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(6) Air taxi, charter service.

(7) Aircraft sales—new and/or used.

(8) Aircraft parts and accessory sales.

(9) Other specialized services such as air ambulance, aerial photography, banner towing, aerial application (crop dusting).

The extent and quality of services provided is determined by the size and activity level of the airport, the type of users and aircraft, the number of operators, and the airport's compliance standards and lease terms.

Small airports with a low level of activity and few based aircraft (12 or less) might offer only aircraft storage and parking since this service requires no personnel on duty. Twelve to 25 based aircraft is generally considered a minimum number to support an FBO offering the first three services listed above. As the number of based aircraft and related aviation activity increases, additional services can be justified. As a general rule, only the medium to large activity airports offer the full range of general aviation services.

An important decision for the airport manager is one of determining if, and when, a second or additional general aviation operator is justified. The Federal Aviation Act of 1958 prohibits the granting of exclusive rights on a federally funded airport. As a result, the airport authority cannot arbitrarily limit the number of operators on an airport. The airport authority can establish reasonable compliance standards for any new operation.

The development of the compliance standards must be done in recognition of the non-exclusive rights provision of the Federal Aviation Act; of the need to maintain a level of quality and safety in new operations equal to or better than existing operations; and, the need to provide reasonable protection for the investment of an existing operator or operators. The latter can only be accomplished by the development of minimum levels of activity necessary to justify additional services or operations. When these levels have been passed, a new operation can be established on the airport provided that operation meets the compliance standards.

The compliance standards identify the minimum standards for facilities and services to be provided and serve as the framework under which the lease is developed. The compliance standards and lease terms vary widely from airport to airport, but a few provisions generally are recognized as desirable:

(1) A lease term of at least 10 years and preferably 20 years or longer with renewal options.

(2) The right to provide desired services and conduct operations in accordance with reasonable standards.

(3) The right to construct facilities for such operations.

(4) Reasonable rental charges based upon the land and facilities provided by the airport or the gross sales volume or a combination thereof. A typical schedule of lease charges by the airport might be as follows:

- 2 percent of gross sales excluding fuel and aircraft sales
- 2 cents-4 cents per gallon of fuel sold
- 6 cents-12 cents per square foot of unimproved land
- 15 cents-20 cents per square foot of improved land (paved aprons, ramps, etc.)
- \$3.00-\$7.00 per square foot of hangar and office space (if such facilities are provided by airports).

The lease is a compromise between the interests of the airport authority which desires to obtain maximum revenue in exchange for the land and facilities used, and the FBO who desires the lowest cost lease in order to maximize his profit and return on investment. Since a major portion of many lease charges is fixed and unrelated to business volume, the operator often blames the lease as the cause of his financial failure.

There are frequent instances, unfortunately, of lease agreements developed by an airport without consideration to the limited profit potential and low return on investment, characteristic of most general aviation operations. There are cases on record of airports which have experienced numerous failures of general aviation operators where sufficient activity existed to support an operator. The fundamental cause was often found to be the lease which, if modified to terms more favorable to the operator would make possible a sound, financially healthy operation and more revenue for the airport in the long run.

AIRWAYS AND AVIONICS

Introduction

This section will deal primarily with both airways and avionics as components of the general aviation system. The airways system will be defined to include the en route traffic lanes in the airspace, the airport terminal area, and the equipment installed in the vehicle enabling it to make maximum safe use of those airways. This discussion will be concerned with the following general topics: air traffic control, navigational aids, and the operation of these components within the national airways system.

Use of the national airways system has increased to the point where the system is badly congested at the hub airports. Increasing congestion along the airways results in an increasing probability of midair collisions. The capacity of the airways system must be expanded to accommodate growth in aviation fleets. Very little land is available near the major population centers for the construction of new airports or for the addition of capacity to existing facilities. Airspace around these population centers is used to capacity during much of the time; a situation presenting safety hazards and unacceptable delays in both the landing and departure of aircraft. The available navigation aids use most of the available time and spectrum allocated to them. Any improvement in system performance will have to be mainly in the capability and sophistication of these aids rather than in an increase of their number. This will permit optimum metering and spacing in the airways system.

General aviation has a problem related to, yet independent from, the air carriers which cause most of the congestion in airways near the major population centers. The problem results from high costs involved in equipping general aviation aircraft with the required navigation and communication equipment necessary for using the airways. Many general operations of such lighter aircraft are in the vicinity of relatively lightly loaded general aviation airports; however, a certain percentage of general aviation activity takes place in the vicinity of the hub airports.

Safe and reliable operation requires that a flight can be initiated with a reasonable probability of completion, between any two points desired barring poor weather and/or mechanical or electrical malfunction.

One severe handicap imposed on most general aviation aircraft is their low speed. Most air carrier and military activities involve high speed jet aircraft, while non-jet general aviation aircraft necessarily operate at much lower speeds. Both exist in the immediate airport environment and in the en route phase of the flight. The great disparity of speed between most general aviation aircraft and the other two segments of aviation activity will always pose a hazardous condition within the airways system. As a result, there will always be pressure on the general aviation community to vacate the airways system, particularly in congested areas. The problem then becomes that of upgrading the ability of general aviation vehicles to oparate in the national airways system with safety and reliability. Since only small breakthroughs seem possible in low speed aerodynamics, most of this upgrading must be realized through better electronic systems and improved pilot ability. Possible future directions in this area will be discussed, following descriptions of the Air Traffic Control System and the navigational aids presently in use.

Air Traffic Control

Air traffic control consists of both ground-based electronic navigational and communications facilities. Ground-based facilities consist mainly of high precision radar and visual displays, while communications facilities provide for both automatic transmission of information and oral communication among air traffic controllers and between them and operators of the aircraft. Much of the automatic transmission of information is provided by the transponder and the encoding altimeters located on the aircraft.

The air traffic control system is the most critical component of the entire national airways system and it is approaching saturation. This is probably the principal factor which will determine design and location of major airports in the future. General aviation is affected by this saturation because unless there is alleviation of traffic, general aviation may be excluded from the major air carrier airports.

En Route System

The air traffic control problem is divided into two major areas. The first is the **en route** system, comprising the airways between the major airports. The second is the area surrounding the major (simplified in this case to air carrier airports) **terminals.** The en route system is governed by two sets of flight rules, VFR (visual flight rules) and IFR (instrument flight rules). In general, VFR means that weather conditions are good enough for the pilot to operate the aircraft in a safe and efficient manner by visual reference to the ground. Under VFR conditions, there is essentially no en route air traffic control except where specifically prescribed; aircraft fly according to "rules of the road" using designated altitudes for certain headings and are responsible for maintaining their own separation.

Positive traffic control is always exercised in IFR conditions and in designated control areas. Essentially, these rules require the controlled assignment of specific altitudes and routes and minimum separation of aircraft flying in the same direction as shown in Figure 1-7. Controlled airspace extends upward from 700 feet Above Ground Level (AGL) in almost all contiguous areas immediately surrounding an airport. In order to achieve greater airspace utilization and safety the area above 14,500 feet Mean Sea Level (MSL) has been designated as a Continental Control Area. Aircraft flying above this altitude are high performance aircraft. In positive control areas above 18,000 feet MSL, all aircraft are controlled by continuous surveillance and are required to be equipped with transponders and communication equipment. Terminal Control Areas, such as the one shown in Figure 1-8, are being designated around major hub areas to impose special operating requirements on all flights in this airspace. Additionally, special purpose areas are designated as areas in which flight operation is either prohibited or restricted Examples of such restrictions are in weapons' ranges, identification zones and student pilot training areas.

The present en route system of airways is governed by the location of VORTAC (very high frequency omni-range radio transmitter with distance measuring equipment) navigation transmitters, and comprises a system of airways called Victor Airways. These are designated with even numbers when they run in east and west directions, and with odd numbers when they run north and south. In addition to the radio navigational aids in the aircraft, there exists an air surveillance radar This is a radar with a range of 200 miles which is installed in certain control centers around the country and used for tracking aircraft along an airway

The United States is divided into control areas covering all the en route airways, so that each control center can know the position of all en route aircraft within its area These long-range center radars give the controllers accurate information on azimuth and distance position of each aircraft along the airway and thus reduce the need for communication between pilot and controller. They also reduce considerably the required distance between aircraft, thus increasing the capacity of existing airways. There are presently 27 Air Route Traffic Control Centers (ARTCCs) which include 91 different radar installations. The following 20 centers cover the airspace of the contiguous 48 states: Albuquerque, Atlanta, Boston, Chicago, Cleveland, Denver, Fort Worth, Houston, Indianapolis, Jacksonville, Kansas City, Los Angeles, Memphis, Miami, Minneapolis, New York, Oakland, Salt Lake City, Seattle, and Washington.

The capability of the entire ATC system will be upgraded further by requiring all aircraft using the system to be equipped with a Discrete Address Beacon System (DABS). In 1975, all aircraft but not all of the ground-based ATC system were required to be so equipped. When implementation is complete, all aircraft using the ATC system will be equipped with transponders which will furnish identification, as well as altitude information. This automatic information transfer will facilitate the ATC mission, and substantially reduce the amount of communication required between ground controllers and pilots.

Terminal Area Control

The next component in the control system is the airport traffic control tower. There are presently 327 control towers in the Untied States located mostly at air carrier terminals. These control towers provide traffic control for aircraft located within a 15-mile radius of the airport. A zone of control involving two airports is shown in Figure 1-8. Most major control towers have approach control facilities and have air surveillance radar (ASR) which guide aircraft to the airport from a number of specific positions called fixes. Those are approximately 25 miles away from the airport and denote the point at which the aircraft is transferred to the control tower from the ARTCC. At these fixes the aircraft are usually "stacked" in a holding pattern. The airport controller is responsible for orderly regulation of aircraft landing and takeoff operations on the airport itself, and for positioning aircraft within its control radius.

Navigational Aids (NAVAIDS)

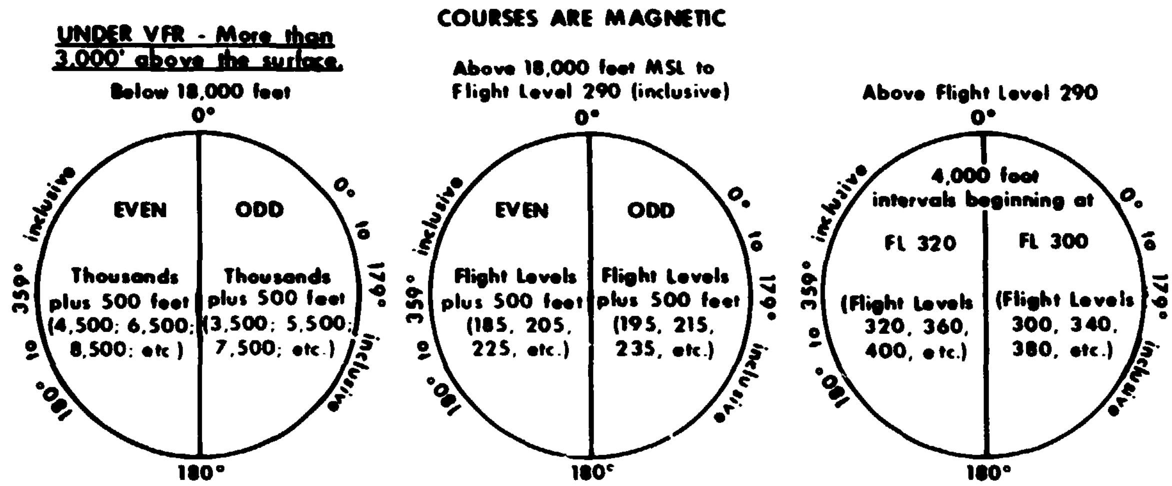
Navagational aids may be classified according to several criteria, such as sensing method, frequency, function, location, method of use, and others. Since none of these categories is definitive, the various items will be discussed separately. Table I-V summarizes the radio aids. [32]

Direction Finders

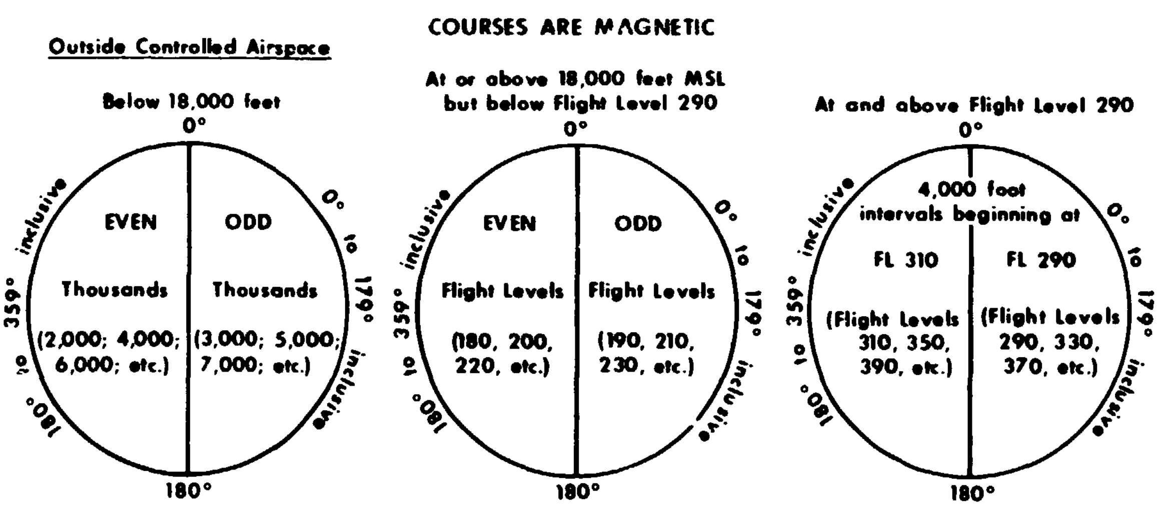
The first three items of Table I-V are basically radio direction finders. The Automatic

[32] Compiled from *National Aviation Systems Plan, Ten Year Plan 1973-1982*, Department of Transportation Federal Aviation Administration, March 1973

VFR ALTITUDES/FLIGHT LEVELS—CONTROLLED AND UNCONTROLLED AIRSPACE

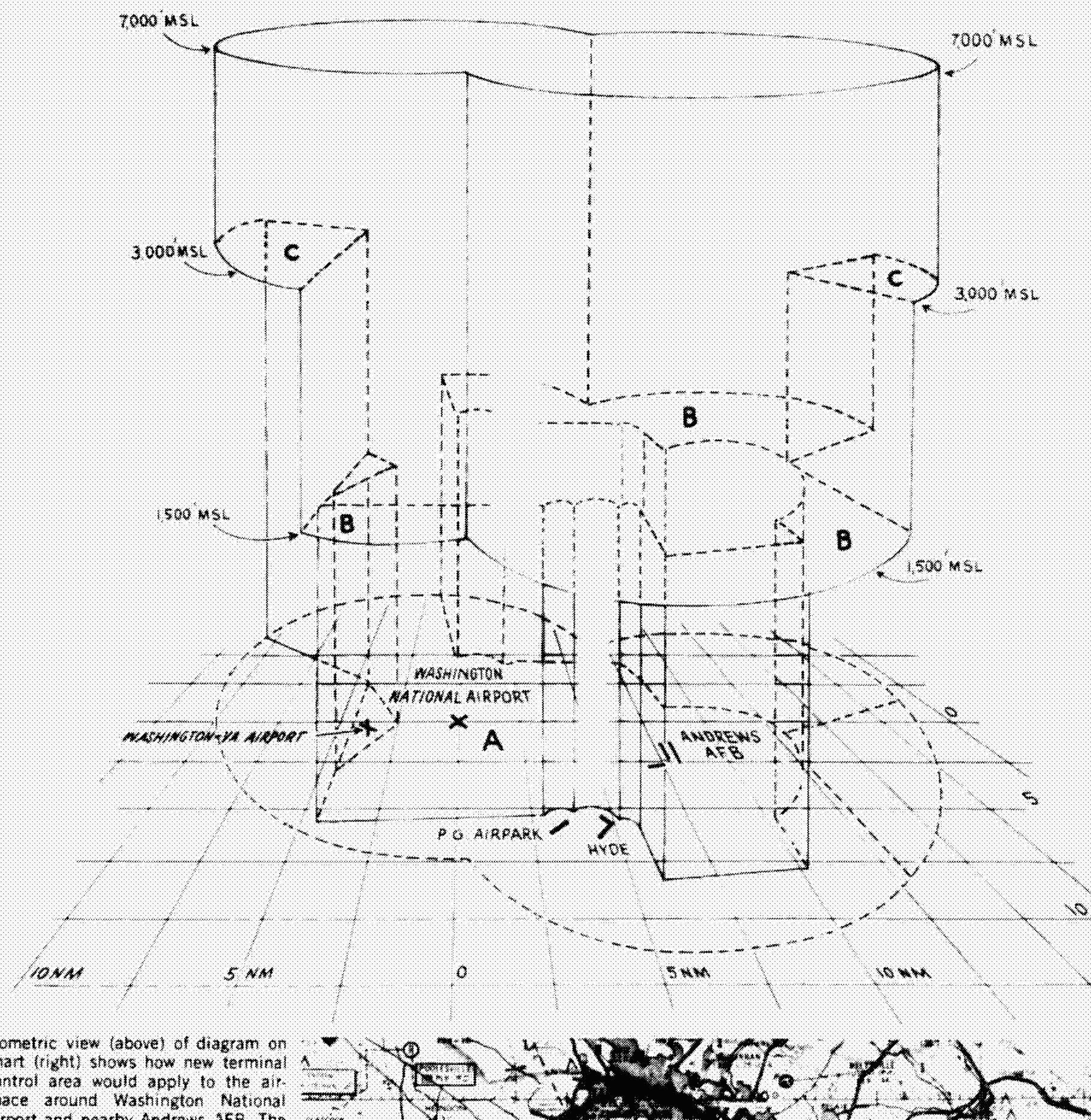


IFR ALTITUDES/FLIGHT LEVELS—UNCONTROLLED AIRSPACE



Source: Airman's Information Manual, Part 1, May 1975, pp. 1-23, 1-25.

CRUISING ALTITUDE CHART
FIGURE 1-7



Isometric view (above) of diagram on chart (right) shows how new terminal control area would apply to the airspace around Washington National Airport and nearby Andrews AFB. The solid line shows how free access would be provided for use of the three smaller airports close to downtown Washington — Washington / Virginia, Prince Georges Airpark, and Hyde Field.

MAP LEGEND

- General Aviation Airports
- Major Airports
- Surface Boundary
- Upper Boundary

ISOMETRIC DIAGRAM OF WASHINGTON, D.C. TERMINAL CONTROL AREA FIGURE 1-8

TABLE I-V
SUMMARY OF RADIO NAVIGATIONAL AIDS

Navigational Aid	Function	Unit Cost $	System Accuracy	Range
Automatic Direction Finder (ADF)	Determines bearing to LF beacon stations and LF radio stations	1,000	$\pm 2^\circ$ (2σ)	50 - 200 nm
VHF Omnirange (VOR)	Determines magnetic bearing to VOR facility	4,000	$\pm 3^\circ$ (2σ)	Line of sight
Distance Measuring Equipment (DME)	Measures slant range to DME facility	2,500	$\pm$ 0.2 nm or 1% of range	0 - 192nm
Loran-C	Determines aircraft position (hyperbolic)	30,000	$\pm$ 1500 ft. (2σ)	Night 1,000nm
Omega	Determines aircraft position (hyperbolic)	50,000	$\pm$ 2 nm (2σ) night $\pm$ 1 nm (2σ) day	6,000nm
Doppler Navigator	Determines vector distance traveled	40,000	$\pm$ 0.5% (2σ) of distance traveled or 1 nm	global
ATC transponder	Provides identification and altitude reporting to ATC controllers	2,200		200 nm
Instrument landing system (glideslope and localizer) (ILS)	Provides directional information for poor weather landing	6,000	Not defined; pilot flies down beam center to runway	20 nm
Marker Beacon	Indicates distance to end of runway	+700		
Advanced Instrument Landing System (AILS) (MLS)	Provides directional and distance information for all-weather landing	N/A	AZ = $\pm$ 0.05° EL = $\pm$ 0.03° DME = $\pm$ 100 or 1%	20 nm
Inertial	Determines vector distance traveled	90,000	$\pm$ 0.05% (2σ) of distance traveled or 1 nm	global
Global Positioning System	Satellite-based system	16,000	10's of feet	global

Sources: Aviation Advisory Commission. *The Long Range Needs of Aviation: Technical Annex to the Report of the Aviation Advisory Commission.* Volume II. Washington, D.C.; Aviation Advisory Commission, January 1973; *Business and Commercial Aviation.* Ziff-Davis Publishing Company, April 1975, pp. 79-150; and Shriever, B.A., and William W. Seifert, *Air Transportation 1975 and Beyond: A Systems Approach.* Cambridge: MIT Press, 1968.

Direction Finder (ADF) operates at low frequency in the broadcast band of AM radio. It is used in conjunction with either a radio beacon at the airport, or a standard broadcasting station. In general, the pilot must have a certain amount of skill to use the device, but no computation is required. The VOR is the mainstay of the national en route airways system. It operates at the VHF portion of the spectrum, which is in the FM-television range. As a result, its range is limited to line-of-sight, just as FM radio and television are. Position determination is made by taking bearing on two stations, with the intersection of the lines giving the position. Distance Measuring Equipment (DME) also operates in the VHF range. It is much more accurate than VOR, and gives a much closer determination of position than two VOR stations. Sometimes VOR and DME signals are found at the same site thus allowing simultaneous bearing and distance measurment. Such a system is called VORTAC, which is an abbreviation of VOR/DME, combined with TACAN, the military VOR/DME system.

Note that this differs from the previously described ADF because usually two or more VORTAC stations are combined to find position. ADF, however, is primarily used, not to determine a position, but to fly towards a point only. It should also be noted that the determination of position from either two angular bearings, two intersecting distances, or the distance and angle from a station is fairly simple mathematically. This is the primary reason that the VORTAC system is the primary element in the national airways system.

An increasing number of aircraft in the general aviation category are able and need to engage in overwater operations. The Loran-C and Omega systems operate in VLF frequency range, producing a wave of around 100+ kilohertz which primarily propagates as an earth wave, thus giving a tremendous range. Navigation is accomplished by solving for the intersections of the families of circles surrounding the transmitting stations. These intersections are defined by hyperbolas, hence low frequency systems are frequently termed hyperbolic. Since there are a great number of hyperbolas to be solved, difficult computations are usually needed. This is reflected by the relatively high prices shown for these systems in Table I-V. Loran-C is the primary method of navigation in the North Atlantic corridor, and Omega provides coverage for much of the rest of the world, through a system of 8 Omega stations. This system is maintained and operated by the military, although it can be used by civil aircraft. Due to the strategic vulnerability of the transmitters of the Omega system, other systems have been designed which are either satellite-based or self-contained, as in the airborne doppler and inertial systems.

Because of the costs involved, neither doppler nor inertial systems are likely to be used on a large scale in the immediate future for general aviation aircraft. However, systems being developed will render inertial systems well within the range of the more sophisticated business and corporate aircraft within a few years. The doppler navigator utilizes a doppler radar, which measures the relative velocity between the aircraft and the ground. Inertial systems provide a gyroscopically or electronically stabilized platform, which is always oriented in a known direction. Accelerometers, to measure the acceleration of the vehicle along the roll, pitch, and yaw axes of the aircraft, are mounted on this platform.

Satellite System

A system which holds future promise for general aviation aircraft is the global positioning system. This is a satellite-based system which would place a sufficient number of satellites in the air to provide at least three bearings at any one time. The equipment required on the aircraft would be a receiver (UHF), decoder, and clock. This would enable the using aircraft to determine position very closely. At present, the Navy has such satellites in use for submarine navigation systems. The tremendous imvestment required to place the required number of satellites in orbit can be expected to delay implementation of the system.

Other Navigational Aids

The ATC transponder, which provides coded information to the ATC controller in the hub airports, will be required on all aircraft using these airports in 1975. In conjunction with these transponders, will be required the encoding altimeters, which will automatically transmit altitude information to the ATC control center. With these devices, each equipped aircraft will be automatically identified, its position shown on the radar screen, and its altitude displayed.

Also considered a navigational aid would be the communications transceiver and the ILS system. Obviously, the airport, the tower, and the flight service stations all must be contacted by radio. Generally, this receiver will operate in the VHF navigation systems. An ILS system will be required in order to land at an air carrier terminal. This system consists of two radio transmitters located at the airport: the localizer,

TABLE I—VI
SUMMARY OF VISUAL NAVIGATION AIDS

Navigational Aid	Function	Range
Visual Approach Slope Indicator (VASI)	Provide directional and glide slope information visually for landing.	5 nm
Runway End Identification Lights (REIL)	Provide positive identification of runway threshold under all weather conditions	
Approach Lighting System	Used with ILS to aid in locating runway	
Runway Lights	Lighting for runway proper	

located at the end of the runway, and the glide slope transmitter, located at its side. The receiver for these signals is usually displayed in conjunction with the VOR information. This enables the pilot flying IFR to find the airport and subsequently to bring the aircraft down close enough to the runway to complete a successful landing visually.

Visual Navigational Aids

Under any flight conditions, VFR or IFR, certain visual navigation aids are often provided. These are as summarized in Table I-VI. The visual approach slope indicator (VASI) is primarily used to provide the same basic visual information as that provided electronically by the ILS system. It is primarily useful for approaches over water and those requiring precise control over glide slope for purposes of noise abatement.

Since the cost of all of the navigational aids discussed above is high, it is instructive to consider what constitutes the system needed to fly the national airways system and to land at the air carrier airports. If reference is made to Table I-V, an ADF would be desirable, a VOR, a transponder, possibly an encoding altimeter, an ILS receiver, together with the necessary display, and a communications transceiver. The total cost of such a minimal system would be approximately $16,400. This would provide the pilot full capability of IFR flights on the national airways system, and enable the aircraft to interface with all airports in the continental United States.

If a corporate or business aircraft is considered, additional equipment would be desirable, enabling the pilot of the aircraft to navigate with greater precision, to decrease the workload under IFR conditions, and to fly a less constrained route than the vector headings of the national airways system.

Two items of equipment which greatly increase the safety and reliability of aircraft are (1) autopilots and (2) area navigation. An autopilot, which may or may not include a sophisticated flight director, accepts commands on flight attitude and direction, and provides signals to the control surfaces of the aircraft. Such control can be obtained in response either to a simple setting of altitude and direction by the pilot, or to a preplanned flight which is set into the flight director or furnished from external sources. The autopilot/flight director greatly relieves the routine tasks required of the pilot, enabling him to concentrate on non-routine decisions.

Computerized Area Navigation

One method for feeding external control to the flight director might be through an area navigation system. An area navigation system, in its simplest version, consists of a simple computer which takes the VOR bearings, and creates a computer VOR station, toward which the plane is commanded to fly. Thus, in accordance with certain preplanned flight plans, the aircraft is enabled to fly any selected route, including, for instance, the great circle route. It is planned that, at a future date, these routes, known as area navigation (RNAV) routes, will be standard in the national airways system.

Since this ability to fly more complex routes is inherent in the less sophisticated one-way point system, additional memory in the computer can furnish a great deal of additional capability.

The average RNAV system presently applicable for general aviation aircraft has the capability of storing about 10 way points (a geographical location along the flight route usually designated with respect to VORTAC). This means that up to eight course changes may be made automatically. These systems provide automatic procedures for standard turns, holding patterns, and climbs. The next step in sophistication is the expansion of the system to include standard instrument departures (SID) and standard terminal arrival (STAR) routines. These routines will include all information required for the pilot to land successfully at the airport, including location, traffic pattern, holding patterns, and obstructions.

Area navigation systems can be made available to a general aviation aircraft for as little as $10,000. An autopilot-flight director might cost an additional $20,000. With this equipment, the general aviation aircraft is truly able to adapt to a wide variety of expected environments. Safety is foremost among the benefits of these two pieces of equipment. The autopilot relieves the pilot of much of the routine duties of flying the aircraft. Area navigation will become the primary method of collision avoidance. The ability of the individual aircraft to know its own position, and to be able to communicate that position to the ATC system quickly and accurately, relieves the controller of some of his responsibility as well. As routine flying and station keeping are minimized, the pilots and controllers are able to deal with emergencies much more effectively. Experience with collision avoidance systems has led to the conclusion that the problem can be solved only by installing sophisticated equipment in each aircraft using the national airspace.

One additional item of useful equipment which is being installed on general aviation aircraft is weather radar. It consists of a transmitter and receiver, an antenna, and a radar scope. In its simplest version, it merely presents information on weather ahead of the aircraft to enable the pilot to avoid threatening storm systems. This is an excellent safety feature, and can be acquired presently for less than $15,000. Furthermore, the screen can also be used for display of other material, such as numerical data, map data, and waypoint listings. In fact, some of the area navigation systems, in addition to digital display of data, provide such cathode ray tube outputs for pilot use.

In discussing such navigational aids, one must bear in mind that the profusion of instruments facing the pilot makes the task of learn-

TABLE I-VII
COMMISSIONED FAA FACILITIES

	1972	1982
Air route traffic control centers	27	25
Air route surveillance radar	91	121
Airport towers	308	447
Combined station/towers	42	0
Airport surveillance radar	126	221
Precision approach radar	0	0
Flight service stations	324	107
Flight service stations, unmanned	15	2,230
International flight service stations	7	7
Low/medium frequency (L/MF) ranges	24	0
VOR/VORTAC	919	1,016
Instrument Landing systems (ILS, MLS)	395	1,052
Non-directional beacon (NDB)	289	311
Airports	12,230	12,700

Source: *The National Aviation System Plan*, Department of Transportation, Federal Aviation Administration, March 1973, p. 37.

ing to operate the aircraft under IFR conditions extremely complex. Certainly, if such improvements are to be added to great numbers of the aircraft fleet, they must be simplified, the cost brought down, and the training time for pilots decreased.

The Future

Future developments in the airways system may be divided into two categories. The first is the programmed improvements which are scheduled to take place during the next 10-year period. Since the present airways system is operating at near capacity levels, implementation of the proposed changes is not dependent upon a high rate of future growth in airways usage. The second category consists of probable future trends. The airways systems, navigational aids and communications, and operational methods will depend upon future economic and demographic trends, as well as on technological developments.

In order to accommodate the expected growth, the following FAA facilities have been commissioned for operation by 1982. These are shown in Table I-VII.

The provision for the en route control system calls for completion of the semi-automation of en route air traffic control facilities, including conflict prediction and resolution (anti-collision system), electronic voice switching, fail-safe features, improved man-machine interface, and revised ATC procedures to take advantage of the upgraded capabilities of the vehicles using the airways. A central flow control facility will be completed to prepare forecasts of air traffic volume and potential congestion points. When such points are detected, the bottlenecks will be eliminated by rerouting and/or regulating air traffic flow. Long range radar systems will be expanded to provide closer en route control. To be developed and installed is the discrete address beacon system (DABS) to improve ATC surveillance and to provide an automatic air-to-ground data link for use in the future ATC system. During this time period, improvements are anticipated in reliability, accuracy, and capacity of the existing radar and radar beacon data acquisition systems.

Terminal control will be improved by providing basic automated equipment for all radar equipped terminal facilities, and automatic metering and spacing of approaches in medium and high density terminals. Radar service will be provided by additional towers, and airport tower control services will be extended to additional air carrier and general aviation airports. Airport surface guidance and traffic detection and control aids will be improved to increase the ground handling capabilities of airports. Flight service stations will be reconfigured, modernized, and automated.

Navigation changes will be made by upgrading the coverage and accuracy of VHF omnirange/TACAN (VORTAC) en route navigation system components. The use of long-range navigation systems, such as Omega, will be implemented. The airways themselves will change from the present system of straight-line "Victor" routes to area navigation routes, shortening distances both en route and terminal. The precise knowledge of position permits the operator of the vehicle to modify his flight plan permitting the most efficient use of fuel, both by the selection of flight profile and of optimum arrival time at the terminal, thus eliminating some of the holding required at present.

The number of landing aids will be greatly increased by installation of conventional landing aids on a great number of additional runways in the lower and medium density airports, and installing improved ILS at high density airports thus raising their capacity. This improved ILS will probably be the microwave landing system (MLS) which is less susceptible than the conventional system to interference, siting problems, and approach path limitations. These advantages mean that very little interference from artifacts located on or near the airport will be encountered because of multipath propagation. Also, approaches other than straight line will be possible yielding significant increases in airways capacity.

While the number of airports is expected to remain approximately constant during the time period under consideration, facilities are to be increased. In particular, the number of automatic and non-automatic flight service stations will rise, facilitating formulation of flight plans by users of the airways system. There will also be an increase in the number of ILS systems installed during this time period. Present high density airports will be upgraded, probably with microwave landing systems; some additional runways at major and air carrier airports will be equipped with instrument landing capabilities; and, many other airports will be equipped with instrument landing systems. This means that many more airports, perhaps as many as twice the present number, will be equipped for full IFR operation. This should prove to be a substantial benefit to general aviation operations.

General aviation aircraft will be required to conform to the requirements of the upgraded national airways system, particularly in the more congested airspace surrounding airports. The changes described above represent only the systems installed, operated, and sited by the FAA. These will be located on the ground. All navigation and communications systems required of the aircraft to fly the national airways system will be an expense borne by owners and operators of the aircraft.

The projections above can certainly change within the near future, and may be altered significantly by energy requirements, national priorities, and other foreseeable factors. While upgrading of the airways system and the systems contained in the aircraft themselves will probably proceed on schedule, there are two constraints on development of the airways system which preclude most radical departures from present plans. First, there is limited airspace which cannot be changed at this time. Second, no **system** for siting airports has ever been followed. They have been sited primarily as a result of economic and political factors, rather than in an optimum manner as considered from the system point of view. There is only limited space in which to make a more reasonable distribution of hub carrier airports. Furthermore, there is a limited spectrum in which to provide the bandwidth necessary for upgrading the communications system. To improve communications over the present state-of-the-art requires the tradeoff between bandwidth of the communications channel and the reliability of the message transmission. Communications channels allocated to these airways activities are unlikely to increase radically in either numbers or quality in the foreseeable future. Improvements will primarily occur in the area of hardware and in the automation of the system, such as automatic tuning, transmission, etc. Advanced modulation techniques furnish some possibilities (e.g., digital transmission).

Within the same framework of navigational aids and communications equipment, the more sophisticated aircraft will be provided facilities enabling them to meter their arrival and departure times to reduce lost time and energy associated with the present practice of establishing holding patterns near the major airports.

Significant changes can be foreseen in applications of microeletronic techniques to instrumentation, radio receiver controls, and digital computer design. The present cockpit of an aircraft fully equipped to utilize the airways system is complex and confusing, even to a skilled pilot. The problems of monitoring aircraft status, determining airport location, and tuning communications equipment to proper frequencies places a burdensome load on the pilot, reducing his ability to respond to emergencies. One key remedy to this is the digital computer and another the microwave landing system currently under development. While the available microelectronic technology (intergrated circuits) permits inexpensive, compact and capable computation facilities to be placed within the aircraft, cost of a complete MLS may be prohibitive for general aviation aircraft.

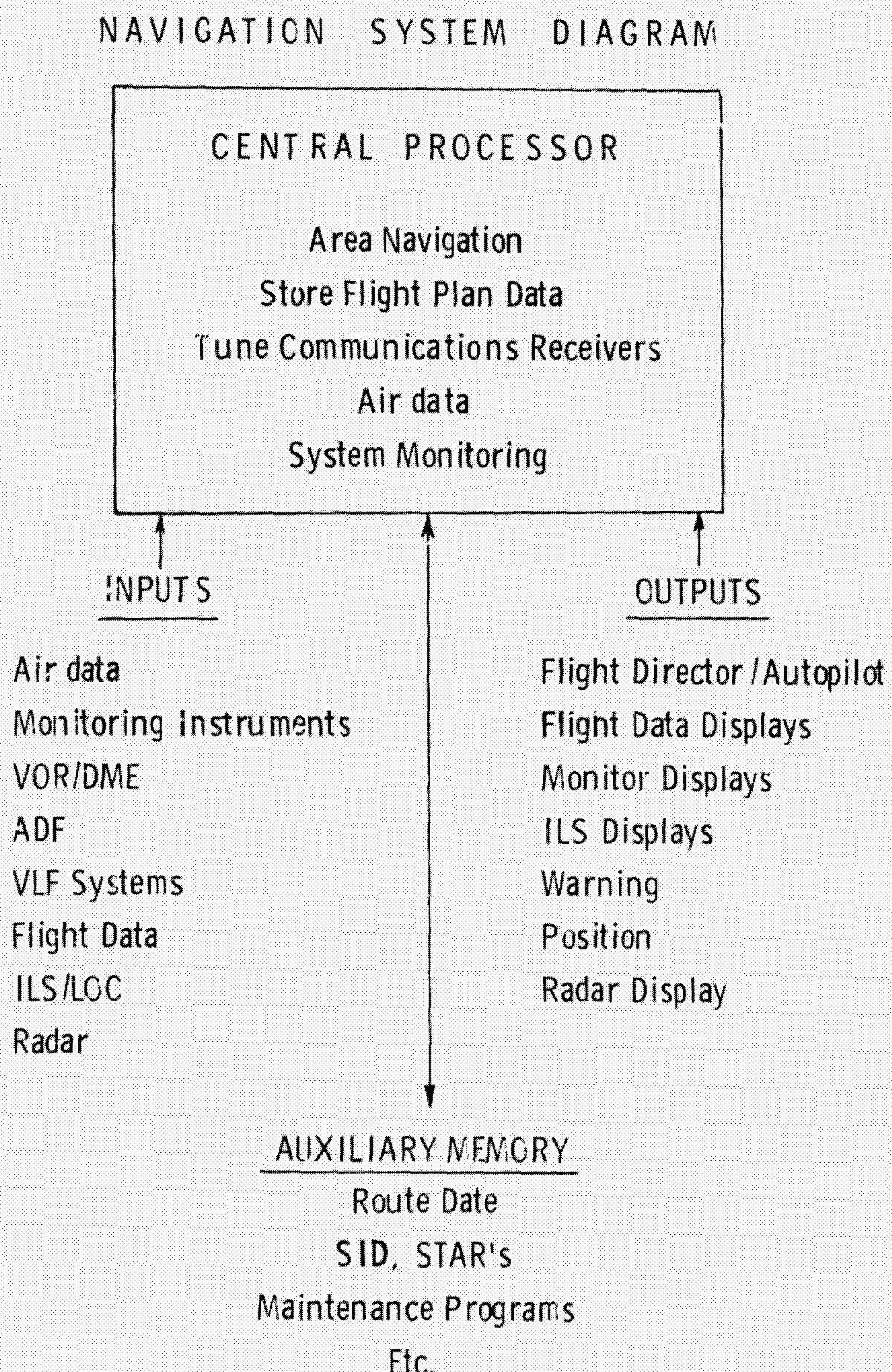
Nevertheless, such equipment might include the flight director/autopilot, automatic tuning of the communication equipment, positional computation for VORTAC, area navigation, and computation for use of VLF navigation aids, with provision or use of satellite data from the future global positioning system.[33]

Future use of such computational avionics in volume could radically lower their unit price. What is required is an analysis of requirements for such an integrated avionics system for general aviation aircraft, and a design philosophy which will permit efficient use of such a system by the average pilot. Figure 1-9 gives a possible configuration for such a system, some form of which probably can be implemented at a reasonable cost. Although the navigation and communications equipment would be similar to that now existing in many general aviation aircraft, the average private aircraft owner probably could not afford such expensive equipment; however, private flying would continue to exist much as it does today with minimal impact on the primary airways system congestion. Also shown in Figure 1-9 are optional items.

All displays would be integrated into a simplified display array, thus easing the task of interpreting the data. A reasonable assumption is that an integrated approach to avionics system design and its interface with the pilot would promote both safety and more efficient usage of the aircraft.

In summary, general aviation aircraft of the future probably will remain similar aerodynamically to those presently in use and will possess an increased capability to fly the total national airways system. Ground-based

[33] Cohn, D. M. et al., *An Analysis of Technology Requirements and Potential Demand for General Aviation Avionics Systems for Operation in the 1980's*. Jenkinstown: Decision Science Corp., June, 1974.



NAVIGATION SYSTEM DIAGRAM
FIGURE 1-9

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navigational aids will be upgraded and standardized at more airports.

HUMAN FACTORS IN GENERAL AVIATION

Introduction

For tens of thousands of years man was a pedestrian on earth, slowly moving and slowly developing his skills and abilities. Yet within the short span of one lifetime he has taken to flying, left his feet and developed the ability to fly. In the history of aviation, there have been two major challenges:

(1) the design and construction of aircraft, and

(2) the training of men to operate them safely.

The response to the first challenge was and is one of mankind's great accomplishments: aeronautical engineering was born and prospered and technological breakthroughs were achieved as airplanes became bigger and flew faster, higher, and longer.

In response to the second challenge, the relatively few men sufficiently skilled and qualified to become operators were selected. During World War II, as airplanes became more complex, there was increasing emphasis on training and training processes. By the end of the war, the capacity to build complex weapons systems and vehicles, particularly aircraft, had considerably exceeded the ability of the average man to operate them. A movement to "humanize" these systems developed. Instead of searching for the "right man for the right job," the job was built around the man. An interdisciplinary area emerged, variously called human factors, engineering psychology, or human engineering; its goal to examine man's uniquely human skills and limitations, his sensory, cognitive, and perceptual-motor capacities, and to apply this information to the design of equipment, vehicles and artificial environments.[34]

VanCott and Altman viewed the emergence and development of human factors as a process occurring in three historical stages:

(1) Primary emphasis on the machine with the human "adapted" to it by means of selection and training;

(2) Primary emphasis on man where the machine is adapted or designed for the man; and,

(3) The newly emerging emphasis on the overall system design in which man and machine components are optimally integrated to achieve system objectives.[35]

A complex man-machine system in general aviation has been brought forth involving man as operator with aircraft, navigation, communications, and air traffic control systems. A concept of growing prominence is that man-machine systems (including men and machines) should be designed to capitalize on those human talents and characteristics that are of optimal use in the system as a whole, i.e., to design the environment and the man-machine interface so as to make optimal human performance not only possible but predictable.[36]

As general aviation operations have expanded, human variables have become increasingly more important. Technological advances have been achieved but flight places demands on man which would have been unthinkable a life-time ago; behaviors such as paying no attention to his senses, moving in three-dimensional space without a visual horizon for reference, and monitoring dozens of instruments simultaneously.

The Human Component: The Individual

Flying holds a unique place in the lives of most pilots. Often a pilot during flight sees the aircraft as an extension of himself. Yet according to Yanowitch, et al., if a pilot accumulates stress in his life with which he can no longer cope, that aircraft may become an instrument of self-destruction. In the context of flying the pilot may engage in subintentional self-destructive acts. These include such behaviors as neglecting important items on the pre-flight check, taking-off with barely enough fuel, or flying an aircraft which has been poorly maintained.[37]

Based on information presented in *NBAA Business Flying* (1974), a typical pilot profile shows that he is most often male, well-edu-

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[34] McCormick, E. J., *Human Factors Engineering*, 2nd Ed. (New York: McGraw-Hill Book Co.), 1964.

[35] VanCott, H. P. and Altman, J. W., "Procedures for Including Human Engineering Factors in the Development of a Weapons System," WADC Tech. Rep. No. 56-488, Wright Air Development Command, WPAFB, Ohio, October, 1956.

[36] Kidd, J. and Van Cott, H., "System and Human Engineering Analysis," Chapter 1 in Van Cott and Kinkade, (eds.) *Human Engineering Guide to Equipment Design*, Rev. Ed. (Washington, D.C.: American Institute for Research), 1972.

[37] Yanowitch, R., Bergin, J. and Yanowitch, E., "The Aircraft as an Instrument of Self Destruction," FAA AM 73-50 Federal Aviation Administration, Department of Transportation, Washington, D.C., March 1973.