Developing Airplanes by Developing 3D Scanning

3-dimensional scanning and reverse engineering companies are constantly challenged by their customers in various industries to develop new solutions to complex problems. One industry that certainly pushes the limits of those capabilities is the design and manufacture of aerostructures. In November 2006, for example, engineers at NASA Dryden Flight Research Center in the Mojave Desert at Edwards, CA, were conducting research aimed at lessening the destructive effects of supersonic flight. The LANCETS research, (Lift And Nozzle Change Effect on Tail Shock) measures the benefits of redistributing aircraft lift to reduce shock-wave pressure, thereby lessening the sonic boom.

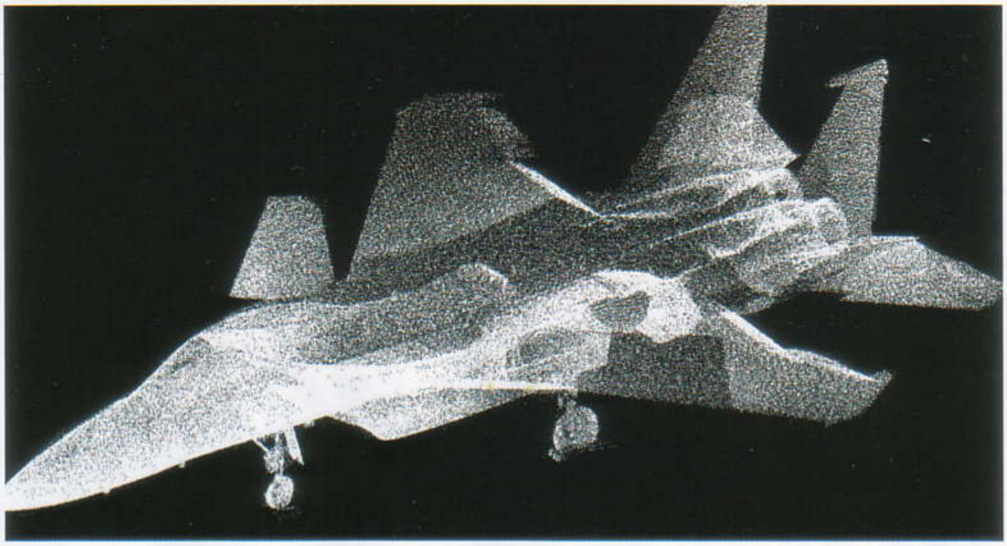
In order to obtain in-flight data, they would need to modify and fly a certain NASA-owned F-15 test plane. However measuring pressures on flight surfaces on a plane traveling at supersonic speed from a chase plane some 200 feet away is risky. So before committing to the expensive aircraft modifications, NASA wanted to see if advanced computational fluid dynamics (CFD) software could simulate these flight conditions accurately enough to predict how these relatively minor flow surface adjustments would reduce supersonic noise levels. This approach would allow modifications to the plane to be made *digitally*, and then the CFD analysis would test the changes without the costs and time associated with actually flying the airplane.

Accurate CFD analysis would require a precise digital model of this particular F-15, which had been previously modified from its original design for other NASA test programs. Traditional 2D sectional drawings of the nominal plane geometry were available, but these would not work in this case. Plus this particular test airplane had been hard landed a few times in its life as a test plane, twisting the airframe enough that the dimensions differed fractionally from the original design. To do this CFD analysis, NASA needed a dimensionally accurate 'as-built' 3D CAD model of this specific F-15 airplane.

Locating an Experienced Team

Through a Google search, the engineers at NASA Dryden found Direct Dimensions, Inc. (DDI), a 3D measurement firm located in Owings Mills, MD, with specific expertise in this type of challenging work. Founded in 1995, Direct Dimensions specializes in a wide variety of 3D scanning and reverse engineering technologies for a wide range of industries and applications. With nearly 25 years of direct experience with aerospace and other industrial 3D problems, Direct

The Surphaser HSX mid-range spherical laser scanner.



Dense raw 3D point cloud of the F-15 as captured by the Faro LS laser scanner and aligned in PolyWorks software.

Laser scanning the Gulfstream with Surphaser HS

Dimensions' founder and chief engineer Michael Raphael felt well qualified to handle this aircraft measurement problem.

"While working in the late 80's as an engineer at what became a Lockheed Martin aerostructures manufacturing facility in Baltimore, I recognized the need for better portable 3D measurement tools to solve complex problems like this," Raphael states. He goes on to claim that he was one the original developers and the first industrial user of the FaroArm portable coordinate measuring machine, the now ubiquitous 3D measurement tool used extensively around the world.

With many aerospace-related projects under its belt, the team at Direct Dimensions was eager to take on this new NASA challenge. Since the company's inception, aerostructures work has been at the core of their business. Early projects, for example, involved digitizing aircraft cockpits for human factors analysis with the U.S. Navy, scanning large aircraft fuselages to accurately design flight simulators, and scanning the exterior of a 29-passenger turboprop with only two FaroArms for a crash investigation, a project the proved extremely challenging. Even with new computerized 3D measurement technology, these projects often took days to capture all of the critical characteristics required for these projects.

In fact, as the nature of these measurement challenges evolved, so too did the 3D technology needed to accomplish these projects. By 1999, for instance, Direct Dimensions engineers digitized and modeled the exterior of a large BAC-111 commercial airliner for flight test modifications design. For this project the engineers utilized the then relatively new portable laser tracker to capture the flow contours of the entire aircraft. While state-of-the-art at the time, the effort still took over eight working days with the tracker just to capture all of the required 3D data.

Laser Scanning the F-15

After the F-15 project was defined and NASA authorized the work, Direct Dimensions engineers

Comparison of laser scanned data to original CAD model

Dominic Albanese and Glenn Woodburn flew to California armed with another new 3D measurement technology, the FARO LS. Being portable and designed to capture the shape of large objects, this new 3D laser scanner could acquire up to 120,000 points per second over ranges of up to 80 meters The FARO LS was the ideal technology at the time to quickly and accurately capture the exterior shape of this jet. With accuracy of +/-6 millimeters, this scanner can take a digital "shapeshot" — like a snapshot but in full 3D — of very large objects, such as airplanes and buildings. The raw 3D scan data is actually a high-resolution point cloud of laser-reflected spots off the surfaces. This dense 3D point data can then be digitally processed and modeled into various CAD formats for a wide variety of applications.

Initial raw data captured on the aircraft using Faro LS laser scanner.

Upon arriving at NASA Dryden, Albanese and Woodburn set up the LS scanner in the hangar and devised their scanning plan. Noticing the bright desert sunlight streaming through the skylights, the engineers rearranged the schedule to perform the bulk of the scanning in the evening and into the night. Sunlight on the glossy surface of an aircraft would cause "noise" in the scan data. Over the course of a single long evening, the team scanned the entire aircraft. Care was taken to capture the plane from all angles to assure even fine details were properly represented.

In the end, over 50 individual scans from different positions yielded over 50 million data points for processing. Upon return to the DDI facility outside of Baltimore, the engineers began to process these huge raw data sets to reverse engineer the F-15.

Reverse Engineering the F-15

One of the more impressive aspects of using 3D scanning technology is the amount of data captured even within a single scan. A lot of this data is not needed, such as the walls of the hangar, equipment in the area, and even people walking through the room during a scan. Consequently one of the first tasks in the modeling process was to digitally remove all this extraneous data. The individual scans were then aligned and knitted together using Innovmetric's PolyWorks software to ultimately create a mesh surface using all the data points. With the polygon mesh complete in STL format, the once immense 50 million raw point file was reduced (called *decimated*) to a somewhat less-staggering 1 million point mesh file by removing redundant data within a certain tolerance.

The next phase of the process was to establish the craft's primary geometry and construction lines such as its main fuselage center line, certain axes of rotations, wing sweep profiles, and various cross sections and contour curves. These geometric elements were then imported into SolidWorks where they were stitched together and reverse engineered to create a complete solid CAD model of the F-15.

The final digital model was sent to NASA Ames Research Center in Hampton, VA, where it was imported into their CFD package. Running the advanced software with the digital model of the F-15 as a virtual wind tunnel, NASA engineers were

Direct Dimensions engineers operate a Faro LS laser scanner to capture the exterior of the modified F-15 aircraft able to test their experimental modifications on an essentially perfect digital recreation of their F-15 jet.

Ongoing Developments for Aircraft Scanning

The F-15 project for NASA, while challenging, allowed the engineering team at Direct Dimensions to refine and streamline their process for laser scanning and digitally replicating aircraft for CFD analysis. In fact, after completing the F-15, the DDI team immediately moved on to digitally recreate an F-16 Fighting Falcon for the same group of engineers at NASA and has since kept busy modeling aircraft and components for analysis for a variety of aerospace customers. While Direct Dimensions created a thorough and refined process that worked for the creation of models for CFD, that process is constantly fine-tuned with the advent of new technologies and tools.

More recently in the fall 2008, the DDI team had another opportunity to scan a plane, this time a Gulfstream test plane for NASA in conjunction with Texas A&M University, and also for CFD analysis. In the two years since the F-15 project, an entirely new laser scanner had entered the market and had been in use and testing by Direct Dimensions for over a year. The Surphaser HSX mid-range spherical laser scanner can collect up to 800,000 points per second and has an accuracy of ± less than a millimeter. The engineers at Direct Dimensions were among the first in the country to adopt this new technology for scanning aircraft for CFD analysis. The technology allowed for full scanning of the much larger Gulfstream plane with significantly increased accuracy and resolution and in much less time than it took for the smaller F-15.

Scanning technologies have been used by other firms to capture aircraft. In 2005 engineers from the scanning firm Berding 3D (now Exact Metrology) used a Cyra2500 from Leica and a Vivid 910 from Konica Minolta to capture a Saab A-35 Draken aircraft. Like Direct Dimensions, they also processed the scan data with PolyWorks to deliver the final CAD models to their customer for use in similar aerodynamic testing.

While new technologies are being developed and implemented all of the time, one necessity stays constant: the aerospace industry will always need the most accurate measurement methods. In essence, the problem stays the same, but the solutions just keep getting better. Fifteen years ago, aircraft reverse engineering was just starting with only a few 3D measurement tools. What then took a month, can now be accomplished in days utilizing a broad range of 3D scanning technologies.

For more information visit www.directdimensions.com