F-16 Designer Harry Hillaker - Interview

By **Eric Hehs** Posted 15 April 1991
TAGS:

- F-16 Fighting Falcon
- Aviation History
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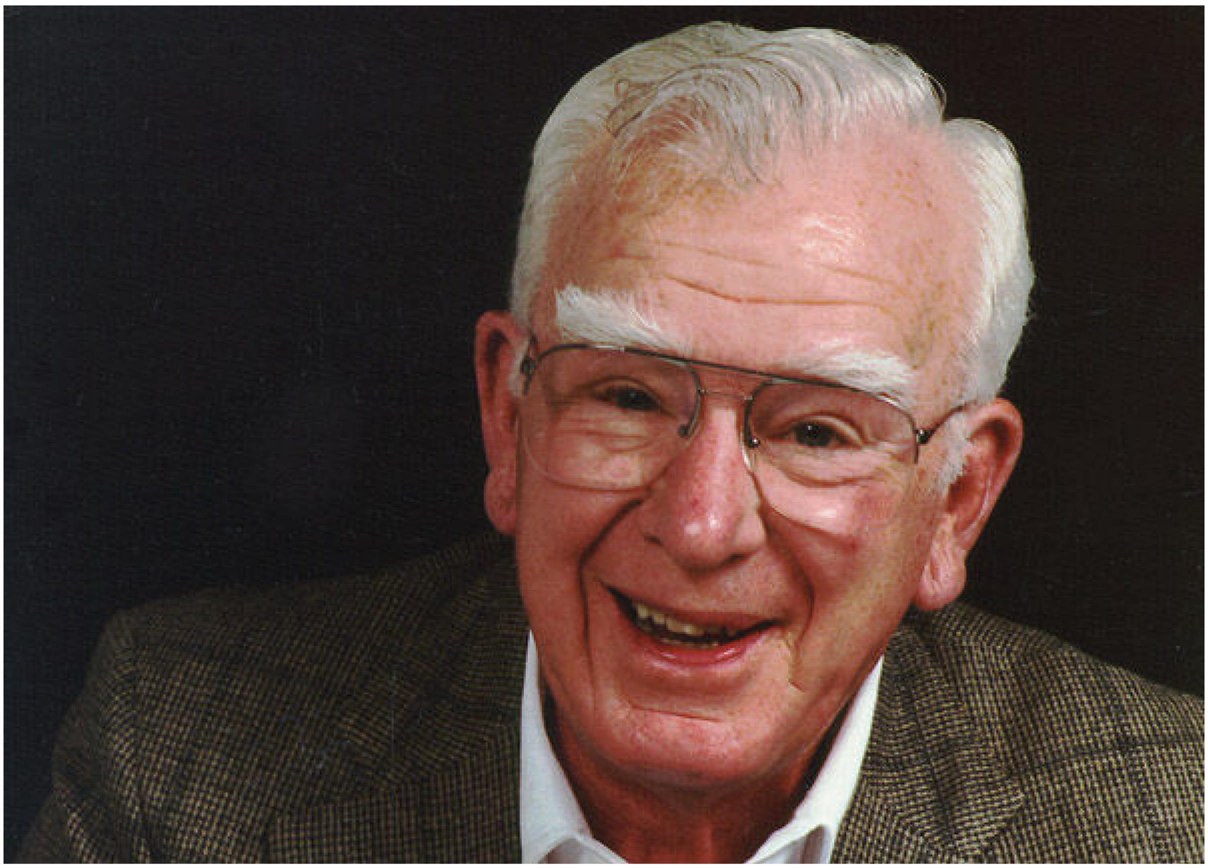

Hillaker retired from the company (then General Dynamics) in 1985, after forty-four years of design work that included the B-36, B-58, F-111, and F-16.

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The F-16 is a revolutionary aircraft. It represents a major change in fighter design. Its fine blend of high technology and common sense requirements emphasizes flight performance-range, persistence, and maneuverability - right in the heart of the flight envelope where air combat takes place. The aircraft's "user-friendly" cockpit and integrated avionic system allow a single pilot to fight and win in aerial combat.

The design also emphasizes low cost in procurement, in operation and support, and in provisions for growth. The F-16 introduced many successful technologies. Fly-by-wire and relaxed static stability gave the F-16 a quantum leap in air combat capability over other fighters when it was introduced and this technology still makes the aircraft an unmatched competitor today. The F-16 disproved the adages that bigger was better, that a lot of capability had to be expensive, and that sophisticated systems rarely worked.

Harry Hillaker deserves much of the credit for this revolutionary approach to fighter design. You might say that the F-16 began as a spare-time project for this veteran designer. Back in the mid-1960s, Hillaker spent his off hours designing the plane of his dreams - a lightweight, high-performance jet that could fly circles around all other fighters. His spare-time project turned into an obsession. The obsession became a reality. Today it is a standard - a plane by which others are measured.

Though Hillaker retired in 1985, after forty-four years of design work, he remains active as a consultant to the US Air Force and industry. In 1990, he was inducted into the prestigious US National Academy of Engineering for his achievements. He spent two terms as chairman of the Aerospace Vehicles Panel of the Air Force's Scientific Advisory Board. Hillaker, who lives about ten minutes away from the F-16 production line in Fort Worth, is always pleased to talk about the F-16 and his part in its development.

In the late 1960s, you found yourself involved in what was called the "fighter mafia." Where did that name come from?

That was the title given to the small group of people responsible for the conceptual design of the lightweight fighter, what became the F-16. The group had three core members: John Boyd, Pierre Sprey, and me. We were given the "mafia" title by people in the Air Force back in the mid-60s. We were viewed as an underground group that was challenging the establishment. We were a threat of sorts.

What made the fighter mafia threatening?

We wanted a change. While most of the Air Force was interested in going north, we wanted to go south. More specifically, they were concerned that we were trying to introduce a new fighter that would jeopardize the F-15.

You see, the F-15 was the first air-superiority fighter that the Air Force had put under contract in twenty-five years. They were committed to the F-15. They felt strongly that our airplane was just a hotdog airplane that was good only for air shows on sunny Sundays at the state fair. This view was strengthened to a degree by their experience with the Lockheed F-104. The F-104 was a really hot airplane that people loved to fly, but it didn't have much capability and not much range. The Air Force bought only 300 of them.

We were threatening for another reason. We were perceived as being anti-technology. Our slogan was "make it simple." The slogan itself may have been an oversimplification. We didn't articulate ourselves well early on.

Does technology discourage simple approaches in aircraft design?

There have been debates through the years about just how much technology should be incorporated in any design. The real issue isn't technology versus no technology. It is how to apply technology. For example, the F-15 represents a brute-force approach to technology. If you want higher speeds, add bigger engines. If you want longer range, make the airplane bigger to increase the fuel capacity. The result is a big airplane. The F-15 was viewed as highly sophisticated because it is so big and expensive. In my mind, the F-15 wasn't as technically advanced as the F-4.

The F-16 is much more of an application of high technology than the F-15. We used the technology available to drive the given end, that is, or was, to keep things as simple and small as we could. Our design was a finesse approach. If we wanted to fly faster, we made the drag lower by reducing size and adjusting the configuration itself. If we wanted greater range, we made the plane more efficient, more compact.

What are the advantages of simple and small?

In general terms, it translates into lower weight, less drag, and therefore higher performance. Also, a fundamental indicator of an airplane's cost is its weight. We were well aware that the avionics folks would be putting a bunch of gadgets in the airplane, which would increase weight and decrease performance. We stacked the deck. We made the airplane so dense that there wasn't room for all that stuff.

As it turned out, our high-density design was one of the things that looked as though it might hinder the advancement of the airplane. It was later graded on the amount of unusable space. We had 4.8 cubic feet. The F-15 had almost ten times that.

Another reason, besides weight, favors small size. Smaller aircraft have less drag. People always talk in terms of drag coefficients. But drag coefficients really don't tell you that much. For example, the drag coefficient of an F-16 is about the same as that of an F-4. However, the F-16 has about one-third the drag of an F-4 in level flight. At angle of attack, it is about one-fifteenth. The airplane's exceptional maneuverability is a consequence of that lower drag and a higher thrust-to-weight ratio.

How were these relationships used in the development of the lightweight fighter?

My first dealings with John Boyd and Pierre Sprey did not involve any airplane designs per se. Our early work was purely and simply an analysis of the relationships of wing loading and thrust loading and fuel fraction (the ratio of fuel capacity to the weight of the airplane). We wanted to understand the relationship between these variables. We knew that we wanted low wing loading and high thrust loading. But we also knew that low wing loading means more weight and more drag. High thrust loading means high fuel consumption. Airplanes with high thrust-to-weight ratios are normally equated with short range. That's why we started looking at fuel fractions. We wanted to tie all these things together to get a better feel for the boundaries involved.

Had anyone looked at the problem this way before?

I would say that people had thought about it, but no one had applied it systematically to get a complete picture.
We were trying to determine the trends. We didn't spend a lot of time looking for exact values. It is one thing to agree that something is better. But how much better is another question. The answer involves finding a trend and asking more questions. Is the design being improved by these actions? How fast is it improving for a given amount of change? The person most responsible for this approach was John Boyd.

What were some of the conventions the fighter mafia challenged?

Range was associated with fuel capacity. High speed was associated with bigger engines. Technology was associated with complexity. Twin-engine designs were considered safer. Size and cost were associated with capability. These were the reigning over-simplifications of the day.

Why were they accepted as truth?

People tend to focus on one part of a given parameter. You can, for example, get a higher thrust-to-weight ratio by increasing the thrust. You can also get a higher thrust-to-weight ratio by leaving the thrust alone and reducing the weight, which is what we did on the lightweight fighter.

We had to take this approach because we had to use a given engine, the F100, which had been developed for the F-15. John Boyd had played a part in defining that engine, and he felt comfortable with it. So the engine was fixed. That meant that the thrust was fixed. If we wanted a high thrust-to-weight ratio, we had no choice but to reduce weight.

The range equation can be treated like the thrust-to-weight ratio. The typical approach to increase range is to simply increase fuel capacity. But increasing fuel capacity increases volume, which means more weight and more drag. People think that big is better. It's not. With the lightweight fighter, we wanted to achieve our ends through different means. We increased range by reducing size.

Did those involved in the early days of the lightweight fighter program take such a historical perspective?

Boyd and Sprey did two things in this respect. Sprey collected all the data he could get his hands on concerning fighter aircraft reliability and effectiveness. They also collected cost data. They were the first people I know of who took Air Force cost data and plotted it against time.

They started with the P-51 Mustang. The minimum increases in cost in jumping from one airplane to another was a factor of 1.9. The increases were as high as 3.1 in same-year dollars. The data showed the increment involved in going to jet engines, to swept wings, to supersonic, missiles, and big radars. It showed the difference between this airplane and that airplane and the effect of these differences on cost.

The cost per pound of succeeding airplanes went up at the same rate as the overall cost. This is true even for the F-16. That is, if I plot a curve of cost per pound for succeeding aircraft, the F-16 is right on the curve. Its increment of cost per pound has gone up the same as any other airplane. However, if I plot a curve of unit flyaway cost, the F-16 falls off that curve. It reversed the upward trend in unit flyaway cost. It was the only aircraft to do this. So the way we got the cost down was by getting the size down. That was another motivation for reducing size.

How was this design approach different from the norm?

We usually rush into form before we really understand what the function is. That gets us in trouble. The lightweight fighter brought a new perspective to maximum speed and acceleration. Everyone wanted airplanes to go Mach 2 to 2.5. No one asked why.

I had the opportunity one time when we were working on the supersonic transport to track all the supersonic flight time on the B-58. We had over one hundred B-58s flying, and the most supersonic flight time on any one airplane was seven hours. Seven hours. This was less than five percent of the total flight time. The entire fleet had a total of only 200 hours supersonic.

A lot of people equate flying top speed with acceleration. Big engines, for those setting the requirements, meant high speed and high acceleration. This is not a true relationship. With the F-16, we addressed function first. We asked, what value is derived from a given capability?

What was the riskiest portion of your lightweight fighter design?

The fly-by-wire system. If the fly by wire didn't work, our relaxed static stability wasn't going to work. And then the airplane would have had higher drag and would have been less responsive, less maneuverable.

We had a backup that not too many people know about. We designed the fuselage so that if the fly by wire did not work, we could go back to a statically stable design by moving the wing back.

We had bulkheads in the fuselage that were designed to carry the load of both placements of the wing.

Were other companies looking at fly-by-wire control systems?

McDonnell Douglas had contracts with the Air Force and with the Flight Dynamics Lab for test programs for fly-by-wire systems, relaxed static stability, and the high-acceleration cockpit for the F-4. The technology was available, but these companies didn't take advantage of it.

Shortly after we won the full-scale development contract for the F-16, I was invited to give a talk to the St. Louis chapter of the American Institute of Aeronautics and Astronautics. My initial response was, You must be kidding. You want me to go into the lion's den? McDonnell Douglas did all kinds of advertising and everything else that was anti lightweight fighter. My immediate reply was, thanks but no thanks.

About fifteen minutes later, I got a call from Dave Lewis [then-chairman of General Dynamics Corporation]. He said, Harry, I hear that you're giving a talk on the F-16 up here to these McAir guys. That's great. I want you to give them hell, and I'm going to be there to see you do it.

I called the AIAA guy back up and said I had second thoughts. A presentation might be fun. I didn't really think that. But I'm influenced by politics, too.

A couple of days before the meeting, the program chairman said that the chapter had sold more tickets to that meeting than to any other past meeting, even meetings with astronaut speakers. He said they had over one hundred coming from McDonnell Douglas alone. You can imagine how I felt.

I gave the talk. After about an hour of questions and answers, the program chairman interrupted to let those who wanted to leave, leave. Two hours after that, the hotel manager came in the room and asked us to leave because they had to set up the room for a breakfast the next morning. At 2:30 in the morning, about fifteen McAir guys and I closed the bar. These were the same people who worked on fly by wire, relaxed static stability, and the high-acceleration cockpit, all the test programs the Air Force and its Flight Dynamics Lab had conducted for the F-4, which McDonnell had the contract for.

Now here's McDonnell building the F-15, the world's latest-greatest fighter, which did not contain one of these technologies. I had 125 McDonnell guys who were more interested in the F-16 than they were in their own F-15 because they saw the fruits of their labors being incorporated in my airplane.

Why didn't they incorporate these technologies?

The F-15 was very expensive. It had been twenty-five years since the Air Force had had an air-superiority fighter. It had taken more than five years just to get the program approved. They couldn't afford to take any risks.

How was it that you could take these risks?

The contract for the lightweight fighter prototype was for a best effort. We did not have to deliver an airplane, legally. Once we spent our $3 million, we could have piled all the parts on a flatbed trailer and said to Mr. Air Force, here's your airplane.

We could fly the airplane when we were ready to fly it. We pushed for a flyable airplane because we were competing against Northrop. But my point is that we were not working against a difficult, but arbitrary schedule. And most schedules are arbitrary. Furthermore, there was no fixed follow-on. The airplane was simply a technology demonstrator.

Why was Northrop unwilling to take the risks involved with the new technologies in their prototype for a lightweight fighter?

Northrop wanted an airplane to replace their F-5. They were more interested in sales to foreign markets and stayed very rigid and conservative in their design because they wanted to be able to show their foreign markets the airplane at any point in its design.

We were interested in what the US Air Force wanted, and we stayed flexible in the design to respond to their needs. We looked at a number of designs. We waited until the very last to choose the best one. We could afford to put these advanced technologies into the airplane. We were more apt to accept the risk.

A number of companies were caught off guard by our winning the lightweight fighter prototype contract. They were out there promoting their ideas around the Air Force. We weren't. We were deliberately quiet about what we were doing because we were handicapped with a bad reputation, though quite undeserved, from the F-111 days. We couldn't brag. Instead, we quietly did our homework and did it thoroughly.

We were ready to fly the lightweight prototype on 1 February 1974. We found out Northrop wasn't flying until June or July. That really worried us. We first thought that they had one-upped us. Their design is a production design, we thought, not a prototype. In actuality, they were just behind. One of the reasons the Air Force eventually chose our design was that it was closer to a full-scale development than Northrop's.

Are you comfortable with the title "Father of the F-16"?

I'm flattered by it. As its father, I had the best part, providing the sperm. Now the gestation period and much of what happened later was something else. Other people can take credit for what happened there. My interest in airplanes is the external shape. I'm not that interested in what goes inside, except as how it affects the outside shape.

PART II Of The Harry Hillaker Interview

In the first part of the interview, you talked about the fighter mafia's unconventional approach to fighter design. What were some of the conventions you challenged?

Range was associated with fuel capacity. High speed was associated with bigger engines. Technology was associated with complexity. Twin-engine designs were considered safer. Size and cost were associated with capability. These were the reigning oversimplifications.

Why were they accepted as truth?

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Innovation requires breaking rules. But organizations are based on rules. How can this fundamental conflict be overcome to encourage innovation?

It requires an attitude. One that places substance before style. We don't mind coming up with something that's mediocre. We don't step on anyone's toes. We don't break any traditions.

The easiest way to change something, unfortunately, is to have a disaster. You take innovative approaches when you have to, when you're forced to.

Can companies encourage innovation by tolerating eccentricity in the right places, in places like advanced design departments?

Yes. You shouldn't constrain the formulation of a design. Once you have one, you can let the organization take charge to implement it. But even then, you need to retain some flexibility.

Who most influenced your career and how did they influence it?

Bob Widmer, GD's Vice President of Engineering in Fort Worth, was my mentor for much of my career. I learned a lot from him. He had vision and encouraged free thinking. He is one of those guys with a lot of curiosity. He was always asking why. Bill Dietz was influential later in my career. He was the best person I ever worked for. We understood each other's strengths and skills. We complemented each other nicely during the lightweight fighter days. Bill recognized my talents and let me use them. It was one of the few times in my life that I felt free and comfortable to go out and do things the way I saw them without worrying about what my boss thought.

Then there's Ed Heineman. He was the equivalent of vice president of engineering for the corporation. Earlier in his career, he was responsible for the A-4, the Heineman Hotrod. He did for the Navy with the A-4 what we did for the Air Force with the F -16. He brought a lot of his enthusiasm to the F-16 program.

There were others who influenced my career, people I debated with frequently, John Boyd and Pierre Sprey, the other core members of the fighter mafia. With them, I was hearing music that I liked, so I danced to the beat.

To sum up, design approaches - Widmer and Heineman. Working relationships - Bill Dietz. Fundamental concepts and approaches for aircraft and their use - John Boyd and Pierre Sprey.

Boyd and Sprey would later admonish you for not sticking to the fighter mafia's original intent summed up by the group's motto "make it simple." They fault the aircraft for getting heavy and overloaded with gadgetry. What is your response?

If we had stayed with the original lightweight fighter concept, that is, a simple day fighter, we would have produced only 300 F-16s, the same number of F-104s that were built. This is not to say that their complaints are unreasonable. When you load up an F-16 with external fuel tanks, bombs, and an electronic countermeasures pod on the centerline, you've doubled its drag. For someone who's worked all his life to achieve minimum drag, that's sacrilegious. Nonetheless, it speaks well for the airplane.

The F -16 has far exceeded my expectations. However, if I had realized at the time that the airplane would have been used as a multimission, primarily an air-to-surface airplane as it is used now, I would have designed it differently.

Is this difference represented by the F-16XL?

Yes. The F-16XL had a better balance of air-to-air and air-to-ground capability. In fact, when I first started going to the Air Force with plans for the F-16XL, some of the Air Force people were so enthusiastic about it that they accused me of holding the design back so that we could sell the airplane twice. If you know anything about the history of the lightweight fighter, you know that this was not the case.

With the F-16XL, we reduced the drag of the weapon carriage by sixty-three percent. The drag of the XL with the same fuel and twice as many bombs is a little over thirty percent less than today's F-16 when you load it up. This points up a fallacy that has existed for thirty years, and I'm concerned that it may still exist. Our designs assume clean airplanes. Bombs and all the other crap are added on as an afterthought. These add-ons not only increase drag but they also ruin the handling qualities. They should be considered from the beginning.

We ought to start with the weapon. That's really the final product. We ought to determine what the weapon is and what it will take to deliver it and then do the airplane. Now, we design the airplane and smash the weapon on it.

Is anything being done to address your concerns?

Concurrent engineering, what is also called integrated product development, is supposed to address these concerns. However, I still don't see much hope. As a member of the Scientific Advisory Board, I've learned that even with concurrent engineering, we' re still not considering the weapon up front in the design. The weapon is not receiving equal consideration with the engine, avionics, and other major systems.

What is your conception of concurrent engineering, and why isn't it being used to address these concerns?

The primary objective of concurrent engineering is to end up with a mature design, one that is closer to the final product. It's the kind of thing that says we're going to start everybody all at once and we're going to be fair. The basic idea is to reduce design changes once production models are rolling out of the factory.

I can't fault that objective. But I don't think it can be achieved by simply glamorizing a process. We wouldn't need to do these things if we had the right attitude and dedication to begin with. The relationship between the Air Force and defense contractors is also important. The Air Force would be well-advised to concentrate on what to and leave the how to to the contractors. I think you would end up with a better, lower-cost product.

Furthermore, this system - concurrent engineering - does not let you select a seed that you can cultivate. You need a skeleton from which to start. We now have people working on a project before we know if its skeleton has seventeen ribs or four ribs, three or two arms.

Is concurrent engineering made necessary because people are specializing?

In part. You have too many people who want equal participation, equal consideration in the design process. Too many insist that they belong in the front row, even when it is more proper for them to be in the second row.

Is this approach affected by the way engineers are educated?

Every spring I lecture to the senior design class of the Air Force Academy. They are a bright bunch. There is no question that the kids getting out of school today are a lot smarter and know a lot more than those of us who got out of school in the '40s. The big difference between then and now is that most of the students are specialists. I think our hiring practices encourage this. If a guy isn't a specialist, he feels that he won't fit into an organization.

So, specialization is a problem?

Specialization is more of an effect than a cause. Several things are getting us in trouble. One is schedules. We're a dynamic country and we want things done right now. When we start a program, we want to see that airplane fly as soon as possible. As a consequence, everything is driven by a deadline. If we don't fly that airplane by that date, we're in trouble. We'll take our chances on whether it performs well or not, but the first wicket is getting it up in the air. Not the cost. Not the performance.

Most people assume that lengthy development times increase cost. That's a false assumption. You don't necessarily save money by shortening development time. It's what you do during the development time that matters. That gets to the heart of my concerns about concurrent engineering and integrated product development. We want to bring everyone on board right away to avoid problems later on. But you can't have thirty-three engineers run through one door at the same time. You have to queue up in some fashion.

I will end up with a better and cheaper product if you let me add six or nine months onto a schedule and give me some time to sit back and contemplate what I've done. Our programs, with their tight schedules and payments conditioned on meeting those schedules, just don't allow us to do that.

I know of no airplane flying that didn't go through an additional phase of development. For example, after building the first eleven F-l11s, we found out that it was not right. The design needed some changes. So the next airplanes were changed.

Those first eleven airplanes were really prototypes, though they weren't done under a formal prototype contract. The F -15 went through the same sort of thing. McDonnell built so many, then they changed them. People don't go back and examine the history of these programs. You always have a certain number of production planes that never make it to the operational units.

Did those involved in the early days of the lightweight fighter program take a historical perspective?

Boyd and Sprey did two things in this respect. Sprey collected all the data he could get his hands on concerning fighter aircraft reliability and effectiveness. They also collected cost data. They were the first people I know of who took Air Force cost data and plotted it against time.

They started with the P-51 Mustang. The minimum increases in cost in jumping from one airplane to another was a factor of 1.9. They were as high as 3.1 in same-year dollars. You can see the increment involved in going to jet engines, to swept wings, to supersonic, missiles, and big radars. You could see what was different between this airplane and that airplane and its effect on cost.

The cost per pound of succeeding airplanes went up at the same rate as the overall cost. This is true even for the F-16. That is, if I plot a curve of cost per pound for succeeding aircraft, the F-16 is right on the curve. Its increment of cost per pound has gone up the same as any other airplane. However, if I plot a curve of unit flyaway cost, the F-16 falls off that curve. It reversed the upward trend in unit flyaway cost. It was the only aircraft to do this. So the way we got the cost down was by getting the size down. That was another motivation for reducing size.

Has this approach been taken for aircraft following the F-16?

We’ve done a pretty good job on improving reliability, but we haven’t on cost. I’m at issue with the Air Force at almost every SAB meeting I attend on cost and affordability. In every presentation, they throw out the words affordable and low cost. When I ask them to show me what they’re doing to keep costs low, they can’t point to anything. They just say they’re going to make it low cost.

As much as I think things are a matter of attitude, here’s a case where attitude alone is not going to get you where you want to go. You must incorporate certain features to have low cost.

I’m concerned that we’re only saluting the flag when it comes to low cost. I don’t see anything specific being done. There are a few exceptions to this. But these are relatively small.

How can affordability be addressed in aircraft design?

As an example, we can get rid of more of the hydraulic and mechanical systems. We can make planes more electric and, of course, smaller.

You said earlier that specialization is more of an effect of tight schedules than a root problem. How has an overemphasis on schedules resulted in specialization?

People argue that we need reliability engineers because design engineers aren’t paying enough attention to reliability issues. That’s not true. Design engineers are interested in reliability. But they just aren’t given the time to think about it. The schedule doesn’t allow it. They can only address so many things between now and next Tuesday when their design is due. It’s not because they don’t want to, or can’t. They just don’t have the time.

So we create reliability groups, parade them over here, and give them their own vice presidents . Now the designer has even less reason to address reliability because there is this other group that does this. Pretty soon, you have reliability engineers talking to reliability engineers.

Like the tight schedules, our increased size is also getting us in trouble. For the lightweight fighter, we had a small group. We had one maintainability engineer and one reliability engineer, not a huge organization or organizations devoted to reliability and maintainability. Again, this gets back to schedules.

All our efforts on integration within the organization seem to have the opposite effect: they have pulled us apart into little factions.

You seem to be dissatisfied with integration attempted from within an organization. Can external factors lead to integration?

Stealth requirements do this. To be stealthy and to fly supersonic supercruise, you have to carry weapons internally. So you have to consider the weapons up front. That benefits the design to some degree, but the approach tends to produce big airplanes. Then you also have the problems involved in getting weapons out of a cavity at supersonic speeds.

Technology itself may have an effect. With today's computer systems, we have a better chance of integration because they're changing the way we communicate

One of the problems we've had over the years has been our principal vehicle of communication - a drawing. With a drawing, coordination can only come about by two means. Either people gather around the drawing to see what was going on or they take the drawing and copy it and pass it around. Both of these are intrusive and interfere with the designer. A computer drawing, on the other hand, can be immediately transferred to other computers, to other places, without interrupting the person doing the work. So, technology may bring about new ways of organizing engineering groups.

With the lightweight fighter, you seemed to have disregarded the organization. You worked outside of it, or at least out of its sight. Two questions: Is this an accurate observation? Could it be repeated today?

I don't think too many people within the company were aware of what was going on for a long time. It was three or four years before anyone outside of Bob Widmer and one or two other people knew what we were doing.

In answer to your second question, I refer to the prototype phase of the lightweight fighter as a Camelot- a bright, shining era that will never return. Nobody told me to start working on the airplane. I just did. I could because of the environment that existed at the time. Nobody told me to do it. Nobody told me to stop.

The system was such that it would let me do it. Today, we're more concerned with style instead of substance. You couldn't do it today because it would look wrong. We have too many controls. So-called controls. I don't think they really control that much. If they did, I don't think GD would have run into what it did with the A-12.

On the lightweight fighter prototype, the entire SPO [System Program Office] consisted of five people. Five people were just enough where you could have hands-on, face-to- face control, not paper-to-paper control. We had several advantages. The Air Force got exactly the same data, in the same format, as we prepared it, in virgin form. The information didn't have to go through various cycles to meet some military format. And it didn't go through a bunch of approval cycles. The way our engineer prepared it was the way the SPO engineer saw it. Because we didn't have to go through all this formalization, they also got to see it a lot sooner.

What brought about all this formalization?

A greater degree of distrust. The overemphasis on schedules and the specialization problem I mentioned earlier. Also the relationship today between the military and industry is more adversarial, less personal.

The result is a formal system that insulates engineers from their counterparts on the other side. We don't have that face-to-face contact that I mentioned. We are rarely asked to communicate with people outside our own group, let alone our own company.

As your structure becomes more complex, you lose that personal contact. Back in the B-58 days, the people working for Bob Widmer were all located in the same place. We could see each other. Our offices were next to each other. We'd find ourselves in big shouting matches. We weren't concerned about using direct language because we were close. We knew who we were talking to. When we were through shouting, we knew where we were going and why we were going in that direction. Today, you don't have shouting matches. Because of this, you don't know the background to the decisions being made. This is a result of our size and complexity.

The formalization also has a lot to do with the attitude of management. Management involves a lot of give and take. While engineers tend to think more in terms of black-and-white decisions, management does not usually involve problems with black-and-white answers. That's one reason good engineers don't necessarily make good managers. Some managers just want to dictate. They never get out of their offices and talk to their employees. That's what we miss most, that face-to-face contact. We're in a culture or an era in our culture in which we don't value contention. We place a greater value on conformity.

Instead of asking what's good for the company, which reflects on what is good for the customer, people are more often asking what's good for their own personal pursuits. Some people base their decisions entirely on what they think their boss wants to hear.

In the early days of the F-16, our energy was focused on the airplane. We had to promote our design. We had to promote not only the airplane, but also the concept behind it. We were breeding a thoroughbred, but that thoroughbred wouldn't do any good if there wasn't a race for it to enter. That's something GD was very good at, that is, promoting the concept behind a plane, seeing that it fulfilled an Air Force need.

Today, I'm not so sure companies do that. I don't think they have the people who look that far into the future. They're more concerned with near-term problems and personal pursuits. We have too many people thinking about how they are going to come out in pursuit of something as opposed to how the company will come out. Now I don't really fault them for the pursuit of their personal interests. For me, the company's interests and my interests have always coincided. As a company grows, however, that basic relationship can be lost.

What part does communication, or lack of communication, play?

One of our biggest deficiencies today is not being able to articulate our ideas and our thoughts. The best idea in the world isn't worth a hoot if I can't explain it to you clearly and with some confidence. Most engineers do not communicate well.

Why not?

Most reports are written to satisfy an author or a requirement, not an audience. We need to make sure that what we're saying is what our audience is hearing. That usually requires a second step. Whatever you write and whatever you say should be tailored to your audience's background and interests. You have to consider your audience, and you have to know how to consider your audience.

More importantly, you have to believe in something in order to articulate it. Today, it is harder for people to assess their roles in an organization because organizations are so large and because there are so many specialties. This uncertainty makes it more difficult to have convictions. It makes it more difficult to be confident.

I always knew where I stood with the people I worked for. It's extremely difficult to work for people who never tell you what they're thinking. I'd much rather work for someone who criticizes me than someone who says nothing. When you hear nothing, you tend to assume the worst.

Our education and training play an important role, too. What little report writing we get in school, for example, usually discourages the use of active voice. This practice is often reinforced at work. Active voice requires a subject. When you associate yourself with your subject, you are more likely to feel more responsible for what you write. It's 'easier to express confidence.

The proposal for the lightweight fighter was written in active voice. We used action titles on all our figures, and we threw out a full third of the figures that various people submitted for the proposal because they could not come up with an action title. Our rationale was that if you can't think of an action title for a figure, that figure doesn't say anything. It doesn't convey a message.

How was the proposal received by the Air Force?

When you submit a proposal, you normally send a team to Dayton to the Aeronautical Systems Division to be on hand to answer questions. I went up there leading a team of about ten people. We sat around for a long time and received only a couple of trivial questions. At the same time, our four competitors were getting swamped with questions.

We were pretty let down by this. We figured our proposal wasn't good enough for them to ask us any questions. We thought they just weren't interested. Like I mentioned earlier, when you hear nothing, you assume the worst. We assumed the worst.

It turns out we were wrong. We won the competition far and away. We learned later that they didn't have any questions because the proposal was so clear and concise. It turned out to be a classic. The ASD said that it was the best proposal it had ever seen. General Dynamics and other companies subsequently used the proposal as a model.

What made your proposal so good?

One reason it was so good was that it was limited to fifty pages. Most proposals sound like they were written by a lot of people. The fifty-page limit allowed me to make it sound like one person wrote it. I received the fourth draft and rewrote that several times until it sounded right. The page limit also allowed all the evaluators to see the same thing. It was so small, you couldn't split it up like they do with multivolume proposals.

How has the way proposals are evaluated changed since that time?

I came from an era when, by and large, the most important factor in a proposal was technical excellence. Today, you cannot win on technical aspects. You can, however, lose on technical aspects. There are other considerations - like politics and cost.

Back then, you could offset a higher cost if you could show technical superiority over your competition. But now you're judged to be technically acceptable or unacceptable. So everybody is normalized. Today, cost and politics playa much larger role.

This approach diminishes the advantages of technically superior companies like General Dynamics. In my mind, GD is far superior to any other company in fighter aircraft design, with the possible exception of McDonnell Douglas. I'd say GD and McDonnell Douglas are about equal, but not equal in the same sense. McDonnell Douglas does some things better than GD, and GD does some things better than McDonnell Douglas. But the system for evaluation no longer accounts for these differences. It wipes them out.

That's not good. The system inhibits companies from taking technological risks.

Has the system changed, become normalized, because there are fewer people who are capable of making these highly technical distinctions?

No, I don't think that's the reason. In my recent work with the Scientific Advisory Board, particularly with people at the Air Force's flight dynamics and aero-propulsion laboratories, I've met some extremely qualified people. I'd say that these people have more experience than most people in industry because they are exposed to what is going on at six or seven companies. A General Dynamics employee, for the most part, can only see what goes on at General Dynamics. I think the government is capable of giving us good technical evaluations.

The reason behind the changes gets back to distrust. We seem to be consumed with all the standards and ethics.

Your current activities seem to concentrate on aerospace systems of the future. Do they include space?

A short time ago, at an SAB luncheon, I was seated next to Dr. Edward Teller. He was preparing for a talk the next day to Space Command in Colorado Springs and asked me if I had anything to add to his presentation. I was quite flattered by his request, but I gave him my true feelings. I told him that our unsolved problems right here on earth - pollution, education, and poverty - seemed to outweigh the importance of space projects. "Aha," he said, "those are the very things that I want to address through the use of space."

He talked about a system of space-based sensors that would provide continuous data on the origins of acid rain, flooding, weather patterns, and a host of other things that impact on our well being. I can now see the potential for some direct benefit to the inhabitants of this increasingly ravished planet. Before I get into trouble, I should quickly add that my attitude on space does not carry over into hypersonic vehicles, such as the National Aerospace Plane, which, by my definition, is a transatmospheric vehicle, not a space vehicle. I am a strong supporter of hypersonics.

What is the biggest challenge facing today's aerospace engineers?

There is no question in my mind that fly-by-wire made aircraft design much easier. Before fly-by-wire, you had a big debate about whether to configure airplanes for performance or for flying qualities. With fly-by-wire, both sides are happy. The tradeoff has been eliminated.

Lockheed's F-117 Stealth is an extreme example. The plane represents everything you would not do for both performance and flying qualities. But the design works because it has a flight control system that is a direct descendant of the F-16's flight control system.

The answer to your question goes back to communication. Our biggest challenge relates to integration and interfaces. There is no one person today that can, within his own discipline, come up with a decent system. We may have seven engineers working on a system. They might talk to each other. And even when they do communicate well, they don't really understand what impact their function has on another function. You will always have the problem of getting people to work together.

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