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Environmental Performance

Leading the Way to a Biofueled Future

Interactive Version of the Quick Reference Handbook

Surface Coatings and Drag Reduction

AERO

Cover photo: *747-8 skin panel*

AERO

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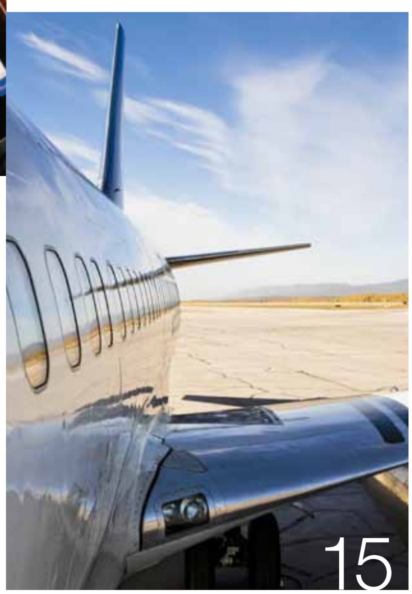

AERO

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BOEING EDGE

AERO magazine is published quarterly by Boeing Commercial Airplanes and is distributed at no cost to operators of Boeing commercial airplanes. *AERO* provides operators with supplemental technical information to promote continuous safety and efficiency in their daily fleet operations.

The Boeing Edge supports operators during the life of each Boeing commercial airplane. Support includes stationing Field Service representatives in more than 60 countries, furnishing spare parts and engineering support, training flight crews and maintenance personnel, and providing operations and maintenance publications.

Boeing continually communicates with operators through such vehicles as technical meetings, service letters, and service bulletins. This assists operators in addressing regulatory requirements and Air Transport Association specifications.

Correction: In the fourth quarter print issue of *AERO*, there were errors on page 20 in figure 1, "Worldwide lightning activity." The colors in the key to the right should have been reversed and the description of flash density in the subhead should have been flashes/kilometers^2/year. Both of these errors have been corrected in the online version of the magazine. We regret any inconvenience to our readers.

Print copies of *AERO* are not available by subscription, but the publication may be viewed on the Web at www.boeing.com/boeingedge/aeromagazine.

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Improving Airplane Environmental Performance

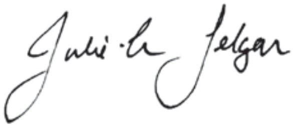
For Boeing, environmental performance is both a challenge and a point of pride. We're proud that airplanes entering today's fleet are 70 percent more efficient than early generation jetliners. Yet, we realize there is much work to be done if we and other industry members are to attain our goal of achieving carbon-neutral growth from 2020. That means no increase in carbon emissions in spite of air traffic growth. We also aim to reduce carbon emissions by 50 percent by 2050 relative to 2005 levels.

One of the ways we are working toward better environmental performance is by designing airplanes that are more efficient. Our investment in advanced materials, aerodynamics, propulsion, and systems have all resulted in lower fuel use and reduced greenhouse gas emissions as demonstrated by the 747-8 and 787.

We're also working with government and others to apply new technologies and methods to improve the operational efficiency of the airspace in order to reduce fuel use and decrease emissions.

And we're actively involved in working with the industry to advance the commercialization of sustainable aviation biofuel — sometimes from some surprising sources. You can read about our efforts in this area in the article that starts on page 5 of this issue of *AERO*.

At Boeing, we intend to lead the way in pioneering new technologies for environmentally progressive products and services — designed, developed, and built in an environmentally responsible manner.



JULIE FELGAR
Managing Director,
Environment & Aviation Policy
Boeing Commercial Airplanes

Biofuels, derived in part from plant oils, can help reduce the environmental impact of commercial airplanes while providing an additional fuel supply.

Leading the Way to a Biofueled Future

Airlines are faced with the challenges of progressively improving environmental performance and lessening impacts to global ecosystems while continuing to reduce operating costs. Bio-derived jet fuel is a key element in the industry strategy to address these challenges.

By James Kinder, Ph.D., Chemist, Propulsion Systems

The aviation industry is committed to achieving carbon-neutral growth from 2020 and aims to reduce carbon levels by 50 percent by 2050, relative to 2005. Boeing is contributing to these goals by investing in technology to improve the environmental performance of its commercial airplanes, providing services to improve flight operations, and supporting the development and use of sustainable aviation biofuel to decrease carbon emissions.

This article reviews current efforts to provide the industry with sustainable biofuels; explains how bio-derived synthetic paraffinic kerosene (SPK) fuels, also known as hydroprocessed fatty acid esters and free fatty acids (HEFA), were evaluated for performance; and provides an overview of current use of biofuels by commercial airlines.

TOWARD A BIOFUEL STANDARD

Biofuels, when produced in sustainable ways, contribute far less to global climate change than traditional fuels produced by processing fossil-based source materials. For example, unlike fossil-based fuels, biofuels have the potential to remove carbon dioxide (CO_2) from the atmosphere in the process of growing the biomass.

In 2006, Boeing became aware of research that suggested that a fuel could be produced from a biomass source material that performed as well as or better than jet fuel produced by traditional fossil-based oil. Boeing contacted companies that were leading the research in this area to determine whether the processes they developed could be scaled up to produce large quantities of fuel that would be required to perform a thorough industry evaluation of the fuel. Boeing also engaged others in the aviation industry to determine whether biofuels could help meet both the technical and environmental challenges of commercial aviation.

Figure 1: Potential sources of biofuels

Potential sources of bio-derived oil to make HEFA include (shown left to right): *Salicornia* (a variety of halophytes), *Jatropha*, *Camelina*, and algae.

After a rigorous evaluation process, it was determined that a “drop-in” fuel could be produced by processing bio-derived oils and fats. The term “drop-in” fuel meant the bio-derived fuel could be blended with fossil-based jet fuel without any changes to the engines, airframes, or fuel distribution system. Boeing and its industry partners led the effort to gain international approval of synthetic blending components made by processing bio-derived oils and fats with traditional fossil-based jet fuel to be used in commercial aviation.

To highlight the technical feasibility study, Boeing and its airline partners helped pioneer a series of test flights starting in 2008 using these new bio-derived fuels with airline and engine company partners on 737 and 747 airframes. The purpose of these flights was to gather data necessary for the approval of these fuels and to demonstrate that the process could be used to produce large quantities of a sustainable fuel with lower greenhouse gas emissions than fossil-based fuels for commercial aviation. All of the flight tests were very successful and underscored the high quality of these new bio-derived fuels.

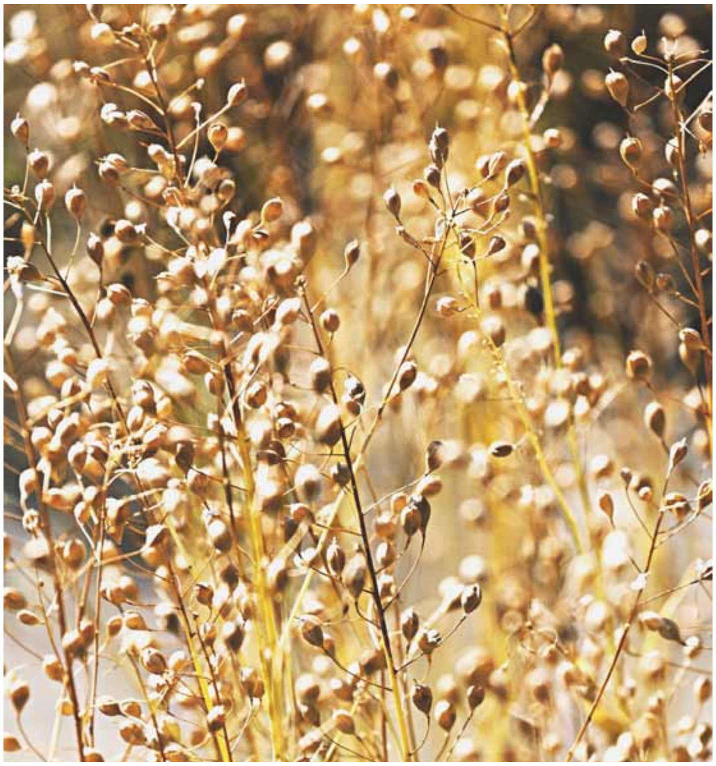
In 2011, the international aviation and fuel communities approved the use of fuel produced using bio-derived oil and fats with petroleum-based jet fuel for commercial aviation. The new bio-derived fuel specification was added to the American Society for Testing and Materials (ASTM) D7566 specification. Early in 2012, these bio-derived fuels were added to the United Kingdom Ministry of Defence standard 91-91 specification for turbine fuels.

Boeing led the development and the approval process of bio-derived fuel produced from fats and algae and plant oils for aviation. This has inspired others to develop new ways to produce fuel from bio-derived sources using a variety of new and novel source materials and chemical processes. For example, companies have developed technology to produce fuel from wood, municipal waste, and sugars. These efforts may result in a variety of ways to produce fuel that not only reduce the environmental impact of aviation but may also lead to the production of a cost-competitive, higher-quality jet fuel.

ABOUT SUSTAINABLE AVIATION BIOFUEL

A sustainable aviation fuel meets or exceeds jet fuel standards, produces lower carbon emissions over its lifecycle (production through use), does not displace food crops, and creates a positive socioeconomic impact where feedstocks are grown. Boeing focuses on sustainable aviation biofuels produced from renewable resources that do not compete with food crops for land or water.

To be deemed sustainable, a biofuel must have a carbon-neutral lifecycle, from production through use. The certification



process considers social and economic factors and land, water, and energy use.

A drop-in fuel must meet or exceed the appropriate jet fuel specification. For example, the biofuel must have an energy density equal to or greater than conventional jet fuel, and it must be able to function at extreme temperatures, both hot and cold.

BIO-DERIVED OILS

A number of bio-derived oils have been investigated for the production of biofuel. The investigation focused not only on the technical feasibility of converting these oils to biofuel but also on establishing the sustainability criteria of these oils. A few examples of these oils are (see fig. 1):

- Halophytes. Plants that grow naturally in saline habitats. One variety, *Salicornia*, has seeds with oil content of nearly 30 percent.
- *Jatropha.* A nonedible plant resistant to drought and that can grow on marginal lands. The oil content of a *Jatropha* seed can be as high as 40 percent oil.
- *Camelina.* A conventionally farmed oil seed crop that is used as a rotational crop in modern agricultural practices.
- Algae. Simple photosynthetic organisms that can be grown in seawater or wastewater.

Using advanced chemical processing methods, the bio-derived oils are converted into the same molecules contained in jet fuel produced from refined conventional crude oil. HEFA fuels made from *Jatropha* and *Camelina* oils using the Honeywell UOP renewable jet fuel process can achieve a reduction of greenhouse gas emissions between 65 percent and 80 percent relative to petroleum-derived jet fuel. Similar results are projected for algae-based HEFA biofuels pending commercialization of efficient oil-extracting techniques.

EVALUATING HEFA FUELS FOR USE AS JET FUEL

The chemical composition and performance of new HEFA bio-derived fuels were investigated as part of the ASTM approval process. Many of the properties of traditional jet fuel that aren't part of the jet specification, but which are critical for the proper operation of the airframe (such as dielectric constant, bulk modulus, and materials compatibility), were tested. Boeing, with the assistance of Honeywell UOP and the U.S. Air Force, produced and circulated a detailed research report to the aviation community for comment and approval. Included in the research report was data from the Boeing test flights as well as material compatibility testing, fuel handling evaluation, and engine test data.

Figure 2: Chemical analysis of HEFA biofuels

Additional requirements for synthetic paraffinic kerosene (SPK) from hydroprocessed fatty acid esters and free fatty acids are potential sources of bio-derived fuel to make HEFA. (See ASTM D7566-11.)

Property		HEFA-SPK	American Society for Testing and Materials Test Method
Hydrocarbon Composition			
Cycloparaffins, mass %	Maximum	15	D2425
Aromatics, mass %	Maximum	0.5	D2425
Paraffins, mass %		Report	D2425
Carbon and Hydrogen, mass %	Minimum	99.5	D5291
Nonhydrocarbon Composition			
Nitrogen, mg/kg	Maximum	2	D4629
Water, mg/kg	Maximum	75	D6304
Sulfur, mg/kg	Maximum	15	D5453 or D2622
Metals (Al, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Sn, Sr, Ti, V, Zn), mg/kg	Maximum	0.1 per metal	UOP 389
Halogens, mg/kg	Maximum	1	D7359

The information in the research report was used to generate the international specification for HEFA biofuels. Included in the specification is a chemical composition table that has very low limits for potential contaminates in the fuel. The chemical composition requirements for HEFA biofuel are stricter than for conventional jet fuel (see fig. 2).

ENGINE AND FLIGHT TESTING

Before HEFA biofuels were used in flight, Boeing and industry partners performed extensive lab, engine, and ground testing. During engine testing, performance, operability, and emissions were evaluated comparing 100 percent traditional petroleum-based jet fuel with 50 percent and 25 percent HEFA biofuel blends. Engine ground runs were also conducted, including a switch of fuel at various progressions of the engine pressure ratio settings. All key testing parameters measured within the expected variation of jet fuel.

Several significant test flights have included:

- February 2008: Boeing, Virgin Atlantic, and GE joined forces to fly a Boeing 747-400 from London to Amsterdam with a 20 percent biodiesel blend in one of the four engines, achieving an important milestone.
- December 2008: Air New Zealand flew a 747-400 with Rolls-Royce engines with a 50/50 blend of *Jatropha*-based HEFA biofuel and conventional jet fuel.

Boeing’s role in developing aviation biofuel

Although Boeing has no plans to produce aviation biofuels, the company is taking a leading role in accelerating their development, creating global availability, and encouraging the adoption of sustainability standards for them.

In 2011, Boeing joined with the École Polytechnique Fédérale de Lausanne in Switzerland to create the Sustainable Biomass Consortium, a research initiative focused on increasing alignment between voluntary standards and regulatory requirements for biomass used to create jet fuel and bio-energy for other sectors. This consortium aims to harmonize sustainability standards for bio-based fuels.

Boeing is bringing together agricultural interests, academia, refiners, and aerospace companies around the globe to establish regional supply chains and develop a sustainable and economically viable biofuels industry. Regional projects are under way in Europe, the Middle East, Australasia, China, Mexico, Brazil, and the United States.

Boeing is also a cofounder of the Sustainable Aviation Fuel Users Group, which works to establish a sustainable fuel supply for commercial aviation. The company is also a founding member of Sustainable Aviation Fuels Northwest and convened the initial meeting that led to the formation of the Commercial Aviation Alternative Fuels Initiative, a broad-based industry coalition including commercial, noncommercial, and military aviation.

In addition, Boeing cofounded and serves on the board of the Algae Biomass Organization, which focuses on creating commercial markets for algae biofuels and greenhouse gas abatement, and is a member of the Roundtable on Sustainable Biofuels, an international initiative bringing together industry, investors, environmental organizations, and producers of biofuels feedstock.

Boeing and the aviation industry have established a goal of having 1 percent of all aviation fuel include some biofuel content by 2015.

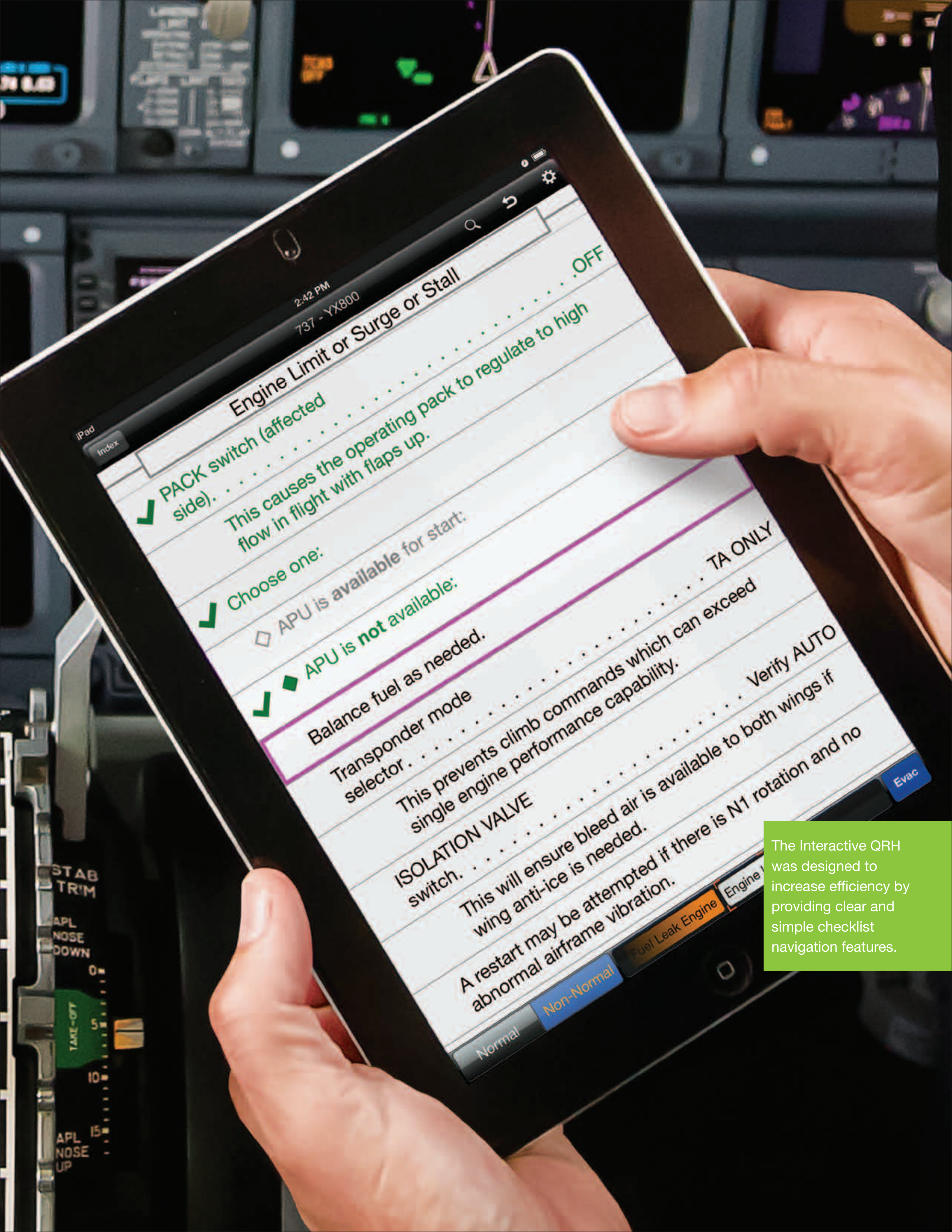
- January 2009: Continental Airlines operated the first flight of an algae-fueled jet, and Japan Airlines flew a 747-300 with Pratt & Whitney engines with a 50/50 blend of *Camelina*-/*Jatropha*-/algae-based HEFA biofuel and conventional jet fuel.
- June 2011: Boeing flew a new 747-8 Freighter to the Paris Air Show with all four engines fueled by a 15 percent *Camelina*-based HEFA biofuel.
- August 2011: An Aeromexico 777-200ER completed the first intercontinental HEFA biofuel flight with revenue passengers as it flew from Mexico City to Madrid. It used a 30 percent *Jatropha*-based HEFA biofuel blend.
- November 2011: Alaska Airlines became the first U.S. carrier to offer regularly scheduled passenger flights on airplanes powered by biofuels.

To date, more than 1,500 commercial flights have been flown using up to 50 percent blends with traditional fuel. The industry is now focused on achieving production on a commercial scale and price parity with fossil-based jet fuel.

SUMMARY

Biofuels can reduce the environmental impact of commercial jet airplanes while providing an additional option for fuel supply. Boeing is working with the aviation industry to expand the use of biofuels and help the industry achieve its goal of reducing carbon levels by 50 percent by 2050, relative to 2005.

For more information, please visit the Sustainable Aviation Fuel Users Group Web site (www.safug.org).



The Interactive QRH was designed to increase efficiency by providing clear and simple checklist navigation features.

Interactive Version of the Quick Reference Handbook

Boeing has recently introduced an electronic tablet-based version of the paper Quick Reference Handbook (QRH) used by flight crews. It is initially available for the Next-Generation 737.

By Keith Kurtz, Senior Manager, Flight Technical Data, Product Support Engineering

Flight crews continue to request the convenience of electronic devices to assist with flight planning and execution. To respond to this customer demand, Boeing has developed a tablet-based version of the QRH, called the Interactive QRH. The Interactive QRH contains all the elements found in the paper version: normal checklists, non-normal checklists, performance tables, and maneuvers; however, it leverages mobile device technologies to allow pilots to execute required checklists more efficiently.

This article describes the Interactive QRH and provides an overview of its features and functionality.

MOVING TO AN INTERACTIVE QRH

Flight crews have long referred to the QRH for normal and emergency/non-normal checklists as well as selected in-flight performance data. Designed to be compact and easy to use on the flight deck, the QRH provides a fast, easy reference to procedures flight crews should follow in a variety of situations.

Boeing determined the nature and use of the QRH made it an ideal candidate to offer on a tablet device (see fig. 1).

Boeing had three key objectives in developing the Interactive QRH:

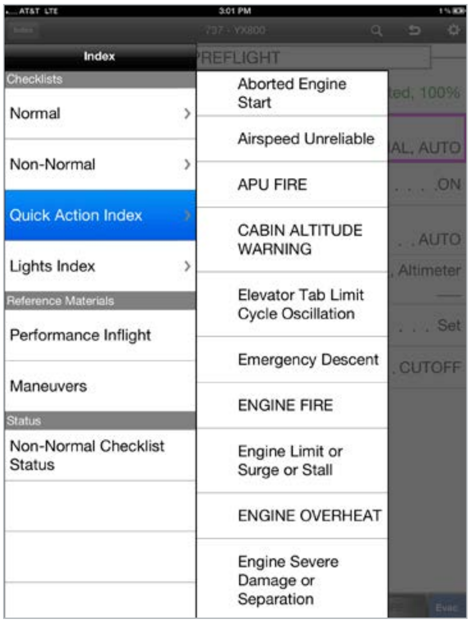
- Use the same data as the paper QRH.
- Make the Interactive QRH easy to use with minimal training.
- Take advantage of the capabilities of a mobile device.

Figure 1: Interactive QRH preflight checklist

As a pilot goes through a checklist, the Interactive QRH provides visual confirmation as actions are accomplished.

Figure 2: Interactive QRH index

All checklists are available from a single index.



ADVANTAGES OF A TABLET-BASED QRH

The Interactive QRH was designed to increase efficiency by providing clear and simple checklist navigation features. These improvements were validated by Boeing human factors engineers and technical pilots during extensive testing.

- The Interactive QRH offers advanced navigation and search capabilities to enable the pilot to easily find the proper checklist (see fig. 2).
- A specific airplane is selected for each flight, which simplifies checklist execution for those customers with multiple fleet configurations.
- The Interactive QRH aids in checklist execution by highlighting checklist steps that have been missed, directing users to the correct checklist as appropriate, and tracking deferred items in non-normal checklists as needed (see fig. 3).
- The Interactive QRH also simplifies non-normal checklist use, especially for those checklists in which the correct condition must be selected from two or more choices (see fig. 4).

These features, which are not possible with paper checklists, are designed to increase efficiency in completing checklists.

REGULATORY APPROVAL FOR THE INTERACTIVE QRH

Boeing coordinated with the U.S. Federal Aviation Administration (FAA) Aircraft Evaluation Group (AEG) to evaluate the Interactive QRH's suitability for operational approval. The AEG found the Interactive QRH satisfies the requirements of FAA Advisory Circular AC 120-76B — Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags. Individual operators will need to obtain approval from their principal inspector prior to using the application. Boeing is also working with the European Aviation Safety Agency for similar approval.

AVAILABILITY

The Interactive QRH is currently available for Next-Generation 737 models and runs on Apple iPad tablets. The application is available at no charge from the Apple iTunes Store, and customized QRH data is available for purchase from Boeing Flight Technical Data or through the Service Request application on the Web portal MyBoeingFleet.com. Boeing will make the Interactive QRH available for other airplane models and additional mobile platforms, based on airline interest.

SUMMARY

The Interactive QRH contains all the elements found in the paper version, including normal checklists, non-normal checklists, performance tables, and maneuvers. By taking full advantage of tablet technology — such as visual confirmation of actions taken — the Interactive QRH can increase efficiency in completing normal and emergency/non-normal checklists.

For more information, e-mail FlightTraining@boeing.com.

Figure 3: Deferred items

The Interactive QRH alerts the user when there are deferred items in an active non-normal checklist (top). If there are any active non-normal checklists with deferred items, the Interactive QRH will provide a reminder in all normal and non-normal checklists, as appropriate (center), and prevent completion of normal descent, approach, and landing checklists (bottom).

Descent Checklist

⚠ Deferred Items from Other Checklists

⚠ You Have Deferred Items in Non-normal Checklists

Checklist Complete Except Deferred Items

Descent Checklist

Figure 4: Dynamic selections

In certain areas of the Interactive QRH, the user can choose among two or more options that will lead to differing steps. Until a selection is made, none of the steps associated with a choice is displayed (top), thus simplifying choice selection. Depending on which choice is selected, checklist steps associated with the choice will be displayed (center). If the wrong choice was made or the user decides to make a different choice, tapping the grayed-out choice displays the associated steps for the new choice (bottom).

Choose one:

◇ APU is **available** for start:

◇ APU is **not** available for start:

✔ Choose one:

✔ ◆ APU is **available** for start:

◇ APU is **not** available for start:

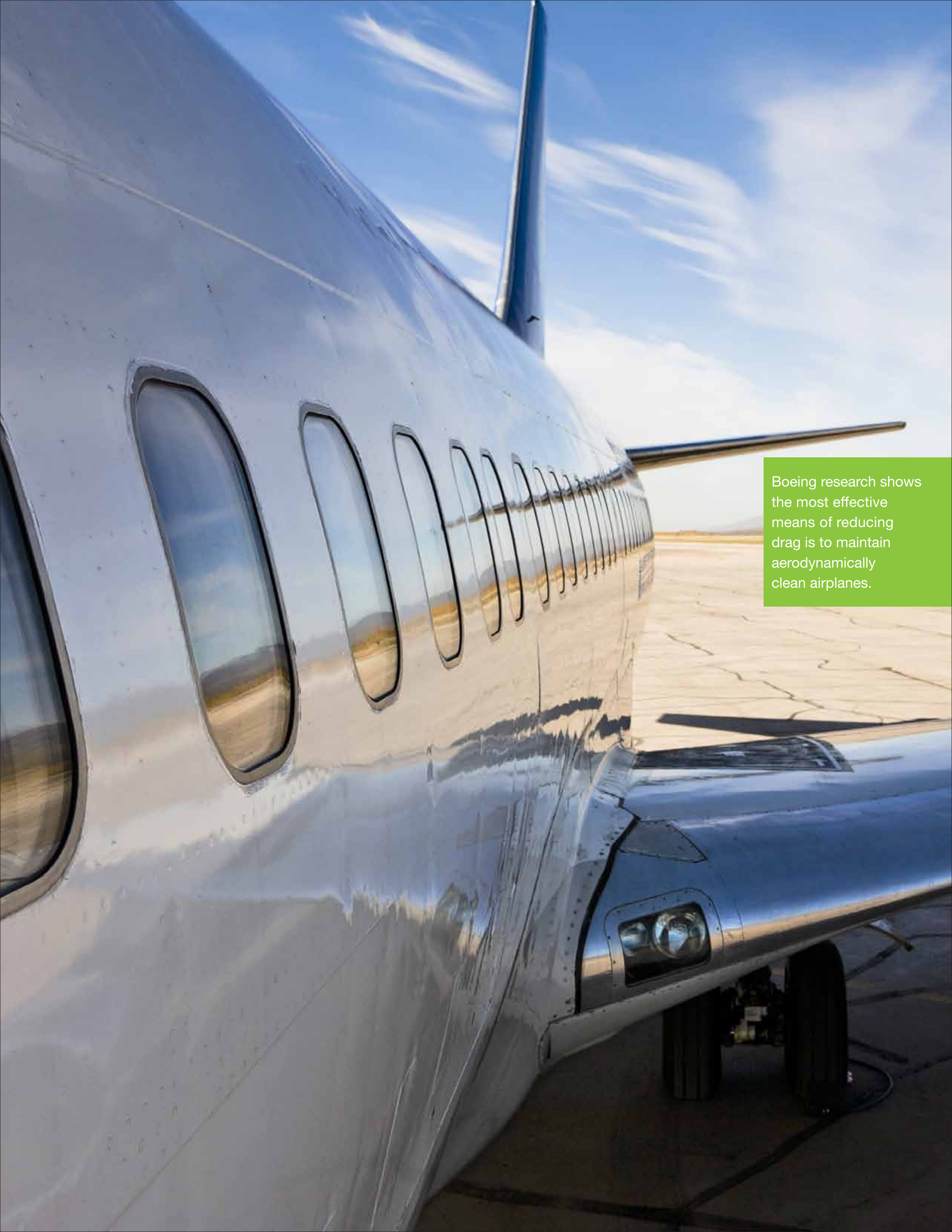
APU . . . . START

✔ Choose one:

◇ APU is **available** for start:

✔ ◆ APU is **not** available for start:

Balance fuel as needed.



Boeing research shows the most effective means of reducing drag is to maintain aerodynamically clean airplanes.

Surface Coatings and Drag Reduction

Fuel cost is easily the largest contributor to cash airplane-related operating costs (CAROC), ranging from 40 percent to 50 percent for single-aisle airplanes and from 50 percent to 60 percent for larger twin-aisle airplanes, at recent fuel prices. Airline customers are keenly aware of the aerosmoothness of their airplanes due to its direct impact on fuel burn. With increasing fuel costs, airlines are looking for new ways of reducing aerodynamic drag of their airplanes to lower fuel consumption.

By Mark I. Goldhammer, Chief Aerodynamicist, Commercial Airplanes, and
Bruce R. Plendl, Senior Aerodynamics Engineer, Commercial Airplanes

Boeing invests significant resources to improve the performance of its commercial airplanes, including improvements for aerodynamic drag, weight, and engine efficiency. Most of the drag characteristics of the airplane are set during the initial design. Key characteristics that affect drag are wing span, exposed surface area, aerodynamic shapes, and numerous design details. After initial design, aerodynamic drag can still be improved. For example, span can be increased or winglets can be added to reduce induced drag, or drag due to lift. Aerosmoothness, or excrescence drag, can also be reduced through detailed design of the fit and fair of external surfaces, through better seals around movable surfaces such as landing gear doors and control surfaces, and through cleanup of other external protuberances.

Recently, a number of Boeing customers have become aware of claims that external surface finish coatings can provide skin protection, paint life improvement, and also skin friction drag reduction. This article provides operators with the technical background to help them assess the potential of surface coatings to reduce roughness drag. It also summarizes other techniques that Boeing recommends to reduce drag and fuel consumption.

POSSIBLE AIRFLOW PHYSICS RATIONALE FOR ROUGHNESS DRAG REDUCTION

In response to numerous questions raised by Boeing customers regarding the efficacy of surface coatings to reduce drag, Boeing has

Figure 1: Laminar versus turbulent boundary layers

Boundary layer growth (top) and velocity profile (bottom).

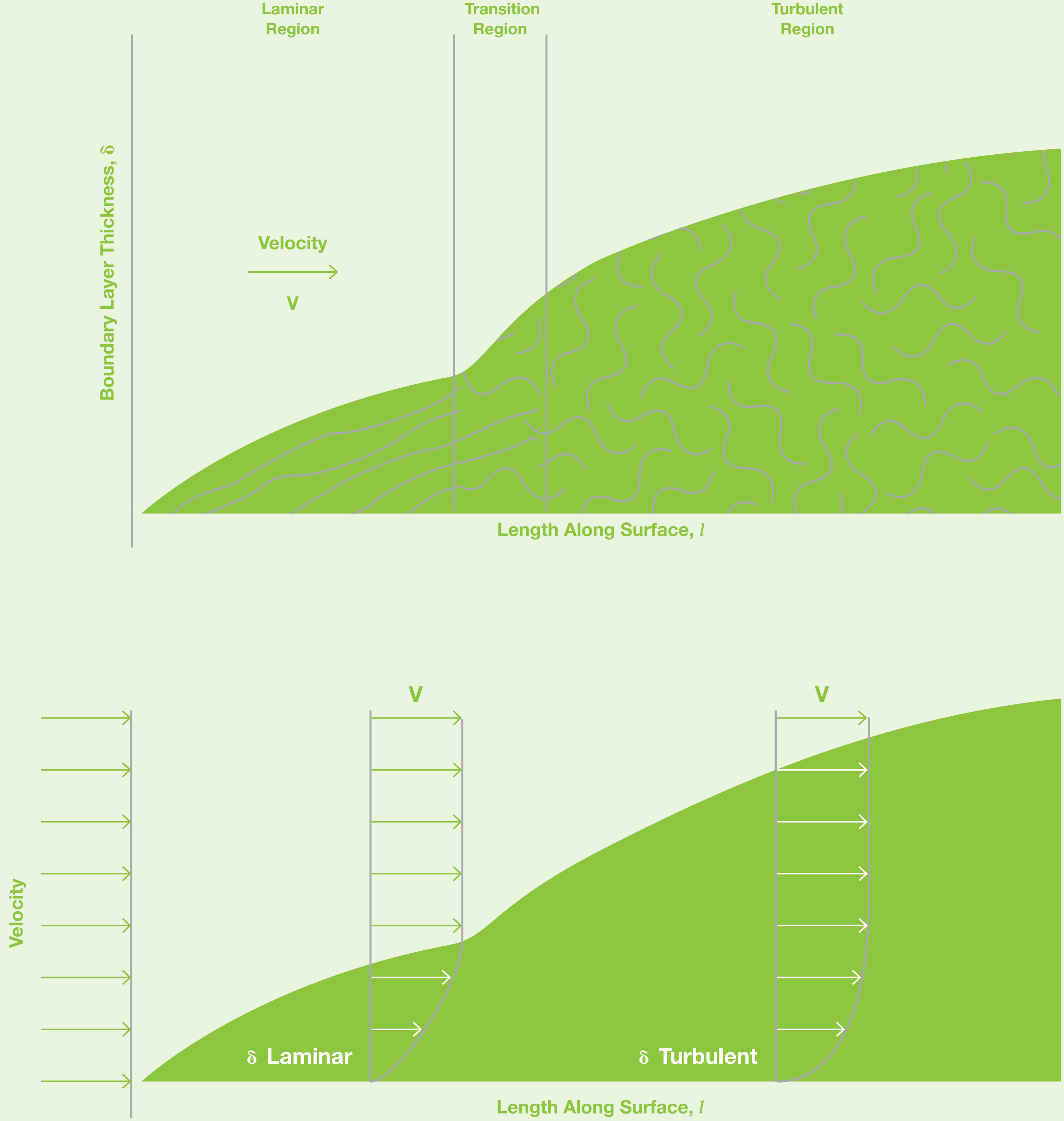
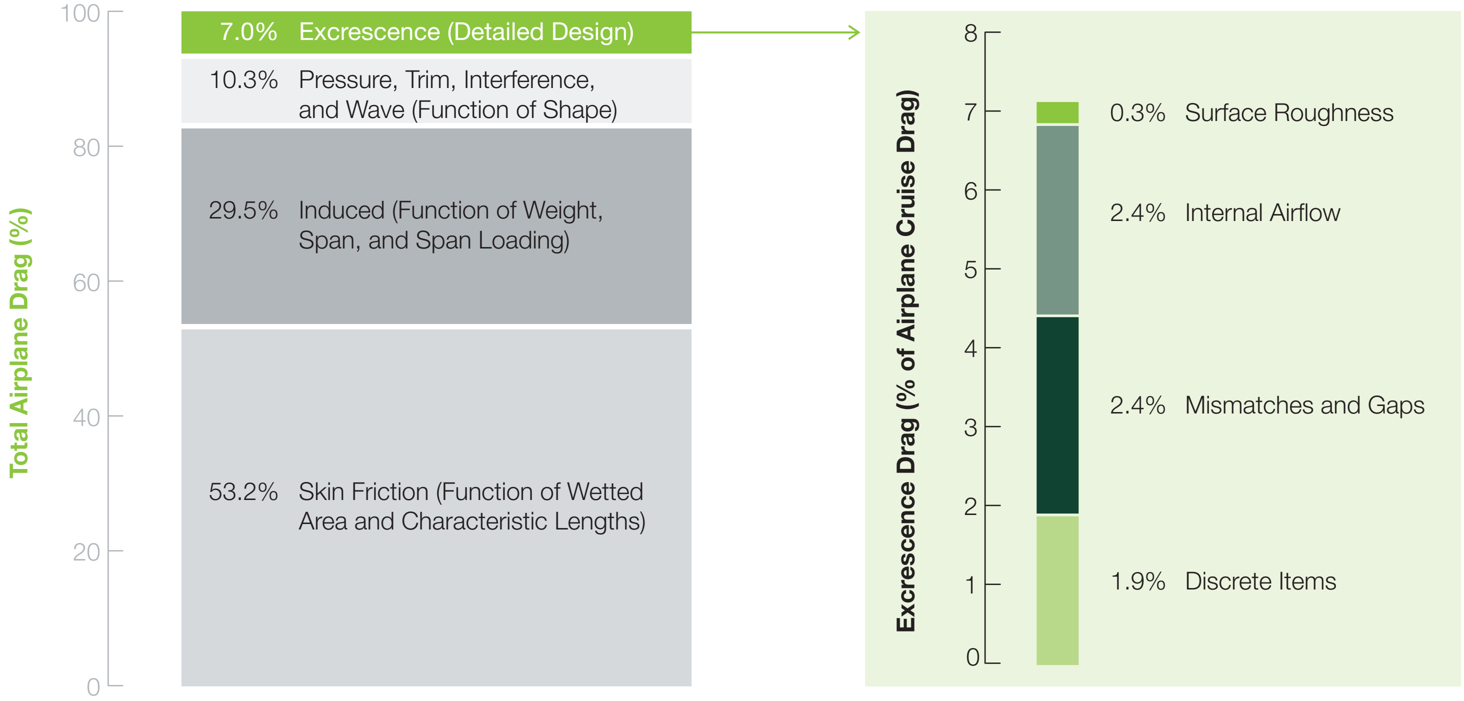


Figure 2: Typical drag component breakdown for Boeing 737

Surface roughness accounts for approximately 0.3 percent of total airplane drag.



investigated some possible airflow physics explanations. Possible explanations postulated by Boeing aerodynamicists include:

- Increased regions of laminar flow due to reduced surface roughness.
- Reduction in surface roughness resulting in lower skin friction drag, when flow is turbulent.
- Reduction in dirt and/or insect adhesion resulting in reduced roughness and hence reduced skin friction drag.

Boeing has thoroughly researched these possible explanations to determine whether methods such as surface coatings can produce a meaningful reduction in drag.

LAMINAR FLOW

The first postulated flow mechanism that may result in reduced skin friction drag due to surface coatings is the promotion of laminar flow. Laminar flow refers to the state of the boundary layer, the thin layer of air next to the airplane skin where the effects of friction would be observed. Normally, the boundary layers on large commercial airplanes are nearly all turbulent, meaning the airflow within the boundary layer is characterized by irregular flow eddies. Laminar boundary layers are characterized by more orderly flow and have significantly less skin friction drag (see fig. 1).

Current Boeing commercial airplanes are not expected to have significant regions of laminar flow, with the exception of the 787 nacelles near the inlet lip, as expressly designed. There may be very limited regions of laminar flow near the leading edges of wings, especially lesser swept wings such as used on the 737 and 757, and blended winglets.

Surface irregularities can cause the boundary layer to transition from laminar to turbulent flow in a shorter distance along the surface than may be achievable with a smoother surface finish. Surface coatings may reduce the local irregularities and extend the distance to the laminar-turbulent transition, hence reducing drag. However, the total surface area that could benefit from such improvements is extremely small, and simple calculations have shown that a small increase in the extent of laminar flow would not result in a measurable drag reduction.

Boeing has concluded that the finished skins on Boeing commercial airplanes, both aluminum and composite, are essentially hydraulically smooth. The equivalent sand grain roughness of the skins of Boeing airplanes is typically less than 400 microinches. As a result, very little additional roughness drag can be assessed beyond normal skin friction dominated by turbulence in the boundary layer.

SURFACE ROUGHNESS

Surface roughness is one of many components that contribute to drag (see fig. 2). Boeing studies and test data indicate that surface roughness typically accounts for less than 1 percent of total airplane cruise drag. These studies included design requirements for surface roughness, the effect of various surface finishes on surface roughness, and wind tunnel testing of specific surface specimen.

As a result of these studies, Boeing has concluded that the finished skins on Boeing commercial airplanes, both aluminum and composite, are essentially hydraulically smooth. The equivalent sand grain roughness of the skins of Boeing airplanes is typically less than 400 microinches. As a result, very little additional roughness drag can be assessed beyond normal skin friction dominated by turbulence in the boundary layer (see fig. 3). These studies concluded that additional coatings would not materially reduce the turbulent flow skin friction drag.

REDUCTION IN DIRT ADHESION

Surface coatings have been observed to reduce washing frequency requirements for commercial airplanes, with a typical improvement from a 60-day to a 240-day cycle. The resulting reduction in dirt and insect adhesion could result in reduced excrescence drag. Boeing believes that reduced dirt adhesion is the only postulated flow mechanism that has observable supporting evidence.

DRAG BENEFIT OF WASHING AIRPLANES

Fluids (i.e., hydraulics, oil, fuel) leaking onto the exterior surfaces of an airplane are the main causes of surface contamination by dirt and dust. This sticky layer of contaminants provides the basis for a buildup of contamination by dirt, dust, and other airborne particles. Insect remains are also common sources of contamination, especially near wing and empennage leading edges and nacelle inlets.

Engine struts, the lower aft fuselage, and the lower surface of the wing (particularly the lower surfaces of the flaps and flap track fairings) experience the highest level of contamination, making the surface rough and potentially increasing excrescence drag.

Figure 3: Definition of hydraulically smooth

A surface that is hydraulically smooth exhibits no effects of decreasing skin friction as roughness decreases. The amount of roughness on a typical airplane is below the generally accepted boundary for a hydraulically smooth surface.

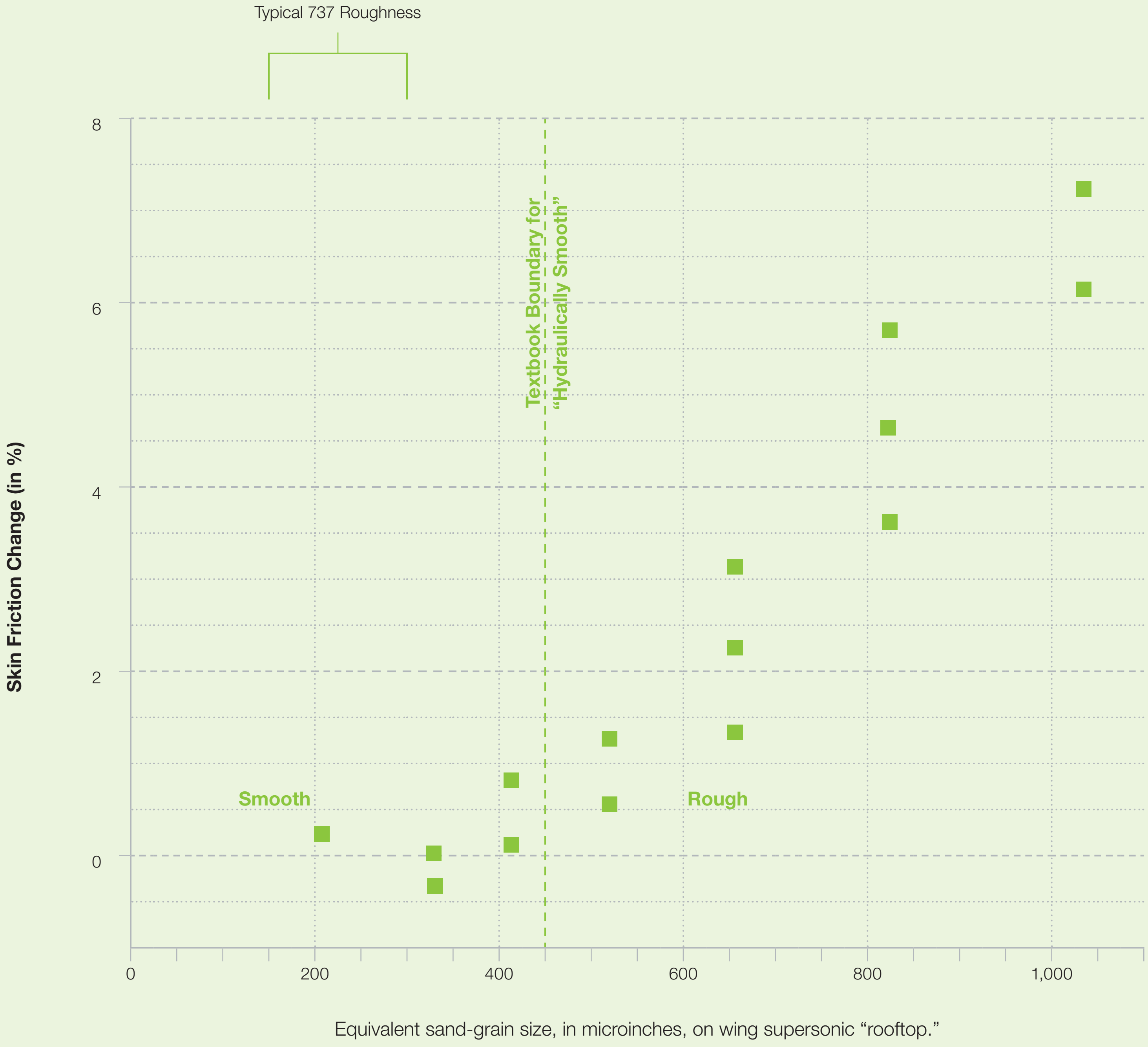


Figure 4: Estimated fuel burn penalty of unwashed airplanes

The expected fuel burn penalties associated with an unwashed airplane are based on the listed reference mission stage length and number of flights per year, factoring the results for alternate usages. The penalties also assume the same ratio of contaminated area to the airplane's respective reference wing area exists, as was observed in an inspection of an in-service 747 airframe (12 percent). If an airplane has a greater level of surface roughness, and/or a higher percentage of surface area being contaminated, the actual fuel penalty may be higher than shown here.

Airplane Model	Fuel Burn Penalty (U.S. Gal/Year/Airplane)	Reference Mission/Utilization
Next-Generation 737	2,200	500 nmi mission 2,420 flights/year
767	7,000	3,000 nmi mission 725 flights/year
787-8	10,300	6,000 nmi mission 470 flights/year
777	15,500	6,000 nmi mission 470 flights/year
747-400/-8	21,700	6,000 nmi mission 470 flights/year

Because unwashed airplanes can experience up to 0.1 percent increase in drag, poorer fuel mileage can be expected relative to clean airplanes (see fig. 4). As a result, one of the easiest, most cost-efficient steps an airline can take to save fuel costs is to maintain clean airplanes. Periodic washing of airplane exteriors also minimizes metal corrosion and paint damage, aids in locating leaks and local damage, and improves the aesthetics of the airplane, enhancing the airline's image with the traveling public.

RECOMMENDATIONS

Boeing research supports the conclusion that use of external surface finish coatings should be based on surface protection properties and airplane cleanliness, not drag reduction. There is no plausible engineering explanation to justify a drag reduction beyond approximately 0.1 percent, nor is there conclusive test data. Boeing wind tunnel data confirm that the production surface finish of Boeing commercial airplanes are hydraulically smooth, meaning that further surface smoothness would not result in a measurable drag reduction.

The most effective means of in-service drag avoidance is maintenance of seals, surface fit and fair, and movable surface rigging (i.e., doors, control surfaces, high-lift devices). In addition, careful management of airplane loading to minimize trim drag can also be an effective means of reducing fuel consumption.

SUMMARY

Airlines are seeking ways to lower fuel consumption. One way is by reducing the drag caused by surface roughness. Boeing research has shown that surface coatings should not materially reduce drag, and that the most effective means of reducing drag is to maintain aerodynamically clean airplanes.

For more information, please contact BCA Aerodynamics Engineering at aeroprod@boeing.com.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