Appendix VI - Technology and Market Trends - Archived 6/98

IR Technology Advances

Thermal Imaging - Developments in passive electro-optical technology advanced slowly after World War II as engineers sought to exploit the thermal signature of objects to create a visual image. This engineering challenge produced a major innovation in the late 1950s in the form of the first infrared linescan reconnaissance system, developed by Texas Instruments for a US Army drone program. This system looked down, scanning a line perpendicular to the line of flight. A continuous map was produced as the linescanner converted infrared imagery to visible light and recorded it on film. Spurred on by the success of its IR-line scanner, TI focused on development of a thermal viewing device. Introduced in 1964, this early system was the forerunner of what is now commonly called the Forward Looking Infrared (FLIR) sensor. TI's experimental FLIR scanned the scene and converted the thermal radiation into an image for viewing on a TV monitor in real time. The image was a pictorial representation of the various temperature differences in the scene.

Basic Operation - In a standard thermal imager, such as a FLIR system, the sensor looks at the terrain that lies ahead of the aircraft. The FLIR includes linear arrays containing hundreds of IR detectors (usually mercury cadmium telluride, or MTC) that sense temperature differences within certain infrared bands as they are scanned by optical mirrors through a field of view. The elevation field of view is covered by the detector array, while the scanning action covers the azimuth or the horizontal field of view. For each line through which an individual detector is scanned, a line can be generated on a CRT display, resulting in a two-dimensional visual representation of the area viewed by the FLIR. FLIRs can "see" through haze, dust, fog, and smoke. They are also less susceptible to light saturation caused by gun flashes, detonating munitions, or illuminating flares that tend to "wash out" other viewing devices.

Within the infrared spectrum are two regions or wavebands that are best suited for thermal imaging: the 3-5 micron (medium wavelength) and the 8-14 micron (long wavelength). Both are commonly generated by natural and manmade objects and are not badly diminished by moisture in the atmosphere. The 8-12 micron region is used for most airborne FLIR applications where definition of surface detail is required for navigation and target detection. A higher level of thermal energy is inherent in the natural environment, with ambient temperatures for most objects ranging between 0^{o} and 30^{o} C. Although the total amount of IR energy emitted is smaller than that found in the 3-5 micron range, it generally peaks in the 10 micron region.

Low temperatures have less effect on signal strength within the 8-12 wavelength than in the 3-5 micron region. Until recently, a thermal imager's detector had to be cooled to maintain its sensitivity in resolving differences in IR energy and thermal noise. Recent developments are reducing this requirement. Detectors in the 8-13 micron region require cooling temperatures of approximately 200^{o}C, as compared to -90^{o}C for the 3-5 micron region. The higher cooling requirement of the 8-12 micron detectors is offset by greater sensitivity and range. However, the 3-5 micron band is inherently sensitive to "hot" objects such as the sun or engine exhaust, making these detectors effective as missile seekers and allowing better performance than the 8-12 band in certain types of bad weather.

Common Modules - By the end of the Vietnam war, it became apparent that newer technologies had to be harnessed to reduce costs as well as offer significant improvements in performance and maintainability. The forerunner of the US Army's Night Vision & Electro-Optics Directorate (NVEOD), the Night Vision Laboratory (NVL), was tasked in 1971 to study the causes related to the FLIR development and propose methods for significantly reducing costs. The study found that the large number of FLIR programs in progress at various manufacturers and labs resulted in high program costs due to repeated development of similar components for different systems. Working with industry, NVL formulated the Universal Viewer Concept that certain FLIR components could be standardized without affecting overall performance.

From these studies flowed the concept of common modules, generic building blocks to ensure a high degree of commonality while reducing engineering time and costs, as well as making the mass production of new FLIR designs feasible. In conjunction with the NVL, Texas Instruments developed a series of common modules that were adopted by the DoD as the industry standard in 1974.

The US first-generation common module series consisted of 12 subcomponents: a mechanical scanner, detector/ dewar, IR optical imager, cooler, DC/AC inverter, preamplifier, postamplifier/control driver, bias regulator, scan & interlace, auxiliary control, LED array, and visual collimator. US common module detectors are 8-12 micron photoconductive mercury cadmium telluride (MTC) arrays available in lengths of 60, 120, and 180 elements.

While TI was the initial manufacturer of the common modules, the DoD expanded the program by qualifying several US sources, including Hughes Aircraft, Loral (formerly Honeywell Electro-Optics), and Magnavox. The common modules were supplied to EO houses as government-furnished equipment (GFE) for a range of thermal imaging programs including the Loral AAS-38A, Martin Marietta's TADS/PNVS, and the Hughes AAQ-16. In 1979 the US DoD attempted to have the common modules adopted as a NATO standard, but because of earlier reluctance to part with this technology, most European EO houses had already begun their own common module programs.

The TICM (Thermal Imaging Common Modules) program was initiated by the Royal Signal and Radar Establishment in 1976. RSRE developed the detector element designs using MTC. Marconi Avionics (now GEC-Marconi) was selected by the MoD in 1980 for prime full-scale development of TICM, with responsibility for developing the processing electronics modules. Rank Taylor Hobson was subcontractor for the scanner head modules. TICM went into production in the early 1980s. Improved versions known as TICM II modules feature the SPRITE (Signal Processing In The Element) detectors developed by Philips Components, which simplified the number of connections between detector elements.

Also in 1976, SAT (Societe Anonyme de Telecommunications) and TRT (Telecommunications Radioelectriques et Telephoniques) began development work for the French common module approach known as Systeme Modulaire Thermique (SMT) under sponsorship of the French Telecoms R&D authority (SEFT). Production began in 1982. The US and Germany signed a memorandum of understanding (MoU) in 1978 for coproduction of US common modules in the FRG. AEG-Telefunken was selected to license-produce modules based on Texas Instruments designs.

Focal Plane Array - The common feature of all first-generation FLIR systems is that they use linear arrays composed of small numbers of detecting elements and a scanning optical system to gather infrared energy. Mirrors behind the sensor's lens scan across a target scene, briefly focusing energy from a portion of the scene on each detector element in turn. The mechanical scanning mirrors move at 45,000 rpm and can scan a scene in milliseconds. Outputs from each detector are fed to high-gain amplifiers driving scan conversion equipment that converts the final pictures into formats for CRT display.

While providing good image quality, array size has been constrained, in part, by limits in downsizing the mechanical components of the scanning system, and by the number of connections between detector elements that can be attained within the size of the cooling dewar in which they are placed. The array is mounted in the vacuum space at the end of the inner wall of the dewar and is surrounded by a cooled radiation shield. An infrared window, usually made of germanium, allows the detector array to "see." The SPRITE (Signal Processing In The Element) detector, which streamlined the number of connections between detector elements, remains a mechanically scanned array.

Infrared Focal Plane Array (IRFPA) technology is being perfected to expand the number of detector elements while still limiting the number of connections between elements. Two types of IRFPAs are in development: scanning and staring. The improved scanning arrays using time delay and integration (TDI) techniques are four elements wide and range in size from 4x48 to 4x960, possibly even larger over time. The signal from each of the four horizontal sensors is added together to create higher signal-to-noise levels for greater sensitivity.

Staring arrays incorporate charge coupled device (CCD) technology to integrate the detector elements with processing electronics onto the surface of a microchip so that the functions of detection, integration, filtering, and multiplexing will be carried out in the IRFPA itself. They thus reduce the number of interconnects and outside signal processing required. Electronically scanned by the array's integrated processing circuits, the optics simply focus the IR image onto the matrix of the detector elements. Each element "stares" or focuses on a small portion of the scene to maximize the amount of IR energy received. The larger the number of detector elements, the greater the sensor's sensitivity and image resolution. Staring arrays consisting of detector elements arranged in size from 32x32 to 64x64 are being developed, although some manufacturers have developed experimental devices as large as 480x640 (see below).

There has been considerable activity in IRFPA development in the US and Europe since the mid-1980s. In late 1987, Northrop Corp's Electro-Mechanical Division announced the development of an IRFPA "chip" with 16,384 detectors in a 128x128 array. The chip has four microprocessors and operates in the 3-5 micron band. Northrop had planned to integrate the chip into its AXX-1 Television Camera Set carried by the F-14 to give it a nighttime viewing capability.

AT&T Laboratories is developing quantum-well semiconductor technology that will expedite the production of staring arrays using molecular beam epitaxy techniques to deposit materials on the surfaces of gallium arsenide. Manufacturing of quantum-well IRFPAs requires depositing materials on the substrate one atom at a time. By manipulating the layering pattern, different sizes of wells can be grown on the device to obtain greater sensitivity. While gallium arsenide is less sensitive than mercury cadmium telluride, it offers lower thermal noise at operating temperature, higher uniformity rates for the production process, and is able to work in different bands of the IR spectrum.

DARPA concluded the first phase of its IRFPA effort in April 1990, with Hughes Aircraft, Rockwell International, and Loral producing prototype arrays and comprehensive cost analysis. Hughes' Santa Barbara Research Center (SBRC) produced arrays configured in patterns of 4x480 elements using mercury cadmium telluride (MTC) material grown by a liquid phase epitaxial (LPE) process. This involves depositing a thin layer of MTC in a liquid state. SBRC has demonstrated manufacturing improvements to include a more producible design of the integrated circuit used to address the array, reduction in the time required to test the array, and a demonstration of an automated method of handling the MTC material during processing. SBRC estimated that its development work will reduce IRFPA cost by 25 percent. Hughes also has produced a 480x640 LWA HgCdTe IRFPA that it claims is the largest staring array of its type.

Rockwell has produced MTC arrays with 64x64 elements using vapor deposition on a gallium arsenide substrate. This is the first demonstration of an imaging-quality IRFPA on gallium arsenide that offers advantages in larger sizes, less susceptibility to handling damage during production, and low cost. Also, the improvements demonstrated by the vapor deposition techniques include a reduction in defect density and improved uniformity.

Lockheed Martin (then Loral) started investigating the manufacture of 488x512 IRFPAs from platinum silicide substrates sensitive to IR energy in the 3-5 micron region. The company was able to demonstrate that in the manufacturing process the number of arrays that pass screening tests for electronic defects had increased by 60 percent. In a separate effort, Loral's Infrared & Imaging Systems Division was selected in 1991 to provide IRFPAs for the RAH-66 Comanche's TAS/NVPS system in development by Martin Marietta.

DARPA's goal for the IRFPA is to reduce the cost of present detector arrays by a factor of 100, from a level of about US$20,000 for a 4x960 array down to less than US$3,000, and down to less than US$2,000 for a 64x64 staring array with greater than 90 percent operability. Other ongoing efforts include the following: demonstrating large-area 480x640 mercury cadmium telluride IRFPAs on a silicon substrate; demonstrating 128x128 IRFPAs on a silicon substrate for greater ease of material handling and compatibility with commercial manufacturing equipment; demonstrating IRFPA manufacturing with four-inch wafers; completing the development of an integrated manufacturing capability for large-area four-inch wafer IR semiconductors demonstrating a 100x cost reduction for both staring and scanning arrays; and demonstrating flexible, modular IRFPA manufacturing with the capability to rapidly reconfigure the line the produce 3-5 and 8-12 micron arrays for tactical and space surveillance applications.

In February 1991, USAF's Rome Air Development Center was seeking sources capable of designing iridium silicide (IrSi) staring IRFPAs in configurations of 256x256, though other configurations up to 480x640 would be considered. Indium silicide offers an alternative substrate material for the long-wave IRFPA devices.

In 1986, France's Thomson-CSF, SAT, and CEA formed Sofradir (Societe Francaise de Detectures Infrarouge), a joint venture specifically to develop and manufacture IRFPA technology. This has been a major force among European EO houses in perfecting IRFPAs for several second-generation EO devices, including weapons seekers, now in development. In November 1990, Sofradir's IRFPA was selected by the US DoD as one of 22 foreign weapon systems for assessment under its FY91 Foreign Comparative Testing (FCT) program. The FCT funds test and evaluation of promising foreign technologies that have potential as US procurement options. The evaluation of the Sofradir system continued in 1993.

Uncooled IR - Traditionally, cooling requirements for IR sensors have placed limitations on detector size, even with new focal plane arrays. Thus, there is a continuing search for alternatives, since even advanced technology such as the FPA is still dependent on cooling. A solution is now appearing in the form of uncooled IR sensors, i.e., ones that work at room temperature. At the forefront of this technology area is the British company, GEC-Marconi Avionics. This company developed the first solid-state uncooled IR detector array in the world. There apparently already existed a vacuum-tube uncooled IR detector called the pyroelectric vidicon, but interest in this seems to have been minimal. The company acknowledged that it knew that the US was working on such a project, but felt that it could at least claim to be first in Europe. GEC, using both its own capital and funds provided by the British Ministry of Defence, announced successful test results in late summer of 1988 with a 32x32 pixel array, and shortly thereafter with a 100x100 array.

According to GEC, four leading-edge technologies went into the new IR system. These included advanced pyro-electric ceramics (lead zirconate titanate) for the sensing elements, charge-coupled device large-area silicon integrated circuits for readout and multiplexing, high-performance multiplexed readout for the display, and solder bump hybridization linking the 10,000 elements to the integrated circuits. The solder bump technology hybridized the detector array with a silicon chip, with GEC using its own CMOS process to do all the signal processing. The company also is hoping to improve performance by a factor of 2 to 4 through introduction of another material for the pyroelectric component, and by increasing the number of pixels from 10,000 to 100,000, which will mean an improvement in image quality.

Two US companies - Texas Instruments and Alliant Techsystems - have developed uncooled IR sensors that operate at room temperature, are lighter, and have much lower power requirements. The Texas Instruments un-cooled IR program - Low Cost Uncooled Sensor Prototypes (LOCUSP) - was to demonstrate four fieldable prototypes that would each use common sensor com-ponents. The prototypes were a medium-range, thermal-imaging sight; an IR missile seeker sensor; an IR security sensor; and an IR autonomous munitions seeker sensor. An October 1991 Commerce Business Daily notice outlined US Army plans to test large-area (80,000 elements) uncooled focal plane arrays in the near future.

<u>Applications Burgeoning</u> - IR systems are finding expanding favor in both military and commercial applications. Missile guidance systems are increasingly being designed to be dual in nature, usually combining radar and IR. This allows a higher kill probability, especially in conditions of radar jamming. Thermal imaging systems for navigation in darkness and adverse weather are increasingly becoming standard equipment on many helicopters and for both navigation and weapons delivery usage by fixed-wing fighters. The airlines are also looking at IR detectors and jammers for their aircraft as a counterterrorist measure. Thermal imagers working with lasers are a developing market segment, and include Ferranti's (UK) ATTACK system. IR seekers are also being applied to conventional bombs in the anti-ship role.

<u>Naval Applications</u> - Most navies are fielding IR surveillance and tracking systems on their ships. Being almost completely passive in operation, this equipment provides a level of enhanced situational awareness without giving away the platform's position by emitting a detectable transmission. Submarines use thermal imagers as part of the sensor array centered on the periscope. These enhance the night attack capability and also provide improved intelligence-gathering capability by providing some information on the internal structure of the target ship. The French Navy has made a heavy commitment to IR systems. The new Cassard class frigates are being equipped with both a dual-band IR system (Vampir) and a dual-band IR target tracker (Pirana). The US Navy was looking at using portable IR thermography equipment for the nondestructive inspection of composite materials onboard ships and is looking for an IR search and track (IRST) system. The latter category is a developing one for naval systems and is a reflection of the increased focus on systems that allow ships to keep a low profile through an expanded use of nonemitting sensors.

<u>Missile Warning</u> - The primary role of infrared sensors in warship design is likely to be that of detecting inbound anti-ship missiles before they cross the visual and radar horizon. The new generation of anti-ship missiles have speeds well in excess of Mach 2 with some weapons, notably the Raduga P-270 Moskit, being capable of Mach 3.5 on their final run to target. This dramatically limits the time which can be taken for defensive countermeasures. Normally the outer detection range for such missiles is set at around 12 kilometers while the inner edge is set at one kilometer per mach number. At any closer range, and even if the missile is shot down, wreckage from it will still strike the target and cause major damage. This scenario generates an intercept envelope 8 km in depth. At Mach 3.5, a missile covers 1.2 km per second, giving a total engagement opportunity time (from first possible observation to too late) of around 6.5 seconds.

These ultra-fast missiles do have a vulnerable point. Their ramjets or rocket motors develop so much heat that the plume is visible to an IR sensor long before the missile crosses the horizon. This can provide the platform under attack with an additional six to ten seconds warning time - enough for the ship to align its defensive systems with the axis of approach of the threat. In the case of optronically guided point defense missiles, this also allows the first defensive shots to be fired while the attacking missile is still over the horizon, again increasing the time available for countermeasures.

Damage Control - The Iraqi missile attack on the USS Stark and the subsequent fires pointed out the critical need for better damage-control techniques. Portable, handheld thermal imagers are proving a popular solution, since this negates the obscured conditions of heavy smoke and allows the pinpointing of hot spots. Fire on a warship is very dangerous, especially because of the explosive materials that are usually found on board, and anything that allows a fire's most dangerous area to be quickly pinpointed will be much sought after. The US Navy has purchased portable thermal imagers from EEV Inc (US), with the company having already supplied units to the Royal Navy, and navies in Australia, Canada, Italy, New Zealand, and Germany, as well as other naval forces around the world. Use of thermal imagers is not necessarily limited to combatant vessels; commercial shipping is also a very likely customer.

Civilian Firefighting - The US Forest Service has for some time been interested in using IR methods for detection of forest fires. It uses FLIRs and airborne IR line scanners to keep track of a fire's size, location, direction of movement, and to detect flare-ups and pinpoint hot spots. IR was a valuable adjunct in the firefighting efforts in the massive Yellowstone National Park fires in the summer of 1988. In the UK, Check Security Systems has introduced a fire detection thermal imaging system for installation in open areas where large amounts of inflammable materials are stored. The thermal camera scans the site continuously and its output is processed by video analyzer to detect the heat from a fire against normal temperature changes.

Other Commercial Applications - NASA uses IR systems aboard the shuttle to take pictures of the shuttle's upper surfaces for the enhancement of research into computational fluid dynamics predictions for a second-generation shuttle. The commercial sector now uses thermal imaging in the manufacturing process to detect faults in materials since cracks or weak spots will show a different temperature. IR is also used for surveillance of pipelines to detect cracks.

The Future - IRFPAs are the next major step in EO technology, something that both US and European teams are diligently working to perfect. The US is pursuing IRFPAs and related component development with work apportioned among academic, government and industrial centers.

New systems will need to be more compact for installation as integral systems or for those applications that will require pod packaging. Though military-oriented, the various EO suppliers also supply the law enforcement and security surveillance market, where cost concerns are more prevalent. This is even more so as the current recession takes its toll on state and municipal budgets, including police functions. Commercial applications for airborne EO will need to be exploited aggressively to help deflect some of the reductions brought on by defense cuts. The FAA is examining the effectiveness of thermal imaging as a night and adverse weather landing aid for commercial aircraft. If proved effective, a thermal imaging landing aid could evolve into a major product area for the large transport fleet.

Technology innovation is no longer the purview of US EO houses. While the Europeans have forfeited major procurement of airborne EO over the last decade, they have supported future developments through several government and quasi-government research organizations. The establishment of the Sofradir consortium and the EUCLID technology development coordination effort underscores Europe's potential for second-generation systems and components for both sensors and weapon seekers.

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Pilot's Associate/Rotorcraft Pilot's Associate Increase Situational Awareness

Increasingly faced with an overload of data from numerous on-board systems, today's combat pilot must manually and "mentally" integrate and prioritize all incoming information, which more often than not includes trivial information mixed in with vital data. Such a bombardment of information adversely affects a pilot's "situational awareness," that is, the ability to be aware of potential threats and other external incidents. As far back as World War II, 80 percent of all combat fighter losses could be attributed to the lack of situational awareness leading to the inability to react until it was too late. The high speed of modern air combat, the hypersonic speed of future dogfights, and the growing abundance of sensors and systems providing feedback, all combine to make it a top priority to lighten and prioritize the information load for the pilot. To do so, tomorrow's aircraft will require "supercockpits" with computer-generated data and imagery that essentially offer X-ray vision of the environment around the pilot - not unlike operating today's submarines. While such a cockpit is still years away from deployment, technology in this area is rapidly advancing, with some features already developed. Designated the

Pilot's Associate (PA), features of this concept could be available as early as the year 2000.

The supercockpit will also include such features as active voice control that allows the aircraft, through its computer, to respond to the pilot's spoken commands. Such technology will allow many fighters to go back to being single-seaters, as the addition of a radar intercept officer will be made redundant. In addition, cockpits in the near immediate future will have a lot more flat, multifunction color display panels instead of the traditional small cathode ray tube instruments.

A secondary driving force behind the development of a windowless submarine-like cockpit is the threat of laser guns. Until a fully laserproof cockpit is developed, shutters and special coatings that make the canopy opaque are being used in the interim. Other laser threat protection includes the development of helmet-mounted displays that enable the pilot to perform close-in air-to-ground missions. According to Lockheed-Martin Aeronautical Systems, a laser-protective shield can be added to aircraft at little additional cost or weight. However, Lockheed-Martin, as developer of the F-22 fighter, would not say what kind (if any) of laser protection was on this next-generation aircraft.

Pilot's Associate - Today, the amount of information coming into the cockpit has reached the saturation level. A primary goal of the joint US Air Force/DARPA Pilot's Associate (PA) program is to lighten the pilot's workload through integrated pilot workstations that prioritize the information presented to the pilot. The advent of artificial intelligence (AI) has allowed the implementation of approaches to this problem that were not possible before. AI still may be a long way from being implemented at the level of authority many people seem to think possible, but there are developmental programs now under way that are incorporating AI to a significant extent.

The PA program saw its genesis in 1986 when pilot input was sought to establish parameters for the direction the concept should go in. This was followed in 1988 with Phase 1 competitive development contracts issued to teams led by Lockheed (using a distributed architecture approach) and McDonnell Douglas (using a more centralized approach). This phase involved the establishment of the functionality and methodology of a PA system. The results were so encouraging that DARPA requested that the focus be changed to a real-time system. Subsequently, during the Phase 2 demonstration stage, Lockheed managed to produce, in 1989, a demonstrator that ran in real time. The roomful of computers used in Phase 1 was successfully reduced to a cockpit-sized configuration. This work established the basis for follow-on laboratory environment testing.

The idea behind the developmental program is to provide what one USAF spokesman calls a "special executive secretary" for the pilot. The "secretary" acts as a filter center for the pilot, deciding which calls to block and which to let through, and assigns priorities. The information is provided in a balanced and integrated manner. DARPA's strategic computing R&D efforts, especially those involving AI, are an essential part of the PA, especially because of the real-time requirement for PA to be truly effective.

PA Functional Areas - The PA program focuses on five functional areas. These are: mission planning, pilot-vehicle interface, situation assessment, systems status and tactics planning. The mission planning function gives the pilot increased flexibility by providing the ability to respond efficiently to new or changed threat conditions or updated target data. Areas covered include threat avoidance, route replanning or modification and navigation. Algorithms supply the pilot with "low observable" routes and monitors these routes for hostile activity, as well as fuel status and positional errors.

The pilot-vehicle interface function provides a variety of communication methods ranging from speech to visual and tactile modes, and can be tailored to use the methods preferred by the pilot, a critical aspect. The information can be presented to the pilot via such media as flat panel displays, a head-up display, HOTAS (hands-on-throttle-and-stick), and voice. AI software is used to optimize content and timing of the data presented, with the aim of managing pilot workload and reducing distraction.

The situation assessment function is a critical area, for if the situation is not clearly presented, the solution may address the wrong problem. Situation assessment provides clear, prioritized data on the external environment based on inputs from sensors, with threats and targets prioritized, and the pilot informed as to the threats endangering his mission. Friendly forces are also monitored.

The system status function monitors internal aircraft systems such as avionics and engines, and diagnoses faults and malfunctions, as well as determining what effect a specific system downgrade will have on the overall mission. The function provides a capability to reconfigure around the fault, and this, along with the system's fault delineation capability, affords the pilot more flexibility in determining his ability to continue the mission.

The tactics function not only assists the pilot in determining how to fight, but also coordinates roles and responsibilities within a squadron, thus ensuring that double targeting does not occur and that no target is left uncovered. This function is particularly valuable in beyond-visual-range air combat.

PA Timeline - The originally formulated PA program was structured as a five-year effort, divided into two phases. The primary purpose of Phase 1 was to demonstrate and evaluate potential benefits of AI technology in enhancing mission effectiveness of future advanced fighter aircraft. During 1987 to 1988, an experimental PA system was prototyped for the purpose of developing a system framework and designing the interaction between the assessment functions (aircraft systems monitoring and air-battle situation analysis) and the planning functions (reactive tactical planning and mission and route planning). This work culminated in 1989 with a successful Demonstration 2 that featured an integrated set of cooperating expert systems, operating within a limited mission scenario and performing in non-real-time (defined as six to eight times slower than real-time). Both McDonnell Douglas and Lockheed completed feasibility demonstrations of their respective designs. McDonnell Douglas had teamed with Texas Instruments on its initial PA work. It demonstrated an operational rate approximately 120 times slower than real time. Since then, Douglas has teamed with FMC and has demonstrated an improved PA design that ran at 1/10 the speed of real time, while Lockheed's prototype ran at about six times slower than real time.

Phase 2, which began in 1990, continued the use of effective technical and management strategies developed during Phase 1. These strategies included a pilot-centered vision of the system, the use of a structured prototyping development methodology, and an aggressive engineering approach with customer involvement at all levels. Phase 2 culminated with Demonstration 4, held in July 1992, which encompassed a full-mission, man-in-the-loop scenario with a series of complex, time-critical problems that exercised the PA system and exhibited the value added to the pilot's performance. Ten F-15 pilots from Langley AFB and Eglin AFB participated in a five-week test at the PA lab in Marietta, Georgia. The pilots flew 16 different advanced air-to-air mission scenarios to test the PA's aiding aspects and situational awareness performance capabilities. The pilots rated the PA as an overall excellent concept that lightened the workload, especially during high-load times such as being attacked by SAMs.

Other PA Developments - Although the initial PA program has been completed, Lockheed is committed to exploiting the PA technology in several applications for the future. Programs or studies are underway in a variety of areas. The PA is being investigated for application to military programs such as the F-22; multicrew aircraft such as the Army's rotorcraft, the B-1 bomber, and the A340 Airbus; and for the C-130 Special Operations Forces Applications Study. The PA concept was potential industrial application, and could also be used in decision aiding systems such as knowledge-based aircraft maintenance systems and the Atlanta Regional Advanced Traffic management System.

Lockheed Martin is applying the PA concept to commercial aviation in program Diverter. In this instance, the main function would be to provide aircrews with real-time flight path advice for unscheduled diversions such as those imposed by inclement weather. The ongoing effort is funded by NASA's Langley Research Center and is aimed at aiding commercial airline pilots who will be operating within the next-generation air traffic control system environment that will result when the National Airspace Plan (now termed Capital Investment Plan - CIP) is finally fully operational. The commercial sector's demands are not nearly as complex as those of the military, but there is a definite need for equipment that increases situational awareness, especially since the growth in air traffic shows no sign of slowing. The skies over Europe especially will be seeing massive traffic growth and, combined with the typically short trip legs, will create conditions which will increase the potential for human error.

Boeing is also performing work on AI-based pilot decision-aiding systems, which the company feels will have a long-term bearing on the work it is doing for the ATF pilot-vehicle interface, although Boeing is not developing the systems with any specific platforms in mind. It has three elements in process: situational assessment, cockpit information management, and hydraulics diagnosis, with the objective of integrating the three functions. Daimler Benz Aerospace in Germany is also doing work in the area, although the company's focus seems to be more on the commercial sector. Dassault Aviation in France is also pursuing a PA system, or "electronic copilot" as it is known, for French Air Force applications.

The US Air Force is funding the Integrated Control and Avionics for Air Superiority (ICAAS) program, an effort that may be viewed as a preliminary PA program. ICAAS's aim is to develop technology that will allow fighter pilots to assess tactical situations faster and more accurately. A primary focus is the enhancement of cooperative efforts while in the combat situation. When installed, the ICAAS will help combine information from several sensors, aid pilots in planning attacks, and provide assistance in defeating hostile missiles. The F-15 is being used as the testbed platform using two ICAAS-modified F-15s. There is a potential for equipping the ATF with ICAAS.

Further down the road in the field of biocybernetics, research institutes are working on the goal of creating a computer that can read a fighter pilot's mind to assist in operating the aircraft. Initial steps required to allow thought-controlled computers are already in progress. The New York State Department of Health Wadsworth Center for Laboratories and Research in Albany has developed a system that allowed trained users to move a cursor around a computer screen using only thoughts. Although such a technique is not operationally productive for true thought-controlled computers, it does provide a great deal of insight into the operations of the human brain. From this insight will come tomorrow's aircraft control/operating systems as aerospace designers explore ways to shorten pilot reaction time.

Rotorcraft Pilot's Associate - The Army's Pilot Associate effort began later than the Air Force program and focuses on rotorcraft applications. This effort began in the mid-1980s with an AI-based concept that was targeted to replace the second-seater. However, by the time that the RPA officially began, the decision had been made to augment the crew instead of actually replacing a crew member. A contract to begin concept development was not actually issued until mid-1993 when a team headed by McDonnell Douglas received a $70 million contract to develop and demonstrate the RPA. Other team members include FAAC Inc, Georgia Tech Research Institute, IBM, Honeywell Inc Systems and Research Center, Martin Marietta Advanced Technology Laboratories, Praxis Technologies, and Reticular Systems.

This is a three-stage undertaking, commencing with initial design and assessment in a rapid prototyping laboratory environment. Phase 2 consists of full mission simulation, with more rigorous and in-depth evaluations. Phase 3 will see the RPA installed on an AH-64C helicopter equipped with MD's full-authority advanced digital flight control system and the Army's Advanced Helicopter Pilotage sensor system. Flight and operational demonstrations are scheduled to be conducted in 1997 at Fort Hunter Liggett, CA. Knowledge-based systems will be applied in areas such as cognitive decision-aiding and the integration of advanced pilotage, armament and fire control, communications, controls and displays, flight control, navigation, survivability, and target acquisition.

The aim of the program is develop an intelligent associate that will aid Army helicopter pilots in understanding the vast array of battlefield information, mission planning, and managing the complex systems aboard his aircraft. The pilot will thus be able to spend his time fighting the battle rather than just flying his helicopter. Another feature will be real-time mission planning, with mission planning updates to be available in five seconds or less. An IBM-developed high performance parallel processor will be incorporated to cope with the massive data flow required for this task.

Market Outlook - The outlook for the PA-type system remains good over the long term. Engineering hurdles and funding priorities will most likely stretch out the program's development through the late 1990s. However, while its development future remains strong, operational acceptance by pilots will be the largest challenge PA must overcome if it is to make it into next-generation aircraft. There appears to be a bit of reluctance on the part of some air crews to accept the benefits of a PA system. They feel that the system would basically be telling them what to do in flying the aircraft or that they would not be able to absorb all the information put forth by the PA, especially in a combat situation. Also, there are psychological factors involved in that most pilots feel more comfortable looking out from the cockpit and seeing their surroundings with their own eyes, as opposed to the submarine-like computer-generated imagery of a windowless cockpit.

The Lockheed/General Dynamics/Boeing YF-22A was selected in April 1991 to fulfill the USAF ATF requirement. While it was originally envisioned that the ATF would have a PA capability, that intent has been modified to incorporate only certain features, including the situation assessment and response planning portions.

Only the mission manager system in the F-22 incorporates an AI capability at present, but there remains the potential for more AI capabilities to be added relatively soon, especially in the areas of diagnostic and health management.

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