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Aircrew Displays and Avionics for Application in a Future National Airspace System

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Seymour Salmirs

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Aircrew Displays and Avionics for Application in a Future National Airspace System

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National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

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SUMMARY

A concept for increased pilot involvement in a future National Airspace System was evolved during the "FAA New Initiatives in Engineering and Development Users Conference." This concept was used to develop pilot and controller tasks and responsibilities and ways in which they might interact.

The technical feasibility of the system is indicated by the sophisticated level of presently manufactured digital computers and display avionics and the application of that technology under design by the major airframe manufacturers. Data collected during simulations and flights with the Terminal Configured Vehicle Program B-737 airplane are shown to have direct application to the new system concept. The adoption of the operational changes envisioned offers some potentially significant advantages to the user.

INTRODUCTION

The Terminal Configured Vehicle (TCV) Program was conceived to address the airborne system problems of operation in the crowded terminal area airspace and the integration of airborne avionics systems necessary to improve the efficiency of those operations. The program objectives were first presented in reference 1 and are summarized in tabular form in reference 2.

The experimental airborne systems necessary to do the research were first described in reference 3 and are illustrated in figure 1, which shows the airplane interior and locations of the computer systems, data systems, and the electronic aft flight deck (AFD). The complex of research facilities necessarily includes an extensive array of capabilities in addition to the airplane. Figure 2 illustrates some of these capabilities. A sophisticated model of a terminal area including controller algorithms is resident in one of the Control Data CYBER 175 series computer systems at Langley Research Center. Data links have also been used to make available to Langley the FAA's live traffic models at the National Aviation Facilities Experimental Center (NAFEC). An airplane simulator which includes a duplicate of the TCV B-737 airplane's AFD, or the airplane itself, can be flown in the model terminal area under a variety of conditions. Data links to the NASA Wallops Flight Center and to the airplane enable flights to be conducted in controlled realistic experiments.

In May 1978, the FAA initiated a series of discussions by five user-oriented groups to obtain a critique of its Engineering and Development Programs. A subgroup was formed under the leadership of William B. Cotton, Chairman, Air Line Pilots Association, ATC committee, to examine increased aircrew participation in the traffic control process. A system operation was hypothesized and described for research evaluation by this subgroup and is discussed further in this paper. Much of what was derived by that subgroup lies within the scope of the TCV objectives and continuing research program. The concepts for functional and responsibility changes derived by the subgroup are discussed within the context of the research and data collection already accomplished. A description of the technology available (or nearly so) that might be of use in implementing some of the promising concepts is also mentioned.

The system operating elements from pilot to controller are listed as follows:

- Pilot -
  - Airplane - controls, displays, computers
  - Data links - radar, radio, digital, procedures
  - Terminal area - Navaids, airports

- Controller -
  - Air traffic - controls, displays, computers

It is essential to recognize that the pilot and controller are the two key "components" and to provide the necessary facilities to enable them to operate efficiently. It is also important to recognize that a change in any element of the system will force change in virtually all the other system elements. If the whole system is to be made more efficient, it is necessary to conduct experiments in as nearly a complete environment as possible.

ABBREVIATIONS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

A/C	aircraft
ACARS	ARINC communications addressing and reporting system
AERA	automatic en route ATC data processing and traffic clearing system
AFD	aft flight deck
ARINC	Aeronautical Radio Incorporated
ARTS	automatic radar terminal system
ATC	air traffic control
BCAS	beacon collision avoidance system
Cat II	Category II; decision height less than 61.0 m (200 ft) but not less than 30.5 m (100 ft), runway visual range less than 732 m (2400 ft) but not less than 366 m (1200 ft)
Cat III	Category III; decision height less than 30.5 m (100 ft), runway visual range less than 366 m (1200 ft)

CDTI	cockpit display of traffic information
CRT	cathode ray tube
DABS	discrete address beacon system
DME	distance measuring equipment
EADI	electronic attitude director indicator (vertical situation display)
EHSI	electronic horizontal situation indicator (map display)
FAA	Federal Aviation Administration
ILS	instrument landing system
IMC	instrument meteorological conditions
INS	inertial navigation system
IVSI	instantaneous vertical speed indicator
MLS	microwave landing system
NAFEC	National Aviation Facilities Experimental Center
NASA	National Aeronautics and Space Administration
Navaids	electronic ground navigation aids
NCDU	navigation control and display unit
RNAV	area navigation
TCV	terminal configured vehicle
TRSB	time reference scanning beam
VMC	visual meteorological conditions
4-D	time controlled (four-dimensional) area navigation

NEW TECHNOLOGY

The flight crew's view of the facilities available for research in the TCV Program is shown in figure 3. This system is duplicated both in a ground simulation and in the test airplane. Both pilots are similarly equipped with electronic vertical and horizontal situation displays (EADI and EHSI). Navigation data displays with a keyboard, the navigation control and display unit (NCDU), are available to each pilot for communication with the navigation computer system. Also apparent are the panel-mounted controllers, which are split to allow full view of the flight displays. The pilots have display mode panels to call stored airport or other information from computer memory to be put on the map. They can similarly reject or erase information depending on its importance during each phase of the flight.

Figure 4 shows one of the EHSI formats under study. The airplane position is at the apex of the isosceles triangle. A three-segment prediction of the airplane's future positions in 30, 60, and 90 sec emanates from the present position triangle. The desired (programmed) path and way points are also illustrated, and the present track angle is shown at the top of the display. Map scale, the description of the sensors then being used to solve the navigation problem (INS, MLS, DME-DME, etc.), ground speed, and current winds are indicated in the lower corners of the display. Also shown are examples of adjacent airplane traffic information which might be provided to the pilot.

A recent EADI format is shown in figure 5. Information may include attitude, present and desired flight-path-angle acceleration, present and commanded flight-path angle, a true perspective drawing of the runway with an extended centerline, glide-slope and localizer deviation scales, and radar altitude.

Figure 6 shows an aspect of an engine systems monitor which is currently under development by the McDonnell Douglas Corporation. The photograph was taken in the Douglas simulator. Additional formats including checklists and emergencies are being programmed. The TCV facilities do not now include this type of display. Engine performance quantities are in an easy-to-understand format, and checklists related directly to the engines, normal cruise operational information, and an emergency condition are also available. These displays can further contribute to the crew ability to engage in newer, more efficient operations.

It is important to realize that the display formats, symbols, scaling, information content, functions, and distribution of information between the displays are continually undergoing change in the research program. Although these particular displays have been effective, they are not considered to be optimized. Additional pieces of functional information, such as pictorial or alphanumeric ground-communicated data, can be studied in this computer-driven display complex.

Another facet of research flight deck operations is the control mode panel located in the center of the glare shield. In this system either pilot can operate the airplane through either of two computer-augmented manual control modes or five automatic modes. These control modes are used at various times in the research program. They are not all needed for all operations.

The basic philosophy that has evolved from these studies is that continuing involvement of the pilot in the control process is certainly desirable and possibly necessary. Pilots can make smooth, satisfactory changes to the system if they are controlling and if they are involved and fully understand the situation. When the automatic system is operating, it is much more difficult to enter the system and to consistently make necessary corrections. In program studies, pilots select the level of automatic mode operation (if the experimenter allows) and most frequently choose a velocity vector (ground referenced) control wheel steering mode.

The development of applicable new technology has been astonishing in the 10 years since the TCV facilities were designed and built. It is estimated that over 30 000 area navigation (RNAV) units have found their way into the air. Most are in "general aviation" airplanes but more than one-third of the commercial trunk-line airplanes are also equipped. All are used in today's airspace system. In many cases local arrangements with the ground processes allow particularly efficient operations. Major avionics manufacturers offer computer-driven color CRT displays which include the capability for checklists, maps, and weather cells display. All the major trunk-line airplane airframe manufacturers are developing some level of computer-driven CRT display capability.

The FAA has developed an MLS technique which has been demonstrated to, and accepted by, the world community. Flight tests have also been conducted on a number of beacon collision avoidance system (BCAS) designs with varying levels of success, and further developments are underway. The discrete address beacon system (DABS) study units are partially in place and tests on its capability are already being conducted. The MITRE Corporation is investigating AERA, an automatic en route ATC data processing and traffic clearance system.

In summary, a very high level of development is exhibited by all the potentially useful technical elements that might be required to bring new advances to an airspace system. Further, the technical elegance is accompanied by more reliable systems which may provide real economic advantages.

Applications

Figure 7 depicts a terminal area and illustrates its major problem areas. Also indicated are some of the system criteria that may have to be met to encourage the continued growth of aviation.

The urban areas and the suburban residential communities which create the demand and which airports serve also house the citizens who feel threatened and who are affected by aircraft noise. As traffic grows to meet demands, so too does the cumulative noise increase. One way to approach this problem is by operationally controlling the airplanes by steep approaches keeping the airplane high above the population near the airport and by curved approaches which keep the airplane over low population density areas. These techniques are used in some measure today, but satisfactory extension of these principles to accommodate increased traffic and instrument conditions is not possible in the present airspace system with present equipment.

The TCV research program has developed pilot displays and control modes using the FAA-developed microwave landing system (MLS) to accomplish just such objectives. Figure 8 shows two approaches to a downtown airport (Dorval) in Montreal, Canada. The two paths were successfully and repeatedly flown. South of the river is the Caughnawaga Indian Reservation which was to be strictly avoided. The paths accomplish the objectives by bringing the airplane over the river, or alternatively far inland, then along a railroad-industrial area to the runway approach. The departure path was similarly constrained. Descent angles were over 4° on one of these profiles. Research flights have been flown at up to 5°.

If delays and related fuel consumption are to be minimized, traffic entry into the terminal area must be predictable, hence scheduled. Another aspect of capacity and efficiency is related to the number of simultaneously usable runways, which in turn makes runway spacing important. Close parallel runways may be the only alternative for those airports which are not now heavily taxed but may become so as demand increases. It seems unlikely that additional airports can be built or even that significant airport real estate expansion can be expected.

Capacity and efficiency are also affected by the spacing and speed of the airplanes in the approach. That in turn relates to the need to get the airplane off the runway quickly after landing, which then requires precision touchdown points with minimized dispersion.

Results

The ability to repeatedly fly the paths illustrated in figure 8 with the aid of the MLS represents a milestone in airplane operational capability. Figure 9 shows something of the variety and locations of paths that have been flown. Note the normal ILS approach included for comparison.

The flights into Dorval Airport in Montreal and John F. Kennedy International Airport in New York brought out an interesting operational requirement as well as providing statistical performance data. Preliminary plans for frequent operations required close coordination with tower personnel at both locations. Ground personnel flew in the airplane and observed its performance during preliminary test flights. Once they became familiar with the demonstrated capabilities, the operations were conducted with virtually only two communications. "Cleared to Canarsie, 2300 ft. Depart runway heading, left turn on course," and - "Report Canarsie inbound, cleared to land, runway 13 left." Occasionally - "Possible holding pattern at Goona for spacing."

Table I shows some of the statistics obtained from the data from many of these flights. Flight data include manual operation in simulated instrument conditions and automatic performance data, both including some severe wind environments (quartering tail winds of 15 to 20 knots).

The data also represent various sets of control laws and gains at various stages in the studies as well as displayed information and formats that have led to improved performance during the research process. For example, the landing dispersion data in table I indicate some preliminary results from flight tests using a new flare law being examined in the research program.

Approach and landing data during manual flights are illustrated in figure 10 (from ref. 4). The paths for the 3 n. mi. final show two significant features. One is that the approach data are initiated from a 0.1 n. mi. offset at the beginning of the 3 n. mi. final. This offset was included in the experiment design (reported in ref. 4) to make the landing task difficult enough so that the ability of the pilots to fly the system would be challenged. Another significant factor is the smoothness of the tracks during the last 2 km and the low dispersions. Figure 11 (from ref. 4) shows localizer and glide-slope errors at a nominal 30.5-m (100-ft) altitude point on the approach. The box outline is the FAA standard for flight director performance on Cat II ILS approaches which are normally conducted from a 10 n. mi. final. Note how well the data from flights with situation display (no flight director) supported by control wheel steering fit within the box. Approach tracks for a 1.5 n. mi. final showed considerable variability (within 91.5 m (300 ft) lateral error) in the tracks at the straight final intercept. However, the performance data at the 30.5-m (100-ft) altitude point were excellent. The pilots reported that the turns onto final were easily accomplished and the overshoots and undershoots were of little concern in that they had knowledge and complete control of the situation at all times.

Reference 5 discusses some results obtained with automatic operation using a 4-D RNAV mode. Briefly, the final result statistics are that position accuracy can be maintained throughout a flight of within 0.1 n. mi., one sigma; and position with respect to time can be maintained within 2.1 sec, one sigma.

Figure 12(a) (from ref. 5) shows a flight profile and a manual control problem in 4-D RNAV. Note the wind vector. After the flight had reached LVL and was proceeding to RMT under automatic control the pilot was told he was to arrive at RMT 6 min later than planned. The pilot went to manual control, initiated a turn, and then introduced the new time into the NCDU. Figure 12(b) (from ref. 5) shows the situation as it developed. The rectangular box is a time box shown on the EHSI. If the pilot is to fly a programmed time profile, he keeps his airplane in the "time" box. From the situation in figure 12(a), he saw the box behind and without any great amount of mental calculation, he simply made his turn to intercept the moving target. He was able to manually recapture the new time with an accuracy of 1.5 sec.

Cockpit display of traffic information (CDTI) has been studied for many years. The most comprehensive investigations were carried out at the Massachusetts Institute of Technology from 1970 to 1975 and are summarized in reference 6. Further studies have been conducted at the NASA Ames Research Center (e.g., ref. 7). The NASA TCV Program has also been active and has helped sponsor the initial portions of a Boeing Airplane Company study (ref. 8) and has done simulation and flight research. Figure 4 shows the flight profiles of other airplanes involved in a test. The pilot was required to fit into a sequence at the entry into the straight final and not to violate a 3 n. mi. separation from the airplane he was following. He flew the test with traffic proceeding normally and with traffic reaching their anticipated way points earlier and later than expected. The pilot had to estimate the actual spacing, hold speed, or increase or decrease speed as necessary. No range measurement marks or scales were provided. The data (mean errors less than 0.3 n. mi., ±0.1 n. mi., one sigma) indicate that the task could be accomplished and that the pilot could do it better and more comfortably with the advanced control wheel steering modes.

SIGNIFICANT FACTORS AFFECTING OPERATIONS IN THE NATIONAL AIRSPACE

Capacity and Delay

The factors capacity and delay are interdependent and one cannot be addressed without consideration of the other. Figure 13 (taken from ref. 2) is a composite of the time intervals combined to construct a city pair flight as scheduled prior to deregulation demand. The times shown are from the published schedules. They include (as indicated by the hatching) a number of categories of delay. The time allotted to each is an average of times that have actually been experienced in each category. If the airplane leaves and arrives at the scheduled times, the passenger is unaware of any of these delays. Note that the time, and indirectly the fuel, required to fly from Newport News, Virginia, to Washington National Airport is now 42 percent greater flying a B-727 under instrument flight rules than it was in 1965 flying a Lockheed Electra under visual rules. These increases occurred in spite of the increase in normal cruise speed and are largely a result of increased traffic in the current ATC system. A flight from Newport News, Virginia, to Atlanta, Georgia, is particularly interesting because it takes place on a B-727, the most common airplane in the trunk system today, and over a route of 468 n. mi. This average trip has the connotation of being the most common flight of the most common airplane and is indicative of the fleet's fuel usage and the percent of fuel used in delays.

Delays become exponentially longer, the closer a terminal approaches its capacity. If traffic flow rates are to be increased and/or delays reduced, capacity must be increased. Studies indicate that, barring adding more airports and/or runways, reduced spacing leads directly to the increase in capacity desired. Figure 14 (from ref. 9) shows what quantitative improvements are possible for a single runway if spacing is reduced. It also shows the very significant improvements that can be derived from precision flight.

Capacity, Delay, and Collision Avoidance

The consideration of capacity, delay, and collision avoidance in combination leads to a conundrum: Reduced spacing resulting in more densely packed airspace under the present system tends to increase the probability of midair collisions or a vortex encounter. Currently, historically, and correctly, official policy and National Airspace System design are aimed at reducing the possibility of accidents by conservatively separating airplanes with large chunks of airspace. Future system improvements should be directed at both capacity and safety. However, safety is not a difficult problem unless traffic levels become measurable portions of the capacity.

The present airspace design is based on a central processor's (air traffic controller) awareness of all traffic. Each traffic element (the pilot) does not and cannot now have a similar awareness. Whether by radio or by visual study of the environment, the pilots are handicapped by a lack of timely data. However, the pilot is still the airborne system operator; he directs the airplane. The controller and the control process introduce time delays in the control of the airplane. These lags, of course, are necessary in today's environment. They can be reduced somewhat by

(1) More precise tracking data
(2) More predictable airplane behavior
(3) Projection of airplane intent into the future
(4) Digital transmission of complex data

In addition to induced time delays which tend to increase spacing, the present system causes pilots to lose precise knowledge of their present position. Further, the tendency is for the air traffic control system to force all airplanes into the same mold; i.e., the same speed regardless of class. This can be inefficient for some and dangerous for others. The traffic demand coupled with such a slow response feedback system sometimes causes difficult operational commands (i.e., descend and slow down).

The problem is complicated by the fact that the controller and pilot are trying to do a very sophisticated task very efficiently. Thus, the level of mutual understanding and the clarity of communications must be extraordinarily high which raises the potential (occasionally realized) for hazardous misinterpretation. One approach is to have more order by having more restrictive systems with less capacity and efficiency. Noise avoidance procedures exacerbate the difficulties of operations in the terminal areas. Not only are some maneuvers difficult but the approaches and departures are different in visual and instrument conditions.

AN AIRSPACE SYSTEM MODEL TO UTILIZE NEW AVIONICS TECHNOLOGY

System Functional Changes

Many of today's problems may be addressed by the introduction of philosophical changes supported by modern technology. The important change in the formal ATC structure that might be possible is the efficient utilization of RNAV capability in the terminal. It can be particularly valuable for the controller to take advantage of the resulting more predictable airplane performance as well as the flexibility inherent in RNAV systems and concepts. For example, flexibility can provide for accommodating various combinations of light and heavy airplanes in closely spaced operations as indicated in figure 15. However, there are technology requirements associated with this type of operation, particularly the MLS as well as displays and controls for steeper descents. Other technologies to reduce vortex strength (i.e., programmed spoiler deflections), if developed, might obviate the need for this particular procedure. Further, flexible application of RNAV provides for the ability to merge different classes of airplanes from different paths, each commensurate with their capability for common runway operations or for crossing approaches to different runways if necessary. Airplanes outside the terminal can be cleared to make direct penetrations to active runways on a predicted time-sequenced basis.

The most complex functional change would be precision point-to-point RNAV to improve predictability for traffic control. Another advantage of RNAV is better flight and configuration planning inasmuch as the pilot will know where he is and when to slow, descend, and prepare for landing.

The RNAV system, when supplemented by appropriate display to the pilot of the location of adjacent traffic and collision warning systems, may enable the airspace system to benefit substantially from advanced technology. There are changes brought about by a variety of causes whose effects are not easily predicted (i.e., wind shifts, pilot error, airplane or ground emergencies, calculation errors, etc.) and are outside the ground controller's ability to recognize and deal with. These effects must be taken into account if the system is to operate efficiently. The pilots can provide the necessary vernier adjustments and should be equipped with the means to modulate their airplanes' progress in an intelligent manner.

The key to the conduct of significantly more efficient operations appears to lie in a redistribution of pilot and controller roles. Such understanding must, of course, be supported by the necessary technical elements and capabilities to make them viable and there must be the development and clear demonstration of their benefits to make them economically rational.

There are five areas in which this combination of flexible precision navigation and traffic display has potential benefits:

(1) Time assigned arrivals. Traffic could be assigned times at way points (consistent with performance and aircrew acceptance), and traffic merging and threshold crossing could be very precisely controlled with minimal modifications to airplane path or configuration. Communications may be expected to be substantially reduced, and better flight planning will be possible with concomitant fuel savings.

(2) Traffic avoidance. The capability may provide needed information useful in visual meteorological conditions (VMC). Under instrument meteorological conditions (IMC), it may make possible more closely spaced operations than are now possible.

(3) In-trail following and spacing. It can make possible IMC operation rates at airports close to those realized in VMC. Simple controller commands (i.e., "Space 3 n. mi.") without vectors or continuing corrections can vary spaces in changing conditions.

(4) Merging with other traffic. This kind of operation might be accomplished at random locations in the terminal area, or en route, simply by providing the pilots with merge locations, sequence instructions, and traffic advisories for identification of other traffic. The most obvious benefit could be the vastly reduced communications because there would be little need for vectors. More significant is the ability to adjust merge way points according to local traffic flow changes.

(5) Explicit options. In the event of any major change or emergency, the options available can be clearly and quickly identified by means of data link and displays with minimum cognitive workload and can be more easily resolved. It might be expected that few diversions would be required.

Redistribution of Roles

Certainly not all airplanes or ground facilities will be simultaneously equipped nor all their personnel trained. The system should then be designed to accommodate a mixture of airplanes, personnel, and equipment. Those airplanes that are equipped should be able to use their equipment beneficially.

The pilot (crew) of an equipped airplane might be expected to respond in four ways:

(1) The crew should follow agreed-to paths and way-point crossing times with greater precision than they have in the past. Errors on the order of seconds rather than minutes and tenths of miles or less will be matters of importance.

(2) The pilot would execute an accepted clearance and not simply respond to a vector. He should be fully responsible for, and in control of, navigation, terrain avoidance, and the location and avoidance of other traffic as his clearance requires.

(3) The pilot should monitor other clearances. In today's environment, pilots frequently do monitor other traffic. In the case of more encompassing clearances, particularly those involving assigned traffic avoidance situations, the pilot must understand his clearance and that of certain other traffic.

(4) Expanded reporting. With the addition of data link and closer spacing of airplanes, there is both the opportunity and the need for greater reporting of intent and environmental data. Interairplane communications might be routinely used.

Pilots of unequipped airplanes are not expected to see a change. Indeed, unequipped airplanes might have more flexibility, over more airspace, because of the better behavior of the system as a whole.

The air traffic controller in the terminal area might be expected to be relieved of much of the moment-to-moment vectoring activity, but the controller will not disappear, nor should the net workload be significantly reduced. Instead they may be expected to perform a larger cognitive role in planning for a larger number of airplanes. Specifically, there are five areas of concern for the controller:

(1) Select and assign traffic sequences based on predicted times at way points and on spacing requirements. All the data may be computer processed and displayed to provide the controller with sufficient processed information to make final decisions and assignments.

(2) Investigate requested flight plans for potential airplane-to-airplane separation conflicts and decide on which airplane is to have the right of way and to assure no third airplane involvement.

(3) The controller will acknowledge and approve flight-plan changes much as is done now. The difference will be that the changes may be related to

random way points and other traffic. The digital data link and computer-driven CRT technology are expected to make these random way points and anticipated tracks directly available in a map display for visual examination and discussion by both pilot and controller.

(4) The pilots of unequipped (or less equipped) airplanes will continue to have a need for various levels of vectoring, traffic advisories, and weather and obstruction warnings. However, the controller can allow conflicts which equipped airplanes can resolve if necessary.

(5) The ability to communicate random and complete navigation information may permit the controller to assist in the resolution of piloting options and contingency planning.

Changes in the Form of Clearances

Flight plan and operation route clearances will now have to include traffic advisories where close approach of two airplanes is anticipated. Both pilots involved should be notified to expect a possible encounter. Further, one pilot will be assigned the full responsibility to maintain safe separation. The other pilot will be assigned the obligation to maintain his flight plan and both pilots will be informed of what each one's responsibility is. The "Right of Way Rules" may be used in making the assignments, based on predicted directions and situations at the time of the encounter.

This technique, prior assignment of responsibility, offers a number of advantages:

(1) Collision-avoidance decisions and maneuvers are not left to last-moment human judgment of the relative positions, speeds, and directions of other airplanes.

(2) A pilot will know before a conflict develops where the other airplane is and that he is committed to avoid it so that the pilot can make very early minor maneuvers.

(3) Airplanes having an assigned collision avoidance responsibility can anticipate the avoidance maneuver and select a direction to avoid close approaches to other traffic.

(4) An airplane assigned to maintain course is more likely to do so even if an "apparent" violation of the rules develops. That airplane's pilot is not likely to make a maneuver which may conflict with the burdened airplane's avoidance maneuver. Should the pilot become concerned, he knows who to look for and can even initiate radio contact. Radio contact might become procedural.

A sample traffic-related clearance for the pilot of a burdened airplane might be

"NE-351 you are cleared direct ABC, climb and maintain FL 180, cross ABC at FL 180, give way to AA-15 crossing at 2 o'clock 16 miles prior to ABC at 13 000 feet."

The pilot of the privileged airplane might receive a traffic clearance as

"AA-15, traffic is NE-351 crossing at 10 o'clock, 16 miles prior to ABC at 13 000 feet will give way to you."

Airplanes that are not equipped should receive clearances in the form and with the content that is used today, including traffic advisories. If digital data links are used exclusively, these airplanes would have to rely on their own clearances and traffic advisories for situation information. The activities implied in these clearances are possible and can be accomplished in dynamic, demanding approaches with very short finals. Further, tests show that the pilot's ability to judge anomalies in the merge situation is adequate and the accuracies attained are acceptable.

A final approach clearance might be given as

"NE-351 you are cleared to land number four from approach path TANGO runway 07, wind 090 at 15, altimeter 29.35. Follow AA-15 on straight final, path GOLF. CESSNA 076 on right approach path QUEBEC will follow you. Your spacing behind AA-15 is 2 miles."

This type of information can be followed and can be understood in flight if it is presented on appropriate displays (i.e., fig. 4) as well as transmitted by normal voice channels.

CONCLUDING REMARKS

A concept for air traffic control in a future National Airspace System which involves extensive pilot participation in the control process has been postulated. Pilot tasks and avionics support have also been defined. Investigations have been conducted at many levels of simulation and the results of those tests have tended to support the control concepts.

The industry has developed and is commercially producing airborne pictorial situation displays whose information content can be reconfigured, which makes it technically feasible to apply the equipment to the tasks that have been described. All the major airframe manufacturers are developing applications in their airplanes for these displays and for flexible digital computers for primary flight control.

All the required technical elements of a traffic control system are available or are under development. These include

(1) Airborne digital computers

(2) Airborne CRT and "flat panel" displays

(3) Air-air data link (BCAS)

(4) Air-ground data link (DABS, MLS, ACARS)

(5) Ground automatic data processing (ARTS III, AERA)

Flight tests have shown that a variety of curved paths with relatively short straight finals can be safely and comfortably flown. These paths can be contoured to help reduce community noise impact problems and have the potential to increase terminal area air traffic flow rates. They can be flown accurately with minimum acquisition overshoots to allow close parallel runway operations where that operation is desired.

Fundamental problems, not yet investigated, deal with the system's operation as a whole. Both the method of system operation and the actual efficiencies, if any have to be developed and measured in research.

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September 26, 1979

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TABLE I.- PERFORMANCE RESULTS FOR TCV B-737 WITH ILS AND MLS GUIDANCE

NAFEC 1976

Approach		Reference altitude, m (ft)	Vertical position		Lateral position	
Type	Number		Mean, m (ft)	One sigma, m (ft)	Mean, m (ft)	One sigma, m (ft)
Cat III ILS (40°, 10 n. mi.)	45	61.0 (200)	58.8 (193)	±0.6 (±2.1)	0.6 (2) Right	±2.4 (±7.8)
		30.5 (100)	28.3 (93)	±1.1 (±3.7)	0 (0)	±2.3 (±7.7)
MLS, automatic (130°, 3 n. mi.)	56	61.0 (200)	58.8 (193)	±1.5 (±5)	0.9 (3) Right	±1.2 (±4)
		30.5 (100)	29.0 (95)	±1.5 (±5)	0.9 (3) Left	±1.2 (±4)
		Overshoot on final	----------	----------	9.1 (30) Right	±18.3 (±60)
MLS, manual (130°, 3 n. mi.)	27	61.0 (200)	59.4 (195)	±3.0 (±10)	1.5 (5) Right	±7.9 (±26)
		30.5 (100)	29.6 (97)	±1.2 (±4)	0.3 (1) Right	±4.6 (±15)

MLS AUTOLAND DEVELOPMENT

Year	Landings	Longitudinal dispersion, m (ft)	Sink rate, m/sec (ft/sec)
1976	45	±111 (±365) one sigma	-0.8 (-2.5) mean
1978	32	±29 (±94) one sigma	-0.7 (-2.2) mean

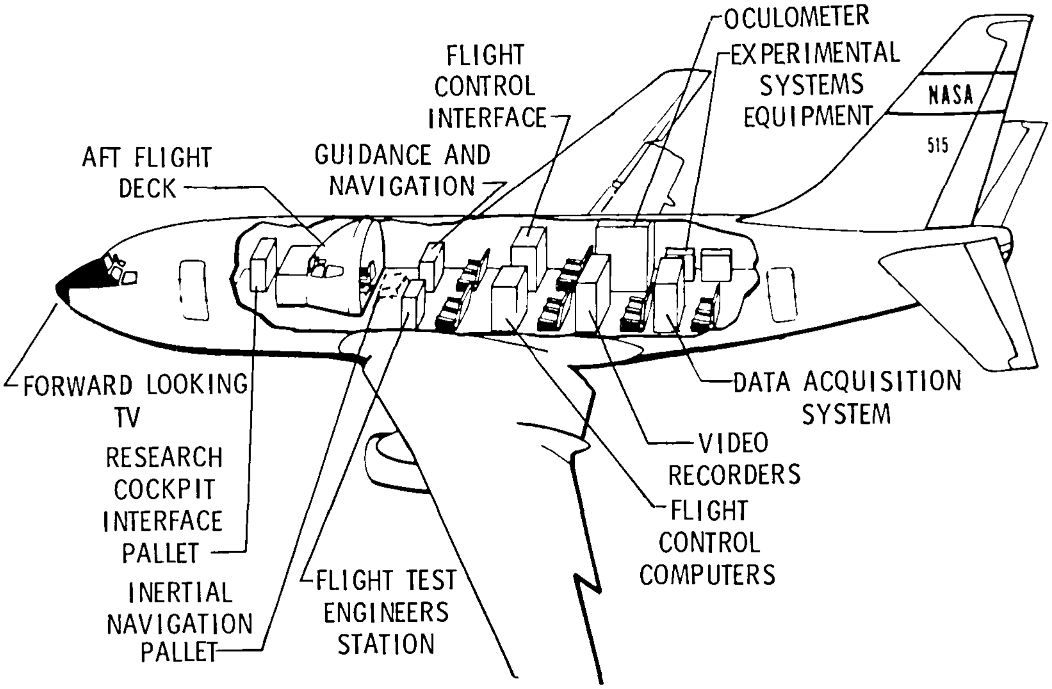


Figure 1.- TCV B-737 interior arrangement.

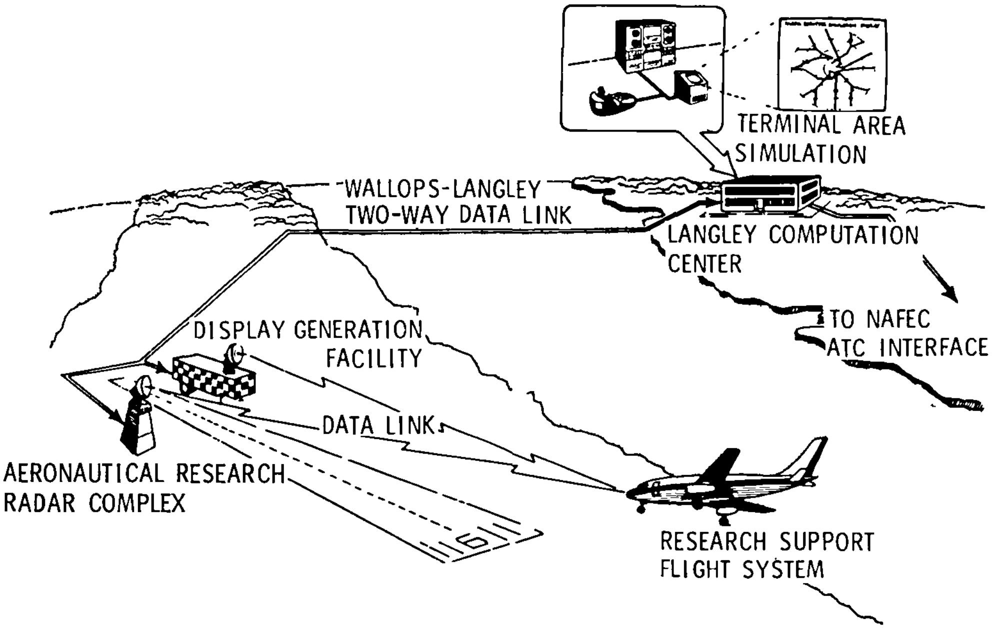
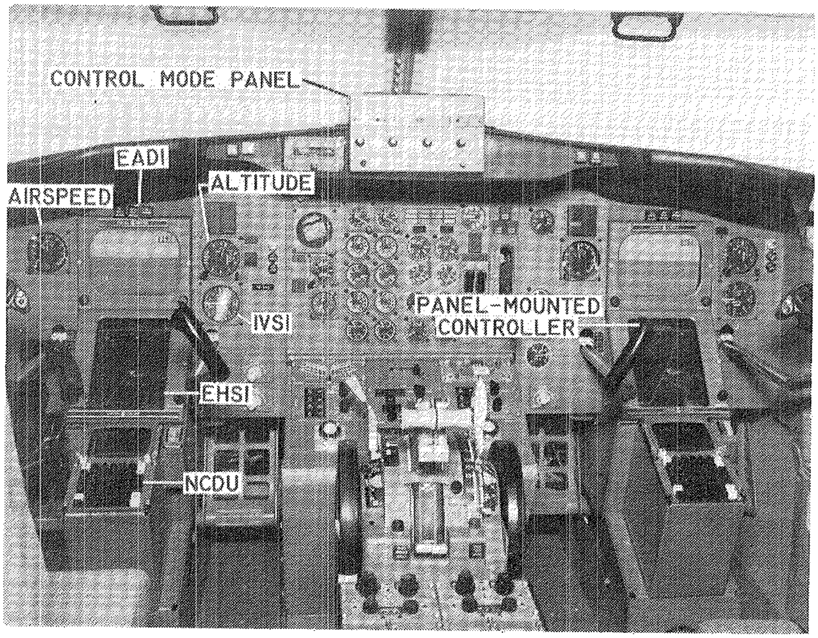


Figure 2.- Flight research facility used in investigation.



L-74-5183.3

Figure 3.- TCV research flight deck.

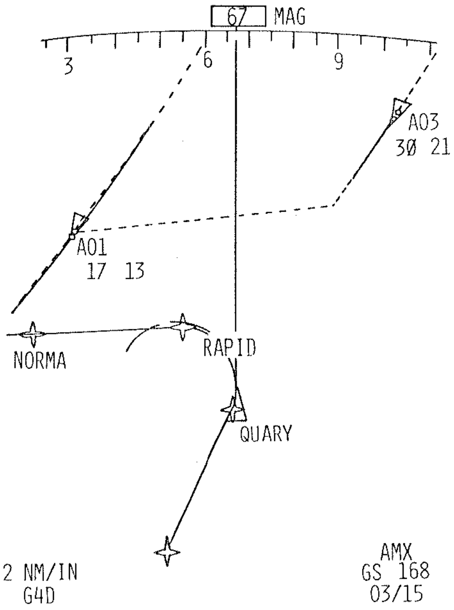
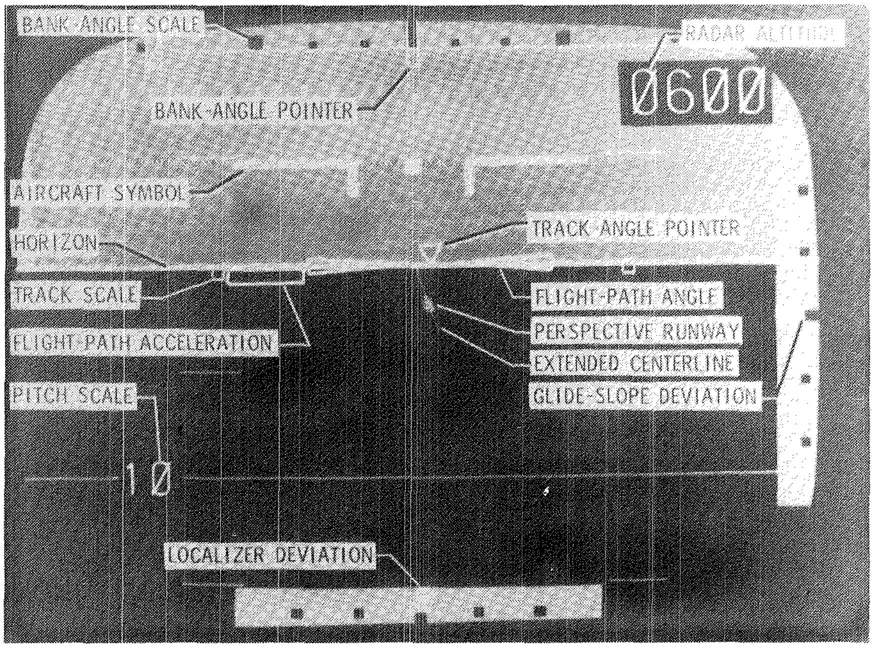


Figure 4.- EHSI map display showing nearby traffic for merge on short final.



L-77-5645.2

Figure 5.- Electronic vertical situation display.

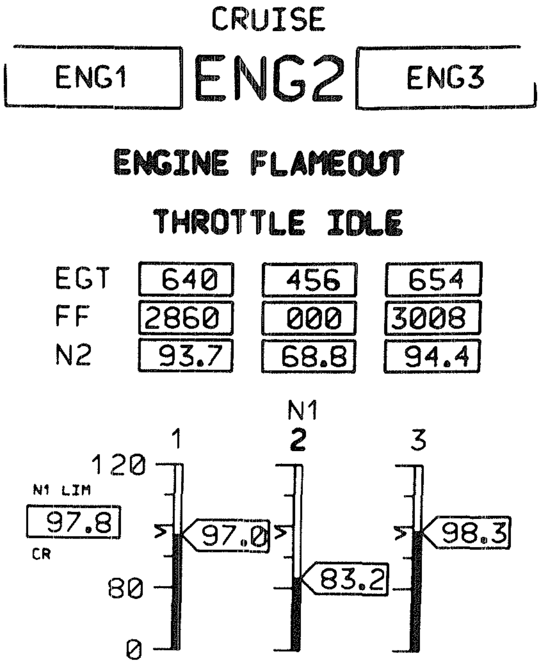


Figure 6.- Engine management and display system under development by McDonnell Douglas Corp.

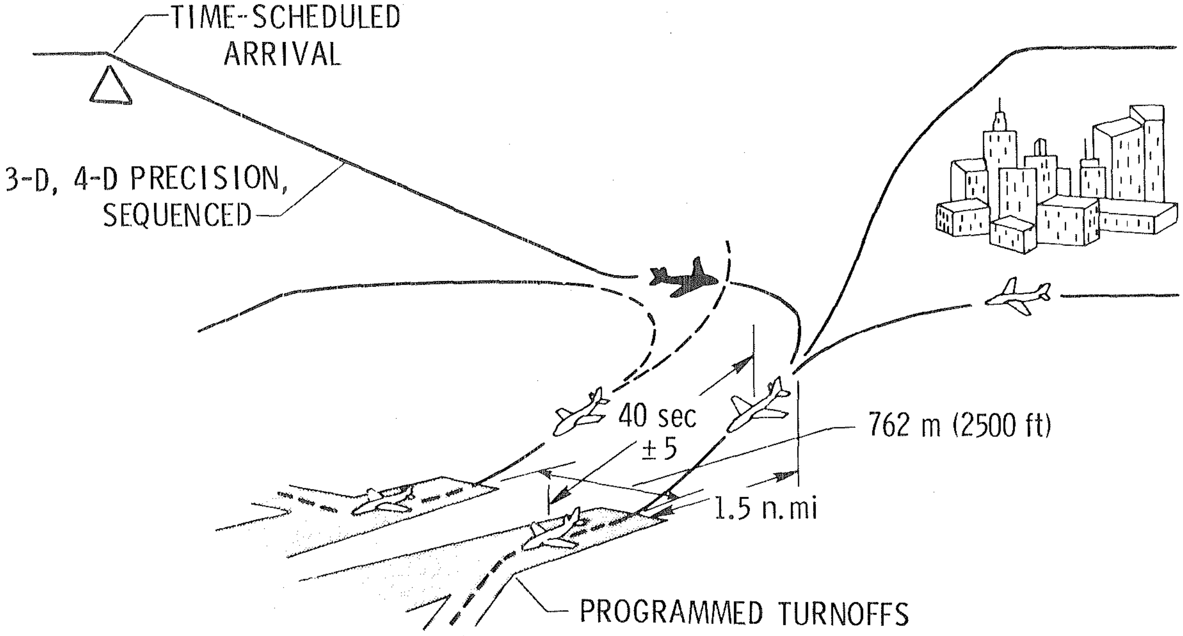
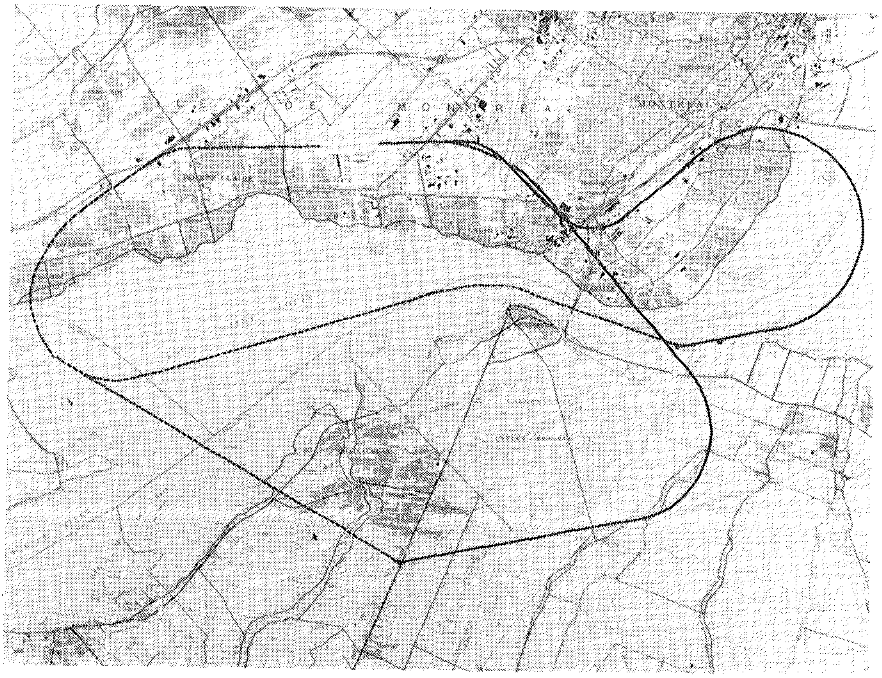


Figure 7.- High-capacity terminal area operations in low visibility.



L-78-4715

Figure 8.- Approach and departure paths flown at Montreal.

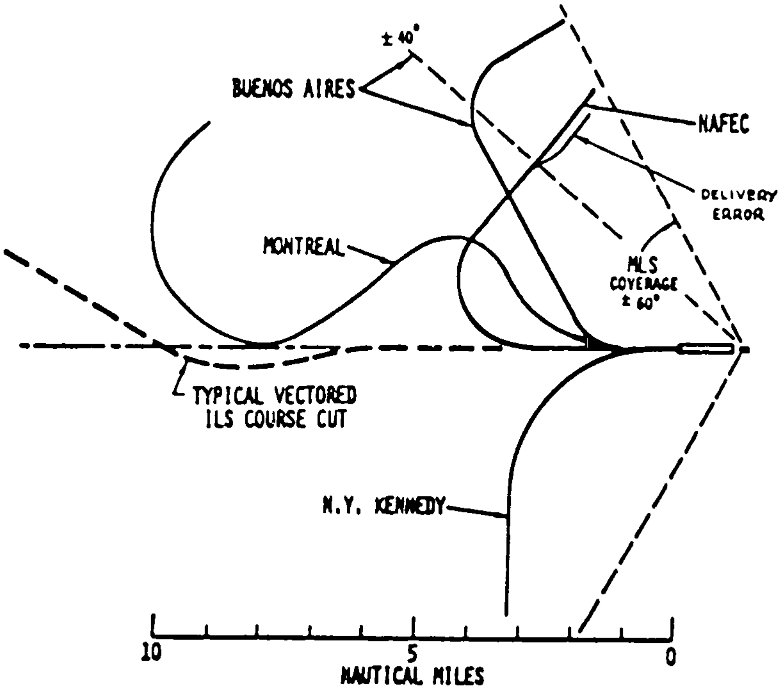


Figure 9.- TCV B-737/TRSB MLS experience.

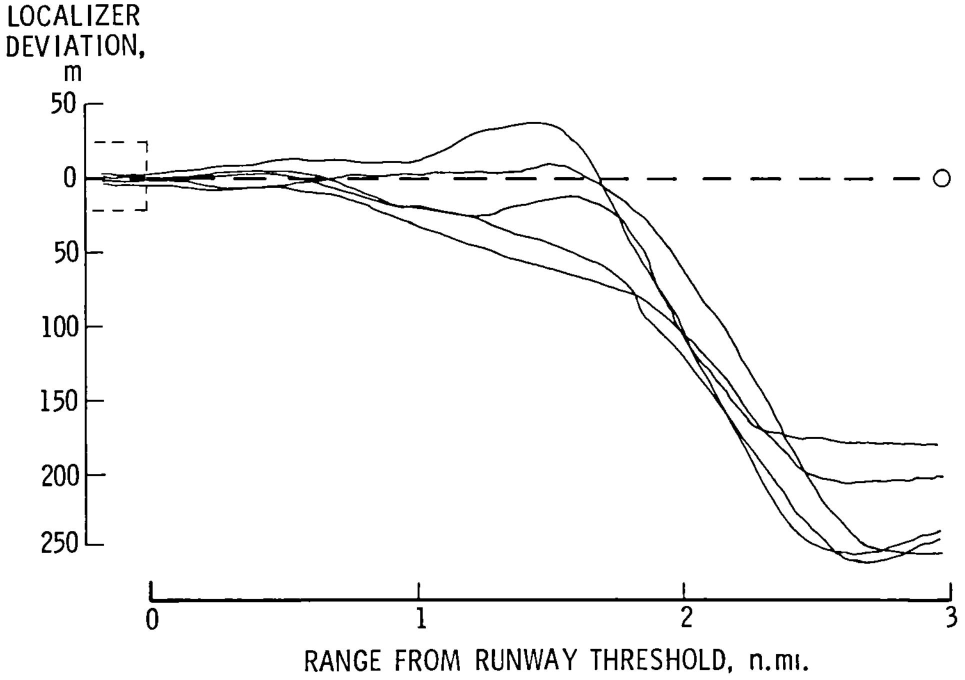


Figure 10.- Localizer tracking using the situation display format of reference 4.

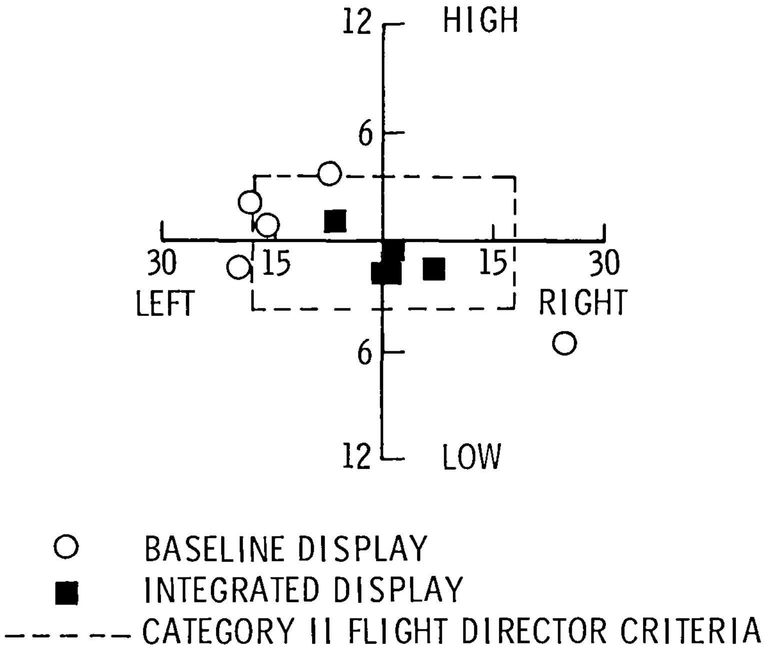
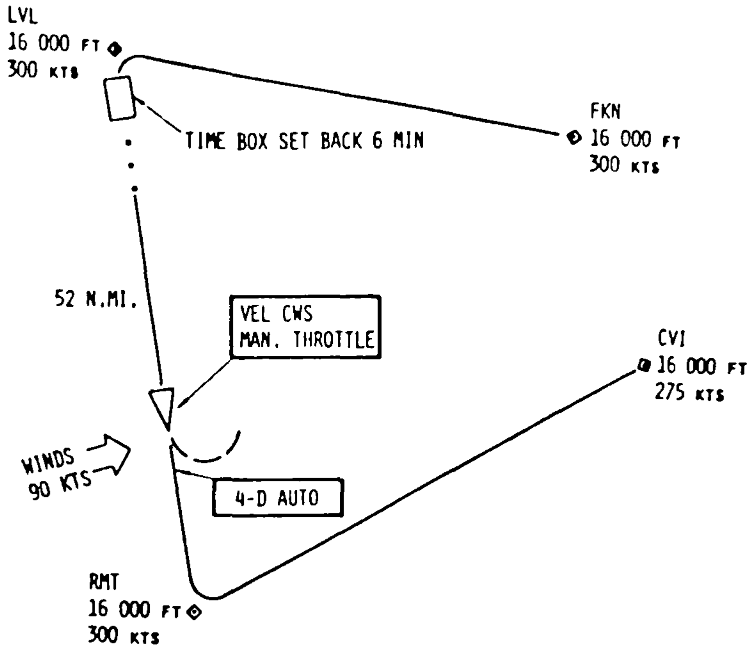
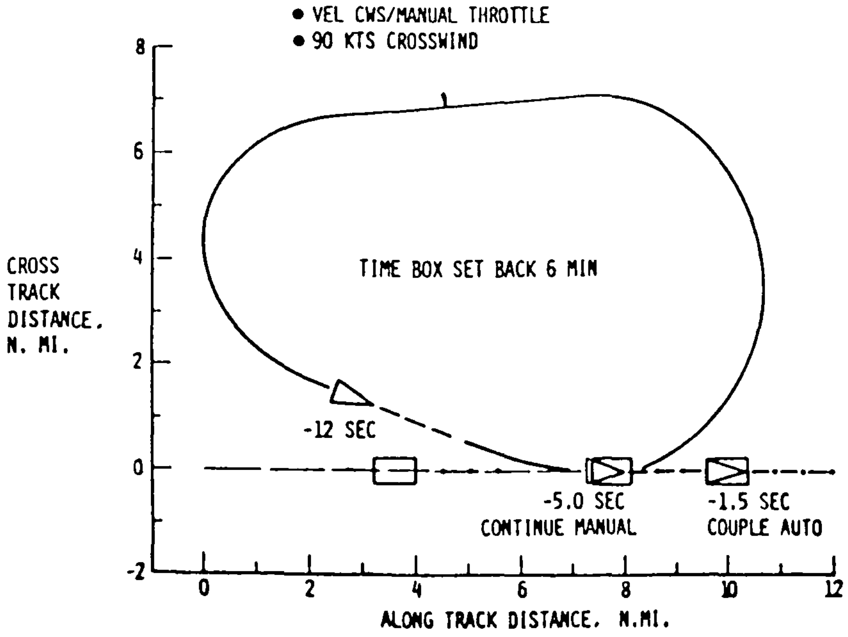


Figure 11.- Manual approach display data comparison from reference 4. All scales are in meters.



(a) Flight profile. (16 000 ft = 49 km.)



(b) Recapture of profile.

Figure 12.- TCV B-737 4-D navigation task from reference 5.

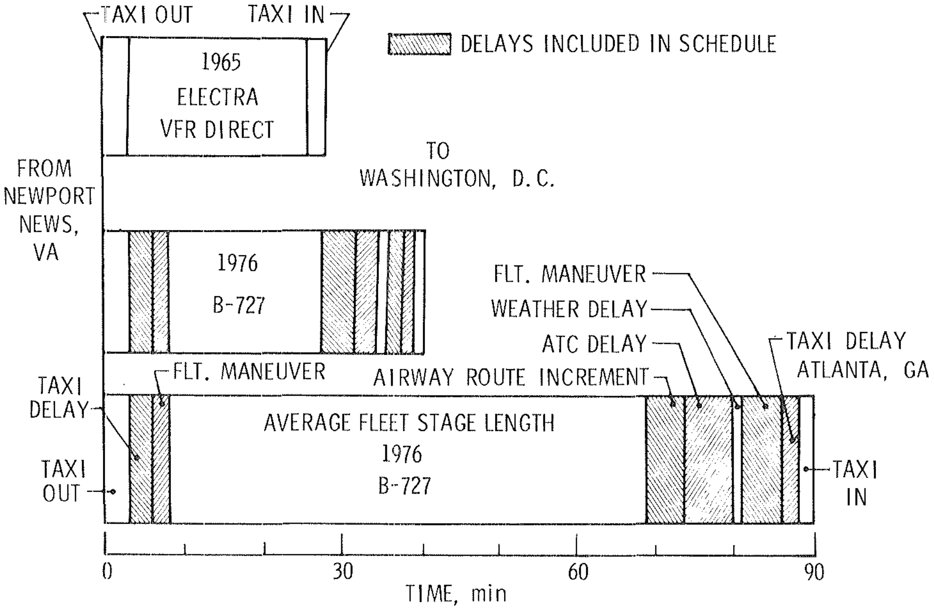


Figure 13.- Airline schedule components (nonstop). (From ref. 2.)

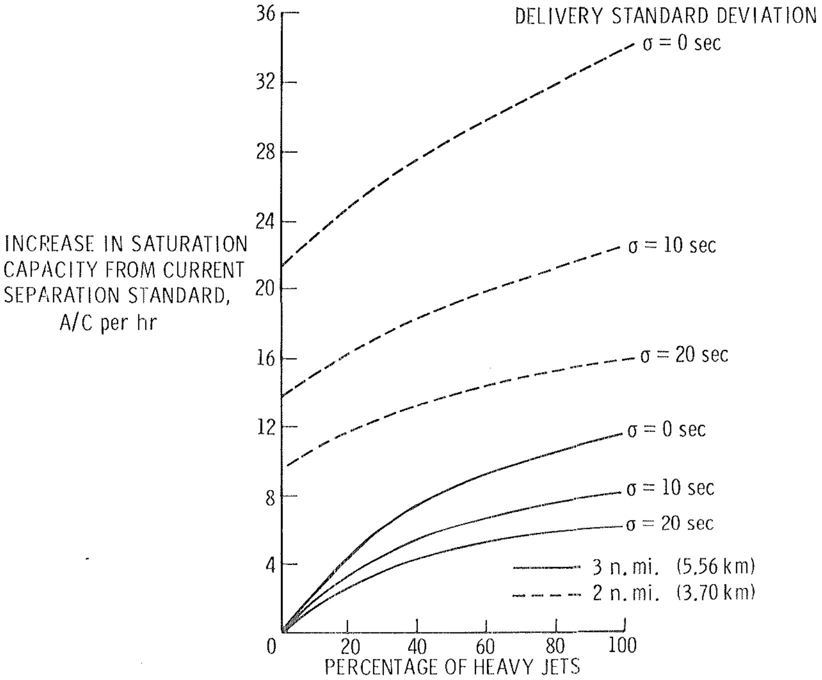


Figure 14.- Effect of delivery accuracy and spacing on capacity. (From ref. 9.)

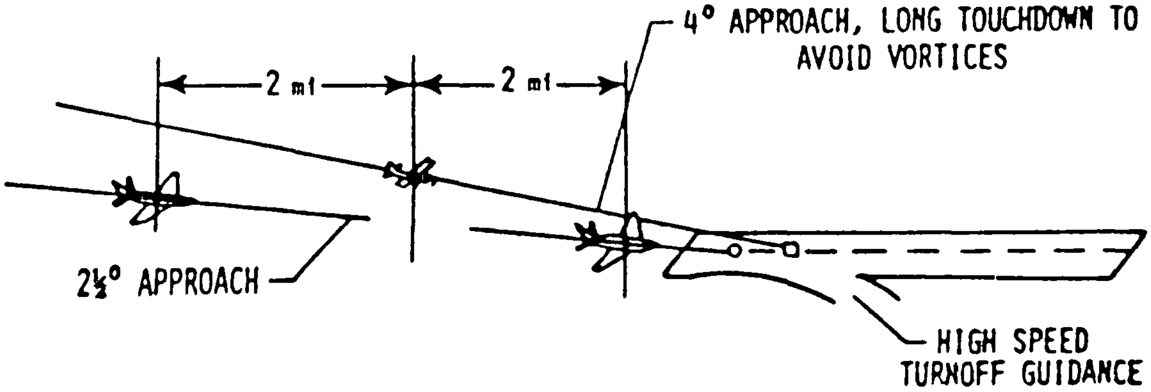


Figure 15.- Conceptual high-capacity runway. Vortex avoidance. Miles given are in nautical miles.

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15 Supplementary Notes

16 Abstract

A concept for increased pilot involvement in a future National Airspace System was evolved during the "FAA New Initiatives in Engineering and Development Users Conference." This concept was used to develop pilot and controller tasks and responsibilities and ways in which they might interact.

The technical feasibility of the system is indicated by the sophisticated level of presently manufactured digital computers and display avionics and the application of that technology under design by the major airframe manufacturers. Data collected during simulations and flights with the Terminal Configured Vehicle Program B-737 airplane are shown to have direct application to the new system concept. The adoption of the operational changes envisioned offers some potentially significant advantages to the user.

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