

## THE ACT TRANSPORT-

## PANACEA FOR THE 80'S OR DESIGNER'S ILLUSION?

## Panel discussion

Active control technology is being promoted as a panacea for the transports of the 1980's, reaping performance gains, fuel savings, and increased return on investment. Are these projections realistic or merely designer's illusions?

A panel discussion was held at the symposium which attempted to make an objective and pragmatic assessment of the standing of active control technology. The discussion focused on the standing of active control technology relative to civil air transport applications, the value as opposed to the cost of the projected benefits, the need for research, development, and demonstration, the role of government and industry in developing the technology, the major obstacles to its implementation, and the probable timing of the full utilization of active control technology in commercial transportation.

The panel moderator was Joseph Weil, Director of Research at the NASA Flight Research Center. The panel members were William E. Lamar, Deputy Director, Air Force Flight Dynamics Laboratory; Richard P. Skully, Director, Flight Standards Services, Federal Aviation Administration; Arthur J. K. Carline, Manager, Advanced Transport Technology, Fort Worth Division, General Dynamics Corporation; Clifford F. Newberry, Director of Engineering, Wichita Division, The Boeing Company; Franklin W. Kolk, Vice President, Systems Planning, American Airlines, Incorporated; and Lloyd L. Treece, Vice President, Flight Operations-Control Division, United Air Lines, Incorporated.

The following is an edited transcription of the prepared statements of the panel members and the subsequent open discussion between the panel and the audience. A list of attendees is presented in the appendix.

*T. L. K. Smull:* Welcome to the ninth session of the symposium, which is a panel discussion on the topic "The ACT Transport-Panacea for the 80's or Designer's Illusion?" The moderator for the panel is Joseph Weil, Director of Research at the NASA Flight Research Center. This session is being tape recorded, and a transcription will appear in the proceedings.

*J. Weil:* Some of you may feel somewhat perplexed at this point. You may be wondering whether active control technology and control-configured vehicles are

ready for general application to advanced transport design or whether they are being oversold. Another question is whether events should set their own pace or the government should increase its support of this technology. The last paper yesterday, by Dick Holloway, provided an indication of what might be done to exploit the new concepts.

This morning we are fortunate to have on our panel six distinguished visitors who will give us the benefit of their experience. We have allowed each panelist the option of using 10 minutes to express any general views he might have on the overall topic of discussion. The panel will then focus its discussion on three inter-related questions: what are the potential payoffs of active control technology, what are the biggest obstacles to its implementation, and what new programs are needed to expedite its use in commercial transports. We are anxious to have enough time to discuss these subjects, because we feel they are extremely important. At the end of the panel discussion, we will accept comments and questions from the audience.

At this point I would like to introduce Ken Carline, who will begin the discussion.

#### COMMENTS BY PANEL MEMBERS

*A. J. K. Carline:* What is active control technology anyway? In the past, we've always been sure to relate advances in technology to the way they affect the airlines. I'm talking now in the context of this particular symposium, which is related to transport aircraft, although we've also heard some discussion of fighters.

The payoff—what's the payoff? I'm not sure that we really know what the payoff is. We've heard about taking weight out of the wing based on maneuver and gust load alleviation systems, but then we have a problem with fatigue, and we have to put some weight back in because now the wing has a fatigue life of only 5000 hours instead of 30,000 hours or something like that. So I'm not sure that all the money we've spent and all the studies we've done have shown a payoff yet. I think we ought to determine what we are doing with active control technology—it's got to pay off. Nothing I've seen yet proves that there is a payoff. We've seen General Dynamics and Boeing and Lockheed comparisons, and the benefits vary from 1 percent to 12 percent, which, I think, emphasizes the problem. I think we ought to spend some money on some really meaningful studies, something on the order of \$1 million instead of \$10,000, and get some meaningful answers on the real payoff. We ought to get the airlines in the act as well, not after the fact, the way we usually do. I was rather disconcerted to find that the panel organized to develop design criteria didn't include a member of the airlines. So I think we ought to determine the payoff. I believe there is one, but I'm not sure how much of one it is.

The other thing we ought to look at closely is how we can get the question of reliability sorted out. And we ought to think about how we could certify an airplane. Then we should implement active control functions, in, say, 10 or 12 cargo airplanes and find out what they do for us. Maybe putting an active control system into a cargo airplane will extend its fatigue life from 40,000 hours to 60,000 hours.

At the same time, I think we ought to have a good demonstrator airplane with active control functions, and not one where we can only alter the wing because we can't move the landing gear or something, as with the JetStar. We mustn't have too many restraints, or the answers won't be meaningful. I suggest that we build an airplane with a digital fly-by-wire system with no mechanical backup. Incidentally, the Concorde has flown 2700 hours, in monsoons and in Alaska, and they have never had a failure which would have embarrassed them if they had not had a mechanical backup system, so the record is pretty good.

Finally, we should take a serious look at flutter suppression, which I think worries people quite a bit.

First, let us determine the benefits of incorporating active control technology systems individually and in combination. We may need different combinations for different purposes. For a short haul we may need one combination, for a medium haul maybe another, because they have different and sometimes conflicting requirements. The studies should include detailed maintenance costs, where this is possible, and equipment redundancy requirements. Then, if the studies show the systems to be worthwhile, and I don't think we've really demonstrated that yet, NASA should sponsor two programs. In one, a technology demonstrator aircraft, for example a business jet with minimum restraints, could be fitted with the most promising active control functions, including a digital fly-by-wire system, which I believe to be the most promising. In the other, a small fleet of cargo airplanes could be modified to incorporate one or more active control functions in order to accumulate a bank of reliability and maintainability information. These programs would prove or disprove the studies we've done. I also think we'd do well to track the record of the Concorde control system. I talked for 2 hours with maintenance people last week, and they gave me a lot of information that showed its record to be good. They hadn't had any really significant failures. And the track record of the equipment was pretty good. I also think we ought to do a lot more research on flutter suppression. I think we are a long way from taking material out of the wing. Perhaps in time, in some future commercial transport, but I don't think it will be the next one.

*R. P. Skully:* I would like to start by saying that the FAA anticipates the incorporation of active control technology into civil transport aircraft with confidence and a sense of readiness. I'd like to mention some of the things we have done and are doing to prepare for the application of active control technology and control-configured concepts in the transport airplanes presented to the FAA for civil certification and commercial operation. First, the Federal Aviation Regulations have already been amended to accommodate the unprecedented technological advances of the decades just past. For example, a few years ago the captain's instruments were really kept separate, and when integrated systems came into being, we amended the rules to require that their design be such that the loss of display of information essential to safety in flight would be extremely improbable.

In addition, the operating rules have been changed to recognize inertial navigation systems and low weather minimum landing systems. In both cases, accuracy and reliability had to meet stringent criteria before we would approve using the equipment in operational aircraft. Area navigation systems of varying degrees of

sophistication have been accepted into the national airspace system. Digital distance-measuring equipment has been taken in stride, and altitude alerting and many other systems have come into being within the framework of the existing operational and airworthiness rules. The ground proximity warning system has been certificated and is being used today in some transport aircraft.

When a new aircraft is presented for FAA certification, we might find that it has flight characteristics or design features that were not envisioned when the rules were first written. We then apply what we refer to as special conditions to make certain that the current high level of safety is maintained when these new features are incorporated. Recognizing that our regulations do not always reflect the state of the art, we've initiated a new system of periodic airworthiness reviews. The last such review conference was held as I recall in 1960. Over 1000 changes to the regulations were proposed and are now being commented on by all interested parties in industry and government. In December of this year we will have a public meeting in Washington, D. C. in which the spokesmen for the various organizations will have an opportunity to present their views. We plan to have a 2-year cycle to minimize delays in implementing amendments to the regulations. This airworthiness review conference is being scheduled for 8 working days, and we are anticipating many people from outside the United States.

Another thing we are proposing is the introduction of flight simulation as a substitute for a significant portion of the airworthiness certification process. As most of you know, we have already authorized the use of approved flight simulators for certain pilot certification and proficiency requirements. The simulator will be used to plan and practice the certification flight program and to make preliminary evaluations of new aircraft, so that critical flight conditions can be pinpointed. Flight tests will be limited to the validation of these critical conditions. This will provide a way for industry to test its ideas against FAA standards, and, where appropriate, the FAA can develop new standards to cover new aircraft capabilities. This, in turn, will offer industry the potential for creating new markets and perhaps prompt international competition.

The responsibility for developing this proposal into a successful program should be shared by NASA, the FAA, and the aviation industry. The role NASA plays may be to provide advanced simulators and data reduction facilities. Automated data processing for the simulator data is needed, of course. In addition, NASA engineering support could help the industry and the FAA to become more familiar with NASA's facilities and provide a useful exchange of research information. Industry can provide a mathematical model for the vehicle, validated, if possible, by prototype testing. Industry could also be responsible for the bookkeeping and updating of the mathematical model, provide the engineering and pilot support for the programs, and participate with the FAA during the simulator tests. The FAA can provide engineering and pilot participation in the simulator tests of the vehicle's mathematical model and establish the requirements for aircraft certification. Of course, both NASA and the FAA would assume responsibility for the proprietary rights of the industry.

The FAA is ready to pursue, with your support, new areas of technology, including new applications of propulsive lift, advanced structures, synthetic

stability, digital controls, and other new designs. We're looking forward to working with all these groups in the near future.

*W. E. Lamar:* The question of transitioning technology is, of course, of considerable interest to people at the Air Force Flight Dynamics Laboratory. The only reason the laboratory exists is to develop new technology and see that it is applied. If it isn't applied, people wonder what the laboratory is for. So the application of new technology is of paramount importance to us.

In answer to one of the comments, I believe we have made progress. I don't mean just the laboratory; industry, NASA, and this nation have all helped to develop the basis for this technology. Many aircraft that incorporate active control technology are actually flying, demonstrating a portion of the technology and in some cases a significant portion. The YF-16 airplane is a brand new vehicle which incorporates a fly-by-wire system and relaxed static stability. So we know how to do it, we know that we can make this technology work.

There are several questions, however. First, what is the real need, and what is the payoff? Now here, I think, there is a lot of room for work. Ken Carline brought this up, and I couldn't agree with his remarks more. Analyses must be made in depth to make it clear that there really is a payoff, and that the payoff doesn't vanish when you get to the suboptimization that results when you look at the whole system. You've got to be sure that the payoffs remain. I remember the Boeing experience and the supersonic transport. They considered active flutter suppression using the flight control system. As I remember, estimates of 9000 pounds in weight savings were made because of the flutter suppression system. As the design progressed and they got into the problems of the total system, a lot of the apparent savings vanished. So you've got to make sure that the studies are in enough depth to have a total system viewpoint. You need that confidence.

It's likely that the first application of this technology will be to provide fixes for current aircraft. The C-5 airplane is an excellent example. Studies of the application of load alleviation and mode stabilization to the C-5 aircraft were made long ago. At that time there was very little need for that technology. Now it is being applied, and I think the papers by Lockheed showed the depth of the studies necessary to find out the best way to apply it. Now, if the application of active load distribution technology improves the aircraft's life by a factor of two, the improvement is significant; it's a tremendous payoff, one that essentially saves an airplane, because you fly double the time.

I think that there are a lot of cases in which this technology will be used to fix problems, but if it is going to be applied to new aircraft I think we'll have to have a crisis of some type, or a national need. That means we need the technology in hand, ready to go. The space program got started because of the Russian sputnik, and the intercontinental ballistic missile program got started because of the missile gap. We couldn't get any money for structural development until an F-111 wing fell off, and then we ran into problems with the C-5 airplane. There has to be a crisis of some type. Sometimes it is in a safety area or in a C-5 type of area.

To apply this to the airlines, and I must say to the Air Force too, maintainability must be determined, because overhead and maintenance costs are taking a big portion of the total dollars available. If this keeps up we won't have any money for new systems, so we'll have to do something about insuring maintainability. We've got to make sure the risks and uncertainties are understood, that there are no surprises that appear after we fly a number of months. This has happened with many aircraft, like the T-tailed aircraft, for example. So you've got to know what the costs are, and our ability to ascertain costs in advance is really only in a beginning stage. People don't have much confidence that we can estimate costs properly. We need a thorough study to do that.

Then there's the question of criteria, specifications. Military specification 8785B in principal provides the criteria, but there is a need for a specific meeting on reliability requirements. The specifications are undergoing revision. I think what's required here is a concerted effort to determine acceptance criteria. There are pretty good criteria for engines: they have a 50- or 60-hour preliminary flight rating test (PFRT), and if an engine passes that test, it's considered adequate for a new airplane. Later, there's a model test, which is more thorough, and when it passes that it's ready to go into production. Now, because of some engine problems they are now changing the engine specifications somewhat, and trying to tailor them more to the usage requirements of the airplane. We need to do the same thing in the flight control area. We need to understand just what the technology people must do to prepare the technology for transition. But this means that the users have to get together with the certifiers and the contractors and agree what kind of proof is necessary to make the transition in the technology. Then maybe we can start filling the gaps.

And there are quite a few gaps. For example, we're still not sure about the effects of lightning on fly-by-wire systems. Right now we do not permit our F-4 fly-by-wire airplane to fly in lightning. We do not permit the YF-16 airplane to fly near lightning either. I'm sure that as the program proceeds things will be done to determine the effects of lightning. These are unusual problems, but we've got to solve them, and make sure we are completely ready for operation. We've got to get clear acceptance criteria, and right now they are not clear.

There are many approaches that one can take to application, but certainly a fix-up approach, as on the C-5 airplane, where the technology is applied step by step in nonflight-safety areas, is the first step. For example, when gust load alleviation is applied and it works, you get gust load alleviation and you save some fatigue damage. When it doesn't work, you get a little more fatigue damage on one flight, but next time you fix it. The problem is to make sure that it doesn't screw up some other system and interact in the wrong way from a flight safety standpoint. That's a way to apply the technology safely and get experience. Certainly the Air Force is getting a lot of experience with command augmentation systems. They are basically the same as fly-by-wire systems. They work, and we get a good understanding of their reliability, so we are much more willing to go to full dependence on electronic systems.

From the airline's viewpoint, I would think that putting a system in a nonpassenger cargo airplane might be a good way to acquire experience with the technology.

Maybe the pilots will want ejection seats, which is different from normal airline practice, but it's a way to get lots of time and experience with the technology in the airline environment. You can also apply the technology with systems that have backups. When we first flew the F-4 fly-by-wire flight control system, it did have a mechanical backup. After flying a while we had enough courage to take it out. So keeping the backup in at first may be a way to build up enough confidence to take it out. Later on, you can apply it to completely new designs. Again, there ought to be clear acceptance criteria. I think these are things we need to do.

*C. F. Newberry:* When the apostle Paul wrote his letter to the church of Corinth, he commented that they compared themselves among themselves and commended themselves. He said that if their spiritual life was as good as they indicated, it should have affected the way they were living. I've spent 2 days at this meeting now, and I think I have somewhat the same feeling. As we compare our technology as experts among experts, we should ask ourselves why we aren't using this technology. Dick Holloway addressed this question a little bit yesterday, and I'd like to reconsider some of his comments and questions.

First, we're faced with a balance between the benefits and the risks of this technology. We want to tip the scales in favor of the benefits. The risks are safety and economics. From an airline's standpoint, the economic risk may be the system's reliability and maintainability. From the manufacturer's standpoint, the risk may be product liability or the cost of retrofitting a fleet if the technology is introduced into an operating fleet prematurely. The other part of the economic risk may be letting the competition get ahead of you. The benefits, of course, include such things as lower cost, better performance, or both.

There is a decided difference between the acceptable risk-to-benefit ratio for the military and the commercial airlines. The military often has the opportunity to test new systems in prototype airplanes or at least to fit the system into an experimental situation and to try it out to evaluate the risk before committing itself to production. This is not generally true in the commercial airlines. The one notable exception to this is the Boeing Model 367-80 (Dash-Eighty), which introduced the -707 fleet. There again, it was a high risk, high payoff situation. Therefore, it is important for the risk to be minimized before introducing new technology into commercial aviation and expecting it to be accepted.

We've reviewed various aspects of active control technology in the last couple days, and all of us can draw our own risk curves. There are different levels of risk for different concepts. The noncritical aspects, such as load alleviation, fatigue reduction, and ride control are pretty well accepted. I think the risk of introducing these would be low. If there is a problem, the airplane can recover easily after it is switched out of the system. What little reduction we might have in fatigue life during landing would be of no consequence.

The fly-by-wire and stability augmentation systems are a bit more risky. I think the date of application depends on whether the application is military or commercial. I would like to congratulate General Dynamics for applying a fly-by-wire system to the YF-16 airplane. If they're successful, the next military application will be a lot easier. If they're not successful, it's back to the drawing board.

for all of us. But I might remind you that on many of the commercial airplanes some of you will be going home on, the system is "fly-by-fluid," and that of course was not too acceptable a few years back. The flutter mode control system is in a more experimental stage, and I think we will have to do much more work in this area, looking at explosive flutter and other aspects, before it will be accepted.

Not only does our technology need to be developed but we need to understand its applications. We have the ability to evaluate the performance benefits of the concepts we can flight test. The benefits of the concepts are configuration sensitive, but we have a reasonably good ability to flight validate them. However, when it comes to the ability to make predictions on the basis of preliminary design techniques, we come up rather short. You've heard discussions of the ability to represent airplane structural modes for paper airplanes or for newly designed and introduced airplanes. Well, I don't share quite all the pessimism, but I do think that we need to do more work in this area.

What I feel is lacking, however, is persuading the designer to take full advantage of these concepts. Ask how many rivets a designer leaves out of an airplane because he has an active control system. Or how much thinner he is willing to make the lower wing skin because maneuver load control is available to him. Our experience to date is that active control technology has been used like Band-Aids. We've been willing to patch up the deficiencies of existing airplanes by using some of these concepts. A history of active control technology applications over the past 10 years includes the B-52 airplane, which had a stability augmentation system that was developed in 1964. The B-52 airplane was designed as a high altitude bomber. In 1958 it was given the role of flying low, and it didn't take it very long to develop a fatigue problem. Now, this stability augmentation system was designed to alleviate part of that fatigue problem, a Band-Aid, if you will. We generally refer to this system as the ECP-1195 system. That system started at the same time as or slightly before the research program called load alleviation and mode stabilization, and there is a 7-year period from the time the program began until load alleviation and mode stabilization was incorporated in a fleet. Now, perhaps finishing the research a little earlier would have reduced the time; however, we saw from Tom Disney's report that it is taking several years to incorporate active controls in the C-5 airplane. And again it is a case of patching up a deficiency, a Band-Aid.

We've also had intensive research for 10 years in the area of active flight controls or control-configured vehicles. On Tuesday Dr. Kurzahls showed bar charts indicating that research in active control technology would take another 8 years, and if so I question the idea that we're on the threshold of a revolution. Instead, we're just continuing an evolutionary process, and maybe that's the way it ought to be. However, if it's true that we require an additional 8 years, I think we ought to change our acronym from CCV for control-configured vehicles to CCC for creation of control careers. Perhaps I'm being a little unfair or impatient in wanting to get on with it, but I believe that NASA has an important role in bringing active control technology into usable shape.

Dick Holloway mentioned yesterday, and I'd like to reiterate, that we need an airline type of airplane to fly with these concepts incorporated in it. It should fly



an airline route, and it should be subject to the same conditions the airlines are subjected to each day. I don't feel that this would be exorbitantly expensive. I think it would be research money well spent. I've heard comments on various ways to bring this about, and I think we ought to consider some of these and investigate this way to spend some of the research money. The other area I'd like to suggest that NASA do some research in was mentioned by others, including Dr. Perkins, and that is preliminary design. So let's create a real design, using some of these concepts. So I say to NASA, you get the money, we've got the ideas.

*F. W. Kolk:* I think economics is the key to all this. We've got to have a payoff. We have to have not only a predictable but an achievable payoff. The airline community has been enamored of a number of things that have had a great effect on our airplanes but which in some cases have had a rather indifferent payoff. One example of that is the all-weather landing system. If we think about it, the all-weather landing system has been worthless so far. That isn't to say it won't be worth something some day, but the admission price has been fantastic and the show hasn't started yet, so to speak. We can't afford another debacle like that. So let's figure out what our real payoffs are and be sure that we get them and be sure that we don't spend too much money getting them.

Acceptance is another problem. In some sessions, people calculated the basic system reliability to be somewhere between  $10^{-5}$  and  $10^{-6}$  (failures per flight hour). Keep in mind that the loss of the airplane is at the other end of this probability thing. I think I also heard Dick Sliff say just a few minutes ago that the FAA is thinking in terms of  $10^{-10}$  for this sort of thing. It seems to me that our airworthiness code is somewhere on the order of  $10^{-6}$  to  $10^{-7}$ . It has been a long time since we were on the airworthiness circuit and had to learn probability, but I think those are the correct numbers.

Now maybe we're at  $10^{-5}$ , but maybe from experience the FAA is right and we need  $10^{-10}$ . It's a long way from  $10^{-5}$  to  $10^{-10}$ . This is going to be a probability game. Now, when we have probability, we have several problems. One of them is that we have a bunch of airplane drivers and they're not much interested in probability. They haven't really been schooled in it as a discipline. All they want to know is whether it will happen or won't happen on an absolute basis; they don't want to be dead. I think we could cause them quite a bit of concern with this kind of thing.

Then, of course, there's the business of the accuracy of the predictions. If you're going to have a system in which somebody comes up and puts a chart on the wall and says it has a reliability of  $10^{-10}$ , how does he know? How can he prove it without spending 20 years testing the components to get failure rates? When you have failure rates like this, it implies that you either have a lot of junk in the airplane with some pretty complex interreactions to protect against failures or you've got things that are so reliable that it's not in your ability to create a failure within your lifetime. I think we have a problem.

Then, of course, there is the infant mortality problem—what happens in the first 500 hours or 600 hours after the introduction of a device into airline service when all of a sudden it doesn't work. Maybe the airline people will understand it and maybe they won't, but we've had to live through a few of these clambakes.

Well, it's not all bad. We've been sneaking up on active control technology for quite a while. Somebody said we've been flying by fluid for years, and we have. We've been flying airplanes around with increasing amounts of power boost to the point where they're really totally powered now. The difference between power boost and fully powered controls is simply the feedback ratio to the pilot. When it becomes infinite, the pilot can't do anything anyway if something happens. There are a lot of airplanes flying with manual reversion provisions. But if a pilot ever has to revert to manual control, he has a pretty limited flight envelope. So we've already faced that problem, although we haven't called it fly by wire.

Another problem is psychological. The airline community has been brought up on hard-earned truths that were learned in the DC-3 era or with early DC-4 airplanes or during World War II. In those days something was reliable if it was a bar of iron or a thick steel cable. If you wanted to have something not quite as good as that but with more muscle, you made it hydraulic. That was somewhat less acceptable. If you really wanted to get fancy and stick your neck out, you made it electric, but the last thing you did was make it electronic, because everybody knew that wasn't going to work and it didn't. Now it's 30 years later and it seems that the order of the reliability of those things has reversed. But most people in the airlines haven't found that out yet. We've got an education problem.

Then you've got the syndrome in which here's the technology looking for a mission. I think that several of our panel speakers have touched on that. I don't know what you do with active control technology. I mean I think what you do is disconnect the pilot mechanically and fly through an electrical system, which sounds pretty good, but I don't know what the benefits are. The full benefits will only come out in a totally new vehicle design, and this totally new vehicle design is going to be pretty hard to come by. Commercial aviation won't be able to afford any kind of totally new vehicle design for a few years. So since we're not going to have an immediate chance for a full-scale application, I would say you have to slug it out and find out what you can on an interim basis, Band-Aids if you will, and keep on making improvements.

*L. L. Treece:* When Joe asked me to appear on this panel, he asked me if I wanted to prepare a 10-minute speech. I said I thought I'd do everybody a favor and not prepare a speech. I do have some thoughts on what I've seen here in the past few days, though. First, I'd like to repeat that those of us from the business end of the airplane are interested primarily in safety of operation and the creation of enough redundancy to insure that. Of course, to prove this we need an adequate test program. In addition, the economic consideration is all important to the industry. Some things have been presented here that look very appealing from an economic standpoint. Much work has been done, and I think we've come a long way already insofar as pilot acceptance is concerned. We've seen a degree of acceptance in the Caravelle, B-727, B-747, and other airplanes of the fluid line with the controls instead of the cable we're used to. And as far as the acceptance of fly by wire with the control wheel steering and so on is concerned, I don't think we'll have any difficulty selling it to the pilots once the safety aspects are proven. I don't know too many airlines that are going to put ejection seats in a \$25 million investment to launch three pilots, who don't want to go anyway under those conditions, into the air to test a system. We're going to have to find a better way to do it than that.

## PANEL AND OPEN DISCUSSION

*Weil:* What I would like to discuss first is the application of active control technology to a medium- to long-haul conventional transport aircraft.

*Kolk:* I believe that there will be great tangible benefits in incorporating active control technology to these aircraft. The performance of the airplane will improve and therefore fuel consumption will decrease because the center of gravity will be back where the horizontal tail helps rather than hinders. This implies flying some unstable airplanes and also implies putting the landing gear back where the airplane won't go over on its back when it's taking off or sitting on the ground. Certainly this is of paramount importance if we're ever going to have a supersonic transport. So I think I would make that an objective, probably an initial objective. I think the other possible objective is to take weight out of the wing by using a system for load relief. I think this is where a failed system will be a big problem. You can actually fly an unstable airplane, provided that it doesn't get too unstable statically, but it's pretty difficult to fly an airplane without a wing because something electric has failed. I would put that order of priority on it.

*Carlisle:* I think without question relaxed static stability and fly-by-wire control systems should be considered for the next airplane, possibly with backup systems. Then, possibly at the same time, I think there's a case for improving the fatigue life of the airplane. We've had a lot of cracks in airplanes that have cost a lot of money to repair. I think the use of active controls to improve an airplane's fatigue life or to reduce the incidence of fatigue damage would be a good objective for the era we're talking about.

*Kolk:* Yes, but I'd like to point out that the budget is limited. Take an airplane like the B-707. It sort of gets tired at 30,000 hours, so you reskin it for a couple of hundred thousand dollars and get another 30,000 hours out of it. Other airplanes I'm familiar with, like the DC-6 airplane, have gone through this cycle; in fact, I think there are DC-6 airplanes flying around that have been reskinned twice to keep them going. And it's actually a pretty economical way to extend the life of a structure. So unless you can do the job cheaply enough to make it cheaper than just reskinning, you haven't saved anything.

*Carlisle:* It's a question of economic payoff. It's a trade, if you like—you've got to weigh one against the other. What about the audience?

*J. A. Gorham:* A few years ago I had some responsibilities on the L-1011 airplane to do with controls and cockpits and avionics, and I was guilty of persuading all the airlines to try all-weather landing systems. I'm not going to argue about that right now.

Much has been said about the possible benefits of active control technology in terms of saving structural weight and space in the airplanes, center of gravity static margins and so on. I firmly believe that active control technology has a role to play, and I think that with an intelligent program by NASA and industry we'll find out what it is and we'll make the tradeoffs. I think enough has been said

about the need to make tradeoffs with maintainability and reliability and the need for engineering proofs. The idea of the 1985 era worries me a little. Do you mean beginning to design a new transport in 1985 or that it will be flying then? I think a better definition of what we mean by the 1985 era would be useful.

*Weil:* We had in mind putting it in operation shortly after 1985, not starting a cycle that might go to 1995.

*Gorham:* I don't believe that. Looking at some of the timetables, I think it might be possible to begin a new airplane somewhere between 1980 and 1985, but not to have it in operation by that time if it's completely control configured and employs active control technology to a reasonable degree.

One thing that hasn't been mentioned is the role active control technology could play in cockpit design. One of the things that I would like to have done with the L-1011 airplane, since a quadruplex automatic landing system has been installed that can be depended upon in landing, is to cut all the cables and take out the control column, which obscures the lower row of instruments. So if we are going to have fly-by-wire systems, let's get rid of the control column and improve the display area in the cockpit. That's obviously one advantage.

Secondly, we have programs at Langley, which I'm concerned with to some extent, on the B-737 terminally configured vehicle in which we're developing all sorts of advanced electronic displays. As most of you who have been involved with commercial or even military transports know, there just isn't any place to put electronic maps except behind the throttles, so let's get rid of the throttle levers too. If we're going to go fly by wire on the primary controls, we can do it on thrust control as well.

In other words, there are advantages up at the front end that to my knowledge haven't been mentioned during this symposium. That's where the pilots are going to see the benefits, and that might just help us persuade them that this thing is worthwhile.

As far as major obstacles are concerned, I think most of them have been discussed already. New commercial transports are begun, not because we plan it or want it, but because of competition. There will be more world competition now, not just competition within the United States, and when we start to race, if I'm anywhere involved, I don't want to try on a new pair of track shoes. I want to know that the shoes are going to take me to the end of the race already.

*J. J. Tymczyszyn:* I think we're all missing one point, and that's the application of active control technology to vortex wake turbulence alleviation. We all realize that active control technology is a powerful tool, but it hasn't been fully explored yet, and that is one point we should be thinking about in the near future.

*Weil:* That's a good point, except that some of the small airplanes that intersect these wakes probably won't have it.

*W. G. Wells, Jr.:* We've been listening, of course, to a discussion of 5 or 6 years of NASA's experience with the merits and demerits of active controls. I'm keenly interested in Mr. Treece's and Mr. Kolk's comments, also Mr. Newberry's, about the great need for reliability, acceptance by the pilots, and economic viability. NASA has worked with the F-8 digital fly-by-wire airplane, but my question is addressed to Mr. Newberry's recommendation that someone ought to fly an airline type of airplane for an extended period of time to acquire this type of information. Now, NASA has not been in the prototype business, and it seems to be buffeted in various directions—told to get out of or into the prototype business. I'd like to get some type of reaction from the panel as to whether this is an appropriate thing for NASA to be involved in in the future. That is, whether it should undertake a prototype program.

*Newberry:* Well, in my view, the role that NASA ought to play is one that's helpful. In the early days, NACA developed airfoils when other people didn't have the opportunity or capability to. I think that through the years NASA has become oriented towards basic research. Certainly I'm in favor of basic research, but I think that any government agency ought to assist and not to resist. If indeed it's the greatest help to put this airplane into service, to drive it around and develop so many hours, and as Frank mentioned it takes a long time for confidence to grow, I think it needs to be done in a good environment. Ted Bowling gave a paper on B-52 stability augmentation system reliability, and in it he showed a growth curve. The growth curve had a slope of 0.56. Now, the average growth curve for those is 0.3. The reason for the difference is that a great deal of attention was paid to that particular program. Something was done about every little thing that showed up. We recently installed a forward-looking infrared system in a low light television system on the B-52 airplane and again we had an extensive reliability program. That program too had a growth curve of approximately 0.56. It takes a lot of attention to get reliability. It takes the minute examination of resistors, solder joints, and what have you. There's just no substitute for time, and we need to get started if we're going to have it. So I think that a prototype program is a good project for NASA. It's a project the rest of us can't afford. I don't think the airlines can afford to set an airplane aside and fly it without passengers just to get time. I don't think a manufacturer can do that. I think this is a role that government can play and can be helpful in doing so.

*Kolk:* I'd like to add to that. I think that not only is the role a proper one for NASA—it's also a role that in other areas NASA has already begun to play. I think that NASA's role in the JT8 refan program is similar, and the end result looks like a finished product. They have also worked in other programs like this, and I think it's a good thing for the total community for NASA to do it. Now, in terms of actually choosing an airplane to fit with active controls, you have to look around at what's available. If you want to use an airplane that will eventually have other uses, you'll have some other problems besides the control system. You'll have to have an airplane with a lot of redundancy built into its design. The earlier generation jet transports do not have this redundancy, and you'd wind up with a whole new airplane by the time you built it in. However, the newer airplanes, particularly the trijets and the B-747 airplane, do have redundancy built in because they all envisioned all-weather landing systems. So the guts of the airplane can take it and these may be the airplanes to use. I don't know how you're going to make the

transition from getting that kind of hardware together and demonstrating that it'll fly to putting it into passenger service, which is the only way you're going to get the kind of time on it to prove it.

*A. B. Barraclough:* I'd like to address the question of the obstacles to greater commitment to active control technology and turn it around and ask what can be done to aid its application, specifically by NASA. One thing that hasn't received much attention is the requirement for reliability data. The requirement is to acquire data in such a way that the data can be used at the drawing board level. One of the significant international benefits of the last generation of aircraft was that there was a data base you could go to and find out the reliability of a given component and how the airlines used it. You could go to a maintenance manual and see where it was used in the system and what it looked like. You could rearrange it to use in your own system and come up with some reasonably good probability figures which told you its safety, its unscheduled removal time, its mean time between scheduled removals, and its maintenance man-hour costs—in effect, everything from its cost to its everyday usage. With some useful trade factors, you could then compare all of these different costs, put them on a unit basis and come up with some kind of total trace of cost. You could compare an electrical system with a mechanical system, a pneumatic system, or whatever. You could then go to the chief designer and say that this system was better than this one on a rational basis. He could of course decide one way or the other. But it is a useful tool. One thing that can be done with the electrical systems is to set up a system that allows information to be collected that can be used at the drawing board level. This requires familiarity with the information system, the ability to become familiar with it, which means some kind of publication, and finally dispersal throughout the industry. So the question for industry is what they can do for NASA along these lines.

*Weil:* I gather that you're suggesting that NASA or some government organization underwrite this type of thing?

*Barraclough:* No, I wouldn't say NASA specifically, but I think there is a major obstacle, which is that we don't have a data bank with which we can compare things.

*Lamar:* The Air Force has a system much like the one you're discussing. The system collects data in quite some detail on component removals, the time between removals, and the cause of the problem. The data are analyzed right down to the basic level. Of course, the problem is that that kind of information does not exist for the new systems we're talking about because there is no flight experience with them. It does exist for a lot of command augmentation systems that do have electronic components, however.

*Barraclough:* I understand. I didn't mean to bypass the Air Force system, but the point is that there is no system that addresses itself to the question of active controls and flying controls by wire.

*Weil:* We've heard quite a bit about ongoing programs and programs that are planned for 5, 6, or 7 years from now. The space shuttle certainly is one. How much confidence are these programs going to produce compared with what exists

right now? Is there any way to increase their relevance or to change their direction in such a way that they could be made more pertinent to the airlines?

*Kolk:* The problem is that active control technology is sort of a technology looking for a mission. I would like to have a better idea of exactly what active control technology will accomplish when it is applied to transports. That will provide a road map for making decisions, and until you have one you cannot address the issue intelligently.

*Weil:* This is a little far afield from the conventional transport area, but the Boeing YC-14 airplane has a digital flight control system which is pseudo fly by wire. It will fly within the next couple of years. If we have a reasonable number of hours on a vehicle of that type, would that provide the type of confidence needed for a long-haul conventional transport?

*Kolk:* Every little bit helps!

*Newberry:* Another question is whether ongoing government and industry programs adequately address the obstacles to the use of active control technology. Unless I misunderstood, Mr. Skully said that in 1960 the FAA held a conference to update its regulations. From what Bill Lamar and I have presented, most of the action has taken place since 1960. Now is that the aggressive action the FAA is giving us in regard to these regulations or did I misunderstand?

*Skully:* Frankly, the FAA has been putting out regulations on a more or less ad hoc basis over the last decade. The FAA is following the Concorde activities. The French and British hope to have it ready to be certificated next spring, and of course that is a fly-by-wire piece of equipment. I had the privilege of riding in it from Boston to Miami and returning, and there were a few things going on that surprised me. The approach mode was made with the autothrottle. A question was raised earlier as to why you have the throttle, and it's a good point. The throttle is there just because it's traditional. The captain was flying the Concorde manually, and he programmed his airspeed with the autothrottle. The autothrottle was just providing the thrust necessary to maintain his reference speed.

We're looking at our landing distance requirement again from a certification standpoint. The Concorde doesn't have flaps, and it doesn't have spoilers. We are working with NASA quite actively to try to determine a better way to assess runway slipperiness. All these efforts will help to establish or modify the regulations.

*C. L. Seacord:* There are two rather new programs that are intended to address the obstacles. One is to determine the measure of acceptability of the advanced systems.

We've had some experience recently with trying to find out what's required for the autoland sensors in terms of reliability for the all-weather landing system. Maybe integrity is the right word these days. It's extremely difficult to find a realistic, usable failure rate probability number. There's talk about changing the probability from  $10^{-7}$  to  $10^{-9}$ . When you look at the reason for doing so there really

isn't one. Neither is there a good way to measure what we have. I think one worthwhile activity for the FAA is the reevaluation and restatement of the integrity requirements and the way in which the requirements are measured.

In addition, there is a series of operations that could be performed to generate the data that the airlines would like to have and undoubtedly need. They don't need to have a prototype airplane or two prototype airplanes flown a few hundred hours a year. They need, as several people have already mentioned, data for on the order of 50,000 hours of flight in a realistic transport environment. The only way these data can be obtained is by installing some of this equipment, representative fly-by-wire equipment, whether it's being used for that or not, on airplanes in scheduled service. Perhaps they operate in a parallel, duplicate way, so you can throw a switch and take it out of the system and the airplane can go on about its business. This is a program that neither the aircraft industry nor an airline is likely to pay for; therefore, I think it is up to a government agency or a combination of DOT, NASA, and the military. I think that even prior to that, though, you need to try to figure out how you're going to run the big program. Because I think that even if someone popped up with \$10 million right now and said "Go do it," there would be about 4 years of confusion about what you were going to do and what you would record and how you would analyze what you did record.

So I think you need a program to define the requirements, to determine what is good enough, what's reliable enough, and how to measure it. Then there should be an introductory program, probably involving flight tests of a representative jet airplane, to develop techniques for the large program. The large program would then consist of the government procurement of the systems and their installation and record keeping for them. The systems should be used in regularly scheduled service to produce at least 50,000 hours of data.

*G. O. Thompson:* It seems to me that programs with clearly defined goals are the ones that make major contributions. I think one reason so much was accomplished in the Saturn-Apollo program was that the goal was so clearly defined. You may recall that in a movie von Braun produced, he stated that that was one of the most important reasons that that program succeeded. It had a clear goal: go to the moon, return, and land safely, by 1970. That goal was accomplished. That goal was kept in front of everyone. It seems to me that one of the biggest problems in active control technology is that neither we nor NASA has a clearly defined goal. I'm somewhat familiar with NASA's plans. I think that one of the biggest contributions we could make would be to motivate NASA's management to establish a clearly defined goal within the framework the panel has discussed and set a time period for that goal.

*Weil:* As I understand you, you're saying that NASA should bite the bullet and instead of going to the moon establish a goal of perhaps 20 percent to 25 percent improvement in performance or fuel savings and then go after it?

*Thompson:* I'm saying that NASA needs clearly defined goals for commercial transports comparable to those that were established for space.



*Weil:* How do you justify that to the Office of Manpower and Budget? I think the answer to that is that we have to run cost-benefit studies, and if we come up with a ratio of benefit to cost of 20 or 25 to 1, and believe it, I think the risk is good.

*J. T. Rogers:* As a conservative structures guy, I would like to see an effort made to separate the benefits of using control configurations from the benefits to an actual airplane. For example, the load alleviation studies generally have talked about moments, but you'll find when you design a wing that torsion plays a fairly important part and that all the controls we have talked about are large torsion producers. So one of the things I think would contribute a lot would be to separate the items that contribute a large payoff from items that fall in the gray area of "is it or is it not a gain."

*Newberry:* In this field, as in many fields, we have a great deal of synergism. When we start to introduce one or two things we get additional benefits. One of the things we saw in the C-5 presentation was that it had a restriction similar to one we had on the B-52 airplane, and that is the use of control surfaces that were already there. Those control surfaces were deliberately designed not to stir up structure modes. Now we're constrained to use them to damp structure modes. I think if the designer has some freedom to apply the concepts we're talking about we'll see many more benefits. The fact that there is torsion is obvious if you're going to use only a trailing-edge device. Why not use the trailing edge and the leading edge together and eliminate that sort of thing? You're right, we need to sit aside and look at these benefits as they are, but I think that we ought not be too quick to say that we'll throw out anything under 10 percent. That one thing may be the catalyst that brings other benefits into being, so it becomes beneficial for the total active control airplane.

*P. G. Felleman:* As far as NASA funding a large program to demonstrate safety or reliability or whatever by implementing active controls in a large fleet of aircraft is concerned, I don't think that is a goal NASA should be involved in. I think NASA should be bringing technology to a state where it is feasible and available. When the cost benefits come along, for example, when there is another 30-percent, 40-percent, or 100-percent increase in fuel costs, the airlines will be quick to look for things that will reduce those costs, and that will make active controls the economically viable thing to do. It happened in the inertial navigation business. Inertial navigation was not developed for the commercial aircraft industry. It was developed for other purposes. When the airlines saw the economic feasibility of using inertial navigation, it became available to them.

*Newberry:* I don't think it's very progressive to say that because NASA has had a certain role over the years, it ought to keep that role and not step into another area.

*J. K. Wimpres:* I think I agree with Dick Holloway's comments yesterday, that control-configured vehicles and active control technology are really just a part of the aeronautical engineer's bag of tricks. They aren't going to revolutionize the whole appearance of the airplane. They're just other things that will have to be integrated into the airplane. And I think it's difficult to set goals for that kind of thing.

I think back 20 years when the airlines were dragged into the jet age. At that time they didn't want anything new either. They predicted dire things for the jet engine; they used too much fuel, you couldn't even stand to taxi out with them; nobody knew what their reliability was; they had terrible balance problems; how were they ever going to maintain them. Of course, once jet engines were in service, the airlines found that they set an entirely new standard and that the problems weren't nearly as great as anticipated. The engines used by the first jet transports were military. They were developed for the military and went through the kind of process Bill Lamar discussed for evaluation. If you look at the number of hours on the jet engine at the time it went into commercial service, it was actually quite low compared with the number the airlines began putting on it, and yet the engine served well. In the case of the engines, then, the commercial incentive got to be such that the engine was constantly improved, and engines like the turbofanjet were developed not for the military but for the commercial people. The point is that the airlines were willing to accept an engine entirely new to them on the basis of military experience that was relatively low, yet large enough to be statistically valid. I can see the same path for the fly-by-wire control system. The military will have to take the lead; they'll put it on some of the airplanes they're going to use over an appreciable length of time, and that will develop enough time to be statistically valid and it can then be put into commercial service. In our thinking we should also distinguish between the electronic control and so-called control-configured vehicles. Confidence has to be developed in electronics and electric systems and not in the ability of the control surface to move and create an aerodynamic load that will favor the airplane. The former can certainly be developed in the way that I've described. I think the latter has just developed as part of the preliminary design process.

*R. E. Coykendall:* I think that we in the airlines are somewhat impressed with what the military has done with some of these systems and the expertise that has been developed. On the other hand, we also feel that the military is somewhat enamored of the airlines' philosophies and practices. That is to say, they are now coming to the airlines, asking us to show them how to maintain vehicles on a long-term basis. This presents an opportunity for a program wherein the military and the airlines pool their information on the maintainability of aircraft and aircraft systems in particular. That could be turned to real advantage in that it would show what the airline maintainability requirement for active control technology really is. Do you agree, Frank?

*Kolk:* That's basically right. You know, we've got a whole host of gadgets on airplanes that are there for a good reason, and if they go awry, funny things happen. I think one of the most startling pieces of machinery I ever had anything to do with was the stick pusher. We operated a fleet of 30 airplanes for a number of years with stick pushers and I never knew the stick pusher to bomb out on us. It always worked when it was supposed to work and it didn't go off when it wasn't supposed to go off. You can come up with all kinds of examples of things that will have to work full time, with no bail-out route, to take full advantage of active control technology.

So the military people get into active control technology and General Dynamics wants to expand the maneuver envelope for their lightweight fighter, so they make

the tail work for them instead of against them. It was a big payoff in an intensely competitive situation. It's a pretty interesting system, but the point is that at least on the face of it they seem to have made it work and for the first time. This kind of background is going to help. Now I think the airlines should be a little less chary of sharing some of the information that they have. They have so much information in bits and pieces collected over the years that it's a monster of a chore just to get it all in one place. Some of that material might relate to these problems. Some of our experience with electronics may also pertain to some of these things, and I would like to see something set up on a cooperative basis. Certainly we can try. And certainly some of the things we found out about engines are of interest to the military people, because I understand that they have to make them work the first time now or they don't sell them. We have the same problem. All of us are faced with this problem. We've got to minimize risk, and how do we devise a system that minimizes risk? Maybe NASA can serve as a catalyst for this.

I think this meeting is significant, because this is the first time in 20 years that I've seen this many people in a room talking about airplanes. I've been going to meetings for a long time and I want to congratulate everyone for coming and I want to congratulate NASA for inventing some way to get everyone together, which I was afraid was a lost art these days. Just talking like this is going to help. There's something there and we need to use it. It's not a cult. It's a tool, and now it's a question of rolling up our sleeves and getting on with the job. Anything constructive has got to be taken in a constructive way and I think we're all willing to do that.

*R. E. Kestek:* The problem we seem to be working on is benefits for commercial transport. We pointed out that the safety required to fly your grandmother is of prime importance yet difficult to achieve. How do you do it? You need her on board to pay for the flight unless you have a large amount of money from some other source. In past programs, the airlines relied on the efforts of the military, which I think has some possibilities. Some people have talked about that. Sitting here, an idea occurred to me. There is a commercial airliner in military service that is being serviced by the commercial airlines. That is the T-43 airplane, and I believe it's being serviced by United Airlines. One of our problems is to get the airlines and the military to talk to each other, and here is a vehicle that is identical to an airline vehicle, being flown at high speeds and low altitudes, where fatigue is a problem and ride is a problem. Here is a vehicle with a need for active control technology, and it is being serviced by the airlines, who we are trying to get the information to. It is being flown by the military, so we can install a system in it for a reasonable price. It seems as though that would be a good approach to take to investigate the various aspects of this problem.

*Coykendall:* To comment on this question, yes, we are under contract to the Air Force to maintain a fleet of T-43 airplanes. Not all of the actual manpower is ours, but the maintenance program is and four of our people are stationed at the Air Force base in Sacramento to supervise the program. I'm not aware of any restrictions on exchanging information in that program.

In this case, the Air Force came to an airline and said that it thought the way the airlines maintained airplanes over the long term had some advantages compared

with the way the Air Force did it and asked the airlines to do it for a while. This presented an opportunity for the Air Force to experience monitoring the results and collecting the information necessary for long-term maintenance. I don't think it's even necessary to have active control technology systems as such installed in those airplanes. What I am referring to is giving the military the opportunity to observe airline objectives and goals in maintenance and maintainability.

*C. D. Bardick:* If we take the stick out of the cockpit, and I guess we would take the rudders out too, and we take the throttles out of the cockpit and put a couple of little switches in there, I wonder how the pilot is going to feel about looking at the instruments and all the information that is presented to him for the purpose of flying the airplane by hand through the stick, rudder, and throttle. Maybe NASA should look at the interface between the automatic control systems, which are creeping into commercial vehicles in increasing numbers, and the human operator, whose role is changing from being the operator to being more of an assistant manager. Are we, in fact, providing the airline captain with the kind of information he needs to manage these automatic control systems in essentially a nonoperator's role? Maybe NASA should undertake it, because if an airline does it, it's kind of touchy for airline management and the Airline Owners and Pilots Association (AOPA). It's kind of a touchy subject for the Boeing, Lockheed, or Douglas people to get involved with, and it's kind of a touchy subject for the FAA to get involved with, so it seems as if NASA may be the only organization that can touch it without having its fingers burned. Since we have an airline captain on the panel, maybe he would like to address the subject of the flight crew's role in increasingly automatic airplanes.

*Treece:* I'd like very much to talk about it. First, we accepted the wheel in transports years ago as opposed to the stick, and now we're back to the stick. So I think we're amenable to something new. I think that there is a general movement in the industry to enlarge the role of airline captain to that of manager. You should realize that he's managing a pretty expensive segment of the airlines and that he is a manager. We're encouraging airline captains to manage better, and they have done a much better job. If you look at our fuel costs and the efficiency with which we have operated over the last 2 or 3 years, I think it is self evident that they are challenged by this and that they are doing a better job of managing. We talked at great length with some of the people in the FAA with respect to removing the control column, the throttles, and the rudders, and it opens up a lot of space we badly need for indicators and navigational equipment and that sort of thing. I think there's going to be some sort of resistance among the pilots to removing these traditional things, but it certainly won't take long to convince them if it is in fact a better way. I don't have any objection to it. I think it could be sold very easily once it has been shown that it's a better way.

Somebody made a remark a while ago about buying new equipment. Not too many airlines are beating a path to airplane manufacturers' doors these days looking for new equipment over and beyond what they're already committed for. There's some thought that some of us have too much, so we're not looking for any new problems at the moment. But the airlines will adopt, and not reluctantly, something that is more efficient, safer to operate, or has some other type of advantage. This is no different than in the past. I don't think the airlines are going to

get together and sell the manufacturers on active control technology or control-configured vehicle equipment. The manufacturers are going to have to grab this ball and convince the users that this is a better way to go.

*Gorham:* I had some comments a while ago, but in view of what's been said I've modified them a little. I was going to say that a new program is essential to establish the benefits of active control technology, and I think we've talked that to death, probably because it's pretty obvious that the tradeoffs have to be pretty well established to know what investigations you have to make. We're investigating active control technology. Fine, but is there anything in the structural area, the cockpit area or any other part of the airplane which the tradeoffs show might bring benefits if changed or modified? Let's not get to a point in 5 years' time where the technology of fly by wire has been thoroughly investigated and is a tool that could be used and when we do the tradeoffs we find some other technology gives a greater payoff. A broad cut of tradeoffs must be established to decide what other areas of technology might relate to the incorporation of active control technology.

Another point I'd like to make is that something happens because there's a need for it. This is getting back to Frank Kolk's point, which I don't take too much umbrage at, but which I will remember for a while, about all-weather automatic landing systems. I well remember the airlines' introducing a system called aircraft integrated data system (AIDS) 7 or 8 years ago. For those of you who don't know what AIDS is, it is a very complex recording system which a certain major airline hoped to install in an airplane. It involved more electronic boxes than were on the airplane at the time, and it was hoped that it would improve the reliability of the lesser avionics that were already being carried. It was kind of irrelevant. I remember standing up just like this in New York, and the speech I made was that I had sat there for 4 days and heard a detailed description of a solution, but that I didn't really know what the problem was. So there are systems that go into airplanes where everybody has been mistaken.

Multiplex entertainer, a complex and difficult system, was introduced, and it fell into a lot of problems on the Boeing B-747, the Douglas DC-10, and the Lockheed L-1011 airplanes. However, when the airlines asked if they could take it off, and we asked if they would accept a 1000-pound weight penalty for taking it off, which is the weight of the wiring, of course they said no. My point is that there was really a big advantage. Some way had to be found to make it work, and we did.

Finally, Mr. Seacord made a point about all-weather automatic landing systems and the need to look at the reliability of the sensors. I take exception to that, and I think the airlines and Mr. Skully should too, because we now have at least three airplanes certificated for all-weather automatic landing systems, and I'm sure the FAA and its British counterpart wouldn't have given that permission if they hadn't been satisfied with the sensors' reliability. His point on  $10^{-7}$  and  $10^{-9}$  is semantic, really. Without going into any details, one involves an individual risk and the other involves a collective risk. It's just a different way to do the bookkeeping.

Finally, I regard the aircraft industry as being all of us, not as separate from NASA, DOT, and the airlines. Even consultants, I think, should be included in the airline industry.

*Skully:* One of the comments I certainly supported was about establishing clear goals. I think that to attain these goals, and there's more than one, we'll have to make a well coordinated effort. It might be helpful to look at some other programs. One that two of my colleagues and I are very much involved in, or have been, is the two-segment approach program. I am happy to see Mr. Wells from the House staff here, because the FAA has been beaten on the head pretty severely. NASA was funded by Congress to develop the two-segment approach. Frankly, I don't know what went wrong. I don't know why we're in the state that we're in at the moment. American Airlines picked up the project and did a great deal of work on the B-707 airplane—Frank Kolk was the master mind, followed by United Airlines. Lloyd Treece and I have flown United's effort in the B-727 and DC-8 airplanes. We just finished the advance notice for rule making. It went over like a lead brick. The comments were due at the end of June, and I'm almost afraid to read them. The position of the Aerospace Industries Association (AIA) is that they are very much against it. The Airline Pilot's Association (ALPA), the AOPA, the National Business Aircraft Association (NBAA)—any organization you want to name thinks it's just terrible. The point I'm trying to get at here is that we've spent a lot of time, effort, and money, and I don't know if it's going to fly or not. Obviously, the objective is to reduce noise. I might add that I'm a little surprised that I haven't heard any comments during this symposium about what active control technology might do in terms of opening or keeping open some of the critically closed-in airports. If it does, it has a payoff.

*Lamar:* I believe ongoing programs in the Air Force address the major obstacles to utilizing this type of technology. Of course, Air Force cargo aircraft do have command augmentation systems in them. We are getting a lot of experience with them, and that experience is directly relatable to fly by wire. I think the next step would clearly be the fly-by-wire transport. Once we depend on fly by wire, we can without too much hesitation incorporate the control-configured vehicle concepts that have been shown to provide real payoffs in the design studies. What we're trying to do, of course, is to make options available to the designers. There are gaps in the program, and we're trying to fill them. For example, there is a lot of work under way right now and being planned to insure the satisfactory integration of digital avionics, so that the capabilities of digital processes are exploited in the military subsystems of the aircraft. We are also trying to exploit them for digital flight control. We are moving towards more digital flight control and the use of multimode capabilities. We are working on the displays, the controllers, and the other components that go with it. We are looking at what it takes to get the human operator integrated into it in the most economical fashion.

The Air Force is concerned about overhead and maintenance costs, operational costs. For that reason we are interested in pursuing any lessons learned by the airlines. If there is any way we can work together, I am sure that we will be willing to do so. I think we ought to develop joint programs between NASA, the Navy, and the Air Force to make our dollar go as far as possible to achieve this new technology. The basic program plans are under way, but they are underfunded.

*Newberry:* I would like to comment on what actions and coordination are needed. I think that this meeting itself is necessary and a first step in bringing industry, the airlines, and the aviation community together. I think that NASA and the Air Force should be complimented for putting together this symposium. I think I speak for many others in saying that it has been an enjoyable symposium, enjoyable in that it has provided an opportunity to meet old friends. All of us tend to become too busy working in our own areas to communicate with others involved in the technology. This symposium has provided an opportunity for the interested and affected parties to discuss this important technology.

*Weil:* Our time has run out for the panel discussion. I think it was quite productive. We at NASA appreciate the constructive comments on our programs from the airlines and industry, and I'm sure your comments will affect our thinking on future programs. I would like to thank the panel members and the audience for their participation.