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FLIGHT TEST PILOT EVALUATION OF A DELAYED FLAP APPROACH PROCEDURE

J. S. Bull, F. G. Edwards, J. D. Foster,
D. M. Hegarty, and F. J. Drinkwater, III

Ames Research Center
Moffett Field, Calif. 94035

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J. S. Bull, F. G. Edwards, J. D. Foster,
D. M. Hegarty, and F. J. Drinkwater, III

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Using NASA's CV-990 aircraft, a delayed flap approach procedure was demonstrated to nine guest pilots from the air transport industry. Four demonstration flights and 37 approaches were conducted under VFR weather conditions at the Sacramento Metropolitan Airport. A limited pilot evaluation of the delayed flap procedure was obtained from pilot comments and from questionnaires they completed. Pilot acceptability, pilot workload, and ATC compatibility were quantitatively rated. The delayed flap procedure was shown to be feasible and suggestions for further development work were obtained.

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FLAP APPROACH PROCEDURE

J. S. Bull, F. G. Edwards, J. D. Foster, D. M. Hegarty,
and F. J. Drinkwater, III

Ames Research Center

SUMMARY

The conventional jet transport instrument landing approach procedure requires high thrust settings for an extended time; the accompanying noise levels are undesirable and fuel consumption is relatively high. Ames Research Center investigated the so-called "delayed flap" approach concept, a landing procedure designed to reduce noise and fuel consumption. In the delayed flap approach, the approach is started at a high airspeed and low drag configuration and is flown along the conventional ILS glide slope. With the engines set at low thrust, the flaps and landing gear are lowered at the appropriate time so that the airspeed slowly decreases to that desired at a desired point from touchdown.

Using NASA's CV-990 aircraft, a delayed flap approach procedure was demonstrated to nine guest pilots from the air transport industry. Four demonstration flights and 37 approaches were conducted under VFR weather conditions at the Sacramento Metropolitan Airport. A limited pilot evaluation of the delayed flap procedure was obtained from pilot comments and from questionnaires they completed. Pilot acceptability, pilot workload, and ATC compatibility were quantitatively rated. The delayed flap procedure was shown to be feasible and suggestions for further development work were obtained.

INTRODUCTION

The conventional jet transport instrument landing approach procedure, which requires high thrust settings for an extended time, is accompanied by undesirable noise levels and relatively high fuel consumption rates. Significant reductions in both noise and fuel consumption can be gained through careful tailoring of approach flight path and airspeed profile. For example, the two-segment approach, which brings aircraft in at a steeper angle initially, can reduce noise because it requires lower thrust settings and higher approach altitudes. However, proposed implementation of two-segment approach procedures has met with some objections; for example, those concerned with wake vortex encounters.

In an effort to overcome such objections, Ames Research Center investigated the so-called "delayed flap" approach concept. The approach is started at a high airspeed and in a drag configuration that allows for low thrust, and the aircraft is flown along the conventional ILS glide slope. Continuing the approach at low thrust to reduce noise and fuel consumption, the flaps and landing gear are then lowered at an appropriate time that permits the airspeed to decrease slowly to that desired at a desired distance from touchdown.

Flight tests of the delayed flap approach were conducted in a typical medium body, four-engine jet transport. This paper describes the delayed flap approach, discusses pilot displays and procedures, and presents the results of a limited pilot evaluation of the procedure. Fuel conservation and noise abatement benefits of the delayed flap approach are given in references 1 and 2.

TEST AIRCRAFT DESCRIPTION

The pilot evaluation test of the delayed flap concept was conducted in NASA's CV-990 jet aircraft (fig. 1). The CV-990 is a swept-wing-and-tail aircraft with four GE CJ805 jet engines with aft fans; it is representative of the DC-8 and B-707 commercial jets. Maximum takeoff weight is about 114,760 kg (253,000 lb) and maximum landing weight is about 91,630 kg (202,000 lb). Typical landing weights range from 72,580 kg (160,000 lb) to 81,650 kg (180,000 lb).

The aircraft is equipped with the digital avionics system (DAS), which is an integrated flight director/autopilot system. The DAS provides all of the conventional autopilot modes as well as an autoland capability. Additionally, the DAS performs the computations and provides the commands to the pilot that are necessary for flying the delayed flap procedure in a consistent manner. A functional description of the DAS is given in references 3 and 4.

TEST DESCRIPTION

Four demonstration flights were flown; two or three of the nine guest pilots participated in each flight. A total of 29 delayed flap approaches (26 coupled, 3 flight director) were flown into the Sacramento Metropolitan Airport. In addition, eight other approaches of various types were flown for comparison purposes. Weather conditions were VFR with winds generally less than 12 knots; there was occasional light turbulence.

The nine pilots who participated in flight tests represented the following organizations: United Airlines, American Airlines, ALPA, ATA, FAA, Boeing, Douglas, and Lockheed. With the exception of two pilots from ALPA, each organization was represented by one pilot. Pilots from Ames Research Center acted as demonstration and safety pilots.

Guest pilots were given a 2-hr preflight system briefing, followed by a 3-hr flight and a 1-hr debriefing. Each participating pilot flew three to five approaches from the right seat and observed three to five approaches from the observer's seat. Flight tests were conducted at the Sacramento Metropolitan Airport, a low traffic density airport; weather conditions were generally "good." After debriefing, the pilots were asked to fill out a questionnaire about their flight. General subjects covered in the debriefings and questionnaire were pilot acceptability, pilot workload, displays, and ATC compatibility. Six of the nine pilots used the questionnaire to evaluate the approach procedure, and the other three prepared a separate written flight test evaluation.

An airborne digital data acquisition system (ADDAS) is installed on the CV-990 for the purpose of recording desired flight test data. Selected data for real time analysis can be output on line printers and strip chart recorders that are aboard the test aircraft, and post-flight test analysis can be conducted using data recorded on magnetic tapes during flight.

DELAYED FLAP APPROACH PROCEDURE

Typical Approach Profile

Figure 2 shows a diagram of a typical delayed flap approach. In contrast to a conventional approach, which is flown at a constant airspeed of about 150 knots and at high thrust settings throughout the approach, the delayed flap approach begins at a higher initial airspeed, 240 knots, and decelerates at idle thrust through most of the approach. The pilot intercepts the ILS glide path about 10 n.mi. from touchdown and at an altitude of 914 m (3000 ft) altitude. He then retards the throttles to the idle detent and begins a slow deceleration. At about 6 n.mi. and 230 knots, the pilot is given a command from the avionics system to lower the landing gear. At about 5 n.mi. and 220 knots, a command is given to lower approach flaps; the command to lower flaps to the landing position at about 4 n.mi. and 200 knots. The aircraft then decelerates to final approach airspeed at an altitude of 152 m (500 ft) at which point the pilot advances the throttles to approach power and the last portion of the approach is flown at a stabilized airspeed similar to that of a conventional approach. In headwinds, extension of landing gear and flaps is delayed; in a tailwind, they are extended farther out in the approach. Thus, regardless of wind conditions, the aircraft is always stabilized for landing at an altitude of 152 m (500 ft), which is consistent with current airline procedures.

Cockpit Displays

Figure 3 shows the CV-990 cockpit and the displays used in making a delayed flap approach. In addition to the normal instruments there is a fast/slow indicator, a message display, and a data entry keyboard.

The fast/slow display, commonly used in most current jet transports, is a "how-goes-it" display to tell the pilot how the aircraft is decelerating relative to the desired airspeed schedule. This is very similar to the way a fast/slow display is normally used; that is, to show the pilot his airspeed error from the reference landing airspeed. In a delayed flap approach, the pilot uses configuration changes as the aircraft decelerates to null the fast/slow "donut," which allows him to leave the throttle at idle until the desired airspeed stabilization point is reached. The fast/slow display drive signal includes energy compensation in the form of altitude error from the desired glide path. This renders the "donut" motion less sensitive to tracking errors and results in a very smooth and uncompelling display concept.

The message display signals the pilot when to extend the landing gear, approach flaps, and landing flaps. The proper timing of signals is accomplished by an on-board digital computer. In essence, the computer predicts the manner in which the aircraft will decelerate during the approach to landing, taking into account the wind. Based on this computed deceleration, the computer flashes a command on the message display to signal the pilot when either the flaps or gear is to be lowered. When the pilot takes the commanded action, the display goes blank until the next extension of gear or flaps is to be made. All this is accomplished in such a way that the aircraft arrives at the final approach airspeed at precisely the desired point from touchdown.

The data entry keyboard is used by the pilot prior to an approach to enter certain required data into the on-board computer. The required data entries are: (1) runway selection; (2) aircraft gross weight, (3) desired landing flap position; (4) desired deceleration engine setting; and (5) desired altitude for airspeed stabilization. A separate keyboard button is provided for each entry and the data entered is displayed on the message display. Nominally the engine setting is for idle thrust and the airspeed stabilization altitude is set for 152 m (500 ft).

RESULTS AND DISCUSSION

Test Conditions

The following conditions should be considered in assessing these results of the delayed flap approach flight tests: (1) a limited number of pilots participated, (2) a limited number of approaches were flown, and (3) operational flight conditions were undemanding. Nine guest pilots participated, flying a total of 37 approaches into a low density traffic airport in generally good weather conditions. The general purpose of the test was to evaluate the feasibility of the delayed flap concept and to obtain developmental direction. A subsequent study was made of the concept's application to the Boeing 727 jet transport; that work is described in references 5 and 6.

Pilot Acceptability and Workload

Guest pilots were asked in the questionnaire to rate the overall pilot acceptability of the conventional approach and the delayed flap approach; the results are shown in figure 4. The conventional approach received an average pilot acceptability rating between "good" and "excellent," with ratings ranging from a low of "good" to a high of "excellent." The very small variance of these ratings reflects the generally widespread pilot opinion of the desirability of a "stabilized" approach.

The delayed flap approach received an average pilot acceptability rating between "fairly good" and "good" with ratings ranging from a low of "minimal acceptability" to a high of "excellent." Even though the average rating of this new concept was high, there is a wide range of pilot opinion on the desirability of a destabilized approach.

The test pilots were also asked to rate the difficulty of the overall pilot workload imposed by the delayed flap approach relative to that of the conventional approach. The results are shown in figure 5. The average rating of pilot workload in the delayed flap approach was between "same" to "little easier" with ratings ranging from a low of "much more difficult" to a high of "easier." The generally good weather conditions and low traffic density were probably significant factors in the pilot workload being rated no more difficult than that of a conventional stabilized approach. Under poor weather conditions and with increased traffic, it would be likely that the destabilized approach would be rated as requiring a greater pilot workload than that indicated here.

Comments by the test pilots indicated that a desirable feature of the delayed flap approach was being coupled to the ILS glide slope (pointed at touchdown spot) and being able to revert easily to a conventional approach if the situation so dictated. They also said that the high airspeeds and deceleration during the delayed flap approach would not affect pilot acceptability but would make the procedure difficult to implement in the present ATC environment (see below).

ATC Compatibility

Guest pilots were asked in the questionnaire to rate the difficulty of operational implementation of the delayed flap approach into the ATC environment compared to that of a conventional approach; the results are shown in figure 6. ATC compatibility recieved an average rating between "little more difficult" and "same" with ratings ranging from a low of "more difficult" to "little easier." Subjective comments by the pilots indicated a much greater concern for ATC compatibility than did their quantitative ratings. Their concern was based on the difficulty controllers would have in suitably spacing aircraft, which might have significantly different approach airspeed profiles, to avoid overshoots and underruns, particularly in high density traffic airports.

Displays

Guest pilots were asked in the questionnaire "Was the information presented on the fast/slow display (energy management donut) clear and useful throughout the approach?". There was virtual unanimous agreement that the display was unambiguous and easy to interpret. Some of the desirable features mentioned were: that it gave the pilot a quick status check without being compelling; that donut motion was very smooth without abruptness; and that the fast/slow display was a convenient display to use. It was suggested, however, that the energy indicator might be enhanced, enlarged, or relocated as another instrument.

Guest pilots were also asked in the questionnaire "Did you find the status message display distracting or helpful and in what way?". A typical response was: "The message readout was excellent and should be further evaluated as a failure monitoring and warning system.". Favorable guest pilot response to the status message display can be attributed to its visibility in the cockpit and its easy-to-read alpha-numerics.

Delayed Flap Airspeed Stabilization

An important measure of system and pilot performance during a delayed flap approach is the consistency and accuracy with which airspeed is stabilized at V_{ref} at the desired altitude (HMIN) regardless of gross weight and wind conditions. Figure 7 shows the standard deviation airspeed profile for the 15 delayed flap approaches that were flown to an HMIN of 152 m (500 ft) by the nine participating pilots. The target airspeed at 152 m (V_{ref}) ranged from 143 knots to 154 knots and corresponded to gross weights ranging from 74,840 kg (165,000 lb) to 85,370 kg (188,200 lb). VFR weather conditions existed on all approaches with winds ranging from 8-knot tailwinds to 12-knot headwinds. Light turbulence was present on 6 of the 15 approaches.

The standard deviation airspeed envelope from an altitude of 152 m (500 ft) down to final flare 15 m (50 ft) was never more than 8 knots faster or 3 knots slower than V_{ref}. These data evidence good accuracy and consistency in airspeed stabilization considering the variation in gross weight of 9,530 kg (21,009 lb) and winds varying up to 20 knots. The guest pilots indicated that airspeed stabilization was achieved smoothly and without great difficulty.

CONCLUSIONS

A flight test to permit pilot evaluation of the delayed flap landing approach concept was conducted using NASA's CV-990 jet aircraft. Nine guest pilots participated and flew a total of 37 approaches in a low traffic environment with generally good weather conditions.

The following conclusions were derived from pilot responses to questionnaires and from comments made during debriefings:

1. Pilot acceptability of the delayed flap approach was given an average rating between "fairly good" and "good"; the conventional approach was rated from "good" to "excellent."

2. Pilot workload of the delayed flap approach compared to that of a conventional approach was rated between "same" and "little easier."

3. ATC compatibility of the delayed flap approach compared to that of a conventional approach was rated between "little more difficult" to "same." Guest pilot comments indicated greater concern for ATC compatibility than did their quantitative ratings.

4. An energy management display concept was evaluated using the standard fast/slow indicator and found it to be "useful and easy to interpret."

5. A status message display concept was evaluated and found to be excellent as a message readout; it was recommended for further evaluation as a failure monitoring and warning system.

The following conclusion was derived from flight test data analysis, as well as from guest pilot comments: airspeed decay during the delayed flap approach was accurately and consistently stabilized at V_{ref} at the desired stabilization altitude without difficulty.

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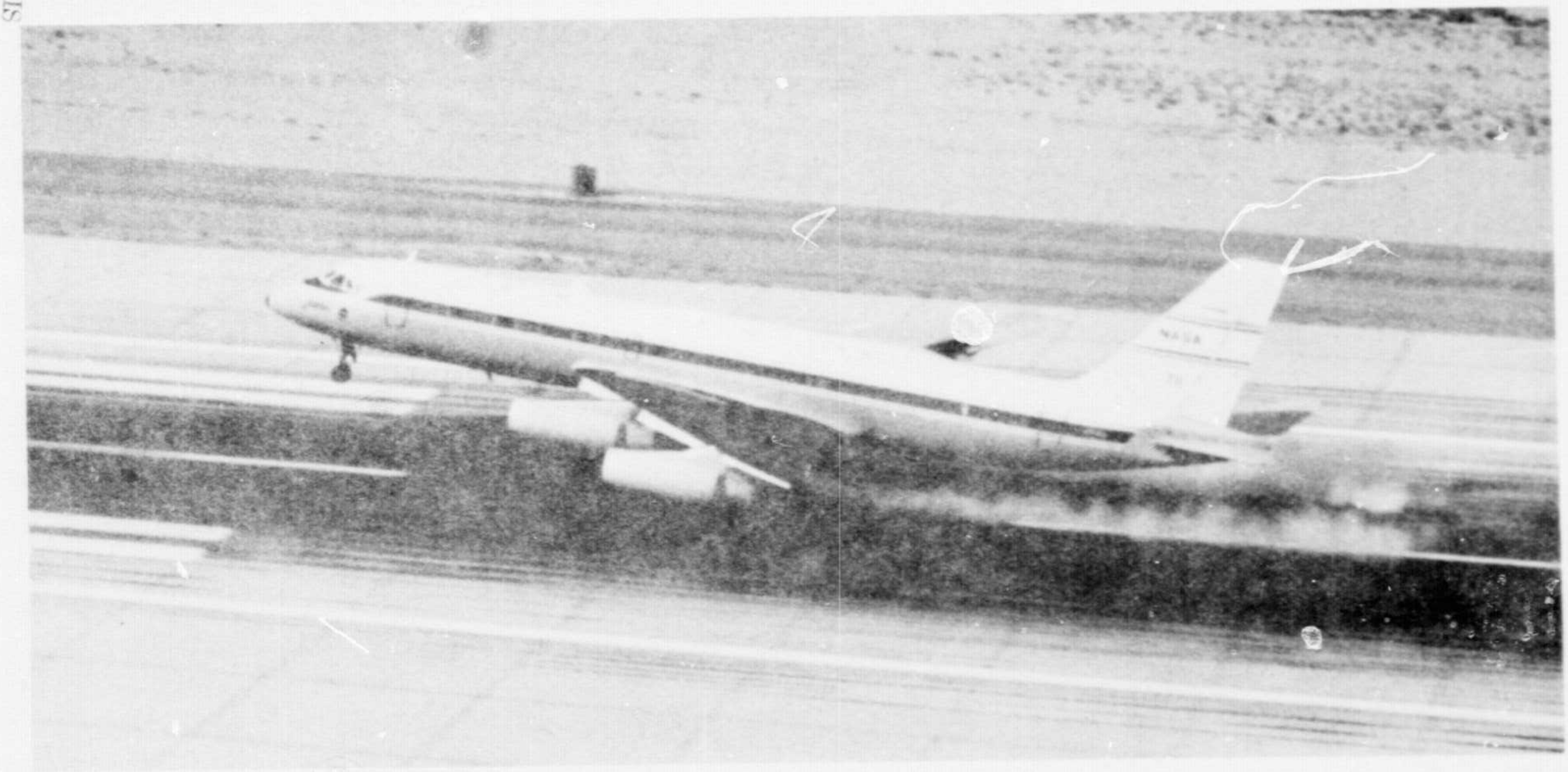
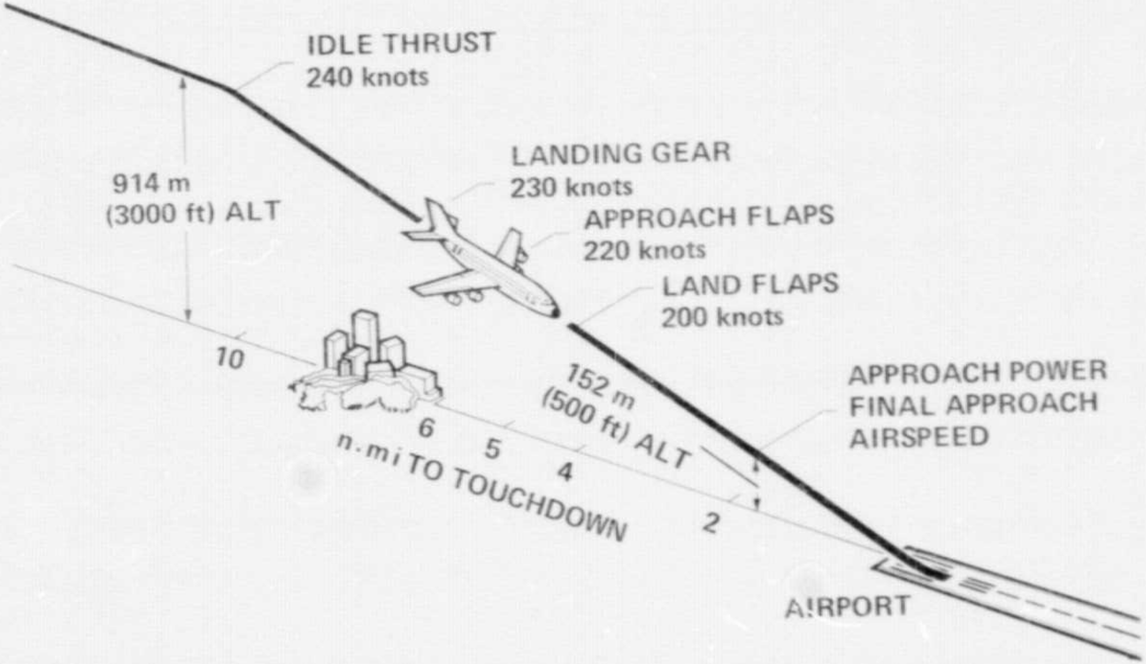


Figure 1.- NASA CV-990 aircraft, "Galileo II."



STABILIZATION ALTITUDE 152 m (500ft)
15 APPROACHES, 9 GUEST PILOTS
8-knot TAILWINDS TO 12-knot HEADWINDS
NONE TO LIGHT TURBULENCE

Figure 2.- Typical delayed flap approach.

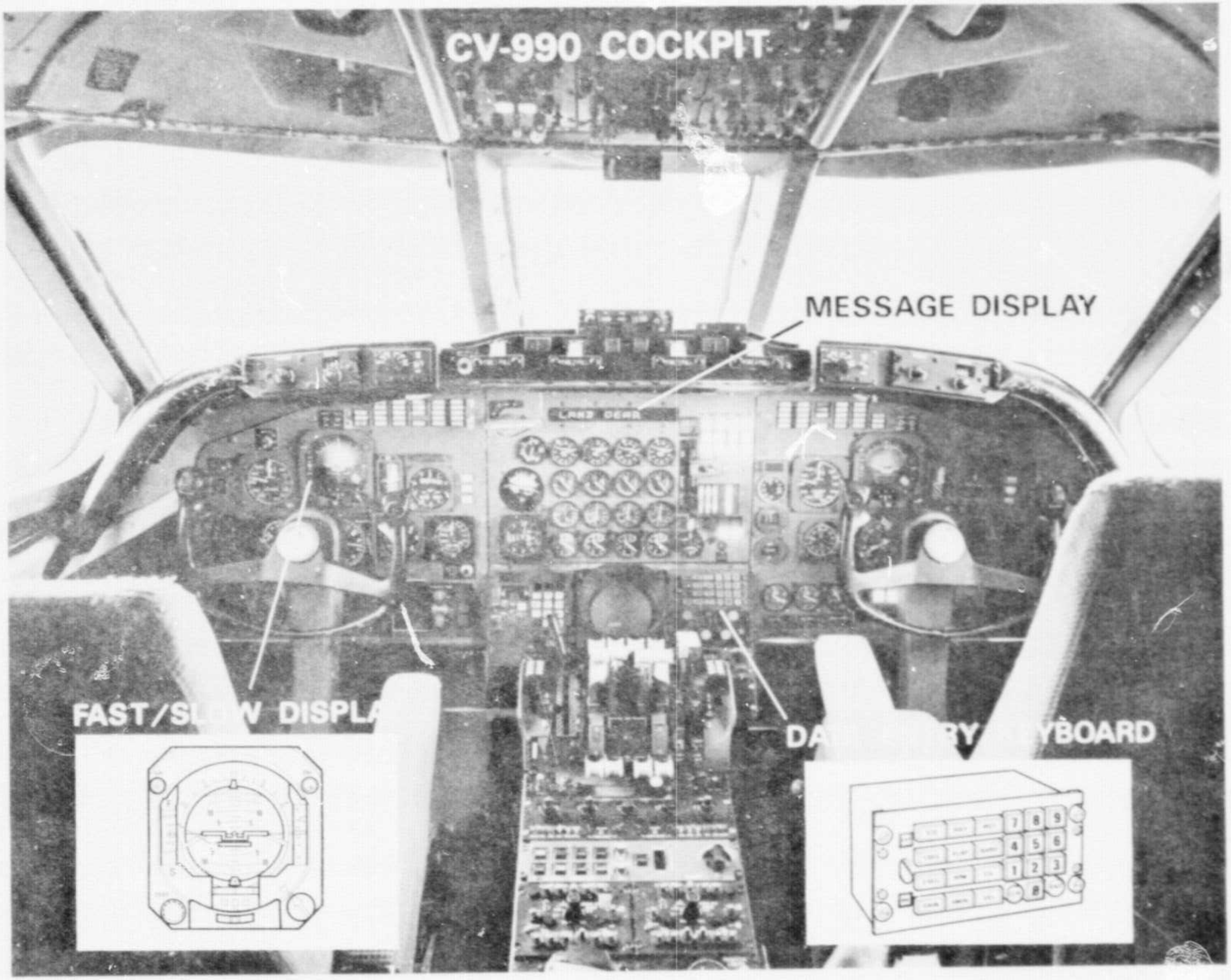


Figure 3.- CV-990 delayed flap cockpit displays.

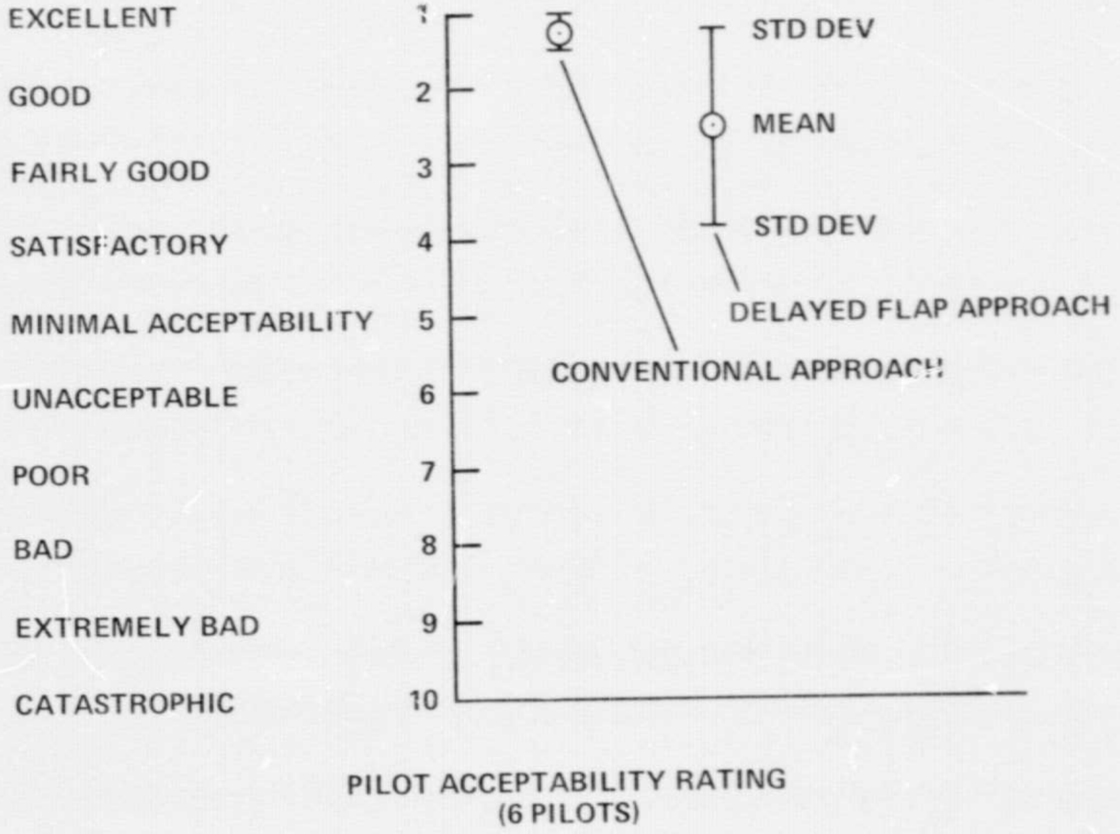


Figure 4.- Pilot acceptability ratings.

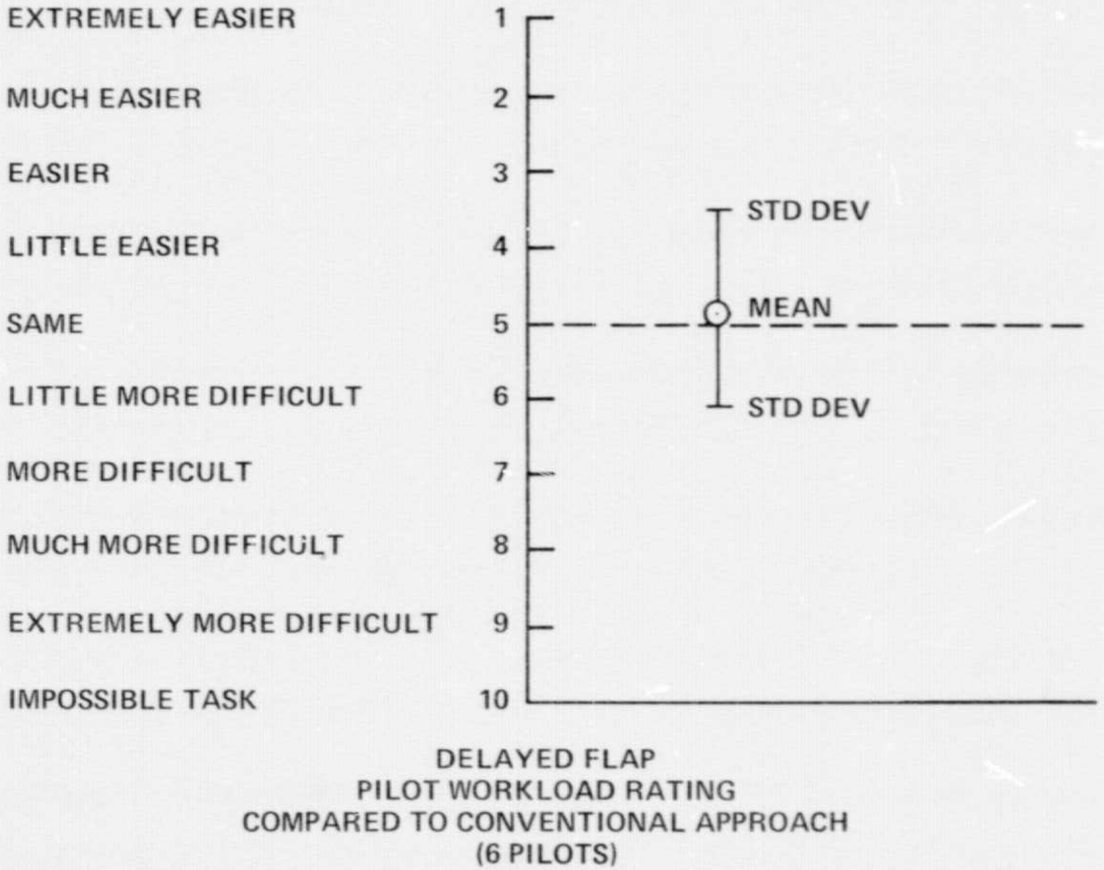


Figure 5.- Delayed flap pilot workload.

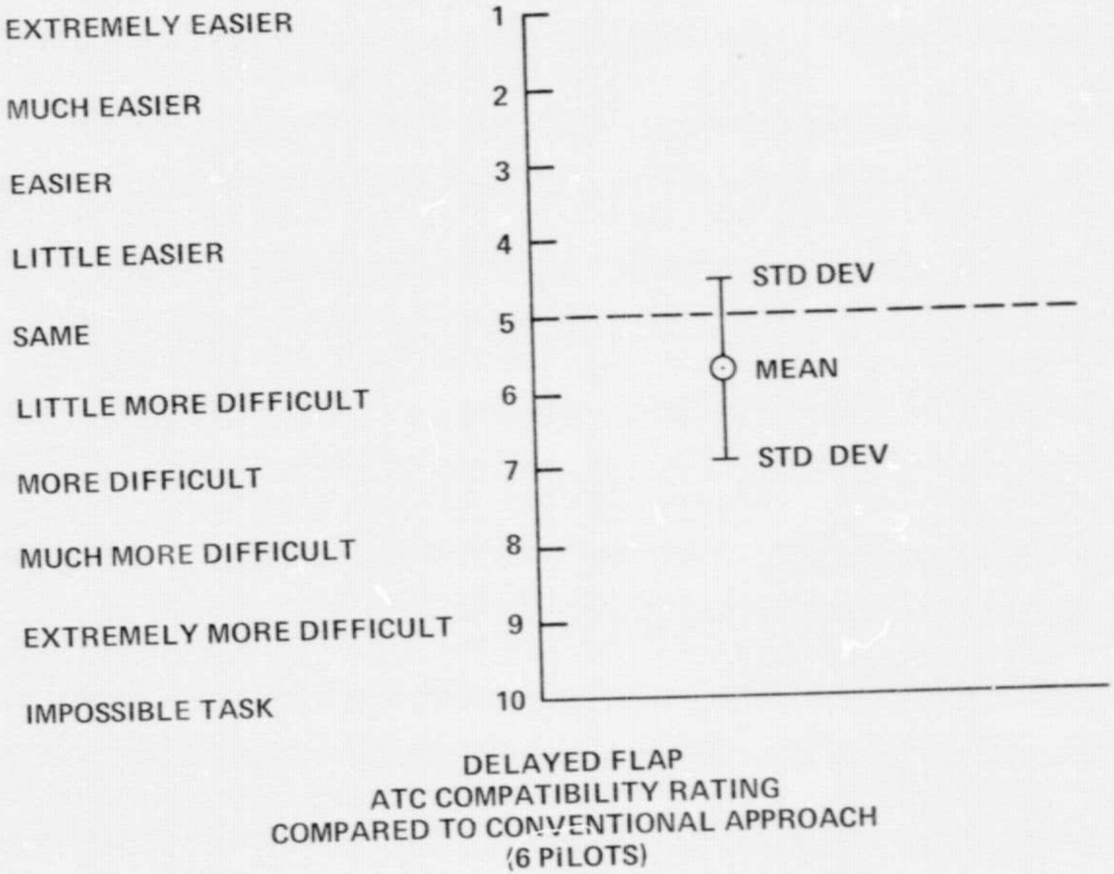
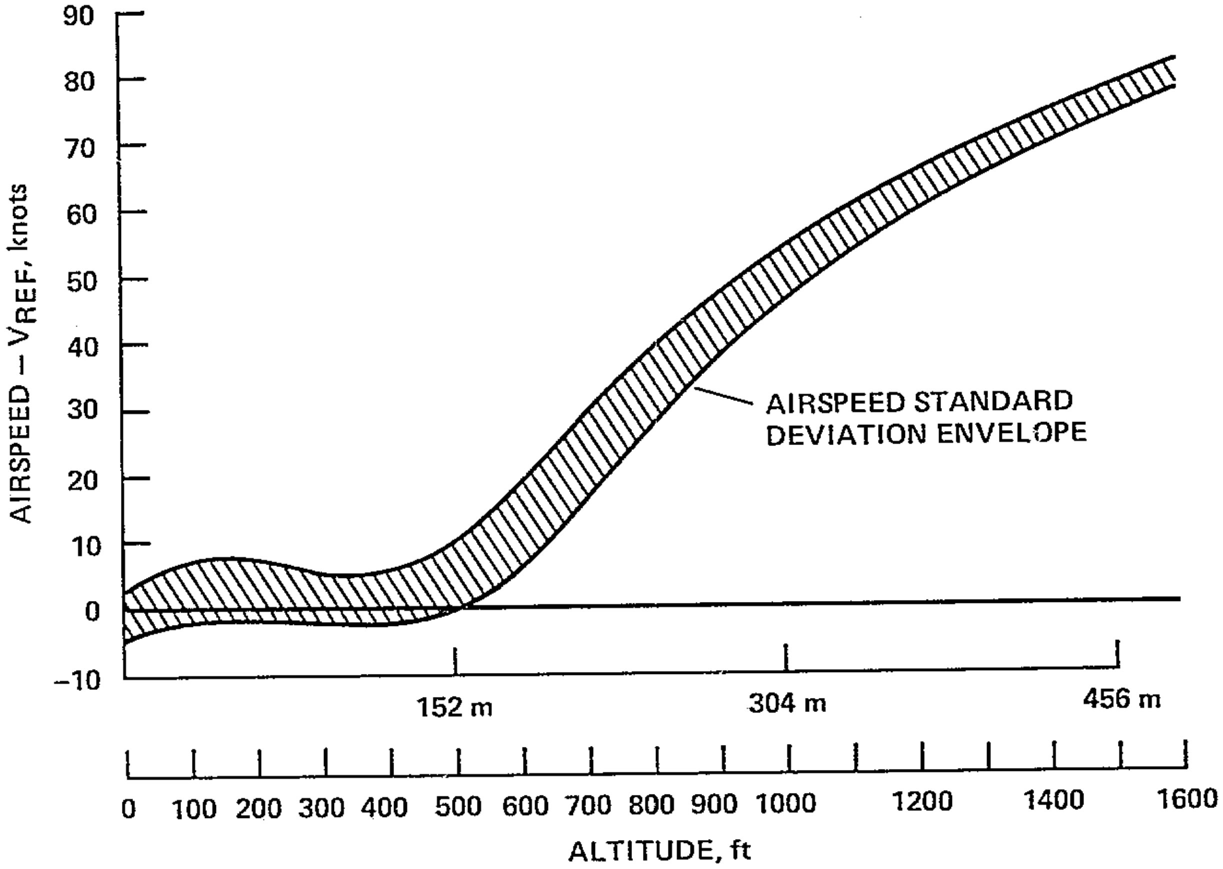


Figure 6.- Delayed flap ATC compatibility.



STABILIZATION ALTITUDE 152 m (500 ft)
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8-knot TAILWINDS TO 12-knot HEADWINDS
NONE TO LIGHT TURBULENCE

Figure 7.- Delayed flap airspeed stabilization.