The Elmer A. Sperry Award
1990

for advancing the art of transportation

The Elmer A. Sperry Medal

The Elmer A. Sperry Award

The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.

In the words of Edmondo Quattrocchi, the sculptor of the Elmer A. Sperry Medal:

"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control for man's purposes."

Presentation of

The Elmer A. Sperry Award for 1990

to

Claud M. Davis
Richard B. Hanrahan
John F. Keeley
and
James H. Mollenauer

for the conception, design, development and delivery of the FAA enroute air traffic control system.

by

The Board of Award under the sponsorship of the:

American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers
Society of Automotive Engineers
Society of Naval Architects and Marine Engineers
American Institute of Aeronautics and Astronautics
American Society of Civil Engineers

At the 1990 IEEE Medals Presentation
Saturday, October 6, 1990, Toronto, Ontario, Canada

CLAUD M. DAVIS

Claud M. Davis was born August 23, 1924, in Water Valley, Mississippi. During World War II he served in the SWPA in the Army Airways Communications System (AACS). He earned his BS degree in Electrical Engineering in 1950 from Oklahoma State University, graduating number one in his class. He also was selected for membership in the following honor societies: Eta Kappa Nu (Electrical Engineering); Sigma Tau (All Engineering) absorbed into Tau Bet Pi, 1974; Pi Mu Eplison (Mathematics); and Phi Kappa Phi (Scholarship). Claud earned the ScM degree in Applied Mathematics from Harvard in 1961.

In 1950 he joined the IBM Corporation. Claud was a member of the design team for the first IBM large scale commercial computer, the 701. He remained in computer systems development throughout most of his career and held positions of responsibility in both technical and management areas. He has made significant contributions in computer systems development, individually and as a team member. These contributions included several firsts — the first fail safe, fail soft dynamically alterable system, the first instruction retry, the first fully checked computer, the first computer system fully compatible with its predecessor and the first system 360 data-flow on a digital chip.

Claud's systems design concepts were used in the IBM response to the FAA RFQ for the Enroute Systems Central Computing Complex and, as the program engineering manager, he was responsible for the technical aspects of this system; the design, build and release into manufacturing of the IBM 9020. Claud is a Life Fellow in the Institute of Electrical and Electronics Engineers and participates in its worldwide activities. He is a 32nd degree Mason and active in the Shrine.

In 1956 he married Virginia Nenni of Poughkeepsie and they have two grown children, Stephanie and Claud Philip. Mr. Davis retired from IBM in 1989 and is presently doing some consulting, remains active in professional societies, is a member of the Board of Managers of The Baptist Home of Brooklyn at Rhinebeck, NY, and enjoys spending time with his family.

RICHARD B. HANRAHAN

Richard B. Hanrahan was born August 25, 1932, in Springfield, Massachusetts. He graduated magna cum laude from the University of Massachusetts in 1954 receiving his B.S.degree in mathematics. He was named to the honor society of Phi Kappa Phi that same year. Following graduation, Dick served for two years as an officer with the U.S. Army armor training command stationed at Fort Knox, Kentucky. In June of 1957, upon return from active duty, he entered the graduate studies program at Georgetown University, Washington, D.C., where he completed course work in mathematics.

Also, in June of 1957, Dick joined the staff of the National Security Agency (NSA) in Washington as an analyst in the classified work of the agency.

In January 1960, Dick joined IBM as a programmer on the Federal Systems Division's (FSD) Project Mercury staff. His early work included developing software for real-time analysis and processing of tracking data to support the first manned space flights. At FSD in the 1960's, he held several management positions, including responsibility for developing all IBM software used at the Goddard Spaceflight Center, Greenbelt, Maryland and the Manned Spacecraft Center, Houston, Texas to support Projects Mercury, Gemini and Apollo. Dick received the NASA Public Service Award in 1969 for his contributions to the Apollo program.

In June 1969, Dick was named Director of IBM's air traffic control project responsible for the IBM software supporting the FAA enroute automation effort. During that period, he directed IBM's support of FAA's qualification of the prototype flight strip processing in Jacksonville, Florida, and the development and installation of both full flight strip processing in the twenty traffic control centers throughout the U.S. and full radar tracking support.

Since March 1971, when he concentrated on commercial software development as Manager of IBM's Advanced Systems programming, Dick has held several assignments managing the development of IBM software systems, ranging from MVS to PC DOS and OS/2. Dick currently is Programming Director, Development, IBM U.S.

JOHN F. KEELEY

John F. Keeley was born April 12, 1927 in Boston Massachusetts. He served in the Marine Corps during WWII. He completed Aviation training and attended various Electronics Schools on Radar and Communications Equipment. He remained on active duty with the Marine Corps until 1947 when he entered college. In 1951 he received a BS degree in Physics from Boston College.

In 1951 Jack joined the staff of the U.S. Navy's Underwater Sound Laboratory in New London, CT as an Electronic Scientist. His work at the laboratory covered applications of Computers to enhance both Anti-Submarine and Submarine Sonar Detection Systems. This work involved Circuit Design and Programming efforts. He was appointed as a Manager of one of the Navy's seagoing experimental lab ships operating with the Atlantic Fleet.

He joined IBM in 1952 as a Project Engineer at the Poughkeepsie, NY Development Lab. His early assignments involved circuit design and initial stored program design for the 700 Series of processors.

In 1955 Jack was appointed Manager of System Integration of the 16 SAGE Air Defense Centers in the U.S. This involved software development to interface the Active/Standby Duplex Systems as well as a System Evaluation Program to check out the total system.

In 1957 he was assigned to manage the IBM team working with the FAA at the National Aviation Facilities Experimental Center (NAFEC) to perform hardware and software experiments to optimize the processing of Radar Tracking and Controller Displays for Terminal Air Trafffic Control Systems.

In 1959 Jack was appointed as Manager of Reliability for IBM's System Development Division where he and his team introduced several Software enhancements to Operating System/360 for Uniprocessing and Multiprocessing Systems. Many of these concepts were used later in the 9020 Enroute ATC System. He was also assigned to hardware and software design efforts on several custom IBM systems in Airline Reservations, Banking, Insurance, and Telecommunications.

Then, in 1963 Jack led the IBM System Design efforts to respond to the FAA Request for Bid on the Enroute Traffic Control System. This included the early software flow design and the performance kernel software demos to demonstrate throughput capability of the 9020 Multiprocessor. He worked as a team with Claud Davis, who handled the hardware design described elsewhere.

In 1965 he was named the IBM System Manager to implement the 9020 Enroute System including the Development, Installation, and Test of Hardware and initial Software at Jacksonville, and Chicago Centers.

From 1970 on he participated in several new product hardware and software development efforts.

Since his retirement in 1988 he has been operating a Consulting Company specializing in Plant Automation and Artificial Intelligence Systems.

JAMES H. MOLLENAUER

James H. Mollenauer was born January 8, 1921 in Eighty Four, PA (Southwest of Pittsburgh). He received a BS degree in Electrical Engineering from the Pennsylvania State University in December 1942, then served in the Army Signal Corp as a radar officer from 1943 to 1946. He then began a civil service career at the Air Force Cambridge (MA) Research Center (AFCRC) where his principal activity was participation in the test of VOLSCAN, an experimental terminal air traffic control system.

While at AFCRC, Mr. Mollenauer became interested in the applicability of air defense (SAGE) technology to the Enroute Air Traffic Control System as well as the potential of improving the effectiveness of both systems by some combination of functions and capabilities. In 1958, he joined the Airways Modernization Board (AMB) as Chief of the Air Defense/Air Traffic Control Integration Division. In that position he initiated and managed a project that involved use of the Evaluation SAGE Sector. Extensive experiments were conducted in flight following and conflict prediction using the SAGE radars, computer, and displays.

From 1961 until 1966, Mr. Mollenauer served in various positions including Director of the Federal Aviation Agency's Systems Research and Development Service. In March of 1966, the Administrator decided to centralize management of the then ongoing program of enroute ATC automation by establishing the National Airspace System Program Office (NASPO) with sole responsibility to develop, procure, test and deploy all designated system elements. Mr. Mollenauer was appointed the first director of the NASPO, and at the same time was appointed to the position of Deputy Associate Administrator for Engineering and Development.

Mr. Mollenauer retired in 1974. During that year, he received the Administrator's Distinguished Career Service Award and the Secretary of Transportation award for Meritorious Achievement "in recognition of his leadership in furtherance of civil aviation research and development, particularly to the improvement and modernization of the National Airspace System".

THE NATIONAL AIRSPACE AND AIR TRAFFIC CONTROL SYSTEM

The U.S. National Airspace System (NAS) is an intertwined complex consisting of the equipment, facilities, and people that carry out the policies and procedures by which air transportation over the United States is managed. The Federal Aviation Administration (FAA) of the U.S. Department of Transportation is responsible for monitoring and regulating aviation activities. The FAA certifies aircraft airworthiness; licenses aviation personnel; makes and enforces the Federal Air Regulations; installs, operates, and maintains air navigation, surveillance, and communication systems; and provides air traffic control services to all airspace users. Safety, efficiency, and availability are the paramount tenets underlying its policies and procedures.

The core of the NAS is the FAA's Air Traffic Control (ATC) system, an integrated airspace and aircraft management system serving all airspace users. The scope of its responsibilities and operations is extraordinary. At the present time, approximately 235,000 active aircraft handle an annual travel load exceeding 300 million passengers. Over 14,000 controllers working at ATC system facilities participate in 180,000 or more aircraft operations each day.

Over the course of its evolution (Table 1), the ATC has been a driver of new technologies to a lesser degree than a consumer of demonstrated technologies that were adapted and melded to its specific requirements and mission constraints. It is a montage of progressive developments in many different fields - avionics, navigation systems, communications, electronic instrumentation, sensors, and digital data processing and display. Since its inception, major improvements and innovations have occurred in all the contributing technologies. Over the decades, as these advances were synergistically incorporated and integrated, virtually every aspect of air travel and transportation changed significantly. In turn, these new technology opportunities promoted and expanded air travel and transportation, further increasing operational demands on ATC facilities.

The airspace is highly structured operationally and physically to ensure an orderly, expeditious, and safe flow of air traffic. There currently are three types of air traffic control facilities: air traffic control towers (ATCT), terminal radar approach control (TRACON) facilities, and air route traffic control centers (ARTCC). These facilities are widely scattered geographically, and each requires its own operation, maintenance, and support staffs. Each facility, according to its type, has well-defined jurisdictional boundaries within which it exercises its exclusive control responsibility (Figure 1).

Within their workplace, the air traffic controllers monitor, advise, and direct dozens of aircraft simultaneously. They use pilot-provided flight plans, strategic traffic management directives, and real-time aircraft positional information to provide immediate and near-term control and separation of aircraft. No individual controller is involved for the entirety of a flight; typically, a participating controller is involved for only a relatively short segment of many individual flights. Extensive communication and intensive coordination between the aircrew of every individual flight and the multiplicity of en route and terminal controllers is obviously essential and critical.

The escalating demands for ATC service, the inherent nature of the diverse tasks and man-man, man-machine, and machine-machine interactions, and the heterogeneity of equipment and facilities led to intractable complexity and compelled the introduction of automation. The ATC system is well suited to the application of high speed, large scale computer systems and networks, and the synergistic integration by engineering practices and principles that have now come to be known as systems engineering. Most of the ATC is now supported by advanced automation equipment of various degrees of capability and age.

Air traffic control systems for the twenty-first century must meet extraordinary demands for service from increasing numbers and types of airspace users for which even the existing automated systems were not planned. Today's passenger load and general aviation traffic is expected to double by the year 2000. To accomodate the demand for management of air traffic and airspace resources now envisaged for the twenty-first century, a comprehensive advanced automation system upgrade of the NAS was initiated in 1982.

Advanced automation continues to be a key thrust in the present NAS, ongoing upgrades, and contemplated successors. Digital processing and communications are the lead technologies in modernization. Scheduled system modernization, new system installation, and consolidation and reconfiguration of facilities along functional lines will simplify the airspace structure from the users' viewpoint. The Advanced Automation System, in which IBM remains directly involved, will bring state-of-the-art capabilities to the FAA's comprehensive air traffic control system well into the twenty-first century.

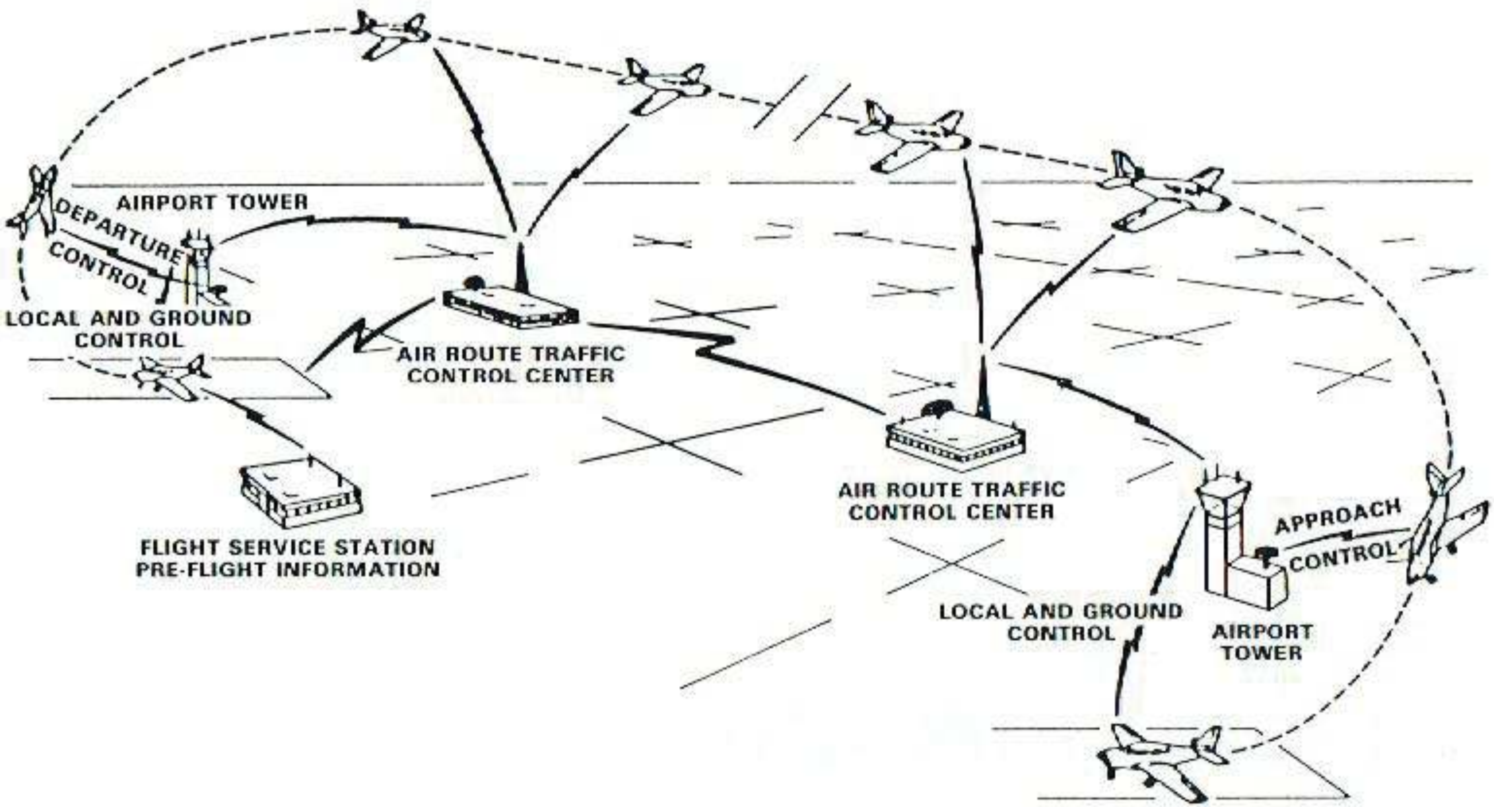
Effective in meeting its objectives and responsibilities, the U.S. NAS and its automated ATC system has become a preeminent model for civilian systems in other countries throughout the world. The four awardees of the 1990 Elmer A. Sperry Award, Claud Davis, Richard Hanrahan, John Keeley and James Mollenauer, pioneered the engineering principles and disciplines that have made this system possible, and established the highest levels of engineering excellence and professionalism by their contributions.

TABLE 1.
MAJOR PERIODS IN AIR TRAFFIC CONTROL SYSTEM EVOLUTION

1903-1925	Aircraft construction and experimentation; piloting and navigation methods; pilot and aircraft "worthiness" concepts developed; earliest avionics development; primitive aircraft controller methodologies developed.
1926-1938	Radio and land-based communications technology; airport facilities development; air/ground system interdependence realized essential; standardized controller methodologies across US begin to create integrated airspace system.
1939-1957	Radar development; aircraft performance increases; integration of radar-based controller methods; communication system advances interfacility coordination; navigation systems mature.
1958-1978	Commercial jet traffic begins; solid state devices proliferate; computer automation initiated.
1979-Present	Advanced digital sensors and processing; routine satellite communications; all-weather operations on international scale feasible; all technologies affecting aviation are accelerating.

Pozesky, M.T. and Mann, M.K., "The US Air Traffic Control System Architecture," *Proceedings of the IEEE*, Vol. 77, No. 11, November 1989: p. 1606.

FLYING THROUGH THE NATIONAL AIRSPACE SYSTEM



OPERATIONS OFFICE	TOWER	TRACON	ARTCC	TRACON	TOWER	OPERATIONS OFFICE
PREFLIGHT	DEPARTURE	CLIMB OUT	ENROUTE	APPROACH	LANDING	POSTFLIGHT
Flight Plan Entry	ATC Clearance	Flight Monitoring	Flight Monitoring	Flight Monitoring	Flight Monitoring	Flight Plan Close-out
• Pre-Stored • Flight Service Station • Military Base Operations • Airline Dispatch	• Surface Operation • Taxi Routing and Control • Take-Off Clearance	• Conflict • Terrain Avoidance • Weather Avoidance • In-Trail Spacing	• Conflict • Terrain Avoidance • Weather Avoidance • Metering	• Conflict • Terrain Avoidance • Weather Avoidance • Sequencing and Spacing	• Spacing • Terrain Avoidance • Landing Clearance • Taxi Routing and Control • Surface Operation	

Transfer of Control — Transfer of Control — Transfer of Control — Transfer of Control

Figure 1.
Courtesy of Dennie L. Walker, IBM Corporation

THE EVOLUTION OF AIR TRAFFIC CONTROL: A SUMMARY VIEW

The art of air traffic control was born in terminal areas, where it was originally employed to control ground traffic. A man armed with a flag during the day and a stationary light at night stood at a prominent spot on the field and signaled aircraft when to turn or take off. These crude instruments were eventually replaced by a flashing red, green, white light that was used to signal the pilot to land, takeoff, or hold. He could not, however, communicate with the pilot beyond visual range. This shortcoming was overcome in 1930, when a radio equipped air traffic control tower began operating at Cleveland Municipal Airport, and soon after at airports around the country.

The first generation air route traffic control system, which was introduced by an airline consortium in 1935 and taken over by the federal government in 1936, was only a slightly more sophisticated manually operated system. It relied heavily on the ability of controllers to visualize mentally the movement of aircraft in three dimensional space, without communicating directly with pilots. Company dispatchers relayed information or instructions between airline pilots and air route controllers.

Controllers posted incoming flight information on a wall-sized blackboard and this information was transferred to a large table map that depicted the air routes under a center's control. Small movable wooden markers represented a flight in the center's control area by indicating position and direction of flight. Controllers used a paper strip to record the flight's identity, time of departure, and altitude, and infer potential conflicts. Much depended on the accuracy and timing of pilot position reports, which in turn depended on the accuracy of the aircraft's navigation system, the level of pilot and controller workload, and the state of congestion on radio voice channels.

Positive control was exercised only on aircraft flying by instruments, and instrument flight was required only when weather conditions demanded it.

The first generation system depended more on technique than technology, but utilized radios, telephones, and teletype machines for communications. In July 1949, the first direct radio-telephone communications service was inaugurated at the Chicago ARTCC, finally providing controllers the means to make voice contact with pilots — though it took six more years before all air route centers acquired the same capability.

None of these innovations changed the character of the system. It was still exclusively manual and highly labor-intensive. World War II, however, had sown the seeds of change. On May 24, 1946, a radar equipped control tower began operating at Indianapolis. Radar permitted controllers to "see" the aircraft they were controlling, in relation to other traffic, air routes, and land marks. That gave controllers the capability to provide positive separation, to vector traffic around severe weather, and to reduce the separation distances between aircraft based on actual distances, not estimates. The appearance of radar marked the inauguration of the second generation ATC system, now rooted in modern technology.

Radar was eventually adapted to three ATC functions: (1) airport surveillance radar for aircraft nearing or overflying the terminal; (2) long-range radar for the air route traffic control centers; (3) airport surface detection equipment for controlling aircraft taxiing to or from runway at large metropolitan airports during low visibility. By 1960, local and long range primary radar began to blanket the airspace system.

Area positive control, the most distinguishing air traffic control technique of the second generation, came into its own with the introduction of secondary radar — i.e., the air traffic control radar beacon system (ATCRBS). This made use of an airborne transponder and a ground interrogator located at radar or air navigation installations, along with the controller's scope. After the pilot is assigned a transponder code, the controller can obtain positive identification by instructing the pilot to "ident." resulting in a momentarily brighter blip on the scope, distinguishing that plane from all other aircraft. The introduction of secondary radar reduced the necessity for voice communications between pilot and controller (such as for routine position reports) and freed many pilots from having to perform time-consuming identification flight maneuvers — as had been required with primary radar. The ability of secondary radar to identify aircraft in a matter of seconds represented such an improvement over primary radar in enhancing radar target reception that it became the essential element for assuring positive control.

Even with primary and secondary radar, however, the second controllers to spend 75 percent of their time in voice communications, preparing flight progress strips, and moving markers which were now positioned on horizontal radar scopes. By the early 1960's, it became clear that most of these functions could be automated.

The device that distinguished the third generation system from its predecessors was the computer. Computers had been employed in air traffic control as early a 1956, when an IBM 650 was installed at the Indianapolis Center. Three years later the Boston, Pittsburgh, and Cleveland Air Route Traffic Control Centers were equipped with UNIVAC File 1 computers. These early machines were employed in relatively sophisticated tasks to accept, process, and print flight progress strips and transfer flight data between adjacent centers. Early in 1961, the newly created Federal Aviation Agency began to look for ways to exploit more fully the computer's capabilities.

The search was intensified when President John F. Kennedy, in March 1961, requested the FAA Administrator to conduct "a scientific, engineering review of our aviation facilities and related research and development and to prepare a practicable long-range plan to insure efficient and safe control of all air traffic within the United States." FAA Administrator N.E. Halaby quickly organized a blue ribbon panel popularly known as the Project Beacon Task Force. The essence of the Project Beacon recommendations, which were submitted to the President in November 1961, was the proposed marriage of secondary radar to the computer. That meant digitizing the signals sent out by airborne transponders and having them appear beside the blip on the radar display to disclose in alphanumeric code the aircraft's identity, altitude, and ground speed. Such development would take the paperwork out of air traffic control, keep track of aircraft with an eye to potential conflicts, accentuate the controller's decision-making process, and expanded the capacity of the system. Applying this recommendation to the en route system was the task that the four distinguished men we honor here tonight successfully undertook in the 1960's.

THE DESIGN, DEVELOPMENT, AND IMPLEMENTATION OF THE INITIAL NATIONAL AIRSPACE ENROUTE AIR TRAFFIC CONTROL SYSTEM

The implementation of the Beacon Report recommendations began with the formation of the System Design Team within the FAA Systems Research and Development Service in January, 1962. The System Development Team faced the task of preparing a system design document upon which to base a detailed plan for implementing the philosophy and concepts of the Beacon Report. The plan was published June 30, 1962.

ATC experimental work was performed at the Atlantic City, N.J. FAA National Aviation Facilities Experimental Center (NAFEC) to derive some of the strategic ATC techniques to be implemented in later systems. Some of these initial concepts were also tried out at the FAA Enroute facility at Jacksonville, Florida. IBM had participated under contract to the FAA in these early software and hardware design efforts.

In 1963, the FAA issued the Request For Bids to the major computer suppliers to submit a hardware and software solution that met the needs of an Enroute Air Traffic Control System.

The IBM response to the FAA requirements was carefully assessed by the FAA and the Mitre Corp. and resulted in a contract Award for an Enroute Air Traffic Control System consisting of the Software, the Hardware, and the Systems Integration responsibilities to do Implementation.

The FAA Enroute Central Computing Complex was the nucleus of a large sophisticated system which included the products of several corporations:

- IBM for the 9020 Multicomputer, the ATC Software, and the overall system Integration function.
- Raytheon Corporation for the ATC Controller Displays.
- Burroughs Corporation for Radar Data Digitizer.

1) Burroughs Corporation

The conversion of raw Radar analog data in the form of Azimuth, Range, and a return signal reflection into a crisp Digital set of target information had been performed by Burroughs previously as part of the Air Defense System called SAGE. A great many design enhancements were introduced in the Radar Digitizers delivered to the FAA as part of the National Airspace System of this time period. The digitizer also screens out "noise" from the genuine aircraft position data needed by the Central Computer Complex to track targets.

2) Raytheon Corporation

The Computer Display Channel (CDC) developed by Raytheon was a key element in the overall ATC system. It is the final link in a process which provides the Controller with what amounts to a three dimensional "picture" of the planes in his Sector of ATC jurisdiction.

Superimposed on the Controller's Radar scope is the CDC produced "alphanumeric tags" which automatically track flights through his Sector of control responsibility. These "tags" include information on the aircraft identification, altitude, his next destination point, his ground speed, and other pertinent data needed for effective ATC control. The CDC receives data display messages from the Central Computer Complex and based on this data generates the alphanumeric, symbolic, and map presentation required by the Controller. It is the visual link to the system for the Radar Controller, and was the Data Entry interface to the CCC for the non-Radar Controllers.

The IBM 9020 Central Computer Complex

The FAA System Specification for the Enroute Central Computing Complex reflected the intent to use a computer to handle many of the Controller's routine tasks and increase both his productivity and safety levels in the primary task of providing adequate airspace separation between the aircraft under his traffic control.

The Beacon Report mentioned earlier offered a long range strategic outlook at Air Traffic Control and some tactical implementation guidance steps.

The Mitre Corporation, consulting team to the FAA, specified the details of system requirements. Their specifications stretched the capabilities of the hardware and software technologies that were "state-of-the-art" at that time. The major requirements were:

- Off the shelf, in production technology.
- Mean time Between System Failure of 10,000 Hours.
- Mean time to Restore the System Failure 30 minutes max.
- Any failure must be isolated to that unit only.
- Dynamic Switching of System Elements to handle Failure must be in a manner to avoid degradation of performance.
- Fail Safe, Fail Soft modular design. Meaning that the first element failure meant no impact other than switching in a Standby Element such as a Computer, and the second failure of a like Element would not stop the system but only impact throughput performance.
- The granular growth steps of the System must handle increments of 100, 250, and 325 Instrument Flight Rule (IFR) controlled aircraft system load.
- In the event of external power utility failure the system must wind down current processing and Safe Store essential data to allow rapid startup on restoration of external power.

No IBM computer system nor combination of subsystems could meet these requirements at that time. No single computer had sufficient compute capacity to handle the ATC workload of 325 IFR aircraft flights simultaneously. The proven system design method to get such high reliability at that time was a Duplex system with one Computer on line with a second Computer on Standby status ready to switch into the Active state. At the time there were no IBM systems available that met the granularity requirements of the FAA Request for Bid specifications.

The IBM response was based on the design of the IBM System 360-Model 50. This system was fully checked including both the Memory and the Arithmetic Unit yet many additional features had to be added to meet the challenging reliability specifications.

Capacity and Granularity were both addressed by using seven tightly coupled peer Model 50 processors with modifications. Four of the Computers were used as Computing Elements (CE) and three as Input/Output Control Elements (IOCE).

The seven way Multiprocessor system had common shared Storage composed of nine independent physical Storage Elements (SE) logically addressed as a contiguous address range. Expansion to 12 SE's came later.

Secondary Storage was provided by Magnetic Tapes (Disks were added later), and up to three Control Units for each I/O Device type. Each Control Unit had multiple Read/Write Tape Drives and other I/O Devices.

Each Input/Output Control Element (IOCE) contained data channels offering multiple independent paths for communication with up to 160 lines connected through three independent Peripheral Adapter Modules (PAM). The PAM's utilized plug in adapters to handle a wide range of data interfaces to handle digitized Radar inputs, teletype, Printers, Communication Lines, etc.

The CE's, IOCE's, SE's, Tape Control Units, and PAM's each contained a Configuration Control Register. The register controlled each Element's communication paths to other parts of the System and facilitated software controlled dynamic reconfiguration to allow Active, Standby, and Maintenance mode.

The requirement for 30 minute maximum repair time per Element imposed many challenging design solutions as follows:
1) All registers were dynamically error checked and if an error condition was discovered the register was blocked from broadcasting incorrect data.
2) Scan In of known test data patterns to all parts of the system logic was compared to expected Scan Out data patterns on single step clock pulses to precisely pinpoint circuit failure. This was particularly effective on complex logic difficult to test.
3) The ability to configure a maintenance subsystem out of Standby Elements to provide Offline diagnostic and repair capability. This capability of complete system isolation by means of Configuration Control Registers and Program instructions was one of the keys to success in achieving the very demanding Reliability Goals.

4) In case of prime power failure all vital data for a rapid restart in a few seconds had to be Safe Stored. To achieve this all Direct Voltages used throughout the system had to be backed up by a large bank of Nickel Cadmium Batteries. The battery system had a constant charge cycle applied to provide constant capability of takeover from external power. This was the first instance of Nickel Cadmium batteries for this purpose and the application was very successful.

5) New computer instructions were required to handle dynamic Multiprocessing of a single Job Stream. The TEST and SET instruction was used to check the availability of a data resource and if it was free (Test) indicate that it was being processed by doing a (Set) operation. This kept the other two processors enqued until the resource was freed up by the first processor. This concept is still in use in today's multiprocessor systems.

6) The above system was delivered on schedule, at target cost, and passed all reliability test requirements measured by the FAA in actual operational use over a period of one year.

The Initial Stages of the 9020 Software System Development

A group of IBM Programmers and Engineers worked with the FAA at the National Airspace Facilities Experimental Center (NAFEC) in the late 50's and early 60's to develop early prototypes of Terminal and Enroute Air Traffic Control Systems to determine the optimum approach to a future computer assisted modern control system. Most of these people were recruited to form the nucleus of a highly experienced IBM team well versed in the requirements of a modern Computer assisted Air Traffic Control System.

The above experience was one of many considerations that led to the award of a contract to IBM in 1964 to implement the development of a seven way multiprocessor system and it's operational software. As described earlier the hardware design included many very supportive features to a highly reliable overall system.

The challenge presented to the IBM System Engineers and Programmers was to exploit these hardware features into an extremely reliable multiprocessing system. Many of the members of that early IBM team had several years of hands on experience with the Duplex systems of one Active computer and one Standby as implemented on the Sage Air Defense and Airline Reservation Systems. It was decided at the initial design review that in the interest of maximum reliability for the total system that complete "Fail Safe / Fail Soft" flexibility would be maintained at all levels of the system.

The typical system consisted of four Computer Elements (CE), three Input/Output Control Elements (IOCE), and three Peripheral Adapter Modules (PAM) for Radar Inputs and Communications. Each of these units was separately powered and logically independent so that the first unit failure of any type would have no impact and "Fail Safe". Should the unlikely event of a second failure in type occur then a "Fail Soft" mode would occur whereby the Operational Software would Reconfigure dynamically the failing unit out of the system while providing continuous system operation.

This required software support for dynamic switching of asynchronous data transfer which meant buffering of data for the short period switching took place.

Many innovative software concepts were developed to provide a maximum level of reliable system performance:

The primary design goals of the Software System design were divided into three areas of concentration:

1) Performance - Provision for up to three Computing Elements to execute instructions and operate on a common Data Base with a minimum level of interference with one another.
2) Flexibility - Logic to allow any of the CE's to execute any portion of the Operating System or ATC tasks. (Subprograms).
3) Complete malfunction monitoring of all hardware Elements and software execution in order to quickly detect problems and take recovery steps as required.

A. Performance

Wherever possible code was designed to be re-entrant, i.e. executable by more than one CE simultaneously. Where code was not re-entrant a Test and Set instruction was invented to allow a CE to Test for availability and Set a Lock on the resource about to be processed. A timeout value was also set to avoid a long-term loss of a CE caused by a software loop. Many of these concepts invented in the early days of the 9020 system are still in use today. A Trace System was also developed to monitor critical points in the Control Program. This system provided Timing Analysis Reports which allowed concentrated redesign of performance bottlenecks.

B. Flexibility

Since it was required that all CE's were equal — any CE could start up the system or perform recovery actions due to a failure of one of it's peer CE's. This required, for one example, that any CE could carry on dynamically the Input/Output operations of a peer CE at its point of failure detection.

C. Malfunction Monitoring and Recovery

A program was developed — The Operational Error Analysis Program (OEAP) to perform On-Line analyses of equipment failure indications concurrently with regular processing. OEAP also assessed the source and seriousness of each potential malfunction for the purpose of activating Reconfiguration software to "Switch Out" the failing unit and "Switching In" a Standby Element. Basically a log was kept of "Soft" error conditions which usually gave a fairly dependable forecast of serious "Hard" failure conditions ahead in time for preventive action.

D. Systems Evaluation

A (SEVA) program was developed that was capable of generating most of the dynamic operational environment of the Hardware as it would be stressed in actual Air Traffic Control usage. SEVA simulated Radar inputs, Air Traffic Controller inputs and requests for system service and presented test messages to the electronic displays at the ATC Controller workstations. This was used to quickly pinpoint problem areas anywhere in the total system.

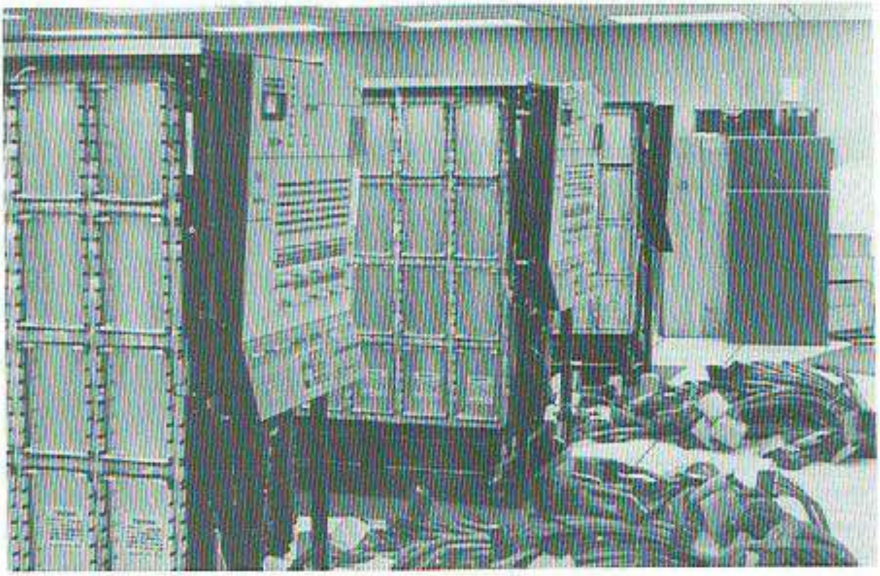
Although the concept of "Software Engineering" was yet to come in those early days of software development a Jovial Compiler was generated at FAA request that was used extensively throughout the software development effort that was instrumental in increasing productivity of the individual programmer.

In summary these early efforts at software exploitation of a highly reliable hardware design were successful and led to years of reliable Air Traffic Control Operations.

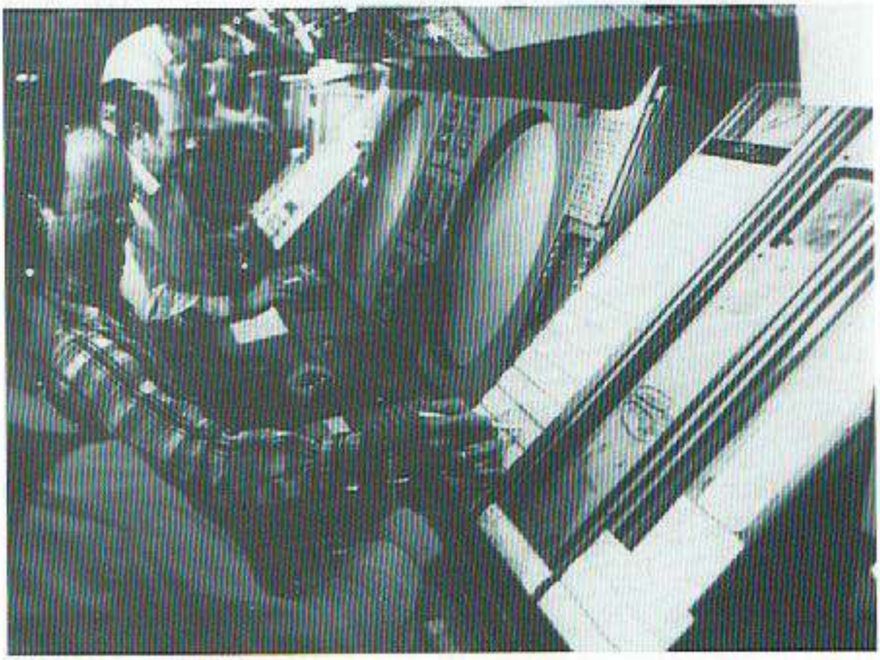
ACKNOWLEDGEMENTS

The Elmer A. Sperry Board of Award appreciates the contributions of memorabilia, memoirs, reminiscences, research and writing for the composition of this monograph to: Claud Davis (IBM), John Keeley (IBM), Richard Hanrahan (IBM), James Mollenauer (FAA), Dennie L. Walker (IBM), Jeffrey Cochran (FAA), Nick Komons (FAA), and Judith Prewitt (Sperry Book).

The FAA Air Traffic Control Center
Courtesy of Nick Komons, FAA Retired



Installing the IBM Central Computer System
Courtesy of James Mollenauer, FAA Retired



Working Casanova Departure Sector at the Washington ARTCC are Joe Alizio (foreground), developmental ATCS; and Anthony Martin, ATCS. Beyond Martin is Dave Coleman, ATCS, working the Moorefield High Altitude Sector. 1984.
Photo by Martin Marietta Corporation

Elmer A. Sperry, 1860-1930

After attending Cornell University in 1879-80, Sperry invented an improved electric generator and arc light and opened an electric company in Chicago. He invented electric mining equipment, locomotives, streetcars and an electric automobile. He developed gyroscopic stabilizers for ships and aircraft, a successful marine gyro-compass and gyro-controlled steering and fire control systems used on Allied warships during World War I. Sperry also developed an aircraft searchlight and the world's first guided missile. His gyroscopic work resulted in the automatic pilot in 1930. The Elmer A. Sprerry Award was established in 1955 to encourage progress in transportation engineering.

Dedication

The Sperry Board of Award joins Claud M. Davis, Richard B. Hanrahan, John F. Keeley and James H. Mollenauer in recognizing the contributions of many individuals who helped design, build and operate the FAA enroute air traffic control system. The Board also gratefully acknowledges the contributions to this Award booklet made by the Award recipients.

PREVIOUS ELMER A. SPERRY AWARDS

1955 to *William Francis Gibbs* and his Associates for development of the S.S. United States.

1956 to *Donald W. Douglas* and his Associates for the DC series of air transport planes.

1957 to *Harold L. Hamilton, Richard M. Dilworth* and *Eugene W. Kettering* and Citation to their Associates for the diesel-electric locomotive.

1958 to *Ferdinand Porsche* (in memoriam) and *Heinz Nordhoff* and Citation to their Associates for development of the Volkswagen automobile.

1959 to *Sir Geoffrey De Havilland, Major Frank B. Halford* (in memoriam) and *Charles C. Walker* and Citation to their Associates for the first jet-powered aircraft and engines.

1960 to *Frederick Darcy Braddon* and Citation to the Engineering Department of the Sikorsky Aircraft Division, *Sperry Gyroscope Company*, for the three-axis gyroscopic navigational reference.

1961 to *Robert Gilmore Letourneau* and Citation to the Research and Development Division, *Firestone Tire and Rubber Company*, for high speed, large capacity, earth moving equipment and giant size tires.

1962 to *Lloyd J. Hibbard* for application of the ignition rectifier to railroad motive power.

1963 to *Earl A. Thompson* and Citation to his Associates for design and development of the first notably successful automatic automobile transmission.

1964 to *Igor Sikorsky* and *Michael E. Gluhareef* and Citation to the Engineering Department of the Sikorsky Aircraft Division, *United Aircraft Corporation*, for the invention and development of the high-lift helicopter leading to the Skycrane.

1965 to *Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook* and *Richard L. Loesch, Jr.* and Citation to the Commercial Airplane Division, *The Boeing Company*, for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720, and 727.

1966 to *Hideo Shima, Matsutaro Fuji* and *Shigenari Oishi* and Citation to the *Japanese National Railways* for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

1967 to *Edward R. Dye* (in memoriam), *Hugh DeHaven*, and *Robert A. Wolf* and Citation to the research engineers of *Cornell Aeronautical Laboratory* and the staff of the Crash Injury Research projects of the *Cornell University Medical College*.

1968 to *Christopher S. Cockerell* and *Richard Stanton-Jones* and Citation to the men and women of the *British Hovercraft Corporation* for the design, construction and application of a family of commercially useful Hovercraft.

1969 to *Douglas C. MacMillan, M. Nielsen* and *Edward L. Teale, Jr.* and Citations to Wilbert C. Gumprich and the organizations of *George C. Sharp, Inc., Babcock and Wilcox Company*, and the *New York Shipbuilding Corporation* for the design and construction of the N.S. Savannah, the first nuclear ship with reactor, to be operated for commercial purposes.

1970 to *Charles Stark Draper* and Citations to the personnel of the *MIT Instrumentation Laboratories, Delco Electronics Division, General Motors Corporation*, and Aero Products Division, *Litton Systems*, for the successful application of inertial guidance systems to commercial air navigation.

1971 to *Sedgwick N. Wight* (in memoriam) and *George W. Baughman* and Citations to William D. Hailes, Lloyd V. Lewis, Clarence S. Snavely, Herbert A. Wallace, and the employees of *General Railway Signal* Company, and the Signal & Communications Division, *Westinghouse Air Brake Company*, for development of Centralized Traffic Control on railways.

1972 to *Leonard S. Hobbs* and *Perry W. Pratt* and the dedicated engineers of the Pratt & Whitney Aircraft Division of *United Aircraft Corporation* for the design and development of the JT-3 turbo jet engine.

1975 to *Jerome L. Goldman, Frank A. Nemec* and *James J. Henry* and Citations to the naval architects and marine engineers of *Friede and Goldman, Inc.* and *Alfred W. Schwendtner* for revolutionizing marine cargo transport through the design and development of barge carrying cargo vessels.

1977 to *Clifford L. Eastburg* and *Harley J. Urbach* and Citations to the Railroad Engineering Department of *The Timken Company* for the development, subsequent improvement, manufacture and application of tapered roller bearings for railroad and industrial uses.

1978 to *Robert Puiseax* and Citations to the employees of the *Manufacture Francais des Pneumatiques Michelin* for the design, development and application of the radial tire.

1979 to *Leslie J. Clark* for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

1980 to *William M. Allen, Malcolm T. Stamper, Joseph F. Sutter* and *Everette L. Webb* and Citations to the employees of *Boeing Commercial Airplane Company* for their leadership in the development, successful introduction and acceptance of wide-body jet aircraft for commercial service.

1981 to *Edward J. Wasp* for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.

1982 to *Jorg Brenneisen, Ehrhard Futterlieb, Joachim Korber, Edmund Muller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler* and *Werner Teich* for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotive in heavy freight and passenger service.

1983 to *Sir George Edwards, OM, CBE, FRS; General Henri Ziegler, CBE, CVO, LM, CG; Sir Stanley Hooker, CBE, FRS* (in memoriam); *Sir Archibald Russell, CBE, FRS;* and *M. Andre Turcat, Ld'H, CG;* commemorating their outstanding international contributions to the successful introduction and subsequent safe service of commercial supersonic aircraft exemplified by the Concorde.

1984 to *Frederick Aronowitz, Joseph E. Killpatrick, Warren M. Macek* and *Theodore J. Podgorski* for the conception of the principles and development of a ring laser gyroscopic system incorporated in a new series of commercial jet liners and other vehicles.

1985 to *Richard K. Quinn, Carlton E. Tripp,* and *George H. Plude for the inclusion of numerous innovative design concepts and an unusual method of construction of the first 1,000-foot self-unloading Great Lakes vessel, the M/V Stewart J. Cort, which revolutionized the economics of Great Lakes transportation.*

1986 to *George W. Jeffs, Dr. William R. Lucas, Dr. George E. Mueller, George F. Page, Robert F. Thompson* and *John F. Yardley* for significant personal and technical contributions to the concept and achievement of a reusable Space Transportation System.

1987 to *Harry R. Wetenkamp* for his contributions toward the development and application of curved plate railroad wheel designs.

1988 to *J. A. Pierce* for his pioneering work and technical achievements that led to the establishment of the OMEGA Navigation System, the world's first ground-based global navigation system.

1989 to *Harold E. Frohlich, Charles B. Momsen, Jr.* and *Allyn C. Vine* for the invention, development and deployment of the deep-diving submarine, *Alvin.*

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Printed in U.S.A.