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Blended Winglets—One Operator's Perspective

Article **5**

Brian Gleason
Southwest Airlines

Introduction

While most people might believe that the main reason for installing Aviation Partners Boeing Blended Winglets on the 737NG aircraft is to improve the looks of the airplane (after all, they do look cool), the business decision to modify or install the Blended Winglets by an individual aircraft operator is much more complex. The business case to incorporate winglets is an individual operator decision, with differing variables and hurdles for each potential operator to consider. For that reason, this article will not address the business process that was used to arrive at the decision for installing the winglets, but will instead focus on implementation considerations, the validation process that was used to verify the advertised fuel savings, and the operational benefits that were realized.

After many months of careful consideration, Southwest Airlines made the decision to retrofit our 737-700 fleet with the Blended Winglets. We modified 172 aircraft over a 17-month period, and we are now having the winglets installed in production for all new aircraft deliveries.

Implementation Considerations

Aircraft Performance

Adding Blended Winglets to an existing aircraft fleet provides some interesting challenges during the transition period from having no winglets installed to having winglets installed on all of the aircraft. The 737NG aircraft with winglets was flight-tested to establish the new level of performance due to the change in drag characteristics. The performance data for this new performance level is provided by Boeing through the normal Flight Operations Engineering publications and software.

This article is presented as part of the 2005 Boeing Performance and Flight Operations Engineering Conference, providing continuing support for safe and efficient flight operations.

Some of the affected performance publications include

- Airplane Flight Manual (AFM) and associated appendixes.
- Flight Planning and Performance Manual (FPPM).
- Operations Manual.
- Flight Crew Training Manual.

In addition, there are changes to the available software and databases, including

- AFM-DPI.
- Boeing Takeoff Module (BTM).
- Boeing Landing Module (BLM).
- INFLT program.
- Airplane Performance Monitoring (APM) program.
- Climbout program.

Additional documents that are affected due to the installation of winglets include

- Master Minimum Equipment List (MMEL).
- Dispatch Deviations Procedures Guide (DDPG).
- Maintenance Manuals.

Introducing the new performance level in the operations at Southwest Airlines involved generating new performance pages for the Flight Operations Manual, incorporating the new BTM and BLM databases into the Dispatch and Onboard Performance System software, and creating new flight planning performance data for the Jeppesen Flight Planning system.

The primary system used for performance data by the Southwest Airlines Flight Crews is the Onboard Performance System (OPS) software by Teledyne Controls (fig. 1). This software is used on a Fujitsu Stylistic pen tablet computer in the cockpit. Since the normal update cycle for that computer is every 28 days (following the same AIRAC Navigation Database update cycle), a provision had to be made so the new performance level could be used on a modified aircraft as soon as it went back into service.

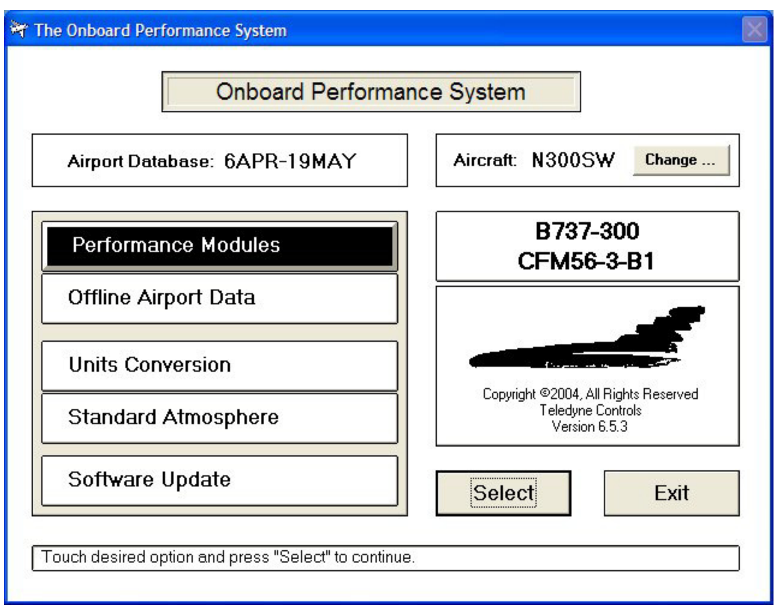
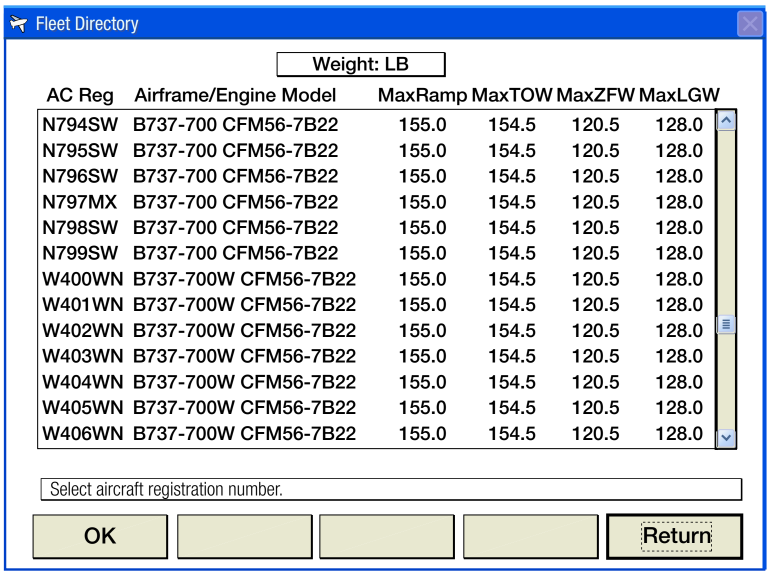


Figure 1. Onboard Performance System

The OPS software is designed such that every aircraft tail number is contained in the program's aircraft database, and each tail number has an assigned performance level associated with it. To allow for the capability of each aircraft having two possible performance levels (with and without winglets installed), each tail number was included in the Fleet Directory twice, with a slightly modified tail number to indicate the winglet modified aircraft.

As an example, an unmodified aircraft would have an N-number (e.g., N705SW) and a modified aircraft would be designated with a W-number (e.g., W705SW) (fig. 2). Once an aircraft was modified with winglets, the tail number representing an unmodified aircraft would be removed from the Fleet Directory at the next update cycle, to reduce the possibility of a Flight Crew inadvertently selecting the wrong performance level.



AC Reg	Airframe/Engine Model	MaxRamp	MaxTOW	MaxZFW	MaxLGW
N794SW	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
N795SW	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
N796SW	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
N797MX	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
N798SW	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
N799SW	B737-700 CFM56-7B22	155.0	154.5	120.5	128.0
W400WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W401WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W402WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W403WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W404WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W405WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0
W406WN	B737-700W CFM56-7B22	155.0	154.5	120.5	128.0

Figure 2. Fleet directory

The same OPS software was also incorporated into the dispatch system, known as Southwest Integrated Flight Tracking (SWIFT). In a screen used for indicating aircraft configuration, once an aircraft was modified, a Chief Dispatcher could indicate with a check box that winglets were now installed, and the interface would then call the OPS program using the W-number of the aircraft to produce the winglet performance data.

This indication within SWIFT would also tell the Jeppesen flight planning system to use the winglet data for flight planning calculations. While this flexibility allowed for real-time changes to the performance level of the aircraft, the reality was that since the actual aircraft modification took several days to complete, as soon as the modification began, the change was made in SWIFT so that it was ready as soon as the aircraft went back into service.

Weight and Balance

In our particular case, there was no change to the center of gravity envelope of the 737-700 with the addition of the winglets. The only change due to the installation was an increase in the operational empty weight (OEW) of the aircraft with the additional weight of 344 lb and a slight shift aft of the center of gravity.

While the shift in CG is slight, this change can have the potential to affect curtailed zero fuel weight (ZFW) and takeoff weight CG limits, especially for ferry flights.

Ground Operations

The addition of winglets increases the wingspan of the aircraft, which may affect the aircraft safety area on the ramp. Incorporating winglets involved a lot of effort and coordination at all of our airports to change the safety area striping to account for the increase in wingspan. At many gate locations, it even involved reorientation of aircraft footprints, or even repositioning of gates to account for the wider aircraft footprint. Care must be taken before operating with the winglets that the aircraft will still be able to operate at the gates.

Training

The FAA concluded during the certification flight tests that there were no significant handling differences in the aircraft with the addition of the winglets. As a result, the aircraft performance in the full flight simulators was not required to be changed or adjusted for winglets.

The information was provided to the Flight Crews using a bulletin with changes in aircraft performance data that was contained in the Flight Operations Manual, in addition to the differences in the Smiths Flight Management Computer System IDENT pages and the Onboard Performance System software.

Pilots' Perspective

The gut feel from the pilots was that there wasn't any major difference in the flying qualities of the aircraft with the winglets installed. The most important thing that the Flight Crews had to be aware of was that they would have to start their descents from cruise earlier in order to meet crossing restrictions. There is also an impression that the aircraft is more stable during the flare and touchdown phase of flight.

Validation Process

During the initial evaluation process, prior to making the decision to purchase the winglets, the normal Boeing Flight Operations Engineering software tools, such as INFLT's flight planning capability, were used to validate the assumptions used in determining the total fuel savings that might be expected.

Once the winglet modification began, a combination of methods was used to determine and validate the actual fuel savings.

Aircraft Performance Monitoring

The quickest method to determine the effectiveness of the winglets was to use the existing technology on the aircraft through the ACARS system and the Aircraft Condition Monitoring System (ACMS) to gather stable cruise data, and use the Aircraft Performance Monitoring (APM) program to determine baseline and post-modification fuel mileage differences.

Using the ACMS Engine Stable Cruise Report, the data is sent from the aircraft via ACARS and then processed to create the input file for the APM program. The results of APM where then put into a Microsoft Excel spreadsheet to plot the differences between the baseline aircraft configuration and the winglet-modified configuration.

The ACMS gathers monitors various parameters during the cruise phase of flight, and once a stable condition is identified, a set of data is collected. The parameters used to define a stable cruise point include:

- Altitude (PALT) variance less than 100 feet.
- Total air temperature (TAT) variance less than 1.0 °C.
- Mach variance less than 0.005 Mach.
- Ground speed (GS) variance less than 4.0 knots.
- Exhaust gas temperature (EGT.1 and EGT.2) variance less than 20.0 °C.
- Engine fan speed (N1.1 and N1.2) variance less than 0.5 %.
- Engine core speed (N2.1 and N2.2) variance less than 0.5 %.
- Fuel flow (FF.1 and FF.2) variance less than 50.0 lb/hr.

The ACMS continually searches for stable cruise conditions and gathers data whenever it finds that the stable cruise criteria are met. The best set of data obtained during a 2-hour period is sent to the ground via ACARS.

The data that is included in the Engine Stable Cruise Report includes the following parameters:

General information

UTC time
Altitude
Calibrated airspeed (CAS)
Mach
Static air temperature (SAT)
Total air temperature (TAT)
Latitude
Longitude
Actual gross weight
Quality indicator

Engine prameters

Fan speed (N1)
Core speed (N2)
Exhaust gas temperature (EGT)
Fuel flow (FF)
Throttle lever angle (TLA)
Oil quantity (OIQ)
Oil pressure (OIP)
Oil temperature (OIT)
Variable stator vane position (VSV)
Vibration CN1 fan (VN1C)
Vibration TN1 LPT (VN1T)
Vibration CN2 HPC (VN2C)
Vibration TN2 HPT (VN2T)
Fan imbalance angle (N1IM)
LPT imbalance angle (LTIM)
Static pressure (PS3)
Variable bypass valve angle (VBV)
Engine discrete word 01 (EW01)
Engine discrete word 02 (EW02)
Engine discrete word 03 (EW03)

Bleed valve positions

Eng 1 bleed valve position (BLV)
Eng 2 bleed valve position (BLV)
Isolation valve (ISOV)
Left ECS pack flow valve position (PCKH)
Right ECS pack flow valve position (PCKH)
Wing anti-ice valve position (WAI)
Eng 1 anti-ice valve position (EAI)
Eng 2 anti-ice valve position (EAI)
Left ECS pack valve position (PACK)
Right ECS pack valve position (PACK)

Bleed valve positions (continued)

Eng 1 bleed valve position (BLV)
Left ECS pack flow valve position (PCKH)
Isolation valve (ISOV)
Left ECS pack valve position (PACK)
Eng 1 anti-ice valve position (EAI)
Wing anti-ice valve position (WAI)
Eng 2 bleed valve position (BLV)
Right ECS pack flow valve position (PCKH)
Right ECS pack valve position (PACK)
Eng 2 anti-ice valve position (EAI)

Miscellaneous

Ground speed (GS)
True heading (THDG)
Drift angle (DA)
Track (TRK)
Rate of change in altitude (DHP/DT)
Rate of change in ground speed (DVG/DT)
Vertical G (VRTG)
Rate of change in inertial vertical speed (DIVV/DT)
Angle of attack (AOA)
Roll attitude (ROLL)
Pitch attitude (PTCH)
Pitch trim position (PTRM)
Total fuel quantity (TFQ)
Initial total fuel quantity at takeoff (TFQI)
Initial gross weight at takeoff (GWI)
APU operating hours (APUH)
Left elevator position (ELEV)
Left flap position (FLAP)
Left spoiler position (SPLL)
Left aileron position (AIL)
Rudder position (RUDD)
Right elevator position (ELEV)
Right flap position (FLAP)
Right spoiler position (SPLR)
Right aileron position (AIL)

While not all of these parameters are required for APM, many have proved useful for trend monitoring purposes.

Once the ACARS message is received by the ground host, the message is converted into the Digital Standard Interface Record Format (DSIRF) for processing by the APM program.

The APM program is then used to calculate the fuel mileage deviation for all of the collected data points. The same non-winglet database is used as the baseline for both the unmodified aircraft and modified aircraft to establish the deviation resulting from the winglets.

Plotting the percentage of fuel mileage deviation versus W/δ shows that the greater the W/δ, the greater the improvement in fuel mileage (fig. 3).

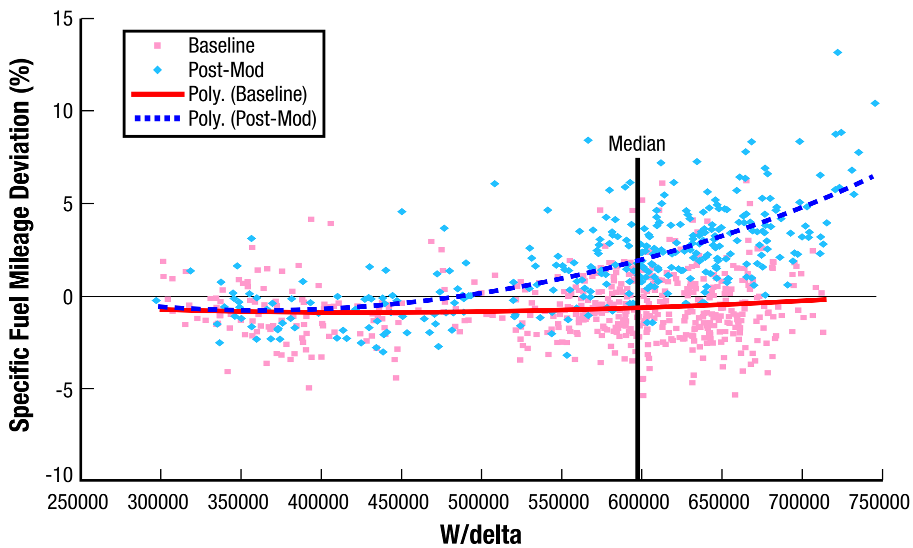


Figure 3. Typical specific fuel mileage deviation

From this chart you can see that there is a definite improvement in the specific fuel mileage of the aircraft with the winglets installed. The advantage is not significant at lower W/δ values, but does increase as the W/δ increases. The median line indicates the median W/δ value for all the data points collected by the ACMS. At the median point, the improvement in fuel mileage was approximately 2.5%.

During the data collection process, several charts were used to monitor the trend of other parameters that are outputs of the APM program. One of those parameters was the specific fuel mileage deviation as a percentage over time. Using a rolling average of 40 data points, the improvement in fuel mileage can be shown in the following chart (fig. 4):

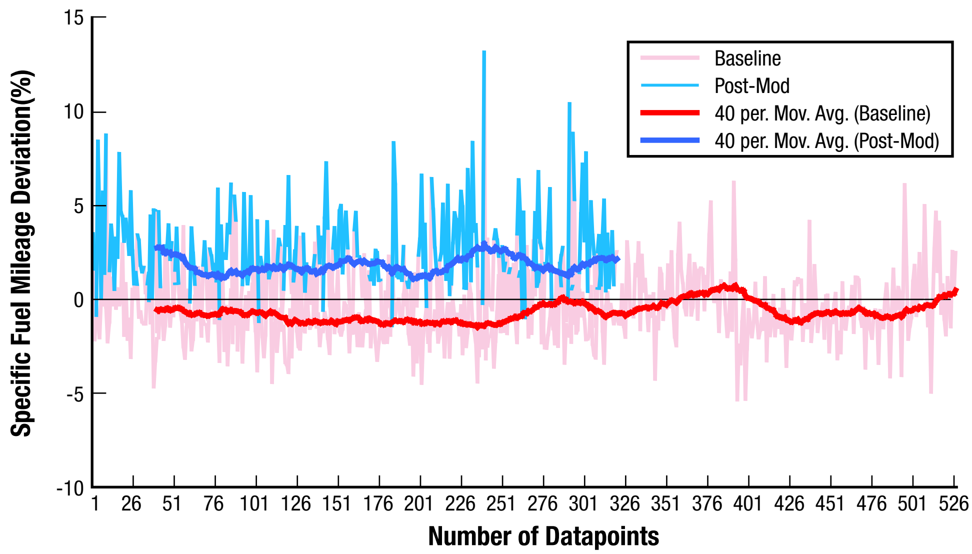


Figure 4. Typical specific fuel mileage trend

In addition to variations in drag, fuel mileage is also directly related to engine performance. Therefore, it is also important to monitor and trend the engine performance during the test periods. Using the Average Fuel Flow Deviation output parameter from APM, the following chart (fig. 5) shows that there was no appreciable change in engine performance during the test period.

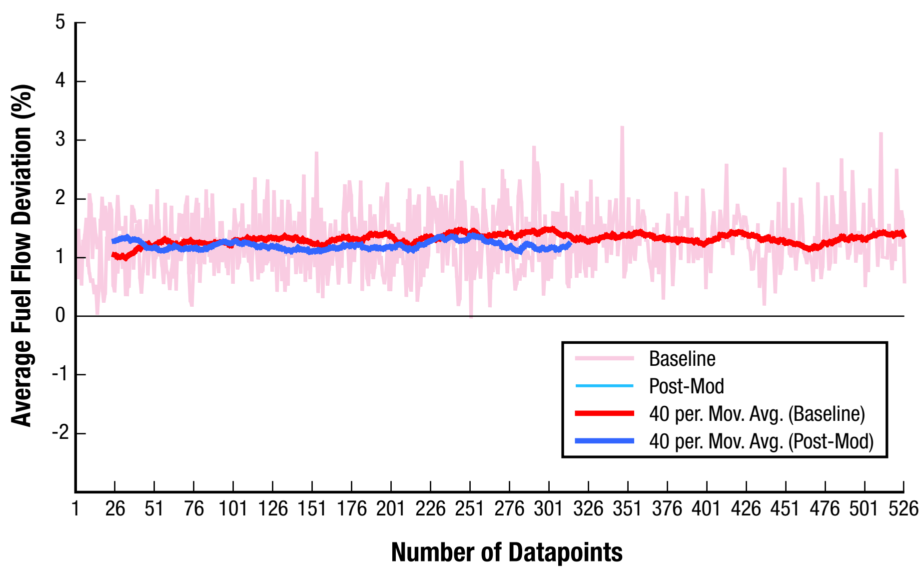


Figure 5. Typical average fuel flow trend

This can also be plotted for each engine to monitor individual engine performance, and in this case, the trends remained flat over the entire period, indicating that the fuel mileage improvement was not influenced by a sudden improvement in engine performance.

Another useful output parameter of APM is the thrust deviation, which is also an indicator of drag, since the amount of thrust required to maintain stable cruise flight is equal to the drag being produced by the aircraft. The following chart (fig. 6) shows that the thrust decreased after installing winglets on the aircraft, thereby indicating that the drag was also reduced.

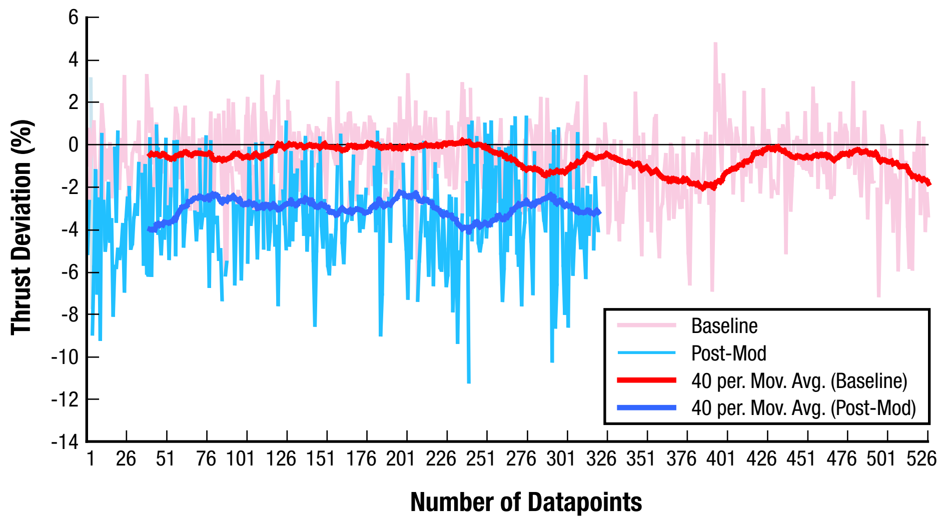


Figure 6. Typical thrust trend

The variations in the trend line correlate almost directly with load factors on the aircraft, which are seasonal in nature. It is also an indication that more accurate aircraft weight information will produce more accurate results with less variation in the trends.

Another way to use the results of the APM data is to examine the actual fuel mileage measured at a specific altitude. Plotting fuel mileage verses weight at FL410 reveals the following (fig. 7).

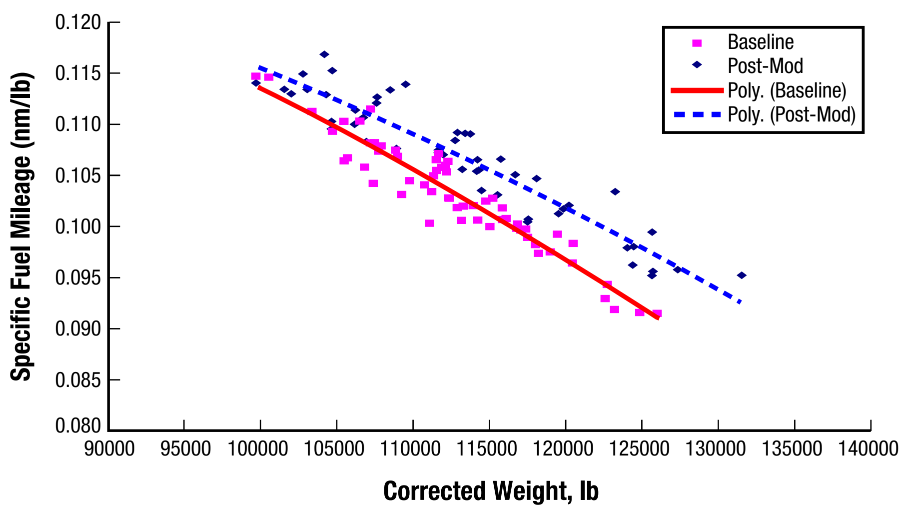


Figure 7. Typical observed fuel mileage—FL410

From this chart, you can see that nautical miles per pound of fuel burned increases with the installation of the winglets on the aircraft. In other words, the fuel mileage improved.

We used this method of analyzing the first five aircraft that were retrofitted with the winglets and obtained consistent results, thereby validating the effectiveness of the winglets on our aircraft.

Fleetwide Fuel Savings

One of the methods that we use to examine fuel burn on a fleetwide basis is to use a comparison of gallons per block hour by aircraft type. This comparison is not a highly scientific comparison, since it includes the effects of burning fuel while on the ground during taxi operations and APU fuel usage while at the gate or during maintenance. However, since the vast majority of the fuel consumed does occur during flight, this provides at least a high-level view of the fleetwide effectiveness of the winglets.

This comparison is made by simply adding all of the fuel that is purchased for the aircraft, and dividing that by the total number of recorded block hours (gate-to-gate) for those aircraft.

This chart (fig. 8) shows the percentage difference in the gallons per block hour calculation between the aircraft that have winglets installed versus those that do not yet have them installed. The two end points on this chart can be considered insignificant, since there is an extremely small number of aircraft being compared that either have been modified (Oct 2003) or have not been modified (Mar 2005).

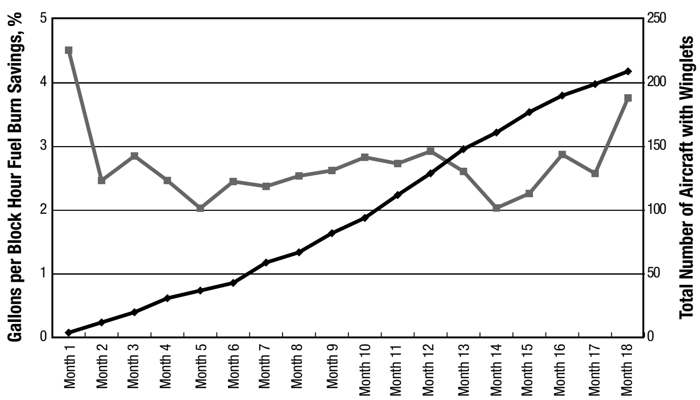


Figure 8. % fuel burn savings of winglet aircraft compared to non-winglet aircraft

In terms of total fleet consumption, this next chart (fig. 9) shows the overall improvement in fuel used, which translates to less money being spent on fuel.

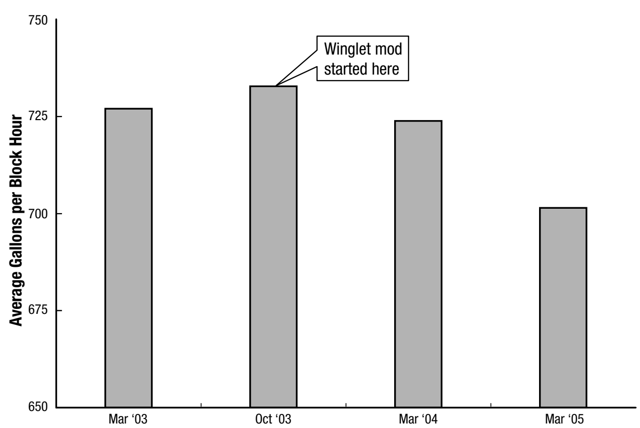


Figure 9. Fuel usage rate (average of gallons per block hour)—700 fleet combined

You can see that from March 2003, when no aircraft had winglets installed, to March 2005 with 205 aircraft winglet-equipped, the improvement in gallons of fuel per block hour improved by 3.5 %.

The bottom line is that the winglets do definitely reduce operating costs by reducing the amount of fuel consumed.

Improved Performance Capabilities

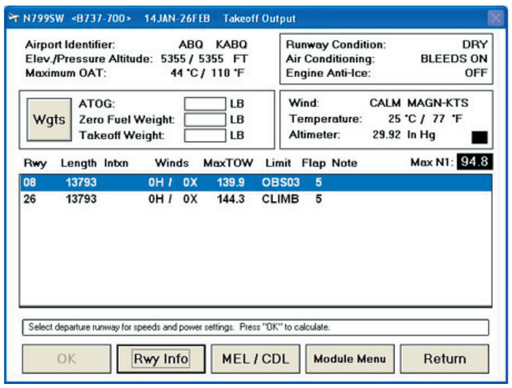
While the greatest selling point for Southwest Airlines was the reduction in fuel usage, there are additional performance benefits that come with the winglet technology. The reduction in drag results in improvements in takeoff and landing performance, increased range, an improvement in thrust reduction, and a reduced noise footprint.

Takeoff and Landing Performance

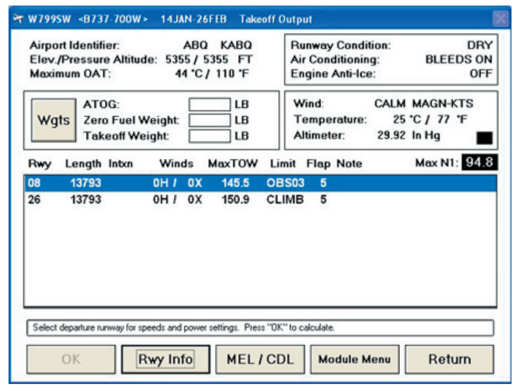
The reduction in drag results in an improvement in climb performance, which translates directly into improvements in both takeoff and landing weight capability. In the case of takeoff, the climb limit and obstacle limit weights are both increased, as can be seen in the following examples:

ABQ, 25°C, Flaps 5, Bleeds ON

Without Winglets



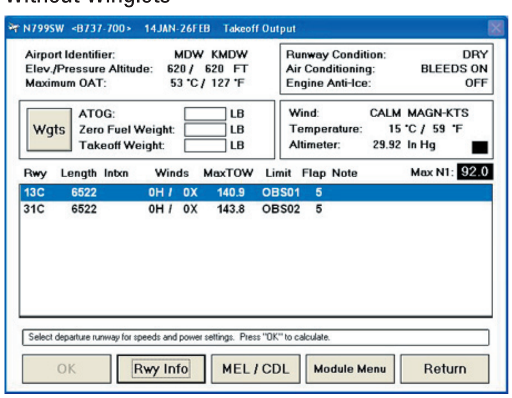
With Winglets



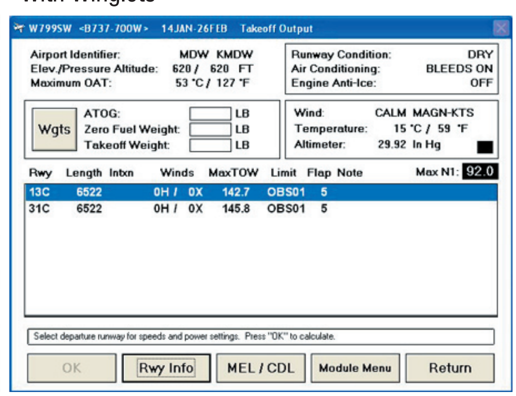
- Runway 08 obstacle limit improvement of 5,600 lb.
- Runway 26 climb limit improvement of 6,600 lb.

MDW, 15°C, Flaps 5, Bleeds ON

Without Winglets



With Winglets

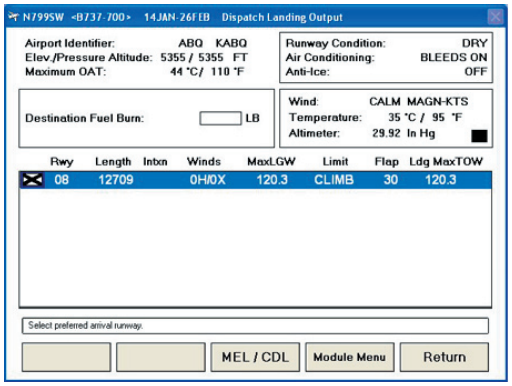


- Runway 13C obstacle limit improvement of 1,800 lb
- Runway 31C obstacle limit improvement of 2,000 lb

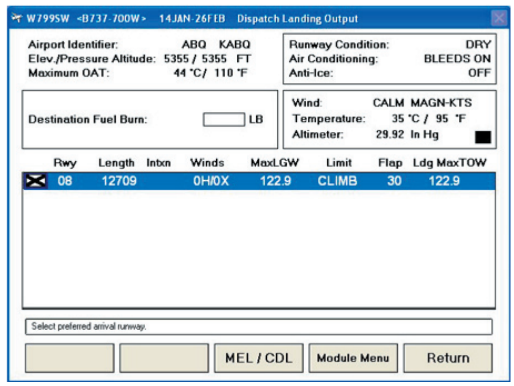
The landing climb performance is also improved with the addition of the winglets, as is shown in the following example:

ABQ, 35°C, Flaps 30, Bleeds ON

Without Winglets



With Winglets



Range

The reduction in drag and the resulting decrease in fuel burn increase the range of the winglet-equipped aircraft. At the maximum structural takeoff weight of 154,500 lb and a full payload of 137 passengers, the range capability of the aircraft increased by approximately 80 nm.

There is also an improvement in range realized from increase in takeoff weight capability. Using the above takeoff example in ABQ on runway 08, the increase in takeoff weight of 6,600 lb means that additional fuel can now be carried, which results in a range improvement of 540 nm. This is just based on the improvement in takeoff weight capability. If we now combine that with the reduction in fuel burn, the total improvement in range under these conditions is approximately 620 nm.

The following payload range chart (fig. 10) shows the typical improvement in range capability due to the reduction in drag.

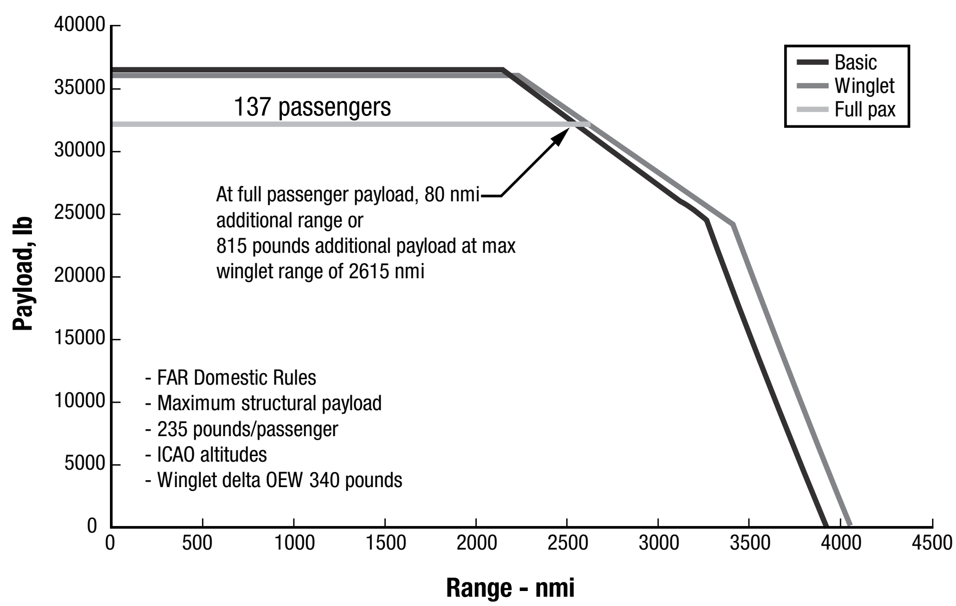


Figure 10. Payload versus range—737-700 blended winglets

With a full payload of 137 passengers, the winglet equipped aircraft can travel about 80 nm further or carry an additional 815 lb of payload.

The combined effect of improved takeoff performance capability and improved range did allow Southwest Airlines to start operating routes that were previously not possible without the winglets.

Noise

The improvement in climb capability also results in a decrease in the noise level of the aircraft. Looking at the certified noise levels from the Boeing AFM shows that at the same takeoff weight, the winglet-equipped aircraft is quieter by 1.0 EPNdB (fig. 11).

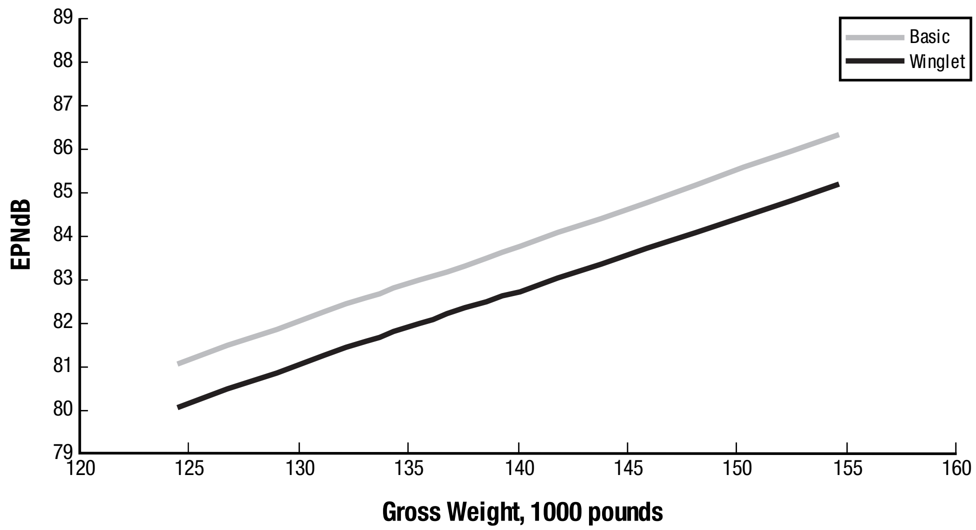


Figure 11. Takeoff noise comparison

For those situations in which operations may be limited by the noise level, the winglet equipped aircraft can take off at a weight that is approximately 5,700 lb heavier at an equivalent noise level.

The same situation is true for the approach noise levels, where the certified AFM noise levels are reduced by 0.1 EPNdB for a landing flap setting of 40 deg (fig. 12).

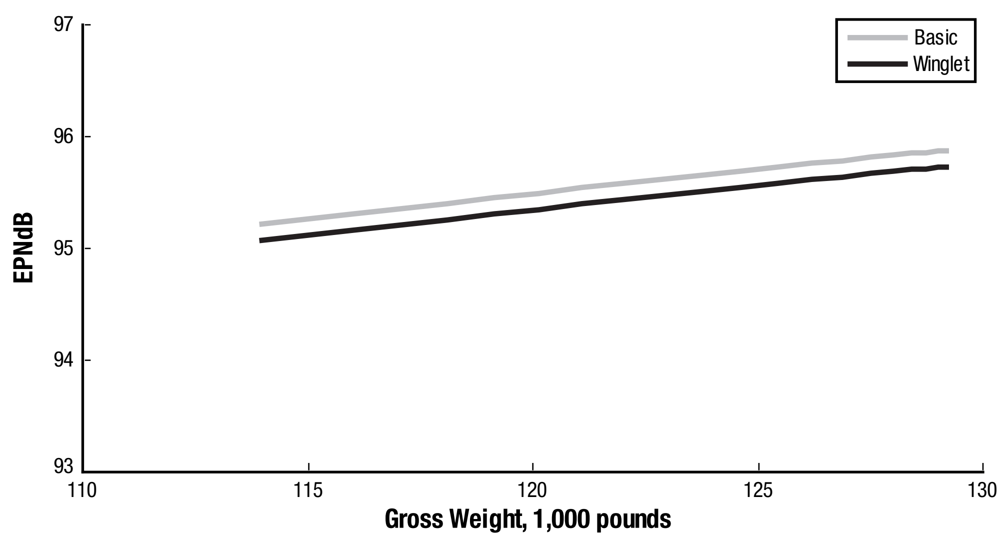


Figure 12. Approach noise comparison—Flaps 40

This reduction in noise is equivalent to approximately 3,000 lb of approach climb weight capability at the same noise level.

The most critical noise airport in the Southwest Airlines network is John Wayne Airport in Orange County, CA (SNA). The addition of the winglets had a definite effect on reducing the noise level at all of the monitors used in the SNA departure profile.

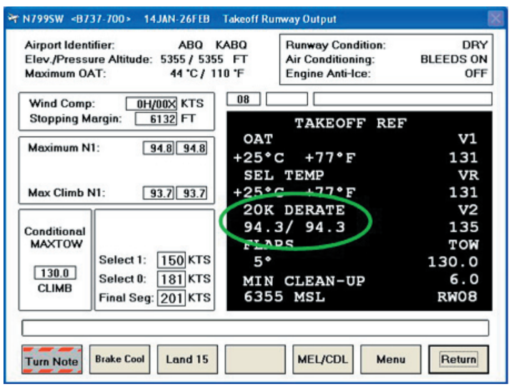
Reduced Thrust

Another benefit of winglets and the improvement in takeoff performance capability is the effect on the use of reduced thrust. It allows a greater amount of reduced thrust to be used, and in some cases, the addition of winglets provides the capability to use reduced thrust when a maximum thrust setting was previously required because of a relatively heavy (or performance-limited) takeoff weight.

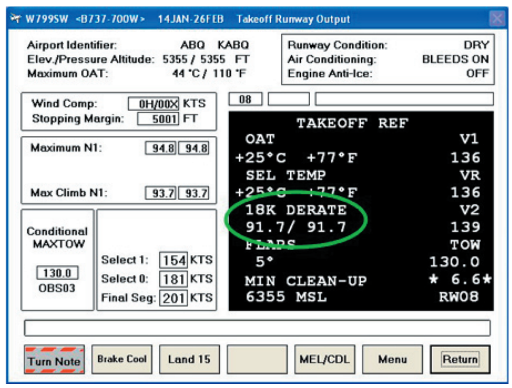
Consider the following examples:

ABQ, 25°C, Flaps 5, Bleeds ON, 130000 lb TOW

Without Winglets



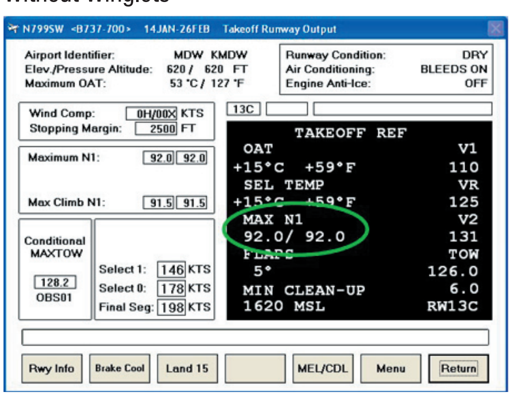
With Winglets



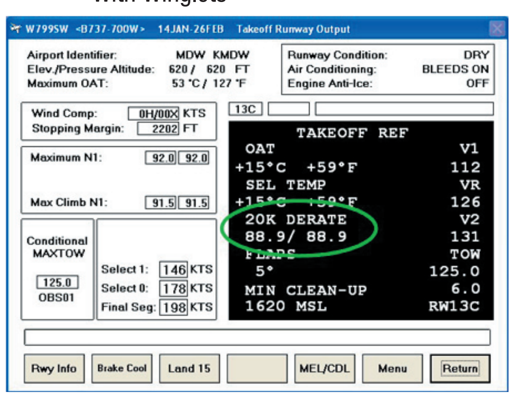
- Lower derate thrust setting possible (18K instead of 20K)

MDW, 15°C, Flaps 5, Bleeds ON, 126000 lb TOW

Without Winglets



With Winglets



- Winglets allow use of reduced thrust where maximum thrust was previously required

The addition of winglets reduces the thrust required to operate on the same routes, which in turn reduces the cost of maintaining the engines, whether you are operating under a "parts and labor" or "power-by-the-hour" maintenance arrangement.

Conclusion

The addition of the Blended Winglets has proven to be a great benefit to the airline operations. From reduced fuel burn, to improvements in payload and range capabilities, to reduction in engine maintenance costs, they have proved themselves to be an extremely valuable technology that will greatly improve the operating efficiencies of the airlines. And as the price of fuel and other operational costs continues to increase, the benefits just keep getting better and better.