a rate-command/attitude-hold flight control system has been performed in a piloted flight simulation program. The following conclusions concerning criteria for satisfactory lateral-directional manoeuvring characteristics during the landing approach and touchdown have been reached:

1. A limiting value (maximum) for the effective roll mode time constant should be observed when no appreciable initial delays in roll rate response after a step-type input of the pilot's controller occurs. The suggested criterion reads:

$$t_{63\,\%} < 0.8 \text{ second.}$$

This is rather strongly in contrast with the present US Mil. Spec. value of 1.4 seconds as a maximum for the basic roll mode time constant of an unaugmented aircraft (Class II aircraft).

2. Bank angle attainable in 0.5 second for full pilot's controller deflection shows promise as a criterion especially suited when time delays do occur in the forward loop between the pilot's controller and the ailerons. The suggested criterion reads:

$$\phi_{0.5\,s} > 4 \text{ degrees.}$$

With respect to this initial response parameter, it has been shown that there exists a trade-off between the effective roll mode time constant and the time delay.

3. The method of (step wise) regression of the average Cooper-Harper ratings of the configurations evaluated in the simulator experiments resulted in a straightforward "estimation" formula using only the above mentioned $t_{63\,\%}$ and an effective time delay, t_d, as parameters. The last parameter is defined as the time to the intersection of the tangent to the maximum roll rate and zero amplitude after a step-type control input. The formula is:

$$CH_{est} = 1.6 + 2.7\, t_{63\,\%} + 7.3\, t_d$$

An illustration of this result is given in figure 8.

The multiple regression coefficient in this formula is R = 0.93 which means that 87 % of the variance of the Cooper-Harper ratings can be "explained".

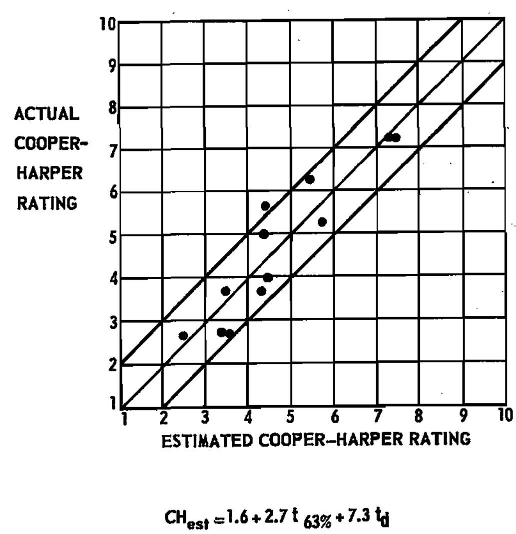

Fig. 8 Comparison of actual Cooper-Harper ratings and ratings estimated on the basis of a linear regression equation

4. A closed-loop criterion for roll control analogous to the one discussed for pitch attitude control could not be defined. Other parameters

than pilot compensation for a certain closed-loop performance have determined the Cooper-Harper ratings as well.

Concluding observations

Besides the discussion of flying qualities criteria concerning a certain category of future flight control systems for transport aircraft in the former chapter, the following additional observations resulted from the simulator experiments performed:

Longitudinal pilot-aircraft performance

The pilots apparently changed control strategy according to the demands of the configurations dynamics and were able to keep the performance on the glide path (deviations from the ILS glide path and the speed) at a relatively unchanged level. [It is interesting to observe that a strong agreement occurred between the measured standard deviations from the ILS glide path and from the reference approach speed obtained during the ground-based experiments and the in-flight experiment for the runs without artificial positive stick force stability].

Rate of descent at touchdown was strongly influenced by the equivalent short-period frequency and to a lesser extend by the pitch overshoot parameter but, contrary to expectations, not by the level of direct-lift effectiveness.

Lateral-directional pilot-aircraft performance

The performance on the localizer (deviation from the ILS localizer), flare and touchdown was only slightly affected by the variation of affective roll mode time constant, maximum available roll rate and time delay applied in the program.

Attitude-stabilization

The high-quality attitude stabilization in pitch and roll (and in yaw in the most recent experimental phase of the study) was highly appreciated by all participating pilots. The presence of a wing leveller system as part of the roll control system (with attitude hold) was highly appreciated by the pilots.

Side-stick control

Side-stick control in combination with the rate-command/attitude-hold systems evaluated in the experiments (in-flight and ground-based) was readily accepted and eventually appreciated by the evaluation pilots.

Experimental technique

According to the pilots, self-imposed manoeuvres, performed during simulator runs without turbulence during familiarization with a configuration did improve the quality of the evaluation. The use of "Effort ratings" in addition to Cooper-Harper ratings were useful in gaining insight in the objections the pilots had against particular configurations. In the (well-controlled) experiments, statistical techniques can be used to identify significant differences in the ratings for groups of configurations evaluated.

Pilot ratings and opinions on handling qualities were mainly assessed during the visual segment of the approach and in many cases specifically during the flare and touchdown phase of this task. Because of the reduced validity of simulation of the flare and touchdown phase, the research program will be continued with a flight test phase using an in-flight simulator capable of actual landing.

References

1 Mooij, H.A.; Gool, M.F.C. van — The need of stick force stability for attitude-stabilized aircraft, Part II. NLR TR 77027 U — 1977

2 Mooij, H.A.; Gool, M.F.C. van — Flight test of stick force stability in attitude-stabilized aircraft. AIAA Journal of Aircraft, Vol. 15, No. 9, September 1978

3 Breuhaus, W.O. — Comment on "Flight Test of Stick Force Stability in Attitude-Stabilized Aircraft. AIAA Journal of Aircraft, Vol. 16, No. 9, September 1979

4 Mooij, H.A.; Gool, M.F.C. van — Reply by Authors to W.O. Breuhaus. AIAA Journal of Aircraft, Vol. 16, No. 9, September 1979

5 Mooij, H.A.; Boer, W.P. de; Gool, M.F.C. van — Determination of low-speed longitudinal manoeuvring criteria for transport aircraft with advanced flight control systems. NLR TR 79127 U — 1979

6 Gool, M.F.C. van; Mooij, H.A. — A simulator investigation of roll response requirements for aircraft with rate-command/attitude-hold flight control systems in the landing approach and touchdown. AIAA Paper No. 79-1679 — 1979

7 Gool, M.F.C. van — Application of existing roll response requirements to transport aircraft with advanced flight control systems. AIAA Paper No. 80-1572 — 1980

8 Gool, M.F.C. van. — Roll response criteria for transport aircraft with advanced flight control systems in the landing approach and touchdown. NLR TR 80 U (forthcoming) — 1980