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THE EVOLUTION OF HANDLING QUALITIES REQUIREMENTS

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THE EVOLUTION OF HANDLING QUALITIES REQUIREMENTS

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Abstract

Handling qualities should be expressed in engineering terms. Early assessments of handling qualities were based on measurements made during elementary evolutions.

Inspection of the block diagram covering the loop pilot-control system - aircraft shows that the evolution of handling qualities requires consideration of many factors. One of the most important being the pilot work load.

Modern study of handling qualities is made in two different ways. One of them is an experimental way, using assessment by the test pilot and trying to correlate the pilot rating with engineering data. The other way is theoretical. It is based on the inspection of the transfer functions of all the elements of the block diagram and tries to use these transfer functions in order to evaluate the ease or difficulty of piloting the plane.

The two methods are complementary.

I. INTRODUCTION

The dynamical behaviour of an airplane can be studied in two different cases:

- pilot out of the loop,
- pilot in the loop.

Pilot out of the loop motions are those where the pilot applies well defined inputs and lets the airplane respond accordingly to its own dynamics. This definition encompass not only motions following a step input control deflection, but any motion produced by programmed control displacements when the program has been chosen beforehand and cannot be modified accordingly to the obtained response.

Computation of pilot response in this situation is possible by means of the well known equations of motion. The established theory defines important motion characteristics, such as

- time constants affecting divergence or subsidiences,
- period and damping factors characterising oscillatory modes,
- amplitude of response following step inputs.

The theory provides the means to calculate these characteristics knowing the aerodynamical coefficients of the airplane, its mass and its inertia moments. We call them mechanical motion characteristics.

Pilot in the loop motions are maneuvers where the pilot wishes to perform a well defined evolution and applies inputs which are at any time determined by the way the plane fulfills the programmed motion or keeps away from it.

II. DEFINITION OF HANDLING QUALITIES

Handling qualities are airplane properties or characteristics, which influence the precision, ease and safety with which the pilot is able to perform the maneuvers and tasks necessary to the fulfillment of a specified program. This definition, given in ref. 1, concerns obviously the case pilot in the loop.

The first aim of handling qualities studies is their identification and their definition in engineering terms. The second is their numerical evaluation, and the determination of values leading to a satisfactory airplane. Such values may be included in requirements edicted by the user, the customer, or any official authority.

I remember I belonged, forty five years ago, to a group (CINA) edicting handling qualities requirements and they found that the only way to write these requirements was just to say that these characteristics, not identified at that time, should allow the pilot to fulfill his program with precision, ease and safety.

Great progress has been made since that time in the development of requirements. This first stage consisted to select some elementary motions, and to appreciate the handling qualities in function of measured quantities criteria such as
- the force that has to be applied on the stick to develop a normal load factor of $n = 2$ ($F = 45$ dnw in ICAO-PAMC),
- the roll velocity p which can be produced by a full deflection of the ailerons,
- the time necessary to obtain a bank angle of say, 30° when a given force is applied on the control wheel.

The user experience indicated values to be incorporated in the requirements. These values varied with the kind of aircraft concerned.

Our aim is not to compare requirements existing at a given time. Such comparisons have often been made. A work made by the group 'Incarbone' has never been published for security reasons, while other studies, such as an analysis of military and civil stability or control specifications, made by the Douglas Aircraft Co., led to a published report (ref. 2). This report compares the CAA specifications of 1953, with the US MIL F 8785 specifications of 1954, amended in 1957.

Nothing can hinder a country to adopt its own specifications for military aircraft, but uniformity of requirements are desirable for commercial planes, as the certification, granted to an aircraft in one country must be valid and accepted in any other. This supposes equivalent technical requirements.

Establishing such requirements should have been the task of ICAO. Political reasons did nevertheless not allow ICAO to legislate, this organization could only produce "Provisional acceptable means of compliance" (PAMC).

A "PAMC" referring to handling qualities and published in 1965 (ref. 3) is still in the process of completion; additions have been proposed at the spring 1968 meeting in Amsterdam (ref. 4).

The former American specifications have been modernised, and mention is often made in technical publications of the recent evolution of MIL F 8785.

The way of thinking used in working out these modifications, made it clear that there is doubt about the possibility of defining the handling qualities of modern airplanes, by the results of some measures made while performing a small number of elementary maneuvers.

The research work made in order to find more accurate criteria has produced, as by product, a handling quality theory.

III. THE BLOCK DIAGRAM

We appreciate better the situation when we consider the block diagram of the system human pilot - controls - airplane.

Intelligence of this diagram is necessary to study aircraft motion in the "pilot in the loop" case (see fig. 1, next page).

III.a The Program

The program of the prescribed maneuver is defined by a set of n time dependent variables $a_{p1} \dots a_{pn}$, while the actual motion of the plane will be defined by a set of n time dependent variables $a_1 \dots a_n$. Mathematicians like to consider each set of these variables as the components of vectors $\vec{a}_p$ and $\vec{a}$.

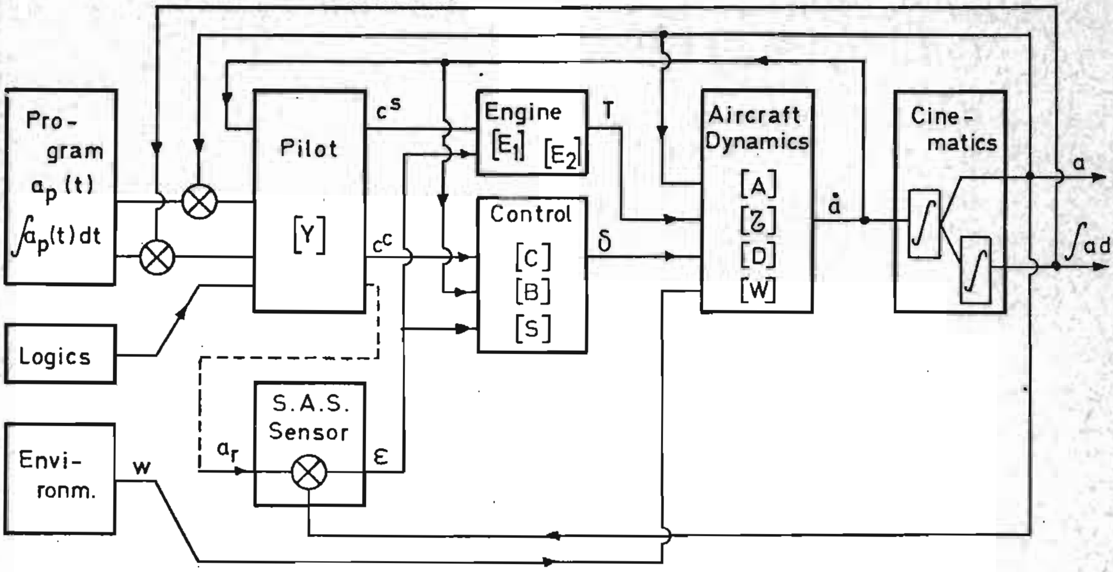

Figure 1

III.b The Environment

The atmosphere in which the airplane flies is subject to changes of air velocity and air temperature. The environment will be characterized by a set of m perturbations $w_1 \ldots w_m$, considered as components of a vector $\vec{w}$. The symbol $\vec{w}$ is chosen here as the main perturbations arise from wind fluctuations.

III.c The Control System

Any aircraft is fitted with a control system which becomes more and more sophisticated. One end of this system is formed by levers, wheels, pedals, on which the pilot acts. These organs may be called 'manipulators'. The other end consists in control surfaces called 'motivators' by some UK scientists. Their deflections are represented by δ_i, which may be considered as the components of a vector $\vec{\delta}$. These deflections produce aerodynamical moments which work as inputs on the air frame.

III.d The Propulsion System

Mention of the propulsion system must be made. This system develops a thrust T dependent, among other variables, on the throttle setting, δ_t.

III.e The Air Frame Behaviour

The air frame receives inputs produced by deflections of the motivators, by changes in the thrust applied by the engine and by perturbations coming from the environment. At any time, the time derivative of the motion vector $\dot{\vec{a}}$ is a function of

- the vector a itself,
- the thrust vector $\vec{T}$,
- the control deflection vector $\vec{\delta}$,
- the wind vector $\vec{w}$.

The dynamics of the air frame may be represented by a matricial equation

$$\dot{\vec{a}} = (A)\vec{a}+(\zeta)\vec{T}+(D)\vec{w}+(W)\vec{\delta} \qquad (1)$$

where the matrices (A) (ζ) (D) (W) are mathematical models of the dynamical properties of the air frame.

III.f The Human Pilot

The human pilot, responsible of the fulfillment of the program, acts on the manipulators. He receives a lot of information. Accelerations provide him physical feeling. A display of instrument provides him the numerical values of most of the variables a_i (air speed, climbing speed, angular velocities) or of integrals of these variables (attitude, altitude, lateral inclination, heading).

External view of the outside world (when available) indicates him his position relative to the horizon or to important spots on the earth surface. These cues are, in fact, integrals of $\int a_i dt$.

Logical information is produced by radio communications. These informations may decide the pilot to alter his program.

Taking all this information into account, the pilot acts on the manipulator by the way of applying forces F and producing displacements s.

For some manipulators, for instance the stick, the applied force F and the displacement are tied together, either by natural reaction of the control system due to hinge moments, or by an artificial feel device. Experience shows that the relation between F and s where it exists, plays an important role in the assessment of handling qualities.

On other manipulators, as the throttle, the force is independent of the position. In any case, a constant break out force may generally be needed for the displacement of any control.

The force F and the displacement s of the manipulators are outputs of the pilot's cerebral or muscular operations. They will be symbolized by c_i^F or c_i^e, the c^c being the outputs acting on the control system, and c^e those acting on the engine. They may be considered as components of a vector $\vec{c}$. They are not only dependent from the difference $(a-a_p)$, but also from some anticipation made by the pilot about the previsible effect of its output.

Incorporating all this in a pilot describing function Y, we may write

$$\vec{c} = (Y)(\vec{a}-\vec{a}_p)$$

The pilot output $\vec{c}$ acts as input either on the control system or the engine.

III.g The SAS

A look on the block representing the control system shows that the components c^s are nevertheless not the only inputs working on the control system. The airplane is often filled with a stability augmentation system, SAS. This system provides inputs ε_i which are error signals

$$\varepsilon_i = a_i - a_{i_r}$$

where a_{i_r} is the reference value assigned to the SAS. This reference value a_{i_r} may be equal to a_{i_p} but sometimes it may be different.

III.h Working of the whole System

The inputs c_i^s provided by the pilot and the inputs ε_i provided by the SAS act on the control system to produce through linkages, actuators or electrical devices the displacement $\vec{\delta}$ of the motivators. It may happen that the inertial forces developed on some parts of the control system by the accelerations $\dot{a}_i$ may influence the output of this system. The masses acting in such a way are called Bobweights. Summing up all these actions, we define the deflections either by

$$\vec{\delta} = \int \dot{\vec{\delta}}\, dt$$

and a matricial equation (3)

$$\dot{\vec{\delta}} = (C')\vec{c}^{\,s} + (S')\vec{\varepsilon} + (B')\dot{\vec{a}}$$

or on a more simple way by

$$\vec{\delta} = (C)\vec{c}^{\,s} + (S)\vec{\varepsilon} + (B)\dot{\vec{a}}$$

This depends on the accuracy of the available model of the control system.

The case of the engine will be dealt with in a similar way; the SAS may act on the engine (automatic throttle), but an action of $\dot{\vec{a}}$ must not be considered. So we write

$$\vec{T} = \int \dot{\vec{T}}\, dt \qquad (4)$$

$$\dot{\vec{T}} = (E_1')\vec{c}^{\,e} + (E_2')\vec{\varepsilon}$$

or a less accurate formula, if we do not consider the derivative of T.

The motion of the plane is defined by the system of equations 1,2,3,4, where the pilot describing function is certainly the less known.

The describing function Y characterises the pilot behaviour. It is a result of training and previous experience. As said before, it may incorporate anticipation of what the aircraft response will be.

It is of course hard to evaluate such functions in numbers. Scientists dealing with human engineering have nevertheless developed some means of establishing them.

A flight program, defined by $\vec{a}_p(t)$, will not be completely realized when the environment develops random perturbations, $\vec{w}$. The actual motion $\vec{a}(t)$ will become different from the programmed one $\vec{a}_p(t)$. The quality of pilot action will be measured by the root mean square (rms) of the difference $a-a_p$. Thus, for any flight program and any aircraft, there will be a relation between

- the pilot describing function Y,
- the root mean square of $(a-a_p)$,
- the power spectrum of w, characterizing the environment.

IV. IMPORTANCE OF THE PILOT WORK LOAD

How can we make use now of this complex relation for the definition of handling qualities ?

Depending on the ease with which the pilot fulfills his program, the handling qualities are in relation with the work load of the pilot. When the pilot must be attentive to many signals and must act on many manipulators, or exert forces nearing the maximum he can develop, in order to perform a flight program with a small rms, he will not be satisfied. He will consider the handling qualities as unsatisfactory. So, it appears that linking the handling qualities of an airplane with the work load of the pilot, is a reasonable point. The pilot function Y describing the pilot behaviour will be less complicated when the handling qualities are good, than when they are bad.

This does not resolve the problem, but it makes clear that all the matrices included in eq. 1 to 4 will influence the handling qualities.

V. THE CASE OF FAILURE

That is not all. One should also consider what happens when there is a sudden failure of an engine, or of one of the mechanical or electrical components of the control system. It is possible to evaluate the probability of occurence of every possible failure. The plane must still be reasonably safe to fly, although the pilot work load may increase considerably in such an emergency. Handling qualities may become less severe when the probability of failure decreases. This conception increases tremendously the number of cases that must be dealt with, and makes writing of complete flying qualities requirements a complicated matter.

The revised MIL F 008785A, or the "Concorde" handling qualities (ref. 5) specifications are good examples of this trend. They make also use of some concepts developed recently while trying to establish a handling qualities theory.

VI. THE MAIN QUESTION

We shall consider here only the main case, when every system of the block diagram is in complete working order, but we must face the question: How will it be possible to determine then handling qualities better than by considering only a limited number of measurements made during elementary maneuvers, as this was done during the 1935-1950 period ?

There are two ways to deal with this question: Experimental work or further theoretical study.

VII. EXPERIMENTAL WAY

The experimental way, which has been used since the beginning of aviation, consists in asking the pilot's opinion. Questionnaires have been established in order to make the pilot's opinion more reliable. Two processes, initially developed by George E. Cooper and Robert P. Harper, have been amalgamated into a unified method where the questions are clarified in such a way that the resultant pilot rating becomes as free as possible from any subjective element (ref. 6). Everybody knows that the pilot rating varies between 1 and 10, 1 being the optimum and 10 characterizing an unflyable airplane.

Such a refined flight test technique can only be useful to the scientist if he finds a correlation between pilot rating and airplane characteristics expressed in engineering terms. This correlation can be obtained by tests using

- ground based simulators,
- variable stability airplanes,
- flying simulators.

In any case, it must be kept in mind that the pilot rating will depend on the difficulty of the prescribed mission and on the environment. When comparing pilot ratings of different planes, it must be understood that they are obtained while performing the same missions, in the same environment.

VII.a Ground Simulators

Description and discussion of ground based simulators are beyond the scope of this paper. Let us nevertheless state that they reproduce, in an imperfect way, the physical cues acting on the pilot.

VII.b Variable Stability Airplane

Variable stability airplanes are those where an adjustable SAS sensitive to α and q, introduces relations such as

$$\delta_e = K_1 \alpha \qquad \delta_e = K_2 q$$

and changes the total derivatives

$$\frac{dC_m}{d\alpha} = \left[\frac{\partial C_m}{\partial \alpha}\right]_{\delta_e} + K_1 \left[\frac{\partial C_m}{\partial \delta_e}\right]_{\alpha}$$

$$\frac{dC_m}{dq} = \left[\frac{\partial C_m}{\partial q}\right]_{\delta_e} + K_2 \left[\frac{\partial C_m}{\partial \delta e}\right]_{q}$$

The same may occur with the derivatives $C_{\ell\beta}$, $C_{n\beta}$, $C_{\ell p}$, $C_{\ell r}$, C_{np}, C_{nr}, through SAS systems sensitive to β, p, and r.

VII.c Flying Simulators

Flying simulators, sometimes called TIFS (True In Flight Simulator), are formed by the addition of a computing unit such as that used on a ground base simulator, and an airplane. This means that the computer is carried on the aircraft. The aerodynamical data, feeded into the computer, correspond to the matrices $(A)_c$ ... of the aircraft to be evaluated, while the matrices $(A)_t$ of the actual aircraft used for the test, depend only from the airplane configuration.

As the ground based simulator, the pilot develops inputs that act only on the computer unit, but there is something more. It is requested that the airplane should materialize the motions determined by the computer. Let $a_{1,c}$, $a_{2,c}$ ... be the components of the computed motions; $a_{1,t}$, $a_{2,t}$ ... the components of the airplane motion, detected by appropriate sensors. The errors

$$\varepsilon_1 = a_{1,c} - a_{1,t}; \quad \varepsilon_2 = a_{2,c} - a_{2,t}$$

must be minimized. Each error must therefore act on a control governing mainly the concerned variable of the actual airplane.

This means that it may be necessary to increase the number of controls acting on the plane. Controls exercising forces X,Y,Z, must be added to the classical controls producing moments L,M,N. The control deflections may be important but experience shows nevertheless that a classical airplane can practically reproduce the behaviour of a new project.

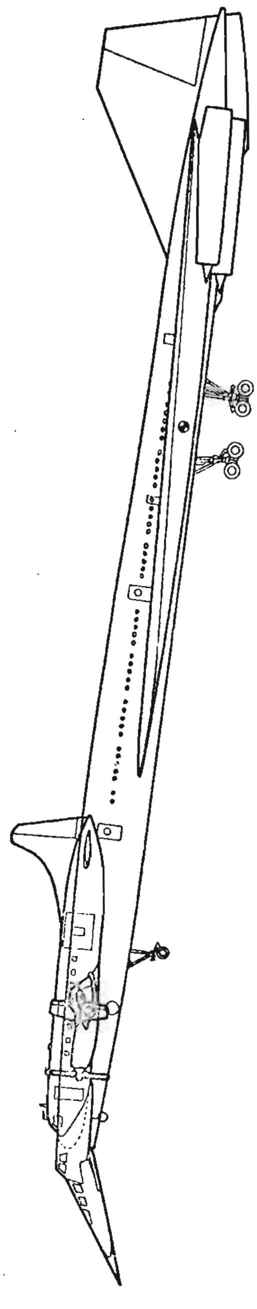

Figure 2

Figure 2 : see opposite page

Figure 2 shows at the same scale a Convair 300 and a SST. The Convair will certainly not be able to fly at a supersonic speed, but in the domain of speeds, it can reach, it is able to simulate the behaviour of the SST. The same principle allows to simulate VTOL flight, through the use of helicopters.

VIII. RESULTS OF THE TESTS

These three experimental processes allow to change progressively the most important aircraft characteristics; the ground base simulator allows, in addition, to simulate a fixed level of atmospherical turbulence.

It has been shown that increasing the rms gust input, the pilot rating becomes worse. Figure 3 shows the rating of a set of configurations where the variable elements are:

- the turbulence,
- the parameter $\zeta\omega$

of the Dutch Roll.

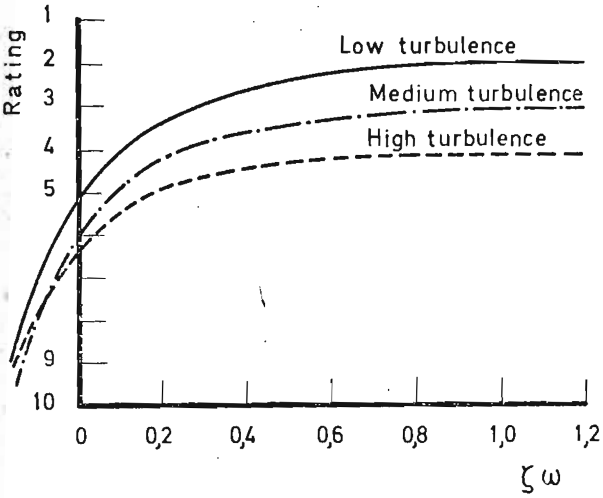

Figure 3

Assuming a constant environment, the way of experimentation consists to select aerodynamical or mechanical parameters and to establish a correlation between them and the pilot rating.

When the number of variable parameters is limited to two, the loci of equal pilot rating can be drawn on a two dimensional diagram.

For longitudinal motion, the first choice of variable elements consists in natural frequency ω_n and damping factor ζ of the short period oscillation. Figure 4 indicates roughly what happens when these parameters change.

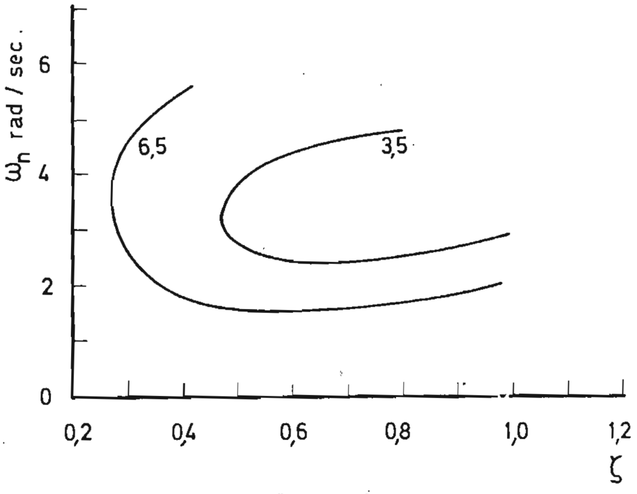

Figure 4

Such tests are in progress since nearly ten years.

The conception of areas limited by the values of two mechanical characteristics, and corresponding to acceptable handling qualities is already included in the MIL F 008785A, as it has already be shown in AIAA published papers (refs. 7 and 8). Experimentation has nevertheless shown that the results obtained for a given family of airplanes, in changing only the characteristics acting on ω_n and ζ are not universal. The results obtained on a family of planes (planes of similar size and performances) cannot be extended to planes of another family.

Reference 9 contains a survey of the state-of-the-art in 1968, presented to ICAO.

The scientists working in this field try to identify among other well defined characteristics, those which seem to influence directly the pilot rating. One of them, related to the longitudinal motion, is $n_{z\alpha}$, the normal acceleration due to a change of angle of attack.

The study of lateral motion suggests that more than two variable parameters should be considered.

In addition to the ω_d and ζ of the Dutch Roll oscillation, an important characteristic is the ratio of amplitudes of perturbations in ϕ and β associated with Dutch Roll. Figure 5 shows curves of iso-rating for $\zeta = 0.1$, when ω_d and the parameter $L_\beta = \frac{\partial C_L}{\partial \beta} \frac{b\rho V^2}{2J}$ changes. Loci of equal $\frac{\phi}{\beta}$ are indicated^x (ref. 10).

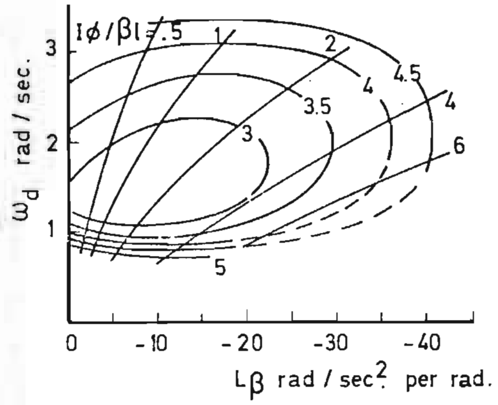

Figure 5

Nobody can predict, at the present stage, how many characteristics will have to be used in order to get wide correlation between pilot rating and combination of these characteristics when airplanes of different size or performances are compared. The iso-rating loci obtained will only become relevant if the number of characteristics that has to be used is small (three or four, maximum).

It is worthwhile to remember here that the longitudinal control of the classical airplane acts in an indirect way. When more lift is needed, the entire plane must develop a nose up pitching motion, which is produced by a decrease of the lift acting on the tail. Evaluation tests show clearly that aircraft configurations including straightforward lift control, deserve a far better pilot rating than the classical ones, when landings are simulated.

IX. THE THEORETICAL WAY

The theoretical method uses the transfer function of all the elements of the block diagram. It is based on the assumption that the human pilot behaviour can be expressed by a transfer function, in the same way as the behaviour of other blocks. The well established servomechanics theory allows then to calculate the motion of the aircraft with the pilot in the loop; it becomes possible to find how a piloted airplane will react to any input.

A theory of handling qualities has been built on this principle; it is for a great deal the achievement of a team working at Systems Technology Inc.

A lot of publications have been made by the leaders of the team, MM. McRuer and Ashkenas. Their quotation would need an important part of the space allowed for this paper; so, we quote only ref. 11, which seems to be the foundation of their work.

The subject 'Pilot Dynamics and Aircraft Handling Qualities' has been developed during a two days symposium in August 1968 at Los Angeles. This shows that there is no hope to deal with the subject in some minutes. Let us only recall following features.

A general form of the pilot transfer function is

$$c_i = Ke^{-\tau s} \frac{(T_{1s}+1)(T_{2s}+1)}{(T_{3s}+1)(T_{4s}+1)} (a-a_p)$$

where K is the gain,

T_1 and T_2 are lead time constants,

T_3 and T_4 are lag time constants.

The degenerated case, without any lead or lag, becomes, of course:

$$c_i = K(a-a_p)$$

Criteria which are not shown by the early handling qualities studies can be developed by consideration of the pilot + aircraft loop.

Let us consider a pilot deflecting the ailerons δ_a proportionally to the bank angle ϕ. The transfer function of the closed loop

$$\phi(s) = K \frac{N_2 s^2+N_1 s+N_0}{D_4 s^4+D_3 s^3+D_2 s^2+D_1 s+D_0} \delta_a(s)$$

can be characterized by a root locus plot. In the considered case, the numerator and the denominator have each one a complex root. Let

$\sigma_\phi+j\omega_\phi$ be the root of the numerator (the zero)

$\sigma_d+j\omega_d$ be the root of the denominator (the pole).

When both roots are not very different, one of the roots of the transfer function will follow a locus joining the pole to the zero when K varies from 0 to ∞. This locus is always described anticlockwise.

If $\omega_d < \omega_\phi$ the locus will pass on the right side of the j-axis (fig. 6a). The system will become unstable with increasing gain K.

For $\omega_d < \omega_\phi$ this cannot happen (fig. 6 b). A stability criterion will thus be $\frac{\omega_\phi}{\omega_d} < 1$. This criterion is already incorporated in modern specifications.

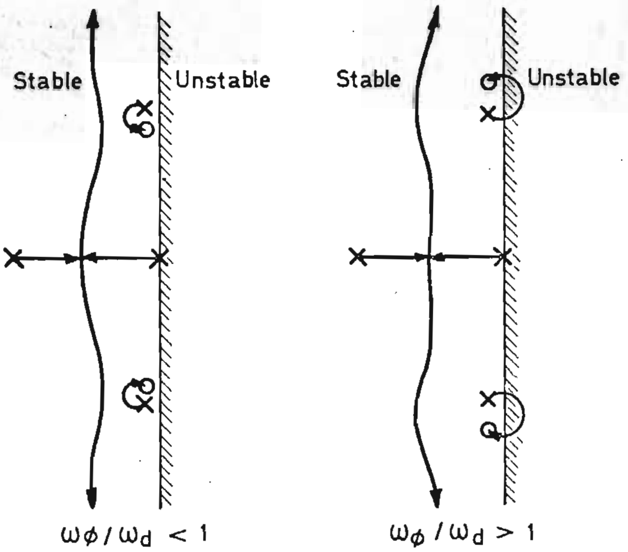

Figure 6

This is not new, it is known for more than ten years, but it is worthwhile to be remembered as it proves the possibility to draw some handling qualities criteria from the poles and zero of the transfer functions and the aerodynamical coefficients.

The physical interpretation of the criterium is easy. Roll control inputs, proportional to bank angle errors, produce at the same time, roll and yawing moments. These moments produce and sustain oscillations in roll and in yaw. The latter reacts on the former through the airframe coupling derivatives. When the ailerons develop what is generally called inverse yaw, the yaw oscillation generated works against the roll oscillation.

It is more difficult to comply with the criterion $\frac{\omega_\rho}{\omega_d} < 1$ with ailerons developing direct yaw, than with ailerons developing adverse yaw.

The very simple case described here is an example showing in which cases instability of a normally piloted airplane may occur.

More complex cases may be studied; every aircraft motion can be evaluated: the consequences of any control law used by the pilot, taking account of leads and lags, can be presented in the form of a root locus plot, permitting the unstable cases to be discovered.

X. POSSIBLE DEVELOPMENTS

The discovery of possible cases of instability does nevertheless not solve entirely the handling qualities problem. One should be able to predict the pilot rating by inspection of the root locus, or of the other diagrams developed by the theory, for instance, the Bode curves. Research is necessary in several ways, in order to progress in this field. Several aspects of the problems involved must be shown.

The first of them is the following one. The description of the pilot by way of a linear transfer function does not provide a definitive representation of the pilot action. Important, yet unpublished discussions occured during an AGARD meeting held in March 1970 at Ames Laboratory. Many European scientists are sceptical concerning the possibility of obtaining a mathematical description of a human being, valid under any condition.

On the other hand, we would like to recall here what is stated in a paper written in 1961 by two experts: Koven and Wasicko (ref. 12): "Without an adequate understanding of the pilot's inherent adaptive, optimizing control capabilities, it is difficult to expect that the systems approach to flying qualities will be successful. Without this approach, however, flying qualities requirements will probably follow the erratic development pattern of the current military specification".

A second question is the following one: Is there a relation between the difficulty felt by the pilot, when he has to develop a chosen transfer function, and the values of the gain K and the time constants T which are included in this function? We think this may be the case, as the lead factors, such as $(T_1 s+1)$ are the result of a sense of anticipation, which must be developed by training and necessitates mental work.

It may also be possible that the T may vary with the forces F that have to be developed on the manipulators: heavy controls will correspond to increased T in the lag terms.

So, it seems possible to us that given values of the gain K and the time constants T, appearing in the pilot transfer functions may be associated with pilot rating.

This gives us the possibility to get a step further. The prediction of the pilot rating, by inspection of the root locus, cannot be based on the mere knowledge of instable roots, but it could depend on the pilot's transfer function which is necessary to realize correctly the programmed motion.

Let us consider the whole system represented on the block diagram fig. 1, where every block is defined by its mathematical model. Consider a variable input, either

1) a flight program involving non steady motions, or

2) random disturbances acting on a plane trying to perform a steady motion.

Following calculations will be possible. When the pilot tries to comply with a flight program, defined by $\vec{a}_p(t)$, it is possible to calculate by analogue computation, the real motion $\vec{a}(t)$, corresponding to any pilot transfer function. The root mean square (rms) error between the real motion and the desired motion may be found; relations between the rms error and the set of constants defining the transfer function that the pilot must develop, can be obtained.

We know beforehand which rms may be accepted. If we assume that there is a correspondence between the time constants T (eventually also the gain K) of the pilot's transfer function, and the rating, a set of calculations would give an idea of what the pilot rating would be.

In the second case, the random disturbance is characterized by its power spectrum.

Existing theory gives the possibility to evaluate the power spectrum of $a-a_p$, knowing the square of the transfer function and the power spectrum of the disturbance. Here also, the relation between the two power spectra will depend on the pilot transfer function.

This means that the necessary transfer function to be developed by the pilot, if the power spectrum of the disturbance must stay under a specified minimum, can be found.

Such results would enable us to proceed a step further: Varying the aerodynamical characteristics of the plane, how should the pilot rating of the pilot change ?

Objections raise immediately. One does not see, at first view, how certain factors influencing the ease of pilot operation, such as the quality of the information displayed to the pilot, will be incorporated in the transfer function. The questionable validity of the pilot transfer function becomes also a strong objection.

The reader may perhaps think that the proposals we make here belong to dream and fancy. In fact, they are possible developments of the theoretical research work in progress, concerning handling qualities, but we agree that such calculations will be more a means of understanding the facts than a means to predetermine them with accuracy.

XI. FINAL REMARKS

As can be seen, we did not describe nor discuss specific handling qualities requirements. More information can be found in an excellent paper written by F. O'Hara (ref. 13). We showed only how the drafting of such requirements has evolved with the growing of our knowledge of flight dynamics and how this trend will continue.

Information obtained through the experimental way should be chequed by the theoretical research.

Much work continues to be done in that field and the efforts of all will certainly contribute to avoid, in the future, the birth of aeroplanes having inadequate handling qualities.

This is, after all, the main problem we are concerned with.

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