

A CAHNERS PUBLICATION

MARCH 4, 1996

design news

AMERICA'S BEST-READ DESIGN ENGINEERING MAGAZINE

Engineer of the Year

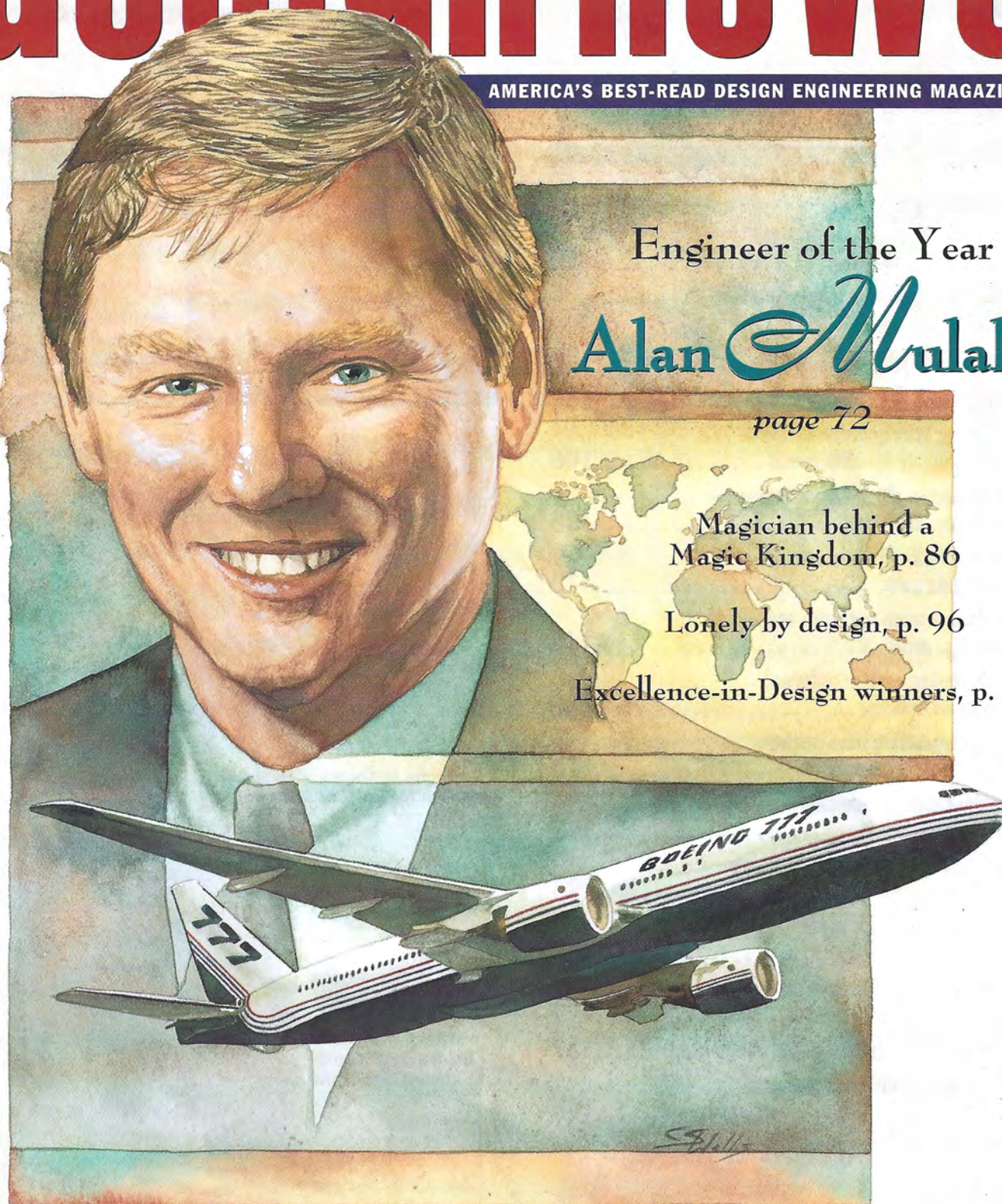
Alan Mulally

page 72

Magician behind a
Magic Kingdom, p. 86

Lonely by design, p. 96

Excellence-in-Design winners, p. 104



design news

MARCH 4, 1996 • VOLUME 51/NUMBER 5

AMERICA'S BEST-READ DESIGN ENGINEERING MAGAZINE

■ features

ENGINEERING AWARDS ISSUE

Introduction	71
<i>COVER STORY</i>	
For the love of flying	72
Magician behind a magic kingdom	86
Lonely by design	96
Fastener taps into a new solution	102
Spacecraft airbag softens blow with Mars	104
Gearless transmission offers continuously variable speed	106
Hydrostatic altimeter measures elevation directly	108
Near-infinite-life seal contains shaft lubricant	110
Extreme-range pressure sensor boasts 1% total error	114
New sealing system reduces diesel air leakage	116
Capillary-action base anchors surface-mount terminals	118
System makes precision farming practical	121
Capacitance technique improves level measurement accuracy	125
Electronics match vapor generation/recovery	126
Compact pumping inverter powers electroluminescent lamps	129
Gas pump compensates for temperature	137
Particle velocity control places salt accurately	138

-COVER ILLUSTRATION BY STEPHEN WELLS-



Engineer of the Year
Alan Mullaly led the
engineers who devel-
oped Boeing's 777
jetliner...**PAGE 72**



A long time colleague of Walt Disney, John Hench (right)
embodies the spirit of Disney's Imagineers...**PAGE 86**



**Why is this Maytag
repairman so lonely?**
Blame Curran Cotton,
winner of this year's
Engineering Quality
Award...**PAGE 96**

Life inside a pressure cooker

When I was reporting this issue's cover story on Boeing engineer Alan Mulally, one theme kept surfacing: It took a great deal of "emotional resiliency" to tame a project as immense as the 777 jetliner.

Engineers today are much in need of such mental toughness. Our studies show that most of you are working harder than ever—handling an average of 15 projects a year. "It's a particularly precarious time for design engineers," says Florida psychologist James Loehr. "The speed at which technology is changing is tremendous. You can go full bore on a design only to have some new development dwarf your contribution. Meanwhile, you must constantly learn new things. All this can create a mountain of stress."

Loehr knows a lot about stress. He has counseled people ranging from Olympic gold medal skater Dan Jansen to professionals from IBM, Motorola, and GTE. His view: Stress isn't the enemy; in fact, we need it to grow as individuals. We get hurt because we haven't learned the proper strategies to recover properly. Loehr says successful people are good "wave makers," oscillating from stressful periods, such as tough job demands, to recovery, through rest, recreation, humor, and family life.

"Wave-making" skills don't come naturally to many of us. "Engineers need to consciously prepare themselves because they play on a pretty brutal playing field," says

Loehr. Like world-class athletes, they need a regular regimen of physical exercise, which conditions the body to handle job stresses. Also vital: good nutrition, especially avoiding fats and heavy meals, and regular sleep habits. These rituals create a sense of order amid the chaotic forces that affect us.

At work, engineers should set aside regular time for planning, for taking or making phone calls, and for creative work. Instead of grabbing another cup of coffee, drink some juice or take a short walk around the building. People also must become "better actors," says Loehr, by learning how to summon more positive feelings about their jobs, rather than giving way to anger, fear, and distress. In other words, have some fun. Over time, such habits enable individuals to function more often in their "ideal performance state." For more of Loehr's ideas, read *Toughness Training for Life* (Plume/Penguin).

So is it possible to find happiness inside a pressure cooker? Look no further than our Engineer of the Year Alan Mulally, who absolutely brims over with cheerful energy and enthusiasm.



Lawrence Maloney
V.P. & Editorial Director

**'Stress itself
isn't the enemy.'**

Lawrence Maloney



EDITORIAL EXCELLENCE

design news

Winner of the Folio Magazine Editorial Excellence
Award in the Engineering Category, 1993-1995.



1996 Engineering Awards

Engineering genius is an elusive quality—it's difficult to describe, but you know it when you see it.

You'll see plenty of it in the next several pages of *Design News*, as we describe the unique achievements of our Engineering Awards winners.

■ For example, Alan Mulally, this year's Engineer of the Year, drew on vast personal reserves of technical talent, organizational ability, and charisma to lead development of the biggest manufactured product of the 1990s—the Boeing 777. Like a symphony conductor, he harmonized the work of 24,000 engineers in the U.S. and 12 foreign countries to create the first jetliner to be designed entirely by computer. He will choose an engineering school to receive \$20,000 from the Torrington Company.

■ John Hench's genius was to help give life to the dreams of one of America's favorite entertainment pioneers, Walt Disney. As senior vice president of Walt Disney Imagineering, he has

been one of the primary creative influences behind every Disney attraction from Space Mountain to Spaceship Earth. As this year's Special Achievement Award winner, he will choose an engineering school to receive \$15,000 from NTN Bearing Corp.

■ And Curran Cotton, described by his colleagues at Maytag as an engineer with "boundless energy," has been so dedicated to product quality that his efforts spawned the "lonely repairman" ad campaign. He is this year's Quality Award winner, and will choose an engineering school to receive \$15,000 from Schneberger, Inc.

Donations of \$10,000 each from Omron, BASF, and the MacNeal-Schwendler Corp. to the *Design News* Engineering Education Foundation supplement these three college grants.

■ You'll also read about the work of Joshua Zulu, Tommaso Rivellini, and Dennis Vories, the Grand Prize winners in our Excellence in Design Contest. Each receives a \$5,000 grant from Computervision.

Congratulations to all the winners.



Alan Mulally



John Hench



Curran Cotton





for the *Love of Flying*

Alan R. Mulally, the ninth Design News 'Engineer of the Year,' drew on his deep enthusiasm for airplanes to propel the biggest product design effort of this decade—the Boeing 777

LAWRENCE D. MALONEY, EDITORIAL DIRECTOR

EATTLE, WA—RISING TO THE TOP of the engineering ranks at an outfit the size of The Boeing Company would seem to be a daunting task for anyone. All you have to do is stand out among some 15,000 other smart engineers.

Not only that, but you have to ride out numerous "right-sizing" campaigns that have trimmed armies of engineers from the ranks of the nation's largest manufacturers—Boeing among them.

But 27 years after the newly minted aeronautical engineer from Kansas packed his worldly possessions in a Volkswagen Beetle and set off for Seattle, Alan Mulally has done far more than just survive. He now charts his company's technical future as senior vice president of Airplane Development and Definition.

Along the way, he's been in the thick of many of his company's most vital

and exciting projects, including:

- Research work on advanced programs like the supersonic transport.
- Flight control, flight management, and flight dynamics assignments on a succession of planes: the wildly popular 737, the 747 jumbo jet, and the fuel-slingy 757 and 767.

- Overall responsibility for the entire engineering effort on the new 777. The biggest twin jet ever built began commercial service this



past June amid rave reviews from the airline industry.

What was it about this smiling, outgoing engineer that compelled Boeing's technical brain trust to put him in the center of so many of the company's high-profile projects?

For some answers, let's first look at what was at stake in the 777 program, the first all-new jetliner from Boeing

An unflagging passion for airplane development took Alan Mulally (left) from his first Boeing job in aerodynamics to his current role of defining the kind of aircraft customers will need for the next century. For the new 777 jetliner (above), put into commercial service this past June, Boeing set tough goals for performance, reliability, and customer satisfaction.

since 1978, when it simultaneously launched the 757 and 767 projects.

Some might argue that Boeing surprised itself in 1989 when it decided to embark on a brand new airplane that would eventually consume an estimated \$5 billion in development costs. After all, the economy was soft, the airlines were struggling financially, and annual growth in air passenger traffic was dismal—well below 5%. Moreover, still fresh in Boeing's mind was the aborted 7J7, a revolutionary plane it cancelled in the mid-'80s amid a cool reception from airline customers.

It certainly appeared to be no time for a "bet-the-company project." Why not just play it safe and work on a derivative of the 767? Depending on the version, the versatile plane can carry from 180 to around 300 passengers, with a range of up to 6,830 statute miles.

But Boeing management knew the company couldn't afford to play it safe. They faced stiff competition from Europe's Airbus consortium, whose share of the jetliner market had risen from 11% in 1980 to almost 30% as the decade drew to a close.

What's more, despite the anemic growth in air traffic in the late '80s, Boeing saw into the next century, when blossoming world trade and the emerging economies of developing nations would lead to sharply higher air traffic. The company is forecasting an \$815-billion market for some 12,000 new transports through the year 2010.

Such foresight is essential in the aircraft business. "We have a very strange product," observes Phil Condit, Boeing's president. "The products we conceive today will still be flying 60 years from now."

With that in mind, Condit—then the general manager of New Airplane Products—set out in 1989 with a small circle of Boeing's top engineering and marketing minds to define a revolutionary airplane with enough flexibility to please a wide range of customers and be able to grow both in size and capabilities.

In 1990, Boeing stated the objectives for the 777 on a simple one-page note to its launch customer, United Airlines—

- Best dispatch reliability in the industry.

Over the years, airlines have purchased nearly 8,000 Boeing jetliners, more than all other manufacturers combined.

- Greatest customer appeal in the industry.
- User friendly and everything works.

Making it happen. Now to put some hardware against those goals. Enter Alan Mulally.

As vice president of New Airplane Development, he reported directly to Condit. Along with Marketing Director John Hayhurst, Condit and Mulally sounded out the marketplace. "We did everything from looking at 'what-if' rubber airplanes to talking to a number of the airlines," recalls Condit.

What emerged was a market need to develop a plane that would be a successor to such trijets as the DC-10 and the L1011. Other companies were already moving to capitalize on the growing market for mid-sized jets, which analysts believe will account for 40% of jetliner sales over the next 20 years. McDonnell-Douglas had decided to go with the MD-11, and Airbus had launched two mid-sized planes—the A330 and the A340.

But Boeing did not want to follow with

Anatomy of the 777

With United Airlines' first commercial flight of the Boeing 777 on June 7, 1995, passengers got a taste of a plane that takes air travel to new heights. The result of an intense, five-year effort by thousands of engineers, the world's largest twin jet boasts a litany of innovations. Among them:

Wing design. Boeing claims that the 777 wing is the most aerodynamically efficient airfoil ever developed for subsonic commercial flight. With a long wing span of nearly 200 feet and a high aspect ratio (8.68), the design gives Boeing ample freedom to grow the plane. With an upper skin made of the new 7055 aluminum alloy from Alcoa, which resists fatigue and corrosion, the airfoil carries a lot more lift towards the trailing edge than in any other Boeing jetliner. The design enhances the air-

plane's ability to climb quickly and cruise at higher altitudes.

Propulsion systems. The three engine manufacturers—General Electric, Pratt & Whitney, and Rolls Royce—all developed new and more powerful turbofans for the 777. For the initial plane, these engines are rated in the 74,000 to 77,000-lb thrust class. For longer-range models, the same engines can provide 84,000 to 90,000 lbs of thrust and could be developed for even higher thrust ratings, depending on future payload and range requirements. Although these engines are 40% more powerful than those used on the smaller Boeing 767, they are just as quiet. Key factors in this performance are larger-diameter fans with wide-chord blade designs and bypass ratios ranging from 6-to-1 to as high as 9-to-1, compared to the typical 5-to-1



Interior of the 777, featuring spacious cargo bins and plenty of headroom for passengers, won an award of excellence from the Industrial Designers Society of America.

ratio for engines on previous wide-body jets.

Also notable: the Pratt & Whitney engines on the first 777s put in service were FAA-approved from the outset for 180-minute, extended-range, twin-engine operations

(ETOPS). This gives pilots many alternate airport choices all along the way.

Flight deck and systems. Principal flight, navigation, and engine information appear on six large flat-panel display screens. Besides sav-

a "me-too" plane. It wanted to achieve a definite technical and marketing edge in building an all-new, long-range plane that would carry from 305 to 375 passengers in its initial versions—a market between that of the 767-300 (220 passengers) and the 747-400 (420 passengers). It would also be designed from the start for long-distance travel—4,350 to 8,320 miles.

To accomplish their vision, Condit and Mulally set out in some very bold directions that would shake up Boeing both from an organizational and technical standpoint. Among the objectives:

- Customers—the airlines—would play an unprecedented role in shaping the plane's design.
- Suppliers, too, would work more closely than ever with Boeing and be challenged to achieve technical breakthroughs in every aspect, from avionics to controls to propulsion systems (see companion sidebar story).
- Boeing's internal organization would be transformed dramatically: the 777 would be the company's first jetliner ever to be designed and modeled almost entire-

ly on computers (see *Design News*, 9/12/94, page 50).

In the face of these challenges, one man—say those closest to the project—became the essential catalyst for bringing it all together: Alan Mulally. First as vice president of engineering and then as general manager of the 777 division, Mulally kept a far-flung team working together on the biggest new manufactured product of the '90s. At its peak, some 4,200 Boeing engineers worked on the program at 13 sites. Joining them were some 20,000 more engineers at 545 supplier companies, including 58 located in 12 foreign countries. In all, about three million parts went into the plane.

"Alan exhibits every quality that you would want to see in a good leader—vision, trust, integrity, and, above all, an overwhelming enthusiasm," says George Broady, who was chief engineer of the 777's interior design. "He's just dynamic when it comes to getting people to pull together."

Adds Gordon McKinzie, 777 program manager for United Airlines: "You immediately respond to his great energy and warm personality, but then you very quickly get a sense of how technically astute he is."

Customer interface. McKinzie should know, because he interfaced with Mulally countless times on the project, dating back to 1989 when the United Airlines engineer first saw a prototype 777 wing in the NASA Ames wind tunnel. For the first time in the development of any of its jetliners, Boeing not only sought design ideas from its airline customers but actually invited the airlines to station teams on site at Boeing as real participants in the 777's design process. Eight carriers in all were involved, including such majors as United, British Airways, All Nippon Airways, and Japan Airlines.

McKinzie cites some 300 design changes that Boeing made as a result of input from United, such as shaping overhead bins to allow greater headroom,

Each day, Boeing jetliners worldwide carry more than two and a half million passengers.

ing weight and space, the new displays consume less energy and do not require the heavy, complex air conditioning apparatus needed on current flight decks. In addition, three multipurpose control display units, installed in the flight deck's center aisle stand, interface with an integrated Airplane Information Management System (AIMS). This modular avionics concept—a first for commercial jetliners—provides all pertinent information concerning the overall condition of the airplane, its maintenance requirements, and key operating functions.

In addition, a patented two-way digital data bus permits airplane systems and their computers to communicate through a common wire path instead of through separate one-way wire connections. This saves weight and boosts reliability.

The flight crew transmits control and maneuvering commands through electrical

wires, augmented by computers, directly to hydraulic actuators for the elevators, rudder, ailerons, and other control surfaces. Such fly-by-wire systems reduce weight, simplify factory assembly, and ease maintenance.

New materials. Composites make up about 10% of the structural weight of the

777, far more than on any previous Boeing jetliner. You'll find composites—primarily carbon-fiber reinforced plastics—in the 777's floor beams, engine cowlings, flight control surfaces, landing gear doors, and wing-to-body fairings, and empennage.

Passenger space. One of the most spacious passenger cabins ever developed, the 777 interior offers great flexibility, allowing airlines to make easy changes to seating, galley, and lavatory configurations. Passenger service units and overhead

stowage compartments can be quickly removed without disturbing ceiling panels, air conditioning ducts, or support structure. A typical 777 configuration change, such as converting from three-class to two-class service, takes as little as 72 hours, compared to two or three weeks on existing aircraft.

For the passenger's comfort, overhead compartments not only offer greater storage capacity but fit neatly into the streamlined contours of the interior structure, allowing for more head room. Depending on the airline, some 777s will be equipped with personal entertainment systems, featuring compact viewing screens and hand-held controllers for movies, video games, and flight information.

The Industrial Designer's Society of America gave the 777's passenger cabin its Design Excellence Award, the first time an airplane interior has won such honors.

General Electric developed powerful new engines, the GE 90 family, for the 777. The engines are designed for maximum takeoff weights ranging from 535,000 lbs to as much as 670,000 lbs in future versions of the plane.



keeping floors flat to allow easier maneuvering of food carts, and making exterior maintenance latches bigger so workers don't have to remove gloves in frigid weather.

United wasn't the only carrier pleased with the new, customer-driven attitude encouraged by Mulally. Among 100 improvements made in response to its input, British Airways recommended a rear galley shape that allowed for four more economy seats. "I'd say Boeing implemented about 95% of the suggestions we made," notes Barry Gosnold, executive VP for British Airways. "We are delighted with the 777. What we are waiting for is to get our hands on more of them." Currently, BA has one 777 in service, 15 on order, and options to buy 15 to 20 more. United leads all airlines, with eight 777s already delivered and 34 on order.

Suppliers, too, felt the impact of Mulally as the guardian of the 777's technical vision. "Alan has a tremendous understanding of what it takes to bring a complex engineering project like the 777 together," notes Brian Rowe, who ran GE's Aircraft Engine business during the 777's development. "From the very beginning, Alan worked with us to define the GE 90, an all-new family of engines for an all-new family of aircraft."

To accommodate future versions of the 777, the GE 90 family is designed to provide from 70,000 to 120,000 lbs of thrust. Pratt & Whitney and Rolls Royce also developed new engines for the project.

"What strikes me most about Alan is his vision," notes Ed Crow, senior vice president of Pratt & Whitney. "A thou-

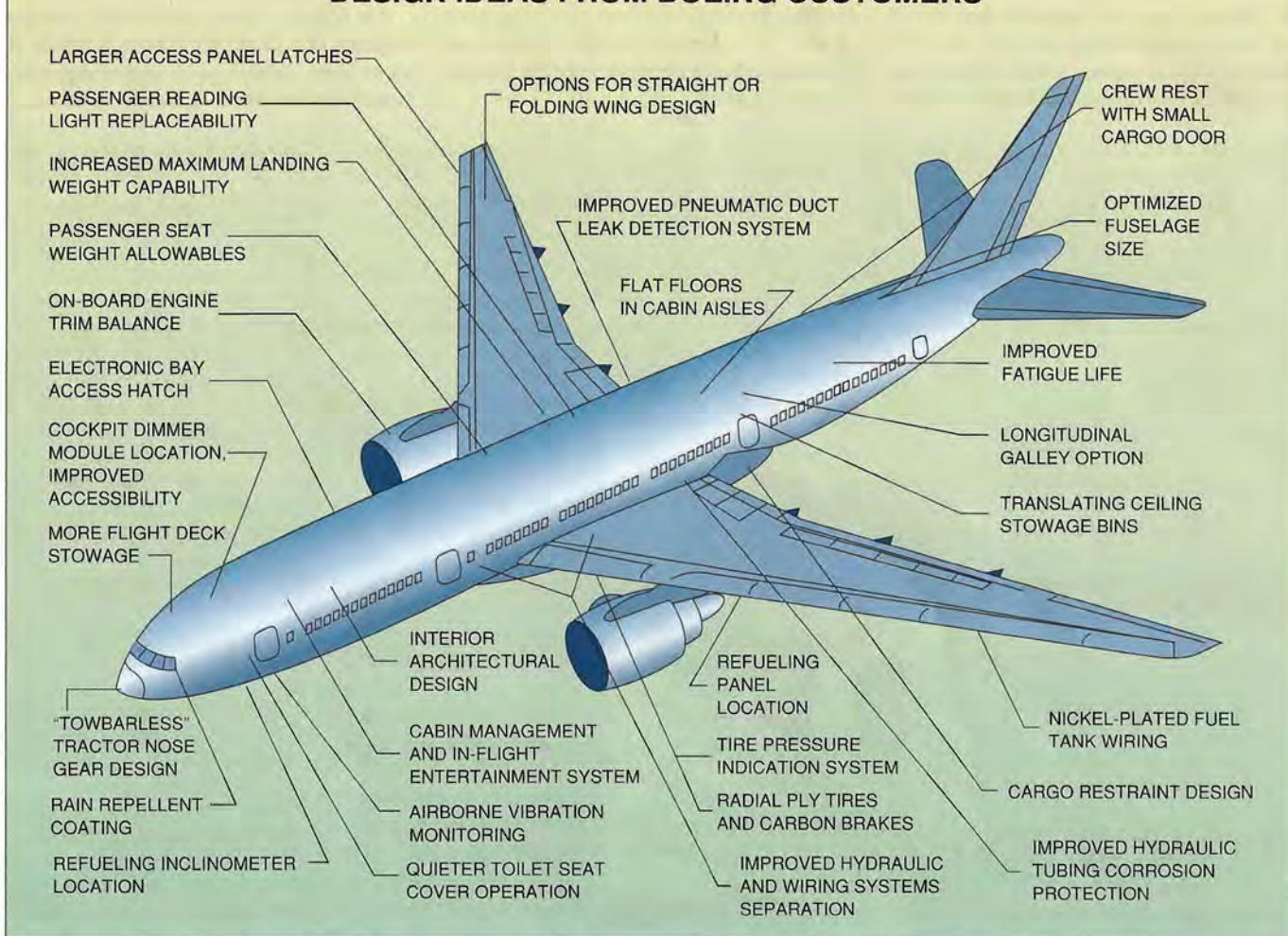
In a typical year, Boeing delivers more than 230 jetliners to customers around the world.

sand times I must have heard him say, 'You've got to have a plan.'"

A year into the program, for example, United decided that it needed a plane with a gross takeoff weight of 535,000 lbs, considerably larger than what was originally planned. And that meant significant design changes for the engine makers. At such moments, Mulally would calmly remind everyone about the "emotional resilience" required to stay the course in a project as big and challenging as the 777.

"When we got into trouble, he never beat us up; he just worked the problem," recalls Michael Kelley, VP of engineering for Honeywell Air Transport Systems, another major 777 supplier. The Phoenix company developed the 777's sophisticated avionics and created a mind-boggling

DESIGN IDEAS FROM BOEING CUSTOMERS



A sampling of just a few of the hundreds of design ideas suggested by the airlines for the 777 and implemented by Boeing engineers.

800,000 lines of software code.

"This was by far the biggest project we'd ever been involved in," adds Don Schwanz, Honeywell general manager. "Alan would come down here and address our work force—sometimes as many as a thousand people. By the time he was through, he would have them excited enough to sign on for what was seemingly impossible."

Midwestern roots. You can't get others excited about their work unless you possess an even greater enthusiasm within yourself, say the management gurus. Listening to Mulally, still boyish-looking at 50, you get a sense that his sunny spirit is 100% natural.

"I loved school and I loved to draw, particularly capturing things from the real world—things that moved, like cars and planes," says Mulally, recalling his boyhood days in Lawrence, Kansas. The refrigerator was always adorned with his handiwork, and his room was filled with toy models, drawings, and posters.

Then came high school and his first physics class. "I'll never forget it, because all of sudden there was an explanation for all these moving things that fascinated me." Mulally recalls riding his bicycle and coming upon the scene of an auto accident.

After determining that the passengers were okay, the young physics scholar began to calculate the vectors in his mind on where the cars had collided.

After high school, he entered the general engineering program at the

University of Kansas, though he had no clear notion that he would go into aeronautical engineering. Then a friend talked him into taking flying lessons. That did it. "For me, flying was art and

physics and creativity all coming together," says Mulally.

In college, he received another career push from an important mentor—Professor Jan Roskam. A former Boeing engineer, Roskam taught Mulally as an undergraduate, then directed him in his master's degree studies in aeronautical engineering. "The first thing that struck me about

Alan was that he was absolutely bubbling over with enthusiasm about airplanes," remembers Roskam. "Secondly, he had an uncanny ability to get other students to work with him on design projects—even extra ones outside of class time."

Roskam notes that Mulally was very strong technically—straight A's—but the professor was even more impressed with

his leadership qualities. "In all my years here, I've only seen three or four students—and Alan's one of them—who possess the combination of design smarts and management skills to drive a highly complex airplane project."

The professor encouraged Mulally to pursue a master's degree project, which involved the design of more sophisticated yet cost-efficient flaps for light aircraft. Objective: Reduce wing size for increased cruise performance and im-

Over 70% of the world's carriers fly Boeing jets, and 40% of all airlines rely on Boeing exclusively.



Though never put into production, the 7J7, with its distinctive ultra-bypass-engines, pioneered many technologies that found their way into the 777. Alan Mulally served as engineering director on the project, which sought to develop a highly fuel-efficient plane for 150 passengers.

proved ride quality. The project eventually evolved into a prototype aircraft—the KU Redhawk—funded jointly by NASA and Cessna. After the young engineer successfully completed his thesis, Roskam shook his hand and said, "Thirty years from now, I expect you'll be president of Boeing."

Armed with Roskam's training and encouragement and solid summer experience working as a design engineer trainee at Beech in Wichita, Mulally in 1969 landed a job with Boeing. First assignment: aerodynamics for the supersonic transport, working with such concepts as oblique wing designs.

A real standout. Engineer Walt Gillette, who worked closely with Alan on the 777, remembers sitting next to Mulally during the newcomer's first months at Boeing. "Here was this red-headed kid who blew in from Kansas and used words like 'golly' and was just in awe of everything. Engineering then was in one big open area where young engineers could mix with veterans. Alan wanted to learn everything he could."

Indeed, to this day, when many engineers are turning away from large companies in favor of smaller, more entrepreneurial settings, Mulally continues to tout the advantages of working for a large manufacturer. These include the chance to learn from a wide range of technical teachers, as well as the opportunity to be part of some of the



Under the direction of Professor Jan Roskam, a former Boeing engineer, Alan Mulally did his master's degree thesis at the University of Kansas on the application of high-lift technology to light aircraft design. The work paved the way for a research plane, called the KU 'Redhawk.' This drawing shows how use of more sophisticated flaps in the Redhawk allowed for reduced wing area, versus a conventional Cessna Cardinal.

biggest and most challenging projects that technology has to offer.

As a young engineer, Mulally learned plenty at Boeing, moving through a variety of assignments that broadened his skills. A key break was a temporary assignment in 1977 to Langley Research Center, VA. There he got his first management job directing a Boeing team in a NASA/FAA research project involving one of the early 737s. The Boeing team assisted NASA in flight tests of the new plane to prove out such technologies as automatic landing systems, microwave landing systems, and global positioning systems.

NASA wrote a letter to Boeing praising the young manager, citing not only his technical competence and his ideas but also his "infectious enthusiasm."

The Langley experience boosted the young engineer's confidence and called Boeing's attention to someone with real leadership potential. It also broadened Mulally's experience, introducing him to

The 737 is the world's most popular passenger jet, with more than 3,100 ordered since 1967. So far, the 737 fleet has made more than 59 million flights and carried 4.3 billion passengers—equal to more than half the world's population.

new technologies, particularly flight control and avionics. "Langley gave me a sense of technical integration," says the engineer. "I started to think of myself not just as an aerodynamicist but as an airplane person."

Returning to Seattle, Mulally got another choice assignment: chief engineer on the design of the avionics and cockpit for the new 757 and 767, the most advanced planes that Boeing had built up to that time. The job put him in close contact with prominent Boeing engineers like Phil Condit.

Soon after that, management had Mulally take time out from his engineering duties to attend MIT's Sloan School, where he received a master's degree in management science in 1982. Clearly, he was on the fast track.

Yet, when asked how he got noticed at Boeing among so many thousands of engineers, Mulally has a rather simple explanation: "Try to do your job 10% better than everyone else, and make sure that what you do fits the company's plan."

Harkening back to boyhood days when he remembers cutting lawns and



Crowds gather for the 777 rollout in 1994. Boeing President Phil Condit calls Mulally the 'emotional leader' of a global project that brought together thousands of engineers from Boeing, suppliers, and the airlines.

delivering *TV Guides* to earn money for a bicycle, Mulally emphasizes the value of having a plan, both in one's personal and business life. "I'm not saying that you can't change your plan, depending on the circumstances," he explains. "The important thing is to have one."

And no one ever had to badger Alan Mulally about getting his job done. He was always asking to do more. He also kept an open mind to learning, whether it was taking night courses on control theory or tackling the latest management books.

"He's got an athlete's courage and has absolutely no fear at trying new things," says long-time colleague Walt Gillette. In fact, Mulally was a standout tennis player and gymnast at the University of Kansas.

Special assignments. With his enthusiasm, ability to get things done, and his skills at relating to others, Mulally was Bo-

eing's choice time and again for high-profile projects in the 1980s. For example, he headed special Boeing technical teams that probed two major airplane safety issues that grabbed the headlines: fatal jetliner accidents caused by warm weather wind shear and by the effects of frigid weather.

Those assignments prompted important steps that have sharply reduced both of these safety threats. For example, the industry has instituted new de-icing procedures and regulations, as well as developed better fluids and equipment to prevent ice buildup on the wings and fuselage. Charlie Higgins, Boeing vice president of safety, recalls tests he did with Alan in which they covered a 737's wings with an artificial substance that simulated frost, ice, and snow buildup.

On the issue of wind shear—the violent downbursts of air that have caused numerous accidents over the years—the work of Mulally and his team in the early and mid-'80s paved the way for new FAA-sanctioned training procedures for pilots, including flight simulator aids.

The new training procedures have made a difference. Higgins notes that since 1985, there have been only two jetliner accidents in the U.S. traced to wind shear. Before that, the industry was

Mulally created a simple drawing and slogan that helped his team visualize the essential engineering feat for the 777: Design the world's largest twin jet with capability to take off from a hot, high-elevation city and with enough range to reach a far-off, over-water destination.



averaging one a year.

Not that there weren't some setbacks along the way for Mulally. In the mid '80s, he became director of engineering on the 7J7, a bold airplane concept designed to fill what Boeing saw as a growing market need for smaller (about 150 passengers), extremely fuel-efficient planes. The project, funded in partnership with Japan, sought to pioneer increased use of composites, fly-by-wire technology, and new ultra-bypass-engines featuring counter-rotating blades.

Unfortunately, despite an ambitious development effort, the 7J7 wasn't what the market wanted, especially with the passing of the energy crisis. McKinzie of United Airlines notes that Boeing had tried to second guess the airlines. "By the time Boeing asked our advice, it was too late."

So the program was scrapped. But Mulally would not allow his team to brood over the 7J7: "We went through the various stages of grief in about five minutes." He insists that from a research and development standpoint, the 7J7 was "one of the best investments Boeing ever made."

Indeed, many of the technologies pioneered on the project have found their way into the 777 project, including: integrated avionics, flat-panel displays, new materials, more flexible interiors, and, perhaps most important—the experience with computer-aided-design. The project also brought together many of the key engineering players who would form the nucleus of the 777 team.

Working together. The 7J7 experience helped forge Boeing's resolve to make sure that every conceivable party was brought into the design effort on the 777. But again, it was Mulally's job to turn the "working together" philosophy into a reality and to keep everyone focused on "the plan."

The skills he exhibited in performing that mission were many. First, he became a master of leading large meetings. At the very outset of the 777 program, for example, Boeing established a series of orientation meetings at an old recreation center called Oxbow. There, key managers from many technical and business disciplines would sit around tables of six or eight and lis-

The 747 jumbo jet is the largest commercial airplane in the world, with some 6 million parts.

ten to presentations about the objectives of the 777 program. Only one person from a given special-

ty sat at each table, and each diverse group would discuss the presentation and give their feedback to the presenters.

"Every person, of course, felt that his specialty was the most important," remembers Lyle Eveland, director of manufacturing for the 777. "But after a few meetings, we began to see our own deficiencies and to appreciate the importance of others' contributions. We also saw the need to have a plan that we could all buy into."

This desire to establish a shared vision carried over into the "megameetings" that Alan would hold later with the design engineering staff—meetings that would sometimes last for five hours. "In those meetings, Alan would drive design decisions and pore over the details," recalls Eveland. "He was absolutely great at visualizing for everyone what we hoped to attain with this airplane."

The fact that Eveland—a manufacturing expert—attended those meetings was another big change brought on by the 777. Prior to that project, Boeing's engineers passed designs "over the wall" to manu-



Among the biggest challenges on the 777 was the switch to 100% digital design. The approach allowed engineers to pre-assemble the plane on the computer screen, eliminating costly physical mockups and providing more design freedom.

facturing, which would then produce a prototype or pass the design back as "unbuildable." With the 777, however, the company established 238 design-build teams, each of them responsible for part of the airframe or aircraft system. Team members included individuals from engineering, manufacturing, procurement, customer support, and other specialties.

Along with the design-build teams came another mammoth "working together challenge:" the switch to 3-D computer design and modeling for the entire 777 aircraft. Hundreds of Boeing and supplier engineers had to master CATIA, while the company spent huge sums on new workstations and other computer hardware and software. To share computer files with Japanese companies responsible for about 20% of the plane's design and manufacture, Boeing went so far as to lay its own data cable across the Pacific ocean.

As a result of the effort, says Charlie Kyle, chief project engineer for engineering operations for the 777, the project achieved its goal of reducing change errors and rework by 50% over the 767 experience for many sections of the plane. Moreover, despite eliminating virtually all physical mockups, major sections of the 777 fit together during manufacturing to tolerances as tight as one ten thousandth of an inch.

Kyle gives much of the credit to Alan Mulally for easing the trauma



Rescuers lift survivors from the frigid Potomac river following a 1982 Air Florida crash, caused in part by ice buildup on the wings. Mulally headed efforts by Boeing to develop better de-icing fluids and procedures to avoid similar crashes.

that can come with such dramatic cultural changes as the design-build teams, and the commitment to digital design. "He was the glue who held it all together," says Kyle.

Adds Boeing President Phil Condit: "Alan was clearly the emotional leader of the entire 777 project."

At the weekly program meetings that chartered the progress of the 777, Alan would insist that his staff observe a set of "principles and practices," which managers have now carried over to other projects. Among these ideas:

- Use facts and figures, because "the data will set you free."
- You can't manage a secret. Get problems out in the open.
- Whining is okay—occasionally—but be ready to propose a plan.
- Listen to each other. No side conversations are permitted when someone is speaking.

The main Boeing factory in Everett, WA, is the largest building, by volume, in the world, with 472 million cubic feet of space and covering 98 acres. It houses assembly operations for wide-body jetliners.

- Enjoy each other—and the journey.

"Some of those principles—like 'it's okay to ask for help'—were rather revolutionary," notes George Broady, the chief engineer for the 777's interior design. "In the past, it was bad form to let your boss know that you didn't have all the answers to his questions."

Mulally also had a knack for coming up with simple symbols that captured the essence of what Boeing was trying to accomplish in a project as huge and complicated as the 777. Borrowing from the sketches that often adorn the hand-written notes he churns out to his colleagues, Mulally drew a smiling, cartoon-like plane and affixed the slogan: "Denver to Honolulu on a hot day." The playful design, which soon showed up on a metal button, captured one of the prime engineering goals of the 777: The big twin would have to be able to take off in the high elevation

of Denver on a summer's day and travel all the way to Honolulu. In addition, it would have to have enough additional range to reach alternate airports, if the airplane had to divert or fly on one engine.

Similarly, Alan would use anecdotes from the double-decker tree house his five kids constructed to illustrate the "working together" principles he wanted to achieve on the 777.

Rave reviews. In the end, all these motivational tools—and Alan's considerable expertise as an airplane integrator—paid off in a new jetliner that has won accolades throughout the industry. By the close of 1995, airlines had placed orders for nearly 230 of the planes, which are priced from \$125 million to \$145 million, depending on the version. The sales are far outpacing such rival models as the MD-11 and the Airbus 330 and 340.

"The 777 is going to be a raging success," says Paul Nisbet, an aerospace industry analyst and president of JSA Research, Newport, RI. "It is an extremely well-made

A vision of Boeing's future

As senior vice president of Airplane Development and Definition, Alan Mulally's job is to assess the kind of planes customers want—and to make sure Boeing develops the aircraft to meet those needs.

That mission calls for bringing on new versions of its existing family of planes, as well as creating revolutionary concepts, such as supersonic jetliners or ultra-huge jumbo jets. For a look at what to expect from the world's biggest manufacturer of jet transports:

737 family. The world's best-selling jetliner. Carrying 100 to 172 passengers, the three current generation 737 models are 20% more fuel efficient than the first 737s, which were deliv-

ered in 1967. Three new versions of the twin-jet plane will come into service in the '90s. They will extend the range of the 737 to 3,000 nautical miles, a 30% increase. Powered by new engines developed by a joint venture of GE and SNECMA of France, the new planes will cruise at .79 Mach (530 mph), up from .74 Mach (500 mph).

747 jumbo jets. This huge



Artist's concept of a high speed civil transport (HSCT). Boeing will build such a plane, says Mulally, but only if customers want it.

plane first caught the world's attention in 1970 when Pan AM put it in service on the New York to London route. The latest model of the four-engine plane, the 747-400, can fly 420 passengers more than 8,000 nautical miles. To smooth the flow of air and increase lifting power, Boeing designers added a six-foot winglet to the tip of each wing. Its upper deck is also 23 feet longer than the original 747-100. Growth in long-range travel and concerns about air traffic congestion are spurring interest in new derivatives of the 747. A 747-600X now being studied could increase capacity by 20 to 30% over today's maximum of 600 passengers (one class economy service).

The 757 and 767. Introduced in the early 1980s, both are powered by very fuel-efficient twin engines. With a single-aisle configuration, the 757 typically carries 186 passengers in two classes up to

3,900 nautical miles. A new 757-300X model now under consideration would hold 20% more passengers and travel 600 nmi farther. Similarly, the larger, twin-aisle 767 could be slated for changes. Now carrying 220 to 300 passengers and with a range of up to 6,000 nmi, the plane would boost passenger and cargo capacity by 20% in a 767-400X model under study.

The 777 family. Though Boeing delivered its first 777s in 1995, it already is planning future versions of the plane that will expand both passenger and range capacity. From the initial model, which carries from 305 to 375 passengers, the big twin will get stretched to accommodate as many as 550 people in a single-class, high-density configuration. Future versions, such as a 777-100x, would bring non-stop service to destinations as far away as 8,000 nautical miles.

All-new airplanes. Boeing is also deep into preliminary development work on whole new classes of aircraft.

plane, has the long-range capability airlines want, and is designed to be a real family of planes, with different configurations and passenger loads. And technologically, it's far ahead of the competition."

With the 777 success behind him, Mulally has moved on to a new job. As senior vice president of Airplane Development and Definition, Mulally sees himself as a "champion for technical excellence" for Boeing's engineers. Already, he has triggered a massive reorganization project that, among other things, will colocate design engineers involved in the same specialty. For example, all engineers working on landing gear design will now work together so they can better share lessons learned from past design projects.

In addition, Mulally is encouraging development of "baseline aircraft." A concept already tested on the 777, the baseline approach involves building in as standard many of the options commonly requested by airlines. It also provides the design flexibility to allow airlines to more

easily customize a plane from an option list catalog. What's more, engineers will be able to draw from a central digital data base of past designs, which will allow for quicker execution of custom designs.

Mulally's new job requires him to peer into the future and conceive the product development strategies needed to meet the needs of airline customers. In that respect, he must decide on future versions of Boeing's existing family of planes. And he faces even tougher decisions over such concepts as huge jets carrying well over 500 people, or ultra-fast jets traveling at speeds up to Mach 2.5.

Such futuristic planes will require financial commitments far beyond anything that Boeing has ever before invested. And that will mean more and more participation from suppliers in the actual manufacture of the plane, including those in foreign countries. Having just weathered a long strike by machinists, who have seen a sharp drop in Boeing's own manufactur-

Boeing ranks in the top 10 of the nation's technical employers, with some 15,000 engineers.

ing jobs, the company is well aware that the change won't come without some pain.

"There's no question that global partnerships will become more and more important," says Mulally. "In the future, Boeing's core competency will be to determine customer needs and to serve as a large-scale integrator of technology. The bigger the project, the more we need each other."

Mulally also has no doubts about how he'll spend his future: developing new airplanes. To him, it's a mission that goes well beyond the technical feat of bringing a highly complex vehicle to market. "Airplanes are more than just a product," he says. "Not only does this industry represent an enormous boost for economies all around the world, but airplanes are a powerful force for bringing people and ideas together. That's why this work means so much to me."

Travel time would be cut in half on an HSCT, but will passengers be willing to pay premium fares?

For example, the company is exploring small jets in the 60- to 80-passenger category that would operate in short-range markets characterized by either light traffic or high-frequency flights. Mulally admits, however, that it is still unclear whether it is economical to develop new turbofan jetliners for this market versus the turboprops now in service.

With projections for a 70% increase in air travel by the year 2005—and faster growth beyond that—an even bigger debate surrounds whether Boeing should build a very large civil transport (VLCT) or a high speed civil transport (HSCT).

Planned for long-range, over-water flights, particularly the surging trade expected in Asia-Pacific routes, both planes would have to overcome enormous technical challenges. These include: new materials to reduce



weight and/or withstand high-temperatures, more powerful yet fuel-efficient engines, improved wing-lift ratios, and much more (see *Design News*, 1/23/95, page 80). Both also pose major environmental concerns, ranging from changes to airport infrastructure as a result of these longer planes to preventing damage to the ozone layer, in the case of the high-flying HSCT.

Nevertheless, Boeing is researching both options,

although full-scale commercial development for either would probably demand an investment of \$10 billion or more—dwarfing the estimated \$5 billion spent to bring the new 777 to market. Such costs demand an even greater reliance on the kind of technical and economic partnerships seen in the 777 program.

As Mulally explains it, whether you build super jumbos that carry 800 to 1,000 passengers or supersonic

planes that travel three times as fast as today's jetliners depends on how you see air traffic evolving.

If future traffic gravitates to hub cities where many passengers must change flights for their final destination, then a new class of super jumbos may make sense, says Mulally.

On the other hand, Mulally points out, most people want to fly non-stop to their destinations, even if they must travel long distances to do so. That fact prompted the development of the 777. But will passengers

pay the extra money to get there in less than half the time, as would be the case on a HSCT travelling at Mach 2.4? Surveys show that the potential market for supersonic travel begins to deteriorate rapidly if passengers have to pay more than a 30% premium for a ticket compared to the typical fare on a conventional plane.

"We will build an HSCT," says Mulally, "but only if we're convinced that the market wants it."



Come Up With
Brilliant Idea
For New Product.



Turn Brilliant Idea
Into Reality.



Win
Engineering
Achievement
Award.

Congratulations, Alan. You made it look so easy.

*Torrington is a proud
sponsor of the Design News*

Engineering Achievement

Award. We're happy to

endow this year's \$20,000

engineering grant to the school

of Alan Mulally's choice,

the University of Kansas.

Alan's tireless commitment in

guiding the Boeing 777 into

commercial service while working

as Director of Engineering

and later as General Manager

of the entire project make

him a worthy recipient of this

prestigious award.

TORRINGTON
INGERSOLL-RAND