NASA Contractor Report 145342

General Aviation Avionics Equipment Maintenance

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ABSTRACT

The Research Triangle Institute has conducted an investigation of factors which impact general aviation avionics equipment maintenance. The factors of concern were those which impact the owners and operators of single engine and light twin-engine general aviation (GA) aircraft. For the most part, these investigations were conducted through literature reviews and telephone conversations with people involved with various aspects of GA; however, FAA facilities, several repair stations, and several owners and operators were visited.

The principal factors considered included the regulatory agencies (e.g., the FAA and the FCC), avionics manufacturers, avionics repair stations, the statistical character of the GA community and owners and operators. These largely define the maintenance environment and, thus, performance, repair costs, and reliability of avionics systems. Based upon a study of these and other factors, this report discusses the impact of the various entities. Some of the conclusions are that a significant economic stratification is reflected in the maintenance problems encountered, that careful attention to installations and use practices can have a very positive impact on maintenance problems, and that new technologies and a general growth in GA will impact maintenance.

It is recommended that a study of the potential benefits of standardization to GA avionics maintenance be considered.

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LIST OF ACRONYMS

AC	Aircraft
ADF	Automatic Direction Finder
AEA	Aircraft Electronics Association, Inc.
AEEC	Airlines Electronics Engineering Committee
AOPA	Aircraft Owners & Pilots Association
ARINC	Aeronautical Radio, Inc.
ATC	Air Traffic Control
AVC	Automatic Volume Control
CAB	Civil Aeronautics Board
CNI	Communication Navigation Identification
DME	Distance Measuring Equipment
ELT	Emergency Locator Transmitter
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCC	Federal Communications Commission
FG	Fixed Gear
GA	General Aviation
GADO	General Aviation District Offices
GAMA	General Aviation Manufacturers Association
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LRC	Langley Research Center
LSI	Large-Scale Integration
MKR	Marker Beacon Receiver
MTBF	Mean-Time-Between-Failure
NASA	National Aeronautics and Space Administration
NAV/COM	Navigation/Communication
NTSB	National Transportation Safety Board
RG	Retractable Gear
RMI	Radio Magnetic Indicator
RNAV	Area Navigation
RTCA	Radio Technical Commission for Aeronautics
RTI	Research Triangle Institute
TACAN	Tactical Air Navigation
TCA	Terminal Control Areas
TSO	Technical Standard Order
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	Very-High-Frequency Omnidirectional Radio Range

SECTION I

INTRODUCTION

The Research Triangle Institute (RTI) has conducted an investigation of factors which impact on General Aviation (GA) avionics equipment and maintenance. These investigations were conducted under a National Aeronautics and Space Administration (NASA) Contract for the Langley Research Center (LRC). The contract was titled, "General Aviation Avionics Equipment Maintenance." The NASA contract number was NAS1-14939, and the RTI project number was 43U-1464.

Objectives

The principal objective of this work was to evolve and document a general perspective of the GA avionics maintenance environment. In pursuit of this principal objective, RTI investigated factors which have a significant impact on GA avionics. These include the impact of regulatory agencies which largely define the interface environment for avionics and, thus, many of the functional characteristics of avionics systems; the impact of trade and professional organizations with an interest in GA; and community attitudes and procedures that pertain to avionics. Other factors considered include the GA aircraft population, the production of new GA aircraft and their potential as an avionics market, and avionics acquisition costs and repair costs considerations. This report documents the results of these investigations as a response to the principal objective.

Approach

The RTI approach in these investigations has been to review current literature that pertains to the GA issues of interest, and to open a dialogue with representative members of the GA community to discuss GA avionics maintenance issues. Many of the contacts with the GA community

were by way of telephone interviews with trade and professional organization representatives, regulatory agency personnel, and with avionics manufacturers. Interviews with repair station personnel, pilots and owners, and some Federal Aviation Administration (FAA) personnel were conducted in person.

Literature - There is a wealth of literature that is either devoted to current GA issues or else includes topics of interest to the GA community as a segment of the larger aviation community. The list of references at the end of this report is indicative of those publications which were useful in the preparation of this report. More importantly, referenced publications and other issues of those publications have provided a current insight into many of the factors of interest in these investigations. To a large extent, the viewpoints of airframe and avionics manufacturers and of trade organizations are well represented in the literature. Statistical data is readily available, for example, as is a perspective on some of the general issues. The purpose of RTI's telephone contacts was to attempt to focus more explicitly on the issue of avionics maintainability.

The FAA and the Radio Technical Commission for Aeronautics (RTCA), for example, have published documents that pertain to GA avionics issues. While these sources have been utilized, there is more to be gained by further investigations into these sources.

In addition to the references listed at the end of this report, a bibliography is attached which tabulates the literature sources that were useful in these investigations.

Interviews - With some notable exceptions, (e.g., the Aviation Consumer) the current literature does not represent the views of the larger population of GA pilots, owners, repairmen, and repair stations to the extent that the views of the larger, more organized members of the community are represented. In attempting to gain an insight into the perspective of pilots and repair stations, for instance, RTI relied heavily upon personal interviews with the members of the GA community.

SECTION II

REGULATORY AGENCIES

Federal Aviation Administration

The Federal Aviation Administration (FAA) is a dominant factor in all aviation in the United States. It is the air transportation component of the Department of Transportation and is concerned primarily with aviation safety. The FAA issues regulatory, advisory, technical, scientific, administrative, educational, and informational publications that affect civil aviation at every level. The FAA's Federal Aviation Regulations (FAR's) govern the certification, maintenance, and operation of General Aviation (GA) airplanes, including avionics. The FAA has developed, operates and maintains the navigational aids and the Air Traffic Control (ATC) system with which the GA community interfaces. Thus, except for frequency and bandwidth allocations that are governed by the Federal Communication Commission (FCC), the FAA defines the electronic environment within which the GA community operates. The FAA certificates airplanes, avionics units, operators, pilots, repair stations, and repairmen. The organization of the FAA is extensive and complex. A general description of the FAA can be found in Reference 1.*

The roles of the Civil Aeronautics Board (CAB) and the National Transportation Safety Board (NTSB) are often complementary with those of the FAA. The CAB has the same statutory charter as the FAA, but operates under different parts. The CAB's responsibilities are primarily for the economic regulation of the certificated air carriers and, thus, it has little impact on general aviation. The NTSB is responsible for investigating aviation accidents and reporting publicly on their cause or probable cause.

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*Reference 1 and other FAA information can be readily obtained by contacting FAA Headquarters, Public Inquiry Center, APA-430, 800 Independence Avenue, SW, Washington, D.C., 20591, (202) 426-8058/8059.

Airplanes - In general, a General Aviation airplane is a small airplane with a maximum certificated takeoff weight of 12,500 lbs. or less. Certification of these airplanes is covered in 14 CFR 23. Airplanes with a takeoff weight of more than 12,500 lbs. are categorized as transport airplanes and are certificated according to other FAR's. (Such an airplane may be used in a service other than transport or air taxi operations, however, and may be considered a General Aviation airplane. The term is not explicitly defined.) In 14 CFR 23, numerous performance and other requirements are established as prerequisites for certification. Certification requirements include an airspeed indicator, an altimeter, a magnetic direction indicator and a complement of powerplant instruments such as gauges for fuel quantity and pressure, oil pressure and temperature, cylinder head temperature, manifold pressure, tachometer, fuel flowmeters (turbine engines), thrust or torque indicators, and others. Although some of these instruments may operate on electrical principles, they are not usually considered a part of the avionics and are of little interest in these investigations. The basic electrical power system, i.e., batteries and alternator, also fall into this non-avionic category. Installation requirements on these and other instruments as well as on the basic electrical power systems are specified in 14 CFR 23.

Title 14 CFR 23 does not necessarily require an airplane to be equipped with avionics to be certificated; however, if the airplane does contain avionics, there are applicable requirements. It is required that the installed equipment perform its intended purpose without introducing any hazards. Moreover, there are explicit performance requirements on installed automatic pilot systems and flight directors.

From a practical perspective, an airplane undergoing certification procedures is likely to be equipped with a significant complement of avionic systems, since operation from many airports require that certain avionics be onboard and operational. Moreover, if the airplane is to be certificated for IFR, some minimum set of avionics would be required.

Airplane certification would require that these systems perform their intended function without introducing any hazards.

Two other airplane certification requirements are of significance from an avionics perspective. First, an owners maintenance manual is required which contains essential maintenance information and includes descriptions of electrical and avionic systems. Secondly, an Airplane Flight Manual (or equivalent) is required which contains operating limitations and procedures, performance information, loading information, and other information that may be required for safe operation. The manual section on operating limitations must specify the kinds of operations (e.g., VFR or IFR) in which the airplane may or may not be used, and list installed equipment that affects any operating limitations.

The avionics actually required for a GA type airplane depends upon the type of certification and the airport facilities to be used. These requirements are summarized in the following paragraphs. All GA aircraft equipped to carry more than one person must be equipped with an emergency locator beacon (14 CFR 91•52). (There are exceptions to this and other rules listed in this paragraph. In general, these exceptions relate to training, testing, and ferrying to a repair station, etc.)

An aircraft carrying passengers and operating VFR at night, in a control zone, or above the cloud cover must have two-way radio communications equipment (25 mile range) and a navigation receiver (14 CFR 135•157). An aircraft operating IFR must have a transmitter capable of reaching at least one ground facility from anywhere along its route, two microphones, two headsets, or one headset and one speaker, a marker beacon receiver, two independent communications receivers, and two independent navigation receivers (14 CFR 135•159). An autopilot can be used in lieu of a second in command under some conditions (14 CFR 135•77). In addition to other requirements, operations in controlled airspace requires that the airplane be equipped with a transponder, and all transponders must conform to TSO-C74 (14 CFR 135•143, 14 CFR 91•24).

In Group I Terminal Control Areas (TCA's) an operable VOR or TACAN receiver, an operable two-way radio capable of communicating with the ATC for that terminal area, and an altitude reporting transponder is required. There are nine Group I TCA's in the United States, two of which are Chicago and Atlanta.

In Group II TCA's, the same equipment is required except that the transponder is not necessarily required to report altitude. There are twelve Group II TCA's including Philadelphia, Denver, and Seattle, for example. In Group III TCA's, two-way radio communications are required. There are forty-two Group III areas including Norfolk, Raleigh-Durham, and Tucson.

Avionics - The FAA certificates most avionics systems or units through the Technical Standard Order (TSO) System which is described in 14 CFR 37. A TSO contains minimum performance and quality control standards for specified materials, parts, or appliances used on aircraft. In order to obtain a TSO authorization for an avionic system, the manufacturer must submit to the FAA an application which contains a statement of conformance certifying that the system meets the applicable performance standards, technical data to substantiate conformance, and a description of the manufacturer's quality control system. After a TSO authorization is issued, the manufacturer must continue to maintain the quality control system and conduct tests and maintain records to insure continued conformance. There are provisions in 14 CFR 37 for obtaining approval for minor deviations from the performance standard and for minor design changes. It is significant that no one other than the manufacturer can be authorized to change a TSO'ed item except under certain provisions of 14 CFR 43 which deals with maintenance, rebuilding, and alterations. Another provision of a TSO authorization is that the FAA must be allowed to inspect any article manufactured under that authorization, the quality control inspections and tests, the manufacturing facilities, and technical data files.

A TSO is somewhat like a consensus standard. It evolves with inputs from many segments of the aviation industry. Most TSO's are developed within the FAA, but a significant number are developed by other professional

groups such as the Radio Technical Commission for Aeronautics (RTCA) and the Society of Automotive Engineers. Approximately 20 percent of the current TSO's were developed by the RTCA. The 1976 issue of 14 CFR 37 lists 91 TSO's. Approximately 26 of these pertain to avionic navigation and communication systems.

Non-TSO'ed avionics are somewhat a problem for the FAA. The TSO system originally evolved to provide a standard for air carrier and transport type aircraft. General aviation manufactures began to produce TSO'ed apparatus as a sales incentive and because there is no other general specification system applicable to GA-type equipment. (There are some exceptions, e.g., all ATC Transponders and emergency locator transmitters must conform to the applicable TSO.) In general, the FAA's position is that installed, non-TSO'ed avionics must perform its intended function and conform to the performance specification of the equivalent TSO unit. However, this is a difficult, if not impossible regulation to enforce. One FAA practice is to note performance deviations and any related restrictions in the airplane flight manual.

Repair Stations - Federal Aviation Administration regulations also govern the maintenance, preventive maintenance, rebuilding, alteration, and inspection of all certificated airplanes and related appliances (avionics). Repair stations are certificated with ratings which apply to specific maintenance activities. Specific ratings are issued for maintenance activities on airframes, powerplants, propellers, radios, instruments, and accessories. Within these general ratings, further categorizations define more explicitly the authorized activities of a certificated repair station. A radio rating, for example, is further categorized as Class 1: Communication equipment; Class 2: Navigational equipment; and Class 3: Radar equipment. The instruments and accessory ratings may also be of interest from the avionics perspective. An instrument rating must further specify one or more of four class ratings, and the accessory rating one or more of three class ratings. Within the instrument rating are categories for Class 1: Mechanical instruments; Class 2: Electrical instruments; Class 3: Gyroscopic instruments; and Class 4: Electronic instruments. The accessory

rating contains mechanical, electrical, and electronic classes. Authorizations under these ratings and subordinate classes are specified in 14 CFR 145.

The FAA also issues limited ratings to repair stations which apply to a particular airframe or a particular radio.

To be certificated, a repair station must provide suitable housing and facilities (14 CFR 145 specifies that certain equipment needed for a given rating be available) commensurate with the work authorized by its certification, and adequate personnel to perform, supervise, and inspect the work for which it is rated. The repair station is primarily responsible for the satisfactory work of its employees.

There are numerous other requirements and privileges associated with repair station certification. Many requirements pertain to maintaining personnel records and to the assignments and qualifications of personnel. Others pertain to maintaining current specifications provided by a manufacturer and necessary for maintenance and inspection procedures and other forms of information such as FAA airworthiness directives and bulletins. It is explicitly required that the repair station maintain in a current condition all manufacturer's service manuals, instructions and service bulletins that relate to articles the station maintains or alters. The repair station must also have an established inspection system that will provide for satisfactory quality control in inventory as well as other facets of its operation. This system must be documented in an inspection procedures manual which states in detail the routine procedures and practices that the station will follow. This manual is required at the time an application for certification is made, and must be maintained current and available for inspection at all times after a station is certificated.

A certificated repair station may maintain or alter any item for which it is rated, and approve its return to service. These privileges must be exercised in accordance with 14 CFR 145.

There are stringent requirements on a certificated repair station that relate to the maintenance of repair and inspection records, and to the reporting of defects or unairworthy conditions to the FAA.

A repair station certificate with a limited rating is readily issued to a manufacturer who is the holder of a Type or Production certificate, or a TSO authorization, for example.

Maintenance - All aircraft maintenance is subject to FAA regulations. In order to clarify maintenance authorizations the FAA definitions of several maintenance terms are repeated here. For maintenance purposes, most avionics are categorized as appliances. A major alteration of an appliance is defined in 14 CFR 43 as alterations of the basic design, not made in accordance with recommendations of the appliance manufacturer or in accordance with an FAA Airworthiness Directive. In addition, changes in the basic design of radio communication and navigation equipment approved under type certification or of a TSO that have an effect on frequency stability, noise level, sensitivity, selectivity, distortion, spurious radiation, AVC characteristics, or ability to meet environmental test conditions, and other changes that have an effect on the performance of the equipment, are also major alterations.

A major repair to an appliance includes calibration and repair of an instrument and the calibration of radio equipment, for example. A preventive maintenance category is also defined in 14 CFR 43, but it does not include any activities that relate to avionics.

In the more general definitions of 14 CFR 1, Preventive Maintenance is defined as simple or minor preservation operations and the replacement of small standard parts not involving complex assembly operations; and maintenance as inspection, overhaul, repair, preservation and the replacement of parts. Maintenance is further defined to exclude preventive maintenance.

Personnel - The FAA certificates maintenance personnel as either mechanics or repairmen, each with associated ratings. A mechanics certificate is valid until it is surrendered, suspended, or revoked. A repairman certificate can also be surrendered, suspended, or revoked. Additionally, it becomes invalid if the holder is relieved from the duties for which he was employed or certificated. A repairman's certificate is only valid in connection with duties for the repair station by whom he was employed and recommended for certification.

Others working under the supervision of a mechanic or repairman may perform the work his supervisor is authorized to perform under the supervisor's personal supervision' except for 100-hour and annual inspections and for inspections subsequent to a major repair or alteration.

The holder of a repair station certificate may perform the work authorized by his certification, and a certificated pilot may perform preventive maintenance on any aircraft owned or operated by him that is not used in air carrier service. It is significant that preventive maintenance does not encompass avionic systems.

Title 14 CFR 43 provides some maintenance authorizations for manufacturers, air carriers, and commercial operators.

Inspections - Inspections are an essential aspect of general aviation operations; however, the annual or 100-hour inspections required by the FAA largely pertain to the airframe and power plant rather than to avionics. (Federal Air regulations provide for a progressive inspection in lieu of a 100-hour or annual inspection. This procedure tends to be exercised by commercial operators. Most GA operators use the annual inspection.) To be authorized as an inspector, an applicant must be a certificated mechanic with both an airframe and a power plant rating, for example. (There are many other requirements.) Inspection authorizations are reviewed on an annual basis through FAA General Aviation Distric Offices or International Field Offices for their respective areas.

The extensiveness of the avionics inspection during the 100-hr or annual inspection varies somewhat. In general, the inspector ascertains that the avionics required for the aircraft's certification is safely installed and performs its intended function. Avionic installations beyond that required for the airplanes certification are also inspected for proper installation and for performance. There are electrical aspects of the inspection, e.g., the routing and security of wires, alternators and connectors, and the condition of the battery.

FAA Service Difficulties Records - The FAA operates a Service Difficulties Program which can be a significant benefit to the GA community. The program consists of a computerized data bank listing reported

discrepancies in aircraft and accessories, including avionics. The computer can be queried to obtain these data for an avionic unit, an aircraft, or some other accessory. The data input is obtained from Malfunction or Defect Reports, which may be filed by pilots, owners, repair stations, inspectors, and others.

Typically, FAA General Aviation Distric Officers (GADO) distribute postage paid Malfunction or Defect Report forms (FAA Form 8330-2) to be returned to the distributing GADO office and, subsequently, to the data bank for entry in the computer record. A Malfunction or Defect Report form identifies an aircraft, power plant or propeller by make, model, and serial number. If the report is on an appliance (which includes avionics), the name of the appliance is also included. Further, the specific part or component is identified by name, number, and location. The format requests a description of the fault, the circumstances under which it occurred, probable cause, and recommendation to prevent recurrence.

The format of the printout may include an identification of the aircraft or avionics unit by name, model number, serial number, part number, and location. It includes space for much additional information, most of which pertains to the aircraft. It also contains a brief textual description of the discrepancy.

In order to evaluate the Service Difficulties Program, RTI exercised the data bank for data on several avionic systems and an aircraft.* The data received covered a period of 60 months (5 years) through November 1977. The data obtained were the following:

1.	Cessna Model 421 Aircraft	1408 Records
2.	Narco Model AT50A Transponder	71 Records
3.	King Model KX 145 Nav/Com	17 Records
4.	King Model KX 175B Nav/Com	40 Records
5.	Narco Model Com11B Transciever	8 Records
6.	Genave Model 200B Nav/Com	5 Records
7.	King Model KT76 Transponder	107 Records
8.	King Model KT78 Transponder	39 Records

*Write to: FAA, through Cashier AAC 23B, Attention Maintenance Analysis Center, AFS 581, P.O. Box 25082, Oklahoma City, Oklahoma 73125. Include $3.00 for each report.

The repair shop and repair personnel interviews conducted during these studies suggest that only a small sample of discrepancies are entered into the data bank. Attitudes toward the program are casual, and data entered seem to be made for diverse reasons, e.g., encouragement from local GADO inspectors, unusual occurrences, and frequently observed occurrences. It has been estimated by the FAA that no more than 10 percent of all service difficulties are reported to the data bank. We think 10 percent is optimistic.

We conclude that data from the bank can be useful for specific purposes. We observed, for example, records of a repetitive capacitor lead breakage that could be easily circumvented by mounting the capacitor differently. The manufacturer and repair shops should benefit from that report. However, the service difficulty reports are not generally useful for evaluating the reliability or maintainability of an avionic system.

Federal Communications Commission

The Federal Communications Commission (FCC) also impacts the General Aviation Community through its authority to regulate radio transmissions, to issue licenses for radio stations, and to license radio repairmen. Thus, the FCC prescribes the manner and conditions under which portions of the radio spectrum may be made available for radio communication and navigation facilities to the aviation community for safety purposes and other necessities.

An aircraft radio station is a mobile station in the aeronautical service on board an aircraft and must be licensed by the FCC and operated in a manner prescribed by the FCC. Its use is limited to the necessities of safe aircraft operations. Many frequencies are available for an aircraft station including several dedicated to specific purposes. These dedicated frequencies include 121.5MHz for emergency communications and 123.1 MHz for search and rescue operations. Air traffic control frequencies

are at 25 MHz spacings between 118.000 and 121.400 MHz, between 121.600 and 121.925 MHz, between 123.600 and 128.800 MHz, and between 132.025 and 135.975 MHz. Many of these are designated for aircraft on the ground for airport utility communications. Other frequency band assignment for aircraft stations of interest to GA include 1592.5-1622.5 MHz for aircraft collision avoidance systems, 4200-4400 MHz for radio altimeters, and 5350-5470 MHz and 9300-9500 MHz for airborne radars and associated beacons. Localizers and glide path transmitters are operated on paired frequencies. Localizers are assigned frequencies between 108.1 and 111.95 MHz and associated glide paths between 334.7 and 350.95 MHz. VOR stations operate in the 112.05 through 117.95 MHz range and also at assigned frequencies within the 108 to 112 MHz band. Marker beacons operate on 75 MHz. There are other designations which apply to air carrier aircraft and others to private aircraft.

Only the holder of an FCC third-class or higher operator permit may operate an aircraft station, and an FCC second-class or higher permit is required if the station is used for purposes other than telephony or if the carrier power is more than 250 watts or the peak envelope power more than 1000 watts. An operator license is not required for flight personnel using airborne radar sets, radio altimeters, transponders, ELT's, and other airborne automatic radionavigation aids.

A transmitter adjustment or test, during or coincident with the installation, servicing or maintenance of a station, which may affect the proper operation of the station, must be made under the immediate supervision and responsibility of a person holding a radiotelephone or radiotelegraph first- or second-class FCC operator license.

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SECTION III

TRADE AND PROFESSIONAL ORGANIZATIONS

Radio Technical Commission for Aeronautics

The Radio Technical Commission for Aeronautics (RTCA) is a nonprofit cooperative association of government and nongovernment organizations. This prestigious organization was formed in 1935 on the initiative of the Department of Commerce (which was the federal agency principally concerned with domestic aviation at the time), and has made significant contributions in the area of avionics throughout its history. The RTCA played a major role in the development of a National ATC system which was the basis of the ATC system in use today. Currently, RTCA is an Advisory Committee to the FAA. The RTCA's membership consists of nine (9) government agencies and more than 90 industry organizations. The membership also includes several International Associates. The RTCA's membership includes the FAA, ARINC, AEA, NASA, King Radio, and NARCO Avionics, for example.

The RTCA's interest are the technical aspects of Aeronautical Navigation, Communications, and Traffic Control, and the Commission has made many contributions in these areas. The RTCA activities are largely carried out by Special Committees which perform the actual technical work. These committees are established to resolve specific problems, and are ordinarily dissolved when their work is completed. Committee participants are usually representatives of member firms with applicable experience and expertise, and serve at no cost to the RTCA. Currently, there are about 130 active RTCA special committees. Many of these are active in avionic areas of interest to the GA community. A recent report of interest is the RTCA document DO-167, "Airborne Electronics and Electrical Equipment Reliability," which is referenced in a subsequent section on reliability.

Aeronautical Radio, Inc. (ARINC)

ARINC is primarily a communications company owned jointly by the scheduled, commercial airlines. Its principal activity is the operation of an extensive system of aeronautical land radio stations to facilitate "Company Communications" between airborne units and ground stations. ARINC sponsors the Airlines Electronic Engineering Committee (AEEC) which formulates standards for airborne electronic equipment. ARINC standards are developed as consensus standards in connection with the airlines, the military services, and with equipment manufacturers. These standards communicate airline technical needs and requisites for new equipment to manufacturers, and enhance the standardization of physical and electrical characteristics which influence interchangeability of equipment. All other ARINC activities are of a lower priority.

ARINC communication services have nothing to do with air traffic control. Its only relationship with the FAA is one of common interest. However, ARINC's consensus standards for form factors, performances, and interconnections are often adopted by the FAA as the basis of a standard. A TSO number usually refers to such a standard. A TSO also specifies an acceptable environment for an equipment, e.g., temperature, vibration, shock, and humidity.

ARINC has little contact with or interest in GA, although the GA community does benefit from some ARINC activities. In general, a TSO'd GA instrument and a TSO'd commercial airline (ARINC) instrument are vastly different. The price of airline equipment reflects this difference. It also reflects the cost of development, the development of necessary test apparatus, and the significantly smaller market.

More than 100 ARINC documents are readily available to the public. Many of these specify characteristics for avionic systems. A complete list of documents and the documents themselves can be obtained directly from ARINC.*

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*Document Section, Aeronautical Radio, Inc., 2551 Riva Road, Annapolis, Maryland, 21401. (Telephone: (301) 224-4000, Extension 300).

General Aviation Manufacturers Association

The General Aviation Manufacturers Association (GAMA) is an organization of the manufacturers of GA airframes, engines, avionics, and components. Its purpose is to promote a better climate for the growth of GA. GAMA committees are active in several areas of GA concern including legislative, public affairs, and safety. Although founded in 1970, GAMA was known prior to 1970 as the Utility Airplane Council. GAMA has 33 members and a staff of about 12. It is located at 1025 Connecticut Avenue, NW, Washington D.C., 20036.

Aircraft Electronics Association, Inc.

The Aircraft Electronics Association, Inc. (AEA) is an organization dedicated to the advancement of the science of aircraft electronics. The AEA was founded in 1958 and has a membership of about 280. Its membership consists of companies engaged in the sales, engineering, installation and service of avionics. The AEA promotes uniform and stable regulations and uniform standards of performance for avionics, and they have established a code of ethics that pertains to avionics repairs. The AEA attempts to advance the education of its members and the public in areas of aircraft electronics by gathering and disseminating technical data. Their principal publication is the monthly Avionics News. The AEA is located, at Box 1981, Independence, Missouri, 64055. (816-373-6565).

Aircraft Owners and Pilots Association

The Aircraft Owners and Pilots Association (AOPA), founded in 1939, has more than 200,000 members. Its staff of some 150-160 is located at 7315 Wisconsin Avenue, Bethesda, MD, 20014. Its interests include the enhancement of the safety, economy and joy of flying. The AOPA's publications include the monthly, The AOPA Pilot.

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SECTION IV

AIRCRAFT AND AVIONICS STATISTICAL DATA

There is much statistical data available to characterize general aviation in the United States. These data delineate the characteristics of the GA fleet by aircraft type, area distribution, costs, age, owner, usage, and avionics, for example. The extensiveness of available statistical data is impressive and encompasses all aspects of aviation, including airport facilities and general aviation personnel. Only recent data that pertains to aircraft and avionics are discussed herein. For more detailed data and more extensive data that pertains to other aspects of GA, the reader is referred to References 2 and 3.

There is some lag in the availability of the more detailed data, perhaps because the analyses are so extensive. For example, the data in References 2 and 3 are applicable to calendar years 1974 and 1975, respectively. These sources are cited herein because of the completeness of the data. More recent data sources are also cited.

There are some minor discrepancies between the data available from separate sources. These discrepancies may evolve from several causes. In Reference 2, the data was acquired from a sampling process and is subject to both sampling error and errors due to sample screening mechanisms applied during data acquisition. In Reference 3, the data came from actual FAA registration forms which also requested certain additional information on a voluntary basis. Most owners were responsive; however, some were not and it was necessary to make some estimates on the basis of the respondents' data. Thus, some uncertainty is introduced. In other sources, the data is not qualified in any way and one must assume that the same magnitude of error exists. Differences observed in the number of registered GA aircraft as published by different FAA-based sources, however, must be due to the way GA aircraft are defined, since the registration is a matter of record and should be accurate.

Aircraft Considerations

The 1978 edition of Flying Magazine's Flying Annual and Buyers Guide lists 144 different types of aircraft manufactured by 24 companies [Ref.4]. This listing does not include 37 conversions, 17 types of agricultural aircraft, 3 types of amphibians, 15 types of sail planes, or 32 types of helicopters. Of the 144 types of aircraft, 120 have a gross weight of 12,500 pounds or less and, thus, are clearly categorized as GA aircraft. The remainder tend to be jets with take-off weights of about 20,000 pounds, although some are significantly larger, e.g., the Grumman American Gulfstream II at 65,500 pounds. Manufacturers offering the largest number of different types of aircraft are: Cessna (31), Beech (19), Piper (18), Bellanca (10), Grumman American (6), Rockwell International (6), and Gates Learjet (11) [Ref.4].

The GA aircraft market can be sized by considering the business and utility aircraft shipments made during 1977. A total of 16,907 aircraft, valued at $1,488,114,000 were shipped in this interim [Ref.5]. This represents a growth of 9.4 percent from the 15,449 units shipped in 1976, and an increase of 24.3 percent in dollar value. Exports in 1977 accounted for 21.4 percent of the total units and 23.8 percent of the total dollars. Table I shows a breakout of these 1977 figures by manufacturers. In Reference 5, the breakout is complete to the aircraft level. These data are updated monthly in Aviation Week and Space Technology.

A recent report places the GA population at 181,000 aircraft in the second half of 1977 [Ref.6]. These data are not incompatible with the more detailed data presented in subsequent paragraphs in view of the 16,907 deliveries in 1977, the deliveries of 15,449 reported in 1976, and 14,058 deliveries of GA aircraft reported in 1975. There will also have been some attrition in the registered, active GA aircraft in this period.

The 1976 population of active GA aircraft totaled 175,271 units. Of these, 81% were singles and 13% were twins [Ref.7].

TABLE I

BUSINESS AND UTILITY AIRCRAFT SHIPMENTS

CALENDAR YEAR 1977 [REF. 5]

Manufacturer	Number Units	Value (Thousand of Dollars)
Beech	1,203	$262,696
Bellanca	252	5,477
Cessna	8,839	483,015
Gates Learjet	105	168,582
Grumman American	866	119,126
Lake	99	4,151
Maule	108	2,812
Mooney	362	(not available)
Piper	4,499	259,229
Rockwell International	432	128,631
Swearingen	28	35,391
Ted Smith	101	19,004
TOTALS	16,904	1,488,114

In a very extensive analysis of the GA fleet, an FAA study categorizes 177,641 registered with the FAA as of January 1975 as GA aircraft [Ref.2]. (Aircraft that weigh 12,500 pounds or less are categorized as GA aircraft. Some larger aircraft are also considered GA aircraft, but the criteria for the categorization is not clear for these larger units. They are a very minor percentage of the total fleet.) This tabulation excluded commercial airlines aircraft, aircraft owned by persons not residing in the United States, non-engine propelled craft, and government-owned aircraft. These somewhat older data are included here because of the detailed distribution data that follows. The distribution of GA aircraft tends toward an

increase in the percentage of multiple engine piston and turbine powered aircraft, and a decrease in the percentage of single engine units. These trends are slow, however, and the distribution data that follows is reasonably valid for the 1978 to 1980 period.

Statistically, a universe of 172,496 GA aircraft can be categorized as shown in Table II [Ref.2]. (The referenced source does not indicate why the universe is not the total 177,641 registered GA aircraft. Other sources of statistical data also frequently refer to a smaller data base.) It is significant that singles and light twins account for about 95 percent of the total fleet and rotorcraft for about half the remainder.

TABLE II

CATEGORIZATION OF GA AIRCRAFT BY TYPE [REF. 2]

JANUARY 1975

Type	Approximate Number	Approximate Percentage of Total (%)
Single Engine Piston (1-3 seats)	64,331	37.3
Single Engine Piston (4^+ seats)	81,405	47.1
Twin Engine Piston (< 12,500 lbs.)	17,937	10.4
Multiple Engine Piston ($\geq$ 12,500 lbs.)	1,207	0.7
Turboprop	1,897	1.1
Turbojet	1,552	0.9
Rotocraft	4,139	2.4
Other	172	0.1
TOTALS	172,640	100.0

It is within the scope of this report to consider other characteristics of the GA fleet. From Reference 2, of the universe of 172,496 GA aircraft, 112,241 are owned by individuals and 60,256 are owned by companies. Table III shows a distribution of the GA aircraft owned by companies and by individuals by type of aircraft. Single engine piston units are dominant with the majority of these equipped for 4 or more passengers. Singles and light twins account for 98.5 percent of the total. Single engine piston units are also dominant in company owned aircraft; however, there is a significant decline in the percentage of 1-3 seat units and a large increase in the percentage of light twins.

TABLE III

DISTRIBUTION OF GA AIRCRAFT OWNED BY INDIVIDUALS AND COMPANIES [REF. 2]

	Owned by Individuals		Owned by Companies	
Type	Approximate Number	Approximate % of Total	Approximate Number	Approximate % of Total
Single Engine Piston (1-3 seats)	48,488	43.2	15,908	26.4
Single Engine Piston (4^+ seats)	55,672	49.5	25,729	42.7
Twin Engine Piston (< 12,500 lbs.)	6,398	5.7	11,629	19.3
Multiple Engine Piston ($\geq$ 12,500 lbs.)	337	0.3	844	1.4
Turboprop	112	0.1	1,747	2.9
Turbojet	112	0.1	1,386	2.3
Rotocraft	1,235	1.1	2,892	4.8
Other			121	0.2
TOTALS	112,354	100.0	60,256	100.0

Table IV shows a distribution of GA aircraft by use categories. Personal use is the dominant use category. Table V is a repeat of these distributions by use categories for the GA aircraft owned by individuals and by companies, respectively. As one would expect, there are notable shifts toward personal use for aircraft owned by individuals and away from personal use for aircraft owned by companies. It is of interest, however, that company owned GA aircraft are used for personal purposes 17 percent of the time.

TABLE IV

DISTRIBUTION OF GA AIRCRAFT BY USE CATEGORIES GROUP [REF. 2]

Use Category	Approximate Number	Approximate Percentage of Total
Personal	79,147	48.6
Business	40,308	24.7
Executive	5,548	3.4
Aerial Application	7,343	4.5
Instructional	12,239	7.5
Air Taxi	4,243	2.6
Industrial	1,632	1.0
Rental	5,059	3.1
Other	7,507	4.6
TOTALS	163,026	100.0

TABLE V

DISTRIBUTION OF GA AIRCRAFT OWNED BY COMPANIES AND BY INDIVIDUALS BY USE CATEGORIES [REF. 2]

	Owned by Individuals		Owned by Companies	
Use Category	Approximate Number	Approximate % of Total	Approximate Number	Approximate % of Total
Personal	69,437	65.2	9,610	17.0
Business	22,932	21.5	17,410	30.8
Executive	533	0.5	5,031	8.9
Aerial Application	3,627	3.4	3,674	6.5
Instructional	3,840	3.6	8,366	14.8
Air Taxi	960	0.9	3,279	5.8
Industrial	533	0.5	1,131	2.0
Rental	1,920	1.8	3,222	5.7
Other	2,773	2.6	4,805	8.5
TOTALS	106,555	100.0	56,528	100.0

Some of the more popular GA aircraft, selected on the basis of recent shipments, are listed in Table VI. Complete tabulation of the 1976 and 1977 shipments of these and other GA aircraft are listed in References 8 and 5, respectively and additional descriptive data can be found in Reference 4. The price data included in Table VI are standard figures provided by the manufacturers and may include varying amounts of avionics.

The least expensive airplane listed in the 1978 directory is the Taylorcraft F-19 at $12,500. The F-19 seats 2 and weighs 1,500 pounds. The most expensive fixed gear single is the Helio Courier HT-294 at $80,286. It weighs 3,400 pounds, and seats six. Single Engine, retractable gear GA aircraft range is priced from $32,700 (Mooney Ranger) to about $95,000. Light twins begin at about $70,000 and include popular Beech, Piper and Cessna models, for example, in the $200,000 to $300,000 price range. Small jets run between $1 million and $2 million.

TABLE VI

POPULAR GA AIRCRAFT (1977)

Manufacturer	Model	Description*	Weight (lb.)	Current Price (1978)	Number Shipped (1977)
Cessna	172 Skyhawk	Single, 4, FG	2,300	$23,495	182
Cessna	152	Single, 2, FG	1,670	17,995	166
Piper	Warrior	Single, 4, FG	2,325	22,360	76
Piper	Archer II	Single, 4, FG	2,550	27,510	45
Cessna	Cardinal	Single, 4, RG	2,809	43,900	30
Beech	A36 Bonanza	Single, 4/6, RG	3,612	77,550	16
Cessna	310	Twin, 4/6	5,535	123,500	26
Piper	NAVAJO	Twin 6/8	6,500	193,000	11

* Engines, Seats FG = Fixed Gear RG = Retractable Gear

The average cost of all GA aircraft delivered in 1977 was approximately $90,000, based on a total of 16,542 aircraft shipped.

Avionics Considerations

A 1978 directory of avionics lists 18 different categories of avionics produced by 45 different avionics manufacturers [Ref.4]. These manufacturers are tabulated in alphabetical order with the avionics they manufacture in Appendix A. For the convenience of the reader, Appendix A also contains a reverse tabulation, i.e., the manufacturers are also tabulated under the avionics they manufacture.

There is a growing tendency for new GA aircraft to be equipped with a greater avionics capability. Factors which influence this tendency are the growing need for avionics in the crowded, controlled airspaces as well as in uncontrolled areas, the increased usage of the GA aircraft as a

convenient means of transportation and in business activities, and recent technological advances which tend to reduce the cost of avionics or provide more capability at the same price. Technological advances have tended to reduce the impact of inflation on avionics systems.

It is instructive at the beginning of this section to consider the existing investment in GA avionics. In 1975, 161,500 GA aircraft were equipped with avionics valued at more than $325 million, an average of more than $2,000 per aircraft. (The more than 2,500 air carrier aircraft were equipped with $400 million or $160,000 per unit.) The investment in ground-based electronics for communications, navigation and radar was estimated at $450 million [Ref.9].

In 1976, there were 15,447 new GA aircraft delivered. The avionics installed in these new units was valued at $174,582,373, an average of $11.3 thousand per aircraft [Ref.7]. The increasing average cost for avionics is indicative of better equipped aircraft rather than an inflation factor. The cost of avionics as a percentage of aircraft cost has declined every year since 1970. The average cost of avionics in new aircraft was 12 percent of the average aircraft value in 1976. Table VII tabulates average new-aircraft cost and average new-aircraft avionics costs for the 5 years inclusive of 1972 through 1976 [Ref.7]. For a small GA aircraft, a complete avionics package may be 25 percent of the total cost.

TABLE VII

AVERAGE COST OF AVIONICS FOR NEW GENERAL AVIATION AIRCRAFT

1972 to 1976 [REF. 7]

Year	New AC Deliveries (No.)	Average New AC Cost ($)	Average New AC Avionics Cost ($)	Avionics Cost as % of AC Cost (%)
1972	9,774	67,081	8,905	13.3
1973	13,645	71,252	9,490	12.3
1974	14,167	76,385	10,032	13.1
1975	14,072	86,112	11,022	12.8
1976	15,447	93,679	11,302	12.1

AC = Aircraft

Retrofit avionics, i.e., avionics for older aircraft, has also been a significant component of the GA avionics market. In recent years, the retrofit market has been boosted by the required installation of TSO'ed transponders for non-TSOed units and required ELT's. This segment of the retrofit market has now leveled off, but retrofits are still about 30 percent of the new-aircraft avionics market. In recent years, it has ranged between about 35 and 55 percent. Table VIII is a tabulation of avionics retail market data for the 5 years inclusive of 1972 through 1976 [Ref.7].

Table VIII also includes a tabulation of the GA avionics services market and the total GA avionics market for the 5 year period. In 1976, the total GA avionics market was nearly $277 million. The market distribution was 63.1 percent avionics for new aircraft, 18.5 percent avionics for retrofit, and 18.4 percent avionics services [Ref.7].

TABLE VIII

GENERAL AVIATION AVIONICS RETAIL MARKET

1972 to 1976 [REF. 7]

Year	New AC Deliveries (No.)	Avionics for New AC ($000)	Avionics for Retrofit ($000)	Avionics Services ($000)	Total Avionics Market ($000)
1972	9,774	87,038	37,205	36,061	160,304
1973	13,645	129,488	45,510	38,016	213,014
1974	14,167	142,120	47,872	41,250	231,242
1975	14,072	155,106	53,617	47,614	256,364
1976	15,447	174,582	51,266	50,897	276,745

Table IX is a tabulation of the percentage of GA aircraft population equipped with various avionics capabilities by type of aircraft [Ref.2]. The larger, more expensive aircraft tend to be better equipped with avionics. This reflects several factors, such as: the larger, more expensive aircraft have greater capabilities and need more avionics, avionics is a smaller percentage of the total cost of a larger aircraft, these aircraft tend to be owned by companies rather than individuals and costs are of less significance, and these aircraft are used in corporate or executive roles and the added costs of advanced avionics is more easily justified.

The twin or multi-engine piston aircraft of over 12,500 lbs. seems to reverse the trend toward an increased avionics capability with increased size, cost, or aircraft capability. Statistically, this type of aircraft is equipped with significantly less avionics than the smaller twin (except for weather radar), and in some categories it has less avionics than the 4-place singles. One reason for this equipage characteristic may be that this category of aircraft tends to be older (98 percent were manufactured before 1960). It is also the smallest component (0.6 percent of the total) of the GA fleet.

TABLE IX

PERCENTAGE OF GA AIRCRAFT EQUIPPED WITH VARIOUS AVIONICS CAPABILITIES BY TYPE OF AIRCRAFT (1/1975) [REF. 1]

AVIONICS	SINGLE-ENGINE PISTON (1-3 seats)	SINGLE-ENGINE PISTON (4 or more seats)	TWIN-ENGINE PISTON (under 12,500 lbs.)	MULTI-ENGINE PISTON (12,500 lbs. and over)	TURBOPROP	TURBOJET	ROTORCRAFT
Total Aircraft	64,331	81,405	17,937	1,207	1,897	1,552	4,139
VHF Communications	54.8%	91.5%	96.2%	84.0%	97.9%	100.0%	62.6%
ILS	8.3	45.9	89.8	60.4	96.8	97.5	6.7
VOR	52.4	93.6	96.4	76.1	99.0	98.8	21.1
DME	1.6	18.4	78.8	38.6	97.1	98.8	6.2
ADF	6.1	58.8	94.3	62.3	98.0	100.0	18.5
Weather Radar	.3	.8	18.0	26.9	88.3	97.5	1.9
RNAV	3.6	10.4	20.7	8.4	35.0	56.5	3.7
Other NAV*	16.2	30.6	30.9	23.5	20.4	34.0	12.8

*Includes Transponders

There are numerous other data which depict the characteristics of the GA fleet with regard to avionics equipage. In Reference 2, GA aircraft avionics equipage is tabulated by type of owner and by primary use. While it is generally true that company owned aircraft are better equipped with avionics than individually owned aircraft, individually owned turboprops and turbojets tend to have reasonably complete avionic packages, i.e., essentially 100 percent equipage with VHF, ILS, VOR, DME, ADF, and weather radar. This suggests that for the GA turboprop and turbojet categories, aircraft are equipped with avionics without regard to cost considerations.

In the primary use categories, the executive aircraft is the best equipped avionics unit followed by air taxi, business, and instruction categories. The personal use aircraft tends to be less well equipped. Statistically, the aircraft primarily committed to personal use is equipped as follows: VHF (73 percent), ILS (23 percent), VOR (73 percent), DME (8 percent), ADF (29 percent), Weather Radar (0.7 percent), RNAV (7 percent), and other navigation including transponders (23 percent). For a more complete presentation of GA avionics related statistics, the reader is referred to Reference 2.

Of the more than 40 companies that manufacture one or more avionic units, Aircraft Radio and Control (ARC - Cessna), Bendix, Collins, Edo-Aire, Genave, King, and Narco produce a nearly complete line of GA avionics and dominate the GA market. King and Narco are the large volume manufacturers.

Avionics has been influenced by the electronics revolution and manufacturers are using LSI and microprocessors. Avionics is also being designed for easier installation and requires fewer antennas. Three recently introduced new families of avionics are the Narco Centerline system, the Bendix BX 2000 system, and the Collins microline. These three have been evaluated in recent publications [Ref.10,11].

The new Bendix BX 2000 system is an advanced avionics system featuring a navigation computer programmer (NP-2041A) that, with keyboard programming, can manage navigation and communication functions. The programmer provides for an RNAV capability with waypoint data storage

so that the work of navigating can largely be accomplished before a trip begins. The programmer provides for an interface with a TI calculator such that the selected route can be loaded into the BX 2000 system from a magnetic card almost instantaneously. Enroute, frequency changes are punched into the system NAV/COM boxes digitally and can be checked before "entered" into the system.

Other BX 2000 characteristics are a memory that provides many advantages (e.g., the programmed route can be readily reversed for the return trip), and the use of light bars rather than needles in the all-electronic course-deviation indicators. It is significant that the pilot interface with the Bendix BX 2000 system is profoundly different from the older, traditional interfaces in GA aircraft.

It is important to note that the BX 2000 is a somewhat revolutionary step in avionics. It is all electronic and largely digital. This implies that new maintenance concepts such as built-in-test and fault tolerance may be feasible. It also suggests that new opportunities for standardization benefits should be investigated.

The Collins Microline is also a relatively new GA avionics system. Its pilot interface is somewhat conventional. Its unique features include the COM radios' ability to store a second frequency in addition to the one on display, a continuous radio magnetic indicator (RMI) readout available from the NAV radios, and electronic readout of the NAV frequencies.

Narco's most recent line of avionic equipment is the Centerline, a totally redesigned replacement for the older Spectrum series. The Centerline units all meet TSO standards (with the exception of the navigation radios with built-in glide slope receivers for which a TSO has not been issued). A recent report on the Centerline can be found in Reference 10.

The Centerline indicators and other pilot interfaces do not differ significantly from older avionics systems and have the advantage of familiarity for experienced pilots. The NAV receiver still uses mechanical meter movements, for example, rather than all-electronic displays such as the Bendix BX 2000 system uses. While it is functionally traditional, the Centerline is a higher evolved avionics system. As compared to the older

Narco Spectrum series, the Centerline series has been significantly improve in performance, ease of use, ease of installation and calibration, and in panel illumination.

A unique feature of the Centerline series is the use of multiplexing to reduce the parts count and the costs of the new combination NAV, glide-slope, and marker beacon receiver. It also features backlighting of the indicators and readouts that enhances panel illumination. Another feature pilots will appreciate is a transmit light that glows whenever the mike is keyed.

Forecasts

An RTCA Forecasting Committee has looked at the history of growth in aviation, several available forecasts, and other factors to forecast the future growth in general aviation [Ref.9]. The potential for growth is enormous. In addition to those factors which will enhance aviation in general, the benefits of GA to a business, the fact that investments in aircraft have not eroded with inflation, and the trend toward decentralization (which favors GA growth at the expense of airline growth) are cited as factors. Today, for example, GA serves approximately 13,000 airports while less than 500 are served by the airlines. Moreover, GA carries one out of every three intercity air travelers, or over 110 million people a year. That total is expected to double in the next 10 years [Ref.18].

In the last 20 years, the GA fleet has had an annual compounded growth rate of 6 percent in units and 14 percent in dollar volume. The higher dollar volume rate reflects better equipped, larger aircraft in addition to inflation [Ref.9].

The RTCA Forecasting Committee's prediction for GA growth in the future is shown in Table X. These data reflect a compounded annual growth rate of 4.3 percent which the RTCA considers to be conservative.

There are other forecasts of GA growth. In a study completed in June 1974 by Decision Sciences Corporation, the GA fleet was estimated to include between 173,000 and 183,000 active aircraft in 1980, and between 214,000 and 238,000 active aircraft in 1985. The medium projections are

179,000 and 229,000 active GA aircraft in 1980 and 1985, respectively [Ref.12].

A more recent source estimates the 1988 population of active GA aircraft to be between a low of 258,000 and a high of 273,000 [Ref.6]. Using the medium estimate at 267,000, it is estimated that some 38,000 or 14 percent will be multiple engine piston aircraft and more than 12,000 or 4.5 percent will be turbine powered.

TABLE X

FORECAST OF FUTURE GA FLEET DISTRIBUTION [REF.9]

Jan. 1 of Year	TOTAL	Single Eng. Piston (% of Total)	Mult. Eng. Piston (% of Total)	Turbine (% of Total)	Rotocraft (% of Total)	Other (% of Total)
1975*	161,500	131,623	20,188	4,038	3,230	2,423
		(81.5)	(12.5)	(2.5)	(2.0)	(1.5)
1980	189,000	150,066	25,704	6,615	3,969	2,646
		(79.4)	(13.6)	(3.5)	(2.1)	(1.4)
1990	294,300	224,257	45,028	14,421	6,180	4,415
		(76.2)	(15.3)	(4.9)	(2.1)	(1.5)
2000	465,800	340,034	79,186	29,346	9,782	7,453
		(73.0)	(17.0)	(6.3)	(2.1)	(1.6)

* (Historical Data)

The avionics market is closely tied to the new aircraft market. Approximately 80 percent of the annual sales in avionics in GA are installed in new aircraft; 50 percent are factory installed and 30 percent are field installed [Ref. 12, 13, 14].

Table XI is a tabulation of the avionics installations estimated for GA aircraft by the RTCA Forecasting Committee [Ref.9]. In this tabulation, the categories differ from the categories included in Table IX, and the communications category is assumed to reflect multiple installations. These estimates are based upon the forecast of new airframes. Unforeseen technological developments could alter this forecast dramatically.

TABLE XI
ESTIMATED NUMBER OF AVIONICS INSTALLATIONS FOR
FOR GA AIRCRAFT [REF. 9]

	1975	1980	1990	2000
Total aircraft	161,500	189,000	294,300	465,800
Communications (Voice/Data)	180,800	239,300	429,600	767,800
ELT	124,700	187,100	289,900	449,400
ATC Transponder (Surveillance & Data)	84,900	127,400	254,700	409,400
DME	32,400	48,600	75,300	116,800
Radio Altimeter	7,700	9,800	16,700	28,400
Doppler (Nav. Radar)	200	200	0*	0*
HF	7,700	10,500	16,300	19,500
CAS/PWI (or alternatives)	0	500	800	1,200
UHF Telephone	2,300	2,900	4,500	7,000
Weather Radar	12,900	16,400	25,500	51,000
Satellite Comm.	0	0	100*	300*

* We assume these data to imply that a satellite-based system will replace Doppler Radar as a navigational aid, e.g., that the satellite comm. entry includes GPS.

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SECTION V

RELIABILITY AND MAINTAINABILITY

It is difficult to make any definitive statements about the reliability or maintainability of general aviation avionics. No source of reliability data has been found for either GA or ARINC avionics and it is doubtful that any data of this type is generally available. Moreover, there is no consensus of opinion about the reliability of GA avionics or even if it is generally reliable or generally unreliable. Opinions abound about avionics reliability, but few, if any, can be substantiated in a scientific sense. There is a consensus about the factors which contribute to avionics failures, and one can conclude that these factors do not receive adequate consideration in many instances.

The avionics industry is characterized by the low volume production of many different types of equipment. Thus, it is inherently very difficult to arrive at a definitive measurement of the reliability of a given avionics unit. Even field data on the reliability of avionics, if it existed, would be suspect because the environment in which the avionics operates is so diverse and uncontrolled. It is generally true that avionics systems fail because they are subjected to excessive and unnecessary abuses. As long as these circumstances are prevalent in the GA community, quantitative reliability assessments for GA avionics will be somewhat meaningless.

It is true that a reliability assessment of avionics systems under controlled test conditions would be of value as a parameter of merit, especially when comparing somewhat similar systems. The low volume characteristic of the industry (and the attendant high cost) makes the acquisition of such data with significant confidence very difficult. Moreover, it is often difficult to make a direct comparison between units because of a growing tendency for GA avionics "boxes" to be functionally different. This tendency is evidenced by Narco's new NAV122 which combines several functions.

In a recent study, an RTCA committee concluded that the mean-time between-failure (MTBF) of an avionics equipment was not an appropriate specification for avionics minimum performance standards or TSO's [Ref.17]. (The MTBF of an equipment is a required parameter if one is to make a definitive statement of reliability in a classical sense.) The reason cited for this conclusion in that the MTBF of an avionics system must be considered in the context of the function the system is to perform. For example, a reduction in component count and, thus, complexity and functional capability is one mechanism (and perhaps the only mechanism in some instances) for enhancing MTBF. If this were accomplished at the expense of functional or a self-check capability, it may actually be undesirable.

In summary, good reliability is a meaningful goal after performance and functional goals are achieved. It is not a goal to be gained at the expense of function and performance. Nor is it often a goal to be gained at any cost. When all other factors are reasonably equal, the more reliable equipment will be the most desirable and will have a competitive advantage. For the moment, the most reliable equipment cannot be identified from an MTBF parameter. Reliability is achieved by buying quality equipment that has the desired performance and function at an affordable price, and by doing those things which are known to enhance the reliability of an equipment.

High operating and storage temperatures are the acknowledged arch-villains of avionics reliability, and the GA airplane can be a very harsh thermal environment. The impact of temperature on the reliability of electronics is well known and every reliability study or prediction model accounts for the impact of temperature as a first priority. Temperature seems to accelerate every known failure mechanism, except those that are explicitly low temperature factors, and it often has a regenerative impact, i.e., an excessively warm component will often tend to dissipate more power and, thus, become even hotter. Thermal "runaway" is a frequent cause of component failure.

It is true that avionics has essentially become solid-state electronics. Narco's new Centerline, for example, has a single vacuum tube in the

entire line, and others have none. However, concurrent with this shift to the solid state, the avionics packages have become extremely dense so as to compound the temperature problem. Moreover, the GA environment is inherently bad from a temperature perspective. The temperature behind the panel of a small GA airplane on a summer day can reach 170°F. When the aircraft is airborne, the cooler air at high altitude is also much less dense and less capable of removing heat from the avionics systems.

There is a simple solution to the excessive temperature problem, and that is to provide an adequate flow of cooling air to remove heat from the avionics systems. Manufacturers are knowledgeable about this problem and, in some instances, will not warrant avionics units unless adequate cooling is assured. The better avionics shops are sensitive to the problem and incorporate cooling-air ducts as a part of an avionics installation package. The knowledgeable pilot will allow cooling air to circulate for a few minutes after the engine is started on a hot day before turning on the avionics systems.

Aircraft that are hangared have less problems with the avionics thermal environment than aircraft parked in the sun, and thermal shades or shields are readily available and are an asset for those aircraft that are parked in the sun.

Another aspect of the GA environment is that moisture-condensation and even leaks, are prevalent and are often a problem. Moisture is much less a problem for avionics that are used and, thus, maintained at "normal" operating temperatures for long periods of time. The "normal" operating temperature is usually defined as a temperature range by the manufacturer and is not the excessive temperatures referred to in the preceding paragraphs.

It is helpful to think of avionics as electronic systems and not in the familiar terms of mechanical systems. The electronic avionics systems do not wear out in the way that mechanical systems wear out, and the avionics systems should either become obsolete or simply outlast the airplane long before wear-out is reached. Most avionics experts agree that the optimum use condition for avionics units is to turn all systems on soon after the engine is started and to keep them on throughout every flight.

This practice will help keep the systems dry, and will minimize disturbances to the system. As an aside, it enhances pilot familarity with systems that are not used that often (e.g., weather radar) and malfunctions in avionics systems will become apparent on a more timely basis. This practice has a long adhered-to precedent in the electronics laboratory.

The airline's avionics environment is cited as more ideal because the avionics is used on a daily basis with long on periods [Ref.16]. This circumstance, along with the extensive use of self-check features, redundancy, and a better controlled thermal environment may account for the good reliability reputation of airline or ARINC avionics. In a classical sense, the MTBF of a given ARINC unit may be less than that of a non-TSO'ed GA unit in a controlled test environment.

There are other aspects to the GA avionics reliability environment. Many failures are traced to poor installation practices such as inadequate cooling, poor connections, carelessly routed wire bundles that are not secured or grommetted, and poor shielding of signal leads. These conditions are unfortunate, but are not chargeable to avionics reliability. It is incumbent upon the industry to do those things which are simply good engineering practices. The aircraft owner should insist upon it when ordering an avionics installation, and the manufacturer and the avionics shops should take an active role by virtue of having the engineering expertise that an individual owner may not have. In summary, avionic system failures that occur after good installations and good practices have been followed are the only failures chargeable to avionics systems unreliability, and those failures are much less prevalent than the avionics failures that are discussed so frequently. It is notable that some owners of any of the popular makes report good experiences with avionics reliability. It is doubtful that this "good luck" is accidental.

In contrast to reliability, there is a consensus that the new avionics systems are configured for maintainability. Installations and removals are easier than in the past, and is usually accomplished from the front panel. Once removed from the airplane, adequately equipped avionics shops are well prepared to isolate and repair failed equipment. Important support in the

form of good documentation and repair guides is available from the avionics manufacturer, and test equipment especially designed for avionics systems is available from still other manufacturers.

Maintainability is further enhanced by ease of accessibility to test points and components once the avionic unit is on the shop bench. Repair facilities report satisfaction with these aspects of the avionics systems.

Some of the new avionics systems, e.g., the Bendix BX2000 system, are profoundly different from the older, more familiar avionics, and there has been little assessment of their maintainability in the literature. These systems tend to be more digital, and also more electronic than mechanical as compared to older systems. It is reasonable to assume that they are also more maintainable. Electronic repairs are characteristically easier than many mechanical repairs, and digital easier than analog where the malfunction is more a matter of degree. The military and others have devoted much attention to enhancing the maintainability of electronic systems and have built in features such as fault tolerance and built-in-test. One has to believe that these new concepts will have a growing impact on evolving GA systems to the benefit of maintainability.

It is also too early for judgement on the impact of other new features showing up in avionics systems, i.e., the sharing of antennas, multiplexing, and the use of microprocessor and large-scale integration (LSI). However, it is a safe assumption that the impact will be comparable to the impact they have had as other electronics (including military avionics) i.e., a very positive impact.

Pilots and aircraft owners express considerable dissatisfaction with some aspects of avionics maintenance. A major source of dissatisfaction is the failure of some repair facilities to check out units that have been repaired after they have been returned to the aircraft. The net result is that those malfunctions which originate in the aircraft, e.g., wiring harnesses, alternator noise, etc., are not discovered or repaired. Another problem is that multiple failures often go undetected because an obvious fault is possibly connected with other related problems (causative faults or resulting faults) and are not searched out. The trade-offs for this practice is the added cost of additional checks in the aircraft and/or the bench.

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SECTION VI

COMMUNITY PERSPECTIVES

The ideas, opinions, and concepts pertaining to GA reported in this section largely derive from conversations and interviews with individuals who are active in the GA community. In some instances, opinions and concepts that have been reported in the literature are cited. Clearly, this is a somewhat subjective section of the report. The sample of repair stations and pilots interviewed, for example, is small and, on some issues, there are contradictory opinions. Nevertheless, these inputs from a microcosm of the GA community are indicative of the opinions and attitudes to be encountered in the larger community and merit some attention.

In our opinion, based upon the many contracts made with individuals in the GA community, most people who constitute the GA community are individualistic and have an emotional involvement with aviation. They are dedicated to excellence and committed to an aviation-related career. Pilots and owners who operate aircraft in support of a separate, non-related business or enterprise also have these characteristics except, of course, for the career commitment. Our many contacts were cooperative and responsive and shared opinions and experiences enthusiastically. GA is, however, a highly competitive industry and apparently attracts some opportunists who do not have the dedication and commitment evidenced by those we met.

Avionics Manufacturers

The GA avionics manufacturers fall into several categories. Some produce a very limited line, perhaps a single unit, of very specialized equipment. Others offer limited lines of high-usage avionics and still others a nearly complete line of GA avionics. The larger manufacturers are King, Narco, Bendix, and Collins. Genave and Edo-Aire also manufacture a reasonably complete line of avionics. King and Narco are the large volume GA manufacturers.

Aside from the usual free enterprise constraints, i.e., a competitive market demanding performance and reliability at lowest cost, the avionics manufacturer environment is characteristically one of low volume production of numerous different units. These units will be committed to a harsh environment and relied upon to perform a somewhat critical function. The environment is determined to a great extent by the installer and the user who can make the environment excessively abusive. The repair shop is also a factor in obtaining satisfactory performance from the avionics unit. Thus, to some extent, the manufacturer is at the mercy of the entire avionics community.

Some design objectives in an avionics unit are: to achieve the intended function with a minimum of pilot interface, to avoid excessive complexity because of the attendant reliability penalty, to keep installation simple, to enhance tolerance limits on component parameters and operating parameters, achieve reliability, and to keep cost to a minimum.

Some factors which influence the cost of avionics are the low volume, as compared to other electronic systems, which increases the cost of engineering reflected in each unit sold; federal requirements which impact on the manufacturing process and on quality control; and rapidly evolving technology which dictates rapid obsolescence on one hand and yields increased capabilities at a lower cost on the other.

The avionics manufacturer tends to feel that the reliability of a GA avionics unit is comparable to that used by the airlines (ARINC Avionics) and by the military. With GA avionics, expecially the lower cost lines, the user sacrifices performance and some operational flexibility; however, the reduced complexity can enhance reliability. A significant point made by avionics manufacturers, as well as others, is that the availability of low-cost avionic lines enables many pilots to afford equipment and functions that would otherwise be prohibitively expensive. Moreover, these lower cost lines of avionics are reliable; the sacrifices are in flexibility, automated functions, and receiver selectivity and sensitivity.

In an effort to enhance the reliability of their avionic units, manufacturers are practicing quality control measures such as component

screening, preassembly and final testing, and burn-in. Warranties are often made dependent upon acceptable cooling practices in an installation as a means of gaining some control over the installation, and they tend to favor the concept of franchised dealers.

Avionics Repair Stations

There are some 500-600 licensed avionics repair stations across the United States staffed and equipped to repair and calibrate avionic equipment. Most, if not all, are also into sales and installations, and sales is a major incentive for some to be in the avionics business. In the opinion of some, there are some 10-15 percent too many avionics shops. There are many stable, reputable avionics shops providing a valuable, needed service.

Several repair stations were visited during this study, ranging in size from 3 to 33 employees. The larger unit has an excellent reputation and is reportedly one of the largest avionics repair stations in the country. All had a large investment in test equipment which, in addition to being expensive, is very specialized and requires frequent recalibration. There is also the necessity of a large inventory of test harnesses due to a lack of standardization in GA avionics.

Sales and installations are a significant aspect of the avionics repair station business. In fact, it is the only reason some stations are in business [Ref.13,14]. Others report the repair business itself to be a profitable aspect of the business. Since sales and installations are an important part of the repair station's business, there is a concern for the growing tendency of the airframe manufacturer to install the avionics. It is reported that more than 50 percent of the avionics market is supplied by the airframe manufacturer. Moreover, the problem is compounded by the fact that the airframe manufacturer pays significantly less for avionics than repair stations pay. Cessna's acquisition of Aircraft Radio and Control (formerly ARC) is indicative of this trend, and there are reports that it

is difficult to buy a new Cessna airplane without factory installed avionics [Ref.15].

Repair stations report that repairmen are difficult to hire and to keep. Most come from a background that includes military training in electronics or aircraft avionics repair. There is much specialization among avionics repairmen as to types of equipment, but most work readily across manufacturer lines. Some shops prefer to hire only trained, experience repairmen rather than recent repair school graduates or military personnel who were principally involved with isolating problems to a line replaceable unit.

Obsolescence is a problem for repair station personnel, and continuing education by way of factory schools is one method of keeping somewhat current. Factory schools are especially helpful for handling a new line of avionics such as the Bendix BX-2000, and factory school attendance is sometimes a requirement if a shop is to be franchised for warranty repair. Factory schools are also a requirement for a shop to maintain a sales franchise.

Repair stations assert that new lines of avionics tend to obsolete older lines about every 5 years. The useful lifetime of avionics equipment averages some 10 to 15 years. Lifetimes are largely limited by the lack of factory support of new parts and components. Life times are increasing. A principal cause of failure in older avionics was mechanical channeling in the complex, mechanical switching systems. This mechanism has been essentially eliminated in new avionics by the use of frequency synthesizers.

Repair stations differ in their attitudes toward older avionics. Some simply decline to work on old vacuum tube units. Others decline to work on certain units, new or old, that they consider to be a poor design because, they feel, customers will usually be dissatisified with the results.

Repair stations also differ in their experiences with installations. Some feel that about 1/3 of all avionics problems originate in the installation, e.g., poor installations that have inadequate cooling, cabling that is allowed to fray and break, poor antenna locations, and corrosion. Others feel that installation related problems are negligibly small. A frequent

pilot/owner complaint with avionics repairs is that the equipment is not checked in the airplane, and units that check out on the bench often do not work on the ramp. This suggests that some repair stations fail to observe installation related failures.

The repair stations visited during this study charge from $19.00 to $23.00 per hour for avionics repair work, depending upon the equipment being repaired. Some feel it is profitable at this rate, and others do not. Apparently, some stations charge significantly more [Ref.13,14]. A repair time of 4 hours is considered by some to be a maximum without further consultation with the owner or questioning the advisability of continuing. Some shops try to limit the cost of repair by charging for a maximum of only 4 or 5 hours, for example, per unit complaint.

There was a consensus among the repair stations about the relative reliability of different avionic units. The most failure-prone equipments are DME's, transponders, and encoding altimeters. ADF's appear to be susceptible to alternator/generator brush noise. The most reliable equipments are marker beacon and glide slope receivers. Transceivers are somewhat "middle" reliability items. Newer units are very maintainable in that they are easily removed from the front of the panel and there is easy access to the circuitry. Repair Stations generally feel that avionics is reasonably reliable and that reliability is increasing. They readily recognize some specific units as being of poor quality.

Pilots/Owners

During interviews with the GA community, pilots were the most accessible segment of the community, and avionics reliability and maintainability were discussed with more than 20. Of these, four were professionals whose occupation was to pilot a GA airplane. Seven were engineers or scientists with considerable knowledge about avionics, and the remainder a cross section of the community flying either for business or personal reasons or both. More than half those interviewed were either owners or else were responsible for the maintenance of an airplane.

Most of the pilots interviewed had from 1000 to 5000 hours of flying experience, although the range was from 250 to 18000 hours. Most flew from 10 to 30 hours per month. One pilot, an aerial photographer, owned two airplanes, each of which was flown about 150 hours per month.

Almost every popular item of avionics was cited by someone as a source of avionics reliability/maintainability problems, e.g., NAV's, COM's, Autopilots, DME's and encoding altimeters. However, if there is a single consensus that evolves from these interviews it is that the DME is the most prevalent reliability/maintainability problem. Autopilots also appear to fail frequently. They were mentioned by only a few pilots, but most of the airplanes involved were not equipped with autopilots. In general, the pilots/owners had little comment on component failures, although frequency stability and switches were mentioned.

The results of these interviews suggest a significant economic-based stratification in the experiences of the pilots and owners interviewed. Those with the most complete avionics systems tend to have the more expensive lines and believe it to be the best quality. They also seem to have less problems with reliability and more satisfaction in the repair process. This stratification is not complete and there are exceptions on both extremes of the spectrum in our small sample.

Repair shops and facilities were readily accessible to all of the pilots, but there was considerable dissatisfaction with these facilities. Corporate and business-based pilots seem to encounter few problems. A prevalent attitude at that upper level of the economic strata is to buy a top quality line of equipment (top quality is equated with high price) and to exclusively utilize the services of a local shop. Corporate and business owners seem to feel that they do get preferential treatment from shops they patronize. Some are willing to fly significant distances to use a preferred shop or to obtain the services of a specific individual, but the use of local shops is clearly a more prevalent practice.

At the lower end of the spectrum, the avionics is less expensive, is used less often, gives considerably more problems, and there is much dissatisfaction with the repair environment. From this segment, one encounters

some rather derogatory views of available repair services. A sampling of the views encountered would include the following: Shops do a quick "pass through" on avionics that only corrects the most obvious problems; avionics systems undergoing repairs for one failure are often damaged in other ways; complete repairs are seldom obtained; repair shops prefer to sell new equipment rather than repair old equipment; few shops are able to diagnose problems; and repaired instruments are not checked out in airplanes. There is a prevalent feeling that owners of less expensive airplanes and avionics systems are usually serviced by the least qualified personnel in the shop. There is also an attitude prevalent among the owners of less expensive systems that the cost of avionics repairs is excessive and that avionics units sometimes pass through the shops without being repaired.

Some miscellaneous views expressed that should be documented are that avionics problems correlate strongly with brand names, and that the maintenance environment is best for the individual who is an established customer in a good shop. There is a consensus that there is little problem with the availablity of an aircraft because of avionics maintenance problems.

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SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The General Aviation avionics maintenance environment is diverse and can only be characterized in a general sense. The diversity largely originates from an economic stratification within the community that impacts the choice of avionics, i.e., the quantity and brand name, the installation, and maintenance practices. At the user level, there is a strong correlation between satisfaction or "good experiences" with avionics and with such economic factors as the type of airplane, the cost of an avionics package, and the cost of maintenance services as compared with other aircraft costs. This is not to say that other factors do not impact GA avionics maintenance. The FAA defines much of the maintenance environment and has a very profound impact. Other factors with significant impacts on avionics include the avionics manufacturer, repair stations, and the growing influence of new electronic technologies.

There is a large potential for and expectation of continued growth in General Aviation. Continued growth will impact the avionics maintenance problem in several ways. There will be a growing market for avionics and an increasing urgency for GA aircraft to be equipped with additional or improved avionic systems. New technologies, e.g., LSI, digital techniques, and microprocessors, which have evolved in and benefit from other areas of electronic technology, will also continue to favorably impact the avionics market. New technologies will tend to provide more capability at a lower cost and to resist inflationary trends in avionics. Microprocessors and computers, especially, are likely to become a significant factor in small GA aircraft avionics in the future [Ref.19]. The continued growth in GA avionics will compound existing avionics maintenance problems. Continued growth coupled with the emergence of new technologies will, in time, require new approaches to avionics maintenance.

New technologies already evident in GA avionics include the use of more digital electronics, the use of electronic displays rather than

mechanical, and multiplexers to reduce or simplify circuitry. Driven by both a growing market and new technologies, cost factors are favorable for avionics. One can predict that, in general, GA aircraft will tend to be equipped with a greater CNI capability at a cost which is a lower percentage of the total aircraft cost.

The FAA's impact on avionics maintenance presents an interesting contrast. In one sense, the FAA essentially governs all avionics maintenance in that it certificates avionics systems, repair stations and procedures, and repair personnel. However, its impact on avionics is significantly less than its impact on other facets of GA. It is evident from the Federal Air Regulations that avionics systems are not considered flight critical, whereas airframes and engines are. Airframes and engines are subject to much more scrutiny than avionics, and tend to be the dominant subjects of advisory circulars, advisory directives, and inspection aids that are published by the FAA. The FAA's surveillance of avionics maintenance per se is largely limited to the certification of instruments and shops, personnel, and a routine check during inspections.

These studies did not yield any definitive reliability data for either GA or ARINC-type avionics. It seems clear that it will be difficult to obtain such data with a significant degree of confidence. There is evidence that manufacturers have not always practiced good quality control, e.g., final performance inspections, but that it is practiced to a greater extent now. It is also evident that good engineering practices are not always practiced in the installation and operation of avionics systems. An installation that does not provide for an adequate flow of cooling air to avionics systems, for example, is likely to have many failures. Good operating procedures, such as starting engines and establishing an air flow before turning on the avionics and operating systems with regularity, can also enhance the reliability of an avionics system.

The statistical characterization of GA and GA avionics included in this report is current. These data are routinely updated and readily available in the literature.

The maintenance of avionics is not a difficult problem for the owners and operators at the top of the economic strata. For this segment of the community, the acquisition of a top quality system, expertly installed, is not an economic burden; and the cost of any needed maintenance is a routine expenditure. For those at the lower end of the strata, avionics acquisition and maintenance costs are more significant expenditures and often are a limitation on the availability of suitable maintenance. One can also conclude that the lower economic strata within the GA community lacks representation within the community. The GAMA and AEA, for example, tend to voice the concerns of manufacturers and organized businesses rather than the concerns of individual airplane owners and operators.

Standardization has had only a minor impact on avionics maintenance. The ATC system and the FAA, for example, define functional, and to a limited extent, interface requirements for avionics systems. There are few if any standards that pertain to installations, cabling, interconnection, and physical characteristics. The result is a profusion of avionics systems with uniquenesses that complicate installations and maintenance processes. There is a need for a beneficial standardization within GA that will not inhibit innovation and design.

The evolving technologies that are appearing in avionics also suggest that standardization should be studied to evaluate their potential for benefiting GA avionics maintenance. The growing use of digital circuits, LSI, multiplexing, and microprocessors enhances the potential benefits of standardization as a maintenance aid. The military, for example, has invested in standard modules and built-in-test as mechanisms for solving burdensome maintenance problems, and ARINC provides for a beneficial standardization of form/fit and interconnections for the aircarriers.

We recommend as a future effort that a study of the potential benefits of standardization to GA avionics maintenance be considered. The study should review standardization as practiced by ARINC and the military, and especially the military experience with standard modules and built-in-tests. It should encompass the potential benefits as well as any disadvantages of standard wiring, physical parameters, and interfaces. Further, the impacts

of any form of standardization on self checks features, reliability, maintainability, and cost should be included. These factors should be evaluated from the perspective of each segment of the GA avionics community.

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APPENDIX A

TABULATION OF AVIONICS SYSTEMS AND AVIONICS MANUFACTURERS

TABLE

DIRECTORY OF AVIONICS MANUFACTURERS

Aero/Comtex:
- Encoding Altimeters
- Area Navigation Equipment

Aero Mechanisms:
- Encoding Altimeters

Aerosonic:
- Encoding Altimeters

Aircraft I & D
- Encoding Altimeters

Airdata:
- Area Navigation Equipment

Airesearch:
- Area Navigation Equipment

Aircraft Radio and Control (Cessna)
- VHF Transceivers
- VHF Navcoms
- VHF Nav Receivers
- Glideslope Receivers
- Marker Beacon Receivers
- Transponders
- Omnibearing Selectors/Indicators
- Automatic Directiom Finders
- Distance Measuring Equipment
- Encoding Altimeters
- Horizontal Situation Indicators
- Auto Pilots
- Flight Directors
- Area Navigation Equipment

Astronautics:
- Auto Pilots
- Air-to-Ground Telephone

Bendix:
- VHF Transceivers
- VHF Nav Receivers
- Marker Beacon Receivers
- Transponders
- Automatic Director Finders
- Encoding Altimeters
- Distance Measuring Equipment
- Horizontal Situation Indicators
- Auto Pilots
- Area Navigation Equipment
- Airborne Weather Radar
- Radar Altimeters

Bonzer:
- Radar Altimeter

DIRECTORY OF AVIONICS MANUFACTURERS (continued)

Brittain:
- Auto Pilots

Comco:
- VHF Transceivers

Collins:
- VHF Transceivers
- VHF Nav Receivers
- Glideslope Receivers
- Marker Beacon Receivers
- Transponders
- Automatic Direction Finders
- Airborne Weather Radar
- Distance Measuring Equipment
- Audio Control Panels
- Horizontal Situation Indicators
- Auto Pilots
- Flight Directors
- Area Navigation Equipment
- Radar Altimeters

Edo Aire:
- VHF Transceivers
- VHF Navcoms
- VHF Nav Receivers
- Omnibearing Selectors/Indicators
- Transponders
- Automatic Direction Finders
- Distance Measuring Equipment
- Encoding Altimeters
- Audio Control Panels
- Area Navigation Equipment

Edo Aire Mitchell:
- Horizontal Situation Indicators
- Auto Pilots
- Flight Directors

Fran Aire:
- VHF Transceivers

Genave:
- VHF Transceivers
- VHF Navcoms
- Marker Beacon Receivers
- Transponders
- Automatic Direction Finders
- Audio Control Panels

Global Nav.:
- Area Navigation Equipment

Hamilton Std.:
- Encoding Altimeters
- Area Navigation Equipment

DIRECTORY OF AVIONICS MANUFACTURERS (continued)

Hoffman:
- Area Navigation Equipment
- Radar Altimeters

HT Inst.:
- Omnibearing Selectors/Indicators
- Encoding Altimeters

IDC:
- Encoding Altimeters

IFR:
- Encoding Altimeters

Jet:
- Auto Pilots
- Area Navigation Equipment

King:
- VHF Transceivers
- VHF Navcoms
- VHF Nav Receivers
- Glideslope Receivers
- Omnibearing Selectors/Indicators
- Marker Beacon Receivers
- Transponders
- Automatic Direction Finders
- Distance Measuring Equipment
- Encoding Altimeters
- Audio Control Panels
- Horizontal Situation Indicators
- Auto Pilots
- Flight Directors
- Airborne Weather Radar
- Air-to-Ground Telephones
- Radar Altimeters

Kollsman:
- Encoding Altimeters
- Radar Altimeters

Martech:
- VHF Transceivers

Mentor:
- VHF Transceivers
- VHF Nav Receivers
- Omnibearing Selectors/Indicators
- Marker Beacon Receivers

Narco:
- VHF Transceivers
- VHF Navcoms
- VHF Nav Receivers
- Glideslope Receivers
- Marker Beacon Receivers
- Omnibearing Selectors/Indicators
- Transponders
- Automatic Direction Finders
- Distance Measuring Equipment
- Audio Control Panels
- Horizontal Situation Indicators
- Area Navigation Equipment
- Encoding Altimeters

DIRECTORY OF AVIONICS MANUFACTURERS (continued)

Northrop:
- Area Navigation Equipment

Radair:
- VHF Transceivers

RCA:
- VHF Transceivers
- VHF Nav Receivers
- Omnibearing Selectors/Indicators
- Transponders
- Distance Measuring Equipment
- Airborne Weather Radar

Ryan Stormscope:
- Airborne Weather Radar

Smith Ind.:
- Encoding Altimeters
- Auto Pilots

Sperry:
- VHF Transceivers
- VHF Nav Receivers
- Glideslope Receivers
- Omnibearing Selectors/Indicators
- Area Navigation Equipment
- Transponders
- Horizontal Situation Indicators
- Auto Pilots
- Flight Directors
- Radar Altimeter

Teledyne Systems:
- Area Navigation Equipment

Terra:
- VHF Transceivers
- VHF Nav Receivers
- VHF Navcoms
- Omnibearing Selectors/Indicators

Tracor:
- Area Navigation Equipment

Trans-Cal-Ind.:
- Encoding Altimeters

United Inst.:
- Encoding Altimeters

Wulfsberg:
- Air-to-Ground Telephones
- VHF Transceivers

TABLE

DIRECTORY OF AVIONICS BY FUNCTION

UHF Transceivers:			
ARC*	Edo Aire	Martech	RCA
Bendixs	Fran Air	Mentor	Sperry
Collins	Genave	Narco	Terra
Comco	King	Nadair	Wulfsberg
VHF Navcoms:			
ARC*	Edo Aire	King	Terra
Bendix	Genave	Narco	
VHF Nav Receivers:			
ARC*	Edo Aire	Narco	Terra
Bendix	King	RCA	
Collins	Mentor	Sperry	
Glideslope Receivers:			
ARC*	King	Sperry	
Collins	Narco		
Omnibearing Selectors/Indicators:			
ARC*	HT Inst.	Narco	Terra
Bendix	King	RCA	
Edo Aire	Mentor	Sperry	
Marker Beacon Receivers:			
ARC*	Collins	King	Narco
Bendix	Genave	Mentor	
Transponders:			
ARC*	Collins	Genave	RCA
Bendix	Edo Aire	King	Sperry
Automatic Direction Finders:			
ARC*	Collins	Genave	Narco
Bendix	Edo Aire	King	
Distance Measuring Equipment:			
ARC*	Collins	King	RCA
Bendix	Edo Aire	Narco	

*ARC - Aircraft Radio and Control (Cessna)

DIRECTORY OF AVIONICS BY FUNCTION (continued)

Encoding Altimeters:

Aero/Comtex	ARC*	IDC	Narco
Aerosonic	Bendix	IFR	Smiths Ind.
Aero Mechanism	Edo Aire	King	Trans-Cal-Ind.
Aircraft I & D	Hamilton Std.	Kollsman	United Inst.

Audio Control Panels:

Collins	Genave	Narco
Edo Aire	King	

Horizontal Situation Indicators:

ARC*	Collins	King	Sperry
Bendix	Edo Aire Mitchell	Narco	

Auto Pilots:

ARC*	Brittain	Jet	Sperry
Astronautics	Collins	King	
Bendix	Edo Aire Mitchell	Smiths Ind.	

Flight Directors:

ARC*	Edo Aire Mitchell	Sperry
Collins	King	

Area Navigation Equipment:

Airdata	Collins	Hoffman	Sperry
Airesearch	Edo Aire	Jet	Teledyne Sys.
ARC*	Global Nav.	Narco	Tracor
Bendix	Hamilton Std.	Northrop	

Airborne Weather Radar:

Bendix	King	Ryan Stormscope
Collins	RCA	

Radar Altimeters:

Bendix	Collins	King	Sperry
Bonzer	Hoffman	Kollsman	

Air-to-Ground Telephones:

Astronautics	King	Wulfsberg

*ARC - Aircraft Radio and Control (Cessna)