FLIGHT EXPERIMENTS TO IMPROVE
TERMINAL AREA OPERATIONS

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SUMMARY

A brief description is given of the objectives and activities of the terminal configured vehicle (TCV) program and of some of the airborne facilities. A short analysis of some particular problems in CTOL operations in the terminal area is also presented to show how the program's technical objectives are related to the defined problems. The test aircraft was flown both manually and automatically with manual monitoring over paths including 130° intercepts and 2.0-km (1.1 n. mi.) and 0.8-km (0.44 n. mi.) finals. Some statistical data are presented from these and other flight profiles designed to address specific terminal area problems. An overview is presented of research studies receiving emphasis in the next biennium and their application to the terminal area. A description of work being undertaken to study the addition of adjacent traffic information to present map displays is also given.

INTRODUCTION

The terminal configured vehicle (TCV) program was conceived to address the problems of operation in the crowded terminal area airspace and the integration of the airborne avionics systems necessary to improve the efficiency of those operations. The airborne experimental systems necessary to do the research were first described in reference 1 and are illustrated in figures 1, the TCV B-737 airplane; 2, the interior of the airplane showing the locations of the computer systems and the all-electronic aft flight deck; and 3, a block diagram of the entire experimental system interconnections. The aircraft automatic controls, manual controls, and displays have been modified to incorporate advances which will be discussed in this paper. The changes needed for operations in the Microwave Landing System environment are illustrated in figure 4.

The program objectives were first presented in reference 2. These objectives have been reviewed by many in the aviation community who have a stake in the terminal area operation. The refined and restated objectives are shown in table I. The problems of the terminal area are complex and interrelated. The classification of table I serves to simplify discussion and does not imply the isolation of issues.

The attempts to solve these interrelated problems lead to the recognition of identifiable and desirable capabilities which contribute to the capacity and efficiency of the airspace system. Some of the system requirements and specifications are illustrated in figure 5. The curved approach capability serves many of the problems stated in table I, as does the freedom to operate in lower minimums with greater regularity. Reduced interaircraft spacing, closer runway spacing, precise navigation in time as well as distance, and rapid runway clearance are also desirable factors which can be quantified.

The terminal configured vehicle program has been working on many aspects of the problems related to the curved descending flight profile. Both automatic and manually augmented modes have been flown using the electronic displays with the Time Referenced Scanning Beam (TRSB) Microwave Landing System (MLS) as the principal navigation aid. The achievements of these flight tests will be discussed.

Many research issues must still be resolved before improvements are realized in the capability of the commercial long-haul air transport system. Those related specifically to the aircrew tasks are shown in figure 6 which presents a breakdown of the approach path into its phases.

Generally, the program is pursuing its goals at a moderate pace by utilizing the research results obtained at the NASA Langley Research Center and at other centers of research. Cooperative research programs are being pursued with the NASA Ames Research Center and with the FAA. The most notable of the FAA cooperative programs which have already received extensive attention are the basic display system evaluation and, more recently, operations with the MLS. The latest advanced research program being considered in cooperation with the FAA and the NASA Ames Research Center will deal with the cockpit display of traffic information (CDTI).

ABBREVIATIONS

A/C aircraft

AFD aft flight deck

AGARD Advisory Group for Aerospace Research and Development

AGCS automatic guidance and control system

ARTS automatic radar terminal system

ATC air traffic control

Az azimuth

BCAS beacon collision avoidance system

CAB Civil Aeronautics Board

CAT II	Category II; decision height less than 61.0 m (200 ft) but over 30.5 m (100 ft), runway visual range less than 610 m (2000 ft) but over 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
CWS	control wheel steering system
DABS	discrete address beacon system
DME	distance measuring equipment
DOT	U.S. Department of Transportation
EADI	electronic attitude director indicator (vertical situation display)
EHSI	electronic horizontal situation indicator (map display)
El	elevation
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
ILS	instrument landing system
INS	inertial navigation system
IVSI	instantaneous vertical speed indicator
MAG	magnetic ground track
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

Runway 13L	left hand runway with landing heading of 130°
TCV	terminal configured vehicle
TRSB	time referenced scanning beam
VFR	visual flight rules
VOR	visual omni range station
3-D	area navigation with altitude information
4-D	time controlled four dimensional navigation
σ	standard deviation

OPERATIONAL PROBLEM AREAS AND POTENTIAL BENEFITS

A discussion of some of the current problems in normal long-haul air transport operation will serve to illustrate the need for the extensive and advanced programs being pursued. A recent projection of air traffic growth is shown in figure 7. The growth projections illustrated are conservative, as indicated by the actual data on fleet size in 1976. Projections have consistently tended to be conservative. The boundaries projected by the DOT Transportation System Center (ref. 3) are an attempt to account for the unforseen demands.

The impact of such growth is illustrated in figure 8. The figure shows the number of airports which are expected to reach IFR capacity (delays in excess of 15 minutes over normal peak hour delay) in the next twenty years. It is expected that by 1984 twenty-one major hub airports will have reached IFR capacity by current standards. That date, incidently, is near the time when our next generation of aircraft is expected to be in the fleet. The number of airports which become IFR limited is projected to increase at a slower rate thereafter simply because the number of major hubs (the places where people want to go) are limited.

How does growth in the present system affect air travel? Figure 9 is a composite of the time intervals combined to construct a city to city flight as presently scheduled. Emphasize the work "scheduled." The times shown here are those published in the schedule. They include (as indicated by the cross hatching) a number of categories of delay. The time alloted to each is an average of the times actually experienced in each category. If the airplane leaves and arrives at the scheduled times, the passenger is unaware of any of these delays. When a passenger arrives late, that event is not a part of these schedule components. Note that the time, and indirectly the fuel, required to fly from Newport News to Washington National Airport is now 42 percent greater flying a B-727 under instrument 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 largely as a result of increased traffic and congestion. The flight from Newport News to Atlanta is particularly interesting because it takes place on a B-727, the most common aircraft in the trunk system today, and over a route of 468 n. mi. The average stage length for the B-727 fleet is about 430 n. mi. The illustration, therefore, has the connotation of the most common flight of the most common aircraft and is indicative of the whole fleet's fuel and time usage. The schedule buildup may be described in the following terms:

Gate departure -	Close doors.
Taxi out -	Engine start, check list, taxi to runway over minimum distance.
Taxi-out delay -	Waiting for other traffic clearance, nondirect routes to the runway.
Area maneuvering -	Vectoring by the air traffic controllers to get the airplane into route system.
Stage length -	Minimum distance to destination at optimum cruise altitude. Includes climb and descent.
Airway route increment -	Additional distance required to be flown to stay within the jet airways system.
Terminal area delay -	Average delay experienced because of other traffic.
Weather delay -	Average delay experienced because of extra distance flown to avoid weather.
ATC maneuvering -	Vectoring from air route to approaches because of traffic, wind changes, etc.
Taxi-in delay -	Delays after departing runway prior to gate arrival for gate assignment, other traffic, etc.
Taxi in -	Time to reach gate over minimum ground route.
Gate arrival -	Open doors for passenger departure.

In discussing delays, it is important to realize the different interpretations of "delay." The CAB concern with schedule adherence sees no delay per se in these schedules. The ATC system is concerned with delays other than normal and above the daily average (different than peak hour delay).

The passenger, however, is vitally concerned with the time to destination (the basic impetus for air traffic growth) and the reliability of his schedules. It is worth noting that the percentage of time related to the normal delays built into the flights represents almost a quarter of the scheduled flight time. This extra flying time is directly related to fuel consumption as well as to other direct costs.

Another aspect of the terminal area problem is illustrated in figure 10. This illustrates the New York terminal area with its four major airports and the instrument approach paths crossing control areas. The controller's communication problem in dealing with traffic across these zones can only be imagined. Further, note the overflights of high density residential areas. Also indicated on the figure is the Canarsie (CRI) approach into John F. Kennedy International Airport (JFK) runway 13L. This approach is designed for the alleviation of noise in the community, but it is only flown under visual flight rules. It is one of the approaches that has been flown with the TCV B-737 using MLS without visual reference from the AFD. These problems in traffic flow are not unique to New York. The Norfolk terminal area, for example, includes twenty-three airports operating in a rapidly growing noise-sensitive residential community.

In order to solve these problems and increase the flow of traffic, additional capability must be incorporated into the airplane. The automatic systems must operate more precisely over a greater volume of airspace, and the aircrew must have more information in easily understood forms. In order to make use of the information and perform necessary extended mission requirements, the flight controls must be better related to the displays and the mission. The interaction of the displays, pilot controls, and automatic controls constitute an inseparable aircraft system. Indeed, the system requirements are a vital part of the traffic flow requirements in the terminal area.

Some potential benefits for today's ATC systems are discussed in reference 4. If the ground aids are available, if the manual and automatic systems are properly designed, if the displays present the proper information, and if the trailing vortex problem can be alleviated, closer aircraft spacing throughout the system can result in an increase in capacity of 85 percent. That amounts to a change in the current separation standard capacity limit from about 30 to 55 aircraft landings per hour per runway. (See fig. 11.) Other built-in delay elements of the individual aircraft, such as taxi delays and RNAV, can be better addressed by more accurate scheduling into the terminal area. The need for accurate time delivery will impose a requirement on the aircraft and on the ground systems. Accurate 4-D navigation can then be made available and can be effectively used to achieve major benefits in air traffic flow.

The planned ATC system components which contribute to these benefits are the MLS and the increased analysis capability in the Automatic Radar Terminal System (ARTS). The addition of automated metering and spacing (M & S) and a digital data link (exemplified by the Discrete Address Beacon System (DABS)) are also expected to provide unique additions. Air derived data links (i.e., Beacon Collision Avoidance System (BCAS)), having more precision and higher data rates than the radar system, may at times have a significant effect. The Global Positioning Satellite (GPS) system is also expected to contribute in all areas of the ATC system.

FLIGHT TEST RESULTS

The TCV program has recently addressed the problem of curved descending decelerating flight onto a short final leg. This program, pursued in analysis and simulation, was flight tested in the spring and summer of 1976. The data have been analyzed and presented at the AGARD symposium on guidance and control design considerations in references 5 and 6. A graphical summary of all the close-in-final flight profiles that have been flown during the past two years is shown in figure 12. This summary figure includes flights during the summer of 1976 and the most recent flights in December of 1977 where the Canarsie approach in New York was flown.

The tests at the FAA National Aviation Facilities Experimental Center (NAFEC) were flown with the two profiles shown in figure 13. The flight was manually controlled from the aft flight deck of the airplane. After takeoff, the pilots engaged the automatic 3-D navigation system which derived position data from the inertial system updated by dual DME's. After entry into the MLS coverage, the navigation solution was switched from the inertial system to the MLS signals. The automatic landing system was automatically engaged as the airplane turned onto the final approach. The two outstanding features of these flights were the short final which was reduced to as low as 1.5 n. mi. and the preceding 130° turn during the descent onto the final. Keep in mind that a typical ILS approach in today's standards starts with 30° to 45° intercept of the final at distances of 8 to 12 n. mi. (See fig. 12.) Figure 14 is a statistical summary of all the automatic 3-n. mi. approaches flown during the NAFEC MLS tests. These data comprise some 200 flights in a wind environment with strong gusts and shears. Data in table II allow comparison of the NAFEC MLS flights with previous flights on the CAT III ILS at NAFEC and with manual flight performance on the MLS.

The profile for the series of display information comparison tests is shown in figure 15. The flight path designed for these tests required the pilot to turn onto final with a 183-m (600 ft) lateral error. This offset was introduced to challenge the pilot with a sufficiently difficult task to tax him in his use of the displays and controls without visual cues on final.

Figure 16 is the graphic representation of performance on the 3-n. mi. final approach with the pilot using a velocity-vector control mode and an integrated situation-display format. It is important to note that the lateral overshoots to the final approach for this unusually difficult approach path are almost within the runway width. The significance of these data on the need for closely spaced runways cannot be understated. Of equal importance are the pilot's favorable comments on the acceptance of these profiles with the displays available to him.

Some results from these manually controlled approaches (ref. 5) are shown in figure 17. Data are shown for both the integrated display and one in which only standard horizontal guidance information was available in the vertical situation display. The data are for the nominal 30.5-m (100 ft) altitude and are shown with the FAA performance requirement boundary for Category II flight director performance. The Category II criteria for performance with a flight director are based on a long stabilized approach and enclose the data and statistics which were obtained from the close 130^{o} approach with the TCV system using MLS guidance. Figure 18 is also of interest in that it shows similar results on approaches of only 1.5 n. mi. under manual control. Even here the overshoots are quite small in relation to proposed requirements for more closely spaced runways. The pilots expressed confidence in the displays and controls on these flights as well.

Quantitative statistical data are not yet available from all the MLS related flights in Argentina and New York, but successful automatic flight performance has been demonstrated. Controlled flights were conducted in Argentina under conditions of reduced angular MLS coverage (40^{o} azimuth) and limited navigation aid availability for the RNAV portion of the flight. The airplane made successful automatic and manual landings with straight finals of 2.0 km. However, the approach intercept angle was designed to 60^{o} in a noise abatement maneuver to avoid a local community. Additional successful automatic landings were made at JFK with finals of 0.44 n. mi. using the Carnarsie approach to runway 13L.

Flight tests (ref. 7) have also been conducted on the operation of the 4-D RNAV system in the airplane with the inertial system updated by dual DME's (DME stations are automatically selected for optimal positioning accuracy). The flights were of about an hour and a half duration and started and ended in a tracking radar environment. They included climbs, descents, turns, and speed changes. The results had 1.4 seconds mean error with a 0.7 second standard deviation. These data represent another basic ingredient of necessary avionics systems to operate with fuel efficiency in the terminal area.

ADVANCED DISPLAY AND CONTROL SYSTEMS PROGRAM

The TCV program has research effort scheduled to address the full range of interrelated issues in the terminal area. The scope of these research programs are illustrated in figure 6.

Profile Descent

The boundary of the terminal area flight profile is envisioned as beginning with descent from cruise altitude. Altitude and speed information displayed on the electronic horizontal situation indicator (EHSI) are being studied to permit precise descent from cruise to a terminal area metering point with minimum fuel requirements. The objective is not merely to invoke the idle power descent but to do so in a precise manner so that the airplane can readily fit into the ATC requirements. With sufficient control capability and adequate display of information including wind data, the flight crew should be able to make good their descent and, at the same time, relieve the traffic controller's workload. Specifically, precise path following is expected to remove controller uncertainty about target progress and reduce the variables he must consider.

Curved Path Guidance

Significant problems still remain in developing the ability to predetermine the precisely follow curved paths. The previously cited automatic and manual flight results were dependent on having adequate navigation information and the accuracy with which the airplane is flown prior to acquisition of the curved flight path. As the low altitude portion of the curved flight was extended and the final approach shortened, the precision, the guidance accuracy, and the information available to the pilots on their display became more critical. The displays were adequate, and acceptable to the pilot, for following the curved flight to the short final as long as his performance kept him nearly on track. The presence of the lateral guidance information in the horizontal situation display was inadequate. As indicated in reference 5, the pilots could perform a much better approach with the lateral guidance information in the vertical situation display. The pilots simply did not like to (could not?) divide their attention between the two displays while maneuvering at low altitudes. They are not generally able to manually control the approaches when the runway is initially at extreme look angles relative to the flight path or when very little maneuvering time is available. The critical nature of the display becomes exaggerated on very short finals.

Two requirements can be defined from these considerations, and both are being studied. First, some clearly defined path to the runway must be identified in the vertical situation display when close tracking is necessary or desired. The two most actively pursued concepts that are under investigation are a "path-in-the-sky," which is described in reference 8 and illustrated in figure 19(a), and a second display being studied at the University of Illinois, which is shown in simplified form in figure 19(b). In the second display, the path is defined by a sequence of "poles" fixed at particular ground locations related to the final approach path. The pole tops are at the 3^{o} glide slope. The lines connecting the poles predict the path of the airplane at those locations.

The second major requirement is the apparent usefulness of predictive information so that the pilot can quickly correlate his controlling actions with his future path tracking requirements. Reference 9 provides an excellent discussion of the state-of-the-art of predictive displays in general. The TCV B-737 displays already include predictive position and altitude information on the electronic horizontal situation indicator (EHSI), or map display. The flight path and track angle symbols on the electronic altitude director indicator (EADI) indicate the instantaneous ground referenced predicted intercept at the runway. Both the "path" and "poles" displays are developing expanded predictive capability. A report on this activity is expected to become available during the summer of 1978.

The pathway displays and tighter path tracking can be expected to have additional advantages outside the scope of the pilots' approach requirements. That capability will contribute to improved traffic flow by permitting more closely spaced (more numerous) runways, more aircraft in trail and more paths in the terminal area. The more predictable and accurate the target airplane performance is the more effectively the controller can handle his sector traffic.

RNAV-MLS Transition

Automatically controlled curved approaches, while performed more accurately than the manual ones, are still very dependent on the delivery of the airplane to the boundaries of the precision navigation aid (MLS) and on the wind environment. The TCV program has planned for the analysis and design of algorithms and control laws for transition from the normal navaids position derivation, and consequent delivery errors, to the more precise data and paths of the microwave landing system. Further work is necessary to anticipate and assure the successful close-in final path achievement of runway alignment, with the associated increase in control gains under an expanded wind envelope.

The automatic control problems are being treated as a compatible whole, as are the display programs. The control laws are being designed using advanced parameter estimation techniques. The laws will then be implemented directly, based on digital computer architecture. They are designed to use a low data sampling rate to reduce computations and to incorporate the basic cross coupling in the aircraft dynamics to enhance system performance.

The advanced estimation algorithms will make use of the discrete data to be available from the MLS and will not require inertial platform quality signals to provide adequate filters for position, rates, and altitudes. The algorithms will also estimate the wind environment for use in the control laws.

Wind Shear

A preliminary set of simulation tests have been started which are aimed at understanding the benefits of presenting flight path angle, runway aim point, and thrust management information to the pilot on a final appraoch in various wind shear environments. Additional tests are planned and will be reported at a later date. These planned studies will cover a wide variety of shears including those the FAA has identified for study. Pilots (in simulator tests) have been able to recognize the effects of the shear on flight path and air speed and have successfully negotiated a variety of shears (but not those associated with thunderstorms as yet) with the displayed information (particularly thrust command). A second program is involved in the flight evaluation of a potential wind (total energy change) sensor. The displays are, of course, dependent upon the sensing of the wind parameters.

A parallel program to improve automatic aircraft control in severe wind shear is now in simulation. Some of the results of the analytical work have been reported in reference 10. The wind shear portion of this optimal control is implemented by estimating winds and using the estimate in the control law. The wind estimate is modified continually on the approach.

Landing and Turnoff

The progress of the airplane to touchdown upon and departure from the runway in reduced visibility has been a concern of the TCV program. High capacity operations cannot be achieved unless airplanes exit the runway quickly, allowing the following closely spaced airplane to land without potential interference. To accomplish this, the aircraft must land in a precise spot, slow, and turn off the runway on carefully designed runway exits. Such exits will, in reduced visibility, include some form of guidance sensor system.

The aircraft automatic landing system is being modified and will be flown in a mode where the distance dispersion resulting from wind variations can be reduced. Modifications to present control laws, including an automatic throttle response loop during flare, will be tested soon. The most promising concept that has evolved in simulation so far is to automatically initiate flare at a constant altitude and to modulate the descent in order to follow an exponential curve to achieve a nearly fixed touchdown distance. Simulation results show the difference in touchdown statistics between a 15-knot tail wind and a 15-knot head wind to be less than 1.5 meters (5 feet) with a maximum touchdown rate of descent of 0.9 meter per seconds (3 feet per second).

A design study has been conducted to incorporate a direct lift control function as a part of the TCV B-737 spoiler operation. The devices are being planned for flight tests in combination with appropriate control law design studies to evaluate precision tracking and touchdown criteria. Simultaneously, a series of display studies are being initiated to permit the pilot to use these powerful flight path control devices. Results from some tests of displays of flight path information have received initial in-flight evaluation in the piloted operations on short finals described earlier. They will be reported on this summer.

Low Visibility Landing Displays

Application of the cockpit CRT displays to the landing situation as both a monitor and as a control device is also being undertaken for low visibility operations. Studies have been inaugurated to see what texture patterns can be added to the outlined computer-drawn runway on the EADI to aid the pilot. It is desirable that the runway represent a surface which provides the pilot with enough information to enable him to make proper judgements on the initiation of flare and on his subsequent control of velocity and altitude. A related issue dealing with the magnification factor (the ratio of apparent displayed runway size to the actual observed runway size) is also being examined in relation to the TCV B-737 display size.

Cockpit Display of Traffic Information (CDTI)

Figure 11 and reference 4 indicate that significant potential benefit to an airplane in a high density traffic situation (routine for long-haul operations) could be realized from better control of spacing and timing in both enroute and terminal air traffic.

A concept for achieving this benefit by providing the aircrew with traffic information has been suggested and studied for a number of years by the Massachusetts Institute of Technology (ref. 11) and by the NASA Ames Research Center.

This concept purports to ease the controller problem by allowing the pilot to have local tactical control and by having him assume his traditional responsibility for continuous navigation. The controller would no longer be required to operate a very slow response control loop with poor data accuracy. He would, however, sequence traffic as always. In addition, two groups (the air and ground crews) can be monitoring the system for blunders. One aspect of a blunder is that it is a gross error that remains undetected by the person that acts. At present only one group (ground controllers) has the capability to detect such errors before they become hazardous. The pilots, of course, do not now have that ability. Further, CDTI might help to relieve the controllers of continuous monitoring functions because of an acceptable level of target behavior; that is, it is hoped that the aircrews would have sufficient information and control capability to achieve and maintain their own separation after being advised of the situation.

The basic TCV display and control work, when supplemented by surrounding traffic information, will be examined to determine whether there is a material improvement in flight performance and terminal area efficiency. When more rapid execution of desired maneuvers and closer spacing is attempted in order to provide increased runway handling and increased airspace occupancy, the issue of workload for all the personnel in the system will be a crucial one to be resolved. The ability to plan and cross check the traffic situation is expected to relieve concerns about safety.

The issues inherent in this concept relate to the means of providing sufficiently accurate and frequent data to the cockpit; the aircrew monitoring functions and the controllers' problems and functions; the potential for unwarranted action; the means for providing for controller awareness; and the determination of specific roles and responsibilities. Determination of additional ground information for controllers and development of methods for presenting this information are necessary to allow optimal use of CDTI in the ATC system. This type of study is a necessary part of the overall program.

NASA is developing a program in cooperation with the FAA to address these and other issues. Both the Langley Research Center and the Ames Research Center are participating in the definition of a plan to resolve these pertinent airborne system issues and to implement the necessary research programs over the next 2 to 5 years.

At Langley, the TCV program is conducting simulation and flight programs on the addition of traffic to the present map (EHSI) display. Experiments will be conducted considering the full range of display and control capability available in the airplane. Simulation and flight test systems are being implemented and some preliminary flight tests will be conducted this spring.

One possible application of traffic information to the present TCV map display is illustrated in figure 20. The basic map display includes our own aircraft and its predicted path; NAVAIDS; area boundaries; magnetic track; present ground speed, wind speed, and direction; identification of current navigation data sources being used; and map scale. It is planned to add ground tracks as shown for two other aircraft, their identification, altitude in hundreds of feet, ground speed in tens of knots, and their positions now, four and eight seconds ago. An alternative display will use a prediction of the future position of other traffic rather than the past position. That symbolism is expected to relieve the aircrew of the need to make that extrapolation.

CONCLUDING REMARKS

The TCV program is vitally concerned with the aircraft's operational capability in the air traffic system. This program involves the capability of the aircraft, its system, and flight crew to imprcve the efficiency and safety of the terminal area in a more demanding weather environment than present. It also includes the capability of the airborne system to work synergistically with the air traffic control system to improve the traffic flow with reduced problems for both the aircrew and ground controller.

So far, the simulation and flight test program has demonstrated that major elements can be responsibly addressed, and in some areas, with considerable success.

The studies conducted to date represent only a small but well defined portion of the system problems. The current programs described in this paper are planned steps in the overall solution of the problem.

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Table I. - TCV GOAL: IDENTIFY AIRPLANE AND FLIGHT MANAGEMENT TECHNOLOGY THAT WILL BENEFIT CTOL TERMINAL AREA OPERATIONS

OBJECTIVES	ELEMENTS
1. IMPROVE TERMINAL AREA CAPACITY AND EFFICIENCY	a. SYSTEMS AND PROCEDURES FOR ATC EVOLUTION b. SYSTEMS AND PROCEDURES FOR RUNWAY CAPACITY c. PROFILES AND PROCEDURES FOR FUEL CONSERVATION
2. IMPROVE APPROACH AND LANDING CAPABILITY IN ADVERSE WEATHER	a. HUMAN FACTOR ELEMENTS FOR EFFECTIVE FLT MANAGEMENT b. SYSTEMS AND INFORMATION TO MINIMIZE WIND-SHEAR HAZARD c. AIRBORNE SENSORS FOR WEATHER-PENETRATION
3. REDUCE NOISE IMPACT	PROFILES AND CONFIGURATIONS FOR NOISE REDUCTION

Table II. - PERFORMANCE RESULTS FOR TCV B-737 WITH ILS AND MLS GUIDANCE

Approaches		Reference altitude, m (ft)	Vertical position		Lateral position	
Type	Number		Mean, m (ft)	1σ, m (ft)	Mean, m (ft)	1σ, m (ft)
CAT III ILS	45	61.0 (200)	58.8 (193)	$\pm$ 0.6 (2.1)	0.6 (2)-R	$\pm$ 2.4 (7.8)
(40^{o}, 10 n. mi.)		30.5 (100)	28.3 (93)	$\pm$ 1.1 (3.7)	0 (0)	$\pm$ 2.3 (7.7)
MLS, automatic	56	61.0 (200)	58.8 (193)	$\pm$1.5 (5)	0.9 (3)-R	$\pm$ 1.2 (4)
(130^{o}, 3 n. mi.)		30.5 (100)	29.0 (95)	$\pm$1.5 (5)	0.9 (3)-L	$\pm$ 1.2 (4)
		Overshoot on final	----------	-----------	9.1 (30)-R	$\pm$ 18.3 (60)
MLS, manual	27	61.0 (200)	59.4 (195)	$\pm$ 3.0 (10)	1.5 (5)-R	$\pm$ 7.9 (26)
(130^{o}, 3 n. mi.)		30.5 (100)	29.6 (97)	$\pm$ 1.2 (4)	0.3 (1)-R	$\pm$ 4.6 (15)

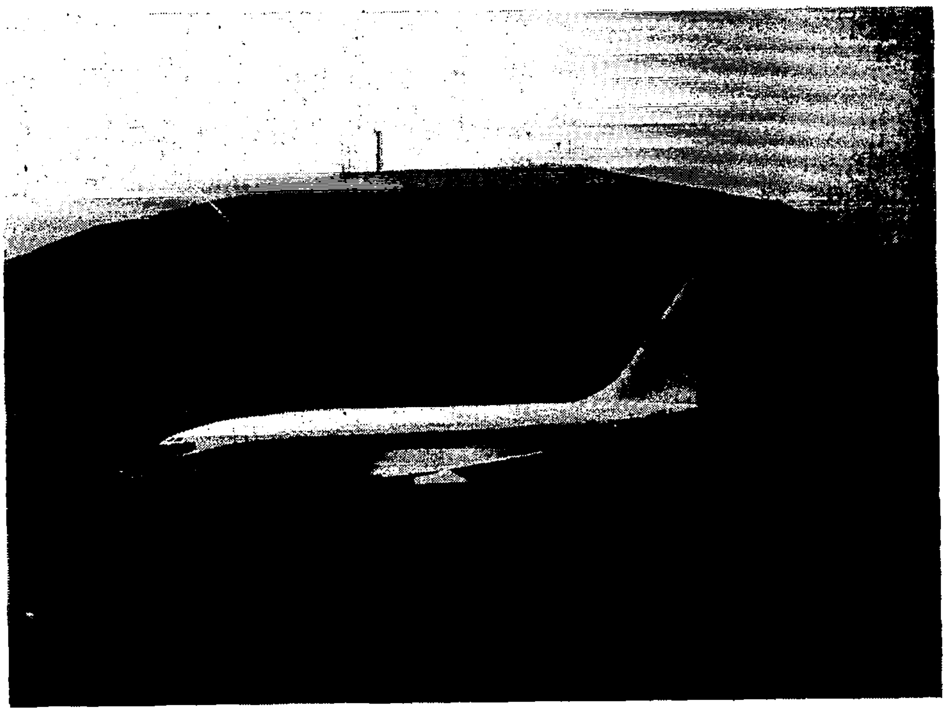
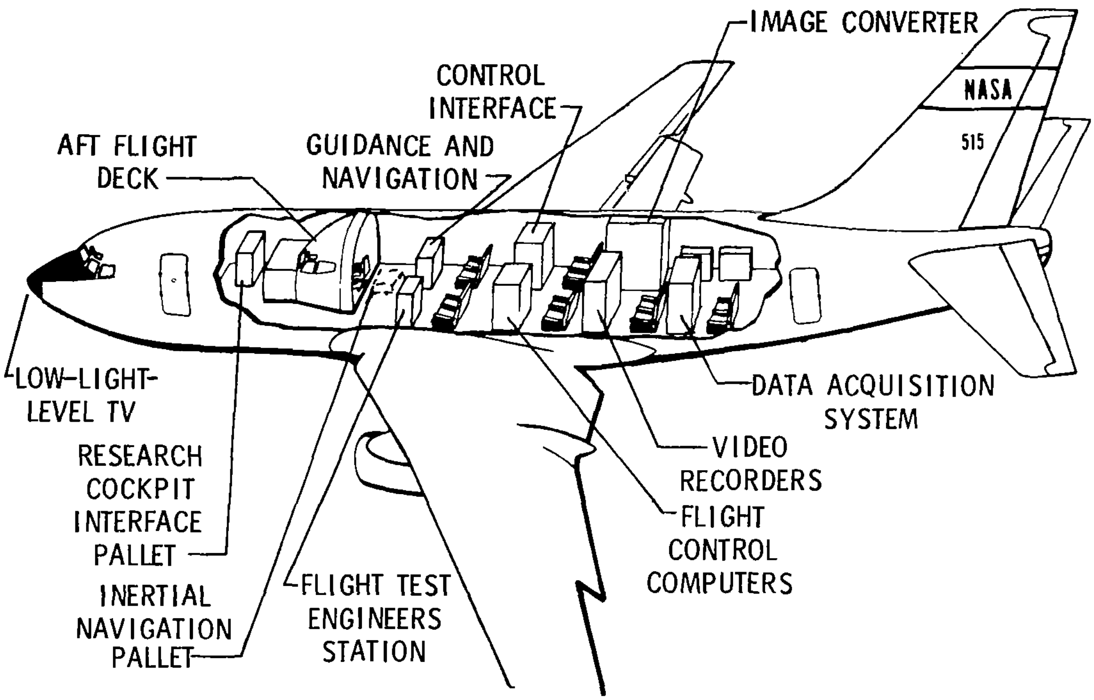
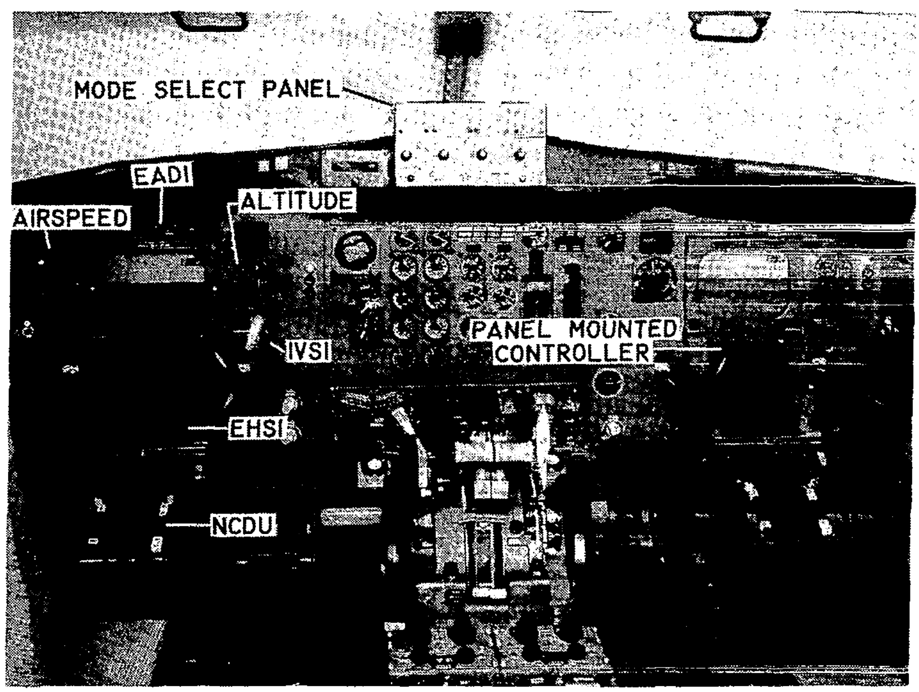


Figure 1.- TCV B-737 airplane.



(a) Location of system components.



(b) Aft flight deck control and display layout.

Figure 2.- TCV B-737 interior arrangement.

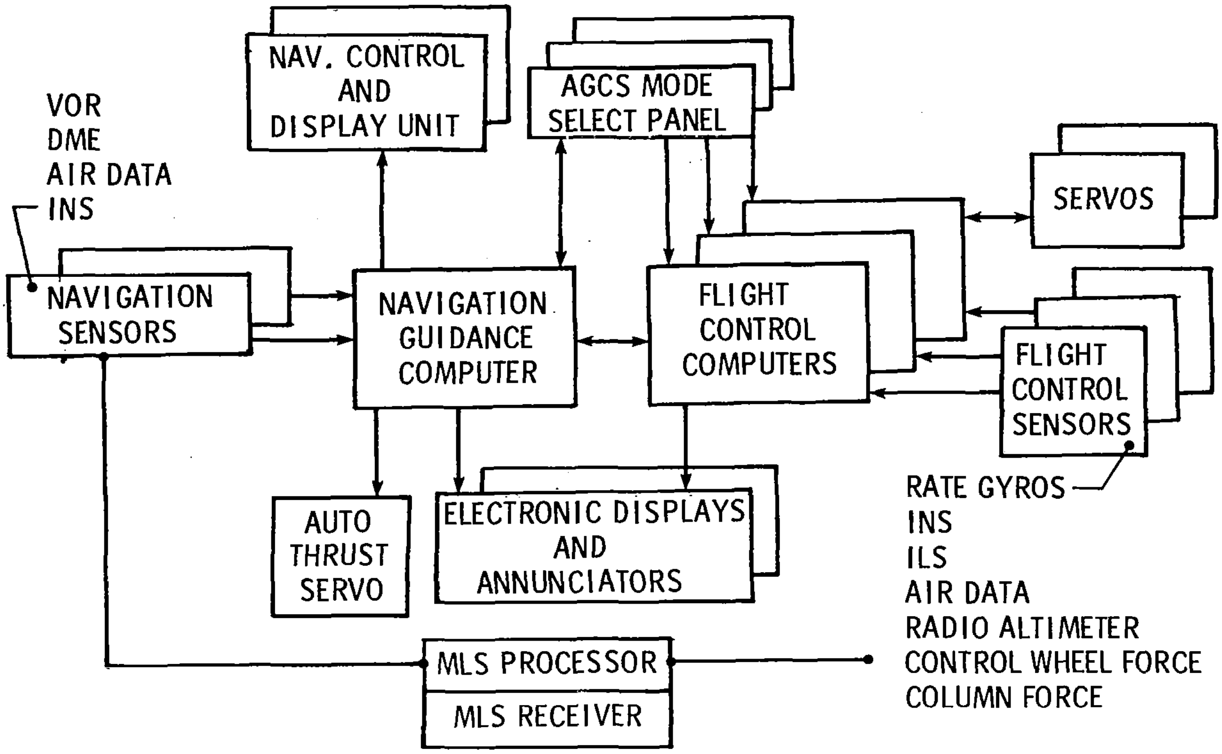


Figure 3.- TCV B-737 experimental system interconnections.

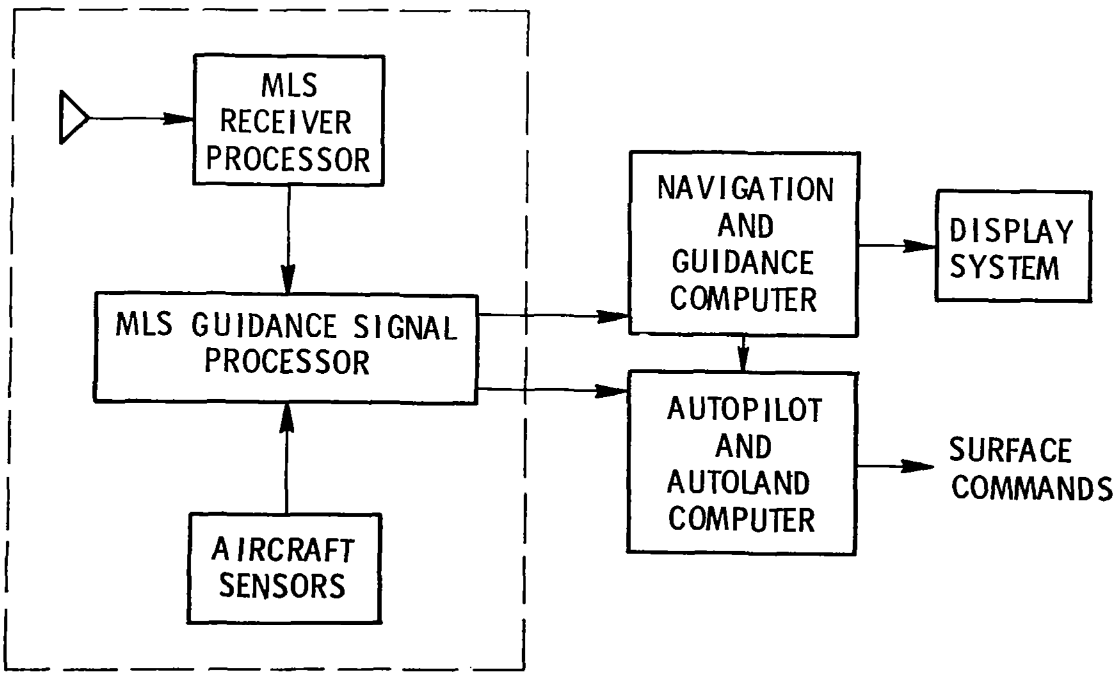


Figure 4.- MLS integration with TCV aircraft.

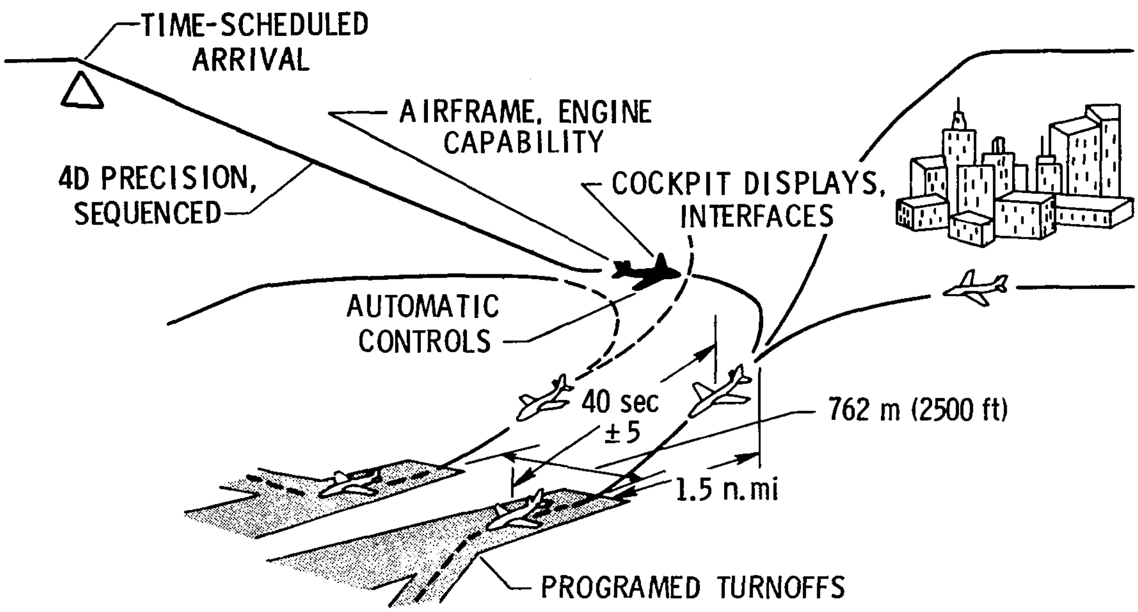


Figure 5.- High capacity terminal area operations in low visibility.

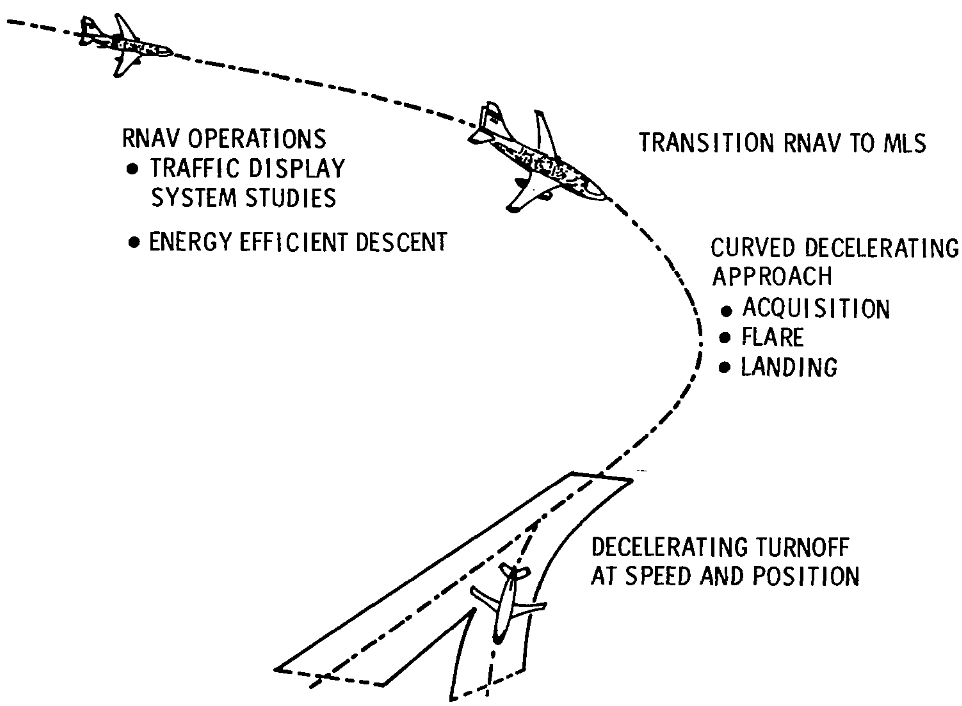


Figure 6.- TCV terminal area efforts.

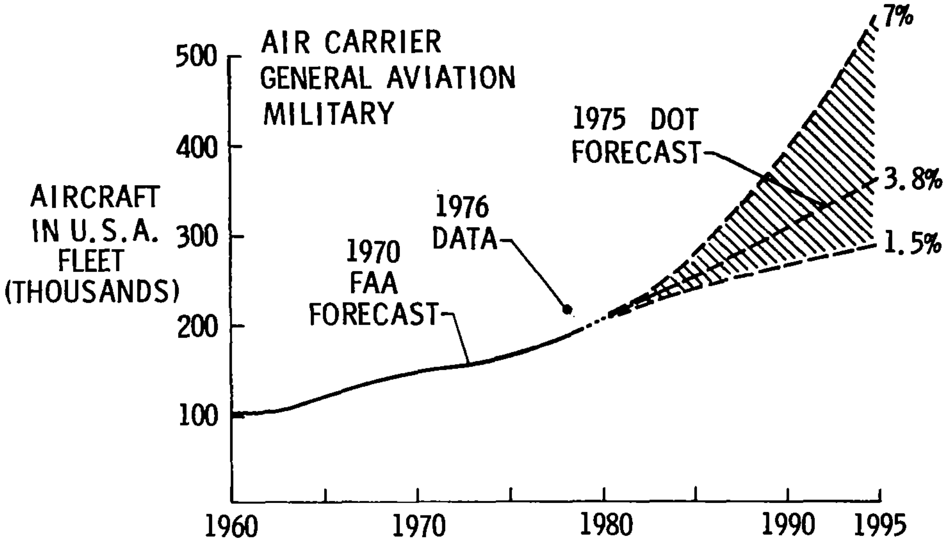


Figure 7.- Airfleet growth projections.

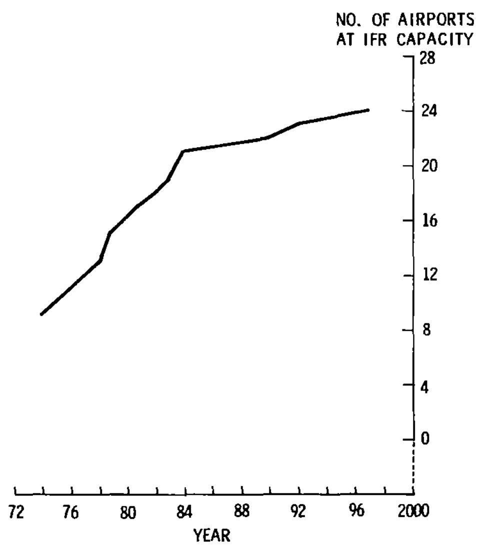


Figure 8.- Number of airports having reached IFR capacity with present ATC.

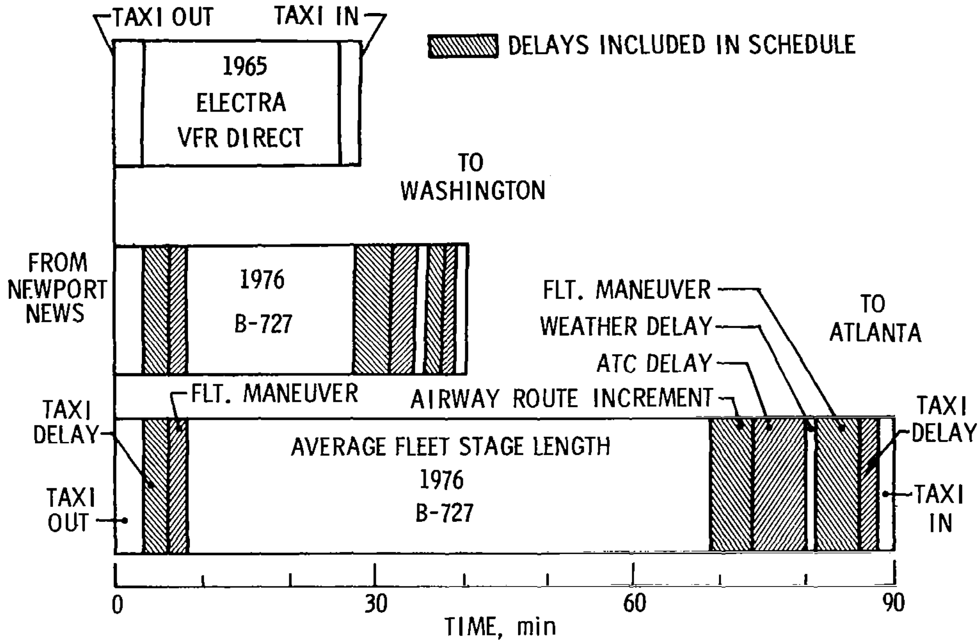


Figure 9.- Airline schedule components (nonstop).

Key

CRI Canarsie beacon
EWR Newark
JFK Kennedy
LGA La Guardia
TEB Teterboro

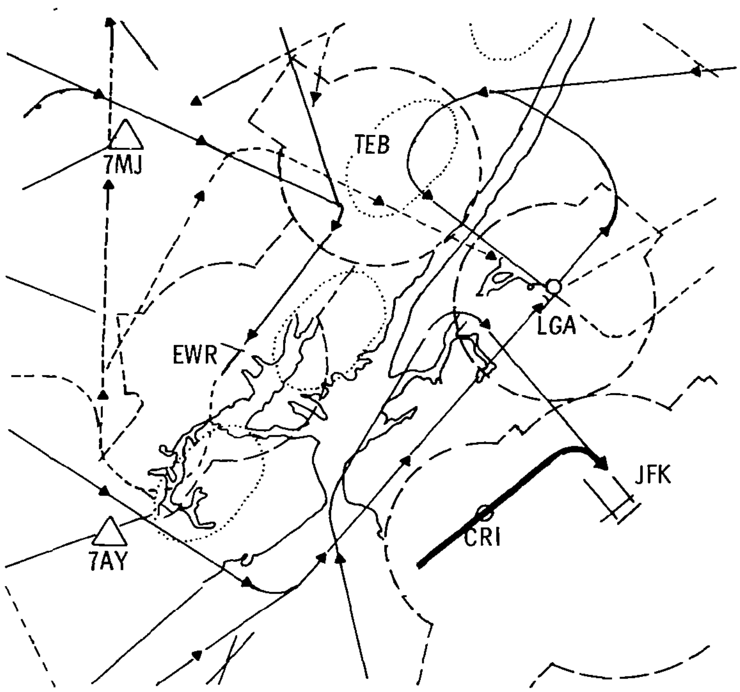


Figure 10.- New York terminal area.

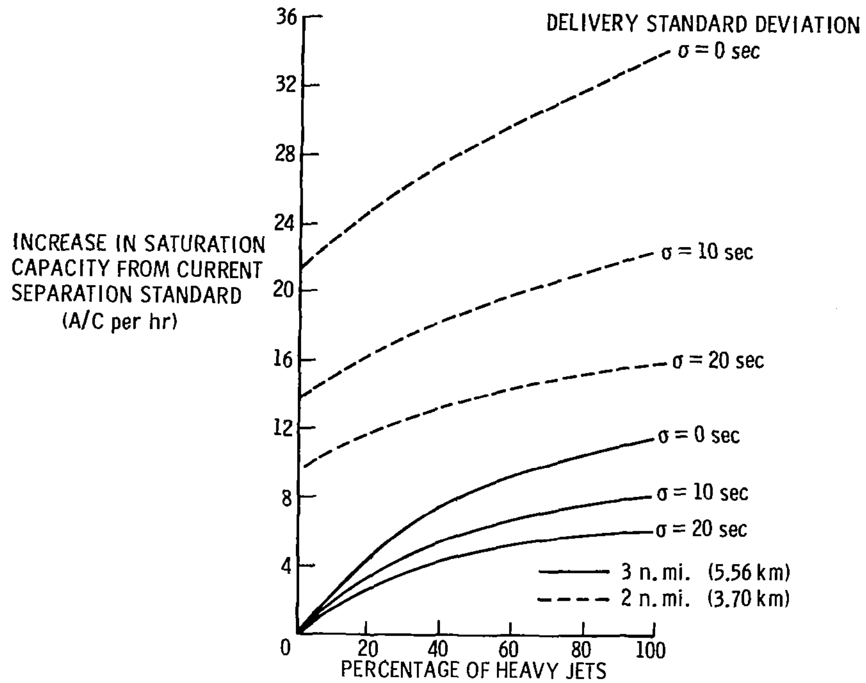


Figure 11.- Effect of delivery accuracy and spacing on capacity.

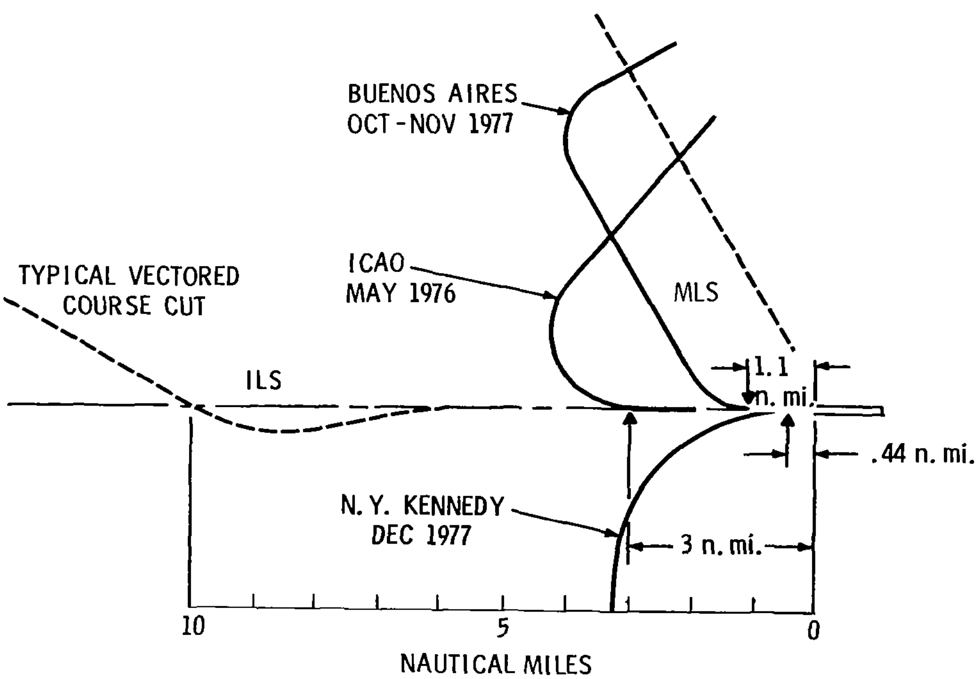
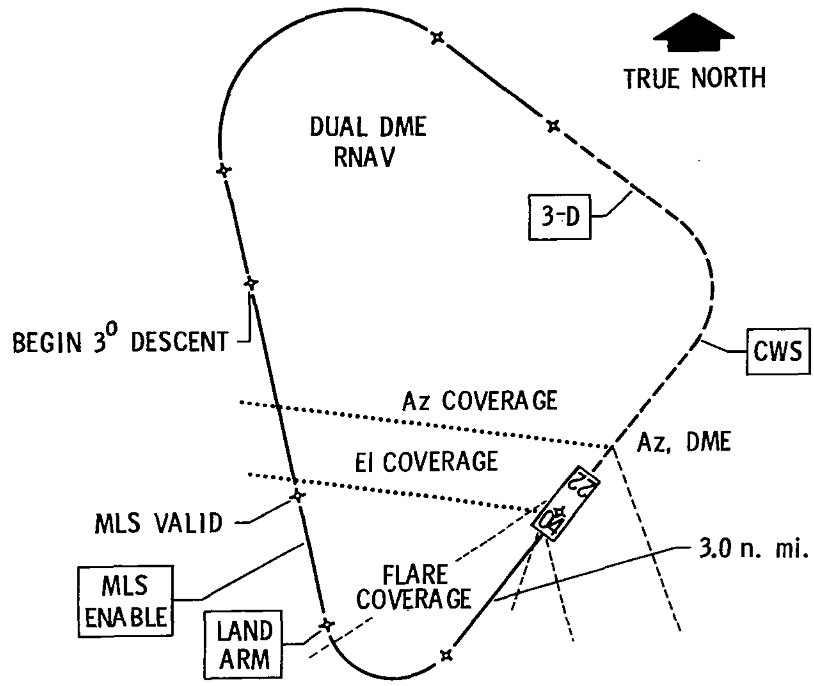
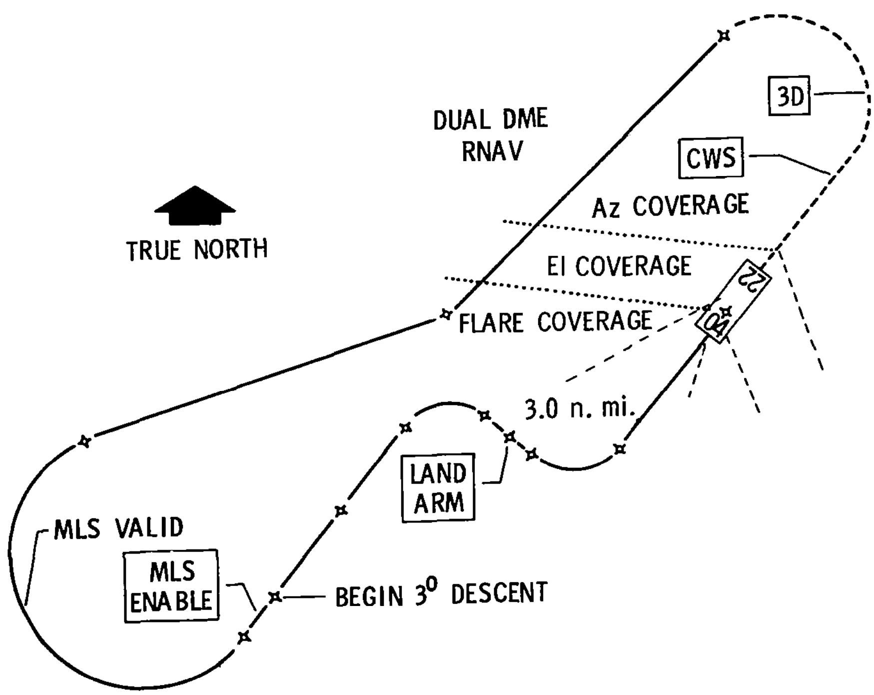


Figure 12.- Landings from close-in finals.



(a) Capture from 130° azimuth.



(b) Capture from S-turn azimuth.

Figure 13.- MLS NAFEC approach paths.

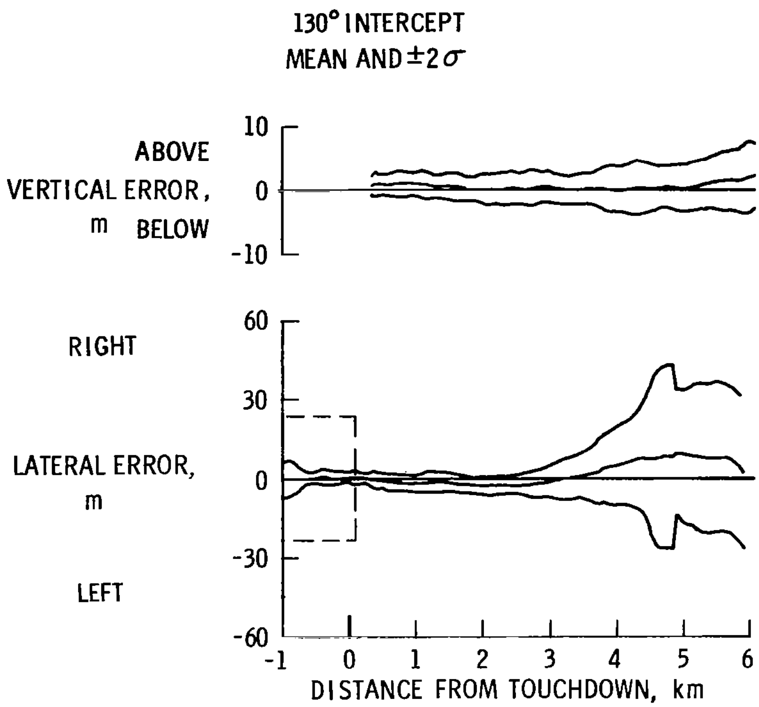


Figure 14.- Automatic tracking results on
3-n. mi. approach path.

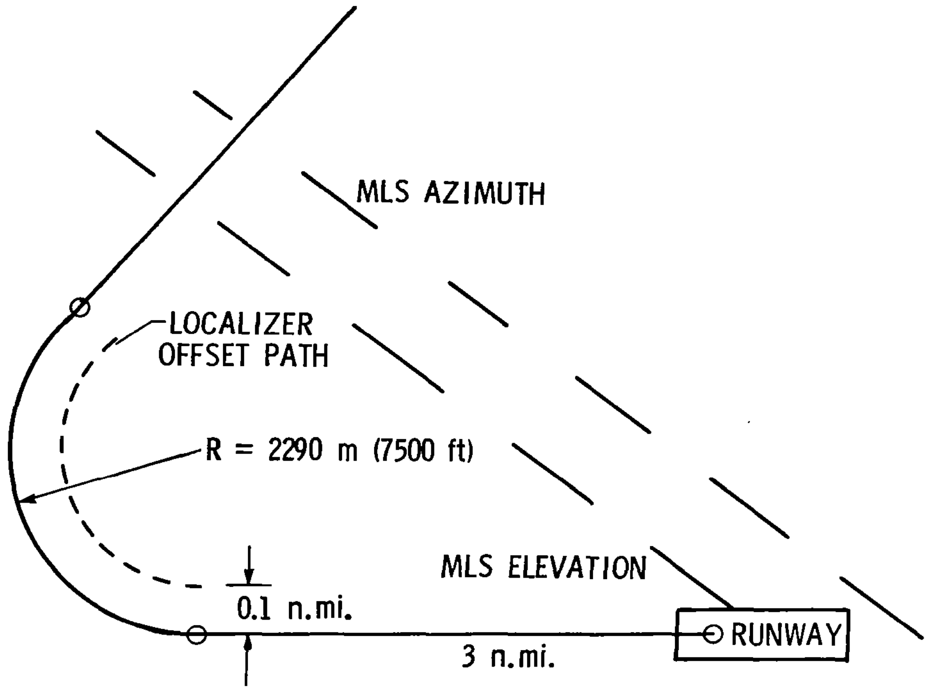


Figure 15.- Plan view of approach path to runway 04 at NAFEC.

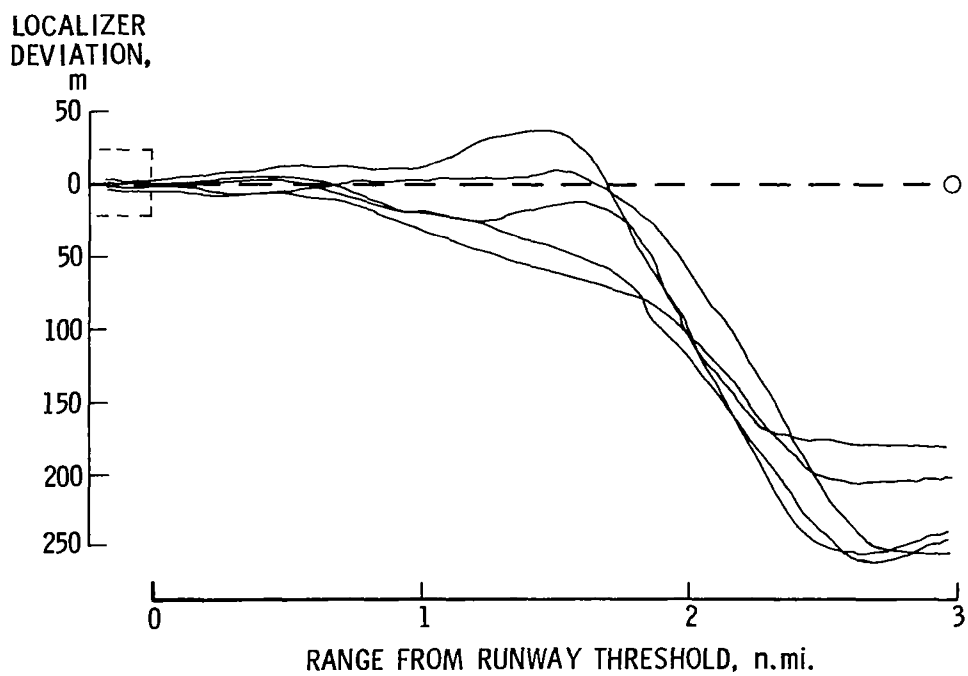


Figure 16.- Localizer tracking using integrated situation display format.

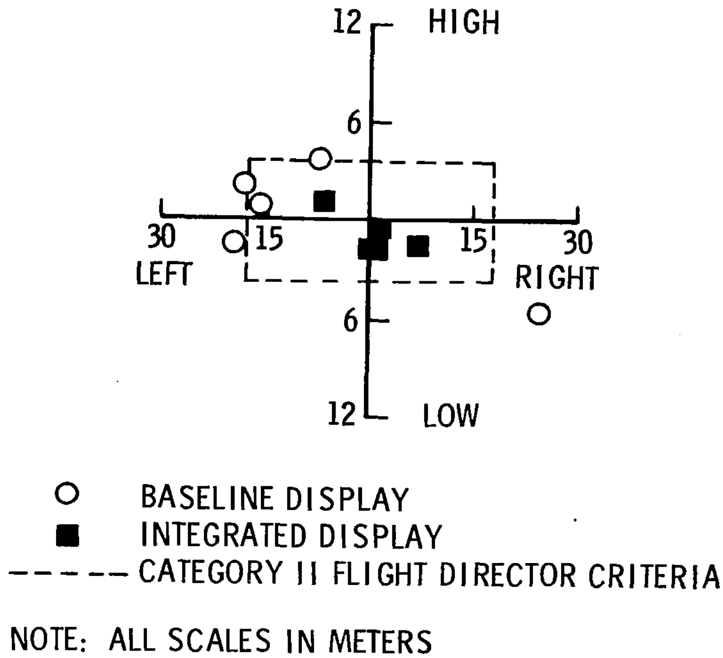


Figure 17.- Manual approach display data comparison.

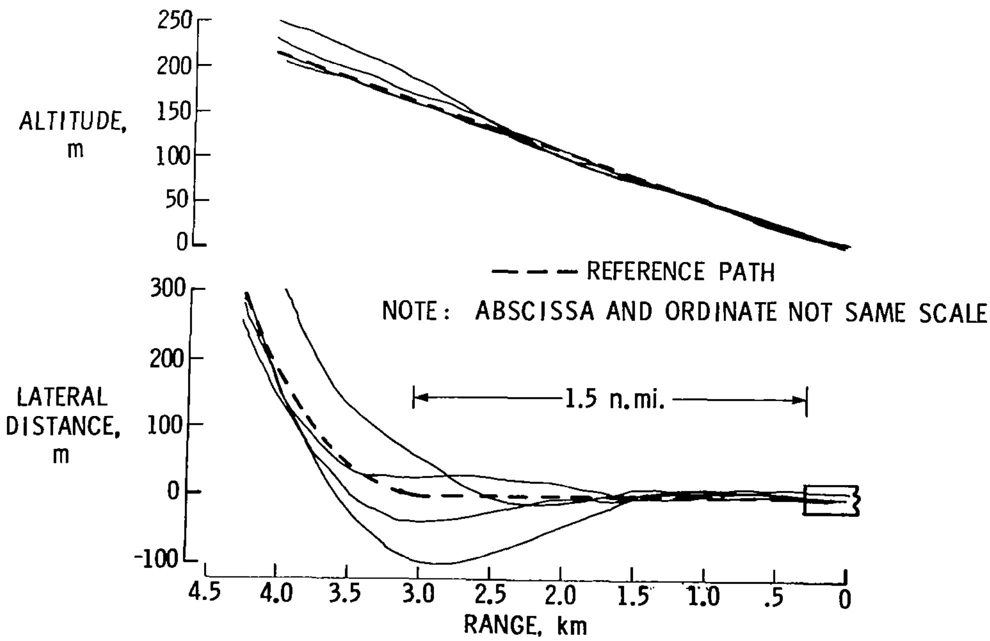
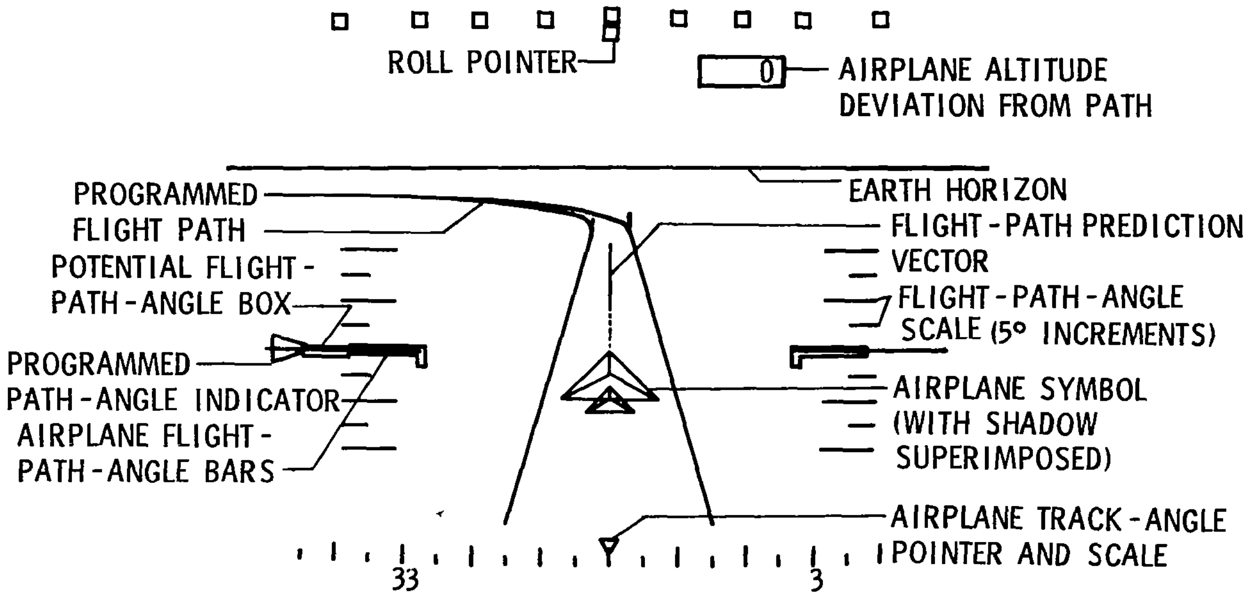
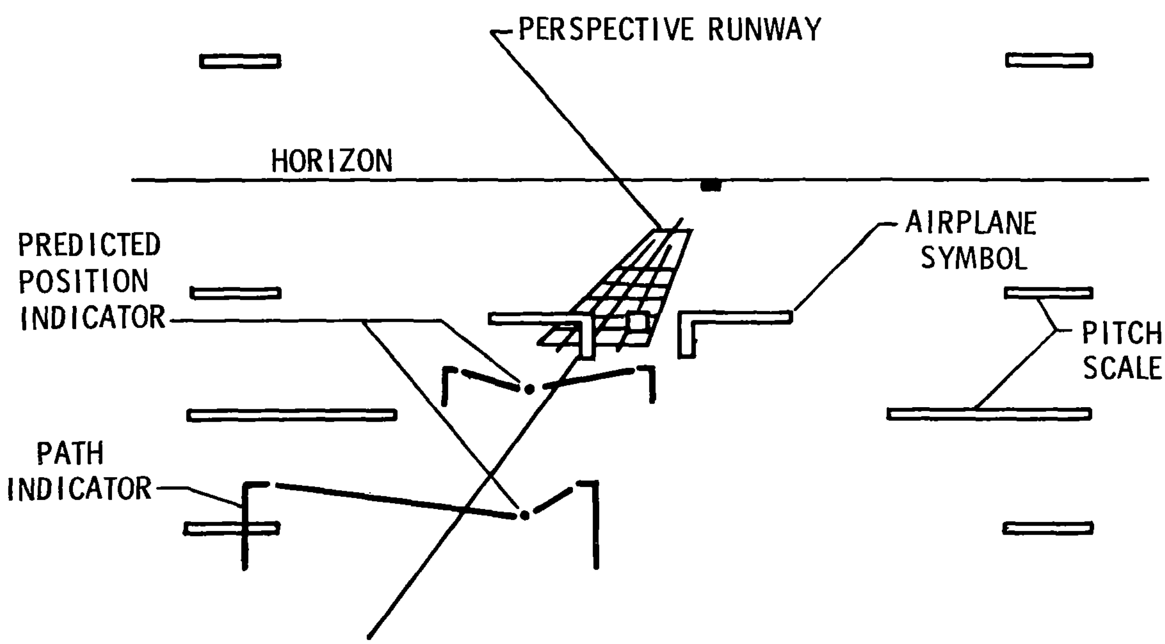


Figure 18.- Manual tracking results on 2.78-km (1.5 n.mi.) approach path.



(a) Path-in-the-sky.



(b) Predictive position and vectors.

Figure 19.- Curved approach vertical situation display.

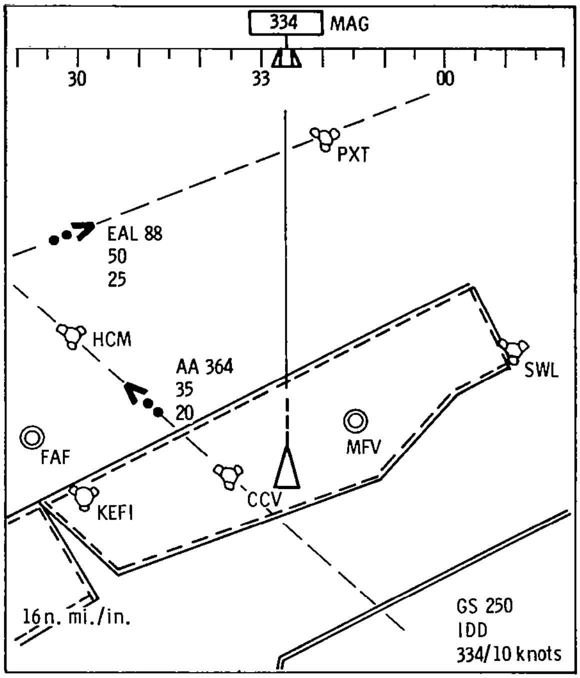


Figure 20.- Proposed CDTI and map display (sample NAVAIDS and other aircraft). Note: Map scale is 1.17 km/mm.