In-Flight Simulation for Training?

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Problems related to the training of pilots to fly future very large, high-performance commercial transports are discussed. It is shown that both safety and economics make the development of more effective flight simulation devices very important. The complementary use of ground-based and in-flight simulation appears to offer a training system for these new aircraft which may better satisfy these requirements than do existing systems. Areas of possible application of in-flight simulation are discussed. Contributions to the training of test pilots made by the use of variable stability airplanes are also discussed. The latter are based upon a number of years of actual experience in this type of training.

Introduction

MODIFICATION of the in-flight stability and control characteristics, or handling qualities, of aircraft has been performed by variable stability aircraft for nearly 20 years. This work has been done to determine handling qualities requirements, to experimentally examine theories or hypotheses that have been advanced relative to handling qualities requirements, or to evaluate in flight the expected characteristics of a specific airplane. With the exception of special demonstration training programs which have been a part of test-pilot school programs for the past eight years, in-flight simulation has not been applied to pilot training.

The variable stability airplane[1–8] contains special sensors and servo control equipment that modify the response of the airplane to the inputs, or commands of the pilot and also modify the response of the airplane when it is subjected to disturbances. The statics and the dynamics of these responses and the pilot's control force and displacement characteristics can be changed in flight by adjustment of the computer portions of the automatic control equipment. A safety pilot monitors the standard controls of the airplane and can at any time, and in a split second, deactivate the variable stability system and take control of the normal airplane in which the special equipment is installed. Therefore, it is possible to permit the evaluation (or trainee) pilot to experience flight conditions which are demanding enough that control may be lost, without a significant possibility that adequate control cannot be promptly regained.

The spectacular increases in the capabilities of commercial transport aircraft of the relatively near future are widely appreciated. Characteristics which are inherent in the very large subsonic transports (Jumbo Jets) and the supersonic transport (SST) are great size, great weight, and great speed. These characteristics yield the ability to move a large number of passengers a great distance in a short time. A satisfactory cost results when measured in cost per seat-mile of transportation supplied. The cost per flight hour, however, is another matter, and this will be unavoidably high. Since training is a function of flight hours in the aircraft rather than seat-miles per flight hour, the cost of pilot training in the actual vehicle will be high. Also, the flight characteristics of these very large, high-performance aircraft will undoubtedly differ from those of their predecessors, and the absolute need for safe and thorough crew training is so obvious that it scarcely needs stating. These factors make the importance of simulation for the crew-training program apparent and underscore the need for effective simulation methods which will provide the required training with a minimum of flight in the actual airline transport. In-flight simulation has characteristics that make it appear to be attractive for pilot training when integrated with existing simulation techniques. In fact, the complementary integration of ground-based and in-flight simulation may well yield the most effective simulation system for training which can be established. It must be stated at the outset, however, that thoughts regarding such a system are speculative. This precaution must be observed since in-flight simulation has not yet been used for pilot training, and since the form of an in-flight simulator which may be best suited to training is only now being developed.

Need for Improved Simulation Techniques

It may be argued that the requirement for operational safety is absolute, and that it is not a function of capital investment in a single airplane or of the number of passengers aboard a single airplane. This argument holds that the introduction of new, high-capacity, high-performance, and very expensive aircraft into airline service does not in itself increase the need for safety. It ignores the question of whether the accident record of the Jumbo Jet or the SST, when measured by conventional standards, must be appreciably better than current performance to offset public reaction to the loss of such large aircraft. The merits of this argument and question are not debated here. Rather the question considered here is: Given that safety standards must be maintained at least at existing levels, what are the consequences (in terms of safety and economics) of training pilots in the actual airline aircraft?

If flight training is conducted in the actual airplane and emergency flight conditions are reproduced, incipient loss of control by the trainee pilot must be checked early. Any violent maneuver, once commenced, must be stopped through the recovery characteristics of the airplane. By definition these characteristics are critical and, thus, one must either depend on the trainee pilots not slipping over the brink (which is an obviously poor assumption in the training situation) or else must depend upon the unfailing alertness and skill of the instructor pilots. Another solution is to stay well clear of the brink, but this is not consistent with good training and does not prepare for the day during actual operation when the emergency occurs.

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To this date, all airline in-flight training has been conducted in the actual transport aircraft. Moss[9] has examined, on a worldwide basis, all fatal accidents of jet transports operated by airlines during the time period between July 1958 and October 1966—a period of 8 years and 3 months. During that time a total of 46 airline-operated jet transports were lost in fatal accidents (16 of which were operated by U. S. carriers). Within these 46 accidents, nine (or essentially 20%) occurred during pilot-training operations. (Three of the 16 U.S. carrier accidents, again essentially 20%, occurred during pilot-training operations.) Moss estimates that only 3 to 4% of total hours flown were devoted to training. Thus, pilot training in existing jet transport aircraft has resulted in a disproportionately large percentage of accidents. These figures do not include one fatal accident which occurred to a nonairline-operated jet transport when emergency flight conditions were demonstrated to airline personnel (essentially training) and one other incident that resulted in major structural damage to an airline airplane during training operations but which did not result in fatality or destruction of the airplane. (It should be noted that several other cases of severe structural damage have occurred during nontraining flight operations by the airlines without fatality or destruction of the airplanes.) Finally, other crashes of airline jet transports have occurred since the cutoff time of Moss's study (October 1, 1966) and these have involved pilot training as well as regular airline operation.

It thus appears to be well established that the performance of pilot training in large, high-performance aircraft involves higher than normal risks. Moss concludes that, "Flight training procedures should be evaluated to equate their hazard to their contribution to line safety," and further states:

> In looking at training procedures, consideration should be given to the paradox that 6 of the 9 training accidents occurred under simulated engine-out conditions, yet not a single fatal accident on the line has been caused or contributed to by engine failure! The total abandonment of engine-out training or "cut guns on takeoff" is not advocated, but they should be done in a safe and sane manner with a full appreciation and minimization of the risks involved.

In other words, you must approach the brink to be sure that you recognize it and learn how to retreat from it. But, when you approach the real brink there is the possibility of a long fall. Therefore, don't approach the real brink more often than is necessary and then be well prepared to retreat.

The monetary equivalent of the loss of human lives and the loss of public confidence caused by training accidents defies calculation. The capital loss caused by the destruction of present-day jet transports at a cost of approximately $5 million each is another story. Still another story is the loss of a Jumbo Jet at approximately $20 million or an SST at $30 million. Clearly the insurance value alone justifies the cost of valid simulation methods that act as a substitute for some of the flight time in the actual transport and which better prepare the pilots for the final training they must undergo in the actual transport to demonstrate proficiency.

A pilot learns to fly an airplane, as contrasted to learning to operate and manage its many and complex systems, only by flying it. This statement is confirmed by the statements of pilots and of airline personnel responsible for pilot training. It is necessary to obtain an airplane that will fly like a large, high-performance transport, but which will give the pilot an opportunity to "back up" and try again.

Although safety during training operations makes consideration of improved simulation methods almost mandatory, economics leads to the same conclusion even if there were no significant possibility of aircraft damage during training. The direct operating cost per flight hour of the Jumbo Jet or the SST will considerably exceed the corresponding cost of operating existing jet transports. The direct operating cost of the SST, calculated by the Air Transport Association (ATA) formula, is approximately $4500 per flight hour, compared to about half of this for the Jumbo Jet and half of this again for the larger present-day jet transports.

Direct operating cost, however, may or may not be a reasonable representation of the cost due to flight operation to be charged to training. This cost contains certain "bookkeeping" charges—notably depreciation. It has been argued that such charges should not be made to training if this training use is small compared to the normal use and if it is made at a time when the airplane "has nothing else to do." Anyone who has had recent contact with airline training operations has learned 1) that the training load is up sharply and is expected to remain up and 2) that the airplanes which are used for training operations are less and less available on the basis that they "have nothing else to do." Rather, these aircraft have been withheld from revenue-producing service, to conduct training flights, which should produce the total operating cost (approximately twice the direct operating cost) plus gross profit. Thus, when operational aircraft are in short supply, the cost of using them for training may be more than double the direct operating cost. Furthermore, this situation produces pressures and uncertainties in the training schedule which reduce the effectiveness of the training operation.

Is the situation described a temporary one? Will it continue if line aircraft continue to be used as the sole method of in-flight pilot training? Possibly the most reliable answers to these questions can be obtained by examining the number of U.S. airline aircraft which are anticipated for the future. Most forecasts that were made shortly before the present decade predicted that the number of U. S. common carrier aircraft would remain approximately constant through 1975. A study performed for the special assistant to the president for Aviation Facilities Planning,[10] stated: "It is not expected that the domestic scheduled passenger aircraft fleet will contain more than approximately 1500 aircraft during the period 1956–1975; approximately 300 additional aircraft may comprise the U.S. international, airfreight and nonscheduled airline fleets."

Other studies placed the expected number of common carrier aircraft slightly higher, approximately 2000, and also forecast an essentially unvarying total number. Up to the present time these forecasts have been reasonably accurate. The Federal Aviation Agency (FAA) numbered the U.S. airline fleet at 2125 in 1966,[11] but predicts that this number will have increased to 3500 by 1977. This expanding requirement for airline aircraft attests to the probability that these aircraft will continue to be in short supply for at least the next 10 years and their use for pilot training must be priced on the basis of lost opportunity for revenue production.

It is concluded that on the bases of both safety and economics it is highly desirable, or perhaps even imperative, that improved flight simulation methods be developed so that the number of flight hours in future transport aircraft which would otherwise be required for pilot training may be reduced substantially.

Flight Simulation Methods

In-flight simulation offers the possibility of simulating the response characteristics, or handling qualities, of future transport aircraft in a completely realistic manner, in the actual flight environment. In general, this simulation can take either of two forms, 1) total in-flight simulation or 2) relatively simple variable stability aircraft. The objectives which are to be achieved determine which of these methods of in-flight simulation is to be preferred.

Total In-Flight Simulation

Total in-flight simulation (TIFS) is defined as simulation that combines the correct significant environment of the pilot

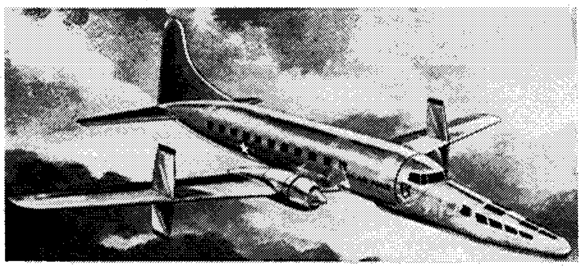

Fig. 1 In-flight simulator for supersonic transport.

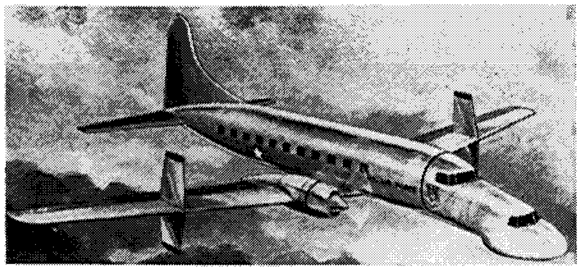

Fig. 2 In-flight simulator for Jumbo Jet.

with the correct sensations of flight. The environment is provided by placing the pilot (or pilots) in a cockpit that has the proper flight controls, instruments, and external vision. The sensations of flight, which must include accelerations and motions due to the pilot's commands and to disturbances, are achieved by making this cockpit a part of an airplane which responds in the required manner to the pilot's commands and to disturbances. The proper response of the airplane is achieved by the variable stability principle.

An example of TIFS which is presently being developed for the Flight Dynamics Laboratory of the U. S. Air Force, with the participation of the FAA, is shown in Figs. 1 and 2. Two different types of cockpits is shown in these figures—the first simulating that of an SST and the second (which is not presently being built) that of a Jumbo Jet. These cockpits include those portions which would be visible to the pilots from the flight deck, and also include the flight instruments and controls that are important to the pilot's control task. The cockpits will be removable so that either can be fitted to to the same basic airplane. The safety pilots occupy the essentially unmodified cockpit of the basic airplane. The variable stability system contains computers whose programming can be changed to permit simulation of various aircraft. The control systems will operate not only the three normal control surfaces (elevator, aileron, and rudder) but also the thrust (or drag), wing flaps for direct control of lift, and specially installed vertical surfaces on the wings for direct control of lateral forces. With independent control of forces and moments, the airplane can be made to fly as if the distance between the trainee pilot's seat and the center of gravity were that of the airplane being simulated, even though the effective position of this center of gravity is well behind the tail of the basic airplane used for the simulator. This produces the proper motions at, and view from, the trainee's cockpit, and means that the TIFS will fly as the forward portion of the airplane being simulated. This is shown on Fig. 3, which illustrates the simulation of a landing. Further description and discussion of the TIFS is contained in Refs. 12–15.

The use of TIFS should permit very excellent simulation of a particular airplane, with handling qualities, vision, cockpit controls, and cockpit display of flight instrumentation all reproduced. Its use should reduce the amount of flight time that will be required for final training in the actual line aircraft.

Simple Variable Stability Airplane

The simple variable stability airplane does not include the separate cockpit of the TIFS, and its variable stability equipment is more rudimentary than that of the TIFS. It would not include direct control of lift or lateral forces, although it might include control of thrust or drag. Thus, it would not be able to accurately reproduce such effects as those produced by large separation between the pilot and the center of gravity. Rather, it would be capable of producing motions of the same general nature as those of large airline aircraft, but it would not truly reproduce these motions. Nor would it reproduce the cockpit view and general environment of these aircraft. This form of in-flight simulation would make it possible to expose trainee pilots to a wide variety of response characteristics and to prepare them for the types of handling qualities which they will experience in large transport aircraft. This concept is similar to the "advanced trainer" concept of the military services which train with airplanes that are lighter and less expensive than the operational airplanes, but which have similar flight characteristics. Reduction in flight time requirements in the actual line aircraft would then result from the generally improved familiarity of the trainee pilots rather than from directly transferable experience.

Interrelationship of In-Flight and Ground-Based Simulation

Ground-based simulators make highly valuable contributions and are necessary for efficient training in the operation and management of the many systems of modern airplanes. The complexity of these simulators has been increased in an effort to simulate more realistically the flight characteristics of aircraft. One of these increases of complexity has been the introduction of limited motion to the cockpit. Evaluation of the effectiveness of this addition is difficult, but examination of various programs which have utilized different schemes of limited motion[8] has led to the conclusion that all of these systems fall appreciably short of correctly reproducing the true sensations of flight. It is believed that a more satisfactory solution may consist of utilizing in-flight simulation for those aspects of training which are concerned with control of the airplane and using ground-based simulation for systems management training. This question was considered several years ago,[4] and excerpts from that paper still seem generally applicable to a proper distribution of effort between ground-based and in-flight simulation:

> Although in-flight methods offer a means for realistically and accurately simulating the flight-control characteristics of aircraft, there is no suggestion that this type of simulation would lessen the need for conventional ground-based simulators. Rather, these two methods of simulation should be considered to be complementary. There are many areas of flight simulation where existing methods are, and will continue to be, superior to either in-flight simulation or flight in the actual airplane.
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> Ground-based simulation is naturally well adapted to simulating the management of the many complex mechanical, electrical and hydraulic systems that will be a part of the SST. Economy and the ability to simulate failures that should not, and probably could not on a controllable basis, be experienced in flight make ground simulation the clearly preferred method in this area. This method of simulation is also the logical one for tasks which involve the management of the performance capabilities of the airplane. These would include operation of the airplane in accordance with planned flight profiles, traffic control procedures, cruise control and coping with changes to these preplanned procedures. Crew integration training can probably best be performed in ground simulators, since this integration involves the establishment of proper coordination between pilots and flight engineer in the management of the many mechanisms and systems of the airplane, rather than the actual control of the flight path of the airplane.
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> It is in the area of the control of the attitude and flight path of the airplane that the ground simulator is least realistic and accurate and the in-flight simulator is best suited. This is because the multitude of ill-defined, but nonetheless important, cues which are combined by the pilot are automatically present during in-flight simulation, but these are difficult to synthesize realistically for the ground-based simulation. Furthermore, the synthesis of the pilot's cues implies that all of the important cues and their

interrelationships are known and can be quantitatively specified. This is certainly a dubious assumption.

The inadequacies of the flight dynamics of conventional ground-based simulators are due primarily to the limitations imposed upon these simulators by their environment, and the necessity that they portray long-term parameters (such as performance and the operation of many complex systems) imposes too many requirements upon them. Their complexity is increased greatly by their attempt to duplicate the detailed control characteristics of the airplane. If this area were left to the in-flight simulator, the ground-based simulator could be simplified.

Cost and Reliability

The cost and reliability of in-flight simulation are, of course, highly relevant questions. Since total in-flight simulation does not yet exist and, since no form of in-flight simulation has yet been applied to the type of pilot training program considered here, accurate figures for cost cannot yet be stated. Total in-flight simulation will inevitably cost more per flight hour than will simulation in a more simple variable stability airplane, and both of these methods of simulation will be more expensive than the same number of hours of ground-based simulation. This is not the proper comparison, however, because the important question is—how many flight hours can be saved in the actual transport? The cost per flight hour of in-flight simulation will be much less than the cost of operation of the line aircraft. Another important factor is the thoroughness and quality of the training achieved.

Although the over-all reliability of the in-flight simulator may be questioned because of the large amount of airborne electronic and hydromechanical equipment which it includes, experience has proven this equipment to be remarkably reliable. This will be discussed relative to actual experience with existing variable stability aircraft at a later point.

Flight Conditions for In-Flight Simulation

In-flight simulation can be applied most advantageously to flight problems that require control of the attitude and the immediate flight-path direction of the airplane during both normal and emergency flight conditions. During normal flight conditions, in-flight simulation permits the pilot to experience the response of the airplane to his commands and to the forces he must exert to execute these commands. Similar information is obtained during emergency flight maneuvers with the important additional advantage of greatly improved safety compared to practicing the same emergency conditions in the actual airplane. The latter advantage exists, of course, because the safety pilot can disengage the variable stability equipment of the in-flight simulator at any time and take control of the basic airplane used for this simulator. Thus, provided that this basic airplane has desirable control characteristics, recovery can be made from substantial upset positions (although it is not necessary to permit the motion to grow to upset proportions before the safety pilot assumes control).

Emergency flight conditions can include rapid encounter of asymmetric power (either at low speed, as during takeoff or landing approach, or at high speed, as during supersonic cruise), failure of stability augmentation equipment, failure of basic control systems (such as jammed stabilizer or runaway trim), failure of variable sweep or other variable geometry, or other similar problems.

It is not necessary that the speed of the TIFS match that of the airplane being simulated, provided that the latter does not perform large departures from a given flight line. The flaps and side-force surfaces of the TIFS permit simultaneous matching of translational accelerations and rotational velocities and accelerations for limited departures from the initial flight path even though the speeds of the simulator and the simulated aircraft are not matched. This should be adequate to familiarize the trainee pilot with the handling qualities of the airplane during high-speed cruise. Large course

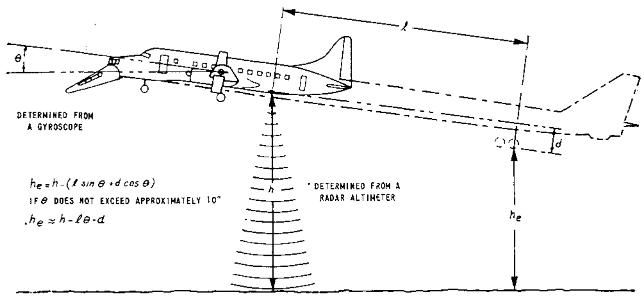

Fig. 3 In-flight simulation of landing.

corrections are a part of navigation training, air traffic control, or cruise control. Such problems are not primarily concerned with handling qualities and can best be undertaken in ground-based simulation equipment without consideration of the short-term dynamics of the airplane.

Limitations on amplitude of maneuvering with respect to the earth disappear, of course, when the speed of the simulator matches that of the simulated airplane. It is expected that no difficulty will be experienced in matching the speed of all future transport aircraft for terminal-area operation. Within the terminal area the airplane must be maneuvered in relatively rapid sequence over fixed points on the ground. It is important that the space-time profile be reproduced as the airplane is maneuvered with respect to terminal-area navigation aids and air-traffic-controller instructions.

It is anticipated that the substantial majority of in-flight simulation would be performed in terminal-area work. Airline experience indicates that most flight-training work is conducted during low-speed, low-altitude flight in the vicinity of airports. A great deal of flight training is carried out during various landing approaches and immediately after takeoff. The importance of training in these areas is confirmed[9] by the fact that, in the time period considered, 54% of all fatal accidents of airline-operated jet transports occurred during landing approaches. Takeoff and landing combined account for 76% of all of these accidents. It is believed that in-flight simulation can be particularly effective for these conditions, for the pilot will not only experience the correct flying qualities and sensations of flight, but he will also see the real world without improper curtailment of view.

Actual Use of In-Flight Simulation for Pilot Training in Test-Pilot Schools

The same qualities that make the variable stability airplane such a useful tool in handling qualities research also make it a superb piece of laboratory equipment for teaching stability and control and handling qualities. The idea of using the variable stability airplane as a teaching device arose in the course of a research project for the navy. A trial course, presented in 1960 at the U.S. Naval Test Pilot School at Patuxent River, Md. proved successful and for the past eight years the variable stability presentation has been an integral part of the curriculum. In addition, it has been presented since 1962 in courses for engineering pilots of the FAA and since 1963 to the Air Force Aerospace Research Pilot School. A small number of pilots of aircraft manufacturers have also received this training. To date, 700 pilots have received various versions of the demonstration program. This work has provided a large body of experience in using in-flight simulation as a training tool on an intensive, scheduled basis, and a review of it provides information on the practicality of in-flight simulation in other training tasks.

Using the Variable Stability Airplane in Test Pilot Training

The variable stability program supplements academic training in stability and control, and instruction in flight test technique given in other airplanes at the schools. The variable stability airplane is used in several ways listed below.

1. *Separation of variables*

The instructor can dissect a complex motion and examine the constituents of the motion and the interaction of them. This permits subsequent recognition of these components in the over-all motion of another airplane. Separation of the variables and exaggeration for emphasis are useful in showing how the theory developed in the academic courses really does describe the motion of the airplane.

2. *Exaggeration*

The instructor can make the airplane exaggerate some aspect of the motion for emphasis. For example, if he wishes to show the effect of adverse yaw, he can set in an exorbitant amount of adverse yaw so the student can see the effect clearly. Then, as the adverse yaw is gradually returned to normal, the student can see what might be a subtle effect, because now he knows what to look for.

3. *Examination of poor characteristics*

The stable of airplanes at the schools consists of ordinary military airplanes, all of which are at least reasonably acceptable. The variable stability airplane permits examination of poor characteristics to see why they are avoided. The pilot can also experience considerable departures from ordinary handling qualities and thus be better prepared as a test pilot when he encounters an airplane that handles quite differently from the ones he is used to.

4. *Examination of boundaries of specifications*

The stability characteristics representing boundaries in military or civil specifications can be examined, and the consequences of exceeding these boundaries can be evaluated in flight. The test pilot thus can appreciate the reasons for the boundaries and the limitations of our knowledge of some of them.

5. *Practice evaluation*

Different sets of handling qualities can be evaluated in the performance of some task. The instructor can teach methods of approaching, evaluating, and reporting upon unknown stability characteristics, and he can also alter aspects that the pilot thought were important, to show whether they were, in fact, the important contributors.

Content and Point of View of the Variable Stability Presentation

The presentation to the student test pilots emphasizes dynamics of the airplane. Static stability is covered adequately by other means at the schools, and the variable stability equipment lends itself to a clear presentation of dynamic effects which are very difficult to show effectively without this equipment. Some interesting static effects, such as neutral static longitudinal stability, which can be produced easily by the variable stability equipment, are included in the presentation.

The instructor-pilot is an engineer-pilot, currently active in research work on dynamic stability and handling qualities. He is, therefore, able to discuss authoritatively the subject matter of the presentation. During the flight presentation, the instructor emphasizes the following points while the student test pilot is actually experiencing the handling qualities in question:

1. *What is the airplane doing?*

The motion of an airplane is quite complicated, and it is often difficult for the pilot to analyze just what is going on, even though he may not have any difficulty in controlling the airplane. The variable stability equipment allows the instructor to show simplified and exaggerated versions of the motion, and also to show interactions, to clarify for the pilot what the motions actually consist of, i.e., what the airplane is really doing.

2. *Why is it doing it?*

The instructor points out the physical factors producing the motion and relates the observed motion, described in "pilot talk" as the pilot sees it, to the theory developed in the academic courses. The aim here is to show that the complex motion of the airplane can in fact be described successfully by the mathematical treatment, which otherwise may seem very remote to the pilot.

3. *Is the motion good or bad?*

The question of what the motion is and what causes it is quite different from the question of whether that motion enhances or complicates the pilot's ability to perform some given task. The latter question can be taken out of the realm of conjecture and ready-room discussion by letting the pilot perform the task with the handling qualities in question. By changing appropriate handling qualities in the variable stability airplane, the instructor can resolve, on the spot, errors in observation or misinterpretation by the pilot. By considering more than one task, the importance of the task can be pointed out, i.e., handling qualities that are good for one task may not be good for another.

4. *What is the physical explanation?*

In the discussion of the aforementioned three points, the emphasis is always on the physical explanation of what the airplane is doing and what the pilot must do to control it. Theory is related to the motion to show that the theory is valid and useful in discussing the motion, but this is done in terminology familiar to the pilots. The instructor points out the difference between the open-loop characteristics (What does the airplane do?) and the closed-loop characteristics (What does it do when I control it?) and how the open-loop characteristics affect the closed-loop characteristics.

Content of the Syllabus

Control of the variables that affect the motion of the airplane permits selection of a practically unlimited number of stability characteristics. The number of sets of characteristics which can be presented must be restricted to keep the flight demonstration to a length that fits into the curriculum, and also to avoid presenting so much information that the pilot cannot absorb it all. The following ideas govern the selection of the characteristics and the order of presentation in the syllabus.

1. *The modes of the motion—the important characteristics*

The pilot sees and feels the motion as a whole. The mode descriptions (period, damping ratio, time constants, amplitude ratio, phase) are convenient and succinct, and can be related to the motion as the pilot sees it. A stability-derivative approach has technical justification, but the effect of a given derivative depends upon the size of the other derivatives present. In any case, the pilot sees the motion that a given set of derivatives cause, not the derivatives themselves. The syllabus was, therefore, set up with the modal characteristics as the prime variables.

2. *Modal characteristics can be studied separately*

To show the effect of an individual modal characteristic, the other modal characteristics are held constant, while that one is varied. Then it is held constant while another is varied. For example, longitudinal short-period and stick-force gradients are held constant while the damping ratio is varied, and so on. After the individual effects are understood, interactions are shown, i.e., the effect of variation of one characteristic upon the appearance and importance of variations in another.

3. *The difference between knowledge of a characteristic and its importance to the pilot*

The explanations and test maneuvers which are part of the presentation are selected to keep the student always aware of this difference. Some characteristics are presented which are easy to distinguish, but which are equally usable by the pilot, and this fact is pointed out explicitly.

These considerations have led to a syllabus, worked out jointly by the test pilot schools and Cornell Aeronautical Laboratory (CAL). Variations in the syllabus have been produced for special purposes. The basic syllabus, outlined below, is presented in three two-hour flights for each pilot.

Longitudinal motion: changes in short-period dynamics (period and damping); changes in stick forces and friction; and neutral and negative static stability.

Lateral-directional motion: changes in Dutch roll dynamics (period, damping, and roll-to-yaw ratio); effect of yaw due to aileron on controllability, for differing Dutch roll characteristics; changes in roll mode; changes in spiral mode; lateral and directional static effects; and changes in control harmony.

Application of the Test-Pilot School Experience to Other Training Use of In-Flight Simulation

The presentation which is being given at the test-pilot schools is an example of an existing, real-life training mission that is currently being performed by variable stability airplanes. It is an example of a suitable use of limited variable stability equipment. Because the object of the program is to provide generalized training for understanding, rather than training in the operation of a specific airplane, there is no particular need for the exact simulation of a specific airplane which can be provided by a TIFS. No attempt is made in the school operation to simulate a given airplane, although characteristics typical of a given airplane or class of airplanes are pointed out as they are encountered.

The variable stability program has been in test-pilot school operation for eight years, long enough to provide some information on the reliability of variable stability equipment in day-to-day use. The airplane is scheduled for two flights per day every weekday for seven weeks, or for four flights per day for four weeks, depending upon the schedule desired by the particular school. This schedule has been met with generally better than 95% availability of the airplane and its equipment. Some lengthy sessions have been performed with 100% availability. The variable stability equipment has seldom interfered with this schedule, and as a trouble-maker, it is rated behind the airplanes themselves and the normal radio equipment. An indication of the reliability of the equipment is given by the fact that a normal field crew for the variable stability operation consists of an instructor-pilot and an airplane mechanic; no electronics technician is needed for regular servicing.

The test-pilot school experience also provides information on some operational points that bear upon other uses of in-flight simulation. For example, very little time is required for the student to accept, understand, and make use of the variable stability concept. A few minutes after the start of the first flight, the student is profitably engaged in learning. Demonstration of marginal characteristics is feasible, productive, and safe. Every student flies the airplane with negative static stability, very difficult Dutch roll combinations, severe friction, and so forth. It is easy and safe for the safety pilot to resume control after letting the student carry a difficult situation quite far. For example, in the Navy program, each student makes approaches with a mirror landing aid (the "meatball") with normal, neutral, and negative static stability. The landing gear on the test airplane is not stressed for mirror touchdowns, so the instructor takes control of the airplane at altitudes as low as 2 ft. This is a safe and orderly operation and has been performed hundreds of times.

In summary, the variable stability airplane performs a useful function in the training of test pilots, a function that cannot be performed as effectively by any other means. Enough experience has been gained in this operation to give confidence in the application of in-flight simulation to other types of training.

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