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NEW DESIGN AND OPERATING TECHNIQUES AND REQUIREMENTS FOR IMPROVED AIRCRAFT TERMINAL AREA OPERATIONS

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16. Abstract

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These problems are being addressed in a cooperative NASA/FAA program on terminal configured vehicles, which includes flight test development and demonstration of the most promising solutions.

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ABSTRACT

Current aircraft operating problems that must be alleviated for future high-density terminal areas are safety, dependence on weather, congestion, energy conservation, noise, and atmospheric pollution. The MLS under development by FAA provides increased capabilities over the current ILS. It is, however, necessary and urgent to develop the airborne system's capability to take maximum advantage of the MLS capabilities in order to solve the terminal area problems previously mentioned. A major limiting factor in longitudinal spacing for capacity increase is the trailing vortex hazard. Promising methods for causing early dissipation of the vortices are being explored. Also, flight procedures for avoiding the hazard will be explored.

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A. INTRODUCTION

The purpose of this paper is to discuss some new design and operating techniques to improve terminal area compatibility with particular emphasis on the airborne part of the required systems. The subjects to be reviewed are: Terminal area problems, capabilities needed for their solution, advanced technology status and requirements, and some specific information on a cooperative NASA/FAA program dedicated to providing some solutions and demonstrations for conventional take-off and landing aircraft (CTOL) in reduced weather minima and future high-density terminal areas equipped with new landing systems, navigational aids, and increased surveillance and automation under development by DOT/FAA.

B. PROBLEMS IN THE TERMINAL AREA

Problems in the terminal area are: Safety; weather effects; congestion; and resulting loss in productivity caused by delays, diversions, and schedule stretchouts; energy conservation; noise; and atmospheric pollution. The exposure of inhabited areas near airports to high noise levels was one of the first problems to cause an impact on aircraft operations. Operations in a number of terminal areas are now restricted by procedures designed to reduce noise exposure. More recently, fuel conservation has rapidly climbed to a place of high national priority in all aircraft operations and this must be a dominant concern in evaluating methods for solving the other terminal area problems.

The deleterious effects of air traffic congestion on operations during peak traffic hours at some terminals, and the near-paralysis of the system that can be caused by weather-induced delays, diversions, or closure of only a few terminals are well-known to air travelers. The effects of reduced visibility on safety occur predominantly in the terminal area, and reliable and safe all-weather operation is a major goal. Atmospheric pollution is also an item of continuing concern to the general public and must be considered in future system developments.

It should be recognized that some of the methods available for solving the various problems listed above lead to conflicting results. For example, engine acoustic treatment to reduce source noise will cause increased fuel consumption, as will be indicated later. Thus, some hard choices must be made, and for maximum effectiveness the solutions for terminal area problems must ultimately be considered and evaluated in an integrated manner.

C. CAPABILITIES NEEDED FOR SOLVING PROBLEMS

To assist in solving terminal area problems, the following new or improved capabilities are required in the airborne systems:

Increased Productivity - Reduced Weather Effects

Example Required Capabilities	Potential Improvement
Zero-visibility operation	Precision automatic control
	Advanced displays (monitoring or manual intercedance for landing)
	Independent monitor of guidance integrity
Increased acceptance rates	Improved tracking for lateral spacing
	Reduced longitudinal separation through vortex reduction/avoidance

Example Required Capabilities (con.)	Potential Improvement
Increased acceptance rates (continued)	Improved threshold arrival accuracy
	Reduced runway occupancy time
Reduced workload	Flight deck design and automation

Conservation of Energy - Reduced Atmospheric Pollution

Example Required Capabilities	Potential Improvement
Reduced air delays	Increased airport acceptance rates
	RTOL (reduced take-off and landing) aircraft capability for use of secondary airports
Reduced route time	Direct routing, deceleration from cruise through landing
Minimum-fuel flight profile	Precise airspeed and altitude scheduling and prediction
Reduced engine use on ground	Powered wheels or aircraft towing
Lowered combustion pollution	Improved combustor design and engine cycles, and new fuels (e.g., hydrogen, methane, etc.)

Reduced Noise

Example Required Capabilities	Potential Improvement
Avoidance of sensitive areas	Curved paths
Reduced source intensity	Quiet engines
	Steep, decelerating approach paths
	High rate of climb

Continuing study and testing will be required to determine the practicality and assess the value of the potential improvement, the penalties and problems involved in their application, and the costs involved. Although listed under specific categories, there is obvious interaction between the various items. For example, the RTOL aircraft capability needed to assist in reducing air delays will most likely also provide increased rates of climb to reduce noise exposure during take-off. The increased airport acceptance rates required to reduce air delays will in turn require the capability to reduce, avoid, or counteract the vortex wake problem.

D. TECHNOLOGY DEVELOPMENTS AND REQUIREMENTS

Recognition of the growing congestion associated with the rapid expansion of air travel and the noise impact of the jet fleet on the airport neighbors has, fortunately, already led to technology development in ground and airborne electronic equipment and in noise suppression, and additional development and evaluation activities should recognize and make maximum use of these early developments.

D.1 LANDING GUIDANCE SYSTEMS – The improved airborne systems will be required to operate in conjunction with upgraded navigation and guidance systems shown in Figure 1. These systems are currently under development by the Federal Aviation Administration (1)*. Terminal area operations will include transition from enroute navigation by means of an area system (RNAV), into the Microwave Landing System (MLS) with much of the operation probably being automated. The MLS (Fig. 2) will provide coded signals over an azimuth range of $\pm 60°$ and an elevation range of $+1°$ to $+20°$ plus distance information. These signals will be received and processed onboard the aircraft to provide position and velocity data. Thus, the guidance system will provide the flexibility for flying the curved and variable angle approach paths required for noise abatement, and will permit multiple aircraft arriving from many directions to be guided into a time sequenced approach pattern with maximum efficiency.

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*Numbers in parentheses designate References at end of paper.

D.2 AVIONICS SYSTEMS — In order to implement the needed capabilities and improvements, new avionics developments must anticipate the operating conditions of tomorrow's terminal area environment and must also be compatible with the evolution of advanced ATC concepts. Many constraints will affect the future systems, including location of airports and sitings of runways, noise, pilot workload, aircraft handling qualities, passenger comfort, ride qualities, aircraft dynamics and flight paths, airline operational considerations, and weather conditions. Recent advances in technologies such as automatic controls, computers, navigation and guidance, and communication systems provide the necessary tools for the development of an integrated system for effective operations within an advanced terminal area Air Traffic Control (ATC) system. There are gaps, however, in the application of technology. These gaps include the integration of the avionics with the aircraft systems and the crew, and the operating procedures required for the Advanced Air Traffic Control System environment. For example, displays, which must be suitable for monitoring automatic operation or for manual control, must be integrated into the aircraft, considering the pilot, flight control systems, guidance systems, traffic flow instructions, and collision avoidance or station-keeping systems. The airborne digital computer having appropriate ground/air data link inputs and outputs; data storage capacity; aircraft control, sensor, and actuator inputs and outputs; and pilot/display and instrumentation interfaces, offers the most promise as an integrating element for the onboard system.

Advanced aircraft operating in the future civil air traffic management system will require guidance and control techniques and enroute and terminal area operating procedures which are significantly different from those currently in use. Advanced flight-path control and landing systems will be required to maintain rigorous schedules during noise abatement flight procedures, and to interface with ground equipment transmitting guidance information. Unique requirements arise from precision horizontal, vertical and time-controlled (4D) navigation and close-in curved and decelerating precision flight-path control throughout landing in Category III visibilities. At the present time, advanced guidance and control systems making full use of digital technology offer the most promising approach.

Although automatic landing systems have been developed and automatic landings made routinely during good weather conditions, they are being used only by two operators in the world in commercial airline operations during actual low-visibility conditions (Category III(a) Interim). This is due, in part, to the lack of suitably equipped runways, but also due to a lack of operationally suitable autoland performance and to the inability of the pilot to adequately assess this performance as defined by the aircraft's situation relative to the touchdown zone as it is approached. The most effective role of the pilot in Category III landing operations has not been defined and his role in automatic systems operation requires study and evaluation.

NASA's on-going research work in digital flight-control techniques involves the application of an onboard system to perform the command and control function, motion suppression (ride control), modal alleviation and flutter suppression, maneuver load alleviation, stability augmentation, guidance and navigation, and performance and failure monitoring. Specific digital computer work includes investigations of logic theory, efficiency of computations, and self-monitoring functions.

The application to aeronautical guidance and control systems of advanced electronic circuitry and systems developed in support of the space program may offer significant advantages. Acceptance of these advanced systems (pure fly-by-wire) is not anticipated until sufficient flight investigation and evaluation is undertaken.

D.3 ENGINE QUIETING AND ENERGY IMPLICATIONS – Conceptual designs of advanced fanjet engines with a primary goal of reduced noise have been studied (2,3). The use of high bypass ratios and extensive acoustic treatment of the engines were both found to be effective, with a combination of the two being required to achieve the magnitudes of noise reduction desired. An example of the noise benefits obtained and economic costs of quiet engines is illustrated in Figure 3, (2). The top half of the sketch represents a high bypass-ratio engine designed to achieve FAR 36 noise levels with no acoustic treatment. The lower half of the sketch shows the acoustic treatment and increased length necessary to obtain a noise reduction of perhaps 12-18 EPNdB. The heavy lines illustrate the acoustic treatment. The increased length and the added acoustic treatment would, of course, add to the weight and cost of the engine and increase the fuel consumption. Variable fan and nozzle geometry can also be used to achieve the lowest noise levels but the weight and cost would most likely be prohibitive.

The curves show that increasing amounts of acoustic treatment can achieve noise reductions as great as 12-18 EPNdB below FAR 36 levels but that the cost in reduced return on investment (ROI) is large. A reduction of 1% in ROI is a significant economic loss to an airline. It appears, at least from this example, that achievement of noise reductions above about 10 EPNdB by engine design and treatment may be economically impractical and noise abatement flight procedures may be a practical necessity.

An example of a typical conflict between energy usage and environmental quality (in this case, aircraft noise) is shown in Figure 4 (for the terminally compatible study airplanes of Ref. 4). For advanced CTOL aircraft designs, the 90 EPNdB footprint areas in square miles are plotted as a function of percent block fuel increase at design range.

Several important observations are suggested by the design estimates of Figure 4:

(a) The take-off (middle set of curves) produced about 80% of the noise footprint for the study airplanes, and this is essentially unaffected by extensive acoustic treatment.

(b) Increased engine acoustic treatment will reduce the approach noise footprint area, but at the cost of increased block fuel usage (about 3%).

(c) Steep approach angles will lower the approach noise footprint to a level comparable to that obtained with extensive acoustic treatment.

(d) The airplane designed for steep approaches will be heavier than one without this requirement, which will result in a block fuel increase of about 1%.

(e) Steep descent procedures will thus lead to a net fuel saving of about 2% compared to an acoustically treated nacelle at low approach angles.

E. TERMINAL COMPATIBILITY

E.1 TERMINAL CONFIGURED VEHICLE (TCV) PROGRAM –

<u>E.1.1 Overview</u> – It has been recognized that new navigation, landing guidance, and ATC equipment and procedures cannot solve the problems that they are intended to solve unless the airborne systems and procedures are

developed to take full advantage of the capabilities of the ground-based facilities. The airborne system is considered to be the basic airframe and equipment, the flight-control systems (automatic and piloted modes), the displays for monitoring or pilot control, and the crew as manager and operator of the system. Because of the urgent need to develop the required airborne system capability, the NASA Langley Research Center (LRC) has implemented a long-term research effort known as the Terminal Configured Vehicle Program. The program will conduct analytical, simulation, and flight-test work to:

Develop advanced flight-control capability for –

- 4D RNAV and transition to MLS
- Precision curved, steep, decelerating final approach, time sequenced, utilizing MLS
- Zero-visibility landings through turnoff

By means of –

- Advanced automatic controls
- Advanced pilot displays for monitoring/control
- Reduced crew workload
- Improved interfaces of avionics, aircraft, crew
- Advanced airframe configurations to be determined

E.1.2 Research Support Flight System – The primary facility to be used in the flight research program is the Research Support Flight System (RSFS). The system consists of a Boeing 737 aircraft shown in Figure 5 taking off for its first flight with NASA markings. An FAA insignia has been added to the aircraft since this is a cooperative program with FAA. The equipment aboard the aircraft includes all-digital integrated navigation, guidance, control, and display systems, the latter developed for the now defunct U.S. Supersonic Transport (SST). These developments were initiated to provide a state-of-the-art digital system technology base for future transport airplanes. The baseline operational requirement for these systems considered low approach operations in future air terminals of high density using noise abatement procedures with consideration for the economics of their operation and purchase; however, Category III landings or close-in curved approaches were not a requirement. Utilization of the technology spinoff from the SST is considered to be a very important element of the TCV program in that the display hardware and computer developments had already taken place under a DOT contract, and it appeared to be a cost-effective means of initiating the operational aspects of the research program. It is to be stressed that these systems are considered a starting point rather than the end points of the equipment to be developed in the program.

A cutaway view of the airplane is shown in Figure 6 illustrating the palletized installation of these equipments and depicting a second cockpit for research (aft flight deck, AFD) installation. The value of the RSFS for research purposes is enhanced by several notable design features:

(a) The system functions are controllable and variable through software.

(b) The hardware is easily removed, modified, repaired, and reinstalled.

(c) Flight station changes are readily accomplished in the research cockpit which has a fly-by-wire implementation for control of the airplane. The Advanced Electronic Display System (ADEDS) pilot displays illustrated in Figure 7 consist of an Electronic Attitude Director Indicator (EADI) at the top, the Electronic Horizontal Situation Indicator (EHSI) in the middle, and the Navigation Control/Display Unit (NCDU) at the bottom. The display system is all-digital and can be readily re-programed with regard to formats and symbology for research purposes. The NCDU is used to call up pre-planned routes and flight profile information or for entering new or revised information to be displayed. Inserted information and flight progress information can be called up on the NCDU for review. This display system will be retained by NASA on a long-term loan from DOT-FAA.

The EADI instrument provides basic attitude information to control the aircraft. Also, error or command symbology can be added to fly predefined horizontal, vertical and speed controlled (4D) profiles and transitions from one profile to another. The EHSI shows the horizontal plan of the flight, either heading-up or with north-up mode, and the flight progress. On it can be displayed moving time slots in which the pilot can maintain position, manually or automatically, for sequencing. Also, the dashed leader line projected from the nose of the aircraft in the figure shown presents predictive information to the pilot as to where the airplane will be (at its present turn rate) in 30, 60, or 90 seconds from the present. Although the entire flight plan could be flown from the EADI alone, the EHSI adds greatly to the clarity of the situation and provides long-term anticipation for the pilot. It is a great confidence builder and a planning aid to changes to the flight plan.

A block diagram of the integrated navigation, guidance, and control system in the aircraft is shown in Figure 8. An implementation of redundant computers and sensors is the heart of the automatic control system in the airplane. It is configured to allow an evaluation of sensor voting techniques. Inasmuch as the basic 737 controls have not been disturbed, the servos remain the simplex system of the basic airplane with a monitor added.

In this diagram, the research cockpit controls appear as another sensor input to the flight-control computers. Other elements of the system make up the navigation, guidance, and display subsystem. The concept would require these systems to be duplex but their implementation for TCV research on the 737 is single thread.

A photograph of the partially completed aft flight deck is shown in Figure 9. Spaces provided for the ADEDS unit are visible as well as the Brolly Handle controls used to permit unobstructed views of the ADEDS.

E.1.3 Avionics Equipment – A major part of the effort in the first part of the TCV program will be to investigate and evaluate the advanced avionic equipment that will be on the airplane initially to determine its suitability for use during the complex approach paths made possible by the MLS guidance. Following these phases, new or different avionic systems will also be considered and evaluated as deemed appropriate.

E.1.3.1 Guidance and Controls – It is necessary to determine the most effective aircraft operating system from the standpoint of cost, safety, pilot proficiency (through use in day-to-day operations), and pilot acceptance during crucial Category III operating conditions. The objective will be to define a system employing a digital computer for aiding the crew in its monitoring, checkout, and flight planning functions. A time line analysis of crew functions to define workload, and the design of software to aid at peak workload times will be undertaken and demonstrated on a flight simulator. The reduction in distraction and workload and its effect on increasing safety during critical flight periods will be determined. The man/machine system, with the added capabilities inherent in the digital computer, will be investigated to further define satisfactory handling qualities of aircraft operating in an advanced ATC system particularly during maneuvers required in heavy traffic situations. The flight-control work will develop an advanced system and evaluate the potential of digital sensors and actuators as well as digital computers. This work will provide technology to allow better command-following for the aircraft in executing ATC flight paths.

E.1.3.2 Digital Flight-Control System Computers — Future transport aircraft are expected to utilize digital computer systems to perform such critical tasks as stability augmentation, flight-path control, and automatic approach and landing. Concepts and techniques required to maintain a high level of aircraft safety and system reliability with the high degree of automation required for future operations are being examined.

During the initial phases of the TCV program, the flight critical functions of the automatic guidance and control system will be mechanized using triply redundant digital techniques. The primary element of this system is the General Electric ICP-723, a triply redundant variable-increment digital computer (Fig. 10) available from a DOT program. All three computers interface with a System Status and Control Unit (SSCU) which serves as a junction box for a Sensor Failure Decoder Unit, a Computer Monitor Unit, and a Memory Program Loader Unit. The SSCU also serves as a monitor for internal equipment failures while sensor failures are monitored by the Sensor Failure Decoder Unit.

The triply redundant computation of this system provides the capability for studies involving a fail-operational control system even though the system actuators are single thread. The digital mechanization is identical in all three channels including the input and output monitors as well as the basic computers. This configuration permits a relatively straightforward implementation of failure monitoring and redundancy management. The system generally reduces to a less redundant operation when subjected to either a system failure or a transient anomaly. Since this is an undesirable feature, alternate schemes for mechanizing a fault tolerant system are being examined for application to the RSFS in the near future. An attractive alternate scheme appears to be the use of a whole word general-purpose digital computer. This computer has the potential to re-order the system organization through software control to (1) recover from a transient abnormality, (2) provide priority processing of critical functions, and (3) modify control algorithms so as to utilize alternate data sources with perhaps some task performance degradation. For longer-term applications during the TCV program advanced computer architectures (i.e., multicomputer, multiprocessor, distributed computer) will be investigated and an architecture selected from several candidates for detailed design. Emphasis will be placed on achieving an ultra-reliable design with modularity and flexibility for differing applications. This design is expected to provide the high level of test and diagnostic capability needed to eliminate the effects of failures during operational use.

The development and application of concepts and techniques for reliable airborne computers is currently being examined. Initial emphasis is being placed on advanced computer processors, systems software, and error detection/correction methods which would take advantage of space system advances. For immediate applications, examinations are being made of "off-the-shelf" computers with redundant organizations (i.e., triple-modular redundant, hybrid, majority voting, spare switching).

E.1.3.3 Aircraft-Ground Data Transfer – Current aircraft-ground information exchange needs are satisfied by voice-radio communications which suffer from limitations in response time, information carrying capacity, reliability of information transfer and the workload, and distractions for both the pilot and controller during communications and frequency changes. The increasing demands on the present ATC system, brought on by increasing air traffic density and the changing performance of new aircraft designs, require a more effective means of managing air traffic. In addition, aircraft will be participating in a changing ATC environment in which at least some of the present functions will be automated. These demands lead to a requirement for a reliable, high-speed communication system for data transfer between airborne systems and ground systems. The design of such a system is dependent upon the division of responsibilities for ground and airborne data processing. Initial studies will be aimed toward the definition of requirements and implementation techniques for the data transfer system. Some of the technical problems which will be attacked during the initial study are multiplexing, digital data transmission techniques, modulation and coding, and data format. A critical interface problem to be investigated is that of interfacing the data transfer system with the displays. The requirement for precision low-altitude navigation information and flow management information in high traffic density terminal areas introduces a question of severity of multipath effects on the data transfer system. This question will be examined and resolved in the preliminary study phase of the program.

E.1.4 Piloted Simulator – The current simulation facility at the Langley Research Center incorporating the characteristics of the RSFS is being utilized in the study of display format and symbology. In order to accommodate the heavy program load of the future and to provide the maximum amount of realism, a dedicated simulator cab is being purchased which duplicates the aft cockpit of the RSFS airplane. This cabin allows for a maximum of center panel visibility utilizing the Brolly Handle controllers shown in Figure 9. This approach is a fallout of the SST display and control developments and will serve as a "jumping off" point for the TCV program. Plans for the study and evaluation of other pilot control concepts include sidearm and pencil-type controllers. The mechanization of these new concepts in the simulator for development and study and in the aft cockpit of the airplane for flight evaluation is seen as a relatively simple operation, since the same hardware can flow from simulator to airplane. In addition to serving the research needs of the program, it is anticipated that the simulator will serve as a "mission trainer" as outside pilots are invited to participate in program evaluations.

E.1.5 Terminal-Area Environment Simulation - Systems development under the TCV program will be directed toward the improvement of aircraft systems performance. However, it is essential to study the vehicle in the traffic environment in which it must operate. A number of vehicle-dependent aspects which impose constraints on the flight paths and on rates of changes of flight speed and direction which are practically achievable must be given proper consideration. For example, aircraft performance and aircraft system characteristics must be compatible with advanced air traffic management concepts. These considerations lead naturally to trade-off studies between future air traffic management system characteristics. For this purpose, a detailed airport terminal-area simulation has been developed for use in these studies. The terminal-area simulation can be used for analysis and synthesis of both current and future air traffic situations and has the capability for representing advanced airborne and ground instrumentation as illustrated in Figure 11. The simulation currently being utilized models a typical terminal area and contains elements to realistically represent: (1) airborne navigation equipment, communication systems, and the primary aircraft sensors; (2) the ground navigation aids, data links, radars, airport configurations, traffic situation displays, ATC procedures, enroute flow control information, runway and airspace constraints; (3) models of traffic samples; and (4) aircraft performance characteristics with constraints on maximum descent, turn, and climb rates.

Fast-time simulations will be used to determine candidate concepts for flight-path control. Analytical models of the RSFS, MLS characteristics, and wind effects are currently being developed. These simulations will assess the performance required of the aircraft and selected airborne systems operating in a simulated air traffic environment of a typical terminal area. A sample of the type of preliminary results that are being obtained with this simulation is shown in Figure 12. A typical traffic situation at the Atlanta terminal with the aircraft mix indicated in Figure 12 was simulated, based on data for a single runway in 1967. With a 3-mile separation between aircraft, the acceptance rate from the simulation levels off at a number in agreement with the known normal IFR rate at Atlanta at that time, which provides validation of the simulation. If a 2-mile separation could be achieved, an increase in acceptance rates could be realized as shown.

Piloted simulation experiments will be conducted in conjunction with the terminal environment simulation to verify candidate system concepts which take maximum advantage of the pilot and aircraft performance characteristics.

These studies will identify technology deficiencies which are most critical. Studies which include air-to-ground and ground-to-air links will place emphasis on determining the effects of time delays, information update rates, human-detected and undetected data loss, or incorrect transmission of data and failure modes. In the evaluation of total system performance, current and projected concepts for surveillance, navigation, communication, airborne computer/display systems, and ground computer equipments and instrumentation levels will be considered.

Subsequently, the RSFS aircraft, flying at the Wallops Station, will be included in the terminal area situation studies via the LRC-Wallops data tie-line. A data link between the terminal area simulation and the aircraft will permit the aircraft to participate in a realistic air traffic control system and environment. The concepts selected for flight investigations will be based on results from the analytical studies and simulations. Flight experiments will provide realistic bounds for, and verification of, simulation studies and results.

The flight experiments will also identify operating constraints imposed by use of the actual aircraft and avionics systems, and will result in preliminary hardware specifications for critical airborne avionics systems.

E.1.6 Wallops Research Facility – The Wallops Station airfield will be utilized for much of the flight activity in this program. It permits a high volume of research on approach and landing problems since the contiguous airspace is controlled by the NASA. A modern control tower, as well as fire, crash, and rescue services, are available on a full-time basis. The station has all the required research support facilities such as meteorology, photography, and computer systems, in addition to hangars and housing, if required.

The MLS capabilities and signal characteristics will be simulated by an FPS-16 radar and laser tracker for precision guidance throughout landing, rollout, and turnoff, as well as take-off until an actual MLS system is available. A display generation facility, a research tool, will also be available to generate, through data downlink and television uplink, display formats and symbologies on the pilot's display to augment the information that can be generated onboard the RSFS. Figure 13 is a photo of the Wallops airfield. Note the unobstructed approaches and the low population density. No civil or military aircraft operate out of Wallops so little interference with the flight research will be encountered.

Facilities at Langley and Wallops will be integrated through a ground data link as shown schematically in Figure 14. This system will permit the terminal area simulations at LRC and at the FAA's National Aviation Facilities Experimental Center (NAFEC) to display and control the RSFS while in flight. The LRC display illustrated in Figures 11 and 14 is only for observation and is not a control display. The system will be used for a realistic study of overall performance and system interactions.

Two of the national standard developmental MLS systems have been installed at the Wallops Station airfield for FAA proof-of-concept evaluations. It is hoped that a winning system prototype can be utilized in early phases of the program to evaluate performance capabilities on an actual MLS system.

E.1.7 Flight Procedures – Figure 15 illustrates the utilization of advanced paths and serves to show how some of these capabilities might be used. Operations in the MLS environment can, with proper controls and displays, allow operators to take advantage of curved approaches with close-in capture, steep approaches and decelerating approaches. Onboard precision navigation and guidance systems are required for 3D/4D navigation for sequencing and closer lateral runway spacing, and displays are under development with the intent of achieving zero visibility operations with sufficient confidence that they become routine. Finally, programed turnoffs at relatively high speed should clear the runway to allow operations to proceed with perhaps 35 to 45 seconds between aircraft, should the vortex wake problems be solved. New take-off noise abatement procedures may require additional thrust and higher take-off climb gradients in order to satisfy some of the noise abatement procedures.

E.1.7.1 Curved Approaches – The utilization of the curved path is proposed as a method of noise control at many locations; however, the impact on capacity of curved approaches with short final legs has yet to be established. Nevertheless, this capability can be used to shorten trip time and conserve fuel. Figure 16 is a chart of the New York terminal area with its included control zones and instrument weather final approach paths for a given landing direction. Note that the final approach paths are 8 to 10 miles in length and that approach paths into JFK, for example, pass through the LaGuardia control zone, Newark's through Teterboro control zone, and so forth. (A STOL aircraft landing opposite Manhattan would be constrained to fly around and underneath the CTOL patterns.) The approach control of these aircraft is, thus, a very involved operation indeed. The airspace required is excessive. Development of close-in curved approach capability would permit containment of instrument traffic within each airport's control zone, would reduce the traffic coordination problem, thus increasing capacity, and would permit more direct routing of STOL aircraft, as an example, between airport control zones. The TCV program plans heavy emphasis on the development of curved approach techniques for both manual and automatic flight. Control law development is underway on some aspects of these advanced all-weather paths.

E.1.7.2 Steep Approaches – Figure 17 shows the effect of increased approach glide-path angle on the airport community noise for two values of landing flap deflection, $\delta_f = 40°$ and $30°$, for the Boeing 737 with acoustically untreated nacelles. At the top of the figure, 90 EPNdB contours shrink as the glide-slope angle is increased. With 30° landing flap, less power is required and the 90 EPNdB contour is smaller in area. Contour or footprint area is plotted in the lower left as a function of glide-slope angle, but normalized to the standard 3° glide slope for each flap deflection. This relative footprint area shows that even at a glide-slope angle of 4° a 50% reduction in area affected by the 90 EPNdB noise is possible. The lower right section of the figure shows the reduction in the FAR-36 approach noise as a function of glide-slope angle. The slope of the curve taken at the 3° glide slope is approximately 3 EPNdB reduction per degree of glide-slope angle increase with 40° of landing flap. The dominant source of noise in these calculations is the propulsion system. An estimate of the airframe noise at a flap setting of $\delta_f = 40°$ is included to indicate the lower limit of possible noise reduction based on a current understanding of aerodynamic noise. The propulsive noise changes are more favorably affected by glide slope than is the aerodynamic noise due to the dual effect of increased distance and the reduced thrust required (the aerodynamic noise varies only as the distance from the ground for a given speed).

Presently, it has been shown to be feasible to reduce landing noise through use of the two-segment approach. Both NASA and FAA data indicate substantial reductions in the resulting community noise levels. Further, there appears to be no difficulty in flying these approaches down to non-precision approach minima, or in passenger acceptance. In addition, many aircraft have more than one certificated landing flap setting and as a result some airlines are using a landing flap setting which is less than the maximum flap when the landing field and other conditions allow. These procedures require no further development, but they form a standard for the comparison of the techniques proposed for operation within the MLS environment.

E.1.7.3 Decelerating Approaches - Much effort has been devoted to assessment, from the noise viewpoint, of the decelerating approach. This technique requires a precise knowledge of the distance from the runway and a continuous closed loop on speed and progress (computer and INS sensors), as well as IAS and flap configuration, to be consistently effective and safe. The technique will be explored in the TCV program to assess not only noise but to explore reductions in flight time and savings in fuel for possible improvement in terminal operations.

E.1.7.4 Terminal Capacity - Many authors and airline passengers have noted the yearly increases in the number of airports which saturate in instrument weather due to the increased number of operations. Even with the present schedule reductions due to limited fossil fuel reserves the number of airports which operate at saturation rates is high since the airlines have reduced the number of flights mainly to nonmajor terminals. The constraints of single runway landing capacity are shown in Figure 18. Here, landing operations per hour are given as a function of the aircraft separation in seconds. The curve represents the maximum number of landing operations per hour on a single independent runway.

Typical known constraints are shown on the curve and illustrate the effect on operations rate (capacity). The first constraint deals with vortex decay (area 1). As will be shown later, some evidence exists that vortex attenuation devices have the potential of alleviating this constraint.

Application of these devices to large airplanes will reduce the separation interval to about that indicated by area (2) or even lower. The area labeled (3) on the curve represents the time required to decelerate to a 5-knot turnoff airspeed and clear the runway. Quicker runway clearance can be achieved by providing (a) higher decelerations, (b) higher turnoff speeds, or (c) a combination of the two. The latter appears to provide the possibility of meeting the TCV goal of an arrival-time interval of 40 seconds ± 5, as indicated by area (4) on the figure, and can be achieved by braking at 0.2g and turning off at 60 knots or by a modest increase in braking force and using a 40-knot turnoff. Increased accuracy in time of arrival over the threshold (± 5 seconds compared to today's ± 15 to 20 seconds) will be required to maintain safety with the reduced spacing. It should be pointed out that current rules and traffic flow rates do not require that a pilot exit the runway quickly even at airfields where congestion is a problem, and at some airfields where high-speed exits do exist, the exiting aircraft are often forced to stop for other taxiing aircraft. To make maximum use of busy runways, the constraints must be recognized and moves made to improve the total picture such as proper use, location, and designation of turnoffs by traffic control. Operations in very low visibility will require automatic guidance from touchdown through braking, turnoff, and taxi. In addition, airport surveillance systems, an FAA responsibility, will need more attention to protect against collisions on the ground.

A conceptual sketch of a high-capacity runway making use of some of the techniques discussed for noise abatement is shown in Figure 19. By using different final approach paths and touchdown points, the trailing vortex wake can be avoided to permit less spacing between aircraft. Raising the lower glide slope to 4° from 3° would reduce the 90 EPNdB footprint by almost 50% and the FAR-36 approach noise by 3 dB. However, if such techniques are to be brought into being, the whole air terminal as well as the airplane must be upgraded. The Microwave Landing System flare guidance antenna must be located so that more of the runway is available for touchdown under instrument conditions. The lower path of 4° shown in the figure could be used by <u>all</u> of the "heavy" aircraft and possibly some of the lighter aircraft as well, and if combined with reduced flap or decelerating approach techniques noise footprints and fuel consumption could be considerably reduced.

The high glide slope could accommodate no "heavies" but could accommodate all other types and maintain noise and fuel improvements even greater than the lower path. The pilot needs better displays of his situation relative to other aircraft and to the runway if he is to gain enough confidence in such a system to allow it to become a reality.

E.1.8 Displays and Human Factors -

E.1.8.1 Primary Displays - New cockpit displays must consider the changing role of the crew from sensor/controllers to monitor/managers. Information presented to the crew should be processed and displayed in an integrated, analog form where possible to convey a naturally assimilated mental picture for assessment of a complex situation. Predictive display information will be needed to provide the required level of anticipation for the pilot whether monitoring or controlling.

The research system will incorporate electronic displays which offer an element of capability not currently found in electromechanical display systems. The cathode ray tube (CRT) system photograph taken in the Langley simulator is shown beside current airline attitude director indicator (ADI) and horizontal situation indicator (HSI) in Figure 20. Note the ADI/HSI instrumentation requires scanning, interpretation, and integration of the information presented on two separate instruments to enable the pilot to assess his aircraft's situation.

The instrument pilot must have and maintain a continually updated mental picture of his aircraft's orientation and flight-path trend with respect to the runway to satisfactorily complete an instrument low approach. This requirement becomes all important if an instrument landing is to be made or if monitoring an automatic landing in Category III visibility. Without a current mental picture of his aircraft's situation, the pilot's workload during the interpretation of his instruments, control of the aircraft while following specific procedures, and the performance of other necessary communication, check and decision making tasks during the instrument approach may easily become excessive, resulting in disorientation and missed approaches. Capability for operating in Category IIIc conditions (zero visibility) is seen as a strong requirement for the future air transportation system. The TCV program will place a heavy emphasis on the primary displays for pilot confidence in operations independent of weather.

A CRT display concept with a computer-generated perspective runway superimposed on a typical ADI instrument format has often been proposed and tried to improve the pilot's "natural" real-world cues for determining aircraft situation with respect to the runway during an instrument approach. However, the runway perspective display algorithms in early simulations gave the pilot a confusing change in runway position and perspective when the aircraft was in a banked attitude. Thus, it was of little use to him in alining himself with the runway. The display algorithms had been based on mathematical approximations, so the algorithms were redone for the complete mathematical expressions. The accuracy of the resultant perspective runway image was checked by means of photographs of a known runway taken with a camera at the pilot's head position in a helicopter and looking straightforward as illustrated by a typical photo in Figure 20. The perpendicular dash on the lateral reference line (not parallel to the actual aircraft lateral axis) at the bottom of the photo represents a parallel to the longitudinal axis of the aircraft. Note that in the photo the longitudinal axis of the aircraft was parallel to the runway axis in this case, as shown on the standard HSI instrument on the left. The symbolic runway perspective was verified by this technique for all situations. The new perspective has significantly improved the usability of the runway symbology for lateral alinement during simulation and the addition of markings for texture have also improved the pilot's ability to judge his approach glide path and closure rate on the runway.

It should be emphasized that the computer-generated perspective runway is not presently designed to give the pilot precision ILS deviation information such as gleaned from the ILS needles. However, the degree of lateral position precision obtained from the computer-generated perspective runway is sufficient to allow the pilot to significantly supplement his primary attitude/command navigation instrumentation all the way to touchdown. It has been found that if the aircraft is within the lateral bounds of the runway and within a mile of the threshold, the pilot can tell whether the flight path is taking him to the first quarter of the runway. This development represents progress but is not to be construed as final in the search for better displays.

E.1.8.2 Independent Landing Monitor - Available technology needs to be be applied to the development of an independent landing monitor (ILM) for the pilot with which he can continually determine the integrity of the basic guidance system (MLS or ILS) and judge the overall performance of the approach to landing, be it automatic or manual. The sensor system and the utilization and integration of the sensor information have not yet been determined for commercial application. Concepts which may be applicable in the development of an ILM include autonomous or active ground-assisted sensors, radar-radiometer imaging and radar triangulation for position determination, and computer-generated predictive displays. It would be desirable for ILM information to be integrated with and usefully augment the basic flight displays. Studies will identify and analyze problem areas relative to propagation effects that are deemed to be critical to the successful achievement of an ILM capable of meeting user needs. Near-field effects, multipath, shadowing, and weather penetration are distinct areas of concern. Concurrently, studies will be conducted to define display criterion; that is, how best to display what information. Simulations will also aid in the determination of the adequacy of existing techniques to meet the program objective. Computer formating and system interfacing will also be investigated via simulation. This phase of the program will provide the information required to procure a flight model. The prototype will have built-in flexibility to permit essentially breadboardlike parameter manipulation of such items as display and computer formating and system interfacing.

E.1.8.3 Traffic Situation Displays - Research will also be conducted to evaluate candidate display techniques for providing the pilot with information concerning other traffic in his proximity for the purposes of increased terminal-area efficiency and safety enhancement particularly during low-visibility conditions. For example, airborne traffic situation displays have been considered as a means of enhancing safety and performing the collision avoidance function in congested areas. However, controversy exists as to the desirability of such displays for the pilot. Hence, further evaluation of this type of display in an operational environment is required. In the TCV program, the terminal-area simulation model will be used to provide high-density traffic situation data for transmission to airborne traffic situation displays. Both cockpit simulation and RSFS flight experiments will be conducted under simulated instrument conditions. During this simulation, conflict conditions will also be generated.

Flight experiments will also be conducted under VFR conditions and, if feasible, one additional aircraft will be used to determine the effectiveness of the traffic situation display in enhancing visual acquisition of potentially hazardous targets.

Types of data, data rates, and data link characteristics necessary to provide pilot-acceptable traffic situation displays for enhancement of terminal-area safety will be explored.

E.1.8.4 Manual Control Modes - The research support flight system is currently equipped with control laws which allow the selection of either of two manual control options: (1) rate command, attitude hold control wheel steering, and (2) velocity vector control wheel steering which combines flight-path angle control wheel steering in the longitudinal axis and track angle control wheel steering in the lateral axis. Figure 21 is an illustration of the performance of the two systems in the lateral axis. On the left of the figure, the aircraft with rate command attitude hold is stabilized on a course until it encounters a shear V_c which blows it off course at a constant attitude. When track angle is used (right sketch), there may be a slight deviation between course and track as a cross shear is encountered but track angle is sensed and the airplane quickly recovers on a parallel track in a new heading attitude. Reduced pilot workload in tracking is expected to ensue.

E.1.8.5 Oculometer - An important research tool for the development of advanced displays is the Langley-developed oculometer. This device tracks the pilot's eye movement without interceding in his scan pattern and automatically records the movement of his eye for later analysis. The device is very accurate and shows within about 1/2 inch where the eye's gaze resides. The device is, at this point, new and all the uses to which it may be put eventually are not known; however, it will be used to track the pilot's eye to see if he scans various new pieces of displayed information. While it is true that if a pilot does not look at his information he cannot use it, if he does regard it with his eye he may not use it. Furthermore, he may stare at information inefficiently and not look at information he should use for the task. Figure 22 shows the superposition of a pilot's scan pattern as measured by the oculometer during a recent night approach at the Wallops airport. While he has no recollection of the fact, the data show his scan rested on the clock during this particular approach. It is anticipated that as experience is gained with the device its utility will grow and its uses will expand in the development of new display formats and systems.

E.1.9 Flight Results to Date – A flight-test demonstration program of 40 flights comprising 78 flight hours (Fig. 23) has been completed by Boeing under FAA and NASA sponsorship. These flights were to shakedown, checkout, and validate the advanced display and automatic guidance and control system. The aft flight deck was not in place and the display and control systems were operated from the forward flight deck. As noted in Figure 23, a variety of weather conditions was encountered during the tests.

Some operational problems not unexpected with complex, digital avionic equipment were encountered but most of these have been resolved and the equipment design is considered validated and acceptable for initiation of the research program. A number of automatically controlled flights were made including 30 which were 4-D controlled through a complete 125-mile flight profile from climbout through touchdown. The touchdown time accuracies obtained (Fig. 23) give encouragement to the belief that further development and experience will result in attaining the goal of <5 seconds in routine operations.

Following installation and checkout of the aft flight deck, an extensive research program will begin with initial emphasis on advanced flight procedures and avionics to contribute to solution of terminal-area problems.

E.2 KEY AIRCRAFT DESIGN AND OPERATIONAL REQUIREMENTS – Previous discussions have dealt with alleviation of terminal-area problems by means of advanced electronic systems and advanced flight procedures made possible by them. To implement some of these procedures and to gain additional benefits, a number of key requirements for aircraft performance will be necessary to achieve terminal-area compatibility. In order to determine quantitative measures of what the requirements should be and the associated cost and benefits, the NASA has underway activities in consultation and cooperation with the FAA; airframe, engine, and avionics manufacturers; airlines; and airport operators.

An example of these activities is a recently completed contractual effort with the Boeing Company, conducted under the management of the Langley Research Center Aeronautical Systems Office, entitled "Advanced Subsonic Long-Haul Transport Terminal Area Compatibility Study" (4). The long-haul class of aircraft was chosen for these initial studies since considerable information existed from the extensive Advanced Transport Technology Studies (5-7) conducted in 1972. It is apparent that short-to-medium range aircraft will spend a considerably higher percentage of their trip time in the terminal area and additional studies on these classes of aircraft are now getting underway.

Some of the key design and operational requirements that have been identified as being technically feasible for the approach and landing phase are summarized numerically in the following table. For comparison, current long-haul aircraft characteristics are also presented.

Key Design Requirements

Characteristic	Current	Objective
Approach and landing:		
Path	Straight, constant velocity	Curved, decelerating
Angle, degrees	3°	6 to 9
Velocity, final, knots	135	120
Aircraft long. spacing, miles	3 and 5	1 to 2
Runway lateral spacing, feet	5000	2500
Arrival accuracy, seconds	18	5
Touchdown dispersion, feet	±320	±100
Aircraft deceleration, ft/sec^2	6	9 to 12
Turnoff velocity, knots	<5	40 to 60
Occupancy time, seconds	55	25

Key Design Requirements — Concluded

Characteristic	Current	Objective
Noise: EPNdB		
Source	FAR-36	FAR-36-10 to -12
Airframe	FAR-36-8 to -12	FAR-36 > -12
Take-off and climb:		
Emissions, CO-HC, lb/cycle	60	25
Noise: EPNdB	FAR-36	FAR-36-3 to -5
Climb angle, degrees	7 to 8	8 to 10
Altitude at FAR-36 point, ft	1300	2000 to 2500

E.3 TERMINALLY COMPATIBLE LONG-HAUL AIRCRAFT — With the key design and operational requirements identified, preliminary design studies were made to determine the technical feasibility and the costs and benefits associated with subsonic long-haul Terminal-Area Compatible (TAC) Aircraft. Two designs were considered: (1) a conventional take-off and landing (CTOL) configuration sized to operate from 10,000-foot runways, and (2) a reduced take-off and landing (RTOL) configuration sized to operate from 5000-foot runways. The latter design utilized essentially the same technology features as the former to achieve terminal compatibility and differed mainly by increased wing area and engine thrust to attain the reduced runway performance.

E.3.1 Technical Design Aspects — To provide a comparative baseline from which to judge the terminally compatible features, an $M = 0.90$, 200-passenger cruise configured three-engine Advanced Technology Transport (ATT) was utilized (4,5). A drawing of this configuration along with some pertinent characteristics is presented in Figure 24. It should be noted that this configuration employed supercritical aerodynamics, advanced engines and acoustic treatment, composite materials, active controls, and advanced subsystems.

An example concept of the four-engine TAC-CTOL aircraft configuration is shown in Figure 25. In addition to the advanced technologies notes for the baseline ATT airplane and the advanced avionics systems discussed previously, the noteworthy features are:

E.3.1.1 Basic Wing Geometry Changes to Provide Aerodynamic Improvements – To provide a landing approach speed of 120 knots, which allows higher runway acceptance rates than those associated with the 135-knot speed generally associated with cruise configured aircraft and to improve take-off and climb-out flight-path angles in order to reduce noise, an aspect-ratio-9.0 wing (compared to 7.6 for baseline ATT) with somewhat greater wing area (12%) than the baseline ATT airplane (Fig. 24) was employed. Although not a prime design consideration, the increased aspect ratio also increased the cruise L/D by 9%. This increased efficiency essentially paid for the increase in structural weight of the wing resulting from the increased aspect ratio and wing area.

E.3.1.2 Tip Vortex Control – To provide potential solutions for both take-off and landing, two vortex control methods were adopted. It should be noted that vortex control methodology is in its infancy and that extensive data as to the validity of these approaches is lacking.

For take-off, where low drag is desired, the outboard engines were located as close to the wing tip as possible without incurring excessive weight penalties dictated by flutter considerations. In the present instance, the engines are located just outboard of the trailing-edge flap tip where the highest vorticity discharge takes place. This is also the approximate spanwise location of the rolled-up vortex core which forms downstream of the wing trailing edge. The discharge of the engine mass flow provides two favorable functions in that it pressurizes the vortex core and thereby diminishes the troublesome tangential velocities (8) and provides a turbulent mechanism to effect early vortex dissipation.

For landing, where low thrust and high drag levels are required for steep decelerating descents to reduce noise, a retractable trailing-edge device is employed to provide a turbulence mechanism for early vortex dissipation. Some preliminary flight-test information on such a device will be presented subsequently.

E.3.1.3 Drag Brakes – To provide steep descent capability to reduce noise, additional drag, approximately equal to the low-speed drag level of the basic airplane in level flight, must be added to implement a 9° glide slope with the engines at flight-idle. This drag is provided by several sets of large drag brakes mounted on the rear of the fuselage. Careful design of these devices will be required to insure that there are no adverse buffet characteristics incurred from their use.

E.3.1.4 Engines – Four advanced high bypass ratio engines (4.0) are utilized which employ advanced combustor technology to minimize pollutants and acoustic treatment (two rings and one splitter) to minimize noise while maintaining acceptable levels of fuel consumption. As previously, the use of steep descent operational procedures might eliminate the need for the more complex acoustic treatment. An increase in vertical tail size was required to maintain directional stability and control in the event of an outboard engine failure.

E.3.1.5 Powered Wheels and High-Speed Turnoff Gear – To provide a means of ground locomotion without the main engines running, powered wheels are utilized to effect pollutant reductions and reduce fuel consumption. This hydraulically powered system is dependent on self-driven taxi/inflight auxiliary power units. No special additions were required for high-speed turnoff capability since the design studies indicated that the baseline gear was sufficient to withstand the loads.

E.3.1.6 High-Capacity Brakes – The brake system was designed integrally with the powered wheels and incorporates sufficient additional brake material to achieve no degradation in life relative to the baseline ATT airplane. It also incorporates an automatic system in order to achieve the desired decelerations without exceeding jerk levels in excess of passenger tolerance.

E.3.1.7 Self-Driven Taxi/Inflight Auxiliary Power Unit (APU) – Redundant power requirements were met by using two auxiliary power units to supply all anti-icing power, all on-the-ground power including powered wheels, and the bulk of the inflight power. Electrical generators and hydraulic pumps on the two inboard engines supply additional channels of safety-of-flight essential loads. The APU's have sea-level ratings of 1800 hp each determined primarily by the anti-icing requirement. It should be noted that the APU's were identified as relatively high-cost items because of maintenance complexity.

E.3.1.8 RTOL Capability – To provide reduced take-off and landing (RTOL) capability, a TAC-RTOL configuration was sized with wing area and thrust-to-weight ratio increased by 6% and 15%, respectively, relative to the TAC-CTOL airplane.

E.3.2 Cost and Benefit Analyses – Cost and benefit analyses considered each of the terminal-area compatibility features separately and in combination. In the interest of brevity, only the combined effects are summarized in this paper. Quantitative measurement indicators employed were Take-Off Gross Weight (TOGW), Aircraft Acquisition Cost (AAC), Direct Operating Costs

(DOC), and Net Present Value (NPV). The TOGW's were determined from preliminary design studies; the DOC's were calculated by use of the 1967 ATA method adjusted to 1972 dollars; and the NPV's of each aircraft, over a 14-year period, were calculated assuming a constant 10% discount rate, depreciation over an 8-year period, and a 7% investment tax credit allowance.

A summary of the cost benefits associated with attaining the desirable terminal-area objectives listed previously are presented in Figure 26 relative to the ATT baseline (no advanced terminal-area features). For each of the benefit indicators (DOC's and NPV's), two comparisons are presented. In the Standard Delay Case (1967 ATA allowance), all aircraft were unrealistically assumed to be capable of accomplishing a 14-minute taxi cycle and a 6-minute airborne delay. In the Expected Delay Case, the TAC aircraft were credited with being able to maintain these minimum delays whereas the ATT baseline was expected to require a 36-minute airborne allowance since it did not incorporate the required terminal-area features.

The TAC-CTOL and RTOL aircraft are shown to be 3% and 9% heavier and their acquisition prices to be 10% and 15% higher, respectively, than the ATT baseline. These characteristics are unaffected by the assumed delays. For the standard delay, the TAC-CTOL and RTOL aircraft are shown to have 9% and 13% higher DOC's and 21% and 30% lower NPV's than the ATT baseline. For the Expected Delay Case, the TAC-CTOL and RTOL aircraft provide 6% and 3% reductions in DOC's and 63% and 47% increases in NPV's, respectively. These large variations in DOC and NPV values show the extreme sensitivity of Cost Benefit to airborne delay time and indicate that profit or loss, or success or failure, of the business venture will require that these delays be minimized.

E.4 VORTEX-WAKE REDUCTION — As noted previously, means for alleviating or avoiding the vortex wake of aircraft will be necessary to permit closer longitudinal spacing and thus increased runway acceptance rate. Past studies have shown that the vortex persistence is of the order of 1-1/2 to 2 minutes but that time can be quite dependent upon atmospheric conditions. Recent work at Langley aimed at reducing the vortex hazard has shown some promise. Water tunnel and other small-scale studies have shown the effectiveness of several methods for attenuating the effects of the vortex. One such method involves the attachment of a retractable spline to the wing tip (9). Flight data have recently become available for this concept whereby flights were made with a PA-28 trailing aircraft penetrating the wing-tip vortices of a C-54 generating aircraft with (Fig. 27) and without tip splines attached to the C-54. Plotted in Figure 28 as a function of distance is the rolling acceleration of the trailing aircraft.

Flying in the wake of the clean C-54, the PA-28 is able to maintain control only to a point about 4 miles behind the C-54. At closer range, the light aircraft is overturned by the tip vortices as the induced rolling moment exceeds its control power and it is ultimately thrown from the vortex in an unfamiliar and dangerous attitude. Such a maneuver could be catastropic if it were close to the ground.

With the splines extended from the C-54 aircraft, however, the rolling moments produced by the vortex are much reduced and the lighter PA-28 can penetrate the larger airplane wake to as close as 1/4 mile. Although both aircraft were flown at 100 kn in this case, analysis indicates that the PA-28 could fly with a margin of control at any distance even at 70 kn. The results shown are preliminary and are intended to demonstrate the applicability of the model scale experimental techniques.

Research investigations underway in small-scale facilities have shown that with modifications to flap systems (to alter spanwise distribution of airload on the wing) along with the addition of splines, greater reductions in vortex strength than for splines alone can be achieved with little increase in drag. Application of these techniques would indicate safe air separations of 1 to 2 miles or less for an aircraft like a DC-9 following a 747. Research is continuing on this problem at Langley and elsewhere and as new techniques become practical the effect on capacity will be assessed.

F. CONCLUDING REMARKS

Problems currently existing in terminal-area operations of the civil air transportation system can be expected to intensify in the future. New flight procedures and advancements in avionics, airframe, and engine design to take maximum advantage of MLS, RNAV, and advanced ATC equipment offer potential solutions to these problems as well as economic advantages. To develop and demonstrate these advantages is an urgent requirement for flight testing. The NASA Terminal Configured Vehicle Program will contribute significantly to this effort. The Boeing 737 Research Support Flight System provides a unique research facility for flight research. Flight demonstration testing to date indicates that the aircraft and its advanced avionic equipment are validated in concept and suitable for initiation of the research effort. In related programs, flight and ground testing has indicated that potential solutions exist to the wake vortex hazard — a major restraining factor in terminal-area operations. Studies indicate high payoff for specific airframe configuration features for terminal-area effectiveness and experimental evaluation of some of these features appears to be desirable.

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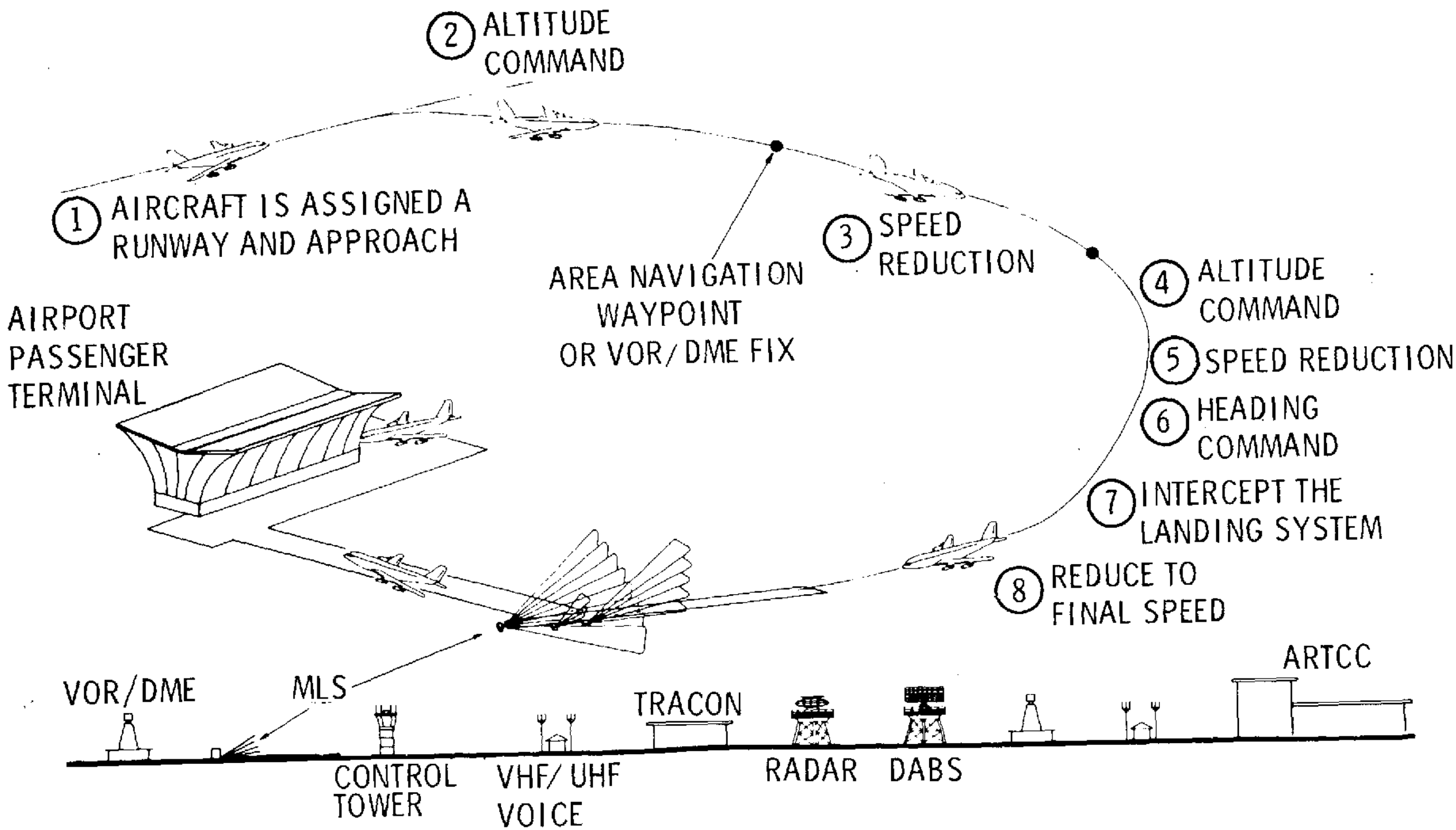
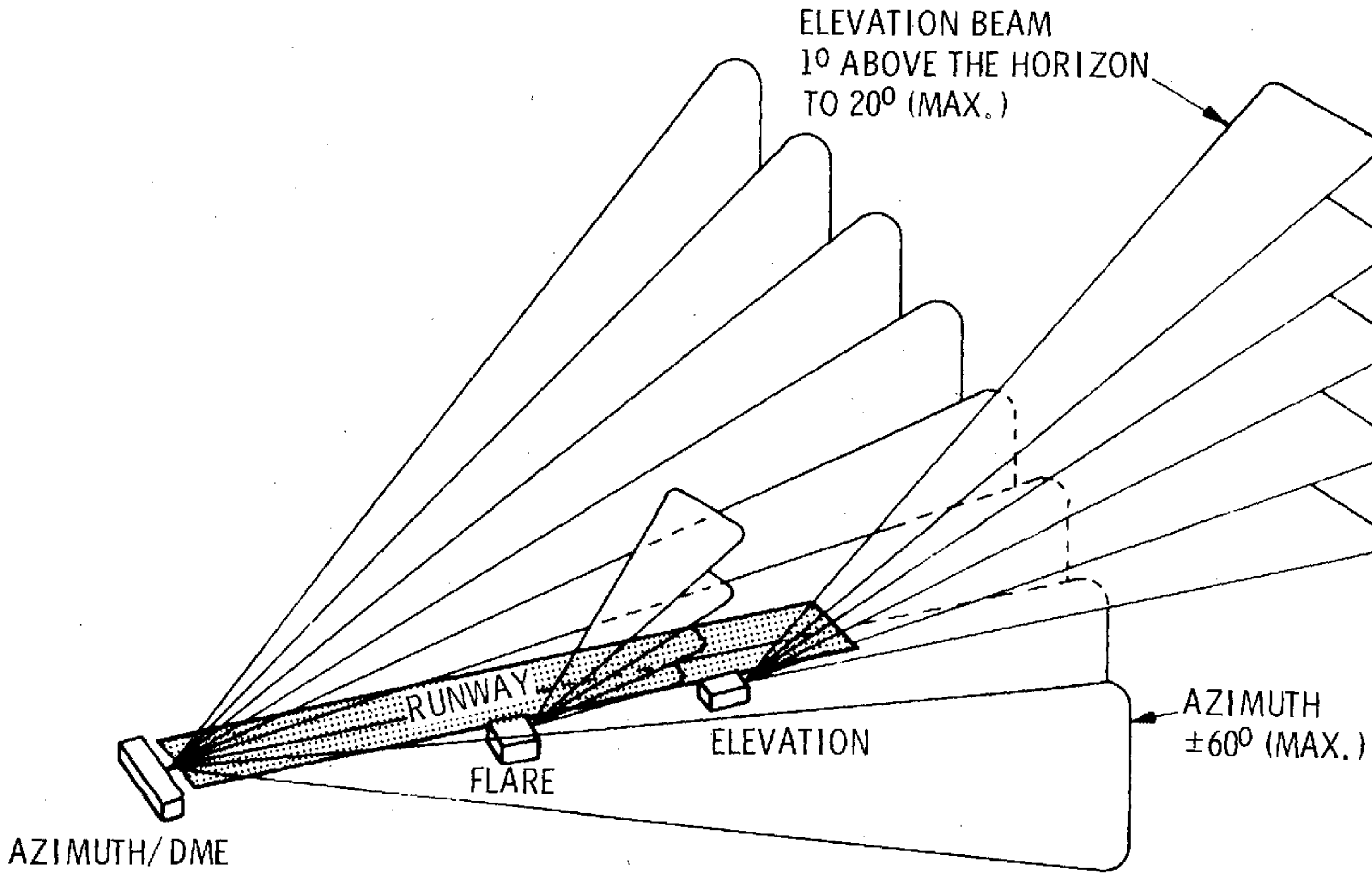


Figure 1. Area navigation in terminal area.



NOTE: SCANNING BEAMS IN AZIMUTH AND ELEVATION PERMIT THE DEFINITION OF PILOT-SELECTABLE 3-DIMENSIONAL APPROACH PATHS TO THE RUNWAY.

Figure 2. Microwave landing system.

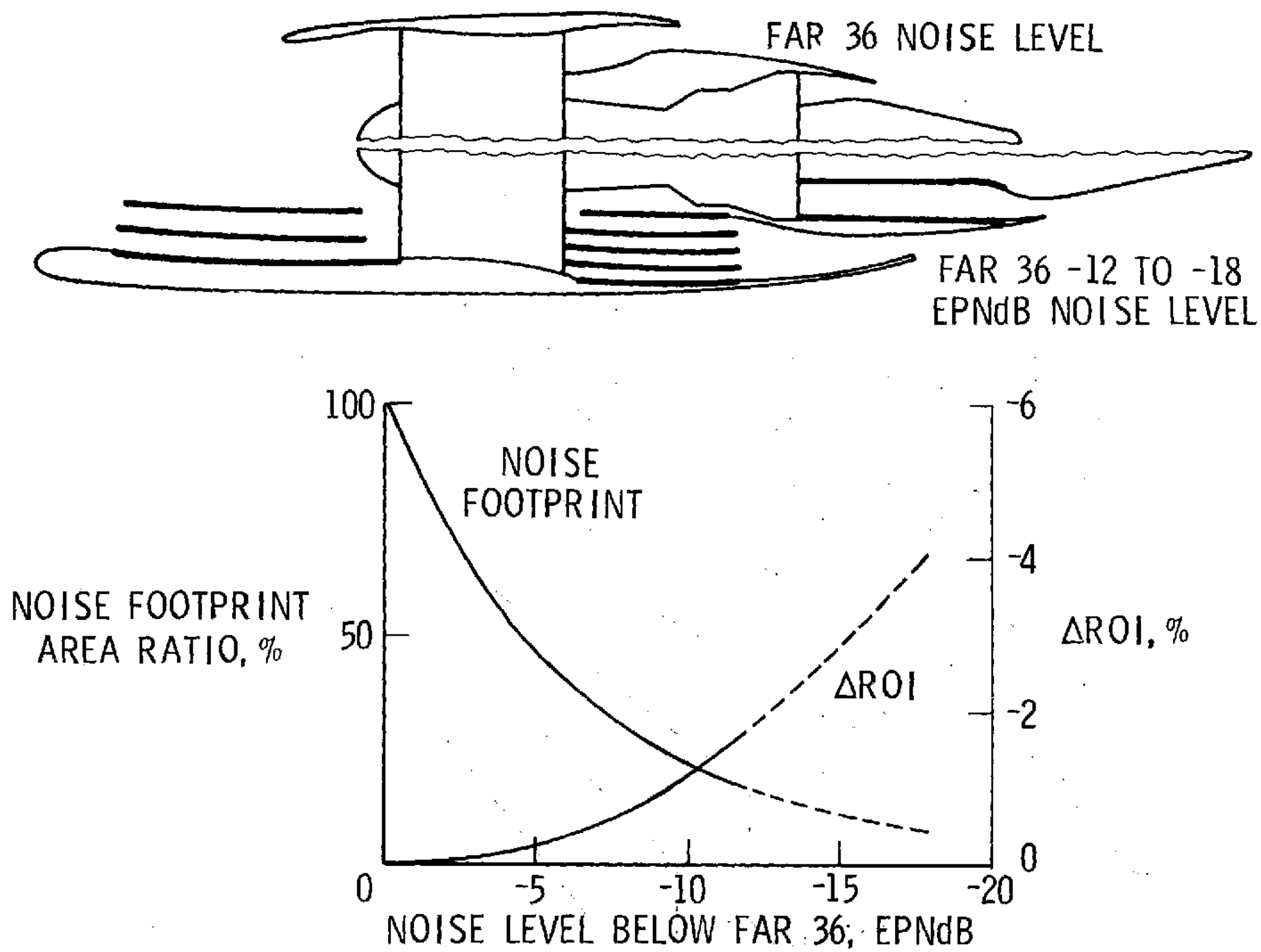


Figure 3. Engine noise reduction by acoustic treatment — high bypass-ratio engines.

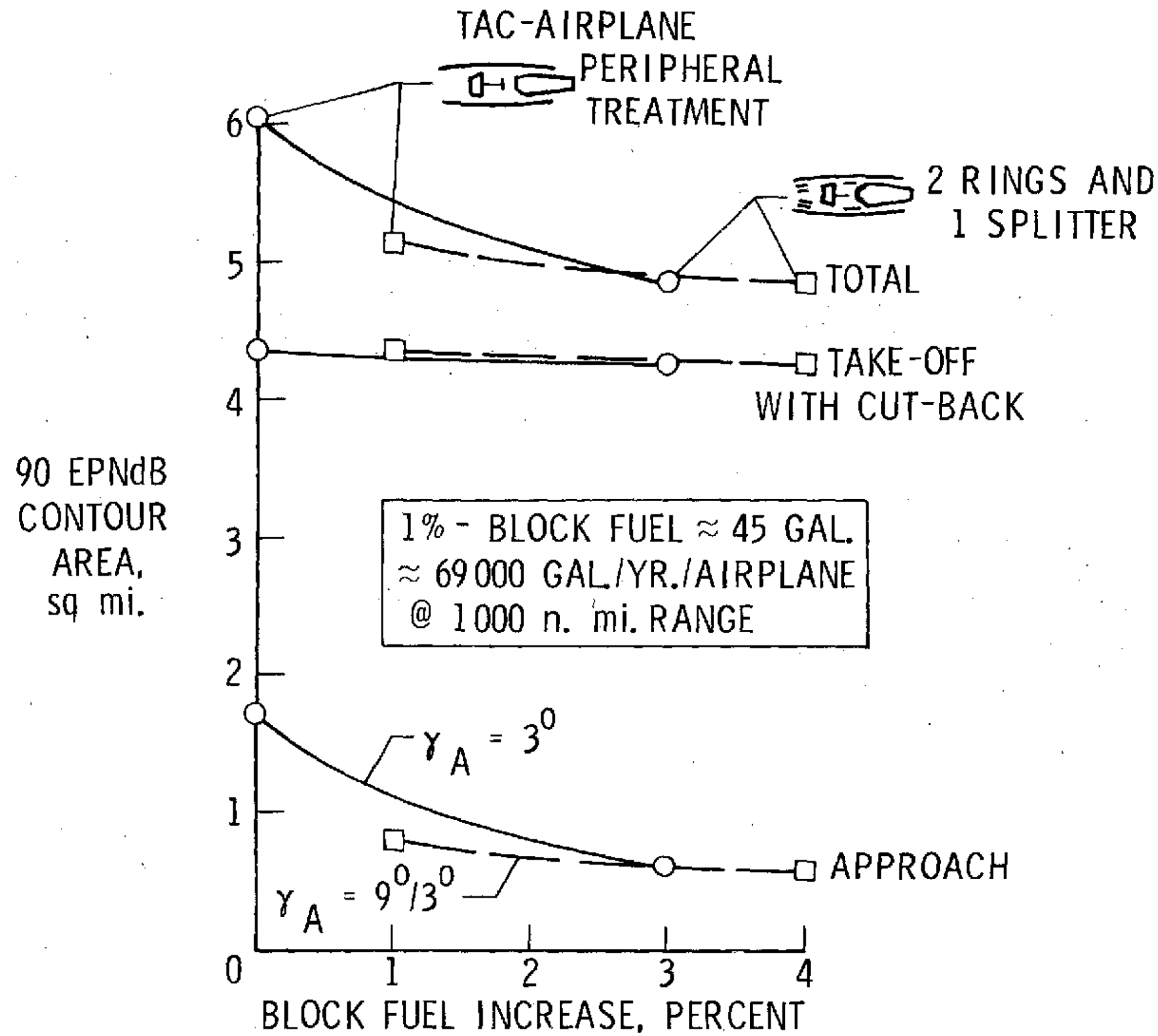


Figure 4. Energy implications of acoustic treatment and operational procedures.

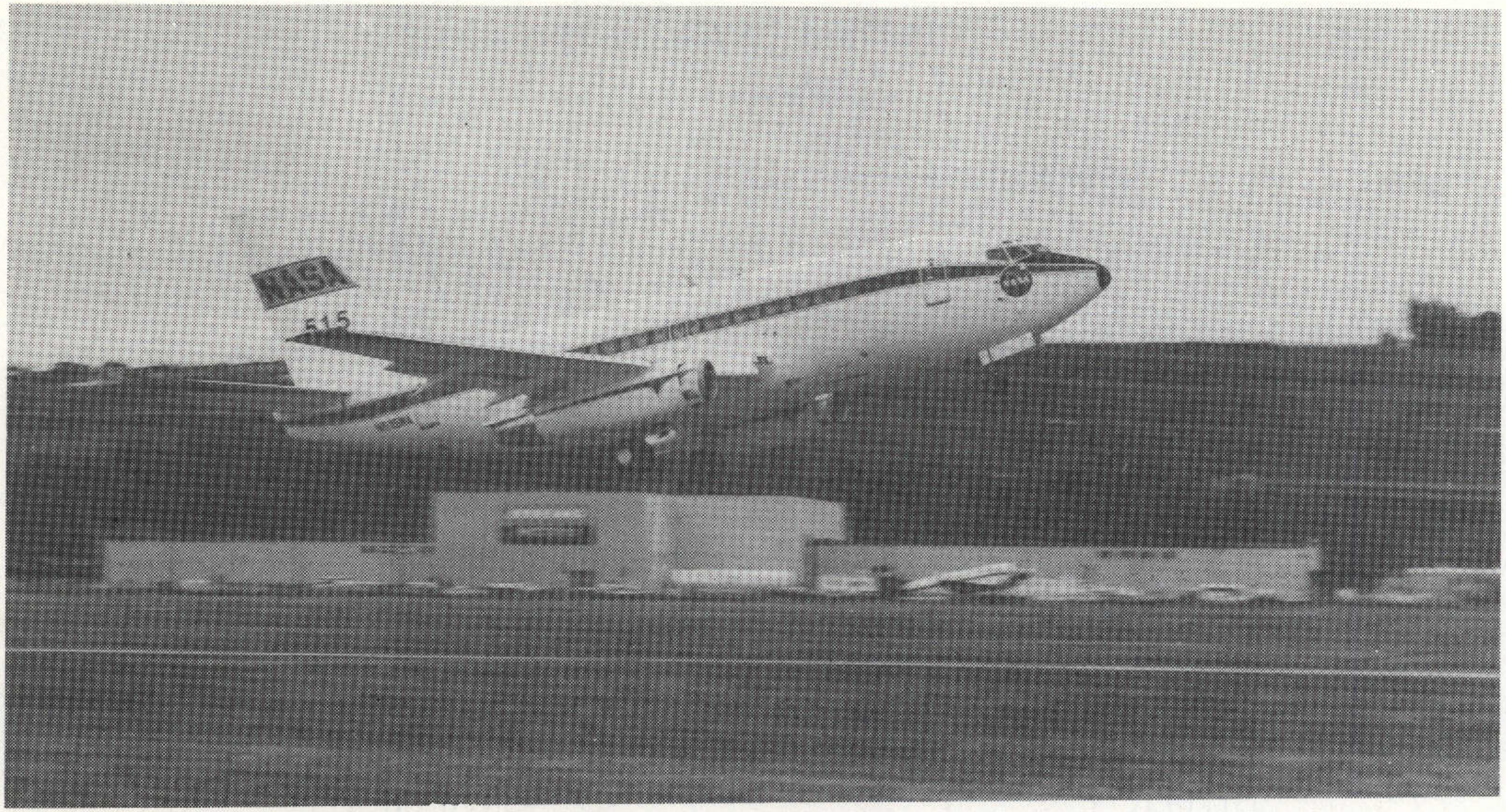


Figure 5. RSFS first flight.

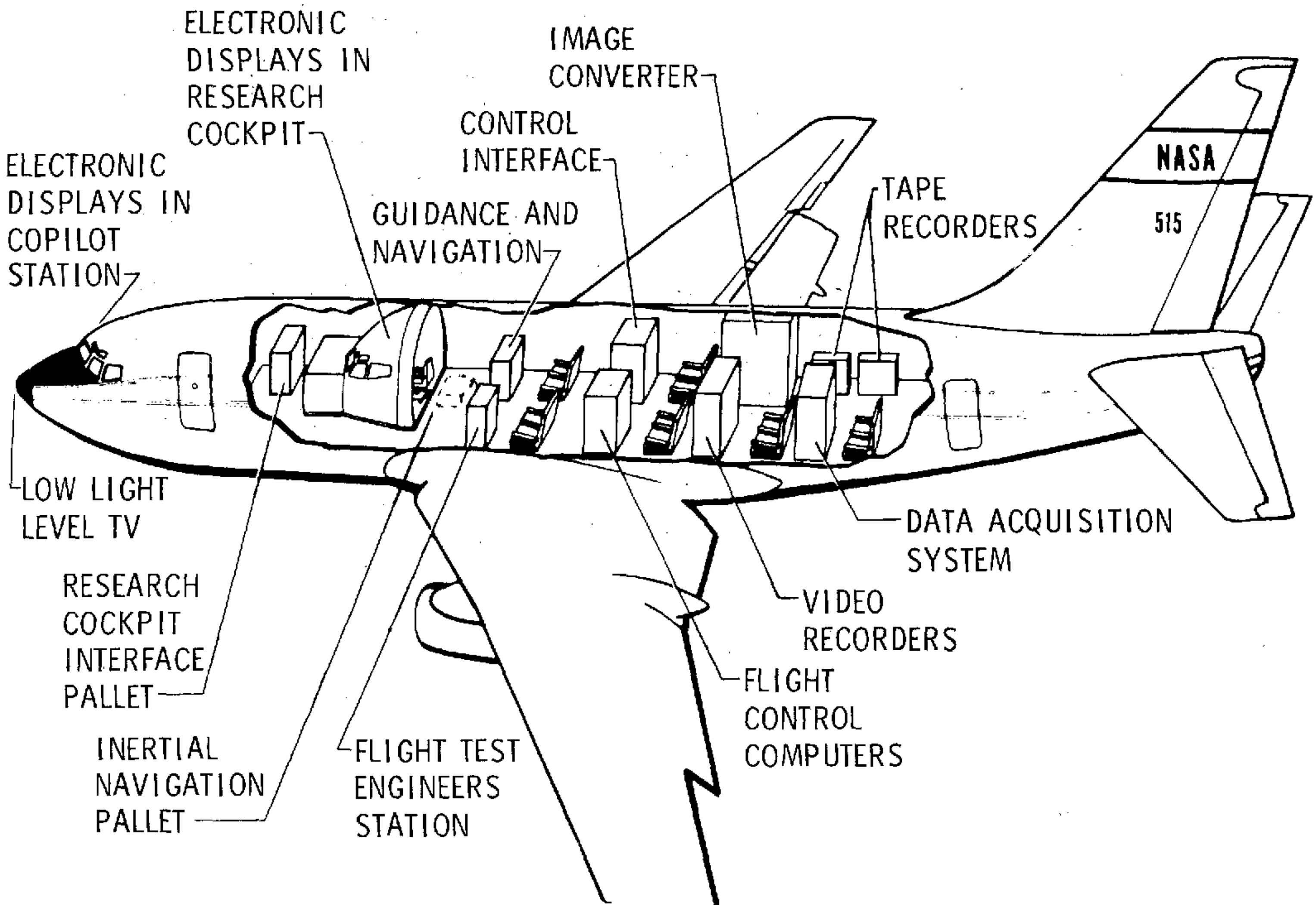


Figure 6. RSFS internal arrangements.

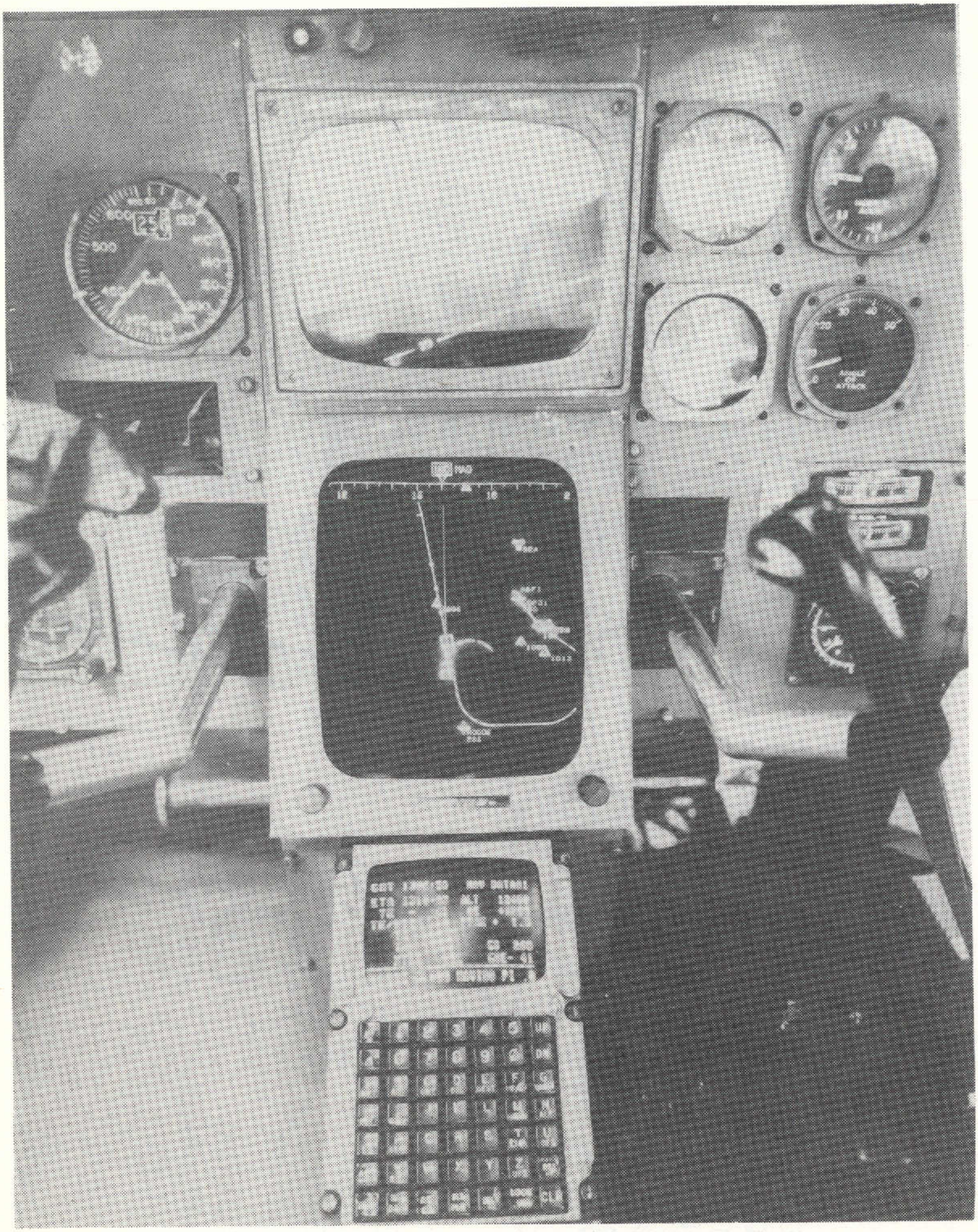


Figure 7. View of ADEDS equipment.

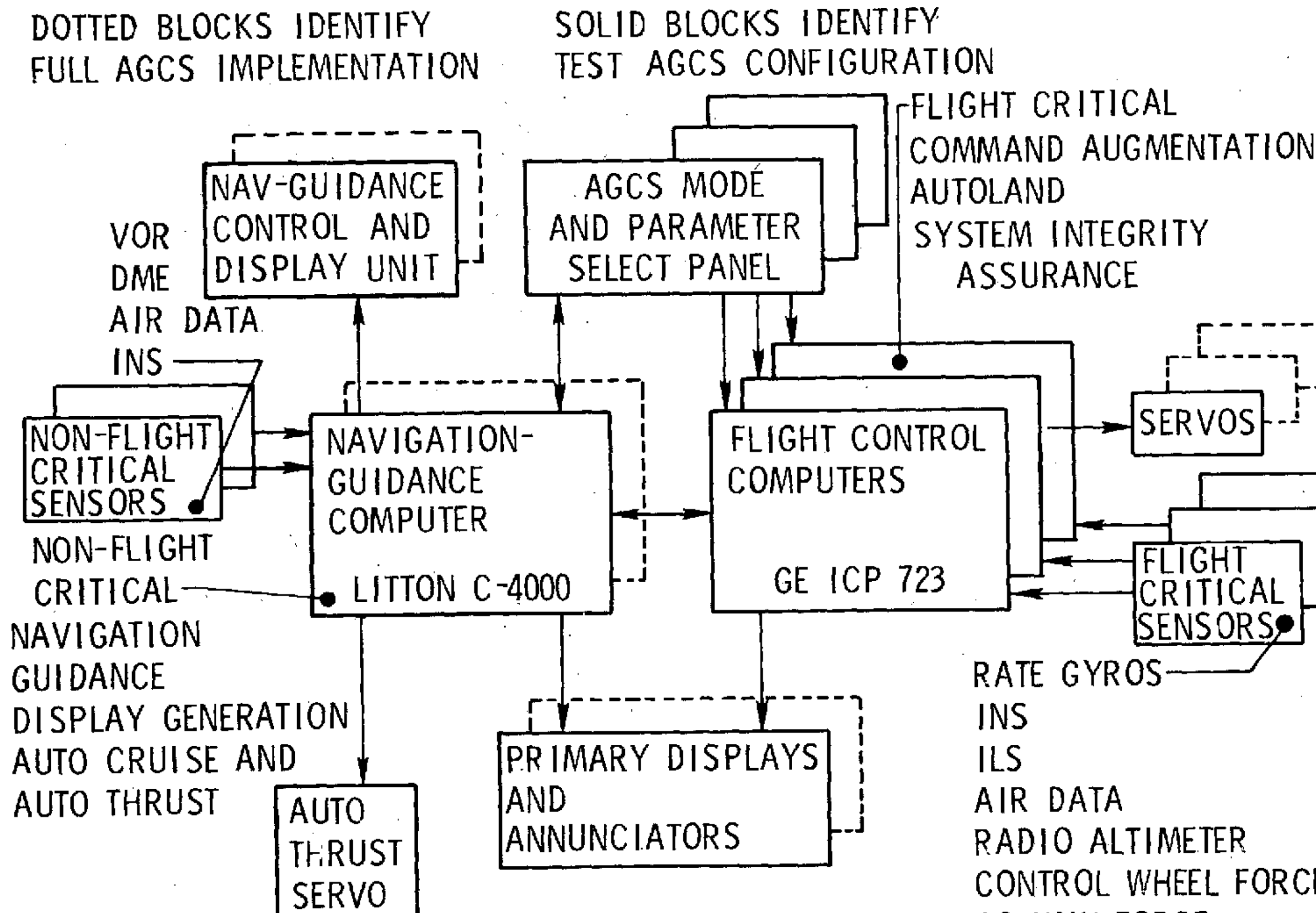


Figure 8. Advanced guidance and control system configuration.

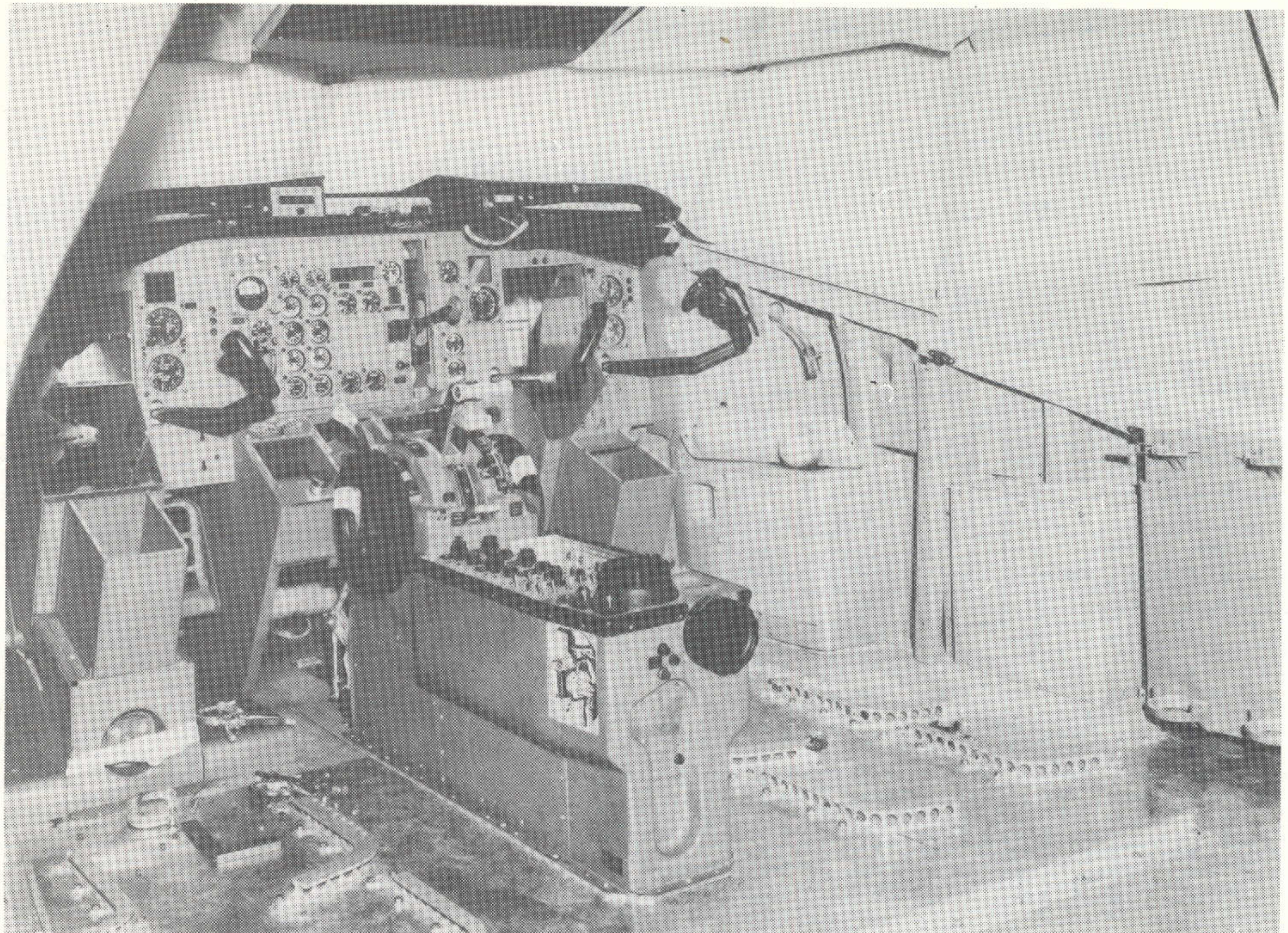


Figure 9. View of partially completed aft flight deck.

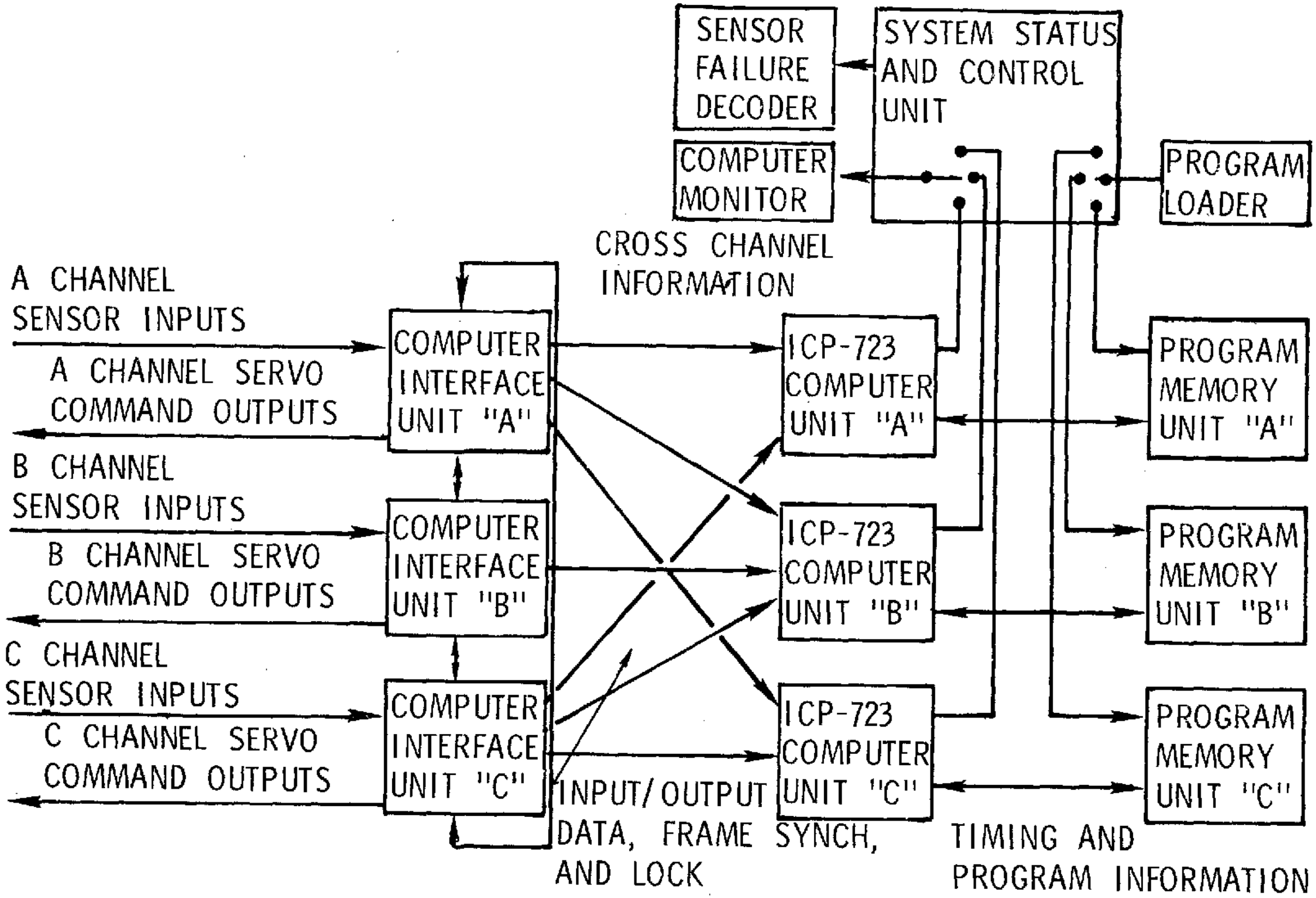


Figure 10. Flight control computer organization.

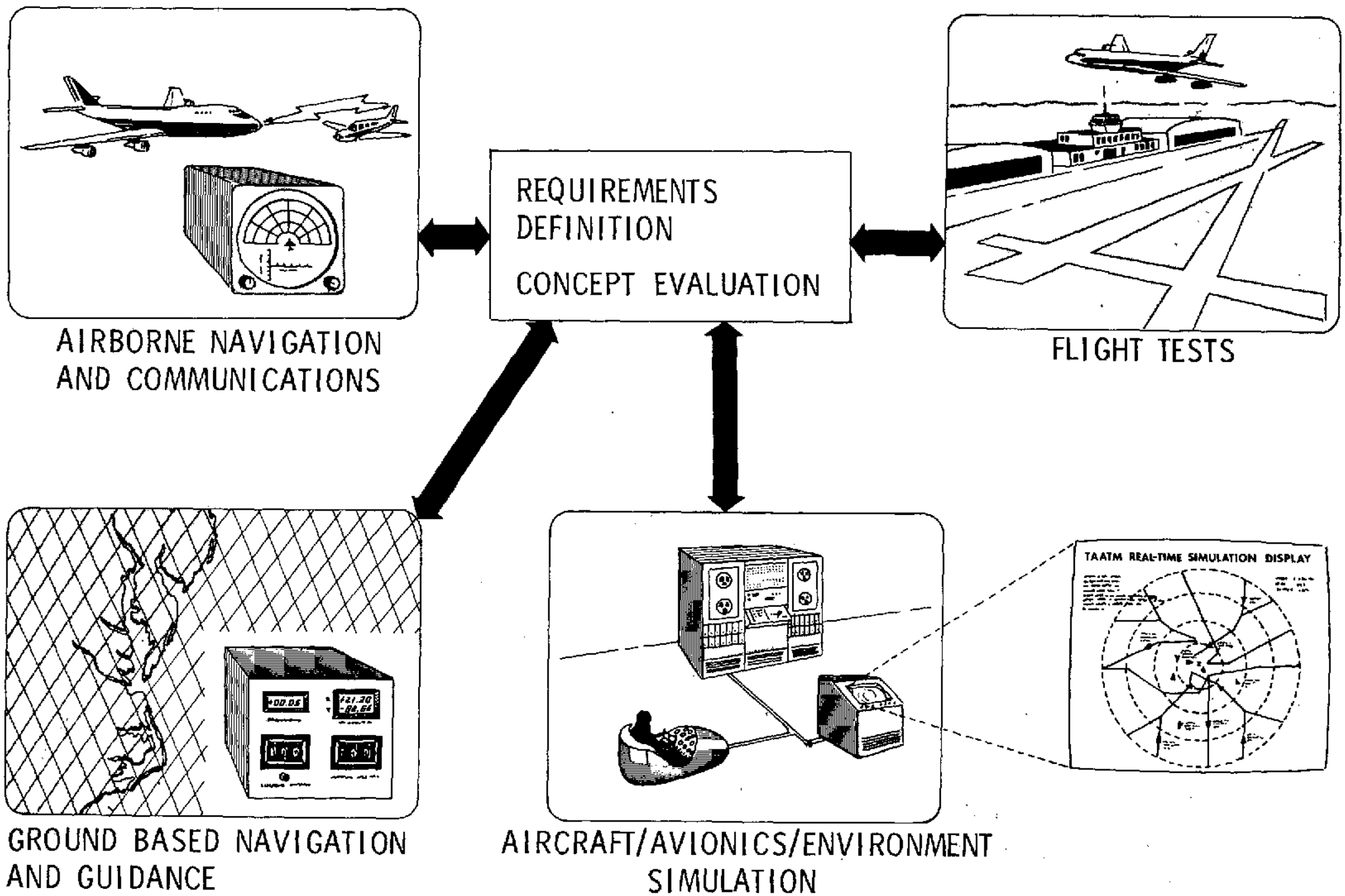


Figure 11. Terminal area environment simulation.

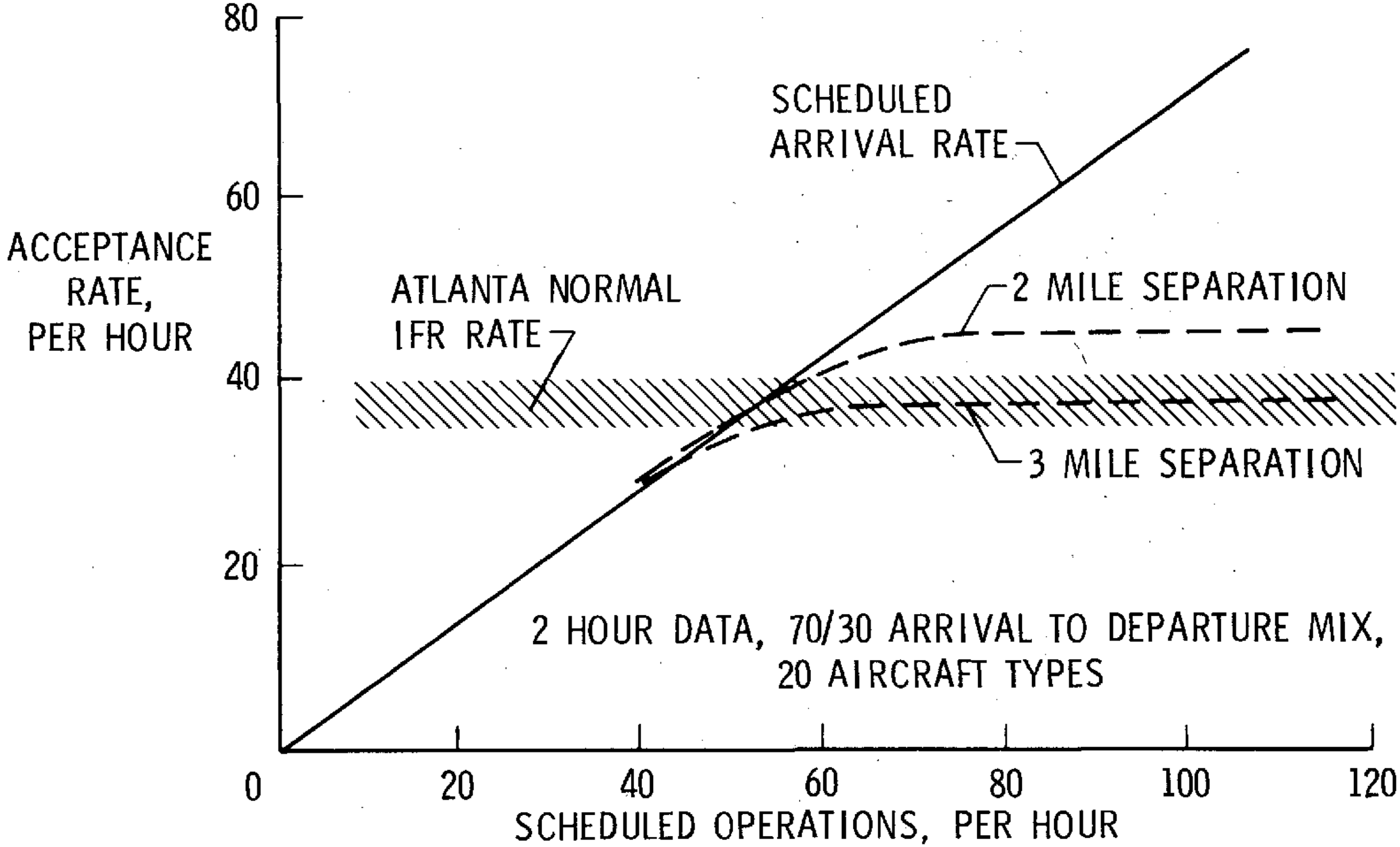


Figure 12. Example of simulated runway acceptance rate data as affected by final approach separation — Atlanta terminal, 1967 data.

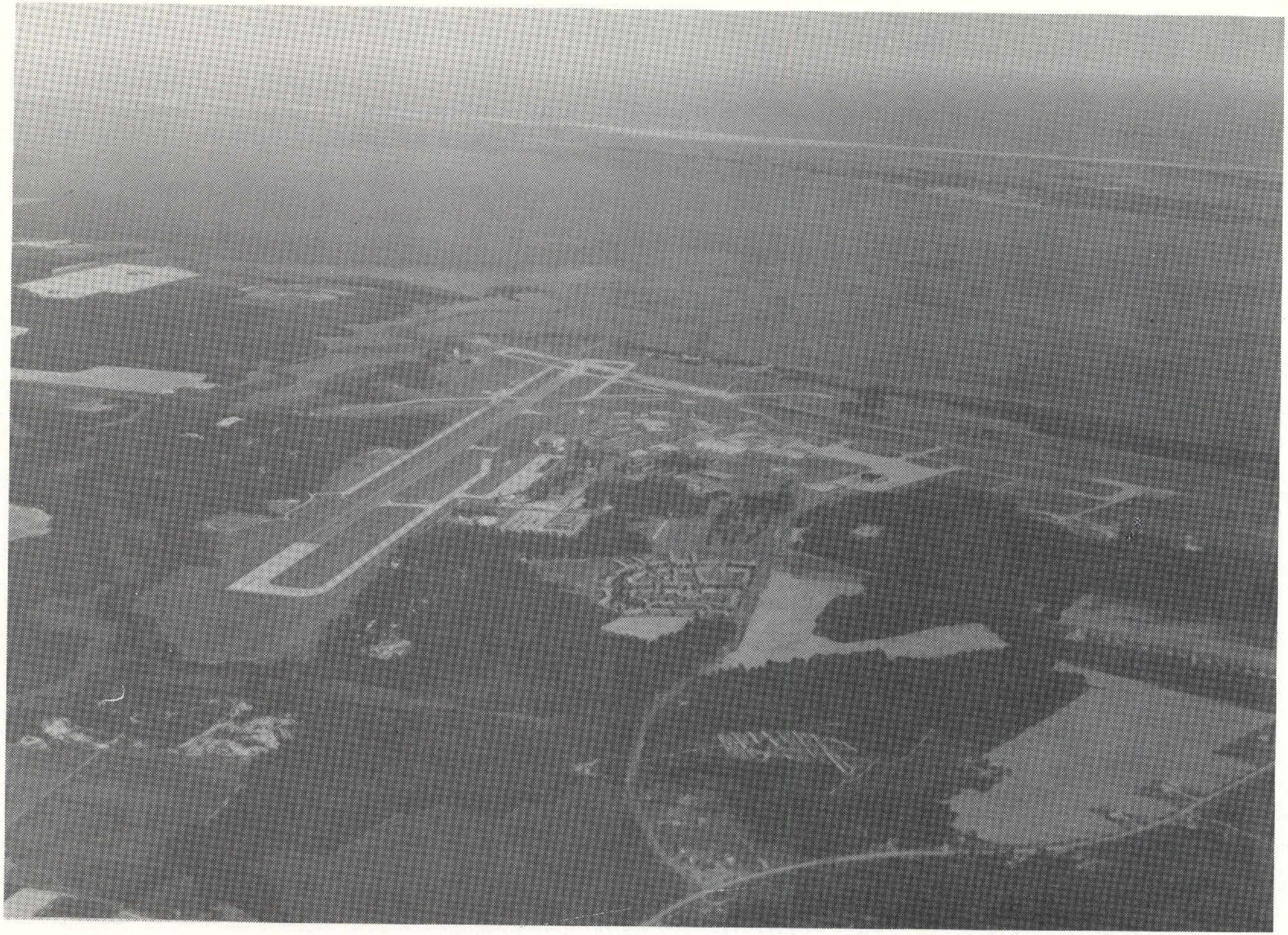


Figure 13. Wallops Station airfield.

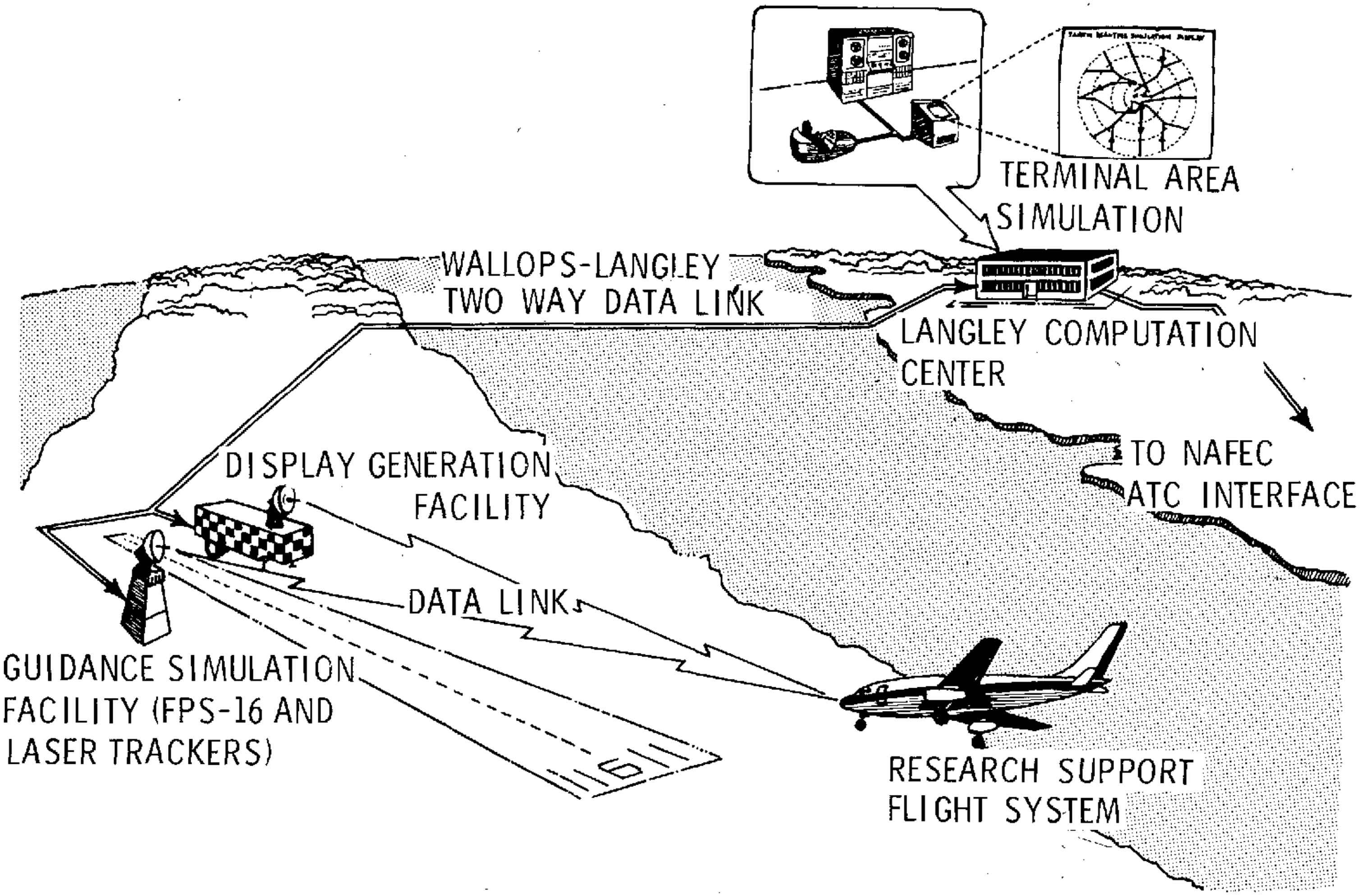


Figure 14. Wallops/Langley aircraft flight research facility.

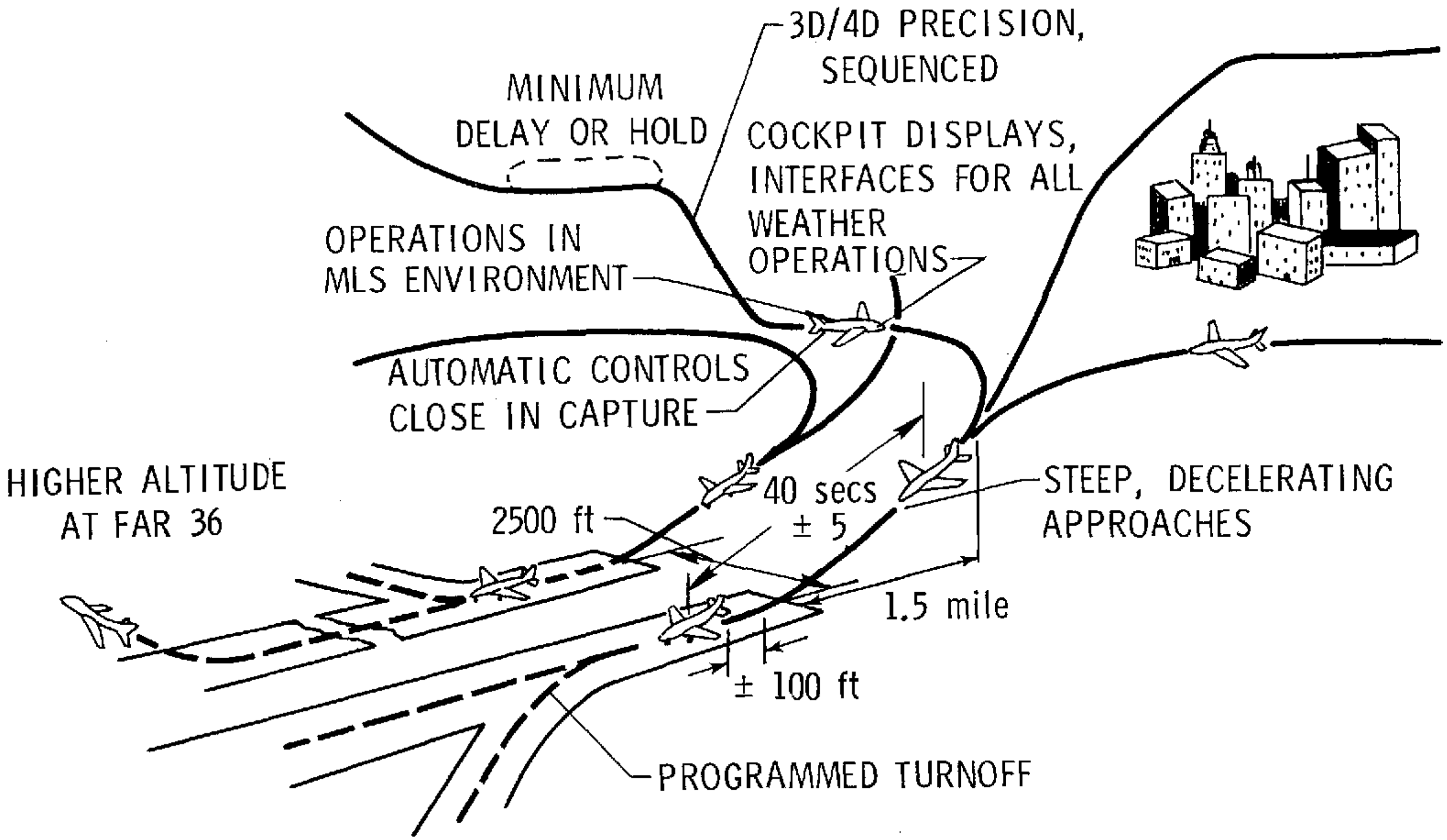


Figure 15. Use of advanced systems and procedures to improve terminal area operation, independent of weather.

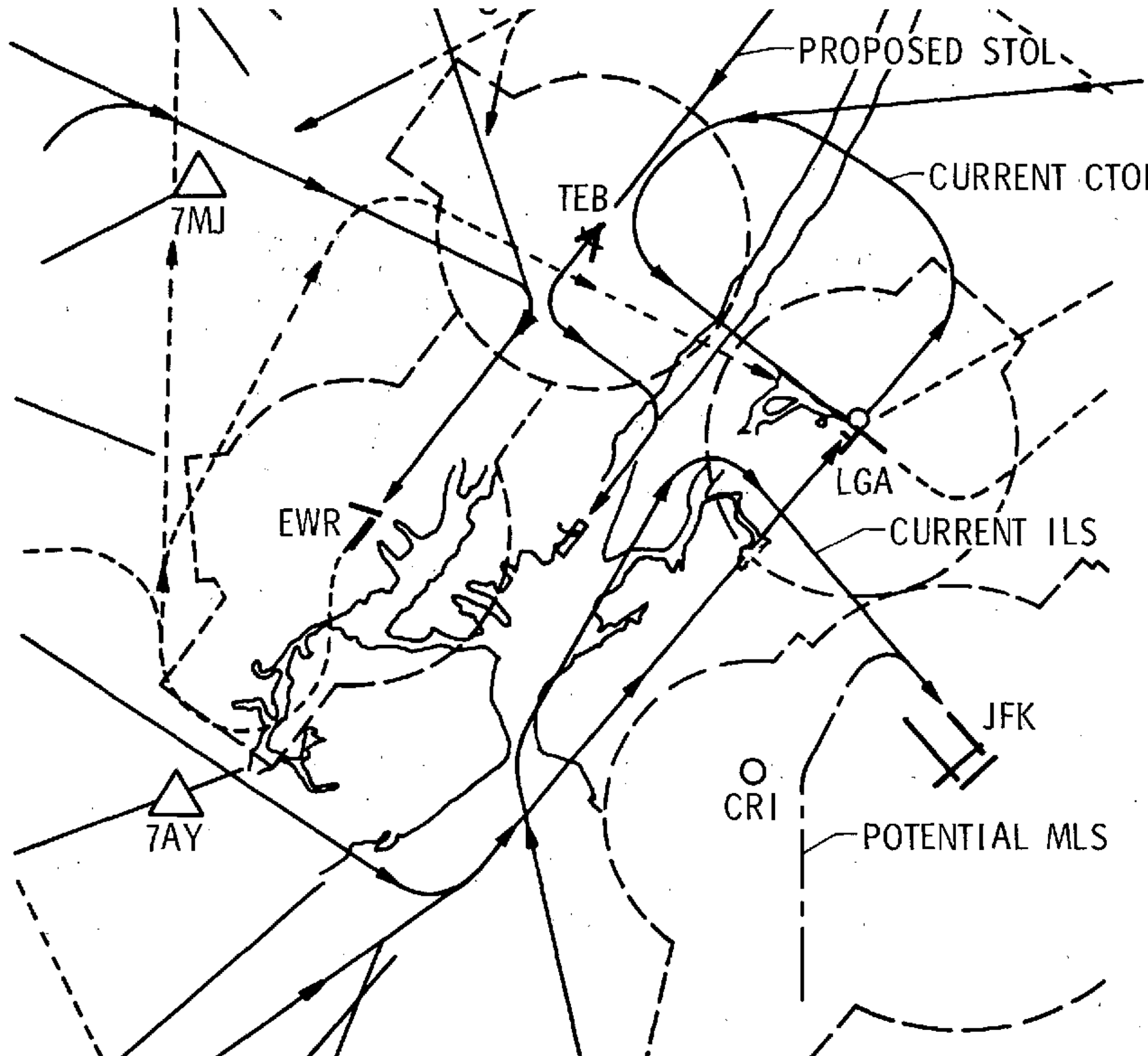


Figure 16. New York terminal area flight paths for one landing direction.

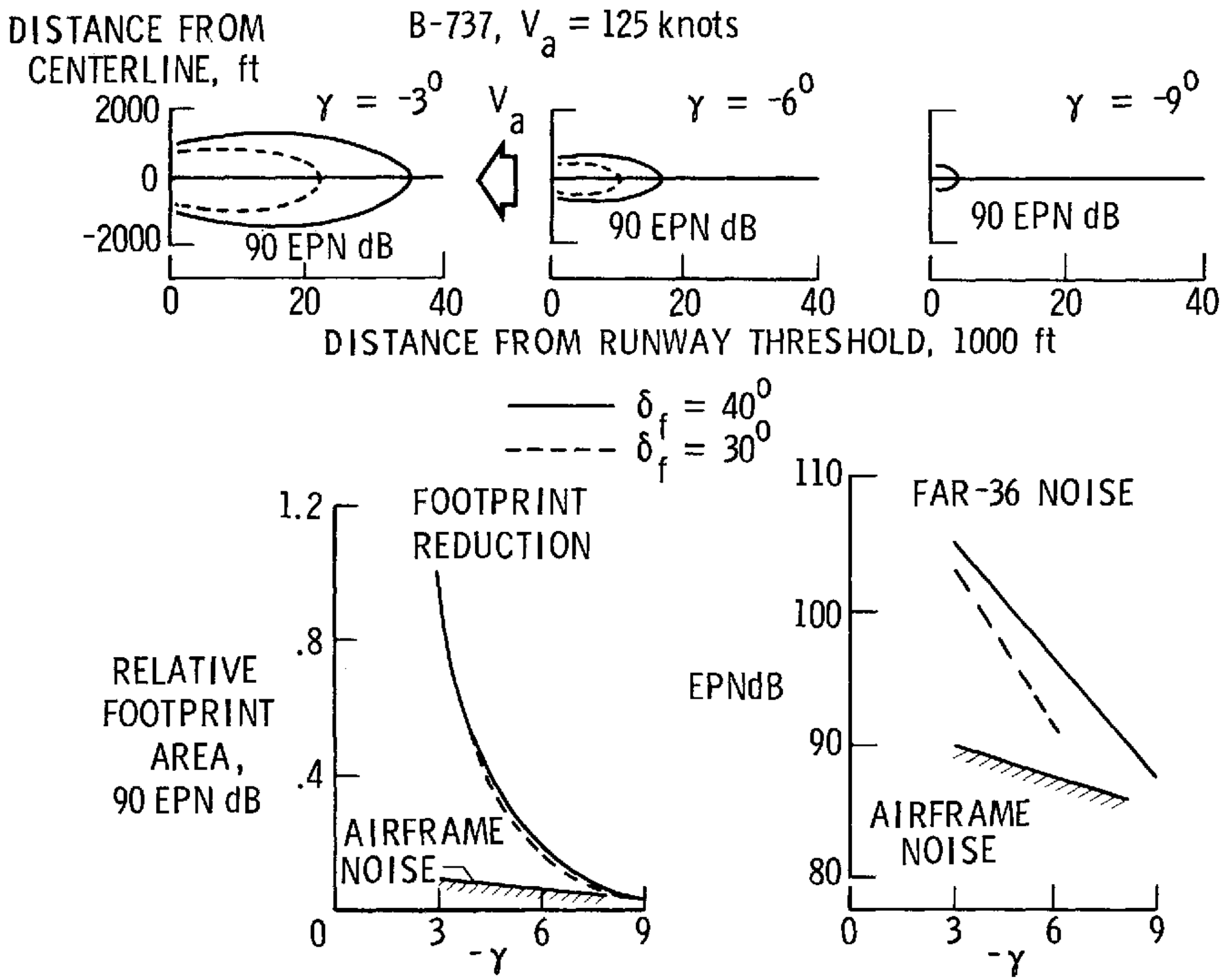


Figure 17. The effect of glide-slope angle on landing approach noise.

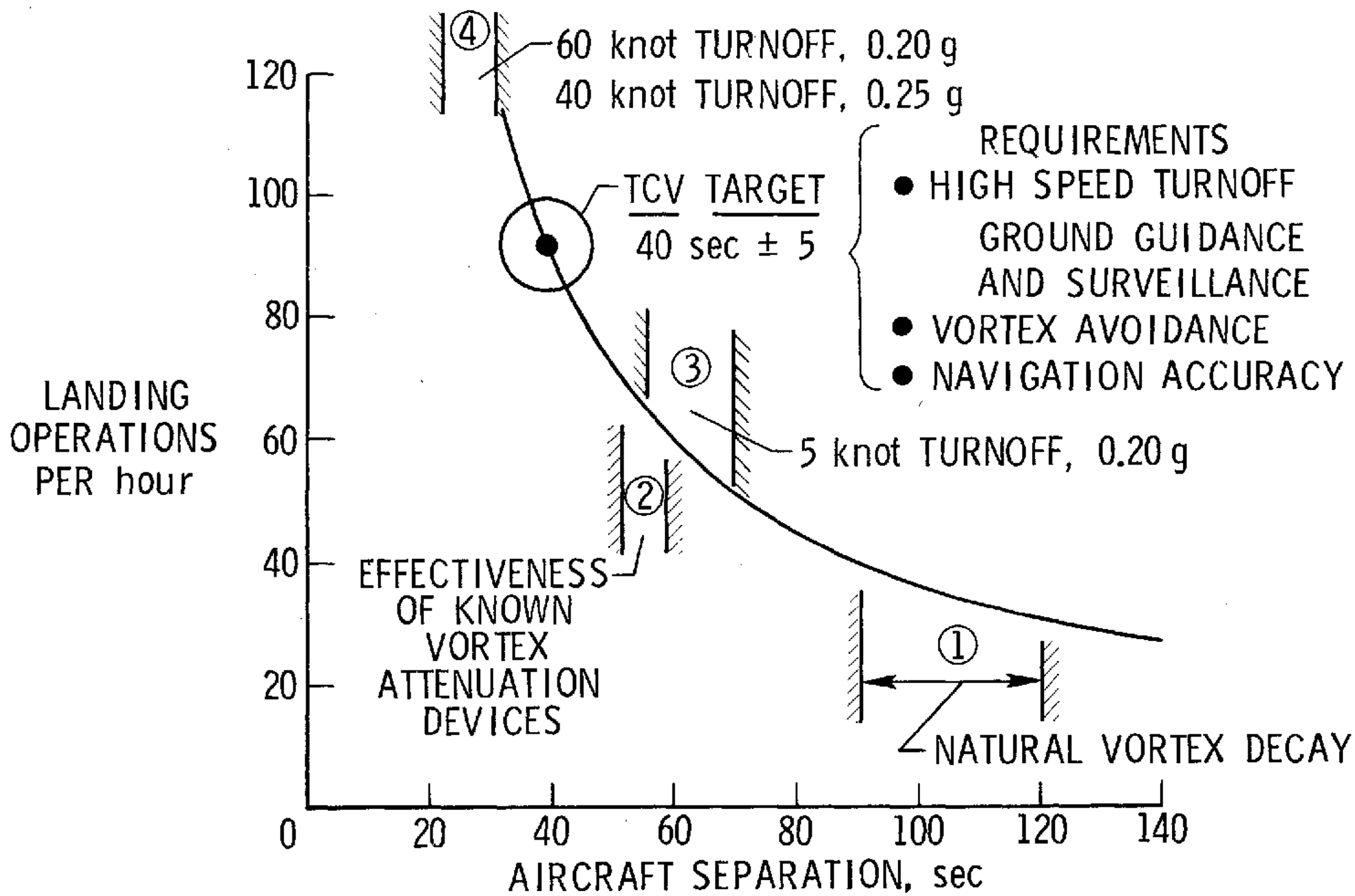


Figure 18. Landing rate constraints.

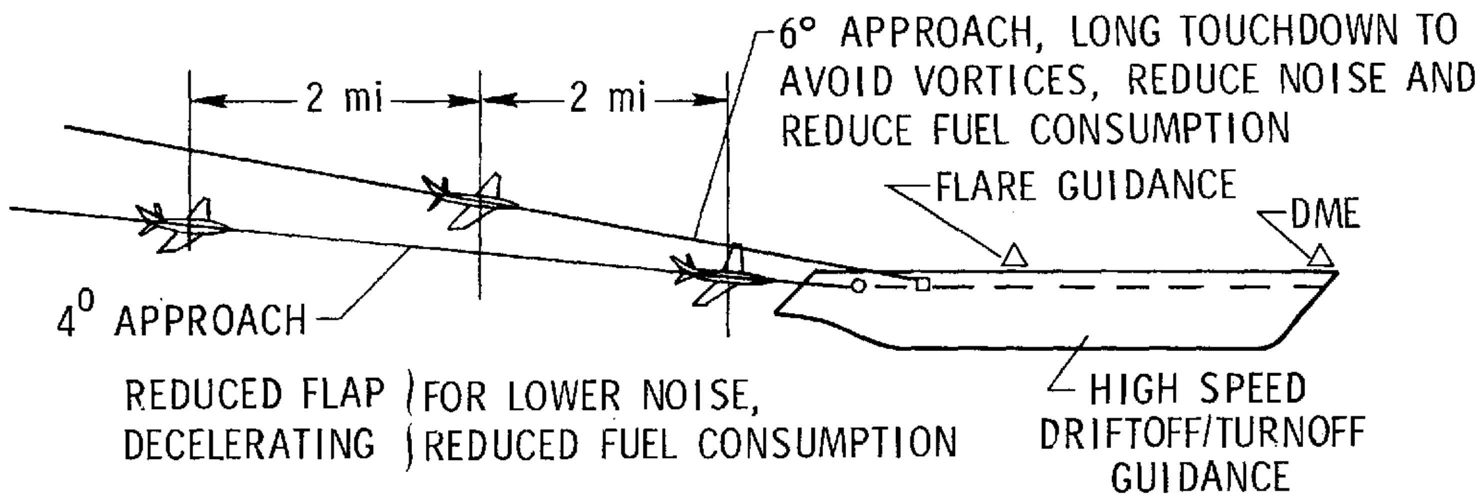


Figure 19. Conceptual high capacity runway procedures for noise abatement and vortex avoidance.

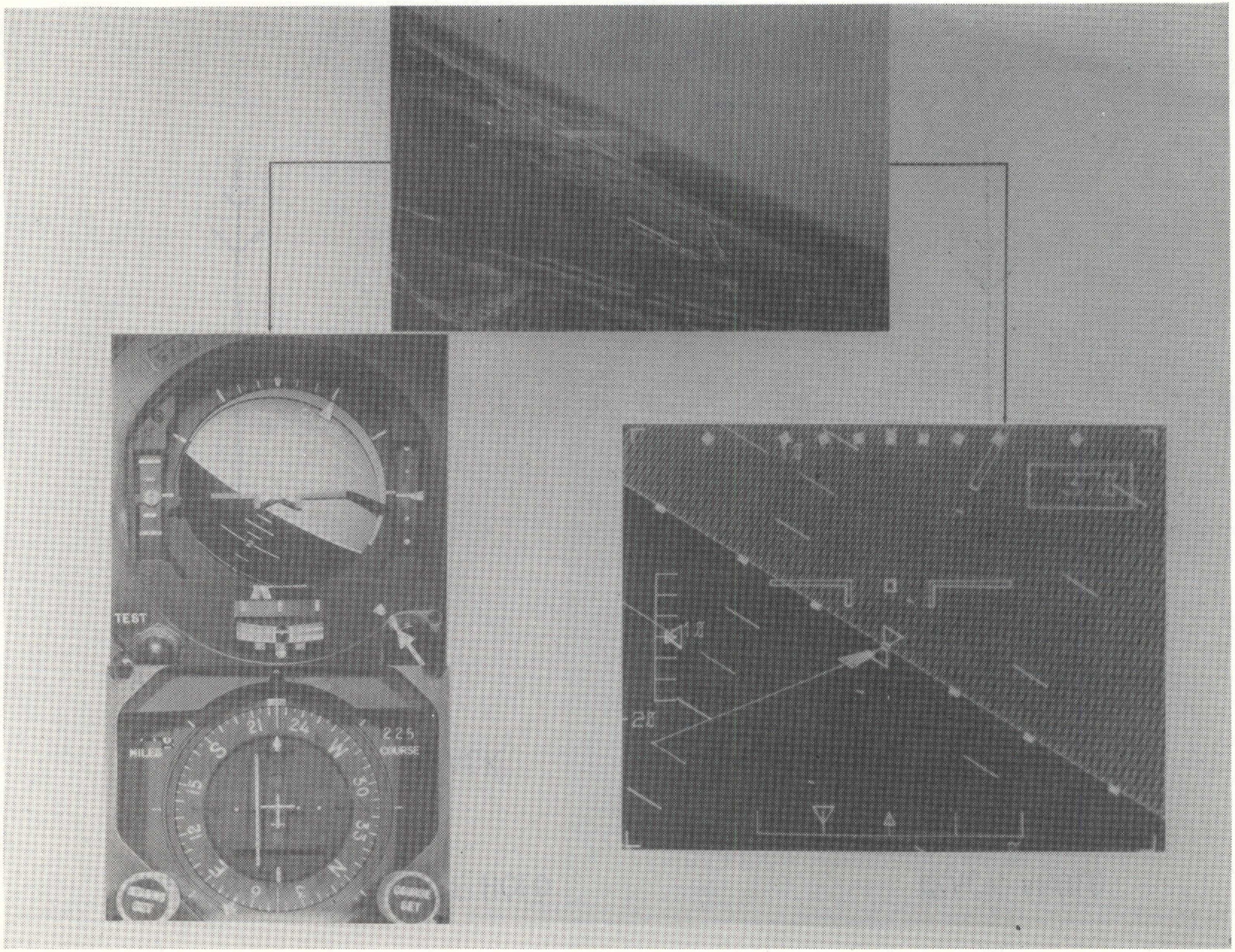


Figure 20. Comparison of electronic displays and visual approach information.

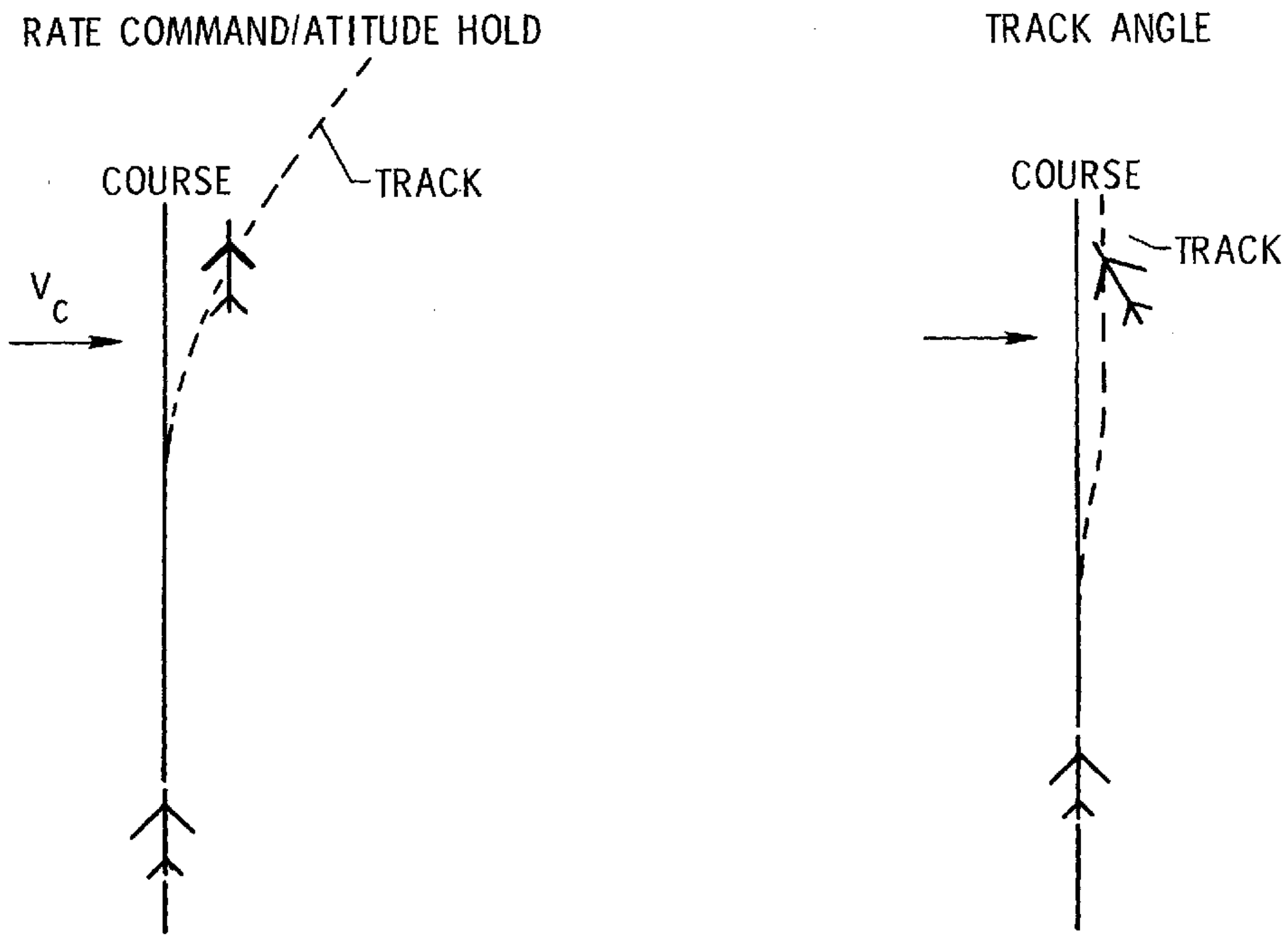


Figure 21. Control wheel steering modes.

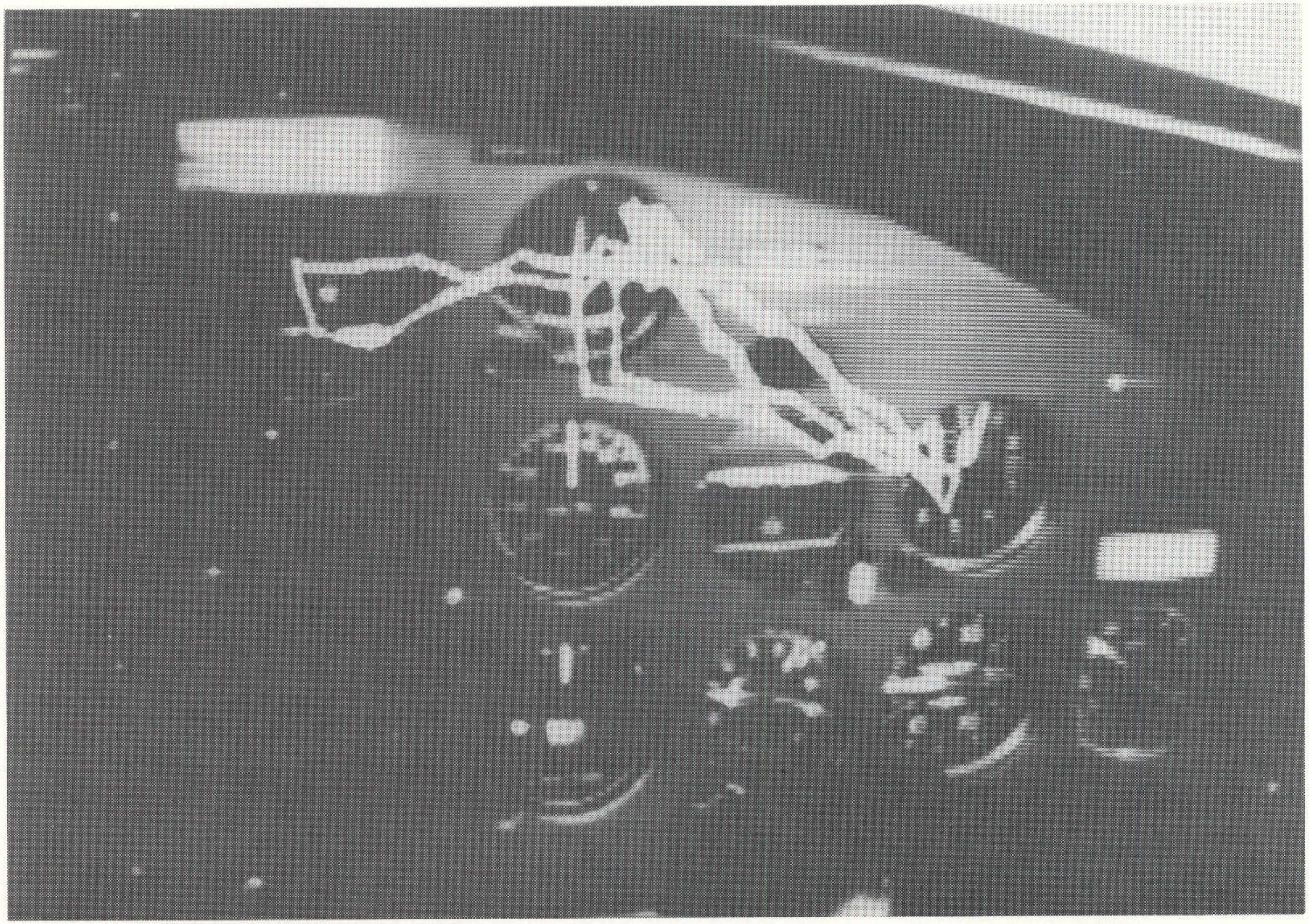


Figure 22. Oculometer data showing pilot eye track on instrument panel.

FLIGHTS

- 40 FLIGHTS FOR 78 HOURS
- 30 AUTOMATIC 4D FLIGHTS OF 125 MILES, 35 MINS.; 76 AUTOMATIC LANDINGS
- ENCOUNTERED 800 ft CEILINGS; 60 KN HEADWIND VARIATIONS; 30 KN CROSSWINDS; ICING; TURBULENCE; WIND SHEARS

RESULTS

- DESIGNS SATISFACTORY FOR CONTINUING TEST PROGRAM; SOME DEVELOPMENT PROBLEMS REMAIN
- FLIGHT RESULTS CONSISTENT WITH GROUND-BASED SIMULATIONS
- AUTOMATIC 4D TIME ERRORS AT TOUCHDOWN 5 TO 8 SECONDS FOR 125 NMI FLIGHTS
- LITTLE PERFORMANCE VARIATIONS BETWEEN 4 PROGRAM PILOTS

Figure 23. Summary of ADEDS/AGCS flight demonstration tests.

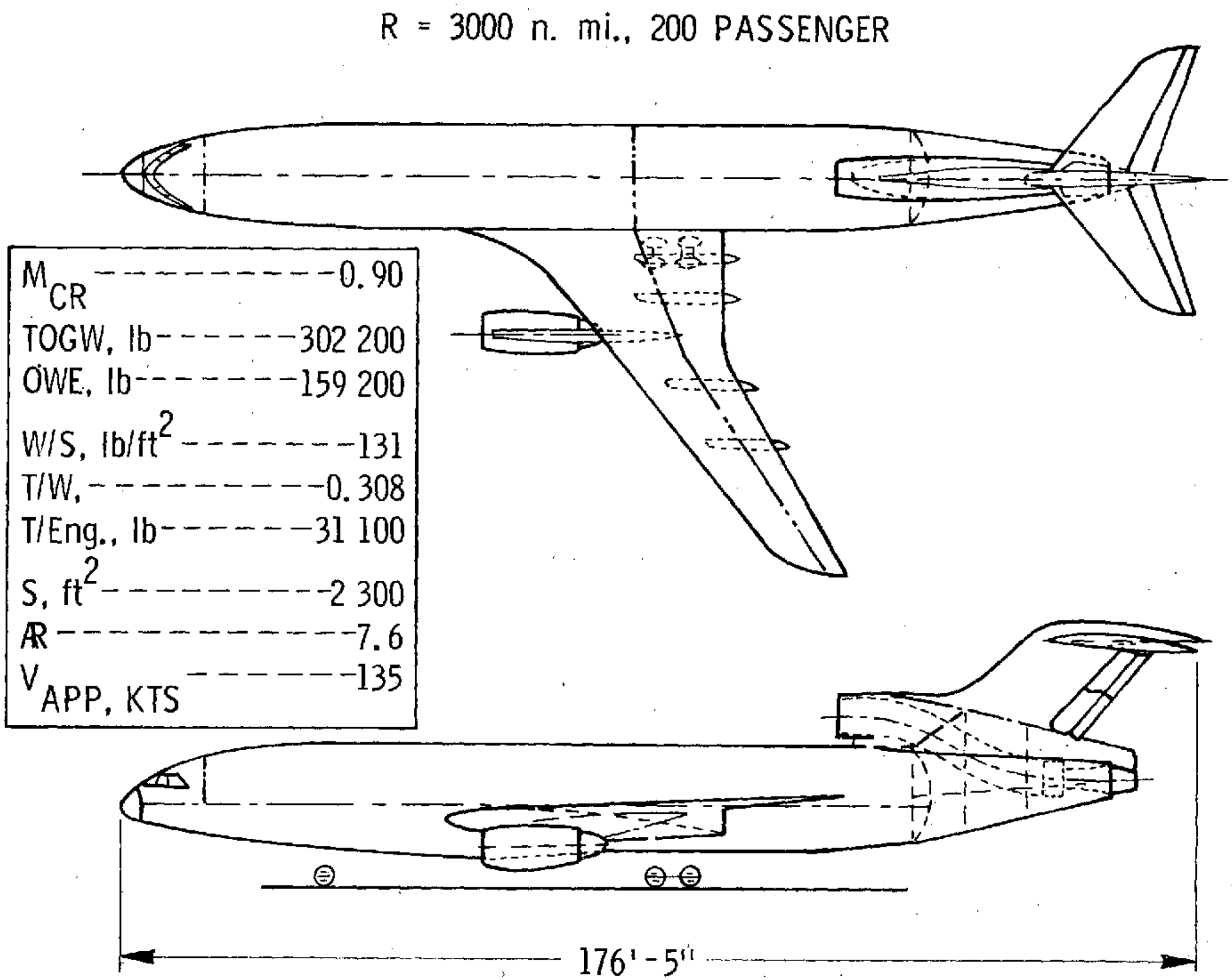


Figure 24. Baseline advanced technology transport airplane.

M_{CR}	0.90
TOGW, lb	311 100
OWE, lb	172 630
W/S lb/ft^2	121
T/W	0.299
T/ENG, lb	23 200
S, ft^2	2 570
AR	9.0
V_{App}, KTS	120

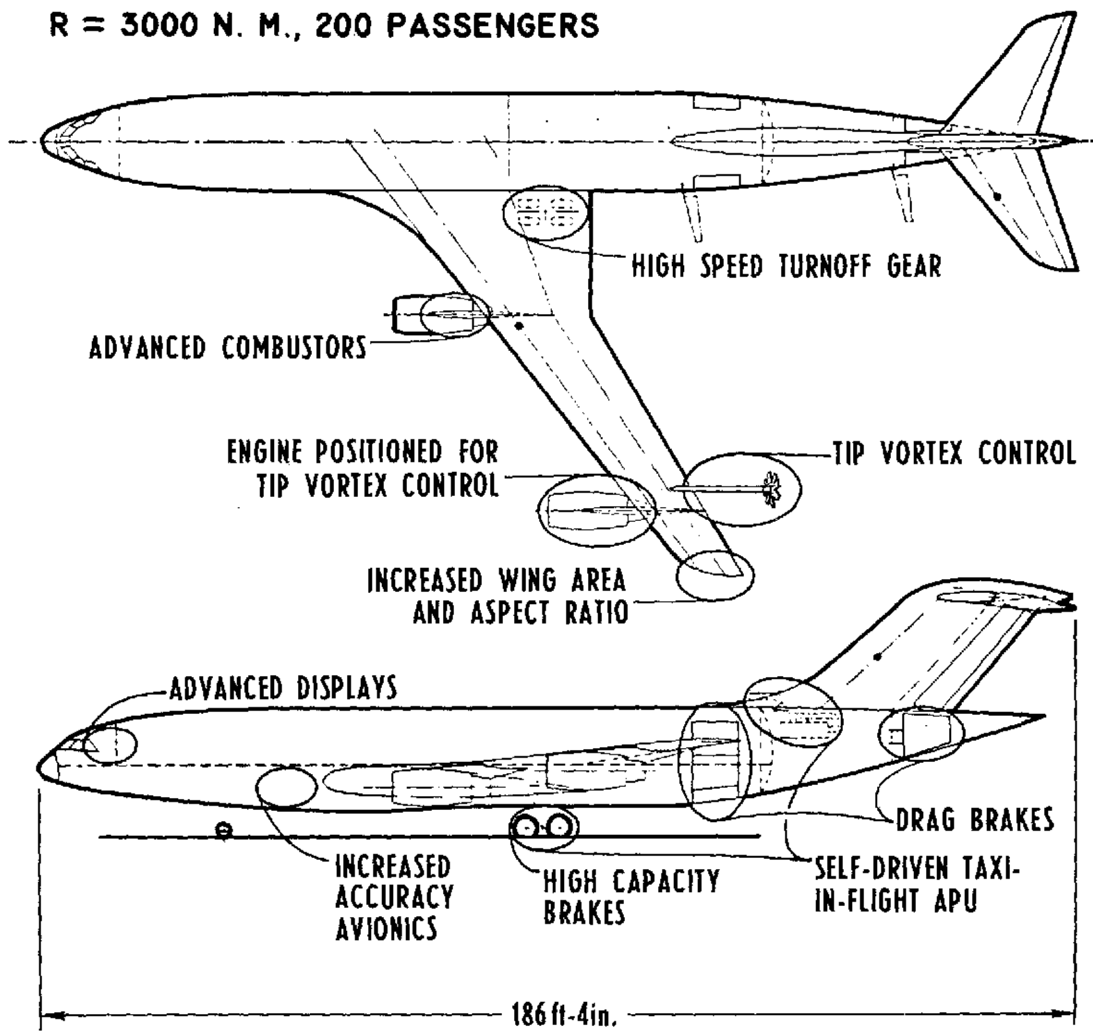
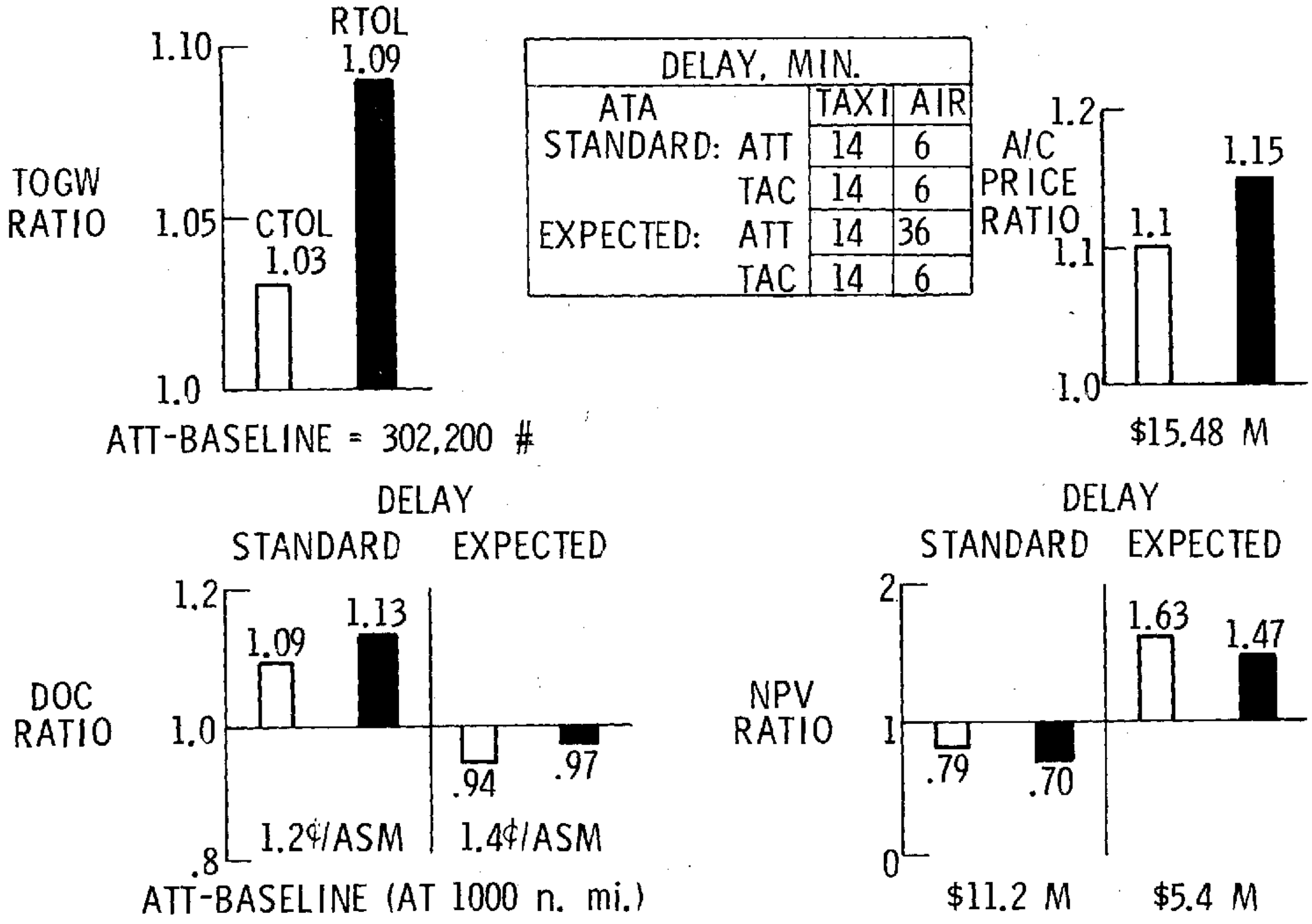


Figure 25. Terminal compatible airplane concept.



DELAY, MIN.			
ATA		TAXI	AIR
STANDARD:	ATT	14	6
	TAC	14	6
EXPECTED:	ATT	14	36
	TAC	14	6

Figure 26. Summary of cost-benefit analysis of terminal compatible airplane.

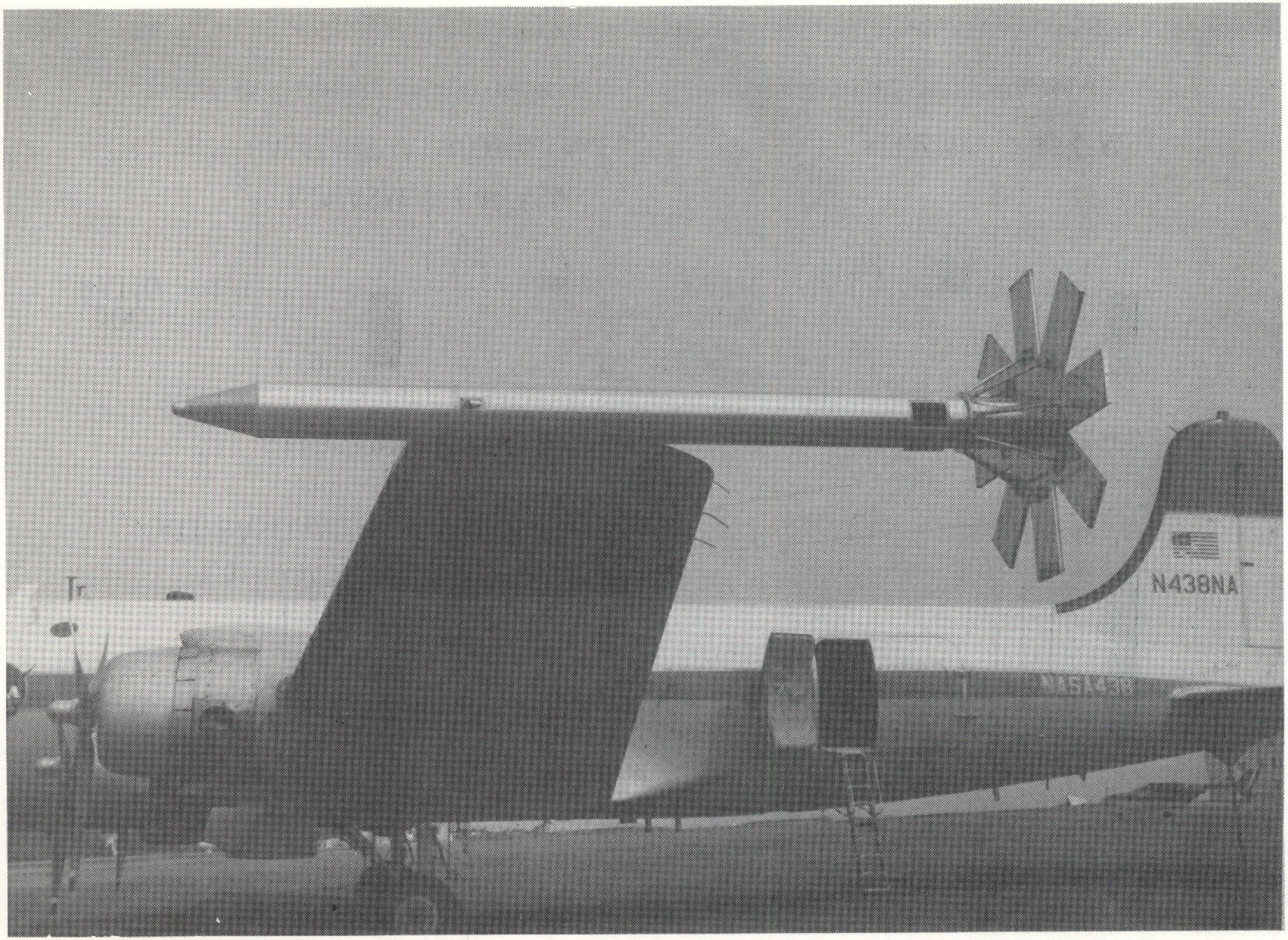


Figure 27. C-54 with wing-tip spline for vortex dispersion.

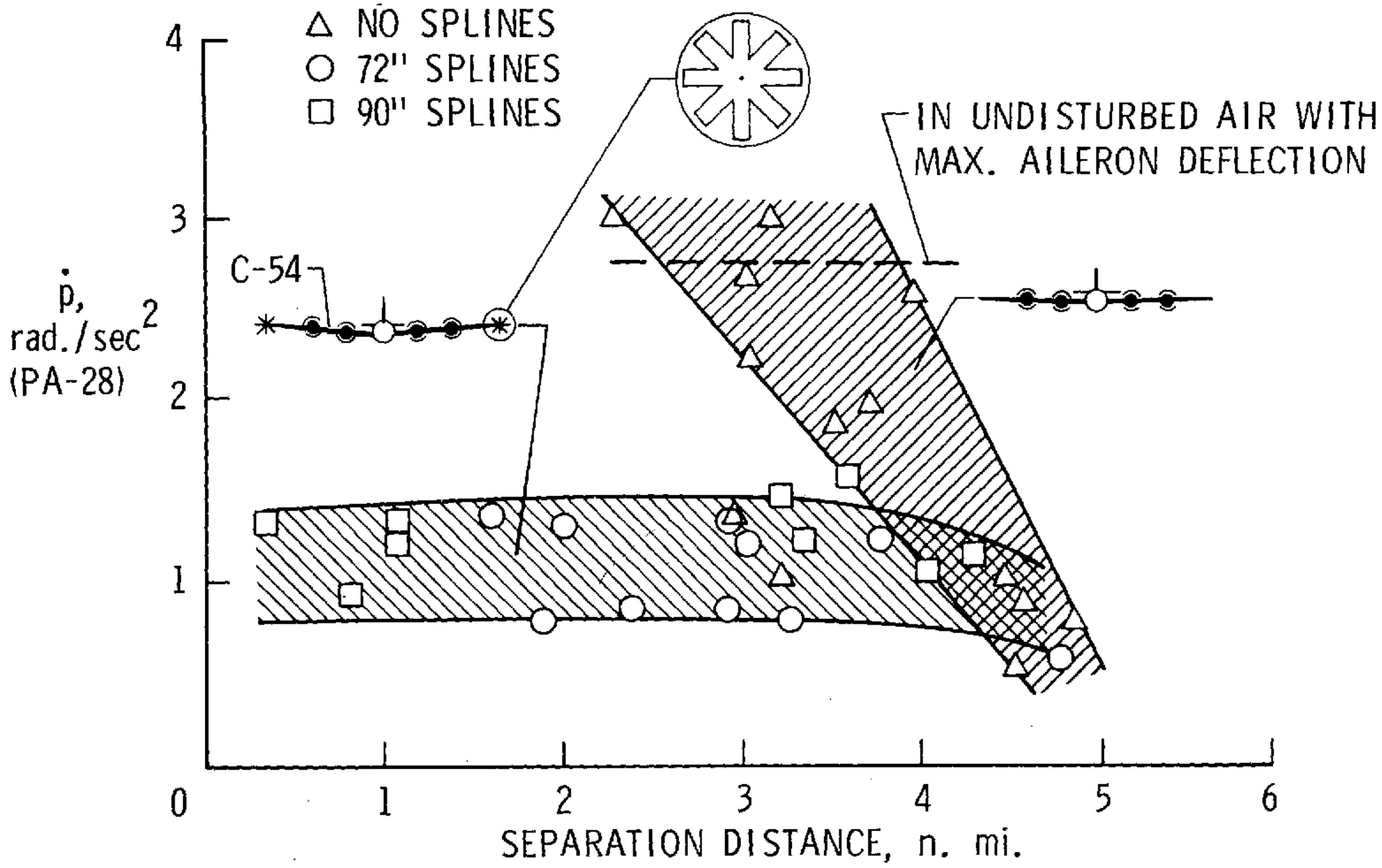


Figure 28. Measured roll acceleration for PA-28 airplane in vortex wake of C-54 with and without splines.

NASA-Langley, 1974