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NASA TM X-56004

FACILITY FORM 602

N65-35235
(ACCESSION NUMBER)
9
(PAGES)
TMX-56004
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
02
(CATEGORY)

Title NASA FLIGHT RESEARCH CENTER HANDLING-QUALITIES PROGRAM

ON GENERAL-AVIATION AIRCRAFT

By William E. Gray, Jr. [1964] 9p refs

1700822 NASA Flight Research Center,
Edwards, Calif.

GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

Presented at
AIAA General Aviation Aircraft Design and Operations Meeting,
Wichita, Kans.
May 25-27, 1964
25-27 May 1964

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Unclassified report

[redacted]

Conf.

April 21, 1964

NASA FLIGHT RESEARCH CENTER HANDLING-QUALITIES PROGRAM ON GENERAL-AVIATION AIRCRAFT

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Introduction

For many years the NACA and the NASA have maintained a research effort devoted to the study of aircraft handling qualities. This research, primarily on contemporary military aircraft and contemporary military problems, proved to be a fruitful source of information during the design and development stages of successive generations of aircraft. Although many of the results of the military research are applicable to civil aircraft, some problems are unique and require specific solutions. Research on civil aircraft, however, has been given only minimal attention since before World War II, primarily because of concentration on military aircraft during the war years and the effort devoted to the X-series of research aircraft.

In recent years, the increasing use of civil aircraft in instrument-weather conditions by pilots who are frequently solo and who sometimes have minimal experience has given rise to an operating problem of sufficient importance to warrant study. The NASA Flight Research Center has, therefore, recently initiated pertinent handling-qualities research. The purpose of this paper is to brief the general-aviation industry on the program objectives, to discuss the general approach that is being taken toward solving the operating problem, and to solicit comments from the industry at this early stage in the program.

Program Objectives

The primary objective of this research program is to formulate updated handling-qualities criteria, with particular emphasis on rough-air instrument-flight operations with general-aviation aircraft. All handling qualities will be evaluated, and special attention will be given to those that are found to be problems. It is anticipated that some handling qualities will assume great importance to a solo pilot in instrument weather and/or turbulent air, such as spiral instability, phugoidal oscillations, lateral-directional oscillations, adverse yaw, rapid speed-increase tendencies, control-system friction, and large trim changes resulting from aircraft configuration changes.

IFR handling-qualities criteria will be based on the correlation of quantitative aerodynamic or response characteristics with opinions expressed by pilots who have flown typical instrument missions. The initial flight tests on each aircraft will be made by NASA research pilots experienced in the particular techniques required for quantitative documentation of stability characteristics. To insure that the pilot opinions represent realistic operational viewpoints, pilots with experience in general aviation will then be invited to participate with the NASA pilots in evaluating the aircraft handling qualities during typical instrument missions.

An additional program objective is the assessment of practical design changes that can be made to improve IFR rough-air handling qualities. During this phase of the program, NASA ground-based simulators will be used to evaluate potential design changes by correlating pilot opinion with varying flight characteristics.

It is expected that five or six typical late-model aircraft will be evaluated in the flight program. Both single and twin-engine aircraft, representative of current production by different manufacturers, will be studied. Tests on an individual aircraft should be completed in less than 4 months.

Instrumentation and Data Processing

In implementing this flight program, the use of reliable instrumentation to measure airplane flight parameters for correlation with pilot opinion is of primary importance. Installation of such instrumentation is a time-consuming phase of any flight-test program and assumes particular importance in the scheduling of this program, since several aircraft are being studied in a short time. A significant development that will make it possible to maintain a rapid pace is the design and construction of an instrumentation "package" (fig. 1) by Flight Research Center personnel.

Prime considerations in the design of the instrumentation package were size, weight, ease of installation in a variety of aircraft, methods of recording data, and a self-contained power supply. These requirements are dictated by the limited space, payload, and electrical power available in some aircraft plus the need to minimize manpower requirements for instrument installation, maintenance, and data reduction. The instrumentation package provides permanent records of airspeed, altitude, angle of attack, angle of sideslip, bank angle, three-axes linear and angular accelerations, three-axes angular velocity, and all control forces and positions. It also has provisions for recording other quantities if the need arises. Information is recorded on photographic film, as illustrated in figure 2. Quantitative measurement of the various parameters is accomplished by measuring the displacement of the individual traces from the reference line. The periodic vertical lines provide time correlation at 0.1-second intervals. In addition to the recorded information, continuous visual information on airspeed, altitude, control forces and positions, and normal acceleration is displayed to a flight-test engineer. The visual display has been extremely valuable in enabling in-flight data reduction with the associated ability to determine during the flight test whether the data are adequate.

An appreciable portion of the data processing involves analysis of the information recorded on photographic film. Processing of these data at the Flight Research Center is facilitated by the use of mechanized film-reading equipment, electronic digital computers for performing necessary calculations, and automatic plotting of the final curves.

Discussion

Handling qualities are defined as the correlation of stability and control characteristics of an airplane with the pilot's impression of the ease of flying the airplane. The result of handling-qualities research is the formulation of criteria in terms of quantities that may be measured in flight or predicted from wind-tunnel tests and theoretical analyses. References 1 to 3 contain numerous examples of aircraft design criteria that are based on conclusions from handling-qualities research programs. When aircraft are designed to such criteria, it is reasonably certain that they will have desirable qualities from the pilot's standpoint.

Evaluation of pilot opinion is an important, though often difficult, part of any handling-qualities study. Occasionally, the opinions expressed by the various pilots vary widely. It has been found that these differences can be considerably reduced by carefully specifying the operational viewpoint to be considered, by devising a rating scale for the expression of broad categories of qualitative opinions, and by choosing the fewest ratings to describe significant differences in operational suitability. During this research program, each important flight characteristic will be rated by each pilot for solo flight in both smooth and rough air in both IFR and VFR flight.

Most handling-qualities studies and many handling-qualities criteria have not differentiated between VFR and IFR handling qualities. There are indications that satisfactory VFR handling qualities do not necessarily imply satisfactory IFR handling qualities. For example, figure 3 illustrates a Dutch roll motion that was evaluated by NASA research pilots as not being objectionable in either smooth or rough air during VFR flight. It was also satisfactory during IFR flight in smooth air, but was considered to be objectionable in IFR flight when combined with rough air. The pilot opinions support comments from numerous sources that the program discussed in this paper should be oriented toward IFR and rough-air handling qualities.

Dynamic Longitudinal Stability

It is anticipated that the dynamic longitudinal-stability characteristics of general-aviation aircraft will pose problems in the IFR rough-air environment.[4-6] The relatively low mass and moments of inertias of these aircraft imply low levels of physical damping of dynamic motions. Thus, various aerodynamic characteristics may greatly influence the dynamic motions in rough air. Although many factors are involved in dynamic longitudinal stability, this discussion is limited to two of the more important: stick-fixed and stick-free static longitudinal stability.

Stick-fixed stability is defined as the variation of elevator angle with airspeed, and stick-free stability is defined as the variation of elevator force with airspeed (fig. 4). High levels of stick-fixed and stick-free stability are indicated, respectively, by large changes of elevator angle and elevator force with airspeed.

Stick-fixed static stability greatly influences dynamic longitudinal stability, since the tendency to return to a given angle of attack or airspeed following a disturbance is directly related to the degree of stick-fixed stability. Further, the tendency to resist a disturbance and to remain at a given angle of attack is increased with increasing stick-fixed stability. High levels of stick-fixed stability are desirable from the standpoint of dynamic stability; however, stick-fixed stability should not be so high that it will impair airplane maneuverability. Similarly, stick-free static stability is important to dynamic longitudinal stability because it also increases the tendency to return to trim airspeed after a speed deviation. It should be noted, however, that stick-free stability provides only minimal initial resistance to a disturbance; the stabilizing reaction occurs only after the speed has changed. If low stick-free stability is combined with low stick-fixed stability, the aircraft may exhibit an appreciable response as a result of gust disturbances and a slow rate of return to trim speed after the disturbance is removed. If the stick-free stability is increased and the stick-fixed stability remains low, the return from a speed deviation may be at such a rapid rate that the trim speed will be overshot. Consequently, the return to trim speed is achieved only after a series of oscillations. Such slow, continuous speed oscillations represent poor dynamic stability characteristics, which will be aggravated by turbulent air.

The relationship of stick-fixed and stick-free static longitudinal stability to dynamic longitudinal stability will be studied on all of the aircraft used in the program. It is expected that this research will result in recommendations on means of improving the dynamic longitudinal-stability characteristics of general-aviation aircraft.

Control-System Friction

Control-system friction is also anticipated to be a problem that will warrant special attention. The ways in which friction affects the pilot's opinion of aircraft handling qualities are too numerous to detail, but it should be noted that the effect is almost invariably adverse. It is realistic to expect that any deterioration of handling qualities will compound the pilot's problem if the airplane is operated IFR, particularly when the pilot is solo.

Figure 5 illustrates the type of problem that can occur when friction prevents a control from returning to an aerodynamically centered position. When a pilot releases the ailerons after having deflected them, they may assume a position anywhere within 2° from the neutral position. The resulting rate of roll may be as high as 2.5 deg/sec (shaded area, upper plot). Normally, this roll rate would not be considered high; however, if a pilot diverts his attention for only 10 seconds, the bank angle can be as high as 25° (shaded area, lower plot). The seriousness of this situation is obvious.

Spiral Stability

The spiral mode, which is of no consequence during VFR flight, becomes important during solo IFR flight. Thus, considerable emphasis is being placed on measuring this mode. In-flight measurement is difficult, and is also an interesting research problem, since the spiral motion depends upon the net result of the relationship of four different stability derivatives:[3] dihedral effect, directional stability, roll due to yaw, and yaw damping.

Figure 6 shows the spiral motions that can occur when the controls are released from a steady bank angle. Whether the bank angle decreases, increases, or remains the same, depends on whether the term $C_{l_\beta}C_{n_r} - C_{l_r}C_{n_\beta}$ is, respectively, positive, negative, or zero, where:

C_{l_β} = effective dihedral

C_{n_r} = yawing moment due to yawing velocity

C_{l_r} = rolling moment due to yawing velocity

C_{n_β} = directional stability

Since positive spiral stability may not be necessary for practical IFR flight, the research problem is to determine, by correlating measured rates of roll with pilot opinion, the maximum rate of spiral divergence that can be tolerated. In addition, to assess potential design improvements, the spiral mode must also be correlated with flight measurements of the pertinent aerodynamic derivatives. Such measurements involve specialized pilot techniques, accurate instrumentation to record the aircraft response to control inputs, detailed data analysis, and accurate determination of the moments of inertia about each axis of the aircraft.

Moments of Inertia

Accurate moments of inertia about the aircraft axes are of sufficient importance that it is desirable to obtain experimental values rather than to rely on calculated estimates. The experimental technique for determining moments of inertia is illustrated in figure 7. Essentially, the aircraft is balanced (restrained only by springs) in such a manner that it is free to oscillate around the pertinent axis. Analysis of information on the longitudinal and vertical location of the center of gravity, location of the center of rotation, restraining spring constant, and the period of oscillation yields experimental values of the moments of inertia.

Simulation

As a means of supplementing the information obtained from flight tests, NASA ground-based electronic analog simulators will be used. Figure 8 is a photograph of typical simulator equipment that is available for this research. The simulator will be mechanized to provide input and response characteristics corresponding to those of the aircraft being studied. Individual stability characteristics can be changed at will, and the resulting flight characteristics can be correlated with pilot opinion. Thus, desirable or undesirable combinations of stability characteristics can be quickly determined with simulators without making extensive changes on the aircraft. The simulator research is expected to provide information from which recommendations on realistic means of improving IFR rough-air handling qualities can be formulated.

Autopilot Considerations

It should be noted that handling qualities not only influence pilot opinion but can also affect the design of autopilot and stability augmentation systems. In general, the simplicity and associated cost of an autopilot depend on the handling qualities of the vehicle being controlled. For example, consider divergent, neutral, and damped long-period altitude oscillations. Any of these types of oscillations are possible, depending on control-system friction, the type of control-surface aerodynamic balance, and the phugoidal mode.[5] Even divergent oscillations are rarely noticed by a human pilot (because of the long period and small amplitude of the oscillations) who automatically corrects for the variations in altitude. Although extremely simple autopilots will be able to control damped oscillations, they may have trouble maintaining constant altitude when controlling aircraft with neutral or divergent oscillations. They may even operate out of phase with the oscillation and, thus, increase the amplitude. Similarly, lightly damped lateral-directional oscillations, when excited by turbulent air, may be difficult to control with simple autopilots and may force the autopilot manufacturer toward more complex designs. Thus, aircraft handling qualities not only influence pilot impressions but can also affect the ease with which simple, low-cost autopilots can control an airplane. Consideration is being given in this research program to the influence of aircraft handling qualities on the design of autopilot systems.

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Concluding Remarks

The primary research objective of the NASA Flight Research Center's study of handling qualities of general-aviation aircraft is to formulate handling-qualities criteria pertinent to operations by solo pilots in an IFR rough-air environment. It is expected that the information obtained will lead to realistic means of designing to meet such criteria. The influence of aircraft handling qualities on the design of autopilots and stability augmentation systems is also being considered.

It is believed that this handling-qualities program will contribute significantly to the solution of some of the operating problems associated with general-aviation aircraft. The results of the program will be published for use by the industry in the design and developmental stages of future general-aviation aircraft. The Flight Research Center will, on occasion, request the assistance and cooperation of individuals in the industry. Comments from any segment of the aircraft industry will be welcome during the program.

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INSTRUMENTATION PACKAGE

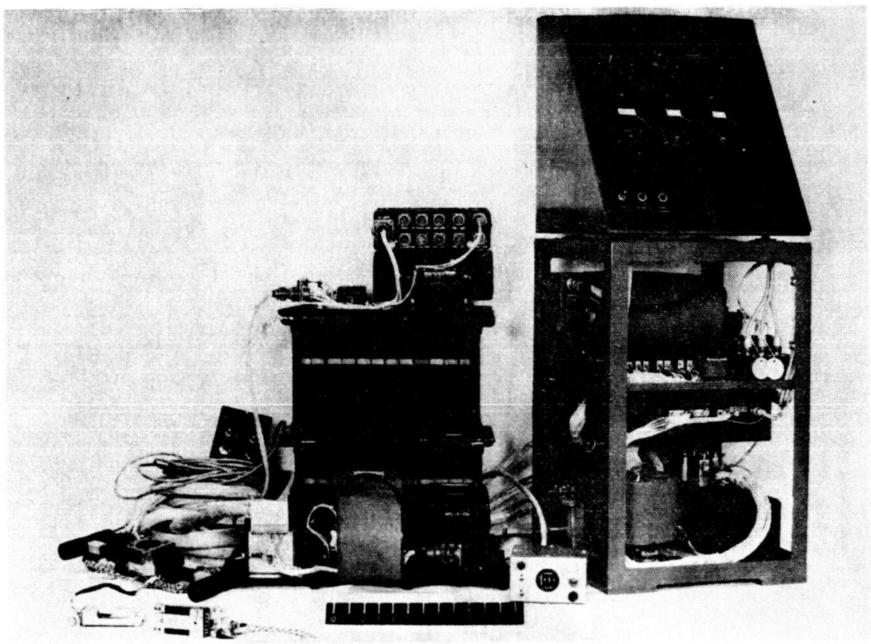

Figure 1

ACCELERATIONS DURING LONGITUDINAL OSCILLATION

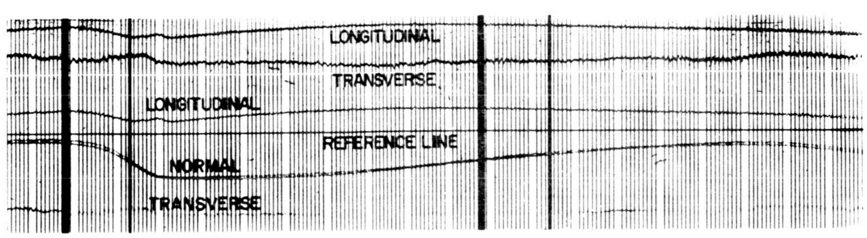

Figure 2

DUTCH ROLL

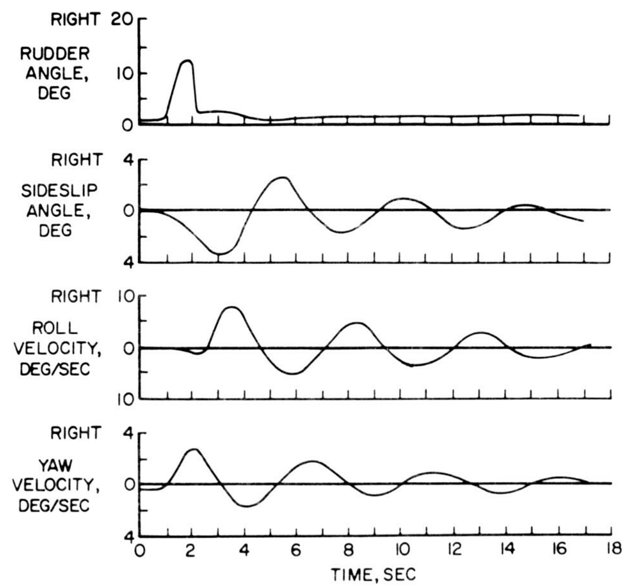

Figure 3

ILLUSTRATION OF STICK-FIXED AND STICK-FREE STABILITY

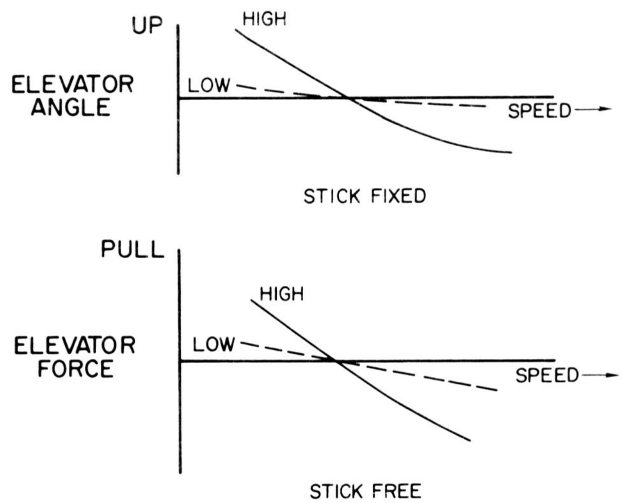

Figure 4

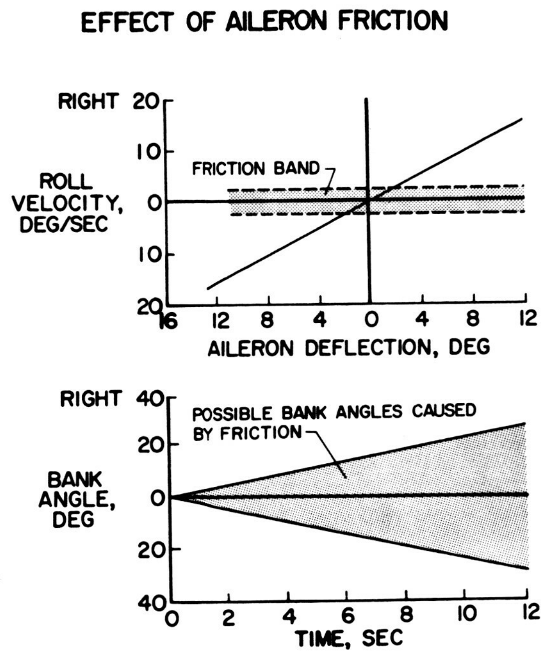

Figure 5

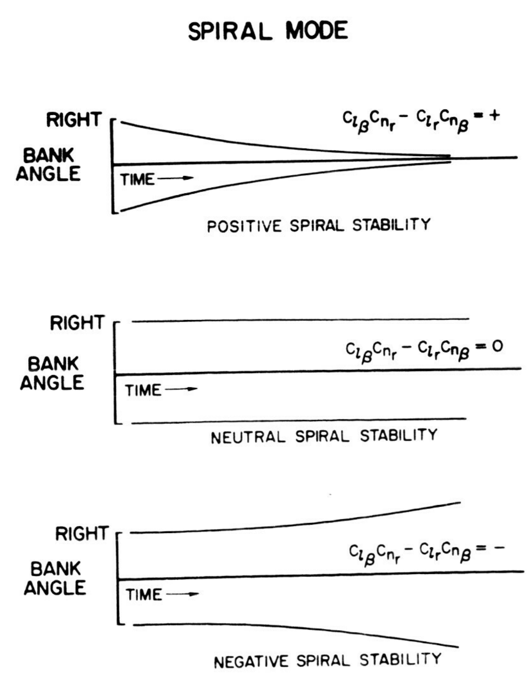

Figure 6

DETERMINATION OF MOMENTS OF INERTIA

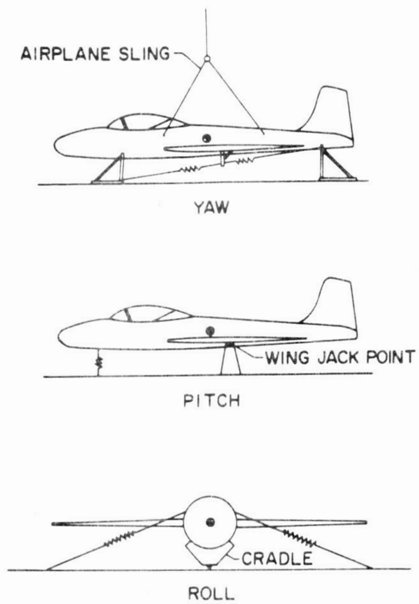

Figure 7

TYPICAL SIMULATOR EQUIPMENT

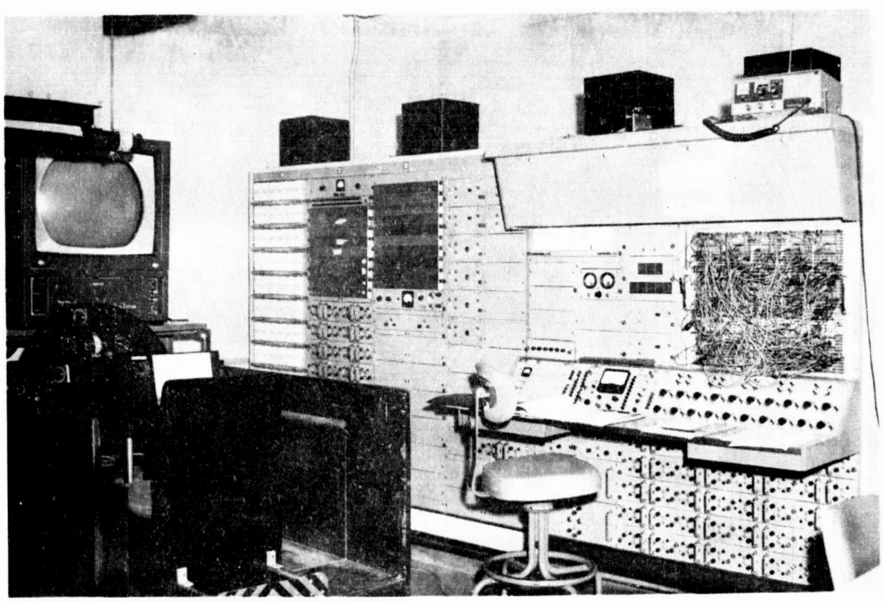

Figure 8