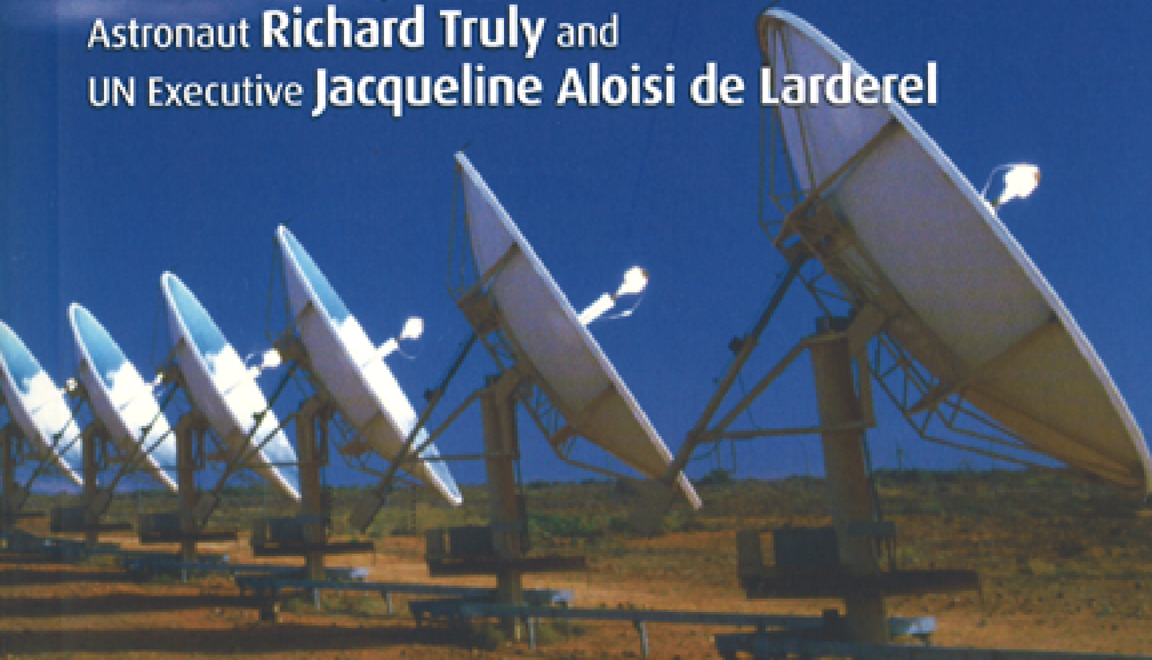
"This is great stuff. Extraordinary results when the genius of industry is turned loose."
Jonathan Lash, President, World Resources Institute

INDUSTRY GENIUS

Inventions and People Protecting the Climate and Fragile Ozone Layer

Stephen O. Andersen and Durwood Zaelke

With Forewords by
Astronaut **Richard Truly** and
UN Executive **Jacqueline Aloisi de Larderel**



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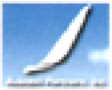
Aviation Partners

The future is on the wing*



How a "dream team" of retired aeronautical engineers and test pilots challenged the conventional wisdom of aerodynamics to develop a new concept for Blended Winglet technology which increases the fuel efficiency of aircraft up to an astonishing 7%, then formed a joint venture with Boeing to retrofit the global aircraft fleet.

Thrust, lift, weight, drag, stability, and control are the technical obsession of all aerospace engineers, from the ancients who first studied the wings of birds to modern computer-trained engineers.

Although he would not have thought about them in those terms, Ibn Firnas was concerned about those challenges of flight when he built the first flying machine in AD 875. Ibn Firnas watched birds flying and studied their wings carefully. But he failed to notice how birds use their tails when they land; and he ended up crashing his invention into a mountain outside Cordoba, Spain. He told the spectators that he had forgotten to add a tail to his machine, like a bird's tail.[1]

Leonardo da Vinci faced the same challenges of flight. Like Ibn Firnas, he studied birds and bats to learn the secret of their flight. He also dissected them. Among other things, he observed that the inner part of natural wings moved more slowly than the outer part, and concluded that the function of the inner part was to sustain rather than to push forward. In imitation of the birds and bats, he developed working gliders with fixed inner sections and mobile outer sections.[2]

* The authors are grateful for interviews and supplementary assistance by the following engineers and managers at Aviation Partners: Joe Clark, Maggie Clark, Dick Friel, Kim Frinell, Louis "Bernie" Gratzer, Robert T. Lamson, W.S. "Bill" Lieberman, Ted Lomax, and R.L. "Dick" Sears; by the following engineers and managers at Aviation Partners Boeing: Kevin Bartelson, Sheldon Best, Mike Stowell, and Jay Inman; and by President Clay Lacy of Clay Lacy Aviation and President Borge Boeskov of Boeing Business Jet.

1 See www.angelfire.com/realm/bodhisattva/flyers.html.

2 Information posted on www.angelfire.com/electronic/awakening101/leonardo.html by Museo Della Scienza e Della Tecnica.

In 1638 in Turkey, Hezarfen Ahmet Celbei built a wing apparatus inspired by da Vinci's design, and launched it from the 183-foot-tall (55 m) Galata Tower near the Bosphorus in Istanbul. Celbei had watched an eagle in flight, and he made adjustments to the da Vinci design based on that great bird. His flight was successful.[3]

In his 1889 book, *Bird Flight as a Basis of Aviation*, Otto Lilienthal wrote "we are forced to consider the flying apparatus of the bird as a most ingenious and perfect mechanism." Later, when the Wright brothers were trying to figure out how to control an airplane in the sky, they too looked at birds. Wilbur Wright noted that birds twist their wing tips to stay in control; and he built a box kite with wings that could be twisted in opposite directions, based on this idea, to make it bank and turn. The Wright brothers called this principle "wing warping," and it has inspired hang-glider designers ever since.

"It doesn't break the laws of physics, but it does bend them rather beautifully," says a Boeing advertisement praising improved performance and fuel economy.

High-tech engineers are still thinking about these same challenges of flight, and are still inspired by the design of bird wings. Today, aerodynamic engineers concentrate their efforts to enhance performance on lift, weight, and drag. Drag is the

BLENDED WINGLET CHARACTERISTICS

The Aviation Partners high-aspect-ratio Blended Winglet is a significant departure from the conventional winglet design. It features a large radius and a smooth variation in chord in the transition section. It is engineered to provide optimal performance, limited by wing structural strength and dynamic characteristics. This allows optimum aerodynamic loading and avoids drag-producing vortex concentrations. Correctly designed Blended Winglets have demonstrated much smaller wingtip vortices than straight wing aircraft or conventional winglet systems with angular transitions.

"Blended Winglets™" are gracefully curved wingtip extensions that enhance the aerodynamic efficiency and flight characteristics of aircraft. Aircraft equipped with Blended Winglet systems are environmentally superior because they can fly farther on the same amount of fuel and they are quieter on take-off. In addition, Blended Winglets allow take-off at higher gross weight, which is particularly beneficial at high-altitude airfields and during hot weather. Blended Winglet-equipped aircraft require less power to do the same job, resulting in lower engine maintenance. Owners enjoy increased range, performance, and cargo payload while significantly reducing greenhouse gas and toxic emissions. Reduced noise helps satisfy increasingly strict standards, particularly in Europe. Blended Winglet technology has changed the way the aviation world thinks about optimizing wing efficiency.

Aviation Partners Incorporated (API) introduced its patented Blended Winglet Systems in 1991 as a performance enhancement to the legendary Gulfstream II business jet. Since then, it has been adapted to an increasing number of airplane types (see Figure 2.1). Blended Winglet technology is equally effective on virtually any make or model of business or commercial aircraft in service today—suggesting limitless market and environmental potential as fuel use and emissions become more important.

3 See the chapter on Hezarfen Ahmet Celbei in Evliya Celebi's book, *Seyahatname* (*Book of Travel*) published in eight volumes 1896–1928, as posted on www.angelfire.com/electronic/zennun/celebi.html.

Figure 2.1 Boeing business jet with Aviation Partners Blended Winglets

aeronautical term describing resistance to airflow. An aerodynamic shape has less drag because it is streamlined and can cut through the air more efficiently. Reducing drag allows aircraft to move forward with less thrust, and so reduces fuel consumption. Conversely, for every increase in drag, there must be a corresponding increase in power and fuel consumption.

To put this into perspective, a Boeing 747 requires a gallon of fuel for every 6.7 lb (3.8 l for 3 kg) of its flying weight. As a result, it has to haul up to 300,000 lb (136,000 kg) of fuel. A more aerodynamic design allows an airplane to carry less fuel and more passengers or cargo, or to have the capacity for longer non-stop flights which add an important margin of safety and usually command higher ticket prices. For people in the aviation business, it is a simple equation: make planes more efficient by reducing drag, and you generate money on cargo and passengers and save on fuel at the same time. It is a central goal in the industry.

For those concerned about the environment, improved aerodynamics and the resulting savings of fuel reduces nitric oxide air pollution, climate-changing carbon dioxide emissions, and acid-rain-causing sulfur dioxide emissions. It also reduces the noise footprint on the ground because aircraft with less weight and drag climb out of airports more quickly.

A brief history of winglets

"Everyone knows that a wing creates a vortex at its tip, which creates drag," explained Dr. Bernie Gratzer when we interviewed him at Aviation Partners about the company's Blended Winglet technology. Without sounding condescending, Gratzer continued his lesson. "Drag, we know, is the enemy of flight, slowing the airplane as it moves through the air. Reduce drag, and you increase lift and velocity."

Gratzer is a young 81 years of age and is the only member of the engineering team at Aviation Partners who wears a tie. His wispy, white hair makes him look like the professor he was after he left Boeing, where he had served as the chief aeronautical engineer. He has a self-deprecating way of smiling and chuckling, almost to himself. Gratzer has the clear eyes and the twinkle that we would come to recognize as the Aviation Partners team trademark.

In order to understand winglets, one must understand wings. Air flowing over the upper curved surface of a wing accelerates when it is forced to travel further than the air flowing directly under the lower wing surface. The difference in pressure between the upper and lower wing surfaces generates necessary lift.

However, high pressure on the undersurface of the wing causes some air to escape at the wingtip, forming a powerful helical wake vortex (see Figure 2.2) which reduces the available lift. The turbulence that results wastes energy by diminishing lift and increasing drag. The turbulence of the wingtip vortex is strong enough to flip airplanes flying too close behind one another and it is a critical reason for the stringent requirements for separation distances between aircraft, particularly at take-off. The margin of safety for any aircraft decreases as the load of fuel, passengers, and cargo approaches the maximum aircraft rating because the aircraft becomes less able to accelerate or to execute the tightest maneuvers.

For more than a century, physicists and aviation engineers have struggled to reduce the effect of wingtip vortex and the drag it exerts. One method is to make the wing longer, increasing its aspect ratio. The aspect ratio of a non-tapered wing is its span divided by its chord. The span is the distance from wingtip to wingtip, and the chord is the distance from the leading edge to the trailing edge. A wing with high aspect ratio is more tapered and loses proportionally less energy to the wingtip vortex than a more stubby wing does. But longer wings pay a penalty in weight from the added materials needed to support increased bending.

Another way to reduce drag is to use winglets, which provide the effect of increased aspect ratio, but with less weight than a longer wingspan. Winglets are small, up-swept attachments to the aircraft wingtips that extend the trailing edge and relocate and reduce the strength of the vortex, thereby reducing drag.[4] Wing-

4 Winglets are wingtip devices that primarily reduce induced drag, which along with other lift-dependent drag forces makes up almost 50% of airplane total drag. This can be expressed by the formula:

$$\text{Lift-dependent drag} = \frac{\text{Lift}^2}{\text{Span}^2\,(p\ q\ e)}$$

In this equation the dynamic pressure, q, equals one-half the product of air density and airplane velocity squared. The Oswald efficiency factor, e, accounts for lift-depen-

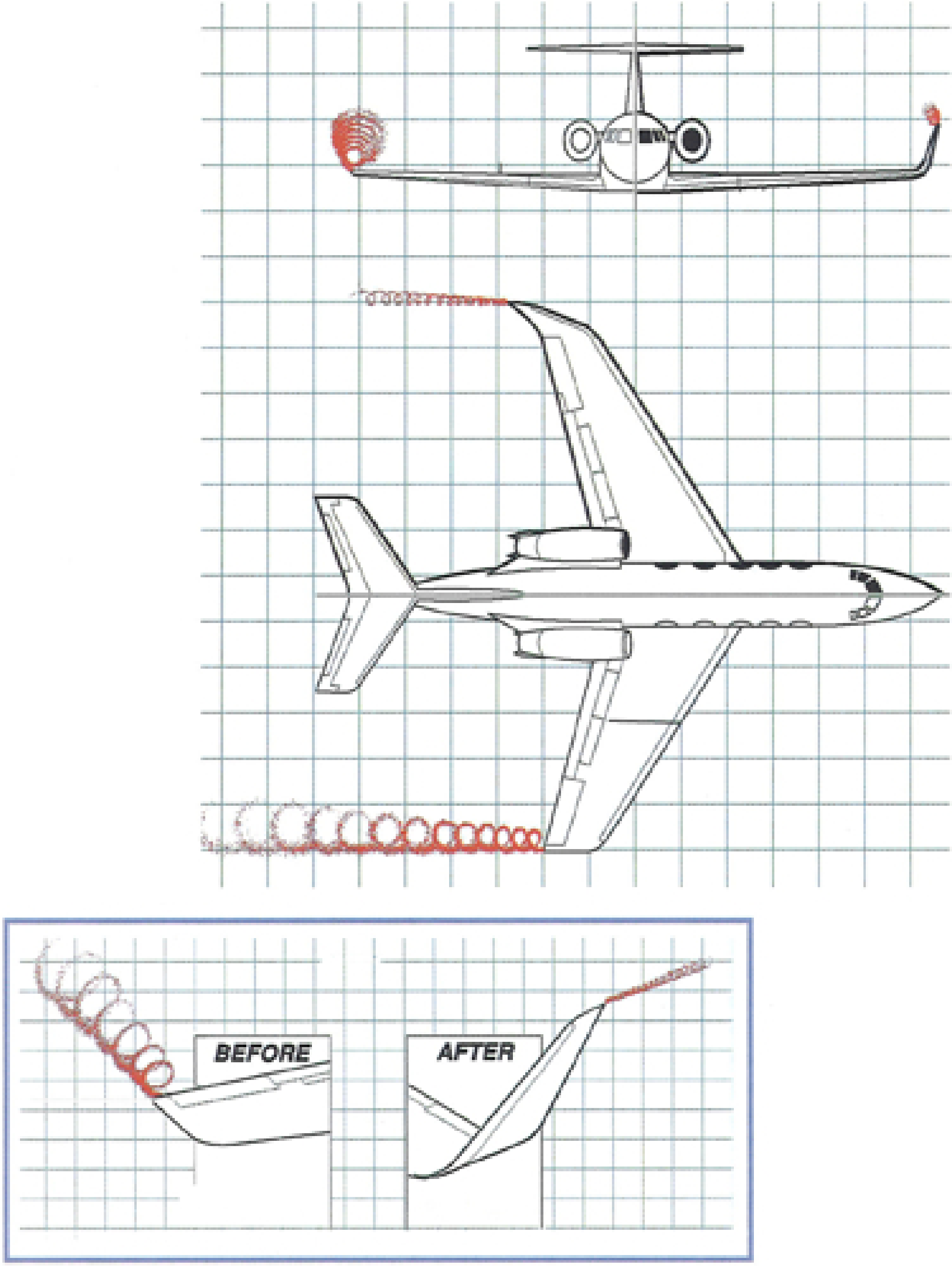


Figure 2.2 Aviation Partners Blended Winglet reduces vortex

lets are not new. "The original idea of winglets has been around a long time," explained Gratzer. In 1897, F.W. Lanchester patented a vertical wing-end plate. But there was scant interest until 1974, when NASA engineer Richard T. Whitcomb published the results of theoretical and wind-tunnel studies predicting potential fuel savings of 4–5% from the technology. NASA and the US Air Force began flight-testing in 1979 and confirmed Whitcomb's estimates on a KC-135 equipped with winglets (provided under contract from Boeing). The US Air Force, however, did not proceed farther with winglet technology after initial testing.[5]

In 1981, McDonnell Douglas tested the NASA designs further, and later used them on MD-11 and C-17 Globemaster III aircraft. Around 1983, Learjet became the first company to install winglets on a business jet. In the 1970s, Airbus had been first to equip a production airliner with small winglets, but the company changed back to a conventional wing for the A330/A340. Later, the Ilyushin Il-96-300 also employed conventional winglets; and Valsan obtained FAA (Federal Aviation Administration) approval to retrofit winglets to the 727.[6]

But these early efforts used large, boxy winglet designs and achieved only marginal improvements in fuel efficiency. By 1990, most aviation experts had dismissed or opposed winglets because they were sized improperly, shaped poorly, and did not work very well.[7]

Never too old to do the impossible

After nearly a hundred years—and the best efforts of NASA and the major major aircraft manufacturers—the aerodynamics of wings and winglets had proven too complicated to improve with winglets. Because the giants of aerospace hadn't been able to do it, many smart people assumed that it couldn't be done. But perhaps this

dent components other than induced drag. The effectiveness of winglets stems primarily from their ability to increase equivalent span, but they also improve efficiency by optimizing the aerodynamic loading of the lifting system. The API Blended Winglet design incorporates a smoothly curved transition between the wing and the winglet. A conventional winglet in contrast, has an abrupt connection to the wing with undesirable flow characteristics that limit winglet performance. The Blended Winglet with high aspect ratio promotes full realization of winglet drag reduction potential while minimizing friction and interference drag factors that detract from the primary benefits. Although a basic wingspan increase will also reduce drag, the fundamental advantage of winglets is that they produce substantially less wing-bending moment than a planar wing. Winglets require less structural weight for the same equivalent increase in span. Thus, for an optimized winglet design application, the benefits appear as reduced drag as well as reduced span and structural weight.

5 Flight tests on the KC-135 indicated that winglets resulted in about 5% fuel savings—45 million gallons (171 million liters) per year—but the US Air Force chose a Fuel Savings Advisory/Cockpit Avionics Systems upgrade instead (Ed Davies, "Winging It: Boeing Welcomes the Winglet," *Airways*, April 2001).

6 *Ibid.*

7 Bob Shane, "Modern Winglets: A Lift for Commercial Airlines," *Airliners* 72 (November/December 2001): 1-4; Fred George, "Getting a Lift Out of Winglets," *Business and Commercial Aviation International*, February 1998.

was really like the economist who was so captivated by his assumptions that the market was perfectly rational that, when he saw a $100 bill lying on the sidewalk, he walked on by, assuming that someone else would have picked it up had it been a *real* $100 bill.

On the other hand, if NASA and the other giants of aerospace couldn't improve on the wing design or the winglet, then who in the world would be audacious enough to try? And would anyone take them seriously?

It turned out that a Montana industrialist named Dennis Washington would try, and his interest would ultimately set in motion a series of events that would pull Gratzer and several others out of retirement and give them a chance to do what no one else had ever been able to do before.

Dennis Washington became an industrialist when he bought the Anaconda copper mine in Montana, back at a time when the price of copper was so low that the mining machinery was worth more than the ore itself. Washington bought the mine with a mind to sell off its trucks and equipment. But the price of copper went up and up, and he ended up keeping the mine. He also ended up making a lot of money.

Washington was flying a Gulfstream II at the time, and he enjoyed the convenience and speed of his own private jet. He was frustrated, however, that his Gulfstream was range-restricted on coast-to-coast flights, and so when the new Gulfstream III came out he was a bit envious. It had a more stylish design and a larger range. But Washington didn't want to spend millions more for a newer-model Gulfstream. He wondered why there wasn't a less expensive way to modify his older Gulfstream to make it look more stylish and to increase its range—to make it more like its expensive sibling, the Gulfstream III.

Washington called his friend Joe Clark. Clark is not an engineer or a former test pilot. He has, however, been hooked on airplanes ever since his first flight on a Learjet in 1964. In 1965, Clark founded Jet Air, the first Learjet distributorship in the Northwest. Jet Air started out with only one jet and only one customer, a company his father operated; but it was the first golden domino in a lifetime of successful ventures. It grew quickly into a profitable business with a sales territory covering Washington, Oregon, Alaska, and all of Canada. After Jet Air, Clark and Milt Kuolt co-founded Horizon Air, a Seattle-based regional airline that was later sold to Alaska Airlines. Clark also founded Avstar, a global sales network that took advantage of good deals on military-surplus training jets and sold them to private companies and individuals.

Washington asked Clark if his Gulfstream II could be modified to look more like the Gulfstream III and to achieve greater flight range. Clark considered the problem. If he were able to dramatically improve the aerodynamic efficiency of the Gulfstream II's wing, he might be able to solve the problem posed by Washington and give him what he wanted. But Clark knew that airplane wings had had the same basic design since the 1950s, and he was familiar with the general consensus among aerospace engineers in 1990 that there were few, if any, possibilities to improve on the standard wing. A different man might have shrugged off his friend's request and gotten on with his busy life.

But Clark's curiosity was piqued. He had been successful long enough to know that the first rule in business is to know your own strengths and weaknesses. Clark recognized that he wasn't the man to say that the wing could, or couldn't, be improved. And this new aviation puzzle intrigued him. He decided to accept Washington's challenge, and see if he could put together a team to figure out how to substantially reduce wing drag while increasing the aesthetic appeal of the Gulfstream II aircraft.

Clark started by calling his friend Kim Frinell, and together they studied the technical and financial feasibility for a one-time Supplemental Type Certificate (STC) to develop a winglet to make a GII more efficient. When the study concluded that the modification would provide significant improvements in aircraft performance, Clark decided to form a new company to develop the project.

Clark called a meeting at Frinell's house, and included Bill Lieberman, Dr. Bernie Gratzer, Bob Stoeklin, and Peter Jennings on the invitation list, along with Dennis Washington. The team Clark assembled had the necessary engineering experience; or at least he hoped it did. And Clark, Frinell, and Lieberman had the key business connections at Gulfstream Aerospace in Savannah that would be needed to make the effort a reality, he hoped. By the end of the evening, the team had a business plan and enough optimism for Washington to agree to fund the venture.

Bernie Gratzer and Joe Clark with Spiroid and Blended Winglets

The team prepares for corporate lift-off

The team was rolling; but it still faced some major hurdles if it was going to accomplish its ambitious goal. Surpassing one hurdle would not be enough. Only by running the full race could the team redesign a major industry. And even practical needs, such as getting data from proprietary sources, could prove to be an insurmountable hurdle.

The engineering challenge was to test the Blended Winglet on the Gulfstream II. When Gulfstream designers balked at providing engineering data and engineering experience, Bill used the back doors he had cultivated as a salesman and got management override. Dr. Gratzer and the team collaborated on the design; a Seattle manufacturer of competition rowing shells fabricated the prototype proof-of-concept winglets; and they were in business. Washington provided his Gulfstream II for flight tests. Dick Sears, Frinell, and Lieberman conducted "before and after" Blended Winglet tests on the Gulfstream II to confirm Gratzer's predictions.

A second hurdle was to get Gulfstream II owners to buy the Blended Winglets. Clay Lacy and Dick Friel were key in accomplishing this step, and their personalities show why. When we came to interview the team for this chapter, Clark invited us to join him at Randy's Diner, a short stretch from Boeing Field. The diner was in a mixed-use area near Boeing field, and had the feel of place where a working man or woman could come for a lunch that would be the same every day. The design was classic: Formica® table tops in booths that were lined up around the outside edge of the diner, and a counter in the interior for those eating alone. There was an added touch: models of Boeing and other aircraft suspended from the ceiling. The cast of regular customers greeted each other by name, and our saucy waitresses knew just what Jo and Clay wanted for lunch.

Clay Lacy met us there. Lacy is a big, genial man in his late sixties who has a winning smile and the soft drawl of his native Kansas. Lacy tells us about a day well spent, going to school with his friend's four-year-old daughter. The twinkle in his eyes shows his obvious delight, and you can see that Lacy is a terrific grandfather. Just about the whole of Lacy's life has been dedicated to flying. He built his first gas-powered model airplane at age eight, and by the time he started flying, at age 12, he was completely enamored with aviation. One of his first jobs was flying "right seat" on Douglas DC3s, back in 1952 as United's youngest pilot. By the time he retired, he was United's number one pilot in seniority, flying 747-400s from Los Angeles to Sydney, Australia. With over 50,000 hours of flying under his belt, in every kind of plane, from Mustang P-51s to the 747s, Lacy has probably logged more hours than any pilot on Earth.

Lacy has flown all over the world, from Beijing to Moscow. In 1968, he founded Clay Lacy Aviation and built it into what many consider to be the premier West Coast business air-charter company. He was one of the first Gulfstream II owners to adopt Aviation Partners Incorporated (API) Blended Winglet technology, and he set more world records in his 22-year-old Gulfstream IISP than in any other aircraft he's owned or flown. In June of 1995, the winglets helped Lacy and Clark set a new Gulfstream climb record and a world speed record from Los Angeles to Le Bourget, Paris, on the way to the Paris Air Show. With an elapsed time of 10 hours and 36 minutes, and an average speed of 531.8 miles per hour (mph) (850 km) over the 5,638 mile (9,021 km) great circle route, the Gulfstream IISP achieved

WINGLET BENEFITS

- Reduced fuel consumption and emissions
- Reduced engine maintenance
- Increased flight range and payload
- Greater margins of safety
- Improved handling and better stability
- Faster climb to altitude
- Higher initial cruise altitude
- Quieter skies
- Sleek and modern profile that modernizes an operator's fleet
- Higher resale value (style and performance)

an 83 mph (133 km) gain over the previous record of 448 mph (717 km). On the return home, Lacy and Clark established a new world speed record from Moscow to Los Angeles. Ultimately, Lacy's world records and the publicity around them, as well as his success with the Blended Winglet technology, helped him and his colleagues to promote the winglets.

The characters of the team

So much about the success of the winglet technology came down to the characters of the individuals involved. Nothing about their personalities was to be taken for granted; and their coming-together was not inevitable. In fact, it seemed quite far-fetched at the beginning. Far from an ordinary corporate gathering, it was more like the elaboration of a film script. It was like the movie *Space Cowboys*, where Clint Eastwood, Tommy Lee Jones, Donald Sutherland, and James Garner are retired test pilots who come out of retirement to fly a dangerous mission to disarm nuclear weapons on an old Soviet space platform.

Even the API's office space came more out of a Hollywood script than from Main Street. At their humble beginnings, with six engineers working around one conference table, Clark housed Aviation Partners' offices in the Flight Center FBO (Fixed Base Operation) at Boeing Field. The design engineers for Aviation Partners and its offshoot, Aviation Partners Boeing, now occupy what used to be the restaurant "Blue Max" in the original terminal building at Boeing Field. Everyone keeps an eye on the long runway outside the window, often interrupting conversations to comment on whose plane is taking off or landing. "That's Clay Lacy in his Learjet;" or "that plane is flying our winglets." Despite Aviation Partners' commercial successes, the office still has the feeling of the start-up that it was not so long ago.

Dick Sears is a former test engineer who was head of flight safety during his last ten years at Boeing. In addition to heading API's flight test program, Sears is also program manager on the new Hawker 800 Blended Winglet project. Sears is a handsome guy, with a full head of white hair.

Lamson is 88 years old, and has the trademark twinkle of the team at API. His long career includes many breakthroughs. His first career was as an engineering test pilot for Boeing back in the forties and fifties, when he won the prestigious Octave Chanute award. He did the experimental test flights of nine different types of plane including the B-50 bomber and the XF 8B1. From 1949 to 1951, Lamson was the chief test pilot on the 377 Stratocruiser. After serving as a test pilot with

THE DREAM TEAM

- **Joe Clark**, aviation entrepreneur
- **Dennis Washington**, Montana industrialist
- **Dick Friel**, sales and marketing master
- **Dr. Louis "Bernie" Gratzer**, chief aerodynamicist and designer
- **Bill Lieberman**, program manager
- **Robert Lamson**, composite guru
- **Dick Sears**, Hawker 800 program manager
- **Kim Frinell**, program manager director of engineering

Boeing, followed by a second career as an aviation technical consultant, Lamson launched a third career in composite technology, reviving his pioneering interest in organic chemistry. Many years earlier, in 1935, he published the seminal technical paper on synthetic plastics and their application to the modern airplane.

In 1965, Lamson built the world's first high-performance pressurized sailplane out of composite materials. When he was honored, in 2001, as a Pathfinder at the Museum of Flight in Seattle, Washington, the award carried the following notation: "This would have been a remarkable technical achievement had [the sailplane] been built by a highly skilled team on a factory floor; that it was hand-built by one man in his own shop marks it as the work of a true Pathfinder." The sailplane, with a wingspan of 70 ft (21 m), now hangs in the Museum of Flight's Great Gallery.

Lamson's role in the API Blended Winglet program is in composite materials. He supervised the construction of all prototype winglets used on API's test flights. Lamson deflects credit to others, "It is the design team and the flight test program guys who are the real heroes here."

Along with Lamson and Sears, the team includes Gratzer, Lieberman, and Frinnel. Except for Frinnel, all are in their seventies or eighties, and all are long retired from Boeing. But they are obviously not done working. Most of them still come into the API office, and for many of them this is not their only job. Several have consulting businesses as well. Clark explains,

> These guys have done it all. They grew up in an era when the best in the field knew everything about the planes they designed and flew; they could see the big picture, and they trusted their intuition. Today, the new generations are far more specialized, and only see the part of the problem they are assigned to solve. It's hard to optimize a plane when you only know part of it.

Lieberman, after a stint as a commander in the US Navy, joined Boeing as chief flight test engineer. At Boeing, he was responsible for flight tests and FAA certification of many planes. At one point, Lieberman took ten years away from aircraft design to sail his sloop *Nomad* about 35,000 miles (56,000 km) around the world. Lieberman also runs a consulting company that had worked for Gulfstream on certification. Like other members of the API team, Lieberman is a confident and respected engineer with a record of success.

Frinell, the youngster of the group, alludes to a checkered past working for Boeing. "Lieberman hired me four times for Boeing flight test programs and only fired me once," he says. Frinnel has two first flights to his credit—the DC 9-30 and the 737-200.

In conversation, Lamson talks frequently about the team. It is clear he not only knows planes, he also knows people. "I'm a lucky man," he says: "I get to work with the best in the business. World speed record holders. Legendary test pilots. The most talented aerodynamic engineers. The smartest folks in the history of the business. Bernie Gratzer is a real engineering genius with the eye of Leonardo da Vinci—he can draw a winglet with performance *and* style."

We were soon introduced to another character: API's Vice President of Sales and Marketing, Dick Friel. Frinnel describes Friel as "a group of people in one pair of

Blended Winglet being installed on a Gulfstream

pants, with the humor of a dozen comedians." Unlike other members of the team, Friel looks very Hollywood in his elegant Saville Row shirts, with French cuff and solid gold cufflinks, his yellow yachting tie, and his suspenders. Friel hired Clark when he was VP of Marketing and Sales for Gates Learjet; and after that Friel took over marketing management of a home improvement retail corporation and then started his own advertising agency. Friel came back to aviation when Clark started API and needed a marketing genius. "I just closed my company and came to work for Joe. I knew he was on to something really good," says Friel.

This top-gun marketing and sales wizard is credited with creating the award-winning Blended Winglets advertising and public relations campaign. In it, he translated the advanced technology terminology of the Blended Winglets into a "top-of-mind" awareness that moved the technology so well that it dominated the marketplace. "The bottom line," says Friel, "is that our winglets let you fly higher, faster, and farther. They make an old airplane look brand new again. They're sexy!" Friel is also an actor who has made more than 100 commercials and acted in several movies, including one with John Wayne. In his spare time, Dick serves on the Marketing and Capital Campaign Committee of the Museum of Flight in Seattle. Friel's experience and character was key to moving the winglets.

The hurdles keep coming

Once the team had jumped the second hurdle by getting Gulfstream II owners to buy the Blended Winglets, the third hurdle presented itself. Despite success with the Gulfstream II program, API faced daunting challenges in persuading Boeing to adopt Blended Winglet systems on its business jets. Boeing aerodynamic and structural engineers believed that the additional weight and drag of the winglets would cancel out the benefits.

But Boeing Business Jets (BBJ) President Borge Boeskov had customers who said that the Blended Winglets looked modern and sexy, and those customers were already asking for winglets. Compared to the small, angular, traditional winglets you often see on commercial and business aircraft, Blended Winglets are noticeably taller and feature a smooth curvature transition between wing and winglet. Boeskov was the best Boeing salesman ever, and he trusted his instinct that something had to be done to distinguish the BBJ from its commercial version, the basic Boeing 737.

Clark cut a deal with Boeskov at the 1997 Paris Air show to design and build winglets for BBJ—on the condition that they would become standard equipment if successful. But when Boeskov put in a request to Boeing for a test plane to bolt the winglets onto, he was told that none were available. Small obstacles such as that, however, just make life more entertaining for him. Boeskov is a Danish immigrant, by way of Iceland, who worked his way from earning $25 a week at a seed store to presiding over one of the most successful executive aircraft companies in history. "Easily discouraged" is not a term anyone would use to describe Boeskov. Earlier in his career, Boeskov had worked in the European sales division at Boeing and had met people over at Hapag Lloyd, a German company that owned a charter/tour fleet of 737s. Hapag Lloyd agreed to lend him one of their jets for six weeks, provided that he let them keep the winglets if they worked. The deal was set with a handshake.

But the Boeing engineers remained pessimistic. Bob Lamson remembers the pessimism that came from a particularly knowledgeable colleague. "My next door neighbor is a retired Vice President of Boeing. In his early years he designed and built the Boeing wind tunnel and is a great believer in wind tunnel testing. One day, in an informal conversation, he told me he suspected that our calculations were in error and our performance enhancement was too optimistic." Imagine being told by the inventor of the wind tunnel that your plans were doomed! A person with less confidence might not have had the courage to continue.

Dick Sears adds his own story about Boeing's pessimism:

> I remember when we were getting ready for the test with Boeing, and needed to visit the plant to go over the wing strength on the Boeing Business Jet to make sure we could fit our product on properly. That day a young engineer met me at the security gate to escort me to the wing division, which is near the back of the sprawling plant.

The 73-year-old Sears has the team's trademark sparkle in his eyes as he continues to tell his story.

> During our long walk, this young man got to talking, and told me he didn't think our winglets would pass the test. He said that the Boeing engineers had calculated that our systems might require an extra 2,000 pounds [900 kg] of weight just to strengthen the wings to accommodate the Blended Winglets. I quietly told the young engineer that we'd calculated a total weight of between 200 and 300 pounds [90–135 kg].[8] He just shook his head. He clearly didn't believe me.

When API rolled out the borrowed Boeing 737-800, fitted with their Blended Winglets for flight testing, a Boeing aerodynamics engineer boasted that if API achieved even a 2% performance improvement then he would fire all of his engineers and would quit his job.

But the API team remained confident, and with good reason: they were right. At the test flight, Boeing confirmed a 5% improvement. To their credit, the Boeing engineers quickly got on board and are now among the strongest advocates of Blended Winglet technology.

Boeing ultimately formed the Aviation Partners Boeing Corporation for application of Blended Winglets to Boeing business and commercial jets. The joint venture has the advantage of providing full access to Boeing aircraft design specifications and engineering to the team, drastically simplifying evaluation of winglet configuration. And each application to the FAA for new winglet configurations builds on previous physics, engineering, testing, and flight experience with other Boeing aircraft—speeding approval.

However, the marketing challenges remain daunting. Engineers and pilots steeped in the old physics and technology remain skeptical about each new application. The benefits of reducing noise and local air pollution are undervalued and under-priced, and regulations on carbon dioxide emissions are not yet implemented globally. The benefits of safety from reduced wake turbulence at airports are neglected as well because "it would be hard to justify a technology that will 'benefit the guy behind you.' "[9]

But problems such as this have only been one more hurdle for the team to overcome. And they have had much on their side. In 1999, for example, Joe Gullion, President of Boeing Airplane Services, said, "With thousands of airplanes as potential candidates for winglets, we see this as a great retrofit option for our customers and a source for profitable growth for both the airlines and Boeing."[10]

API faced other challenges while they were trying to set up the joint venture with Boeing Business Jets. They had to bridge multiple cultures among engineers and business colleagues. "Many of the young engineers don't believe anything that isn't in their computer program," says Clark. "While the computer is a fantastic tool, if you're not careful it also can limit your thinking, especially when you are looking for a breakthrough, like we were. Our guys still know how to use a pencil,

8 Winglet designs for retrofit must accommodate the existing wing shape and structure for each aircraft, but can choose height, cant, toe, twist, taper, and transitional curvature. Cant is the angle the winglet is bent from the vertical. Toe is the angle of the winglet surfaces relative to the direction of airflow. Twist is the rotation of the winglet as seen from above, and taper is the rate of change in the thickness of the winglet airfoil surfaces.

9 "News Scan: Creating a Wake Vortex," *Scientific American*, February 2002: 16.

10 From Aviation Partners files.

a piece of paper, a formula, a slide rule, and the seat of their pants. Let me show you the first model of our elegant winglet . . ." Clark recovers from his office a winglet cut-out glued on one end to a piece of paper and propped up on the other end with a toothpick. Formulas and critical angles are penciled in. Somehow it seems impressive.

And it is impressive. API's Blended Winglet technology has demonstrated significant fuel savings on every demonstration airframe tested, and it should be suitable for virtually any aircraft. Figure 2.3 shows the performance benefits on Boeing 737s.

737-700/-800/-900:

With Optional New Technology Winglets

Winglet Performance Benefits

	737-700	737-800	737-900
Lower fuel consumption			
500 nmi	-2.4%	-2.5%	-2.2%
1,000 nmi	-3.3%	-3.4%	[illegible]
1,500 nmi	-3.5%	-3.5%	-3.4%
Increased payload-range			
Design range increase	+115 nmi	+130 nmi	+65 nmi
Payload capability increase (fixed range)			
Fuel capability limit	+5,500 lb	+6,000 lb	+6,550 lb
Maximum takeoff weight limit	+1,500 lb	+1,000 lb	+1,000 lb
Improved takeoff performance			
Engine	CFM56-7B24	CFM56-7B27	CFM56-7B27
High/hot takeoff weight increase			
Denver, 30°C	+ 5,400 lb	+4,200 lb	+2,800 lb
Obstacle-limited takeoff weight increase			
Close obstacle (50 ft high, 300 ft out)	+2,200 lb	+1,600 lb	+1,300 lb
Distant obstacle (500 ft high, 8,000 ft out)	+3,400 lb	+3,600 lb	+3,600 lb
Reduced certification noise			
Takeoff noise reduction at cutback	-0.5 to -1.0 EPNdB*	-0.5 to -1.0 EPNdB	-0.5 to -1.0 EPNdB*

* Estimated performance for the 737-700 and 737-900

Range Capability

737-700
737-800
737-900

- Full passenger payload
- Typical mission rules
- 85% annual winds

- Airways and traffic allowances included
- Two-class seating

With winglets
Without winglets

The Boeing Company
Commercial Airplanes
Marketing
P.O. Box 3707
Seattle, WA 98124-2207

Figure 2.3 Winglet fuel savings, increased range and payload on Boeing 737s

Over 10,500 commercial Boeing airplanes are in service today. The Aviation Partners Boeing (APB) business strategy includes winglets for Boeing 747 and 767 airframes, including 747-200 freighters and the 747-400X passenger jets. "Induced drag and lift-dependent drag is responsible for almost half of the total drag of an airplane. We are able to reduce induced drag 12–18% or more with Blended Winglets and this translates into a reduction in overall drag of about 5–8%," says API's Chief Aerodynamicist Dr. Gratzer.

AIRCRAFT LEASING COMPANIES OPERATING WITH API BLENDED WINGLETS

- Air Berlin
- Air Europa
- American Trans Air
- Boullioun Aviation Services
- COPA
- GATX Capital Corporation
- GECAS
- Hainan Airlines
- Hapag-Lloyd
- ILFC
- Kenya Airways
- Pegasus Airlines
- Polynesian Airways
- Qantas Airways
- South African Airways
- Tombo Aviation
- Travel Servis
- VARIG
- Virgin Blue

The sky's the limit

You can't stop a team that is really on a roll—and Clark's team of retired engineers and test pilots has turned out to be the "dream team." Aviation Partners considers the extraordinary energy-efficiency benefits of Blended Winglet technology to be just the beginning. API's Blended Winglets are rapidly being transferred beyond their beginnings on the Gulfstream II business jet.

Soon, Blended Winglet technology will be introduced to dramatically improve the range and performance of the Raytheon Hawker 800 series business jet. In the commercial airline world, APB has brought Blended Winglet technology to next-generation series Boeing 737-800s and 700s. By mid-2003, this performance-enhancing technology will be available as a retrofit for Boeing 737 Classic series aircraft, including the 737-300/400/500. And APB's business strategy includes Blended Winglet systems for Boeing 747 and 767 series airframes.

Future products are in the works as well. Following the Gulfstream II winglet STC, Clark made good on his promise to flight-test Gratzer's closed-loop Spiroid winglet design (see Figure 2.5). Those tests on a high-speed jet validated a new concept, and indicated a 10% reduction in drag. Overall, they may be 40–50% more efficient than Blended Winglets. So far, however, only Lockheed's Skunkworks division has shown interest in this radical new performance-enhancing design for the U2.

Advanced-generation Blended Winglets with controllable twist and toe angle could be optimized in flight. One day, aerospace designers will likely integrate Blended Winglet and Spiroid technology into the design of entire wing and aircraft shapes. The future is on the wing, and there is no stopping it.

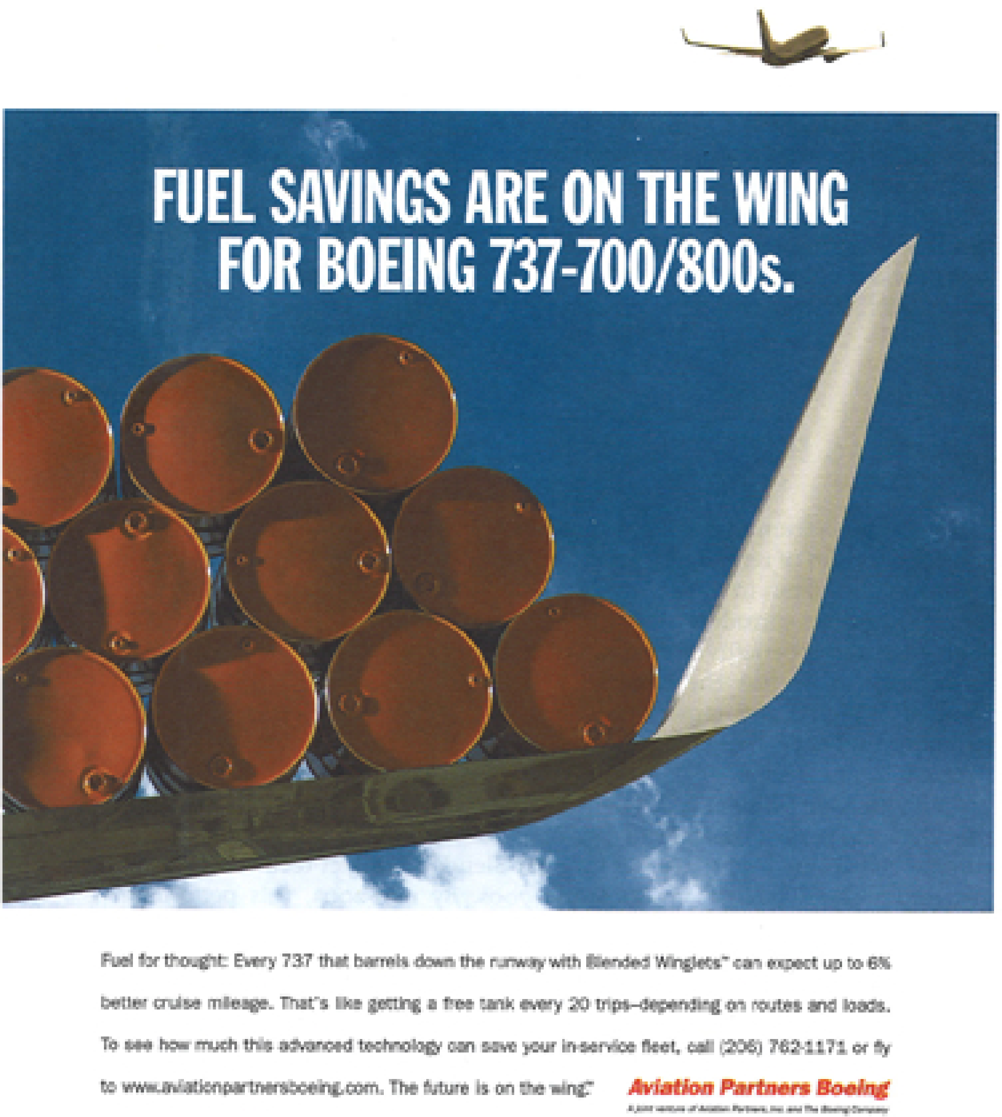


Figure 2.4 Partners advertising barrels of fuel savings

Figure 2.5 Spiroid winglet during test flight

REVOLUTIONARY BENEFITS OF BLENDED WINGLETS

Safety benefits

Increased range, resulting from improved fuel efficiency, provides an added margin of safety to the Blended Winglet-equipped operator. On critical long-haul, over-water flights—such as Los Angeles to Hawaii—a Blended Winglet-enhanced Gulfstream II benefits from a 50% increase in landing fuel reserves due to improved cruise efficiency. Aircraft experts speculate that safety may also be enhanced for aircraft taking off behind Blended Winglet-equipped aircraft because there is less vortex wake turbulence.

Quieter skies

A Blended Winglet-equipped aircraft achieves normal take-off at reduced power settings and will climb faster with a significantly reduced noise footprint. For example, Blended Winglets on a Boeing 737-700/800 allow 39 additional flights per day at noise-restrictive John Wayne Airport in San Diego. Blended Winglet Systems generally reduce the noise-affected take-off area by 7.5%, a particularly important benefit in Europe where take-off and landing fees are based on the noise-affect area.

Fuel efficiency

API Blended Winglets reduce aerodynamic drag by up to 7.5%, which translates into higher fuel efficiency and lower greenhouse gas emissions—benefits *continued* →

Fuel savings of commercial aircraft equipped with Blended Winglets

Aircraft: Boeing	Average flight (hours per year)	Annual fuel per aircraft (US gallons)	Number of operating aircraft	Total annual fuel savings (million US gallons)
737-700/800 New Generation	2,800	55,000	1,045	57,475
737-300/400	2,800	60,000	1,548	92,880
747-200/300	2,000	275,000	318	87,450
747-400	4,750	530,000	582	308,460
757-200	3,000	90,000	976	87,840
767-300	4,500	210,000	605	127,050

that are sustained over the lifetime of the airframe.* Long-range cruise fuel efficiency is increased by up to 7%, CO_2 emissions are reduced proportional to fuel savings, and nitrogen oxide (NO_x) emissions are reduced proportionally greater than fuel savings under typical flight conditions. The financial and environmental benefits of winglets depend on the airplane model and configuration as well as the route. Even a relatively small increase in flight range can save substantial amounts of fuel and emissions if a refueling stop can be avoided.

Blended Winglet-equipped airliners, flying a typical 2,000–3,000 hours per year, will save astonishing amounts of fuel (see Table above).

Style, prestige, and performance benefits

"Gulfstream II charter customers feel like they are on a much newer aircraft, so it pays back that way as well," says Air Group President Jon Winthrop.† The improved performance of a Blended Winglet-equipped aircraft translates into increased profits for airlines by improving payload and range, decreasing fuel use, and lowering engine-maintenance costs. Range issues are particularly important for aircraft operating from hot or high-altitude airfields, and for long routes where headwinds decrease range. For example, Blended Winglet systems allow South African Airways to add 11–21 more passengers on long-haul flights during hot-day take-off from its Johannesburg hub. At current fuel prices, fuel savings alone pay back the cost of Blended Winglets in two years of commercial use. Additional benefits include routing flexibility, aircraft resale value, and the enhanced image of a stylish, aesthetically pleasing, and environmentally friendly aircraft.

Competitive sales benefits

Blended Winglet technology translates into increased airliner sales for Boeing in highly competitive market arenas where the added performance of this technology is

continued →

* The winglet will provide sustained environmental performance over the entire life of the airframe. Competing investments in fuel efficiency from engine upgrades, on the other hand, achieve their highest performance when they are new—and their performance degrades as parts wear until the next maintenance cycle.

† Quoted in "The Ultimate Winglet," *World Aircraft Sales*, May 1999.

often the deciding factor. One such sale occurred in 2001 when Qantas purchased 15 Blended Winglet-equipped Boeing 737-800s with options for 40 additional aircraft. South African Airways recently ordered 18 Blended Winglet-equipped 737-800s, rather than Airbus 320s, because Blended Winglets provide the range needed to serve important markets non-stop. "People close to the deal said the Blended Winglets offered on the Boeing plane gave it an important performance edge over the Airbus A320 on new long-haul domestic routes planned by Qantas," said one analyst.‡

Payload benefits

The 737-800 can carry an additional 6,000 lb (2,720 kg) payload or add 130 nautical miles (240 km) to range. This advantage, in turn, brings in additional revenues, reduces costs, reduces pollution, and has other benefits.

Top-quality materials and construction

Blended Winglets are designed to be as light as possible so that benefits of lower aerodynamic drag can be maximized. API's Blended Winglets are built with carbon-fiber composite material combined with a Nomex® honeycomb stabilizing core, and they use solid laminate spars with aluminum leading and trailing edges.

‡ James Wallace, "Aerospace Notebook: Partnership with Boeing 'Starting to Take Off,' " *Seattle Post-Intelligencer*, February 25, 2002.

Aviation Partners time-line

- **1492** Leonardo da Vinci (Italy) describes a flying machine.
- **1783** Joseph Montgolfier and Étienne Montgolfier (France) launch the first hot-air balloons.
- **1891** Otto Lilienthal (Germany) succeeds with the first reproducible gliding flights.
- **1897** F.W. Lanchester (USA) patents simple wing-end plates for gliders and in anticipation of powered flight.
- **1900** Ferdinand von Zeppelin (Germany) builds the first successful dirigible.
- **1903** Orville and Wilbur Wright (USA) are the first to fly powered aircraft.
- **1927** Charles A. Lindbergh (USA) completes first solo non-stop transatlantic flight from New York to Paris.
- **1937** First experimental pressurized-cabin airplane, a Lockheed XC-35, made first flight at Wright Field.
- **1947** Charles E. Yeager (USA) completes the first supersonic flight in a rocket-powered Bell XS-1.
- **1949** First non-stop, round-the-world flight.
- **1976** NASA's Richard T. Whitcomb invented vertical wingtip extensions as a means to increase lift-to-drag performance.

- **1981** McDonnell Douglas installs winglets on the MD-11 and C-17 Globemaster III.
- **1983** Learjet installs winglets on its business jet.
- **1988** Airbus is first to install winglets on a commercial passenger aircraft (Airbus A320).
- **1991** Joe Clark and Dennis Washington form Aviation Partners (AP) and hire Dr. L.B. Gratzer and a dream team of retired Boeing and Lockheed aerospace engineers.
- **1993** AP installs high-aspect-ratio Blended Winglets on Gulfstream II and immediately markets the retrofit after FAA approval.
  - AP flight-tests Spiroid wingtips on a Gulfstream II and achieves more than 10% greater fuel efficiency at cruise but delays commercialization in favor of Blended Winglets that are more stylish and more easily satisfy FAA and aircraft authorities.
  - Bernie Gratzer receives patent #5,348,253 for Blended Winglets.
- **1995** Clay Lucy knocks two hours off the Los Angeles to Paris World Speed Record on a Gulfstream II with AP winglets.
- **1996** Clay Lucy establishes seven new time-to-climb records, including a dramatic climb from sea level to 40,000 ft (12,000 m) in just 6 minutes and 20 seconds on a Gulfstream II with AP winglets.
- **1999** AP Blended Winglets tested on Boeing business jet.
  - Aviation Partners Boeing (APB) joint venture formed to apply winglets to all suitable Boeing aircraft. The winglet is offered as a standard feature of the Boeing business jets.
  - Qantas purchases 15 winglet-equipped Boeing 737-800s and takes options for at least 40 more—citing the winglet as a deciding factor.
- **2000** Hapag-Lloyd is first airline to operate a Boeing 737-800 with retrofit Blended Winglet technology.
  - South African Airlines is first to order winglet-equipped Boeing 737-800s, stating that the winglets make the 737 outperform the rival Airbus A320 on long flights.
  - Air-Berlin first to fly a Boeing 737 with factory-option Blended Winglets.
- **2001** Blended winglet program announced for Raytheon Hawker 800 business jet with 7% increase in cruise fuel efficiency and significant improvements in take-off, initial cruise altitude, and range.