MODERN APPLICATIONS OF ELECTRONICS TECHNOLOGY IN CIVIL AVIATION
- PRESENT STATUS AND FUTURE TRENDS -

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Abstract

The paper reviews the latest technological developments in the field of electronics applied to Commercial Aviation, dictated by the increasingly stringent requirements in navigation accuracy, all weather operations, air traffic environment, quality of radio communications, operational safety etc.
Development trends are reviewed for each functional area, in order to forecast the configuration of commercial jetliners in the nineteen eighties and the environment in which they will operate.

I. Introduction

When in that famous December of 1903 Orville Wright lifted his wood and canvas aircraft at Kitty Hawk, the only electrical component onboard was the magneto firing the 13 horsepower engine driving the two propellers. The magneto weight was about 6 pounds, and the weight of the aircraft, including the pilot was 650 pounds.

When a modern Jumbo Jet lifts from the ground, out of the 750.000 pounds of the aircraft, fuel and payload, 10.000 pounds are of electrical and electronical equipments.

By comparing the ratio of 6 to 650 of Orville's aircraft to the corresponding 10.000 to 775.000 of the Jumbo Jet, one should derive the conclusion that the progress of the technology has been tremendous. Orville's aircraft carried no instrumentation and no communication nor navigation equipments. A modern civil aviation aircraft carries at least five separate communication transmitter/receivers, six or more radio navigation receivers, three Inertial Navigation equipments, two or three Radar/pulse equipments, four or six computers for the automatic guidance of the aircraft plus a number of ancillary equipments required to obtain the desired standard of safety, regularity and confort in the operation of the aircraft. Fig. 1 shows the radio rack of a Jumbo Jet, with all the electronic equipments installed.

There are onboard generators capable of producing more than 500 KVA of power, sufficient to satisfy the requirements of a town of 5.000 people. The aircraft flies in an environment where modern electronics are playing a fundamental role: ground based radio beacons, radio paths for automatic landing, ground based radars for air traffic surveillance, computers to make air traffic controllers job easier and more precise are typical examples of ground application of electronics in today's Civil Aviation.

II

Let me try to review with you each functional area of Electronic's application in Civil Aviation, from the requirements and application aspects. For each application area we will also try to identify existing development trends, in order to create a picture of this particular field in the 1980/1990 decade.

Let me list first the eleven main functional areas of electronics in Civil Aviation that I have identified :

Airborne Functions

1. Flight guidance and navigation
2. Systems monitoring and control
3. Communications
4. Passengers entertainment

On the ground

5. Maintenance of the airborne equipments
6. Flight Simulators
7. Aids to navigation
8. Passengers and traffic handling, reservation, check-in, flight planning etc.
9. Traffic surveillance and control
10. Communications and data transmissions
11. Weather forecast

My conversation will concentrate on the description of the airborne functions, as the challenge imposed by "size", "weight" and "reliability" requirements peculiar of airborne application has stimulated the most advanced developments. I will however briefly cover also the most recent application in ground based functions of electronics in commercial aviation.

III

The first of the airborne functions is

"Flight Guidance and Navigation".

Safety, regularity, confort and economy are the requirements for a modern commercial aviation. Those requirements reflect in a number of objectives that the designers of a modern commercial aircraft are trying to meet using the latest developments of the applied sciences of aerodynamics, thermodynamics, flight dynamics and material technology.

The use of sweep wing for economical high speed operation, the requirement for ample Center of Gravity excursions for loading flexibility, extensive use of powered controls for improved manoeuverability are somehow detrimental to the natural dynamic stability of the aircraft. Some forms of artificial stabilization are therefore required. Those devices take the form of yaw dampers (to damp the natural tendency of a sweep wings aircraft to "Dutch roll", the roll and yaw spiral instability), of pitch trim compensator (to compensate for the rearward shifting of the aerodynamic pressure center when the aircraft is approaching its critical Mach flight number) and automatic pitch trim (to automatically compensate for movements in flight of the Center of Gravity of the aircraft, consequent to fuel utilization or passenger movements).

Automatic guidance of the aircraft requires :

1. First, maintaining a prescribed attitude of the aircraft (movements of the aircraft around its Center of Gravity)

2. Second,to have the Center of Gravity of the aircraft following the desired path in the aerospace.

The desired attitude of the aircraft around its Center of Gravity is maintained by sensing with vertical gyros the attitude and by correcting it until the desired attitude is obtained, by sending the error signal (present attitude - desired attitude) to the servomechanisms acting on the control surfaces.

Accelerometers or rate gyros are also used to sense the rate of movement of the aircraft around its axis and to damp the signals of the Vertical Gyro.

In other modes of operation, the automatic guidance system can maintain a preselected airspeed or Mach number or a preselected rate of climb or descent.

An engine thrust computer acts directly on the engine throttles to obtain the required thrust level. Engine limitations (maximum turbine temperature, limit R.P.M. etc.) are memorized in the digital computer and observed in setting the thrust levels.

Guidance of the aircraft along the desired flight path is achieved by detecting the position error of the aircraft from the desired flight path, and by applying a properly processed error signal to the control surfaces.

The flight path may be :

1. A constant magnetic heading at constant altitude

2. A radio path in the horizontal plane, generated by a "Very High Frequency" ground based beacons (VHF omni Range VOR operating in the band from 108.00 to 117.95 MC). The aircraft will fly to or from the station along a preselected radial, identified by measuring the time interval elapsing from the reception of an amplitude modulated omni directional signal and a frequency modulated directive signal.

3. A Radio path, both in the vertical and horizontal plane, for guidance of the aircraft to a landing in poor or zero visibility conditions.

The left/right recognition is obtained by modulating differently the VHF carrier generating the radio field on the left and on the right of the runway axis. In the vertical plane modulation of the VHF carrier is again utilized to detect whether the aircraft is above or below the desired glide or descent path.

Altitude is detected with a very high degree of accuracy (± 1 ft) by a radio altimeter, operating in the 4.300 MC band on the radar principle. The outputs of the radio altimeter are utilized, in addition to display the altitude to the pilot, to feed altitude information to the Flight Guidance Systems, for a fully automatic landing,

Fig. 2 shows a typical automatic guidance control panel, with its various mode selection switches.

4. A inertial or Doppler navigation track, passing through preestablished way points with "great circle segments". In today's Inertial Navigation Systems, a 6 ./. 8 K memory computer processes the signals generated by three accelerometers installed on a gyro stabilized platform to obtain velocities (first integration) and distances flown (second integration) along the three axis of the aircraft. Doppler Navigation operates in a similar way being however velocities detected by measuring the Doppler effect of microwave signals emitted by the aircraft antenna and reflected by the ground or sea surface.

A display panel (see Fig. 3) will dispay on request of the pilot :

1. Present position
2. Heading/drift angle
3. Track angle/ground speed
4. Way points
5. Cross track deviation/track angle error
6. Distance/time
7. Wind (Direction and magnitude)
8. Desired track angle/system status

A keybord allows the pilot to preselect the desired flight path, by inserting in the computer's memory the coordinates of up to nine way points.

Fig. 4 shows a typical ARINC 561 INS, which has a weight of 87 pounds and a nominal accuracy of 2 miles/hour on a 95% probability. As it is well known, accuracy in INS navigation is essentially associated with the drift of the gyros used to stabilize the platform. Present accuracies have been achieved with the development of noise free gyros and with the use of computer programs that, on the basis of the navigation error resulting from previous flights, automatically introduce a compensation (bias) in the data computations. Actual accuracy is therefore better than 2 miles/hour and quite often, after an eight ./. nine hours flight (for example Rome/New York), the radial error is less than five miles.

It may be worth to take Inertial Navigation as a typical example of electronical technology development in aviation.

The first airborne Inertial Navigation System dates back from 1950.

This system contained a four gimbal gear driven platform with two floated two degree of freedom gyros and two floated linear accelerometers. The electronics modules consisted of discrete transistors, diodes, resistors and capacitors mounted on printed circuit boards and the computer was analog with some electromechanical components. The display devices were servo driven elements each of which was dedicated for display of a specific parameter. The system capability to do anything more than provide position and attitude was limited by the size, weight and power of the electronics and electromechanical devices required to perform additional computation, interface funtions, and display.

Fig. 5 shows the block diagram of today's INS. The diagram illustrates the types of inputs and outputs required by the Airlines and includes a functional block diagram of the INU. The main elements of the INU are the platform, comprised of the gimbal set and gyros and accelerometers,the platform electronics,a digital computer and memory; and interface electronics, which consist of analog-to-digital conversion, digital-to-analog conversion, buffered synchro repeaters, digital transmitters and digital receivers.

Systems produced today still use the four gimbal platform (as in the early systems) but the sizes of inertial instruments, direct drive torquer motors and pickoffs have become smaller and thus the gimbal set is smaller. Fig. 6 illustrates inertial platform developments from the late 1950's to today.

Fig. 7 shows the development of platform gyros. The earliest gyros had ball bearing supported spin motors. Ball bearing noise has an adverse effect on random drift.
Second generation gyros had gas bearing spin motors, third generation gyros have again ball bearing motors, however use the tuned rotor principle which is essentially insensitive to bearing noise.

Early accelerometers, see Fig. 8, used 122 discrete parts. Today technology accelerometers require a total of 21 parts.

Amazing progress has been made in the development of electronic components by semiconductor manufacturers since the advent of the transistors and semiconductor integrated circuits. Today a large variety of logical functional building block elements, each packaged on a single medium scale integrated circuit chip, are available from multiple suppliers. These elements require generally only a 5 VDC voltage source, consume low power, operate over wide environmental conditions and exhibit low failure rates. Utilization of these components has made it possible to expand the computation, interface and display capability of inertial systems significantly at no cost penalty while at the same time improving reliability.

The two parameters displayed on early INS are now replaced by the thirty-three which can be selected for display on today's generation INS.
This indicates not only the progress made in electronics but also the increased functional use to which the inertial system is being employed.

The reliability of the early inertial systems left much to be desired. These systems were employed by the military and achieved MTBF figures were generally not available. In early 1968 the Federal Aviation Agency specified that for a dual inertial navigation system installation to be certified as a sole means of global navigation, its individual system in-flight Mean Time Between Failures had to be 544 hours.

Today, systems are achieving substantially greater than 5.000 hour MTBF in flight. In less than 10 years the reliability of inertial navigation systems has increased more than five fold. The improvement in inertial system accuracy over the past 10 years is illustrated in Fig. 9.

To close the review of this first functional area, that we have called "Flight Guidance and Navigation" let's have a look in existing development trends. Three main paths of development can be detected in this field :

1. In the technology of the equipments, the booming utilization of semiconductors, in more and more sophisticated way, leading to lighter and more capable circuits. Digital equipments are progressively replacing analog computers, to improve output signals accuracy and repeatability.

2. The requirement to make the aircraft capable of operating in any weather condition, including landing in zero visibility. This requirement reflects into the flight guidance hardware in terms of a very high level of redundancy (duplication or triplication of the signal processing path), reliability (great attention is paid, in the design stage, to the failure analysis of each individual component), self failure detection capability (the performance of each individual signal processing circuit is continuously monitored by a self generated signal which is processed and then compared with a nominal value).

3. The requirement to continuously improve navigation accuracy, both in long range navigation and in terminal area navigation, to reduce aircraft separation requirements and therefore increase the capacity of the airspace.

Long range navigation accuracy has already achieved outstanding levels with the use of Inertial Navigation Equipments. Further improvements can be expected with frequent updating of the INS present position output, with the use of radio fixes utilizing a navigation satellite or ground radio stations (VOR/DME updating, Omega etc.).

Terminal area navigation accuracy has also already achieved more than satisfactory levels, with the utilization of VOR/DME ground stations (DME, stands for Distance Measuring Equipments, is conceptually based on the principle of measuring the distance from the aircraft to the ground station by measuring the time interval required to a microwave pulse to travel from the aircraft to the ground station and back).

Improvements are already available with the use of the Area Navigation concept allowing the aircraft to fly any predetermined path in a certain area, and not just to and from a station, by continuously computing the present position using the VOR/DME radio fixes and steering the aircraft with the error signal deriving from the comparison of the present position and the desired path.

Automatic tuning of the aircraft navigation receivers, while the flight progresses and memorization by an airborne computer of the terminal area procedures of each individual airport are additional improvements that will substantially relieve pilot's work load by further automation of the navigation. Of course, this will require a preflight loading of the Navigation System with the necessary information on the desired path, however this can be efficiently done with the use of card and/or tape readers.

We can then visualize in the future of navigation in commercial aviation a ground phase where data on the planned flight are loaded in the airborne computers, and a flight phase where the navigations systems will automatically update the position of the aircraft, with the pilot exerting only a monitoring role.

IV

Let's now go to the second functional area of our list of Airborne functions: "Systems monitoring and control".

In this area, as the title specifies, electronics are exerting the role of monitoring the operation of the aircraft systems and exerting the necessary controlling actions.

This normally means that a number of parameters for each system (electrical, hydraulic, air conditioning, pressurization pneumatic, engine control, etc.) shall be monitored, and, if their present value or if their change trend falls outside preestablished limits, a corrective action shall be taken, either automatically or, through a pilot alerting system, by the crew. Electronic Transducers are utilized to collect the necessary data and analog or digital computers to process the data in order to obtain the necessary control outputs.

A recent development in this functional area, is the use of "proximity switches" instead of mechanical switches, to detect the position of a movable part of the aircraft (i.e. : the landing gear).

A target fixed on the movable part when positioned sufficiently close to a sensor (a coil creating a small magnetic field) will change the impendance of the circuit associated with the sensor, sufficiently to trigger a logic and switch ON or OFF an indicating light. Proximity switches have all the advantages of solid state technology, when compared with the old mechanical switches.

At this point, it may be worth having a closer look at how the figure of 10.000 pounds of electrical and electronical equipments installed onboard a Jumbo Jet, and that I mentioned at the beginning of my presentation, is composed:

- 300 pounds of instruments,
- 1.900 pounds of electrical equipments,
- 2.100 pounds of electronic equipments (the famous black boxes) and
- 5.700 pounds of wiring.

Wiring, instruments and electrical equipments can be considered to fundamentally constitute the equipments of the functional area we are presently reviewing. We can then conclude that 80 per cent of the weight of the electrical and electronical equipments of a modern aircraft are dedicated to monitor and control the aircraft systems and the power plants.

Fig. 10 lists the systems of a Jumbo Jet, having their operation monitored and controlled by electronic computers.

There are no doubts that future aircraft will have more and more functions monitored and operated by electronics. The "fly by wire" concept, for example, were pilot inputs are transmitted to the flight controls by electrical wires only (instead of push-pull rods or control cables), has already been implemented in some military application and, due to its advantages in terms of weight accuracy and easiness of interface with other systems, will no doubt be installed in future Jetliners.

Another development that can be forecasted, is the centralization in a single or dual digital computer of the many functions presently performed by a number (in the Jumbo Jet I have counted 58 of them) of analog and digital computers, exerting systems monitoring and control. The centralization will add flexibility and reliability, simplify maintenance requirements and reduce substantially the weight of the flight hardware.

Before I close the review of this area there is one particular application that I feel is worth describing : this is the use of "in-flight" recorders to improve flight safety. Data are continuously collected in flight, by mean of transducers, from the aircraft systems and instrumentation. Data are then converted from analog to digital, multiplexed and recorded on magnetic tape. Every day the cartridge with the recorded tape is removed from the aircraft and the data are transmitted to a processing center, where the data are processed by a ground processor to detect :

1. Any deviation or tendency to deviate of the engines and aircraft systems from the expected performance.

2. Any deviation from the operational standards of the aircraft.

In some applications, processing is performed in flight, and processed data can be displayed to the crew or printed to be available for maintenance corrective action as soon as the aircraft lands.

Let's now cover briefly the third functional area of our list: "Communication".

V

A safe Air Traffic Control requires continuous contact between the aircraft and the Control Center. Only "voice" communication are used today, even on Long Range communications, as a result of the substantial transmission quality improvements made available in the High Frequency Band (2/30 MC) by the SSB (lateral band suppression) technique. Normal enroute and terminal area communications are performed on the VHF band (118.00/135.97 MC) with channels spaced 25 KC.

A typical civil aviation VHF transmitter can deliver 25 watts to the antenna, with a weight of only 12 pounds.

Saturation of frequencies, especially in the VHF band, in spite of the recent decision to reduce channel spacing from 50 to 25 KC is one of the major obstacle to the expansion of civil aviation traffic. This is a direct consequence of the "slowness" of human voice transmission. Faster communication means are therefore essential if air traffic should maintain its present rate of expansion. High speed data transmission, ground to aircraft and aircraft to ground, is the answer.

Messages, converted in digital signals will be transmitted over the VHF or HF bands and decoded after having been received by the ground or airborne receiver. Decoded data will then be displayed on a CRT or printed by a high speed printer. Some experiments have already been done to convert the coded signal directly in "Voice" with the use of a voice synthetizer.

The future will no doubt see high speed data transmission (Data Link) widely used for enroute communication covering position reports, weather information, Air Traffic Control clearances.

Terminal area communications will probably remain in VOICE, for a good number of years.

Another development with a very high probability of implementation, is the use of stationary Satellites to allow the use of the VHF or L bands even for long range communication.

Some experiments have already been performed by a number of US Airline in the VHF band and using the SYNCOM 3 satellite.

Intense programs are now in progress, both in the VHF and L band. All the Jumbo Jets (B747) have been delivered with provision for a Satellite Communication Antenna in the VHF band.

Figs. 11, 12 and 13 show the location of the navigation and communication antennas on a Jumbo Jet (B747).

VI

Let me now spend just a few words for the fourth and last airborne functional area of electronic in Civil Aviation; passenger entertainment. Use of passenger entertainment in flight is quite a recent development and most of you, flying into Tel Aviv for this conference, have watched a movie and listened to stereo music in flight.

However few of you are aware that the movie sound track and the 10 channel of stereomusic are distributes to each individual seat by only two wires as the signals are multiplexed and are decoded, at each individual seat, by a decoder having a weight of less than one pound.

So the Beethoven symphony you are listening is a reconstructed signal consisting of the summation of milliseconds of Beethoven music and hundreds of second of empty and silent intervals.

Fig. 14 shows a multiplex decoder, having the size of 5 x 3 x 2 inches. One of this decoders is installed every two seats, so there is a total of about 180 decoders in a B747.

VII

This concludes the first part of my presentation : the description of airborne application of electronics in Civil Aviation. As I mentioned at the beginning of this conversation, the challenges of reliability, limited weight, size and power consumption, peculiar of airborne applications, have stimulated in this field the most advanced technological developments. However, also in the ground, to keep pace with the continuously growing civil air traffic, electronics have been utilized on large scale to support the functions of maintenance, sale, administration, flight planning, traffic handling, traffic control etc. associated with the activities of civil aviation.

Let's have a quick look at those applications.

The first one takes place in the maintenance shops of the airlines. I'm here referring to the test equipments required to check the airborne equipments. In this field the recent years have seen the development of Automatic Test Equipments, capable of performing in a reasonable amount of time the thousands of tests required to certify the airworthiness of today's advanced technology airborne equipments.

Fig. 15 and 16 show tipical Automatic Test Equipments, where a central computer (in this particular case a 16 K general purpose computer), controls a number of signal generators which will generate in the appropriate sequence the test stimuli, memorized in magnetic tapes or magnetic disks. The reactions of the unit under test,(see Fig. 7 and 8) are measured by appropriate devices, and compared with nominal values. Test results are printed by a high speed printer, so that for each test a permanent record is available. The programming language utilized to program the test specifications, called ATLAS, has been jointly developed by ARINC, the American Air Transport Association and the International Airlines Association. A compiler, resident in the computer, translates the instruction received in ATLAS language in machine language, thus permitting the utilization of a rather simple programming language, with all the associated advantages.

Compared to traditional test equipments automatic testing has a 10 to 1 (in some cases up to 50 to 1) advantage in testing time, together with a superior accuracy and repeatability. There are no doubts that computer controlled automatic testing will be the way and the only way of the future to test the highly sophisticated electronic equipments of tomorrow aircraft.

Another area where the recent past have seen tremendous developments is in the field of flight simulators.

The degree of simulation reached in a modern, six degrees of motion, flight simulator is such that many Authorities have agreed to approve the training and the checks performed in the simulators as an alternative to in flight training and in flight periodic checks. The addition of computer generated image to create an accurate night or day time view of any airport, with its individual geographical layout, made available by the latest technologies in digital simulation, has greatly improved the "sight" and "feel" realism of flight simulators.

There are no doubts that the high degree enjoyed today by civil Jetliners has been achieved through the use of flight simulators. This conviction is based on the improved training made possible by : the high fidelity of today's advanced simulators and visual systems; the ideal training atmosphere of the simulator, unhampered by traffic problems; the ability to "freeze" the problem to permit discussion; to elimination of unproductive flying by using position resets and experiencing "real world" emergencies that, in the majority of cases, must be simulated in the aircraft itself.

A tipical six degree of freedom simulator is controlled by a 200 K computer, can create up to .8g vertical and .6g longitudinal and lateral environments, and up to 15°/sec pitch, roll and yaw rates.

In the area of passengers and traffic handling, computers are today used even by the small regional or supplemental airlines for passenger booking, check-in procedures, preparation of load sheets and flight planning.

In traffic surveillance and control, Radars, active and passive decoders, data processing computers and CRT displays have highly automated the air traffic control functions thus letting the controllers concentrate on abnormal situations only, still requiring human intervention.

Accurate weather forecasts are obtained with the use of satellites and computer generated weather maps.

Optimized flight plans are computer generated on the basis of the latest meteorological situation.

VIII

In conclusion, it would be extremely difficult to identify an area in the fascinating world of civil air transportation were electronics are not playing a fundamental role to make air transportation safer, more reliable, more confortable and more economical.

Much ground has been covered since that famous December 1903 day : a story of successful developments, which has seen electronics as a key factor in establishing a safe, reliable and economical commercial air transportation system. It will be even more so, in the future.

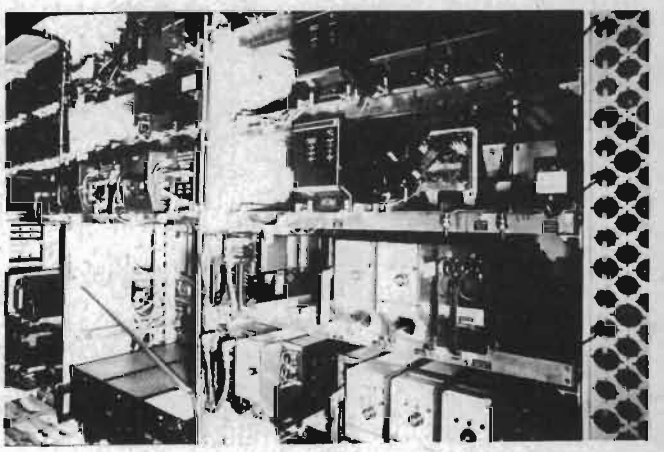

FIGURE 1. RADIO RACK B-747

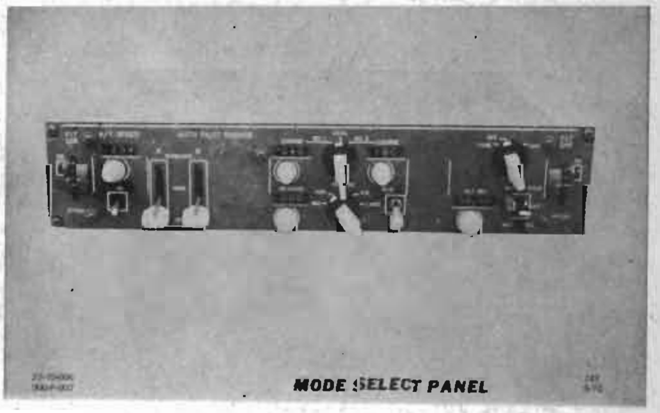

FIGURE 2. B-747 AUTOPILOT CONTROL PANEL

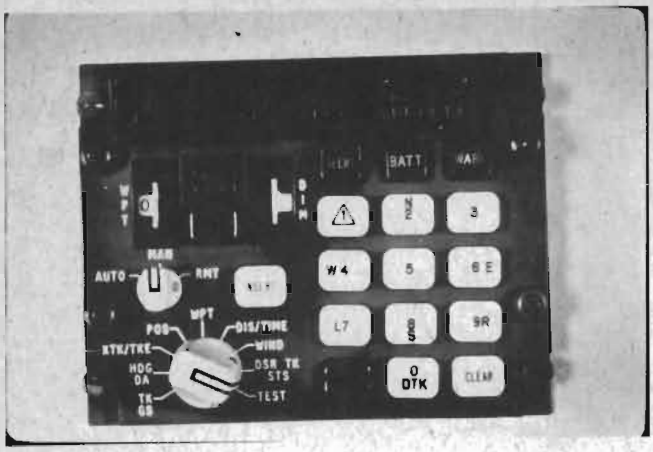

FIGURE 3. INS/CDU DISPLAY PANEL

FIGURE 4. TYPICAL ARINC 561 INS GEAR

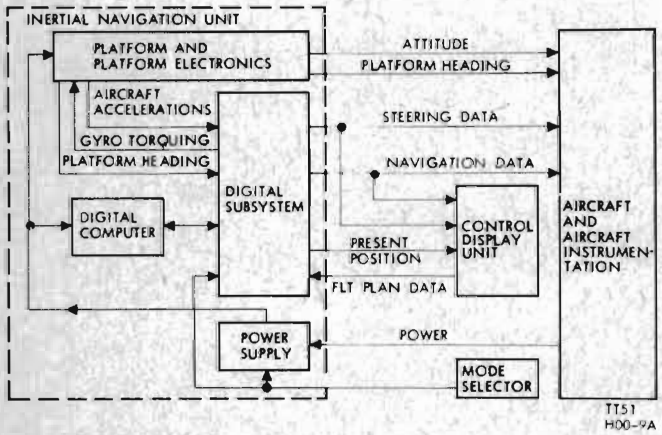

FIGURE 5. INS BLOCK DIAGRAM

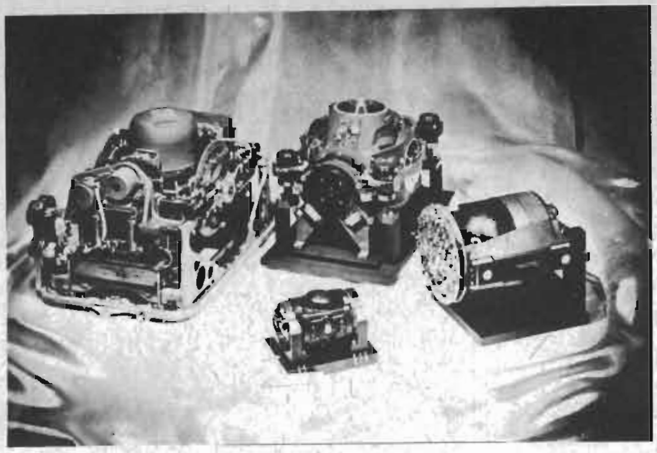

FIGURE 6. INS PLATFORM DEVELOPMENT

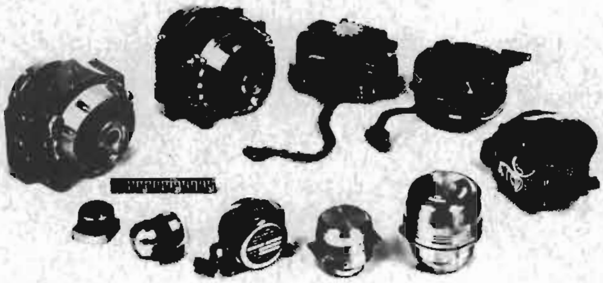

FIGURE 7. INS PLATFORM GYROS DEVELOPMENT

FIGURE 8. INS ACCELEROMETERS DEVELOPMENT

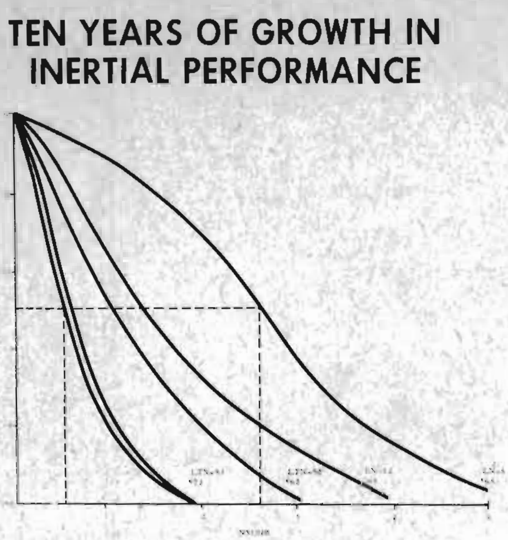

FIGURE 9. INS PERFORMANCE GROWTH

B.747 MAIN COMPUTERS LIST

AIR CONDITIONING SYSTEM

CABINE PRESSURE CONTROLLER
ZONE PRESSURE CONTROLLER
PACK TEMPERATURE CONTROLLER

AUTOFLIGHT SYSTEM

PITCH COMPUTER
ROLL COMPUTER
YAW DAMPER COMPUTER
AUTO STAB. TRIM COMPUTER
MONITOR AND LOGIC UNIT
AUTOTHROTTLE COMPUTER

ELECTRICAL POWER SYSTEM

GENERATOR CONTROL UNIT
BUS PANEL CONTROL PANEL

WINDOWS AND WINDSHIELD SYSTEM

WINDOW HEAT CONTROL COMPUTER

WEIGHT AND BALANCE SYSTEM

WEIGHT AND BALANCE COMPUTER

FLIGHT RECORDER

FLIGHT DATA RECORDER
FLIGHT DATA ACQUISITION UNIT

AURAL WARNING SYSTEM

AURAL WARNING CONTROL
AURAL WARNING DEVICE

ANTISKID SYSTEM

ANTISKID CONTROL COMPUTER

LANDING GEAR SYSTEM

PRIMARY LANDING LOGIC MODULE
ALTERNATE LANDING LOGIC MODULE
LANDING ALTERNATE EXTENSION CONTR. MODULE

NAVIGATION

CENTRAL AIR DATA COMPUTER
ALTITUDE ALERTING COMPUTER
INS NAVIGATION UNIT
CENTRAL INSTR. WARNING COMPUTER

FIGURE 10. B-747 MAIN COMPUTERS LIST

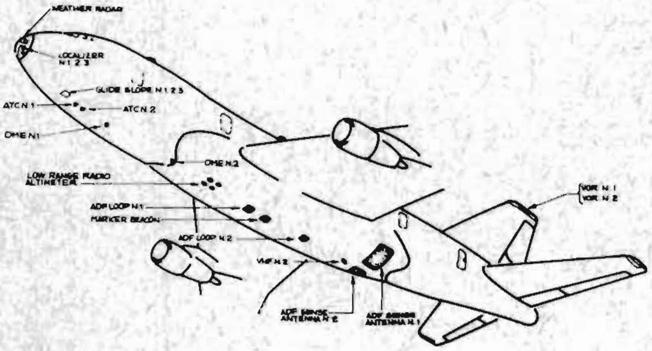

FIGURE 11. B-747 ANTENNAS LOCATION
(BOTTOM VIEW)

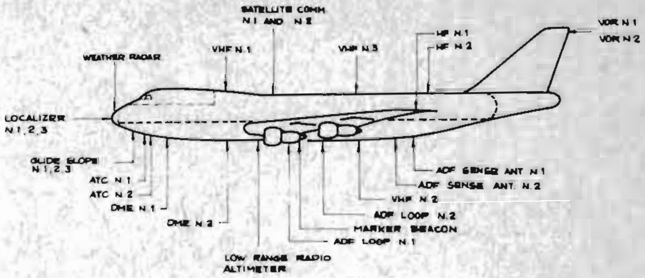

FIGURE 12. B-747 ANTENNAS LOCATION
(SIDE VIEW)

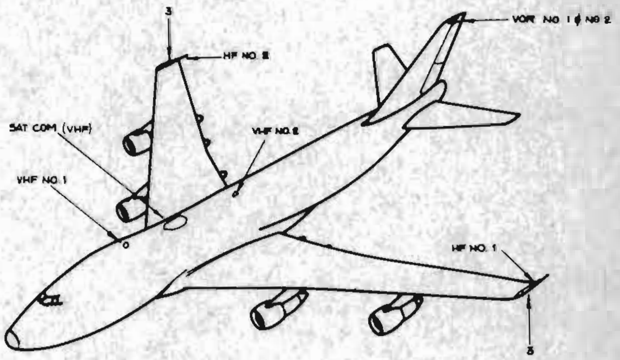

FIGURE 13. B-747 ANTENNAS LOCATION
(TOP VIEW)

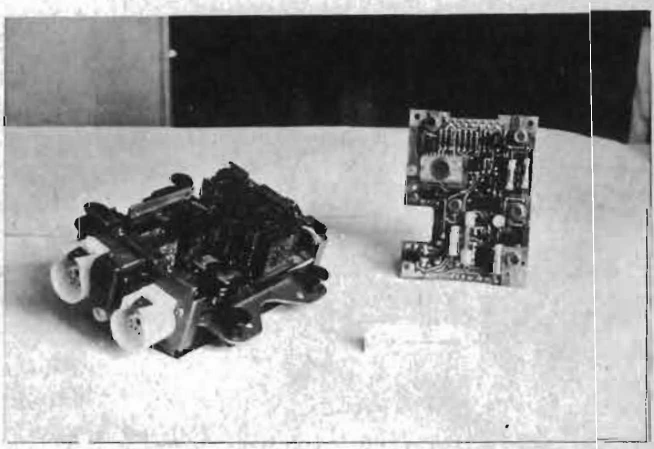

FIGURE 14. PAX ENTERTAINEMENT
MULTIPLEXER DECODER

FIGURE 15. TYPICAL AUTOMATIC TEST EQUIPMENT

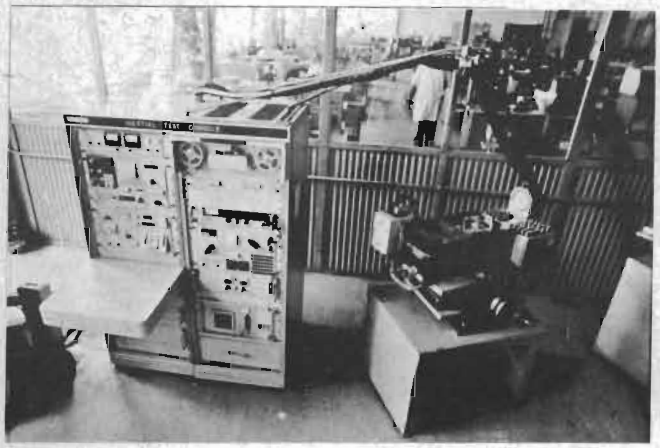

FIGURE 16. INS AUTOMATIC TEST EQUIPMENT

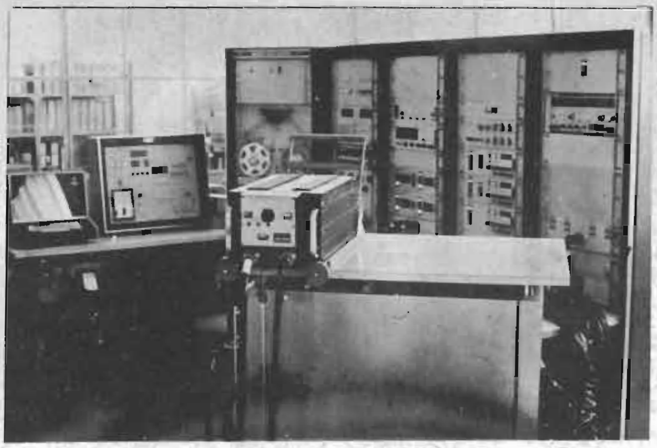

FIGURE 17. TYPICAL AUTOMATIC TEST EQUIPMENT

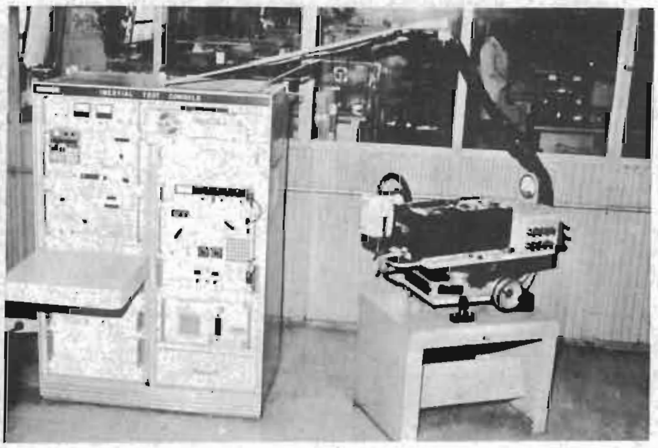

FIGURE 18. INS AUTOMATIC TEST EQUIPMENT