Photogrammetry Measurements of Airplane Passenger Entry Doors

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All airplanes must be pressurized when altitudes exceed 12,500 ft (3,800 m). The typical cruising altitude of commercial airliners is generally between 29,000 ft and 40,000 ft (from 8,800 m to 12,200 m). At this altitude, interior cabins are pressurized both for safety as well as passenger comfort.

INITIAL TESTING ON NEW AIRCRAFT MODELS

Pressure testing is performed on every line number (aircraft) as part of the U.S. Federal Aviation Administration (FAA) requirements. Pressures that are equivalent to maximum flight altitudes are tested on the ground to ensure the airtight integrity of the fuselage and its associated components. The leakage rate is determined by the cumulative area of all open holes throughout the entire fuselage. Cumulative leakage must not be greater than that of a hole equivalent in size to a U.S. quarter with the airplane still holding positive pressure. The primary leakage paths on all airplanes are the passenger entry doors. Often, multiple pressure tests are required to repair leaks. All repairs must be completed and hold positive pressure before the airplane is allowed to fly.

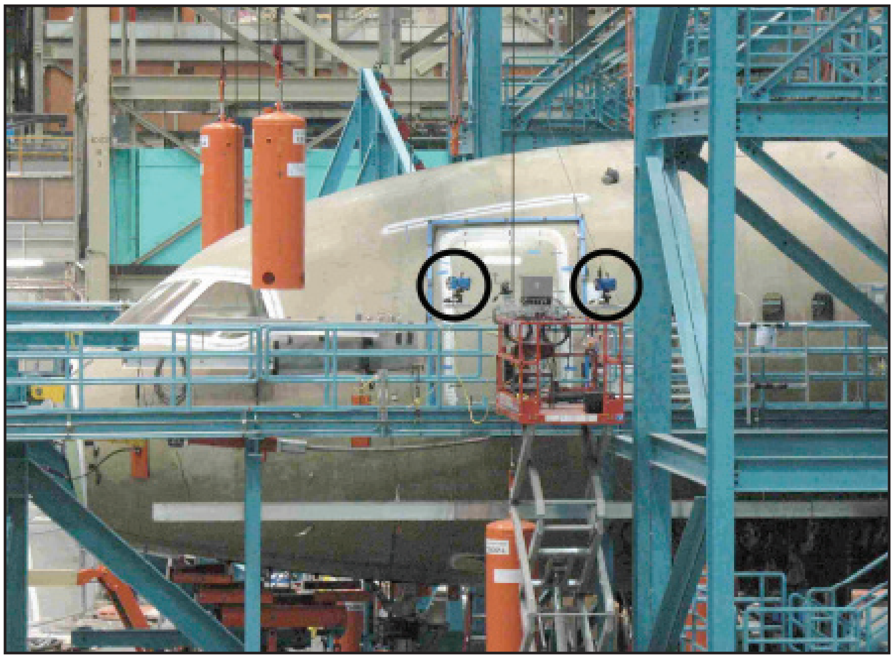

Figure 1. Sequential photogrammetry

At the inception of any new program, an initial test is performed that exerts maximum pressure on the airframe structure. As mentioned in the previous paragraphs, all production aircraft are required by the FAA to go through pressure-testing operations, but only a single unit of new aircraft models will be tested at what is known as "extreme high-blow" pressure.

For the Boeing 787, the static test airplane was chosen for the extreme high-blow test. Note that this is the test vehicle used to stress, bend, and flex the airframe until the wings finally break. The passenger entry doors are designed to flex within the door frame structure while still maintaining positive pressure during all testing. During the extreme high-blow test, the airframe will experience much more pressure than during any commercial flight.

To assess the integrity of the entry doors and surrounds, a photogrammetry, multiple camera (M-mode) survey was performed on door number one, left hand, using two Geodetic Services Inc. (GSI) INCA 3 cameras, as seen in figure 1.

During extreme high blow, no personnel are allowed near the airplane, and the entire bay must be cleared as a precaution. Remote-control devices were mounted to the cameras, allowing measurement capture beyond 50 m. A separate, independently valued picture frame was attached to the outer door structure, providing a common point network that also included a scale.

Individual targets were placed on the outer door structure of the airplane and corresponding entry door. Collectively, with the M-mode cameras, picture frame, and remote control devices, real-time data capture was possible, even when inspecting at a great distance from the actual test article.

Measurements were taken at various pressures, starting at level or zero pressure, low-blow pressure, cruise altitude pressure and extreme high blow. Data were evaluated to see how much deflection was occurring during each pressure variation. All analysis results proved to be within engineering designed limits. SpatialAnalyzer software from New River Kinematics (NRK) was used to perform the data reduction and report generation. Comparisons were easily made through point-to-

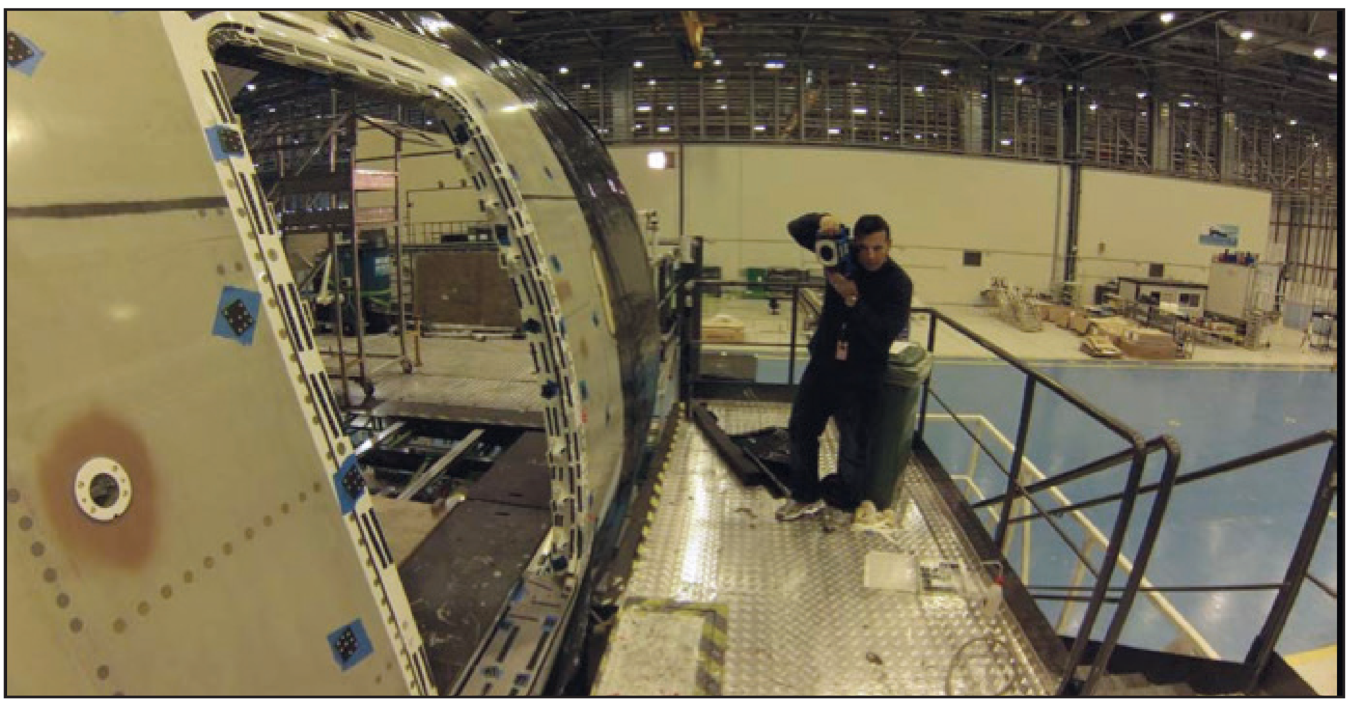

Figure 2. Photogrammetry inspection of a completed door surround

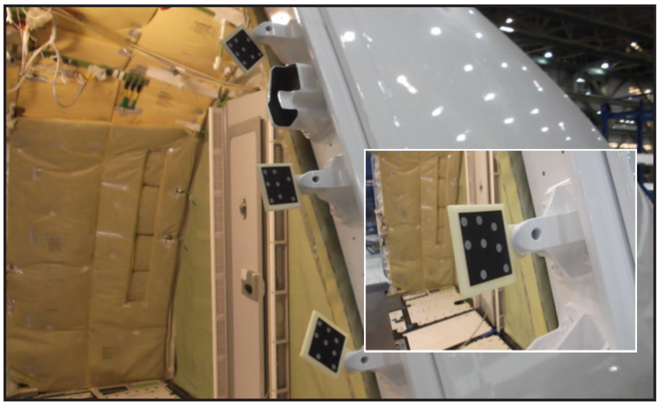

Figure 3. Rapid prototyped feature targets installed on the door-surround datums

point delta deviations with the software, categorizing results between the different pressures. Deflection results were within the engineering tolerances at all pressures.

PRODUCTION TESTING

As part of our Boeing 787 inspection procedures, photogrammetry measurements are taken at various stages of the production process on every aircraft to ensure that data are within engineering designed limits. These measurements are taken to identify and remedy leakage problems that could occur during production pressure testing. Inspections are performed at the detail level on all door-surround structures, validating the frames, as seen in figure 2. Hard tooling and floor assembly jigs (FAJs) support the door-surround build. Within the production framework of the door surround, provisions for determinant assembly (DA) pinning exist. The DA holes are used to locate the door-surround structure into the next higher assembly within the fuselage.

To test the effects of assembly and properly track the production hardware throughout the build phase, retroreflective targets are placed at critical locations and aligned through the DA holes. In some cases, data have been collected at one supplier, shipped to a different location for additional assembly, and then measured in final assembly for acceptance at Boeing facilities in Everett, Washington, or North Charleston, South Carolina, prior to delivery. Through the use of the photogrammetry targets, direct comparisons can easily be made in a point-to-point fashion and without retargeting prior to each inspection.

To align into the door-surrounds datum structure, targeting is affixed to the 12 interior fuselage door-stop buttons. The center of the button must be measured in a calculated manner, extracting the true center. This can be an extremely tedious process. Early measurements required circular points collected around each door-stop button. Points were also required on the flat door-stop buttons' planar surface. Together, the circular and planar measurements were used to create a single door-stop button center point. Best-fitting of the 12 datum targets using a least-squares transformation method takes place to secure the final alignment of the door surrounds. In later measurements, to simplify the center extraction procedure for alignment,

Figure 4. Top view of the network geometry, and photography from the support platform

rapid-prototyped parts were fabricated to create an easy way of measuring the center point, as seen in figure 3. Feature targets, magnetically attached to the door-stop button locations, are self-recognized through the photogrammetry software, automatically extracting the true center point.

Unfortunately, some pressure leaks may develop after delivery and require in-service repair. Through the portability of the GSI photogrammetry system, the equipment can be brought onto the airplane as checked luggage and travel to any destination. For example, a repair was necessary to remedy a door seal discrepancy on door one, left hand, on one airplane in service. To deduce the nature of the error, a photogrammetry survey was performed at 0 psi and again at pressure, as seen in

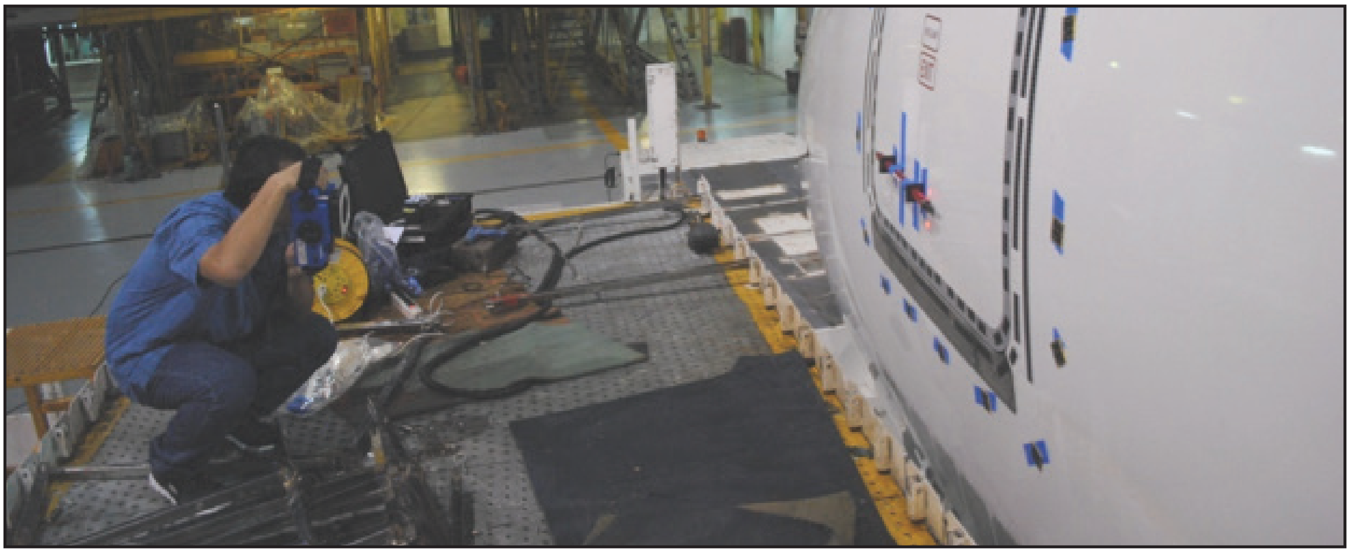

Figure 5. Boeing 787 in-service airplane interior photogrammetry survey, with the door closed

figure 4. To minimize the effect in terms of revenue-generating flights, the inspection was performed during an originally scheduled downtime. Routine maintenance was taking place while a concurrent photogrammetry inspection session was performed.

Because multiple inspections were required, both at zero pressure and with pressure, a common reference system network was necessary to link the two surveys. With the primary datum structure located within the interior of the door-surround frame, on the stop buttons, and the inspection area of interest on the exterior door and corresponding fuselage, a total of three independent surveys was necessary. An initial survey performed the actual alignment and inspection of the interior features while assigning transformation values to the exterior targets. With the door closed, a second survey was performed at zero pressure, transforming back into the datum structure through the common point network, as seen in figure 5. The final survey performed at pressure utilized the same exterior target transformation points. Outcome between the zero and at-pressure tests revealed a stepped condition of the door's edge protection with respect to the upper seal edge, as seen in figure 6. The step or under-shimmed condition resulted in a high-speed airflow disturbance that was noticeable to the customer at cruise altitude and speed. A shim was installed under the edge protector at the upper-forward corner to remedy the discrepant condition.

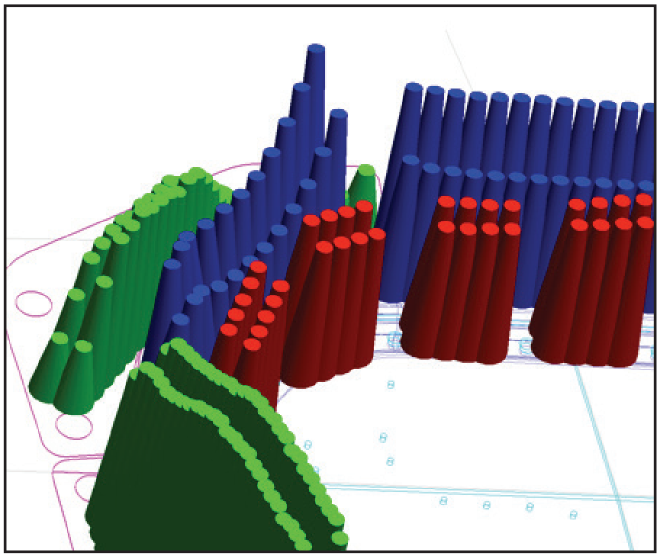

Figure 6. Upper seal surface example

CONCLUSION

Considering that high-accuracy requirements (± 0.005 in., ± 0.127 mm) are needed to meet the variable engineering tolerances, the photogrammetry system has performed extremely well in all aspects of our data-collecting phase. Data are exported to the SpatialAnalyzer software for further report generation and comparative analysis. Repetitive tasks are performed through automated sequences found within the software's measurement plan scripts.

Next steps include updating our photogrammetry systems with probing capability and the latest camera versions. Probing will make real-time data analysis and concurrent build operations possible. As our measurement results become more repeatable, a sampling strategy will be implemented to reduce the overall inspection requirement. Through more accurate measurements and analysis, our results are producing more precisely aligned surround structures while still maintaining airtight integrity of Boeing airframes.