Appendix B

COMPUTER AND COMMUNICATION TECHNOLOGIES IN FAA'S NATIONAL AIRSPACE SYSTEM PLAN

Members of Working Group 2 (March 9, 1982)

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Summary

In its National Airspace System (NAS) Plan made public in January, the Federal Aviation Administration (FAA) outlined its proposals for modernizing the Nation's air traffic control (ATC) system.

Working Group 2 commended the NAS Plan as a worthwhile statement of goals and an advance over previous plans. However, the panel also suggested that FAA may have underestimated both the technological risks inherent in individual elements of the Plan and the scheduling risks involved in implementing and integrating these elements into a highly automated system. In general, the participants felt that there was sufficient uncertainty in FAA's traffic forecasts to require greater flexibility in its implementation schedule, particularly for the en route computer replacement.

While the group agreed that improvements are needed, most members were skeptical of FAA's plan to "rehost" the current en route software in a new mainframe computer. Because that software, too, will eventually be replaced, some suggested that the interim rehosting step could be bypassed. By upgrading 9020A computers to 9020Ds, FAA could increase its computational capacity sufficiently to postpone congestion at any en route center until the mid-1990's. This would give FAA additional time to benefit from improved software and the distributed architecture of modern computer hardware.

The group also indicated that the lack of a clear description of system architecture made it difficult to judge the details of computer and communications system design. Members also suggested that FAA devote additional attention to satellite-based systems for communication, navigation, and surveillance, as well as the impact of greater automation on those who use the ATC system.

Though the word "National" is in the title, the group noted that the NAS Plan is structurally incomplete. It largely excludes military aircraft and ATC facilities, as well as the majority of the general aviation (GA) fleet which operates under Visual Flight Rules (VFR). Some participants also questioned whether the sharp distinction between "controlled" and "uncontrolled" airspace can be maintained in the future.

The Plan

Working Group 2 agreed that the Nation's ATC system needs to be modernized, despite their questions on technology and timing. In an observation that reflected the group's thinking, Chairman H. Clark Stroupe, vice president of Booz-Allen & Hamilton, Inc., said, "No one . . . has seriously entertained the concept of doing nothing. " The group also had general praise for FAA's 1982 NAS Plan, which the agency made public in January. Consultant Gilbert F. Quinby felt it was "to be commended at a policy level, " and Stroupe called it "a fairly significant set of goals, even bold in some sense, compared to some of the previous plans FAA has had. " Other participants echoed these overall evaluations.

The choice of technologies was generally considered to be well within the state-of-the-art, although there was disagreement about specific components. George Litchford, president of Litchford Electronics, commented that, "As far as using the new technology (goes), I think it's being used in a conservative sense. In aviation you can't plunge ahead with brand new technology. You usually have to use quite well-proven technology, and I think in that sense it's a fairly conservative plan. "

Others felt the Plan might be too conservative. "I looked at the technology, " said Paul Baran, President of Cable Data Associates, "and it looked very, very old . . . . There seems to be a slight mismatch there between what we're able to do and what we're proposing to do." W. W. Buchanan, senior associate with SES, agreed. "Certainly the technology doesn't show an awful lot of advancement over the plans of 5 years ago or even 10 years ago, " he said.

Several participants expressed apprehension, however, particularly when the discussion shifted from the individual technologies to the way they would be integrated and implemented by FAA. Dr. Willis Ware of The Rand Corp. put these concerns most strongly, saying "It's dripping with technical risk all over. About every third project talks casually about software. I would judge that most of those software remarks are not well-founded in terms of the resources needed to accomplish them. The en-route-control computer replacement I would regard as especially risky, primarily because of the software as it now exists in FAA. And they have a terrifying problem of how to get anywhere from where they are now." (See below under "Rehosting" and "Software and Sector Suites.")

In addition to its technological risks, the NAS Plan was also criticized for its omission of important elements of the aviation community, notably the armed services. "The military seems to be much more aware that they're part of the National Airspace System than FAA does in this planning document, " said Stroupe. Litchford agreed, adding,"To FAA, it's like the military doesn't exist, and I think that's one of our major problems in all this documentation. "

"The National Airspace System is defined in the FAA plan as an FAA system only," said Mike Ball of the Air Force, who represented the Department of Defense (DOD). It "doesn't address an architecture for the entire system because it leaves out the military-agency facilities. But beyond that, it's definitely not an airspace system plan because it doesn't address the overall needs of other people who are currently operating outside the IFR (Instrument Flight Rules) system. " This includes most of the general aviation fleet, which FAA puts at 214,000 aircraft, whose operations are largely under VFR. (See below under "General Aviation.")

The group was also concerned about the haste with which FAA proposes to implement the NAS Plan. It was the consensus of Working Group 1 that FAA's traffic forecasts, based on last year's economic projections from the Office of Management and Budget (OMB), were unduly optimistic. Working Group 2 seemed equally skeptical of agency projections of an overloaded en route ATC system in the mid-1980's.

In addition, there were questions about the timing of the implementation schedule itself. The high level of automation in the NAS Plan involves "a whole new series of problems, " according to Dr. James Burrows, director of the Institute for Computer Science and Technology. If one component falls behind schedule, it would send "ripples into everything else" in a way that "is not clear from looking at this book. " Ware shared this view: "If anything slips, the whole thing slips. "

Dr. Robert W. Simpson, professor, Flight Transportation Labs, MIT., who chaired Working Group 1, observed that, "One thing I'm sure of is that the forecasts are uncertain, and if I were planning a system this large I'd be planning it in such a way that I could accommodate it one way or the other. " Ware agreed: "It (looks) like a logical sequence if you have no problems . . . (but) there's no plan for what happens if you have real problems."

Technologies

Rehosting

The group devoted a considerable amount of attention to FAA's decision to "rehost" the existing en route computer software in a larger mainframe computer, and only then replacing the trouble-plagued software itself. In an observation shared by many members of the group, Stroupe said, "I couldn't find the compelling reasons for a short-term rehosting approach to the computer (replacement) that seem to outweigh a lot of compelling reasons for a better long-term solution with more modern technology. "

FAA spokesman Neal Blake explained that agency forecasts of air traffic growth were crucial in Administrator J. Lynn Helms's decision to rehost the ATC software in a new computer. "We clearly needed to get on with increasing the capacity of the air traffic control system in this decade, now in the late 1980's or early 1990's or beyond . . . . He (Helms) felt that we could not take on a program which had both hardware and software risks and be able to provide any near-term improvements in, say, the mid-1980's timeperiod."

Ware, who felt that the two-step computer replacement was "especially risky, " reacted to Blake's argument by asserting that "the portability of software is mythology" and adding that "the system-design contractor (for phase two) will be constrained, for better or for worse, by the choice of the rehosting instrument or by whatever reasonable enhancement can be made in the host by upgrading within a family of computers. "

Several members of the group then suggested that FAA might be able to skip the rehosting step entirely if it were willing to upgrade its present 9020 computers where necessary. FAA forecasts "operational delay days"* during the 1980's at only four en route centers, all of which use the 9020A computer. The 9020D, already installed at 10 centers, has 2.5 times the computational capacity of the A-model. FAA documents suggest that upgrading 9020A computers to D models would alleviate congestion at ATC centers until the mid-1900's. FAA has already successfully upgraded from 9020A to D in its Jacksonville center, and the complete engineering and data package resulting from this experience considerably reduces the technical risk of doing so at other centers.

In the shorter term, FAA might also be able to relieve en route congestion by redrawing the boundaries of certain ATC sectors. Zalman Shaven of OTA pointed out that the centers where congestion has been projected "are adjacent to areas covered by centers that have excess capacity. " Ball suggested that "maybe the solution to this capacity problem is to bulge out your center boundaries" to alleviate congestion.

When asked if the agency had considered upgrading the affected A-models to D-models, Blake replied: "We looked at it, obviously . . . . I think the Administrator felt it was better to get a new system . . . we could build on . . . until we could get what we like . . . . The earlier we can get the new system in, the earlier we can start consolidating—saving people and saving money. "

Buchanan agreed with Blake. "I am, perhaps, a little bit more uncomfortable with keeping the 9020s any longer than is absolutely necessary . . . . I would think it would be very important that FAA get some new, modern computer power at the earliest possible time. "

This appeared to be a minority view, however. Baran's observation seemed closer to the group's general perception. "I wonder, " he said, "whether it may pay for us just to start now working on the high-level (programing) language and go parallel with development of the computers, so when the time comes, we won't find ourselves implementing computer systems that are 5 or 10 years old to start with . . . . You either swallow a big pill now, or you're going to have to swallow a lot of pills the rest of the way. "

Several members of the working group also expressed concern about FAA's strategy of awarding both contracts (new host and new software) at the same time. They raised the possibility that only one contractor, IBM, might be in a position to win them.

Burrows characterized the situation as "a procurement morass. It seems to me that when you start talking about replacing a 9020 and converting the current software, that is IBM . . . . Once you have emplaced IBM equipment as the follow-on equipment and talk about modifying that equipment to be compatible with the new software, . . . that is IBM again. So what they have . . . (is) a two-phase procurement which has guaranteed IBM in both of them. "

Litchford agreed: "It is going to be hard for them to really solicit open, system bids before they select the whole. " Anthony Csicseri of the General Accounting Office (GAO) added, however, that GAO had already informed FAA that the plan was subject to GSA procurement regulations requiring competitive acquisition, and that compliance "(would) not slow down the acquisition process needed to bring in a rehost system, if that's what's really required. "

In the end, however, the issue of rehosting remained unresolved. "It looks to me, " speculated Ware, "that what the Administrator has announced as a strategy

*Defined by FAA as a day when utilization of the 9020's processing capacity exceeds 80 percent of its available capacity for 1 hour or more.

is to get the money flowing, because he can’t count on what the congressional attitude will be in 10 years . . . . Given the vagaries of how Government works and congressional funding, just the prudence of delaying a decision that might otherwise be sensible becomes questionable. So, therefore, it is really a judgment call. ”

Stroupe agreed. “It is a political and not a technical issue .“

Software and Sector Suites

In his written presentation, FAA’s Valerio Hunt indicated that “two major parallel efforts will be initiated . . . this summer. One of these efforts will be the procurement of a host computer that will possess the capability of executing the existing **9020** software. This strategy will provide the earliest increase in computer capability that can also be used as an integrated part of the total system replacement . . . . The second parallel effort initially focuses on a total integrated system design for the entire system. This is followed by development of the new sector suite (of display terminals for controllers), a suitable data network, and the new software system.”

Although Hunt as well as Blake characterized these programs as “parallel,” they are not independent of each other because FAA expects its host computer will subsequently run the new system software. As a consequence, the hardware decision could have a considerable impact on software design and the functions assigned to the sector suites.

“The consolidation and integration of the terminals with the en route system seems very bold, ” said Stroupe, yet in examining the NAS Plan he found that “the whole partitioning and architecture of the system is not clear in many of the alternatives. ” Later, he asked: “has their proposal precluded going to any appropriate architecture for a very advanced, very automated system in the **‘90s?”**

Ware replied that “your question is unanswerable because, in this document, there is no evidence of a system architecture . . . . It’s the classical jurisdictional partition. The en-route centers are doing their upgrading. The communications guys are doing their upgrading. The Jacksonville center is doing its thing. There is no system architecture described in there. ”

When members of the group sought more details on the architecture of the new ATC system, Blake indicated that the agency has placed most of the burden of system integration on the contractors who will provide FAA with the elements of its new ATC system. “The vendor will deliver us an operating system which includes the hardware with whatever modifications he feels are proper ones for his machine . . . So he is delivering us, really, a turnkey system . . . . We will assume that in this decade we cannot build a perfect hardware-software package and that we will have to operate at the sector-processor level during certain types of failure . . . . The system contractor delivers a set of sector suites suitable for terminal and en route operations and tower operations. He delivers a new software package which includes all of the functions that were resident in the 9020s plus direct-route capability, which are the first steps of the AERA (Automated En Route Air Traffic Control) program. ”

Ware characterized this development and procurement strategy as “kind of a neat gambit, ” one that “pushes a lot of risk off FAA and onto those vendors.”

Communications

In his presentation to the group, FAA’s Norman Solat outlined the agency’s planned changes in the ATC communications systems. Several participants had indicated that this aspect of FAA’s proposal was difficult to assess because of the lack of detail in the NAS Plan.

They also questioned Solat’s conclusion that the agency’s investment in the existing communication system precludes major change or the substitution of a radically different technology. Solat pointed out: “What we have got at the facilities are the rights of way and the equipment and the microwave links. They are already there and paid for and owned by the taxpayers.”

Ware took issue with Solat on this point. “I would argue that communications technology is not an issue, ” he said. “Just go out and buy it . . . . How do people in the present world shove data around mixed with message traffic? Packet nets. Look at the world. That’s the way it’s going, and FAA’s dedicated line (approach) is kaput. ”

Harrison Rowe of Bell Laboratories wondered about characteristics of the data transmissions that determined FAA’s design of the communications portion of the NAS Plan. “The basic things that drive what goes on in communications are not spelled out here in enough detail to let you get an informed opinion about whether it makes sense or not, ” he said. “We haven’t heard any of the technical details about this Mode-S (transponder) and the (air-ground) data link and how it is all going to work. ”

Rowe pointed out that the frequency of transponder interrogations can be of critical importance. If they occur infrequently, the Mode S system would be adequate. “But if all these people flying around are interrogating each other all the time, there may be a lot of traffic going on up there. You wonder if that system is going to overload or if it's going to create interference hundreds of miles away. "

Satellites

In "reading the communications part" of the NAS Plan, said Baran, "one has the feeling that you're reading papers maybe 20 years old. There is no appreciation for the satellite and what it means in communication systems. " Litchford agreed. "Nowhere in the Plan, " he said, "are they really looking at satellites seriously until after the year 2000."

Solat argued that it is not clear whether a satellite-based communication system is cost-effective for handling trunk message traffic in the ATC system. FAA now has 2,000 equivalent voice-grade circuits, and Solat envisioned that a satellite Earth station could serve as the distribution center for messages on those circuits. But, he added, "right now, because of the capacity and the loads that are on those circuits, we don't see that there is a major payoff."

DOD is also concerned, Ball noted, because FAA appears to have "summarily dismissed" the NAVSTAR satellite and the Global Positioning System (GPS) used by the armed forces. "The problem between the FAA and DOD is how much of the coding are we going to release to civil use, " he said. "In other words, we can locate (aircraft) extremely accurately, but we don't necessarily want to give that capability to everybody in the world. " He went on to say that the amount of coding proposed by DOD for release to civil aviation more than meets the navigational accuracy requirements for nonmilitary users of the airspace.

FAA, according to Litchford, "argues that you really can't get landing accuracies" with GPS. Stroupe took a different tack. "The fact that you can't use GPS to land an aircraft doesn't say you shouldn't use it to replace one-mile-accuracy radar. "

User Impacts

Some participants felt that, in drafting the NAS Plan, FAA did not give sufficient attention to the needs of certain elements of the aviation community. The Plan focuses almost exclusively on how to achieve a highly automated form of control for IFR traffic, especially during the en route portion of flight. There does not appear to be adequate concern for VFR traffic or operations at low altitudes (under 6,000 ft).

Moreover, the plan is written almost wholly from the perspective of the ground-based air traffic controller. Litchford labelled the plan as "a controller's wish book. In other words, it is aimed at the controller himself; it doesn't talk about the user's needs."

Department of Defense

The military services account for about 20 percent of all domestic traffic and as much as 46 percent of operations at en route centers like Albuquerque. In addition, they must also protect the Nation from airborne intrusions and attacks. Nevertheless, DOD "was not consulted by FAA prior to the announcement of the plan, " according to Ball. The NAS Plan, in his view, "essentially has been designed as an improvement to a point-to-point air transportation system. But the majority of DOD use of the national airspace is not point-to-point air transportation but, rather, training missions . . . and they are basically left out of the system. "

That omission also seems to be reflected in the air traffic growth projections on which the NAS Plan was based, FAA's "definition of the system demand is misleading, " according to Ball. FAA's "traffic count, which gives the military traffic as 4 percent, is based on (operations at) FAA towers only. But if we take a look at all the traffic that is controlled in the IFR air traffic control system in the CONUS (Continental United States), DOD accounts for about 20 percent of the traffic count. " Much of this traffic (and a good bit of civilian traffic as well) is handled by DOD's 233 ATC facilities and nearly 8,000 controllers in CONUS.

DOD has cooperated with FAA to ease the effects of the controllers' strike by transferring "a good deal of our flight operations from demand on the FAA system or the FAA portions of the system to our own facilities, " according to Ball. Moreover, DOD has "a large program under way to relocate most of the training areas . . . to get away from the (areas of) heavy civil air traffic and try to help out. "

DOD is concerned that FAA's requirement for Mode-S transponders may cause an increase in military expenditures with no appreciable increase in benefits. "Cost estimates to equip DOD aircraft with Mode-S are in excess of a billion dollars, " said Ball, "and we're not sure Congress wants us to spend that kind of money for something that doesn't enhance our war-fighting capability."

While Mode S avionics may have no appreciable effect on the aerodynamic performance of commercial or GA aircraft, they could have an adverse impact on military aircraft. "There is great concern (at DOD) about sticking more black boxes and more displays and more antennas on high-performance fighter aircraft, " said Ball. "From what we've heard about the antennas that will be required for TCAS (Traffic Alert and Collision Avoidance System), we're going to lose operational capability on fighters and other high-performance aircraft. "

On the broader question of airspace surveillance, FAA indicates that, in the future, it will rely less on primary radar to monitor air traffic. "We see an evolution toward a system that is more directly based on Mode-S, " Blake told the group. "The plan says that by the year 2000 we hope to have pretty well dropped our dependence on primary radar for en route services. That is, the current ATC type or the joint type radar. And we will be using primary radar , . . primarily for weather detection. "

FAA believes the ATC system will be able to maintain better surveillance over air traffic through secondary radar and Mode-S transponders. But what about aircraft not equipped with these beacons? Ball expressed concern about the implications of this basic change in the surveillance system. "The elimination of the surveillance capabilities by the year 2000 is acceptable if we feel that (there is) another means . . . of maintaining the air defense and air sovereignty missions of the Department of Defense. "

Military training missions will also be affected by the shift to secondary radar. "Half of our low-level training routes right now are flown under Visual Flight Rules because we don't have adequate communications or surveillance from the FAA to operate under Instrument Flight Rules, " said Ball. "There is concern about the validity of VFR when we have got an F-4 down at 300 feet, going at 500 knots. It is a bit difficult for him to see and avoid (other aircraft) or for the Piper to see and avoid him. "

Ball carried this criticism one step further. "The military expends a lot of money and effort in providing to the FAA system information on the scheduling and actual use times of those routes, . . . but the whole thing is totally inefficient right now. The schedules are buried in a pile of messages that are still on a clipboard somewhere. There is no graphic display. The Flight Service Station guy is overworked, giving weather briefings and everything else. He is not required to give a mandatory briefing of military activities to the general aviation VFR pilot—only on request. "

General Aviation

Even though the NAS Plan affirms freedom of access to the airspace as a basic right, FAA envisions a highly automated ATC system oriented toward operation of well-equipped aircraft flown by experienced pilots. Some segments of the GA fleet, notably turbine-powered business aircraft, are of this type and regularly use the ATC system, but most GA aircraft do not. Yet the NAS Plan devotes little attention to the 90 percent of GA operations that take place under VFR. The NAS Plan apparently assumes that the present distinction between "controlled" and "uncontrolled" airspace will continue far into the future, but if FAA projections of a greatly expanded GA fleet come to pass, the extent of positive control may have to be broadened considerably into uncontrolled areas where most VFR flights now occur.

Some participants did not think the difference between IFR and VFR, or between controlled and uncontrolled airspace, could be perpetuated indefinitely. One of them was Ware, who asked: "Does this plan provide a system which is a proper foundation for gracefully extending (air traffic control) . . . down to sea level?"

"That's an important issue, " said Baran, on which FAA "punted . . . implying that we're going to have VFR forever . . . , I think a plan that covers the period through the end of the century should include the implications of that potential change. " In the future, perhaps near the turn of the century, said Ball, "the Visual Flight Rules concept just will not work, and we'll have too many 'midairs, ' and the American public will demand a total airspace system. "

The direction charted by FAA for the ATC system will necessarily increase the cost of entry with the requirement for Mode-S transponders and other avionic equipment. "If one expects people to voluntarily equip with something, there has to be a benefit; there have to be services, " said Blake. And in the future, he continued, "if you want to get the good ATC services, you will have to buy it. If you don't want them, that is your choice. "

FAA forecasts indicate that significant growth in the size of the general aviation fleet will result in much greater demand on its ATC centers. Quinby took a mixed view of that projection. "The count of the active general aviation fleet that comes out of this forecast is substantially higher than what seems realistically attainable, hangarable, maintainable, manufacturable and so forth, " he said. However, he also contended that "it's conceivable . . . that half of the total general aviation active airplanes will be routinely engaged in the ATC system" in the future. High-performance corporate aircraft, the heaviest GA users of ATC services, today comprise the fastest growing segment of the fleet.

Automation

The new ATC system would make more extensive use of computers and automated modes of operation to increase the productivity of controllers. FAA claims that, when hardware and software are operating, higher productivity will lead to lower manning levels and significant cost savings,

"I was interested in the claims that are made for personnel savings, " said Buchanan. "It seems that all of the actions, principally the automation phases of the project, claim substantial savings in personnel. One wonders if FAA has really considered, though, what kind of staffing enhancements they would have to have to adequately support (and maintain) . , . a considerably higher level of automation than they are accustomed to handling. "

Burrows expressed similar concerns. "There are statements about how we are going to load up the people by adding more automation, " he said, "and I was wondering whether we've done experiments to show that was true . . . or whether those were just faith statements, that somehow between here and there we'll figure out how to do that."

Simpson stressed the importance of "human interaction" with an automated control system, where much routine decisionmaking is done by computers. "It's not going to be just keyboarding and monitoring and watching the software do the work. (Ideally, it should) be the controller commanding that software to do what he wants it to do. " No decision should be "made by other than a human being. The machine can present the decisions to him. He's got to pass it through his brains and say, yes, that's what we want, and pass it back to the machine . . . . Otherwise, the machine is controlling, and the controller is trying to keep up with the decisions the machine is making. I don't think we'll ever get to that position. "

The Rand Corporation Report

The Rand Corp. recently released a report entitled "Scenarios for Evolution of Air Traffic Control" in which it takes issue with FAA's approach to automation in the AERA program. The Rand report was not discussed specifically by the group, since it was not available at the time of the meeting. However, the concerns about automation expressed by working group participants closely paralleled the findings of the Rand study (see attachment B-l).

Rand's principal conclusion is that the goal of full automation sought under AERA is a questionable research and development strategy that may present serious problems with regard to safety, efficiency, and increased productivity. An ATC system in which computers make most of the time-critical decisions in controlling aircraft, while the human operator serves in a managerial and back-up role, implies a needlessly complete and irrevocable commitment to automation.

Rand argues for an alternative approach, called "shared control, " that would construct the future ATC system as a series of independently operable, serially deployable modules that would aid—not replace—the human controller and keep him routinely involved in the minute-to-minute operation of the system.

ATTACHMENT B-I: EXCERPT FROM "SCENARIOS FOR EVOLUTION OF AIR TRAFFIC CONTROL"[1]

VI. CONCLUSIONS

We have considered several alternative ATC futures, beginning with a Baseline case in which nothing beyond the most conservative R&D projects paid off. We have concluded that the approach of simply adding more and more controllers is ultimately counterproductive from a performance standpoint. We have examined the FAA's plan to use advanced computer science technology to construct a fully automated ATC system for application near the year 2000. The expected aircraft safety levels, fuel-use efficiency, and controller productivity have led us to question that plan and to suggest that there maybe a middle ground consisting of a highly, but not totally, automated system.

We believe that pursuing the goal of full-automation AERA—with little regard for interim systems or evolutionary development-is a very questionable R&D strategy for ATC. It seems unlikely that a large-scale multi-level AERA system that can effectively handle non-routine events, show stable behavior under dynamically changing conditions, and be virtually immune to reliability problems can be implemented in the foreseeable future. Human controllers may be required to assume control in at least some of these situations, although at present there is no conclusive evidence that they would be able to do so; indeed, some evidence and opinions from the human-factors community suggest that they would not be able to.

The AERA scenario presents serious problems for each of the three major goals of ATC—safety, efllciency, and increased productivity. By depending on an autonomous, complex, fail-safe system to compensate for keeping the human controller out of the routine decisionmaking loop, the AERA scenario jeopardizes the goal of safety. Ironically, the better AERA works, the more complacent its human managers may become, the less often they may question its actions, and the more likely the system is to fail without their knowledge. We have argued that not only is AERA's complex, costly, fail-safe system questionable from a technical perspective, it is also unnecessary in other, more moderate ATC system designs.

Some AERA advocates assert that it is necessary to keep the human out of the time-critical loop to achieve productivity and fuel-use gains. We question that belief as well. AERA may well achieve 100 percent productivity increases in the en route high and transition sectors, and it may indeed facilitate more fuel-efficient air operations. But if the controller work force almost doubles, as expected, by the time AERA comes on-line, and AERA's domain of applicability is limited to the

[1]The Rand Corp., R-2698-FAA, November 1981

simplest of sector types, its ultimate effect may hardly be felt, since the actual ATC bottlenecks occur elsewhere. Further, greater fuel efficiency comes from many sources-some as simple as present-day relaxation of procedural restrictions, some as complex as the planning modules of AERA and Shared Control. AERA may meet the goals of ATC by 2000, but the costs incurred along the way will be very great-in dollars, in fundamental research that must be completed, and in restrictions on the controller's role.

Ultimately, the AERA scenario troubles us because it allows for few. errors or missteps, The right choices have to be made at the right times, or a failed AERA scenario would degrade to a more costly and delayed version of the Baseline scenario. In the attempt to construct a totally automated ATC control system, unacceptably high possibilities and costs of failure overshadow the potential rewards of success, .

Our main conclusion is that such an overwhelming dependence on technology is simply unnecessary. If the planned AERA scenario were altered only slightly, it would be essentially equivalent to the Shared Control scenario. All of its technical building blocks are present in Shared Control:

- Air/ground datalink communication.
- Strategic planning (profile generation and alteration) and operator displays.
- Tactical execution.
- Track monitoring and alert.

Missing, however, is the right principle for piecing these building blocks together. Under AERA, they would be fully integrated into a single problem-solving system which extends its capabilities by infrequently requesting human action; under Shared Control, the building blocks would themselves be extensions of human capabilities. Operationally, this shift in perspective requires two modifications of AERA plans:

- **The role of man under AERA would be expanded so that he is routinely involved in the minute-to-minute operation of the system.**
- **The system would be constructed as a series of independently operable, serially deployable aiding modules.**

The state of the art in ATC problem-solving techniques does not validate the minimal AERA human role; neither does established knowledge about human limitations or capabilities in this domain, Insisting that man be essentially automated out of such a critical control system is an unnecessarily high-risk approach.

If the system is designed to support him, we would expect the future ATC specialist to take a very active and creative role in manipulating his aiding modules. Safety could be assured by assigning the machine primary responsibility for routine separation assurance tasks at the lowest levels. The specialist should be responsible for comprehending situations at high levels of abstraction and activating modules to meet the ever-changing demands of those situations. He should be able to adjust a module's parameters and its relationships to other modules so that instead of simply monitoring the machine's preprogrammed sequence of instructions, he actually controls the outcome. He should be given the authority to determine which operation the machine performs and which he performs. He should be given the opportunity to learn all of this gradually and to influence the system's design before it is finalized.

This shift in perspective captures the spirit of this report. Specifications of module capabilities and their sequence of implementation are best left to designers who are intimately familiar with the engineering details. We have presented just one of many alternatives in which man has a significant ATC role; the details of the system design need refinement and may indeed undergo great change in the process. For example, our Shared Control scenario suggests implementing digital communications before providing any planning aids at all. Perhaps events will dictate otherwise-a late DABS introduction and an early development of automated planning techniques could reverse this sequence. Fielding a planning aid first as a stand-alone module would not compromise the Shared Control scenario in any way. The essence of the Shared Control scenario is reflected in its name-man and machine must work together and *share* in the overall control function of ATC.

Our key concern is that the human specialist's unique capabilities be acknowledged and the technical uncertainties of an AERA-like system be recognized and dealt with before too much of the Baseline scenario comes to pass. If this is not done, we risk relying solely on an unproven, costly technology to meet the nation's demands for ATC service. We have shown not only that there is a feasible alternative, but also that this alternative may result in lower costs, a higher level of performance, and a more satisfying role for the personnel who will be responsible for moving air traffic safely and smoothly.