ICAS PAPER
No. 72 – 04

FUTURE TRENDS IN AIR TRAFFIC CONTROL AND LANDING

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The Eighth Congress of the International Council of the Aeronautical Sciences

INTERNATIONAAL CONGRESCENTRUM RAI–AMSTERDAM, THE NETHERLANDS
AUGUST 28 TO SEPTEMBER 2, 1972

Price: 3. Dfl.

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Abstract

Future trends in Air Traffic Control and Landing will have a large impact on the future of aviation as we know it today. A total systems approach to integrating the disciplines of electronics and aeronautics is essential if we expect to solve the many major problems already identified such as area navigation, microwave landing, collision avoidance and the acceptance of tens of thousands of light aircraft. An advanced example of this new total system thinking is the Microwave Landing System National Plan and its interface with Air Traffic Control and present day operational aircraft and those of the future.

Introduction

Aviation has now matured from its early days of uncertainty to a major industry, and it is now time to examine its future in a much broader context than ever before. When a few aircraft existed that flew low and slow, there was little need for radio navigation, Air Traffic Control, Instrument Landing Systems, Communications, etc. These simple days are past, and we now use a wide spectrum of aircraft costing from ten thousand to twenty million dollars. This wide differential of over a thousand times involves users that want to share some common segments of the airspace. We see major jetports whose capacity is so limited that at peak hours large delays are incurred. Air collisions continue, and landing approach accidents remain our most critical safety matter.

In the United States, each user of our airways and airports is now paying into an aviation trust fund to be used in overcoming the inadequacies of the existing airways and airports and in designing new systems to cope with the projected growth of aviation. It is estimated that the trust fund will accumulate as much as 800 to 900 million dollars per year. The Airport and Airway Development Act of 1970 that created the trust fund concept may lead to better communications between the implementers of airports and airways and the users of airports and airways. The user is now being taxed directly for such services and is therefore more conscious of the investment of these trust funds into future airways and airports.

Public opposition to aviation noise and nuisance will probably prevent new jetports from being built at anywhere near the rate they were one or two decades ago. For example, New York has been stalemated from implementing plans for a new jetport for over a decade. It is increasingly evident that few, if any, major new jetports will be started in the United States. We must now find ways to improve the efficiency and utility of those we have. The wide-bodied jets allow more passengers to be carried, thus reducing the plane movements for a given passenger volume; however, even so, the total number of air carrier aircraft will increase significantly over the coming decade. Each airframe, costing more and carrying more passengers, is much larger--a set of factors that makes traffic delays, accidents, and other matters we have tolerated in the past now completely unacceptable. A single major airline accident can now include total losses of over 100 million dollars, considering airframe costs and the average settlement in the courts for airline passenger fatalities.

The era of the "black-box" solution to our airways problems is also in the past. Such black boxes as the Automatic Direction Finder, and similar approaches to airways and airport traffic handling were great steps in 1940, but in 1972 the problems are far more complex, and "total-system" solutions must replace "black-box" solutions. In nearly all cases, cooperative ground and air units are involved.

The ground portion of the cooperative system is easily implemented and operated by some governmental authority, while the cooperative air units are usually implemented, operated, and maintained by some private party. The point is that the implementation of the two halves is by different parties, not always with the same objective. Economics of various solutions, if viewed only from one side, such as reducing costs of the ground environment, may add unnecessary cost burdens or risks to the airborne user. Since the user's costs do not appear in any governmental budgets, it is often difficult to judge the best approach. Seldom does the user control the implementer's policy.

On the other side of the coin, a private or limited user may create his own independent electronic device or system for what he honestly thinks is the best solution to an ATC problem and then finds the other users or governmental authorities do not concur in that particular solution to the problem.

A Total Aviation System Approach

Aviation is now at a stage of maturity where we must find "total-system" solutions to our problems. This involves mostly aeronautic and electronic experts sitting down with pilots, authorizing government agencies, and civil and military users of the airspace to establish realistic requirements suitable to all users and implementers. Then the technical challenge is presented to synthesize systems that will meet what is becoming an enormous range of requirements. This wide range is due to the wide differential in airframe costs, aircraft speeds, climb and descent pattern to cruise, jets and pistons, military and business jets, general aviation and airlines.

We are now experiencing in the United States the first major effort along these lines of "total-system planning." We are very hopeful that it will be successful and result in a new Microwave Landing System. If the plan is not successful, one can predict considerable chaos resulting from widely differing technical approaches will exist; each incompatible solution nullifying the others and stifling aviation progress.

We will discuss briefly four categories of new system areas in ATC, and then go into some depth on the fifth, the national planning for a Microwave Landing System (MLS).

Ground Automation of Air Traffic Control

The general characteristics of this problem have been evident ever since a joint military/civil agreement was reached nearly two decades ago to use a "common" system of "Secondary Radar" on the ground that depended on aircraft-installed Beacon Transponders. The air transponders reply to these new radars conveying the aircarft's identity, altitude, range, and angle (position). Each aircraft provides this data automatically in a digital pulse form to the ground environment.

Through international actions at ICAO, the Secondary Surveillance Radar system (SSR) is now available in its basic forms in most countries, so that aircraft that cross international boundaries have access to the same services. Since the aircraft transmissions are in a coded form that is quite suited to computer "processing" techniques, this data is instantly converted with the ATC information it conveys into graphical forms (lines, symbols, numbers, and letters) for the ground ATC controller to observe. A controller's ground display presents a great deal of automatically processed data or "automation" of ATC data through a choice of pushbuttons.

In the United States a vast SSR automation program is now well on its way to full implementation (completion by 1975). Nearly all the usable airspace will be covered with hundreds of ground radars, and some 100 to 150 thousand aircraft will probably be equipped. Already approximately 70,000 aircraft are transponder equipped, and over 500 SSR ground stations are operating.

The SSR system essentially provides all the ATC information to only the ground controllers, since the airborne transponder is but a slave unit and has no pilot data output concerning ATC. As a consequence of this successful electronic development, the techniques of "radar vectoring" have evolved. The imbalance in data quality and usefulness gives all the advantages to the ground controllers rather than the pilots. The controller "vectors" or guides by commands the air traffic using voice communications.

The automation of this system by the addition of another electronic unit, ground-to-air "data link," is now under serious consideration. This added automation step tends to add even more burden to the ground responsibility since it removes the pilot even further from the ATC control loop. With voice ATC instructions, the pilot hears all instructions to aircraft near him and can judge their safety and credibility. Each pilot also knows other pilots' reactions to ATC instructions by simply listening. Instructions to others might be doubtful as the ground units are not infallible.

The pilot is in a position to be the first to suffer if a mistake is made, say in altitude assignments. Today he can quickly judge the credibility of his ATC instructions in voice, but with increased "automation" (using a "data link"), only his own specific instructions will be available. Even then he has less ability to exercise his judgment of their safety and credibility. Because of technical limitations of ATC automation, he is denied the data going to others, even where their instructions may be of concern to his own safety since they are in his proximity. He must have nearly blind faith in the automated system, something hard to "sell" to modern pilots.

Pilots currently create a "mental picture" of the traffic about them by listening to all ATC instructions. Pilots participate in the judgment of the instructions, certainly to the extent of detecting errors or omissions in the ATC process. One has only to listen to air-ground communications for a while to realize the importance of this matter.

It is not clear that the next step in ATC advances should be automated communications to the pilot, particularly if other needed improvements such as Area Navigation can be used to <u>return</u> some of the pilot participation, responsibility, authority, and safety considerations to the cockpit. The concept of Area Navigation in several forms, including MLS, is our best hope at present for balancing the air and ground responsibilities and participation in ATC. ATC automation with Data Links increases the imbalance in favor of the ground control and to the disadvantage of the pilot.

Area Navigation

Most of the important airways today are based on the principles of VOR. By assigning radials from this omnidirectional (ground-referenced) navigation system, the pilot is provided an "on-board" display to his track and can fly to or from the VOR station. By the addition of collocated Distance Measurement Equipments (DME), he can judge his distance to the stations also by cockpit displays.

These two elements create polar coordinate signals in space surrounding the VOR station that, if modified from "radial-only" displays with a computer, can create parallel airways that are no longer limited to going to or from the VOR. The pilot now can participate more in ATC functions since he can adjust his "Area-Nav" displays to go where the traffic demands or mutual "pilot-controller" decisions may dictate.

However, since the current airways and tens of thousands of aircraft equipments are dependent on "radial-only" type of "Victor" airways, there is still increased traffic congestion since all the routes tend to focus to a single point, thus making very inefficient use of airspace and unnecessarily lowering the total potential system capacity. By creating "Parallel-Airways" instead of radially "converging airways," much greater capacity can be added to the VOR/DME system than now exists. It unfortunately requires, in addition to the VOR/DME units in the aircraft, a means for computing the assigned airway taking into account the elevation of the many VORTAC stations and the elevation of the user aircraft, since DME is a slant-range measurement. For large aircraft costing over a million dollars, the added cost of Area-Nav is minimal and justifiable when the benefits are examined, such as more direct routing, fuel savings, fewer ATC delays, and better alignment for final approach into the airport. With the airline trend toward even larger aircraft that are more sophisticated and costly, airborne inertial inputs and digital computing capacity are not out of order. One then has a very versatile Area-Nav capability using both ground-based sensors such as VOR/DME, Loran-C, and complementing airborne sensors such as inertial and/or Doppler.

However, the cost to the airway user for such services (including the three-dimensional airway computations for sloping (or "slant") airways used in descent or climb of heavy jets) are somewhere in the 50 to 100 thousand dollar category. These costs are acceptable to users of large aircraft where benefits are great, but these costs are unacceptable to the tens of thousands of light aircraft owners and users. This light aircraft portion of aviation is predicted to grow much more extensively than the airlines. This is true not only in population statistical (50:1) ratios, but also as far as aircraft movements are concerned.

We appear close to airline authorization and implementation of (VORTAC) Area-Nav in the United States, which will greatly aid ATC since the pilot will now be able to fly on more direct and more independent routes instead of only radial routes. We could have possibly 4 or 5 parallel airways going in a given direction rather than just one from a VORTAC. This will greatly increase airway capacity for airborne users that can afford the Area-Nav avionics.

Some airlines with experience in the use of Area-Nav report a significant reduction in air-ground communications, and they also report more pilot acceptance since the pilot participates more as an equal partner in the Air Traffic Control process.

This and other forms of Area-Nav, using the volumetric microwave system or ground-based, long-range radio such as VLF or Omega stations, are a significant trend favoring pilot participation, which is far enough along to suggest that the trend will be operationally implemented as users are equipped. We can now postulate new ideas and techniques of ATC using Area-Nav with reduced dependence on radar vectoring and commands to the pilot. This is a healthy trend as it creates a much needed improvement in the balance between the "pilot and controller," giving each a more optimized set of functions and responsibilities. Furthermore, each is better situated to judge the performance of the other, which will add to greater safety and efficiency of the ATC process. With automatic altitude, identity, and position reporting taken care of for him by the SSR system, the pilot can now devote himself to flying his assigned airspace or route assignment using Area-Nav displays of earth referenced position with greater precision and timing accuracy. More accuracy in pilot prediction of specific airspace occupancy times or critical timing in terminal areas increases system capacity. This new Area-Nav potential reduces dependence on "radar vectoring."

Collision Avoidance

It has been recently agreed in the United States by military, civil, and Congressional authorities that the basic function of collision avoidance will remain with the SSR and its associated ATC system. The two elements discussed above--SSR automation (with three-dimensional air and ground reporting via the transponders) and

Area Navigation, where airways no longer converge to a point of congestion but go more directly to the pilot's destination--definitely typify basic ATC functions that will reduce the risks of air-to-air collisions.

If the total aircraft population were to remain permanent for the next two decades, it is likely that the fully implemented "Area-Nav" and "SSR Automation" concepts would take care of the collision avoidance problem. However, with increased densities of traffic, simply created by the numbers of aircraft aloft, errors and equipment malfunctioning remain a possibility. Some experts feel collision risk can increase as the square of the instantaneous airborne aircraft, inferring a nine-times increase in collision risk with the estimated three-times growth in airborne traffic.

Furthermore, the "see-and-be-seen" rules of 20 years ago are nearly useless today in most airspace, with the high closing rates and the decrease in visibility caused by industrialized areas. Smog seems to surround most of our dense air terminal areas, as this is where industry is also located. Consequently, some form of measuring the "proximity" of controlled aircraft will probably be developed. This is not a "collision avoidance" technique but a technique for aiding in assuring that adequate control of separation exists between proximity aircraft.

The term "proximity control" depicts a more descriptive and progressive view that is compatible with the trends already discussed in Area-Nav and SSR-Automation. Thus, pilots may pursue tracks and schedules, continue to use voice for critical ATC functions, and utilize a proximity control display or signal of other aircraft. Proximity control provides the pilot assurance that the "automation" and "Area-Nav" are all working according to the plan. Proximity control would aid in spacing of traffic and in assigning tracks; both displayed (track and separation) in the cockpit. This functions as a double check on these basic systems to assure that a ground computer has not made a mistake or that an aircraft's Area-Nav computer has not somehow been mis-set or has shifted the displayed track. Again, "proximity control" provides the pilot with a means for participating in the ATC process that is equitable, such as direct control of spacing of his aircraft on a common track with the fore and aft aircraft. Also, a direct contribution is made to ATC since air-to-air direct measurements of proximity take place permitting pilots to maintain spacing or to be assured the ATC spacing safety limits are not violated by closing of fast and slow aircraft on a common ATC track. "Proximity control" rather than "collision avoidance" is using positive thinking in ATC, and recognizes the need for a harmonious relationship with the other elements we are already committed to with vast air and ground investments.

General Aviation

As noted above, the "price of admission" to the ATC process is rising rapidly. Parallel to and offset to the VORTAC high-density parallel airways could be a set of airways created by low frequency (LF) or very low frequency (VLF) transmissions. Several LF/VLF candidate systems are now being implemented, such as Loran-C and Omega, that will provide the needed evidence as to whether a very, very low cost, widely dispersed Area-Nav system can be created for use by tens of thousands of general aviation aircraft. About 200,000 light aircraft may be in use in the United States by 1980.

This LF/VLF system of navigation has multiple angle, oblique-parallel coordinates everywhere and would assist in distributing traffic over much airspace that is not now useful because of VOR/DME limitations. LF/VLF provides signals at all altitudes down to the runway elevation, so that non-precision approaches could be made to any runway regardless of its size, location, or angular orientation. Direct centerline descent paths rather than "offset-VOR" tracks would be possible with LF/VLF, greatly reducing the high number of non-precision approach accidents that now seem to dominate aviation accident statistics.

Widely distributed airways, based on LF/VLF universal, uniform coordinates, allow a different type of ATC to be employed, since the high-density conditions in jet terminal areas are avoided at the low-density highly dispersed airports that number over 10,000 in the United States alone. Thus, we would conceive of a new type of pilot-oriented, "Broadcast" type of air traffic control for this (1) low-density, (2) dispersed, (3) slow, and (4) low-flying type of air traffic. This leaves the jetport terminals and VOR/DME airways to the jet airliners or similar aircraft where, even though the costs may be much greater, they are still justifiable. This tends to segregate traffic and should off-load some of our dense areas.

Microwave Landing System (MLS)

We have left this program to the last since it is probably the most significant new technological development being initiated, as the others above are either partially implemented or at least highly evident as to what they will do for aviation. The problems of increasing the capacity of the jetport are just as important as solving general aviation's problems. Reduction in noise, reduction in low-visibility landing, CAT II and III accidents, and just generally replacing the aging and inadequate VHF-ILS system are assigned as goals to achieve with this new development.

The many potential users are anxious to obtain a microwave landing system for various reasons. Some users and implementers want more airport capacity and flexibility on the one hand, while others see the enormous potential for portability of a precision landing guidance system suited even for the lowest visibilities (such as CAT III). For example, a localizer antenna can be reduced in size by 50 times a VHF/UHF localizer. Shortage of radio channels, economics, joint airport operations, and many safety considerations dictate that several independent, non-standardized landing systems cannot be operated in the limited microwave spectrum assigned to aviation. A National/International Microwave Landing System Plan is needed.

We will outline a pioneering effort in joint agency planning that created a U.S. national plan for a Microwave Landing System, which is perhaps without precedence, and discuss its implications to the future of aviation.

In reviewing past developments in landing systems one comes to realize that the predominant background and outlook of those responsible is "radio navigation and guidance." This is not surprising since the basic guidance system concept, technology and operational requirements were established many years ago. Very large investments have been made which cannot be disregarded and therefore black box "fix-it" or improvement programs have resulted which have fallen primarily to the radio navigation and guidance engineer. As we have progressed to lower minimums, the problems have become immensely more complex demanding a much broader "total systems" approach. The "landing system" involves a much broader scope of technological considerations than the "radio guidance" function alone. The "system" demands proper attention to aeronautics (in the broadest sense) electronics, human engineering, control/display, dynamic analysis, etc. However, we engineers have a long way to go to fully integrate the two most powerful aviation technologies, aeronautics and electronics, for the public use. Few aeronautical engineers really comprehend Air Traffic Control and Landing and its many electronic ramifications in the same depth they understand aircraft design or flight mechanics. Similarly, there are probably even fewer electronic engineers who really appreciate the impact of their electronic designs on the pilot, the aircraft and flight dynamics. The ultimate customer is the pilot/crew and the aircraft and it "all comes together" in the cockpit in controlling and maneuvering the aircraft precisely. Therefore, a pacing consideration in developing and implementing any air traffic control and landing system must be the flight physics/flight mechanics problem and associated airborne elements of the pilot, manual and automatic control and instrument displays.

As mentioned before, until recently there has been far too much emphasis on "black box fix-it" programs in ATC and landing and too little on more innovative systems responsive to growing present and future needs. This is far from easy, and demands high-level management perspective possessed by few. It is significant, therefore, that the U.S. National Microwave Landing System program was initiated with a system approach to the low visibility landing problem and promises to serve as a forerunner for future ATC development programs.

Interagency Planning For MLS

The June 19, 1970 letter from the Under Secretary of Transportation, Mr. James M. Beggs, requesting the preparation of a five-year national plan for development of a new microwave landing system, indicated the breadth and depth of activity desired. The letter stated that the plan should include:

a. "The initial investigatory phases and proof-of-concept, testing and development phases that would meet common civil/military system objectives.

b. Because of the interaction of the landing system with new aircraft that will become available in the next twenty-five or thirty years, as well as the impact of the vehicles' flight properties on the design of a landing guidance system, aerodynamic and flight control considerations must be included in the program."

This latter statement established the required plan on a "total system" basis.

Impetus toward a national solution to the landing guidance problem was provided in October 1967 in a letter from the Air Transportation Association to the FAA. This letter established the need for a new landing system for airlines. As a result, Special Committee 117 of the Radio Technical Commission for Aeronautics was formed in December 1967 to develop ". . . a precision guidance system concept for approach and landing and an associated signal structure. This concept and signal structure shall satisfy, to the maximum extent possible, the various operational needs of the several classes of users."

The Committee's work began with its first meeting in February 1968. Participation by representatives of foreign countries and international organizations was encouraged. Widespread interest was evident by their attendance at many meetings, and the contributions of foreign experts were considered outstanding.

The RTCA SC-117 work resulted in a "strawman" system concept and signal format. The recommended system was designed to meet operational requirements of all users and these requirements appear to be realistic and capable of achievement. The RTCA recommendations, although compromised to some extent, were believed to represent the best technical foundation for undertaking development efforts in an expeditious manner and were used as the foundation for establishing the national plan.

MLS 5-Year Plan

The plan which resulted delineates a five (5) year program of integrated activity considered necessary to provide an MLS that meets the wide range of user operational requirements set down by RTCA SC-117. Included in the plan are two interdependent and complementary activities:

(1) an industry oriented system development program designed to produce prototype equipments for flight test and evaluation, and

(2) a concurrent series of supporting government programs, to be undertaken by Dept. of Transportation (DOT), Dept. of Defense (DOD), and NASA. These programs include validation efforts independent of the industry program, investigations of sub-system concepts and techniques, performance of flight tests and system evaluation efforts, and application of the microwave guidance system to the requirements of the individual users.

Special emphasis has been placed on the need for expeditious development of an MLS basic design that will use a standard signal structure and feature highly flexible modular building-block concepts that will facilitate its being appropriately configured to meet the complex requirements for full scale all-weather automatic landings on the one hand, and the lesser requirements of general aviation users on the other. Representative configurations are shown in Table 1-1. There are, of course, many more combinations of modules which can serve other user needs. A typical microwave landing guidance system is shown in Figure 5.

Progressing now to more finite details of the plan and its "systems" approach, the functional elements of an advanced landing system can be viewed in a number of ways depending upon the point of view and technical interest of the observer. Figure 1 is the broad general view. Figure 2 reflects somewhat more the system as viewed by the aircraft/flight control engineer. Figure 3 is more oriented to functions to be performed in landing. Each offers insight into the total problem to be treated and each reflects the scope of the program required.

The industry-oriented program, mentioned above, concentrates primarily on microwave guidance and places on the contractors the full responsibility for undertaking all phases of the work. These phases range from initial analysis and experimentation through construction of prototype equipment and preparation of a set of production specifications. The contractors are not to develop prototype airborne equipment, other than that necessary to receive the MLS signal, decode it, and provide outputs that are usable for display and aircraft control. However, each contractor is to install, in designated aircraft, the prototype MLS airborne equipment and appropriate hardware and/or modifications to existing airborne equipment necessary to demonstrate that the MLS outputs are suitable for display and automatic aircraft control.

Interrelated and interdependent supporting programs will be conducted concurrently by the individual participating government agencies either in-house or with separate contract support.

The supporting government programs will include three areas of effort: (1) techniques investigations; (2) application to user needs; and (3) flight test and evaluation. A series of tasks to be accomplished under each of these areas has been defined and responsibility for funding and accomplishment of each task has been allocated among the participating agencies in consideration of existing and/or planned capabilities and the individual requirements of each agency.

Techniques Investigations

This effort includes analyses, tests, and experiments directed at establishing a knowledge data base in the government to enable the government to conduct comprehensive technical evaluations of industry proposals and subsequent analytical and experimental efforts. This work not only will assist in the selection of the technique/signal format to be authorized for prototype development, but also will support the required technical validation of the selected technique. Early investigations using existing R & D hardware will address issues such as required data rate, low angle ground effects, C-band and K_u-band propagation (including multipath effects) and effects of siting geometry on airborne signal processing requirements. Other investigations will involve encoding/decoding techniques, modulation techniques, the planar/conical antenna design question and problems associated with a two-frequency-band system. New design techniques or technological developments having potential for improving performance or reducing component costs will also be investigated; for instance, a feasibility study will be conducted on phased arrays to determine their potential for use with the MLS.

Application To User Needs

Included in this area of effort are those activities required to assure effective utilization of the airborne receiver's output. This must be done to verify that the selected system technique will satisfy the spectrum of established operational requirements. These activities will provide the technological data base required for the development and evaluation of flight control and display techniques, and will determine the performance requirements for signal processors.

Other studies will be conducted to assure suitability of proposed and selected techniques to meet certain unique military requirements. For instance, the Navy must determine the effects of a moving platform (carrier flight deck) on a Doppler scanning system, and those antenna techniques that are suitable for C-band operation from ships.

The interface between the MLS and the ATC/NAS will be analyzed in consideration of system requirements. The most effective means of using and integrating the MLS into the ATC/NAS will be determined. Included here will be the application of the selectable and curved path capability of the MLS to increase operational capacity of an airport and to distribute and control noise levels in airport approach and departure corridors.

Flight Test and Evaluation

This effort encompasses those activities necessary to validate the overall adequacy of the selected MLS in meeting the diverse requirements of all users. Extensive flight tests will be conducted not only to determine whether the MLS will meet nominal operational requirements, but also to determine its adaptability to special user requirements. Operational acceptability from the pilots' viewpoint will be given primary consideration. The FAA is responsible for system validation in accordance with the range of operational requirements established for civil aviation.

The effectiveness of the MLS for STOL operations will be evaluated by NASA and the Air Force.

Each of the participating services of the DOD will be responsible for validating the MLS for its unique requirements.

A total overview of the industry-oriented and government programs are shown in Figure 6.

The National Microwave Landing System Development Program leading to our future landing guidance system which will eventually replace present-day ILS has been briefly described. The breadth and depth of the effort can be seen. As we stated earlier, in the final analysis, the customer of a new landing system is the aircraft and the pilot/crew. To satisfy both, the signals must suit the pilot displays, the aircraft control system and the total flight mechanics and flight physics aspects of the vehicles' flight dynamics. Let us look briefly at some of these aspects of the problem.

Aircraft/Control/Display

With the high level of technical sophistication that has developed in radio guidance concepts based on scanning beams, it is difficult to estimate accurately some of the results of different configurations (such as the 7 of SC-117) on the control aspects of various aircraft using scanning beam signals. With today's ILS we use continuous data related to a single fixed path in space; a nominal 3-degree glide slope and associated localizer. With scanning beams we are dealing with non-continuous data, bursts of data with silence in between, related to a large volume of possible paths.

Similarly, the modern theories of flight control (high performance autopilots, new instrument concepts, changing piloting techniques, etc.) and the sophistication of the flight vehicles themselves (SST, VSTOL, direct lift control laterally and vertically, control configured vehicles, fly-by-wire, etc.) make it most difficult for the radio guidance engineer to assure himself that he has provided the optimum signal formats, beamwidths, data rate, etc., to satisfy flight control needs.

Data rate is probably one of the most critical problems in interfacing the landing guidance elements with aircraft flight dynamics. The difference in approach speeds, for example, of a STOL at 40 knots and an SST at 200 knots is 5 to 1. From a control point of view we are often dealing with V^2 making the difference between extremes 20 to 25 times. With a scanned-beam system, there is a delay between guidance information samples which is inherent in the time-sharing process of such a system. One needs to realize that we have quantified guidance information only about 2 percent of the scan cycle time and have data samples not available 98 percent of the time. Guidance data, then, occurs in "bursts" and must be processed differently from fixed-beam continuous data.

We can expect data rate to be most critical during the flare maneuver with high-performance aircraft. The path geometry and relative motion of parts of an aircraft such as a double/delta SST 300 feet long, may create a very serious need for very high data rates. With the antenna mounted in the nose, for example, during pitch rotation in flare, the nose travels up at a relatively high angular velocity as the wheels descend toward touchdown (Figure 4).

Recent studies, not yet complete, have alerted us to the fact that severe atmospheric turbulence and moderate windshears contribute to the predominant approach tracking errors which can lead to a rather low probability of landing success. Contemporary flight control systems provide a lower flight control system response bandwidth and more low frequency rigidity in pitch attitude and heading than are desirable for suppressing approach course-following and glide slope tracking errors induced by turbulence and shears. To land aircraft with high probability of success in the presence of wind gusts and shears requires improved aircraft control capability and higher performance (high band pass) flight control systems than we have installed in aircraft today. To keep data rates within practical limits, higher order terms will probably have to be derived from airborne sensors such as rate gyros and accelerometers. Direct lift control, both laterally and in the vertical may be in order. We are probably faced with resorting to reduced quality of ride to achieve better tracking.

With the increased complexity of flying high performance jet aircraft in today's and tomorrow's ATC and landing environment, the problem of "painting pictures for pilots" has increased. Of great importance is the ability of the pilot to comprehend and act on the information. Cockpit space is limited and multifunction displays are required. Human factors efforts have provided the cockpit designers with more accurate information on brightness/contrast requirements, speed of human response vs symbol size, accuracy of differing formats of information such as round dial, numeric read-out and tape type presentations, the effect on pilot performance caused by multiple display types and, finally, the idea of total pilot workload as a design criteria for total cockpit integration and automation.

It is not difficult to comprehend the fact that individual displays must be designed with knowledge of how they affect total pilot performance. If one display presents status and another gives commands, the pilot has a transition to make in his thinking as to how he must react to each display. A consistent methodology is required to reduce pilot response time and improve performance. In mission segments where workload exceeds 100% pilot capabilities, automation or improved information and control integration is required. Human factors studies, cockpit integration studies, and pilot workload and performance analysis have established the need for flexibility in formatting cockpit displays to unburden the pilot by giving him information only when needed and in a more easily assimilated form. Cathode Ray Tubes (CRT) have been used for these purposes and despite their flexibility have serious limitations. Although many advances are being made in contrast, brightness and stability of CRT's, the basic inherent problems of tube depth, alignment, low-life and shock protection still create serious barriers against general application.

A number of technical possibilities have been explored to replace CRT's. Of several contenders, namely, light-emitting diodes, gas discharge, liquid crystals and D.C. thin film, the light-emitting diode LED has the most exciting potential and presently meets all the desired environmental, human factors, dynamic, construction and economic requirements for graphic display use and has an excellent potential for the eventual elimination of the CRT. The ATC and landing arena of the future can expect to benefit greatly from the development of LED displays.

The advantages are spectacular and exciting. The LED's are rugged and small solid state devices requiring 2.7 to 3 volts, are compatible with rugged and small solid state large scale and peak brightnesses in the thousands of foot-lamberts, have nanosecond turn on, are self-isolating in an X-Y matrix array, and hold the promise of a total color capability. The total system can be contained in a box with a ½-inch border around the viewing area and a 2-inch depth, a true flat display. All cockpits can be standardized to LED matrix displays saving procurement cost, logistics problems and maintenance problems. A modular construction will allow mass production of a large quantity item. The modules will contain all of the electronics needed for storage of data and display operation. The modules will be easily replaceable by maintenance personnel with minimal training. The display will outlive the aircraft system and can be reused, will interface directly with the digital computer and needs only a small three or four wire cable for information and power transfer. Figure 7 is an artist's conception of an attitude director indicator only 3 inches in depth, operates from 5 volt d.c. with an MTBF of 15,000 hours.

Summary

Aviation is entering an era of extreme dependence on ATC and landing. This will require new approaches to development of new systems such as our first attempt with MLS. A typical major system such as MLS can cost over $1 billion to develop and implement. It is mandatory, therefore, that we do total system planning and validation.

References

1. Air Transportation and Society, Papers and Presentations, Vol. 2, Appendix II, Sept. 15, 1971. (AIAA Conference sponsored by the FAA, Key Biscayne, Florida, June 7-10, 1971)
2. National Plan for Development of the Microwave Landing System, July 1971.

Table 1-1. Capabilities Of Ground Station Configurations

SC-117 CONFIGURATION	B	D	E	F	G	I	K
	Straight Azimuth (Az) Basic DME	Straight Az Straight Elevation (El) Basic DME	Straight Az Select El Basic DME	Straight Az Straight El Basic DME	Straight Az Select El Precise DME	Curved Az Curved El Precise DME Missed Approach	Curved Az Curved El Precise DME Missed Approach
FACILITY PERFORMANCE*	CAT I	CAT I	CAT I	CAT II	CAT II	CAT III	CAT III
MINIMUM GUIDANCE ALTITUDE	150 Ft.	150 Ft.	150 Ft.	50 Ft.	50 Ft.	Touchdown	Touchdown
COVERAGE							
ELEVATION	Not Applicable (NA)	8°	20°	8°	20°	20°	20°
AZIMUTH	±20°	±20°	±20°	±20°	±20°	±40°	±60°
MISSED APPROACH	......	......	......	......	......	±40°	±40°
ACCURACY**							
ELEVATION (2σ)	NA	7 Ft.	7 Ft.	1.4 Ft.	1.4 Ft.	1.4 Ft.	1.4 Ft.
AZIMUTH (2σ)	26 Ft.	26 Ft.	26 Ft.	11 Ft.	11 Ft.	9 Ft.	9 Ft.
RANGE (σ)	300 Ft.	300 Ft.	100 Ft.	100 Ft.	20 Ft.	20 Ft.	20 Ft.
DATA RATE (Max)	2.5 Hertz (Hz)	5 Hz	5 Hz	5 Hz	5 Hz	10 Hz	10 Hz

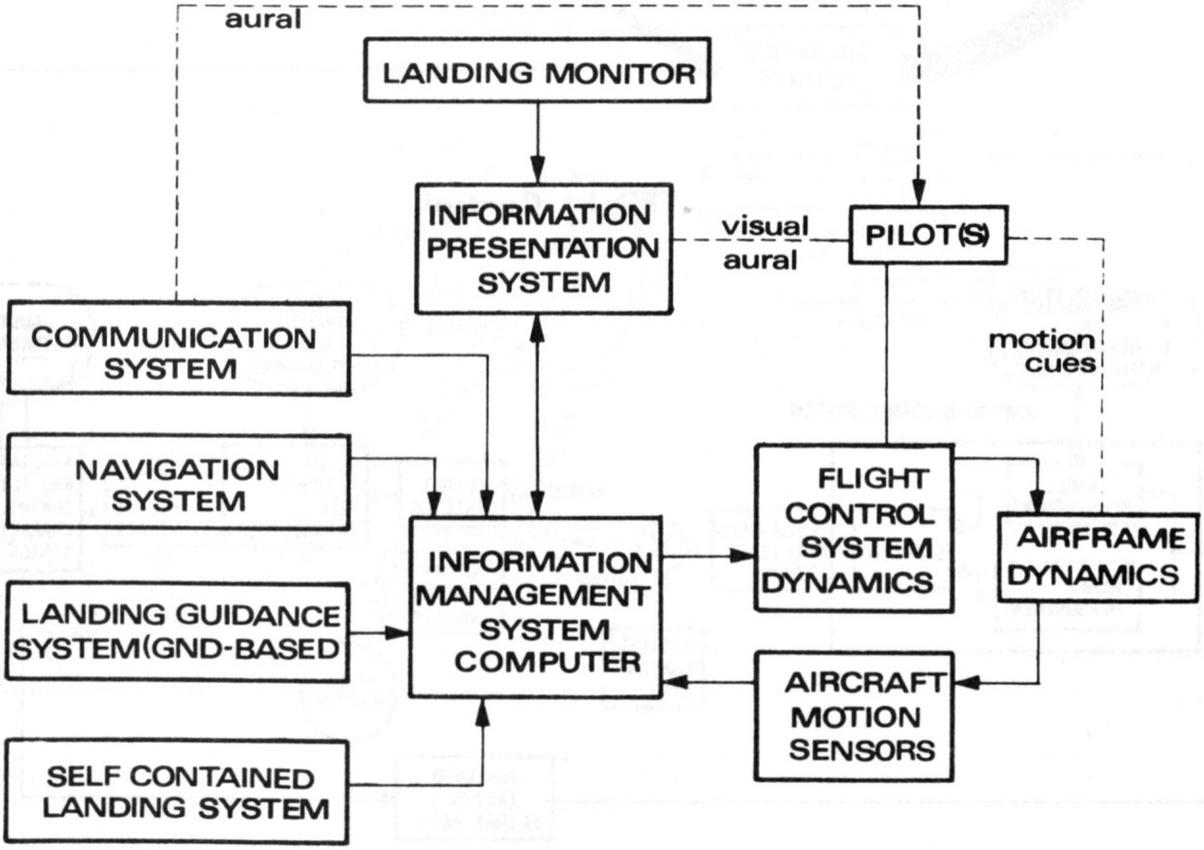
*A CAT I facility provides guidance information from the limits of coverage to the point on the runway centerline extended on the glide path at a height of 200 feet or less above the horizontal plane containing the threshold.

A CAT II facility provides guidance information from the limits of coverage to the point on the runway centerline on the glide path at a height of 50 feet or less above the horizontal plane containing the threshold.

A CAT III facility provides guidance information from the limits of coverage to and along the surface of the runway.

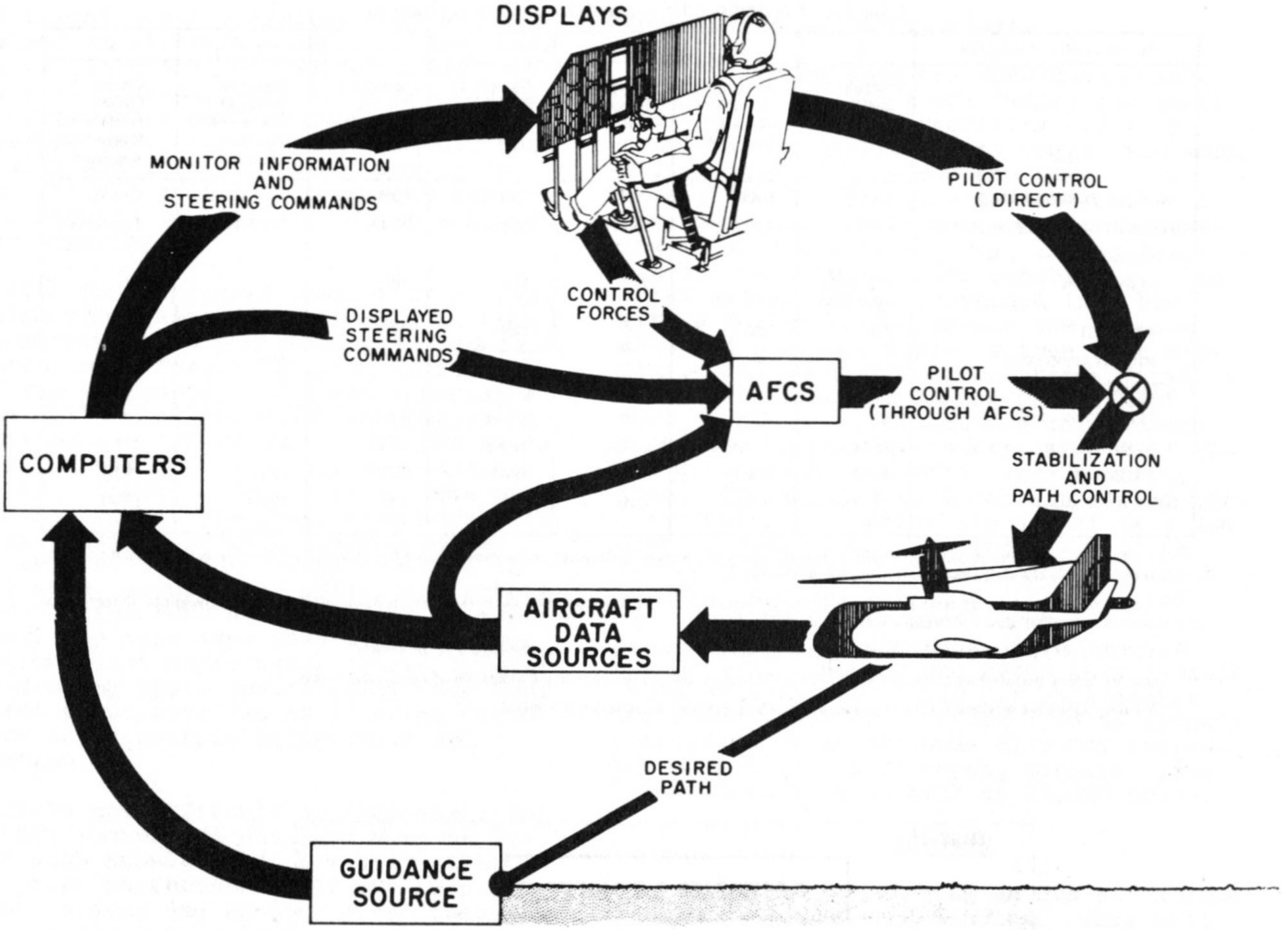
These are facility performance categories and do not in themselves indicate the operational utilization of a particular facility.

**Accuracy values are specified for the minimum height where guidance information is required.



APPROACH & LANDING SYSTEM

FIG 1



Flight Control

FIG 2

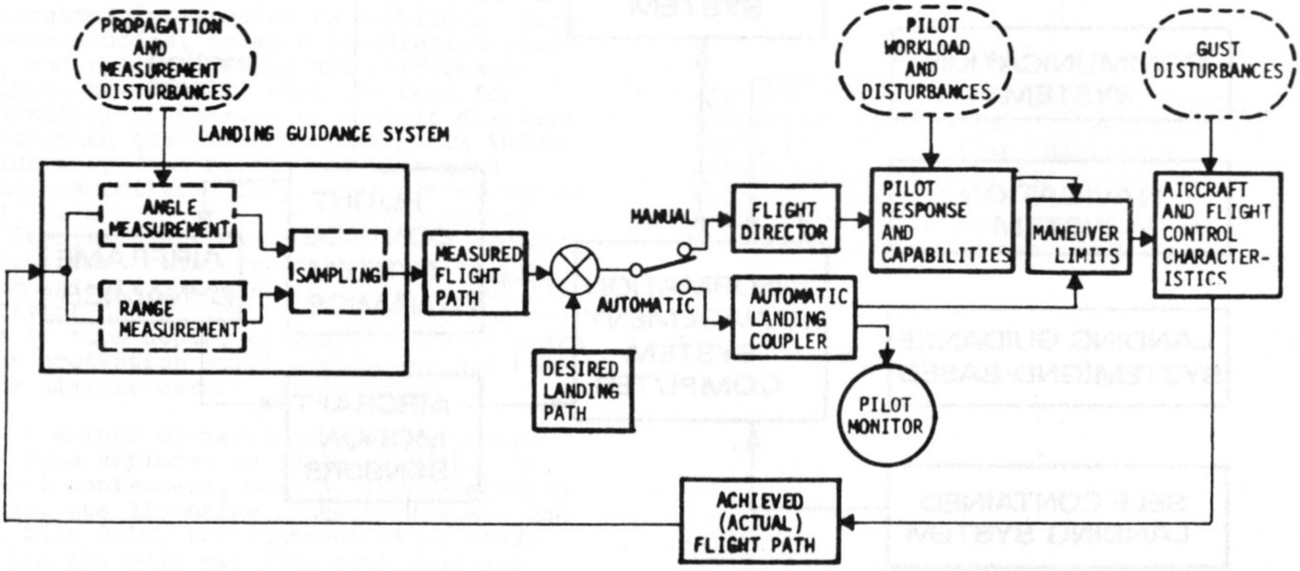


Figure 3. AIRCRAFT LANDING FUNCTIONAL DIAGRAM

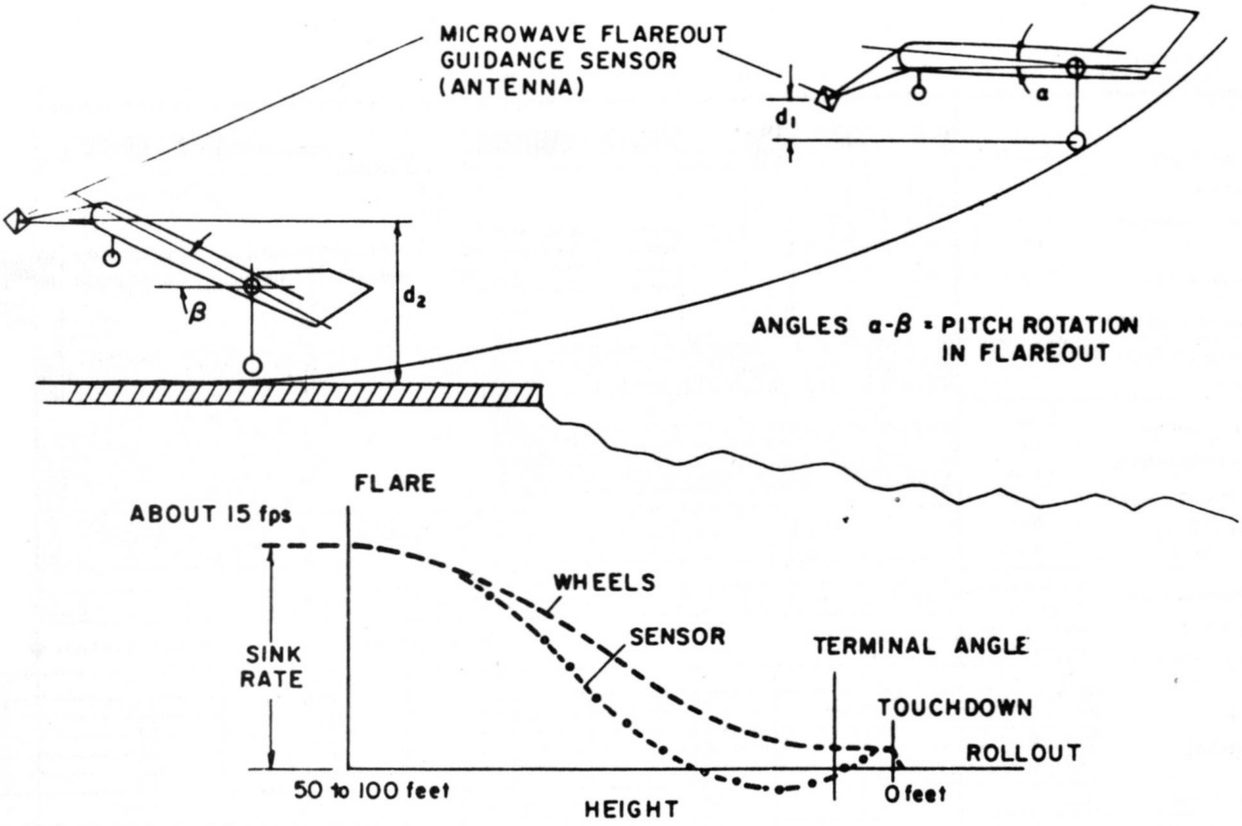


FIGURE 4. SINK RATE DIFFERENCE BETWEEN SENSOR AND WHEELS ON LARGE-BODIED AIRCRAFT

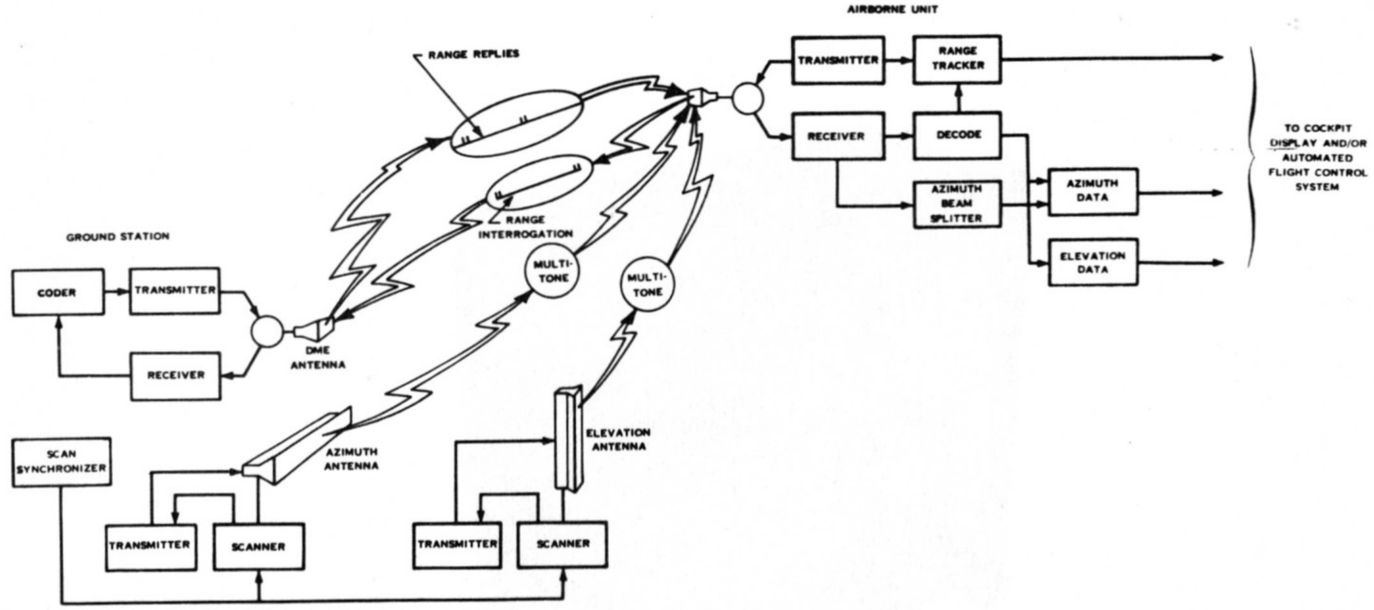
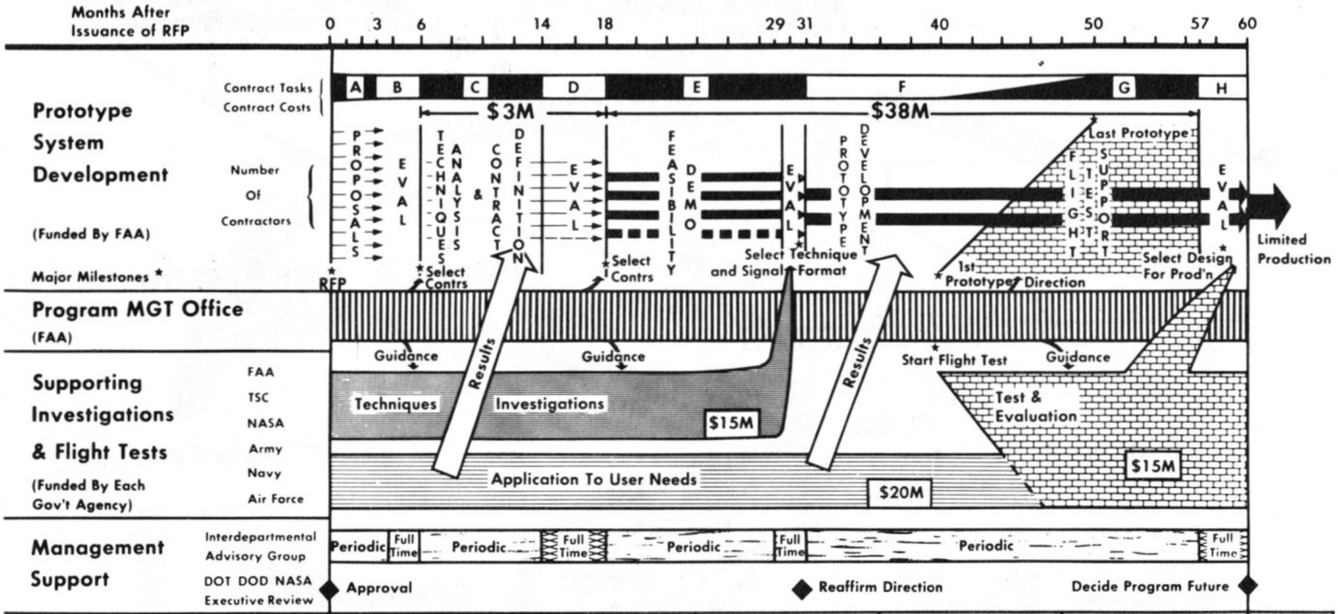


Figure 5. Block Diagram of a Typical Microwave Landing System



		Fiscal Year	71	72	73	74	75	76	Total
R & D Funding		FAA TSC	1.0	3.8 (3.0) *	3.7 (10.0)*	3.1 (20.0) *	3.7 (6.0) *	2.2 (2.0) *	18 (41) *
		NASA	0	0	0	0.2	0.7	0.8	2
		Army	0	1.7 **	3.5	2.3	2.3	0.6	10
		Navy	0	1.1	1.1	0.6	0.8	0.7	4
		Air Force	0.8	5.9 **	4.0	2.5	2.3	0.5	16
($ In Millions)		Total	1.8	12.5 (3.0)	12.3 (10.0)	8.7 (20.0)	9.8 (6.0)	4.8 (2.0)	50 (41)
Related Programs	STOL Avionics (NASA)		1.8	4.0	3.5	1.6	0.7	0	11
	STOL Program (USAF)		1.1	1.1	1.2	1.2	0	0	5

* FAA funding of main contractual effort is shown in parentheses and is separate from the funding for supporting programs.

** The U.S. Army and the U.S. Air Force will require program adjustments in FY72 in order to meet these funding requirements.

Figure 2-4. Microwave Landing System Development Plan

2-33

Figure 6

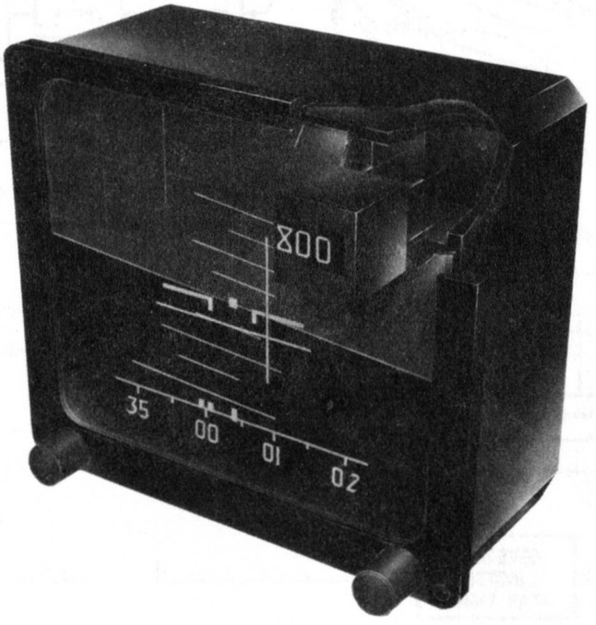


Figure 7