Development of 3D Ice Accretion Measurement Method

Sam Lee
Vantage Partners, LLC

Andy Broeren
Harold Addy, Jr.
NASA Glenn Research Center

Robert Sills
Sierra Lobo, Inc.

Ellen Pifer
St. Louis University

Outline

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- Scanner Selection Methodology
- Scanner Selection Results
- Conclusion

Introduction

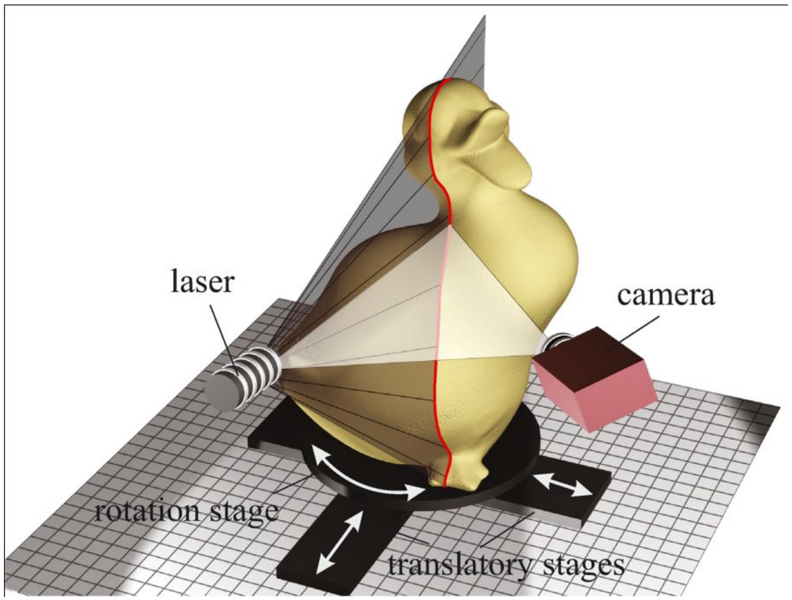
- Icing wind tunnels are designed to simulate in-flight icing environments.
- The chief product of such facilities is the ice accretion that forms on various test articles.
- Documentation of the resulting ice accretion key piece of data in icing-wind-tunnel tests.
- Number of currently used options for documenting ice accretion in icing-wind-tunnel testing.
  - Simple and quantitative photography
  - Pencil tracings
  - Mold and casting methods
  - Each method has limitations

Introduction (cont'd)

- Method to accurately and efficiently digitize ice accretion in three dimensions is needed.
- Laser-based scanning methods have been investigated.
  - Number of challenges with processing the raw point cloud data into a closed surface.
  - More recent research indicated new advances may allow complex three-dimensional point cloud data be acquired and closed to form a "water tight" surface.

- NASA incorporated development of three-dimensional ice accretion digitization methods into its current research plans.

Laser Scanner – How it Works



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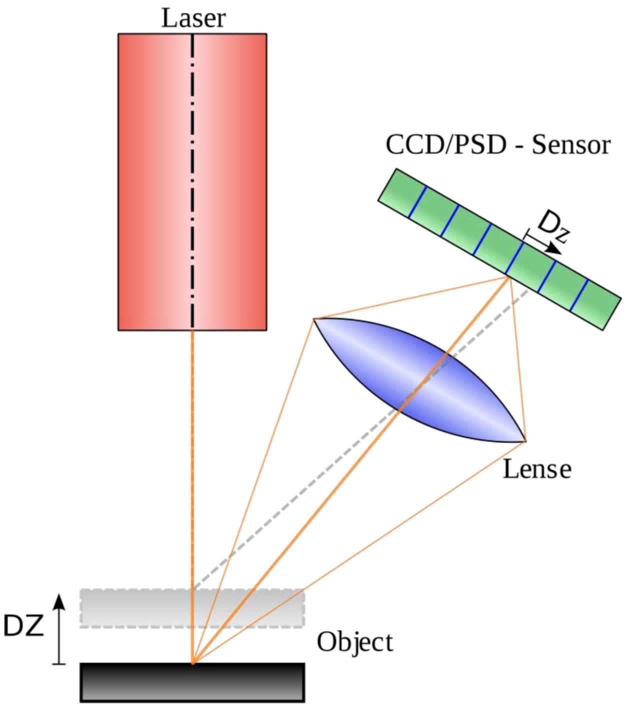

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- Laser line projected on surface to be scanned
- CCD camera uses triangulation to determine surface location

Selection Methodology

Objective:

- Identify most suitable 3D laser scanner for further development

Approach:

- Establish selection criteria for scanner hardware and software.
- Evaluate several commercially available 3D laser scanners and software using selection criteria.

Selection Methodology - Software Selection

- A thorough evaluation of several commercially available 3D scanning software was planned.
  - This was not possible due to cost and time constraints.
  - Required purchasing and becoming proficient on all of the software that were being considered.
- Instead, two most widely used software packages were considered, Geomagic and Polyworks.
  - The most critical factor was the ability to create water-tight surfaces from the scan data.
  - Conversations with the scanner factory representatives indicated that Geomagic is better able to process and generate water-tight surfaces of “organic” shapes typical of ice accretion shapes.
  - This led to the decision to select Geomagic as the scanning software.

Selection Methodology – Hardware Evaluation IRT Test Procedure

- All of the scanners were evaluated in NASA Glenn Icing Research Tunnel.
- Four ice shapes on NACA 0012 chosen for evaluation:
  - Horn ice – 0 deg sweep, 21" chord
  - Roughness – 0 deg sweep, 21" chord
  - Streamwise ice – 0 deg sweep, 21" chord
  - Scallop ice – 45 deg sweep, 36" chord

Ice Type	***V* (kts)**	**α (°)**	***MVD* (μm)**	***LWC* (g/m^3)**	**T_0 (°F)**	***t* (min)**
Horn	200	4	20	0.55	25	7
Streamwise	200	4	20	0.55	1	7
Roughness	200	4	20	0.55	25	1
3D Scallop	200	0	32	0.45	20	19.9

Selection Methodology – Hardware Evaluation
IRT Test Procedure

- The IRT scanner evaluation procedure consisted of the following six steps:
  1. Accrete ice on the test article
  2. Photograph the ice
  3. Spray the ice with white paint
  4. Install and set up the scanner
  5. Scan the ice shape
  6. Make hand tracings of the ice shape

Selection Methodology – Hardware Evaluation Scanners Evaluated

- Three laser scanners were evaluated in the IRT during spring 2011 using the procedure described above.
    - Faro Quantum
    - Romer Absolute SI
    - NVision HandHeld
- All arm-based laser scanning systems.
- Faro Quantum
    - The body of the arm made of aluminum and used a temperature senor to compensate for the expansion/contraction of the tube.
    - Arm used relative position encoders
    - Could be operated directly from Geomagic

From Hexagon Metrology

Selection Methodology – Hardware Evaluation
Scanners Evaluated

- The Romer Absolute SI
  - Constructed of thermally stable carbon fiber.
  - Did not require any thermal compensation.
  - Arm employed absolute position encoders.
  - Could be operated directly from Geomagic.
- The NVision HandHeld
  - Used a Romer arm with an NVision scanner head.
  - Carbon fiber arm with absolute encoders
  - Did not require any thermal compensation.
  - Could not be operated directly from Geomagic since a plug-in was not available.

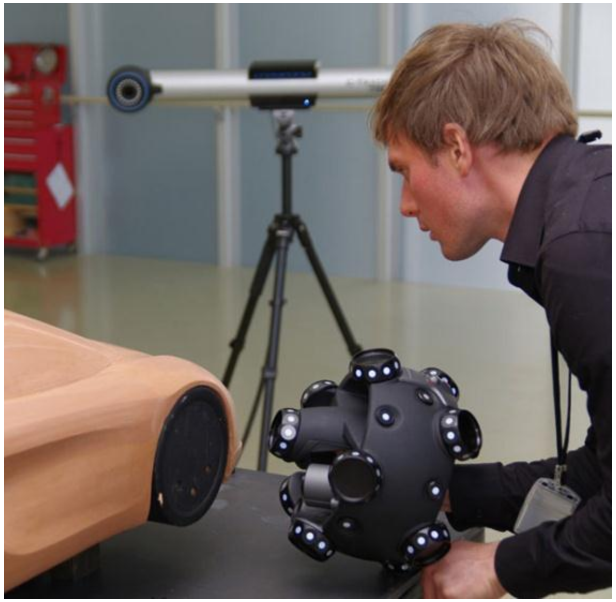
Selection Methodology – Hardware Evaluation Scanners Evaluated

- Two scanning systems manufactured by Creaform were evaluated but not as part of the standardized evaluation process.
  - HandyScan system - evaluated during an IRT icing test demonstration in 2008.
  - MetraScan system – evaluated with artificial ice shape in IRT with tunnel off (2011).
- HandyScan system
  - Arm-free system
  - Used reflective targeting dots on the scanned objects for positioning.
  - Scan data from the HandyScan were referenced to these targeting dots.

From Creaform

Selection Methodology – Hardware Evaluation Scanners Evaluated

- The MetraScan system
  - Used a "C-Track" base that tracked the position of the laser scanner optically using reflective dots on the scanner.
  - The scan data from the MetraScan were referenced to the location of the "C-track".



From Creaform

Manufacturer	Model	Type	Max. Line Resolution	Line Width	Scan Rate	Arm Encoder Type	Geomagic Plug-in
Faro	Quantum	Arm	0.002 in	2.5 in	30 Hz	Relative	Yes
Romer	Absolute	Arm	0.002 in	2 in	30 Hz	Absolute	Yes
NVision	HandHeld	Arm	0.002 in	2 in	30 Hz	Absolute	No
Creaform	HandyScan	Armless	0.002 in	2.5 in	25 Hz	N/A	Yes
Creaform	MetraScan	Armless	0.002 in	2.7 in	25 Hz	N/A	Yes

Selection Results – General Findings

- The findings detailed below should not be viewed as a determination by NASA of one system being superior to another for general use.
- All of the scanners demonstrated were able to scan ice shapes (or simulations) in the IRT test section
- Quality of the ice shape scan depended greatly on the experience of the scanner operator.
- Emphasis on the scanner evaluation was placed on usability, operability, and software compatibility.

Selection Results – Scanner Setup Procedure

- Arm-based systems
  - Set scanner up in test section
  - Begin scanning
- Creaform arm-free systems
  - Handyscan - Wire mesh had to be installed after each icing spray before the ice shape could be scanned – time consuming process
  - MetraScan - Large access panel had to be created on the test section ceiling to provide a clear line of site between the C-track and the handheld scanner head.

Selection Results – Software Compatibility and Data Format

- All scanners except Nvision Handheld scanner could be operated directly from Geomagic
  - Geomagic plug-in not available for Nvision
- Scan data format differences
  - All of the arm-based scanners outputted point cloud data.
  - Two Creaform scanners did not output point-cloud data. Data already in a semi-processed triangular surface mesh
  - This was considered by NASA evaluators to be a significant limitation because it does not allow the user to work directly with raw, unprocessed data.

Selection Results – Operability in IRT Test Section

- Two Creaform arm-free systems easier to manipulate than arm-based systems
- Two Romer-arm based systems easier to manipulate than Faro arm
- All scanners except Faro arm demonstrated ability to operate at 0° F.
- For Creaform scanners, the part of the scanning system that was brought into the test section did not have any moving parts.
    - Although no reliability issues were observed with the arm-based scanners during the IRT evaluations, it is not known what effect (if any) repeated exposure to the IRT test section environment would have on the scanners.

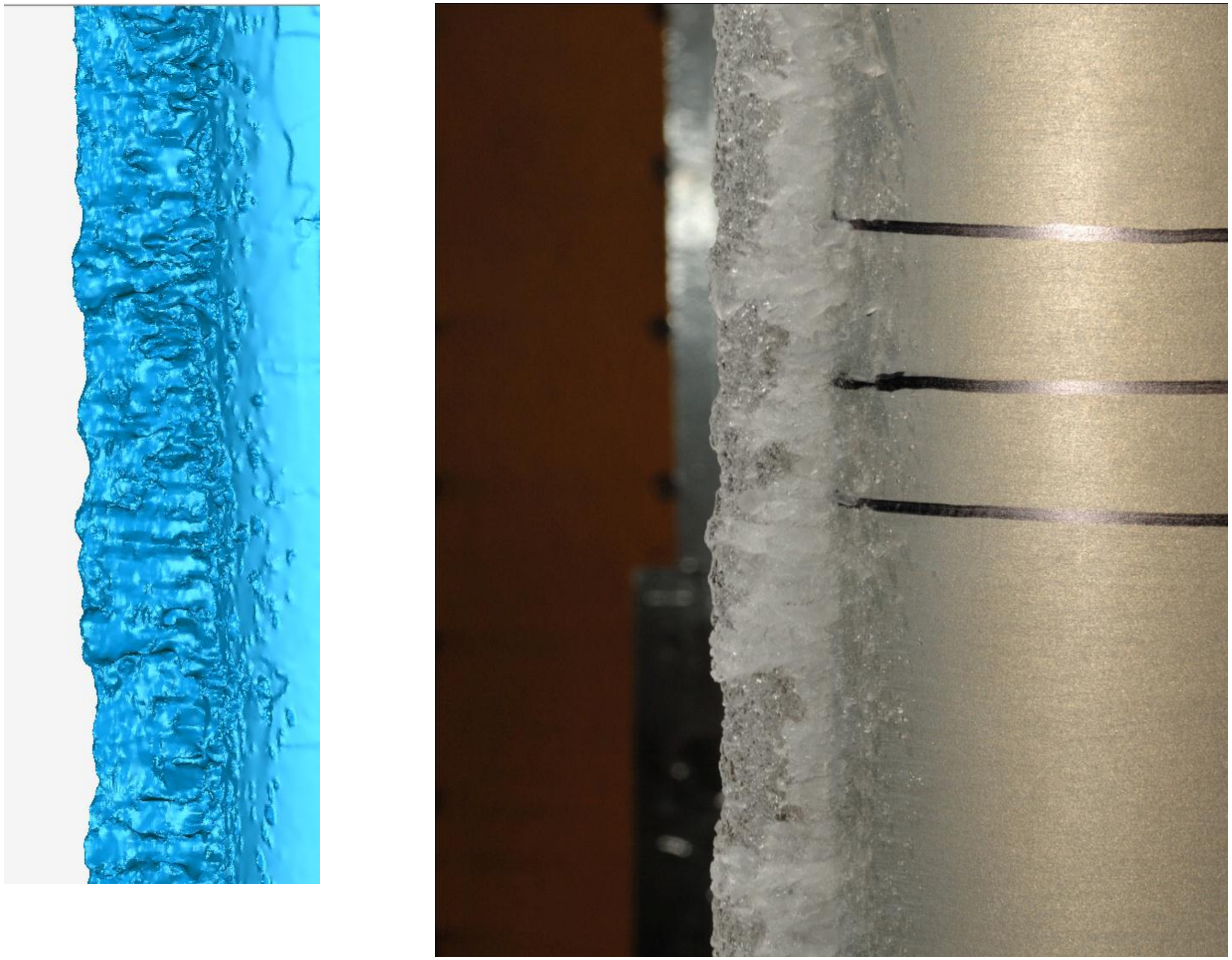
Selection Results – Scanner Selection

- Romer Absolute system selected for further development in IRT.
  - Required minimal modifications to the test section, resulting in fewer risks in implementation for use.
  - It generated “raw” data in an unprocessed state, allowing more control over post-processing of the scan data.
  - Romer arm counterbalancing system was found to be more effective than Faro arm.
  - Romer system can operate at temperature down to 0° F.
  - Romer system can be operated directly from Geomagic

Selection Results – Sample Evaluation Data

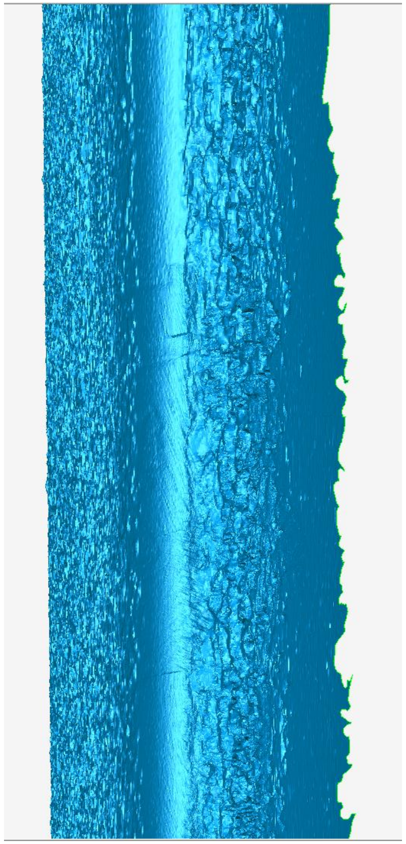
- The data shown below were obtained during the evaluation of the Faro Quantum Arm.
- The results are shown only as a general indication of typical results one would expect from a modern 3D laser scanning system and software.
- More research is planned to improve quality of scan data

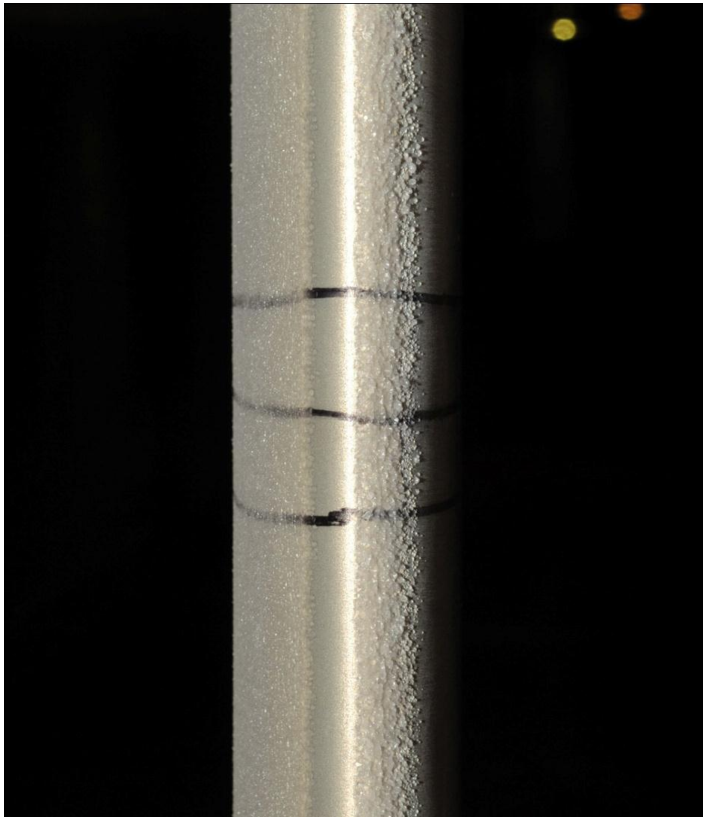
Selection Results – Sample Evaluation Data



Horn Ice Shape

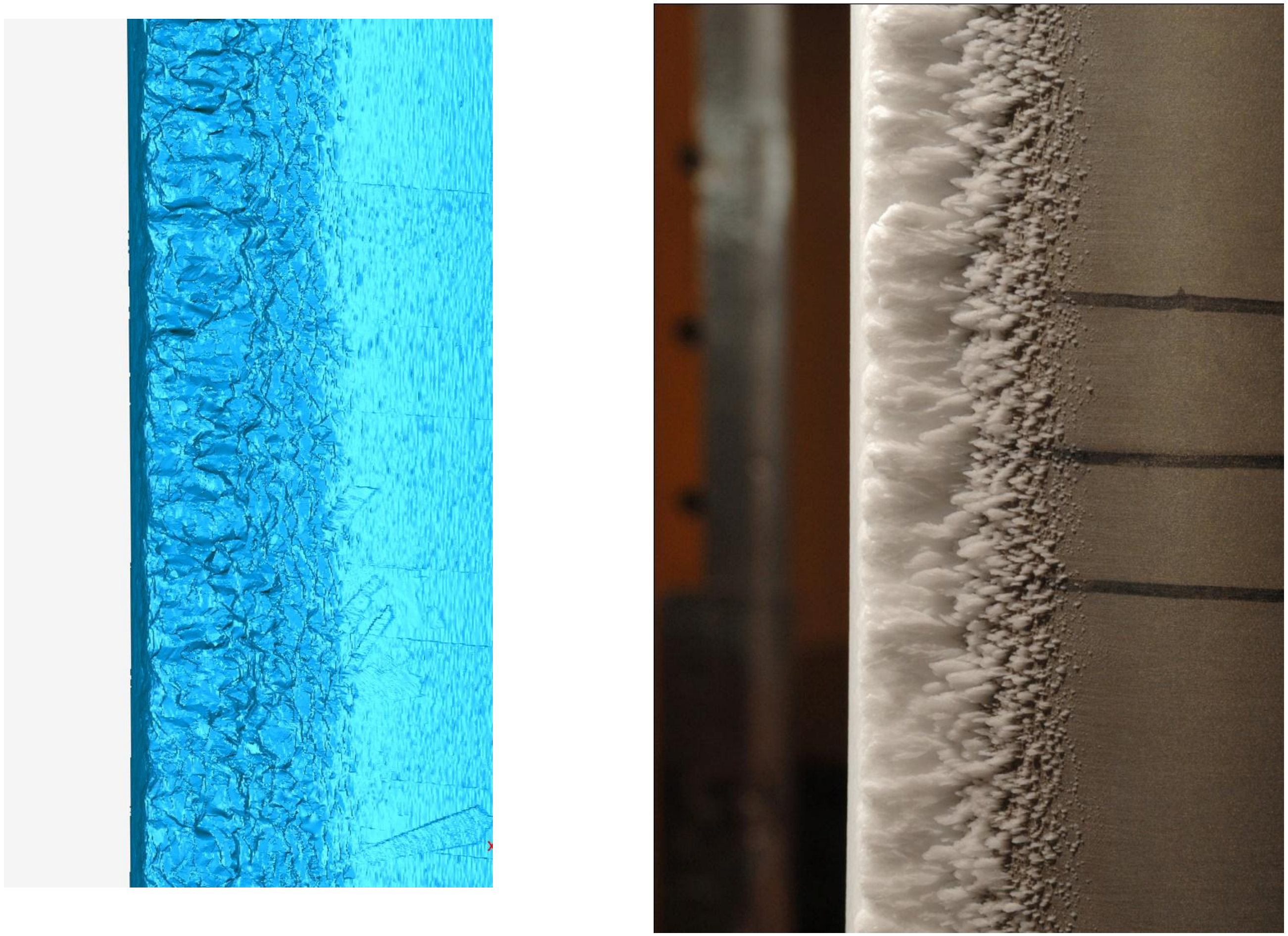
Selection Results – Sample Evaluation Data





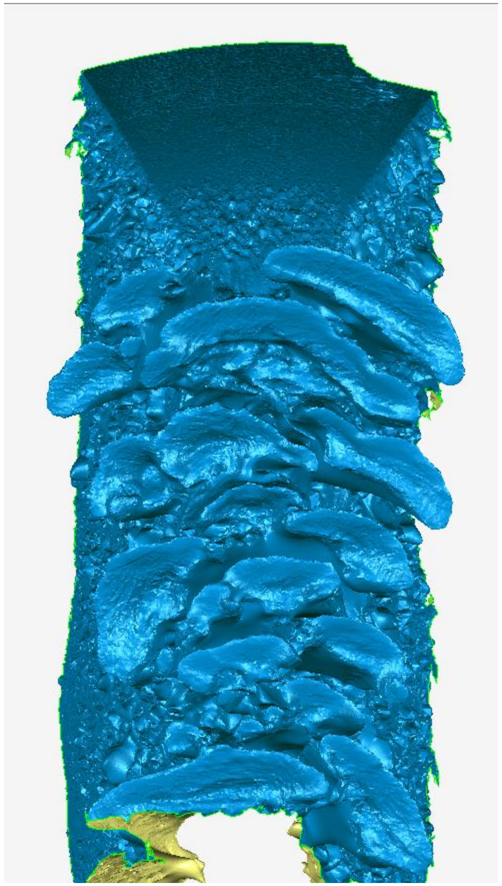
Roughness Ice Shape

Selection Results – Sample Evaluation Data



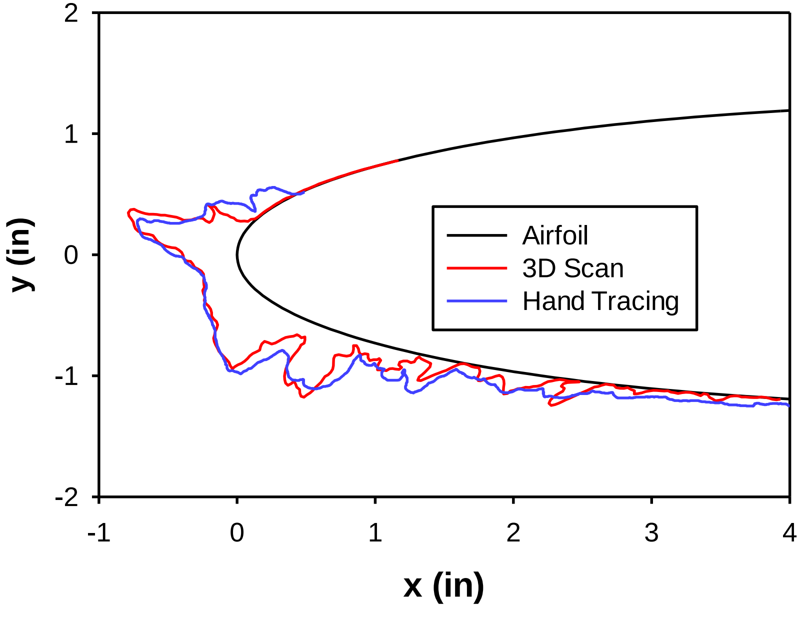
Streamwise Ice Shape

Selection Results – Sample Evaluation Data

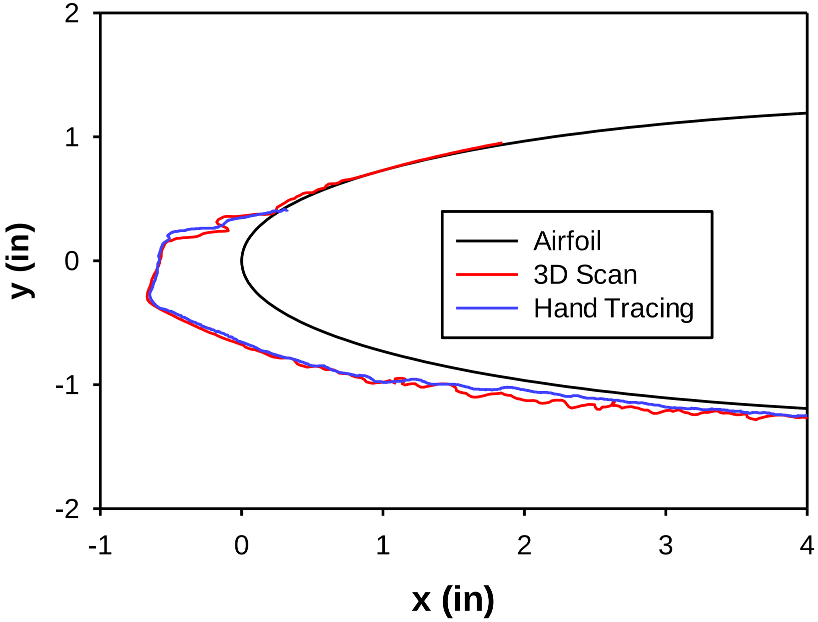


Swept Wing Scallop Ice Shape

Selection Results – Sample Evaluation Data



Horn Ice Shape



Streamwise Ice Shape

Comparison of 3D Scan to 2D Pencil Tracing

Conclusion

- A research program is currently being implemented to develop and validate the use of a 3D laser scanning system to record ice accretion shapes in the NASA Icing Research Tunnel.
- First step - identify the most suitable laser scanning hardware and software for further development.
- Several scanning systems were evaluated against selection criteria
  - Arm-based system was found to be the most promising
  - Evaluation results showed that commercial 3D laser scanners were capable of recording many details of various types of ice shapes, and post-processing software were capable of generating “water-tight” surfaces.

Conclusion (cont’d)

- The selected scanner system will be used to implement and validate the use of this technology through a series of icing and aerodynamic tunnel tests.
- With continued success of this research a suitable means of recording and archiving fully three-dimensional descriptions of experimental ice accretion geometry will have been developed.