Reverse Engineering, 3D Scanning & Prototyping Within COMFRC

27 June 2017

Presented to:

Joint Technology Exchange Group
Monthly Webinar

Presented by:

Justin Reynolds
FRCE MBD Lead
Digital Manufacturing PSE

R David Price
FRCSW AMSREL Lead
Metrology and 3D Printing SME

Michael Renstrom
FRCSE F/A-18 MFG Project Lead

Fleet Readiness Centers

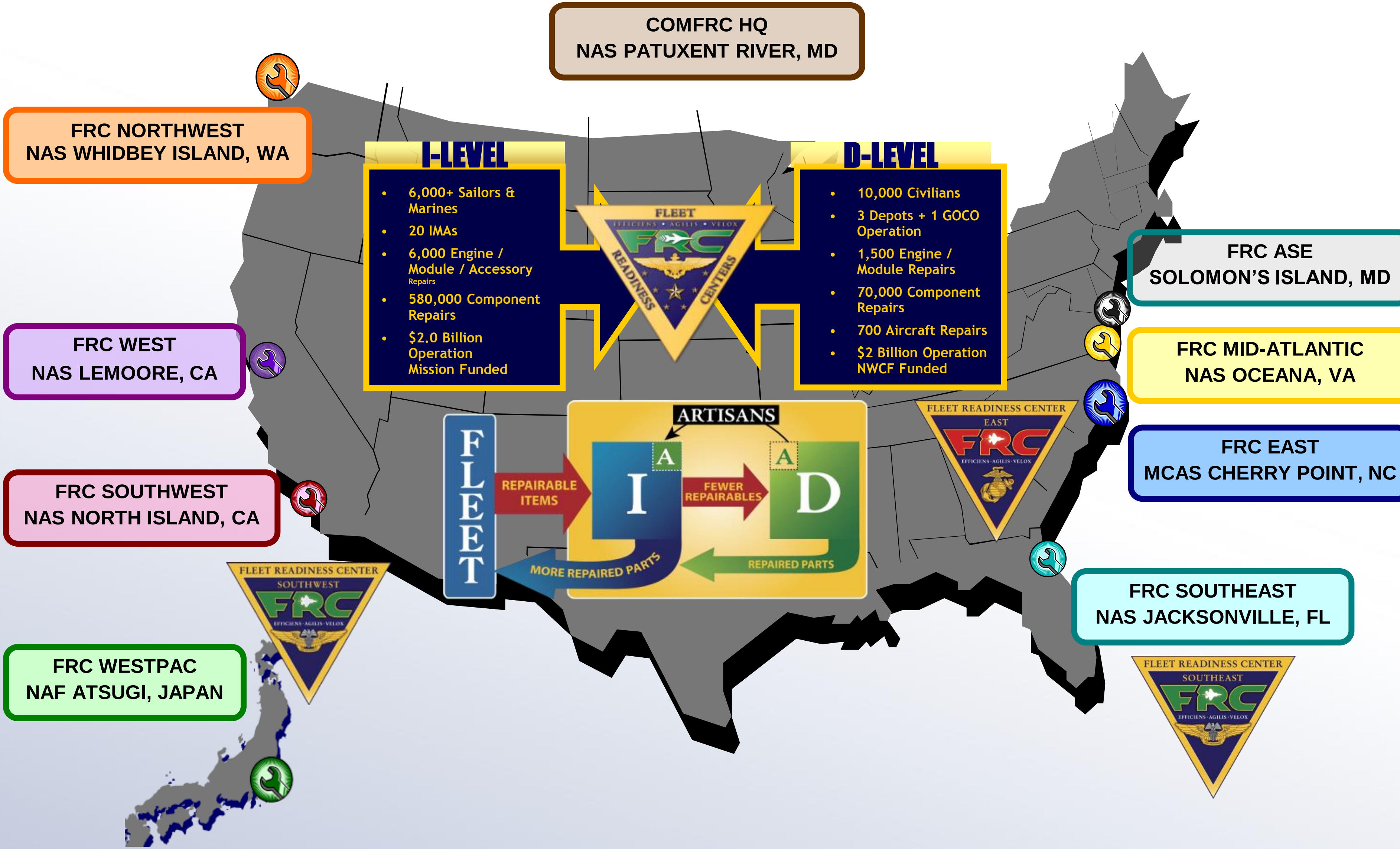
VISION

To be the provider of choice for aviation Maintenance, Repair and Overhaul capabilities and services

MISSION

To produce quality airframes, engines, components, and support equipment, and provide services that meet the Naval Aviation Enterprise's aircraft ready for tasking goals with improved effectiveness
and efficiency. (Best Value)

FRC Locations



*Slide courtesy of Doug Greenwood and Ron Francis

The Industrial FRCs

FRC East

FRC Southeast

FRC Southwest

FRCSW AMSREL

AMSREL
Advanced Metrology Systems Reverse Engineering Lab
FRCSW

FRCSW Advanced Measurement Systems Reverse Engineering Lab (AMSREL)

– Formed c. 2008 to meet a growing need to digitally certify 3D models.
– ATI IPT grew the lab by seeking new hires and encouraging multiple equipment purchases.

Problem

- Some new manufactured parts (produced locally and by contractors) don't fit on the aircraft or match off-aircraft parts.

Causes

- Human error creating a 3D model from a 2D print.
  - 2D prints can be extremely complicated, erroneous, non-dimensioned, and in some cases illegible.

Solution

- Utilize a metrology technology that can digitally compare a 3D model to an off-aircraft part.

FRCE Manufacturing DDC

FRCE Manufacturing Digital Data Center (DDC)

- Formed c. 2010 to meet a growing need to digitally certify 3D models.
- No formal lab to date, consists instead of organically imbedded engineering support staff aligned to the Manufacturing IPT.
- Extensive CAD/CAM resources, limited RE and AM capabilities
  - RE – FARO 9ft EDGE Arm (AAPCMM) with 3rd generation blue light laser scanner
  - AM – Stratasys FORTUS 900mc and 400mc Fused Deposition Modelers

Problem

- Some new manufactured parts (produced locally and by contractors) don't fit on the aircraft or match off-aircraft parts.

Causes

- Human error creating a 3D model from a 2D print.
  - 2D prints can be extremely complicated, erroneous, non-dimensioned, and in some cases illegible.

Solution

- Certify models to available 2-D technical data and authorize use thereof from an engineering. Employ RE when applicable to rectify discrepancies internal to drawings, or when compared to in-service components. perspective.

FRCE PMC

FRCE Precision Measurement Center (PMC)

- Formed c. 2000 to meet a growing need to measure with increased precision.
- Lab consists of 16 (11 CMM's & 5 Laser Trackers) devices and 14 full time staff.
- All PMC assets are calibrated annually by the OEM IAW ISO 10360-2 Standards.
- PMC lab supports measurement functions for various fleet platforms including: AV-8B, CH-53, MH-53, C-130, H-1, V-22 and F-35.

CMM

- Engineering Investigations, First Article Inspections, Crash Damage Assessments, Dimensional Verifications, Calibration-Preventative Maintenance & Gold Plate items.
- Repeatable accuracy down to 0.4+L/850 µm (volumetric).
- Complete Gear, Blade, Vane and Engine component verifications.
- 3-D Model programming and 3-D probe scanning capabilities.
- Full Geometric Dimensional & Tolerancing and Characteristic Analysis

PORTABLE CMM

- Install, setup, reverse engineer and complete inspection capabilities of aircraft rework fixtures and specialty tooling.
- Avionic, Navigation and Weapon system alignments.
- Measurement volume of 3.5-262 feet.
- Two dedicated travel teams for all on-site setups, validations and inspections.

FRCSE Engineering

- Dedicated group formed c. 2012 to meet a growing need to digitally certify 3D models using the 3MS process.
- No formal lab to date, consists instead of organically imbedded engineering support staff aligned to the Manufacturing IPT.
- Extensive CAD/CAM resources, limited RE and AM capabilities
  - RE – Access to a FARO arm laser scanner, Leica T-Scan, and CMM, with a Handyscan 700 being purchased
  - AM – Stratasys FORTUS 400mc and uPrint SE Fused Deposition Modelers

Problem

- Some new manufactured parts (produced locally and by contractors) don't fit on the aircraft or match off-aircraft parts.

Causes

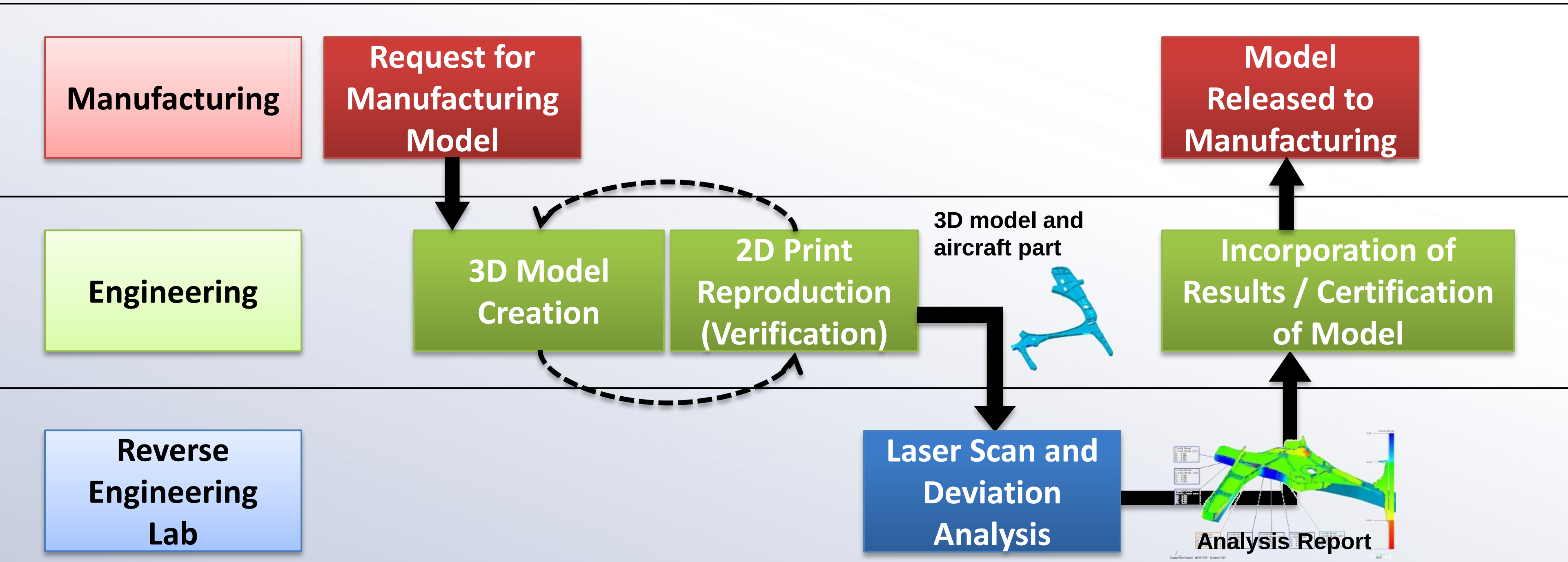
- Human error creating a 3D model from a 2D print.
  - 2D prints can be extremely complicated, erroneous, non-dimensioned, and in some cases illegible.

Solution

- Utilize a metrology technology that can digitally compare a 3D model to an off-aircraft part.

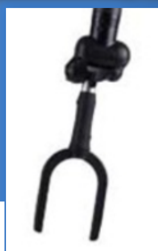
Manufacturing Model Management System (3MS)

- Created at FRCSW to add a higher level of scrutiny to 3D models prior to manufacturing.
- Similar processes used at all FRCs. Slight variances attributable to aircraft platform differences with state of incoming data: 2D vs. 3D, etc.



Metrology Tools



Romer AAPCMM

FARO AAPCMM

Articulated Arm Portable Coordinate Measuring Machines (AAPCMMs)

Surphaser Hemispherical Scanner

Other Scanners

HandySCAN Portable Scanner

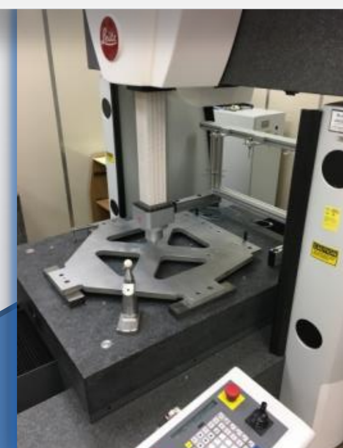
Coordinate Measuring Machines (CMMs)

Leica Laser Tracker

Faro Laser Tracker

Laser Trackers

Coordinate Measuring Machine - Small



Coordinate Measuring Machine - Medium

Coordinate Measuring Machine - Large

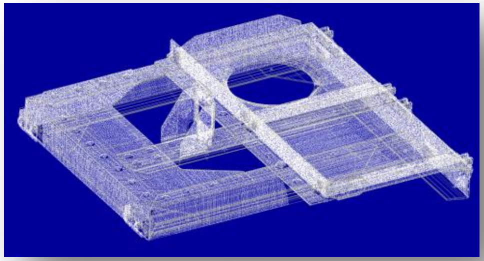
Metrology Tools

Measurement Device	Model	Location	Quantity	Measurement Scale	Measurement Accuracy (in)	Typical System Cost
Articulated Arm PCMM	Romer w/ Scanner	FRCSW	2 (1)	Small-Medium	± 0.006	80K
Articulated Arm PCMM	FARO	FRCSW	(2)	Small-Medium	± 0.004	60K
Hemispherical Laser Scanner	Surphaser	FRCSW	1	Medium-Large	± 0.010	100K
Laser Tracker	API, FARO, Leica	FRCSW	1 (8)	Medium-Large	± 0.0006	Varies
Stationary Laser Scanner	Konica Minolta	FRCSW	1	Small	± 0.001	100K
*Portable Laser Scanner	Creaform HandySCAN	FRCSW	1	Small-Medium	± 0.0005	80K
Coordinate Measuring Machine	Brown and Sharpe, Zeiss	FRCSW	1 (2)	Small-Medium	± 0.000008	250K
Articulated Arm PCMM	FARO w/ Scanner	FRCE	1	Small-Medium	± 0.006	125K
Articulated Arm PCMM	Romer w/ Tube Probe	FRCE	1	Small-Medium	± 0.006	80K
Laser Trackers	FARO, Leica	FRCE	9	Medium-Large	± 0.0006	Varies
Coordinate Measuring Machines	Zeiss, Hexagon, Leitz	FRCE	10	Small-Medium-Large	± 0.000008	Varies
Laser Tracker	Leica	FRCSE	4	Medium-Large	± 0.0006	120K
Stationary Laser Scanner	FARO	FRCSE	4	Small	± 0.002	100K
Portable Laser Scanner	Creaform HandySCAN	FRCSE	1	Small-Medium	± 0.0007	66K
Coordinate Measuring Machine	Zeiss	FRCSE	3	Small-Medium	± 0.000008	250K

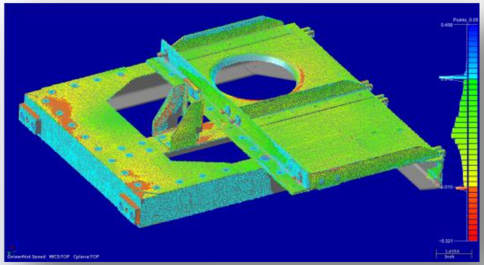
* – Future Acquisition
() – Assets managed outside AMSREL

Data Acquisition for Dimensional Analysis

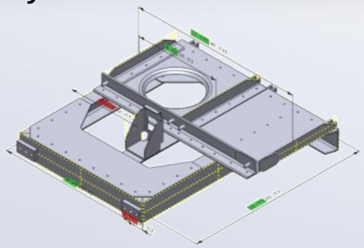
Dimensional Analysis



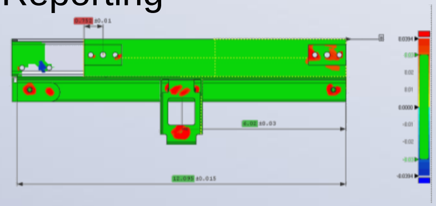
Data collection



Analysis



Reporting



Name	Nominal Value	Actual Value	Deviation	Tolerance
Linear Dim.3	9.63	9.6262	-0.0038	±0.02
Linear Dim.4	12.75	12.7574	0.0074	±0.03
Linear Dim.5	5.358	5.2921	-0.0659	±0.03
Linear Dim.6	12.095	12.0973	0.0023	±0.015
Linear Dim.7	6.02	6.0199	-0.0001	±0.03
Linear Dim.8	0.752	0.733	-0.019	±0.01

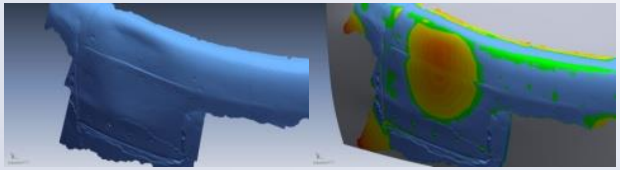
Laser scanning a physical part or aircraft creates a cloud of discrete points, each with an XYZ location in space.

When overlaid onto a 3D model, it is possible to measure the distance of each point to the nearest surface.

This geometric analysis can show:

- If a wall is too thick or too thin
- If a rib or flange is mislocated
- If a geometry is missing
- If a hole is out of tolerance
- If a wall height is incorrect

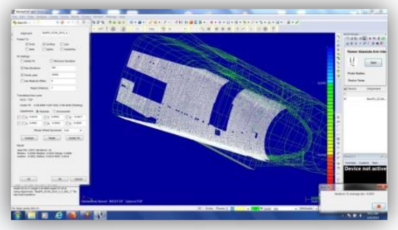
In short, laser scanners can be used to compare a 3D model to a physical part.



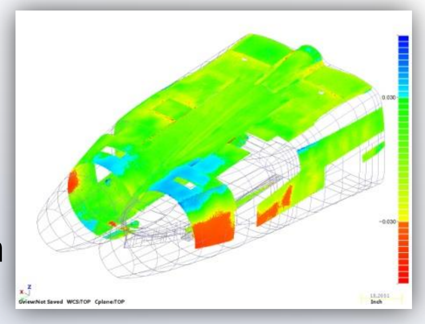
Point cloud deviation from 3D model

Data collection

Point cloud merging



Fitting the data to the aircraft model



Laser scanning a C-130 blade during buildup of a prop to ensure acceptable blade angle for full feathered and reversed conditions.

FARO (deg, min, sec)

Blade 1	15	deg	47	min	44.49	sec
Blade 2	15	deg	47	min	12.69	sec
Blade 3	15	deg	56	min	10.63	sec
Blade 4	15	deg	38	min	43.27	sec
Blade 5	15	deg	11	min	26.73	sec
Blade 6	15	deg	44	min	9.67	sec

FARO (deg, min decimal)

Blade 1	15	deg	47.74	min
Blade 2	15	deg	47.21	min
Blade 3	15	deg	56.18	min
Blade 4	15	deg	38.72	min
Blade 5	15	deg	11.45	min
Blade 6	15	deg	44.16	min

FARO (deg)

15.80
15.79
15.94
15.65
15.19
15.74

Manual (deg, min)

Blade 1	15	deg	38	min
Blade 2	15	deg	49	min
Blade 3	15	deg	38	min
Blade 4	15	deg	33	min
Blade 5	15	deg	18	min
Blade 6	15	deg	44	min

Deviation (min)

9.74	min
-1.79	min
18.18	min
5.72	min
-6.55	min
0.16	min

Manual (deg)

15.63
15.82
15.63
15.55
15.30
15.73

FARO Results (degrees)

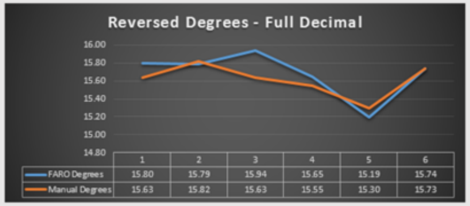
15.68	average		
15.5	to	15.83	req
result = pass			

Manual Results (degrees)

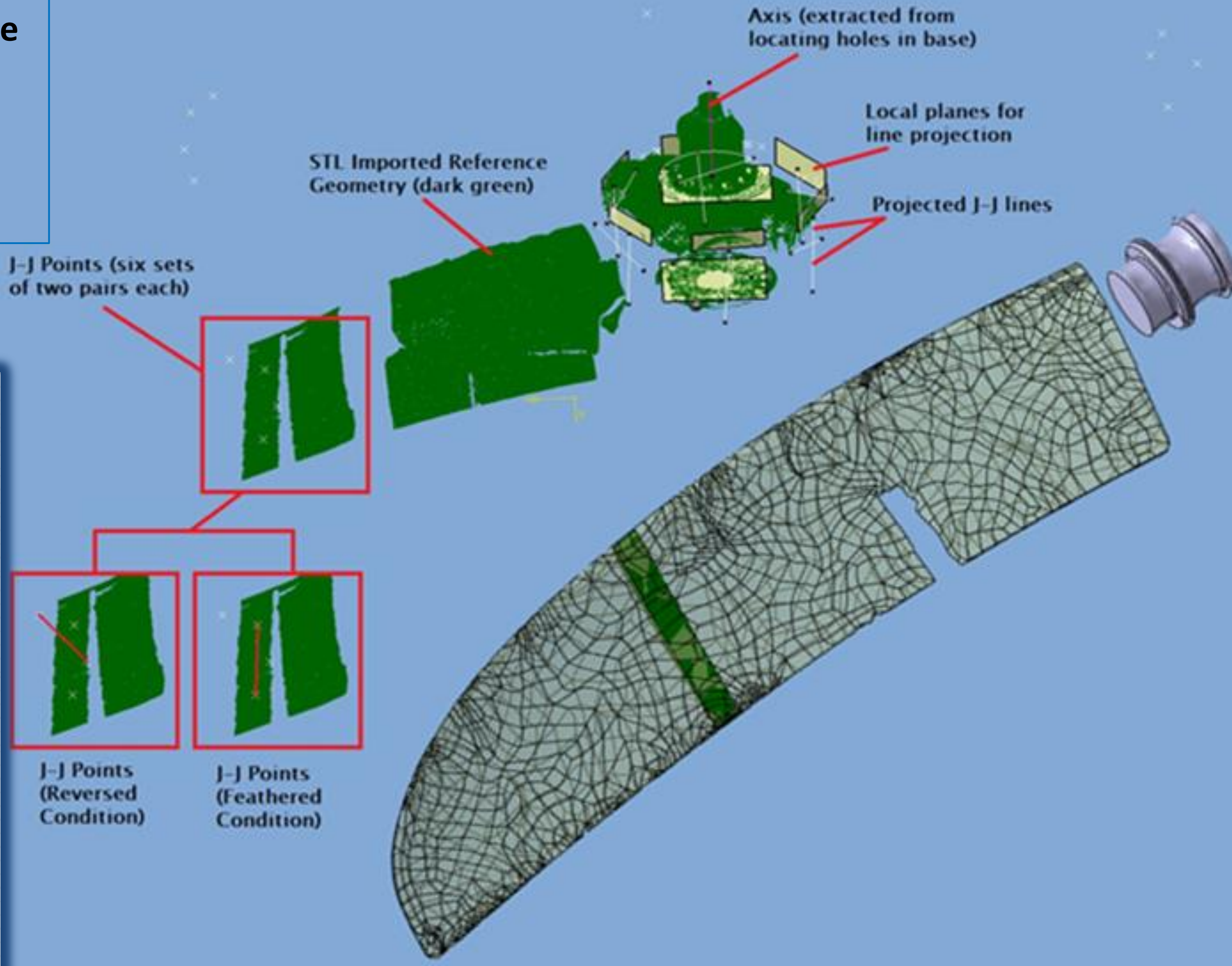
15.61	average		
15.5	to	15.83	req
result = pass			

Difference in Averages

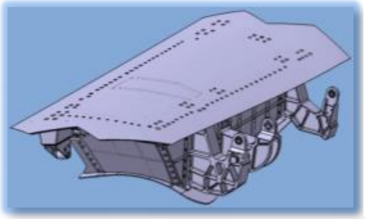
0.0707	degrees different
4.243	minutes different



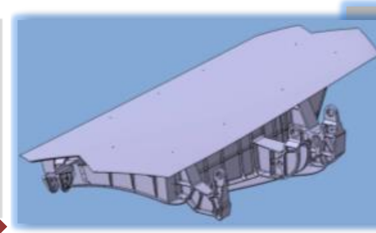
	1	2	3	4	5	6
FARO Degrees	15.80	15.79	15.94	15.65	15.19	15.74
Manual Degrees	15.63	15.82	15.63	15.55	15.30	15.73

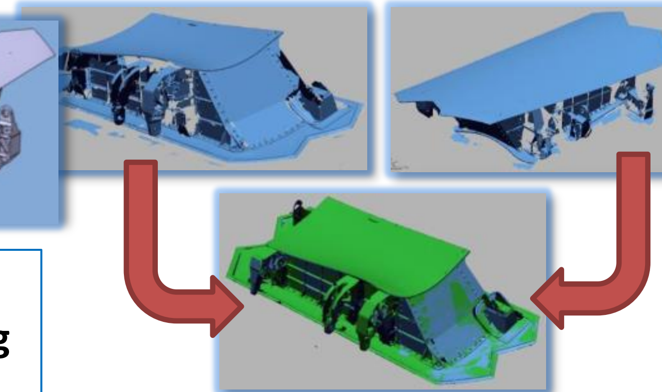


Dimensional Analysis



CAD assembly of door received as .CATPart file containing hardware and consisting of 381 bodies. Modifications for analysis included conversion to .stp, removal of fasteners, collars, nutplates, and shims, and reduction to 13 bodies which were merged for deviation analysis.





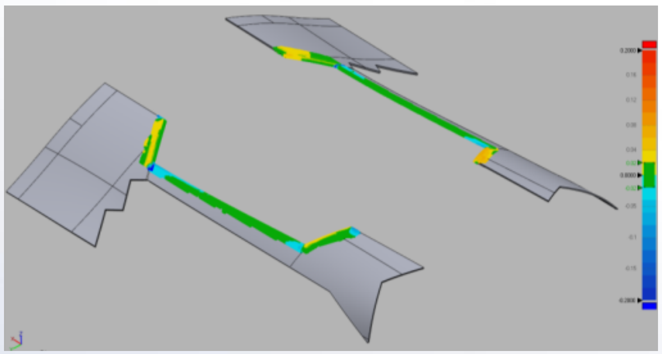
Door scan data had to be acquired in two set-ups and merged. This was done in a controlled setting on a granite table.

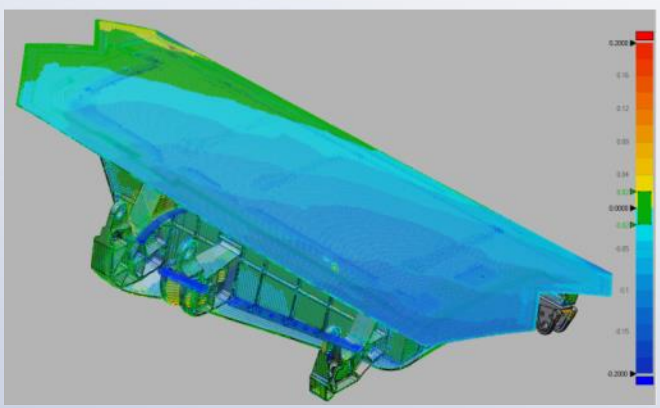
Laser scanning F-35 engine intake doors and door opening to analyze fittment issues.

Data was acquired by mounting the FARO scanarm to the back of an aircraft using the suction cup base and hand-actuated vacuum pump.

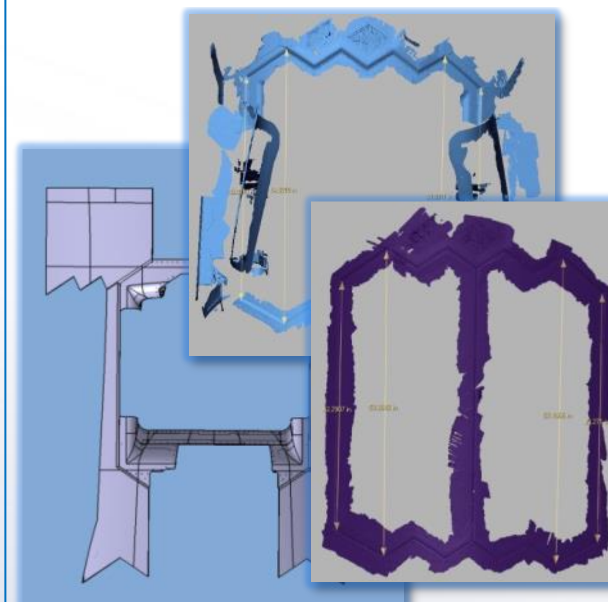
This geometric analysis showed:

- Dimensional inconsistencies on both aircraft and door sides
- Warp in the door skins





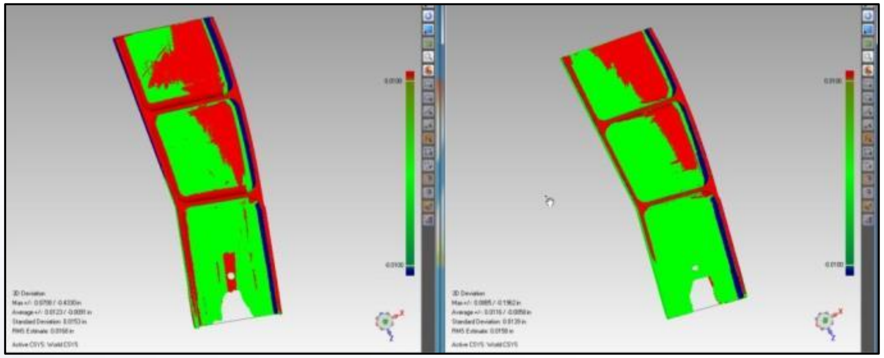
Deviation mapping of doors and door opening

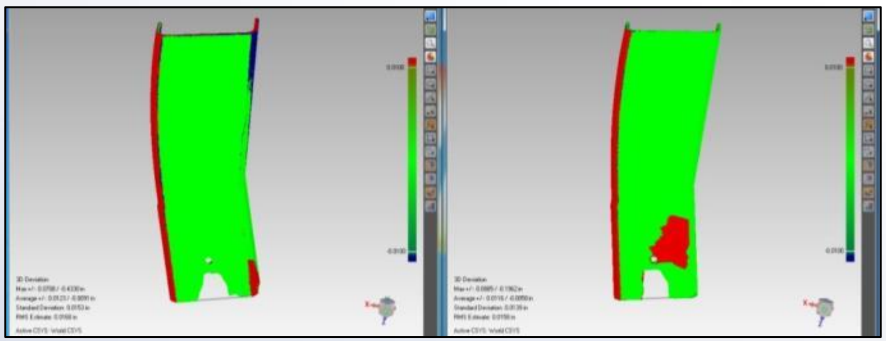


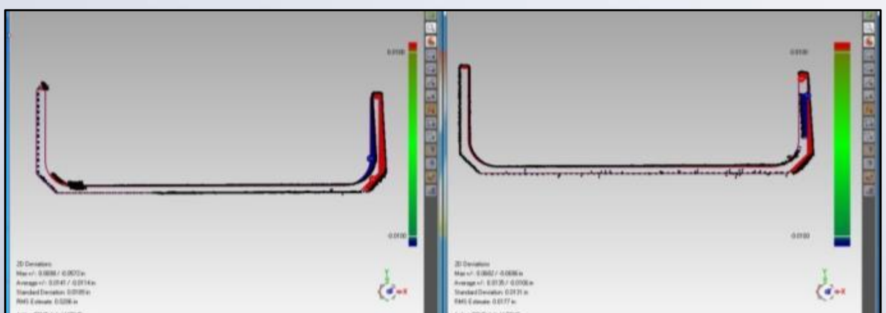
Aircraft scan data with doors open (blue) and with doors closed (purple) as well as aircraft door opening CAD model.

Dimensional Analysis

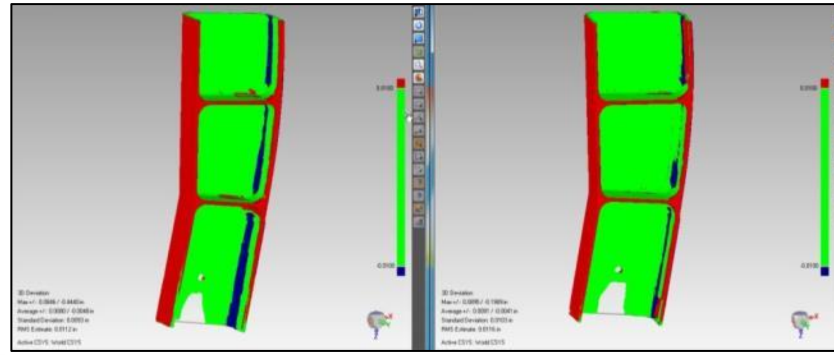
Digital Go, No-Go Gauging of Locally Manufactured Components

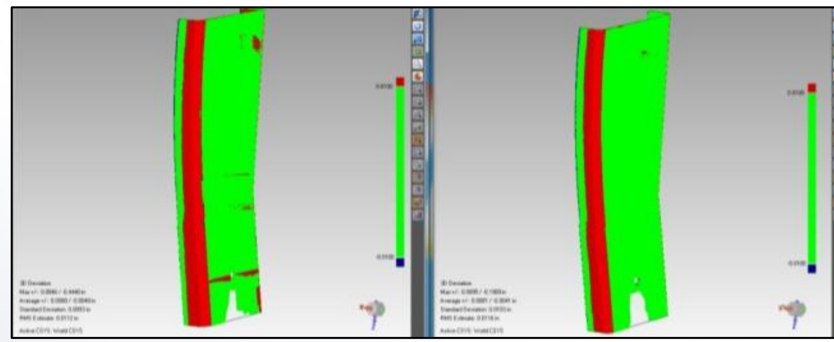


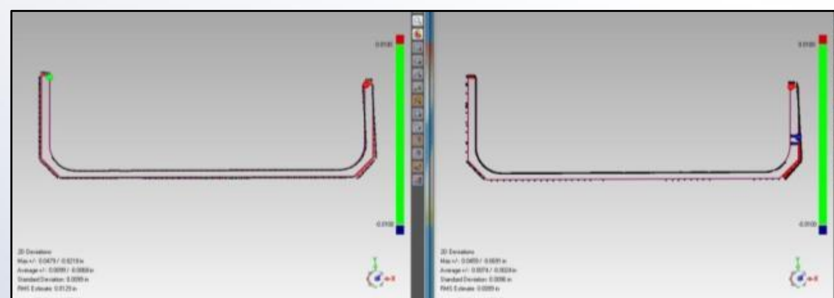




Datum Based Alignment

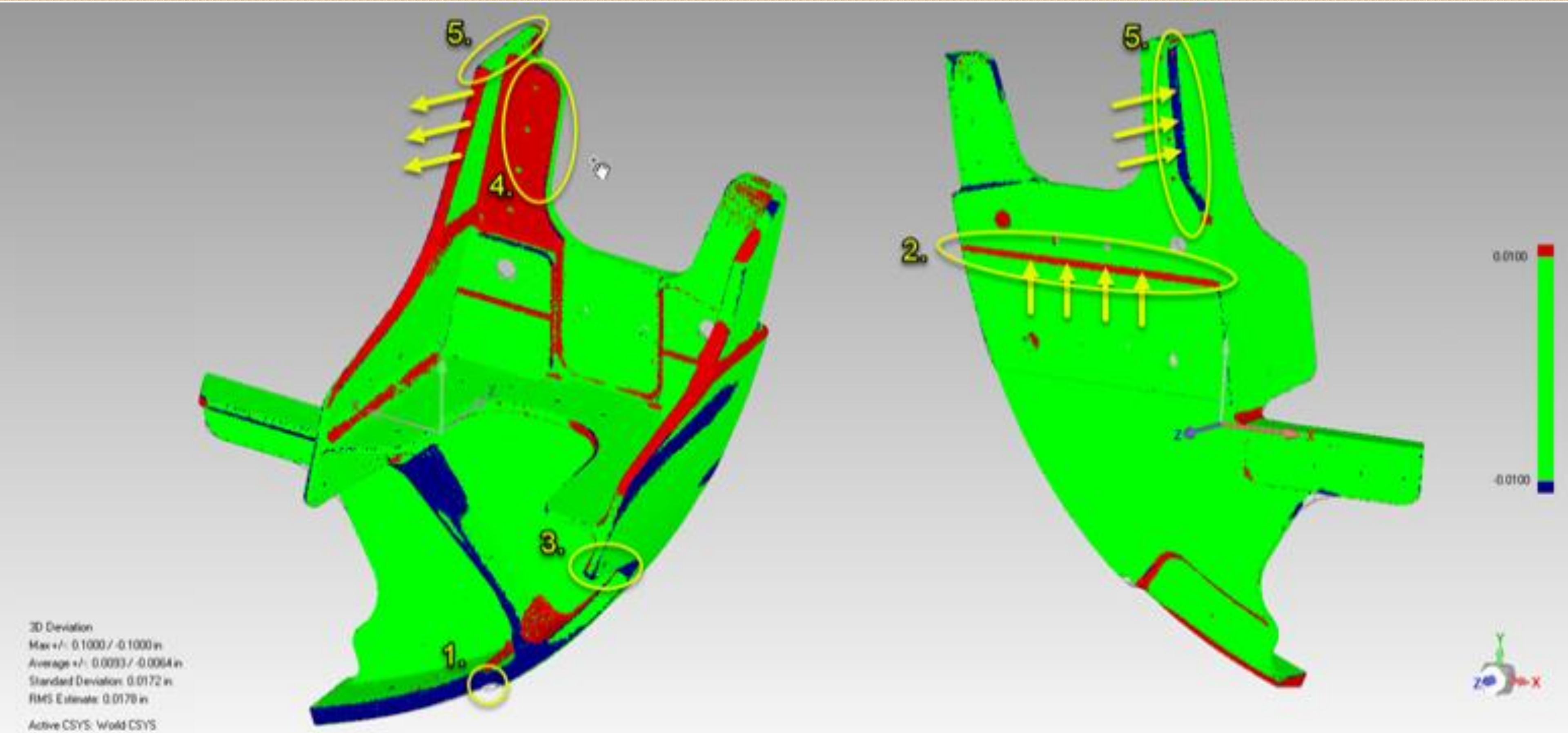






Iterative Alignment

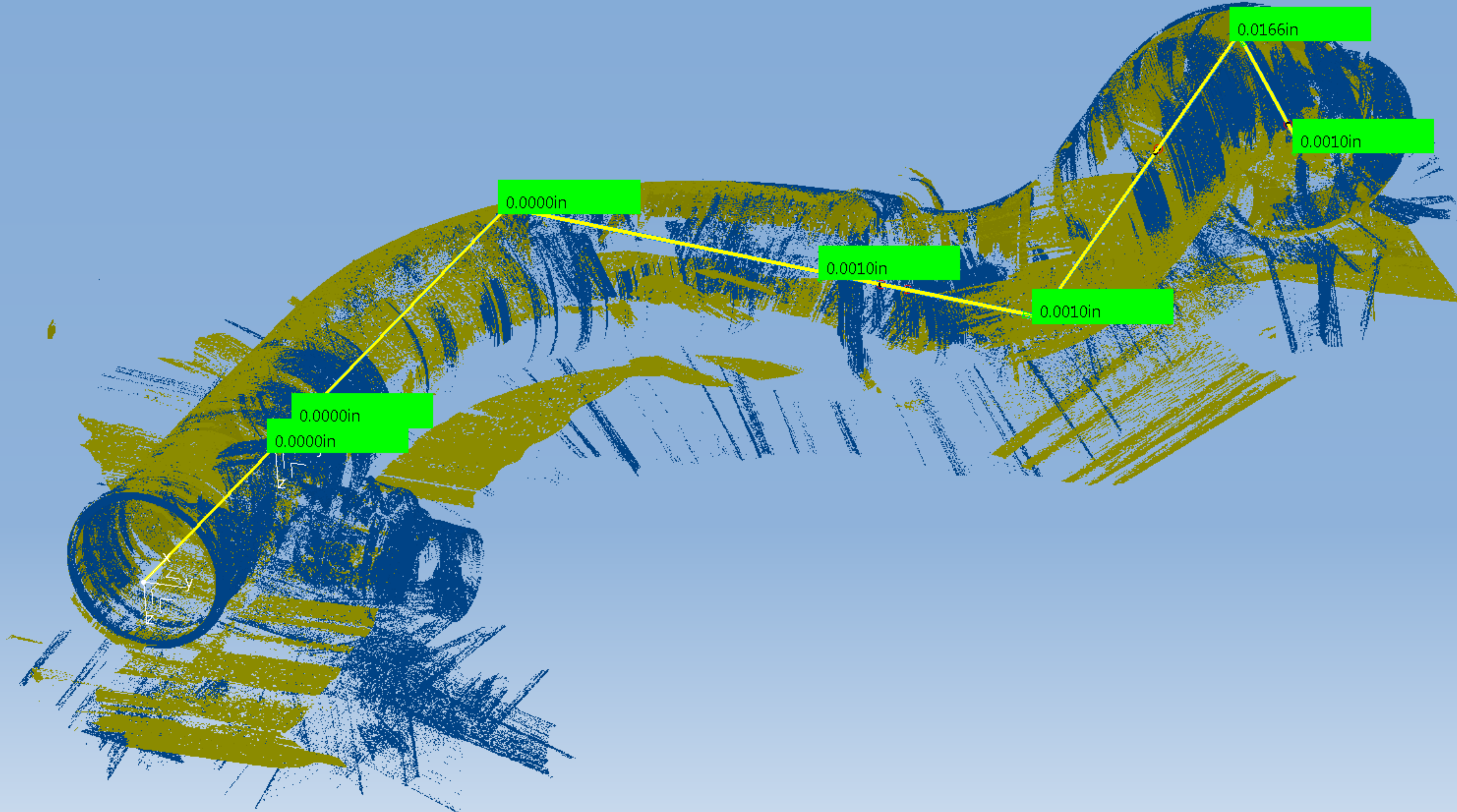
Dimensional Analysis



Acceptance/Rejection of OEM/Vendor produced components:

- H-53 structural corner fitting where tail transition section mounts to aft cabin
- Flight Critical Safety Item
- Extremely difficult to interpret forging and finish machining drawing with 320+ dimensions
- Substituting machining from forged billet

Dimensional Analysis



Tube Length, Rotation, & Angle (LRA) measurement

Dimensional Analysis

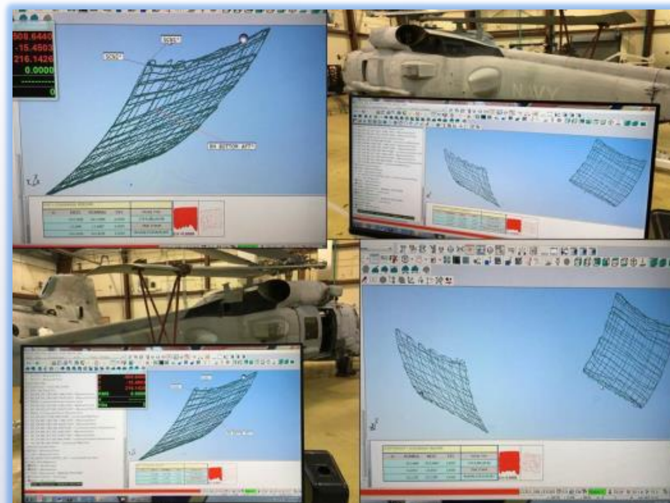
Laser Tracker -- Alignment

Measurement Alignment (Facility Workload)
We dimensionally verify a large majority of the rework fixtures that are located throughout the facility. These fixtures are verified on an annual basis to ensure that all specifications to the original O.E.M drawings are met. Examples of this workload would include the following:

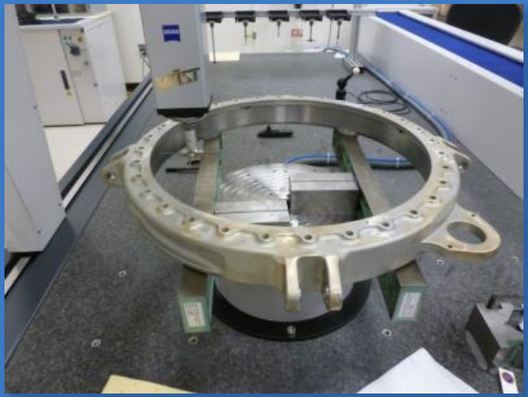
- AV-8 Crash Damage Maintenance Fuselage Fixture
- AV-8 Crash Damage Maintenance Wing Fixture
- AV-8 Flap Assembly Fixtures
- AV-8 Rudder Assembly Fixtures
- AV-8 Canopy Repair Fixtures
- UH-1Y Fuselage Repair Fixture
- UH-1N Fuselage Repair Fixture
- UH-1/AH-1 Tail Boom Repair Fixture
- AH-1W Fuselage Repair Fixture
- CH-53E Tail Pylon Repair Fixture
- CH-53E Overhead Door Repair Fixture
- CH-53E Fuselage Transition Repair Fixture

Measurement Alignment (Fleet Workload)
We are routinely required to measure various fleet alignments for special avionic, navigation or weapon systems that are either first time modification requirements or to realign systems that have either encountered a "hard landing" or been removed for various rework procedures. Examples of this workload would include the following:

- AH-1W E.G.I (Embedded GPS/Inertial Navigation System)
- CH-46 DIRCM (Directional Infrared Radar Counter Measure) Alignment
- CH-53 DIRCM (Directional Infrared Radar Counter Measure) Alignment
- V-22 FLIR (Forward Looking Infrared Radar) Alignment
- V-22 LWINS (Light Weight Inertia Navigation System) Alignment
- V-22 DIRCM (Directional Infrared Radar Counter Measure) Alignment
- H-60B/R ALQ-205 (Omni-directional infrared countermeasures) Alignment
- CH-46 Drive Shaft Alignment
- CH-53 Drive Shaft Alignment
- AV-8 Boresight Weapon Systems Alignment
- AH-1W Boresight Weapon Systems Alignment
- H-3 Doppler Radar Installation/Alignment



Dimensional Analysis

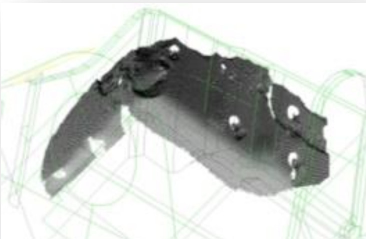


Touch Probe CMM Inspection

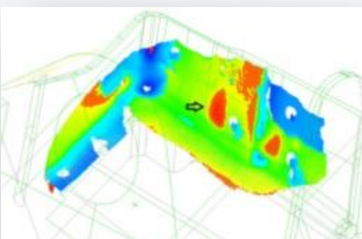
ZEISS	ZMC-550
ZEISS	PRISMO ULTRA 12-24-10
HEXAGON	GLOBAL 5-7-4
HEXAGON	GLOBAL 5-7-5
HEXAGON	GLOBAL 5-7-5 ADVANTAGE
HEXAGON	GLOBAL 7-10-7
HEXAGON	DEA GLOBAL 12-60-12
HEXAGON	GLOBAL 9-12-8
Leitz	PMM 60-38-25
Leitz	PMM ULTRA 12-10-6

Data Acquisition for Damage Modeling

Damage Modeling



Scan of putty splash fit to CAD nominal

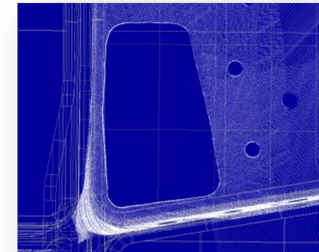


Analysis vs CAD

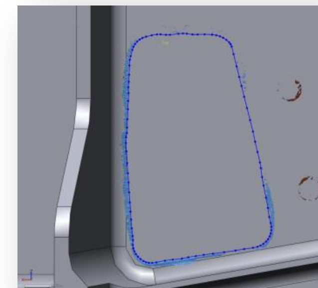
Beyond a simple deviation analysis, it is also possible to model (reverse engineer) physical damage into 3D models. Damage examples include:

- Artisan blending
- Dents
- Mislocated holes

This is typically used to aid in repair design, to quantify damage, and to perform FEA on **as-damaged models**.

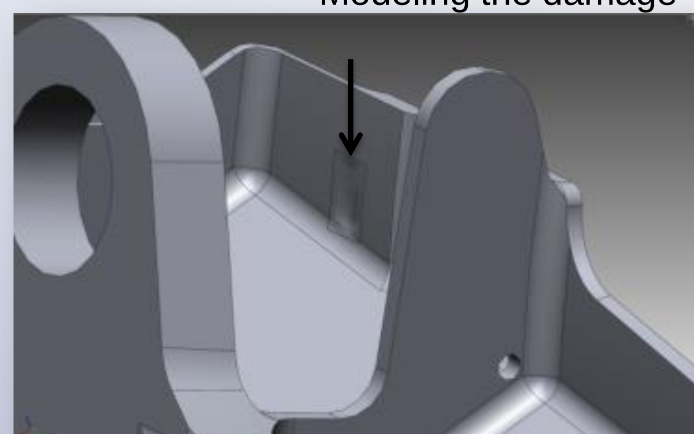


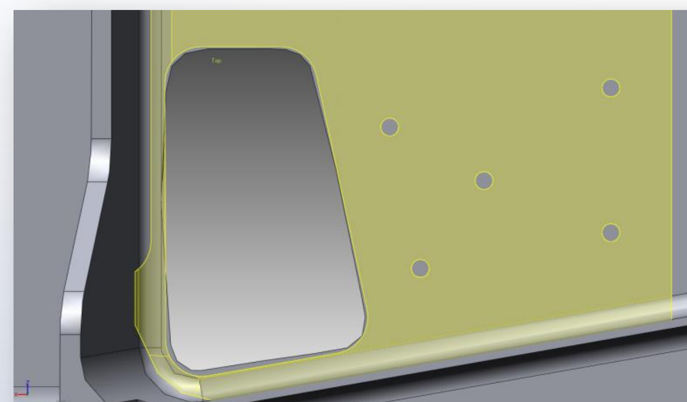
Scan data fit to nominal



Trace line created of artisan cutout

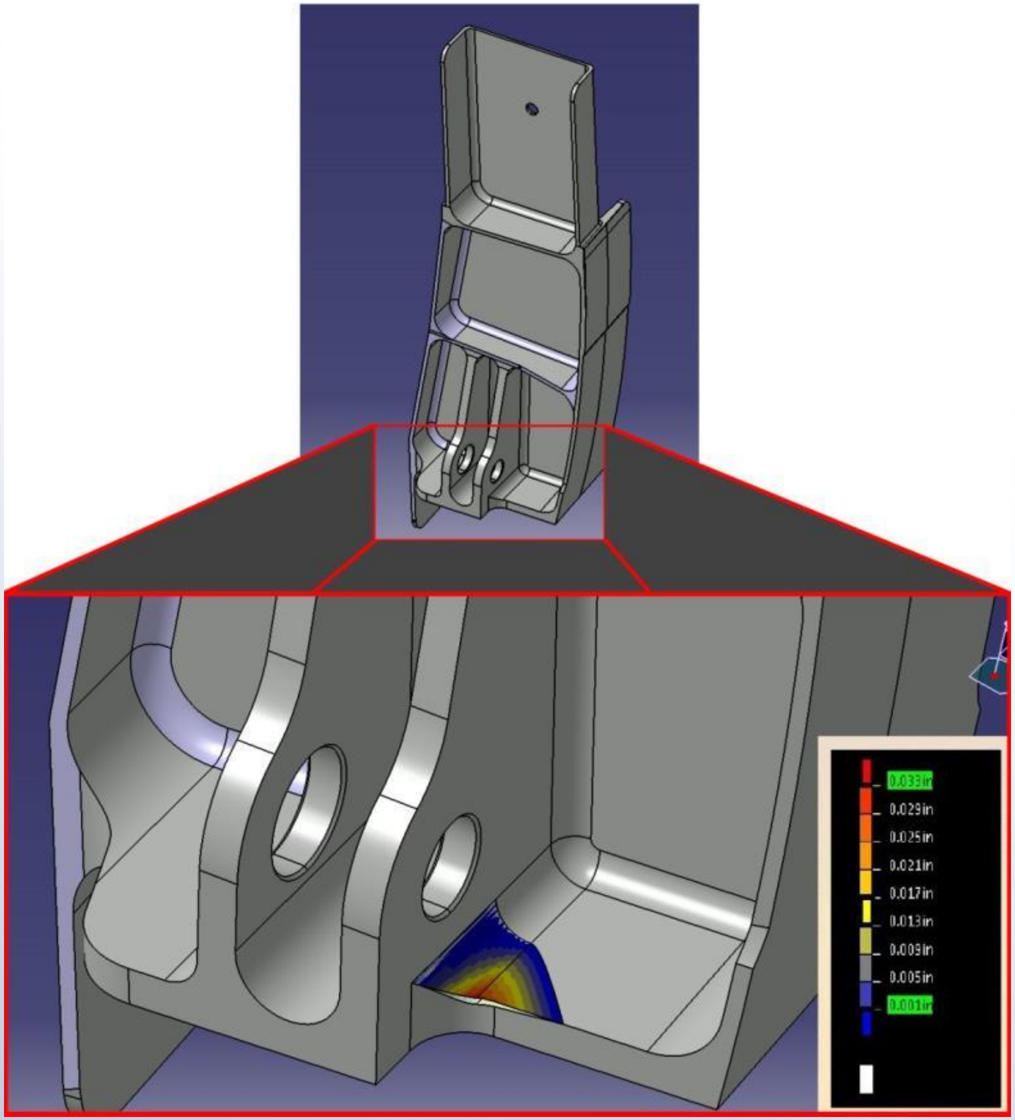
Modeling the damage





Comparison of hole profile to nominal guide tool

Damage Modeling



Stainless steel structural repair fitting for a **V-22 bulkhead frame**:

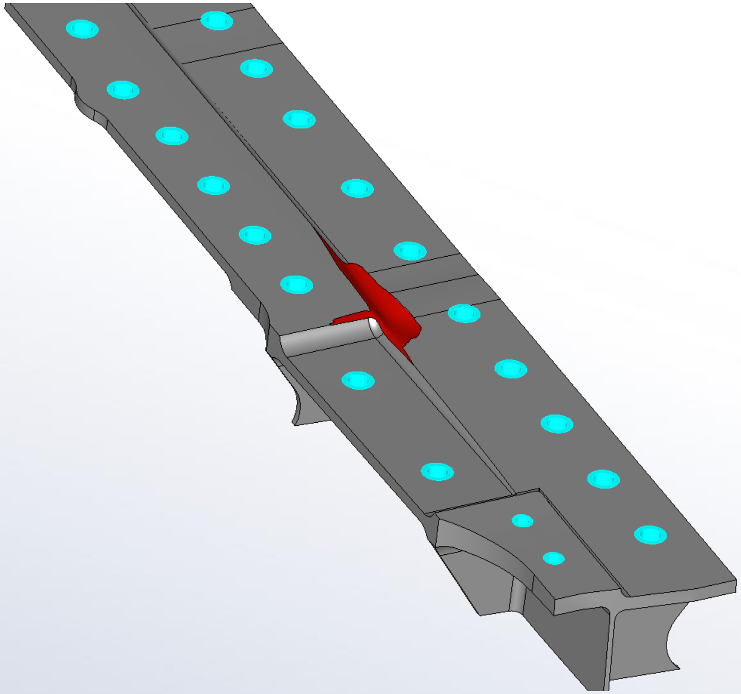
- Difficult material to machine
- Tight tolerances
- Unpredictable tooling overcut during finish machining operation
- Yielded thin-wall condition at a filleted transition between flanges in the proximity of the primary load path

The resultant OOT condition was measured and modeled into the solid body for analysis purposes to determine acceptability in the as-is condition.

Parts were unusable; the analysis showed failure in the thinned area under load. CNC toolpath was corrected and new parts were produced.

F-18 Spar Blend and Analysis

- An area of the spar was blended due to corrosion.
- The blended area could not be hand measured, so it was scanned and the damage was modeled in NX.
- The modeled area was then able to be analyzed



Data Acquisition for Reverse Engineering

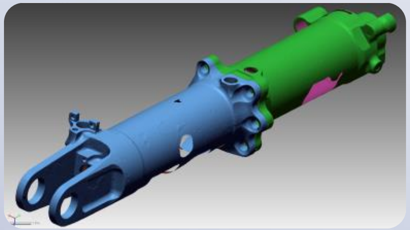
Reverse Engineering

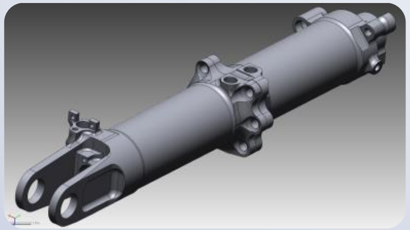
Creating a solid model with limited or no technical data

- Uses the physical part as the nominal
- Can use a combination of scan data and traditional measurement techniques

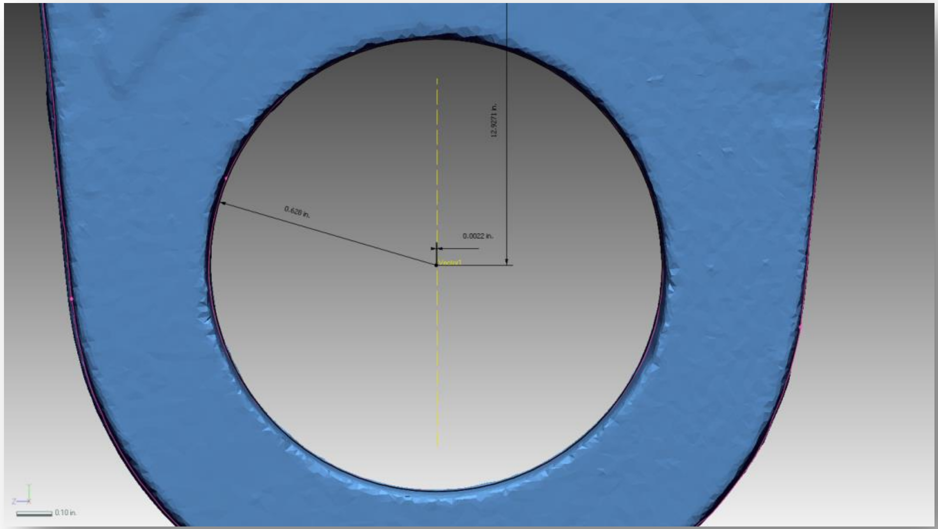
End uses include, but are not limited to:

- Manufacturing (non-critical)
- Finite Element Analysis
- Technical data creation
- Job Performance Aids
- Inspection models
- Custom fittings and tooling
- Artisan aids
- Support equipment





Possible Issue:
Design Intent vs Scan Data



Best-fit circle
Radius: 6.2798”
X: -0.0022”
Y: 12.9271”

Design Intent?

CAD circle
Radius: 6.28”
X: 0.0”
Y: 12.925”

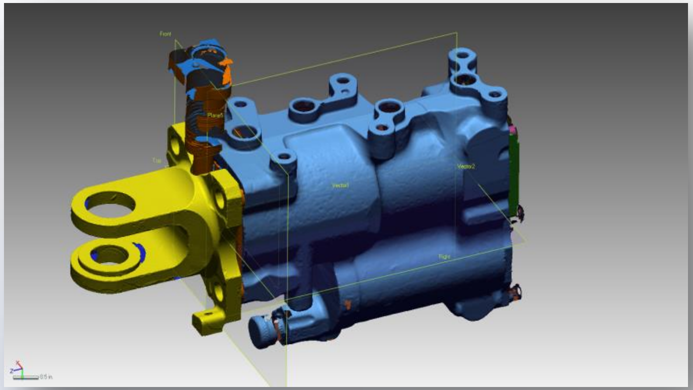
Reverse Engineering

Task: Create a solid model of a servocylinder assembly

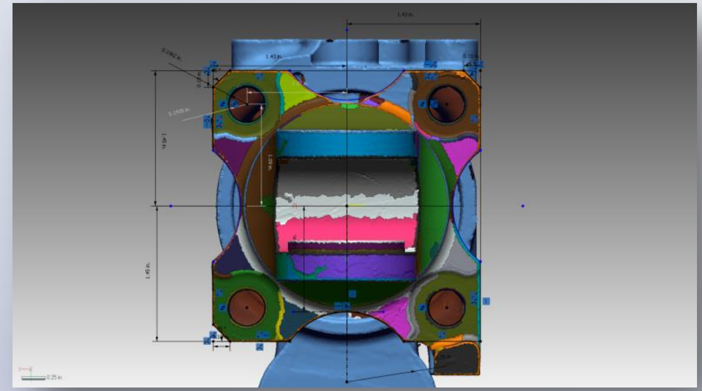
Existing Technical Data: none

Intended Use: FEA

Tools Used: PCMM, micrometer, gage pins

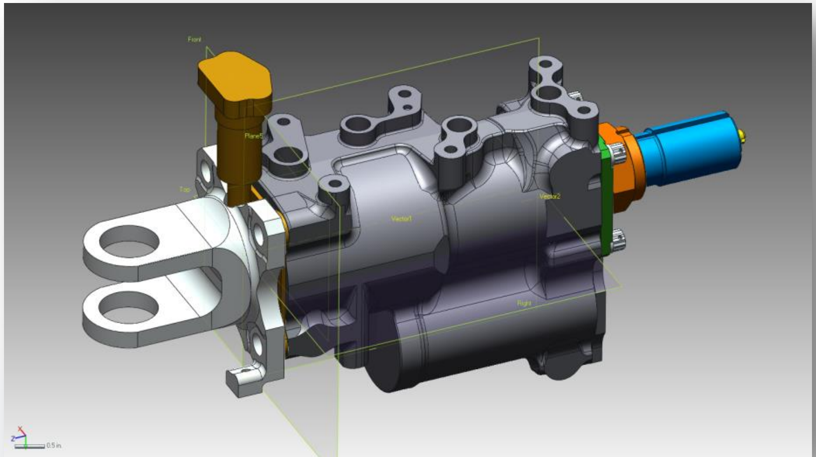


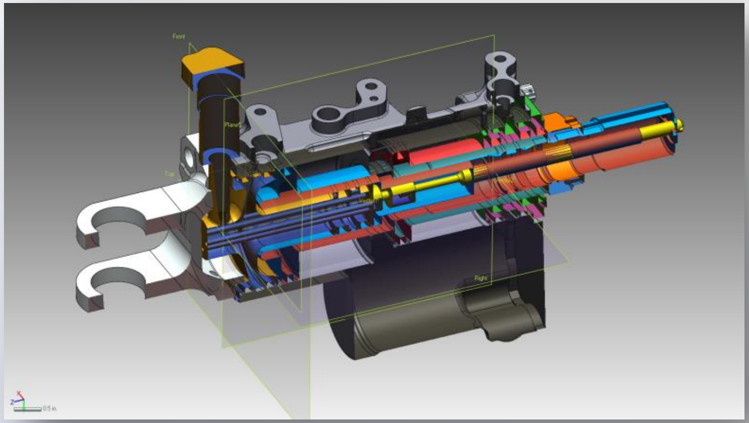
Scan assembly and fit the data to a coordinate system



Model using the scan data, one feature at a time

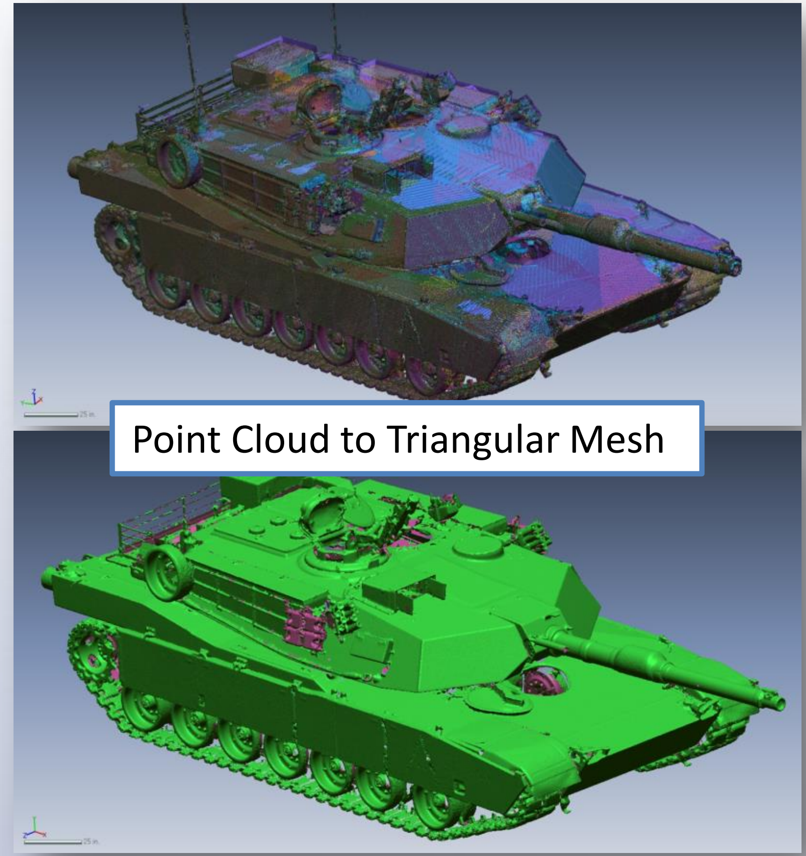
Assemble CAD models





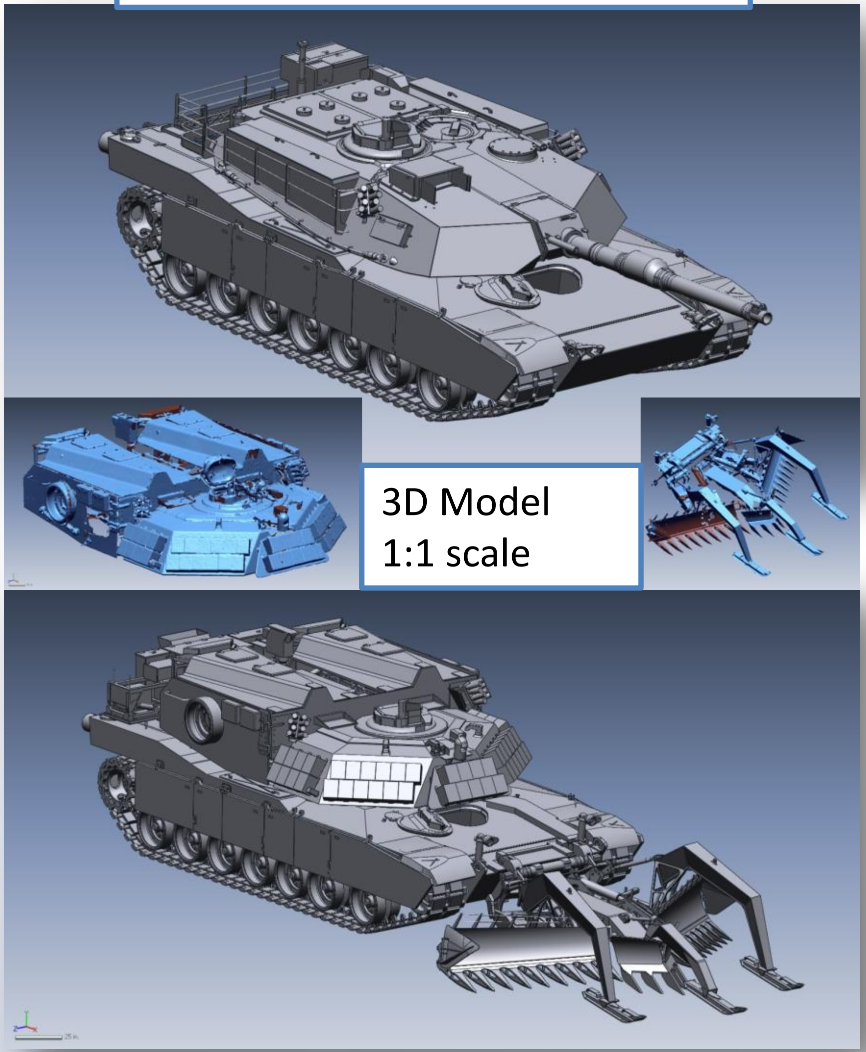
Reverse Engineering

Task: Create a solid model of an Abrams tank
Existing Technical Data: none
Intended Use: radar signature analysis
Tool Used: hemispherical laser scanner



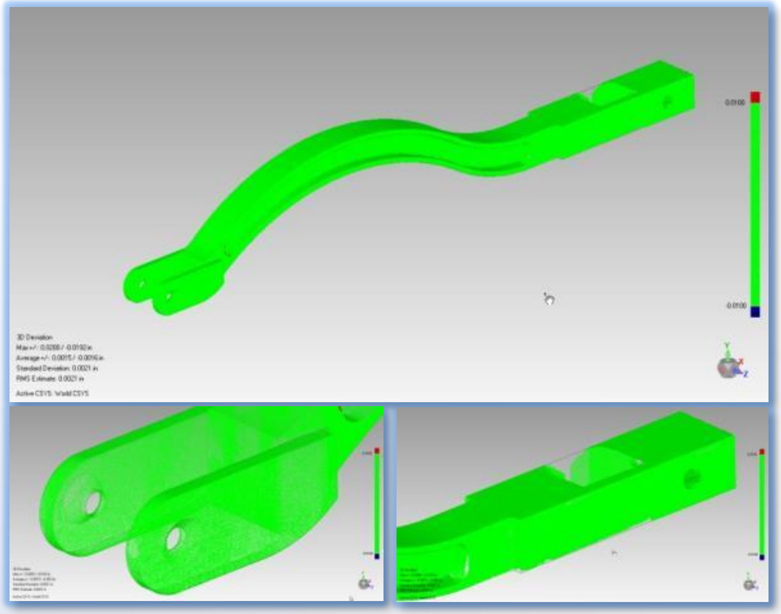
Point Cloud to Triangular Mesh

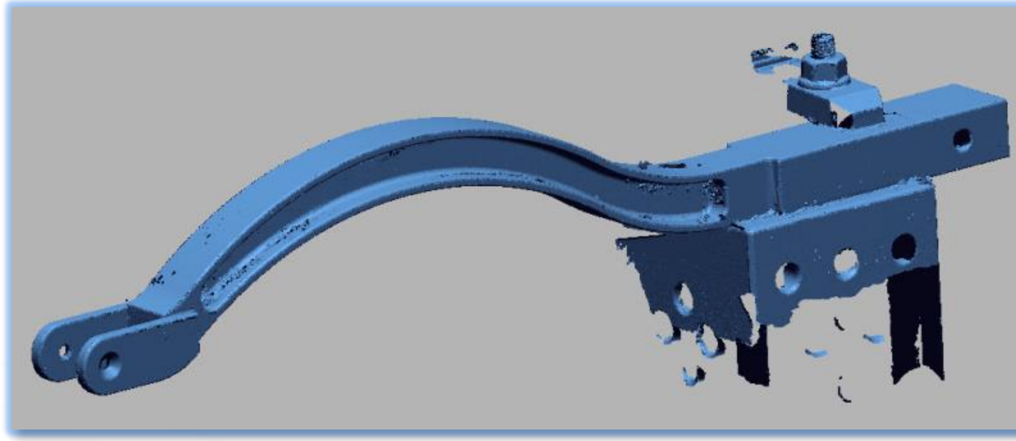
Mesh used as guide to help model

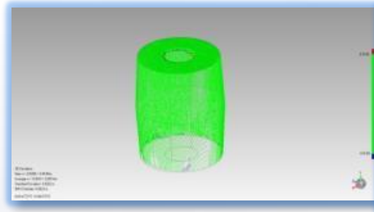


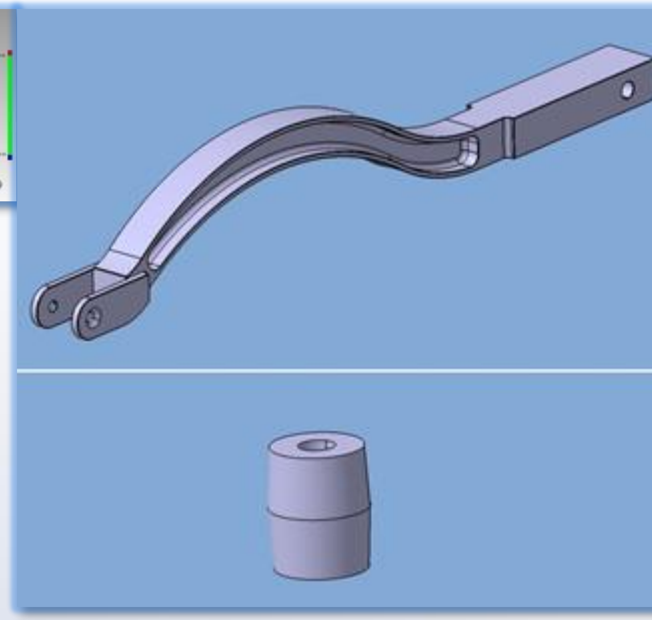
3D Model
1:1 scale

Reverse Engineering



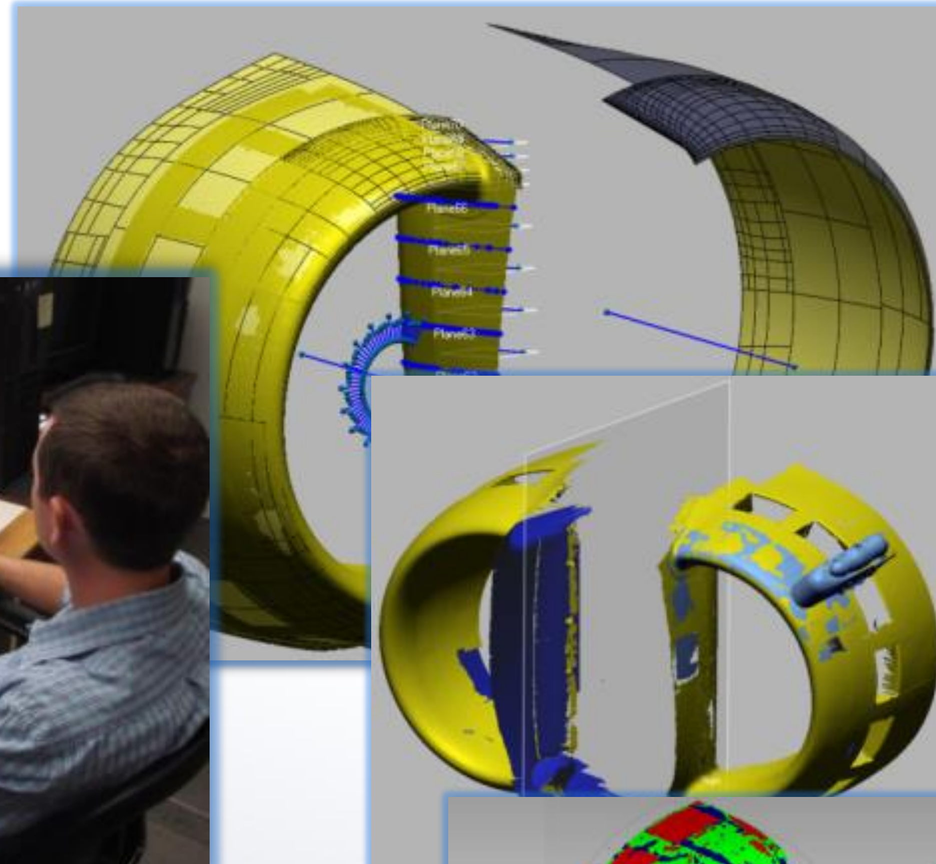


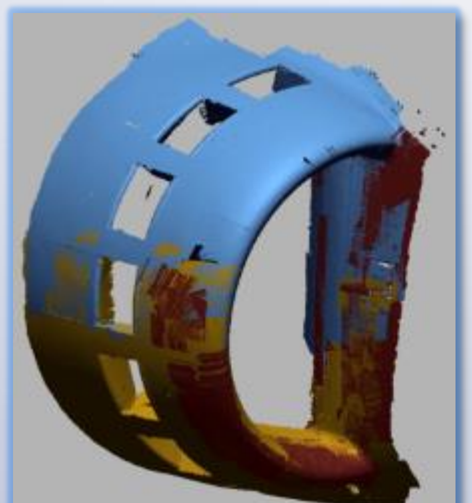


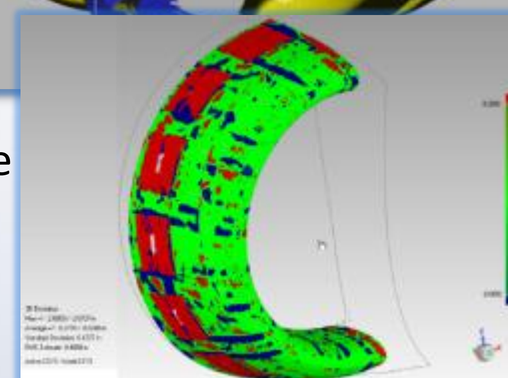


FRCE Digital Data Center was contacted to produce a solid model from a demo assembly of a door brace tool. Using a FARO Edge Arm and a FARO Laser Line Probe, raw point cloud data was collected into Geomagic Design X from the disassembled parts. The point clouds were cleaned and processed into planes, wireframe sketches, and reference surface bodies. This information was imported into CATIA and used to create a solid model for each of the components of the assembly. For downstream ease-of-use, planar features and common shapes were used to best approximate the disparate surface and wireframe bodies from Design X. The resulting solid bodies were compared to the original point cloud data using Geomagic Control to ensure minimum deviation between the final product and initial data.

Reverse Engineering



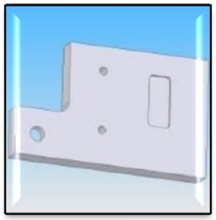




Task: Create a surface model of an AV-8 Intake
Existing Technical Data: Poor quality drawings
Intended Use: Intake cover design data
Tool Used: Faro Scanarm

Direct Digital Manufacturing

CNC Manufacturing

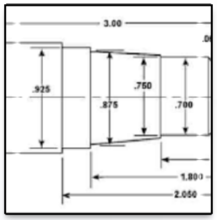


Category 1: Simplistic

Manually milled or turned simplistic features such as holes, bores, simple cuts, etc.

Category 2: Fairly Simple

Lathe parts not requiring C-axis capability and similar processes for straight bushings, hat bushings, shafts, etc.

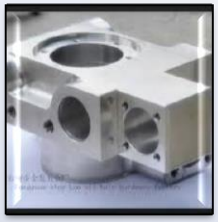


Category 3: Moderately Complex

3-axis milled parts, C-axis lathe parts, parts requiring multiple setups, intricate internal cuts, millings/engravings, etc.

Category 4: Complex

4-axis CNC milled parts with multiple arcs, curves, internal features, etc. that are difficult to measure. Requires rotation and/or closed angles.



Category 5: Highly Complex

5(+)-axis CNC milled parts with complex lofted surfaces and complex datum definitions. Free shapes, swarfs, compound angles, closed pockets.

Composite Manufacturing

Oak Ridge National Laboratory

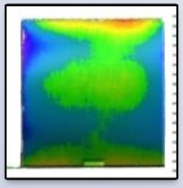
CINCINNATI®
CINCINNATI INCORPORATED
BAAMCI™
BIG AREA ADDITIVE MANUFACTURING™

THERMWOOD
First in CNC Routers
LSAM
Large Scale Additive Manufacturing

TECHMER PM
POLYMER MODIFIERS
TECHMER ES
ENGINEERED SOLUTIONS

BASF
We create chemistry

BOEING



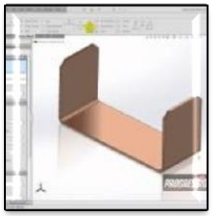
Sheet Metal Manufacturing

Category 1: Simplistic

Flat parts governed by 2D geometry and material thickness. Washers, tabs, etc.

Category 2: Fairly Simple

Thin, malleable material with no closed angles, tight radii, or tight tolerance band. Box and pan brake, simple form block for machine presses, 6061-O aluminum, etc.

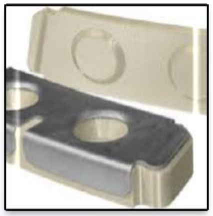


Category 3: Moderately Complex

Medium thickness, relatively malleable, closed angles up to 100 degrees, moderately tight radii, compound bends, medium tolerance. CNC brake, hand bent or machine pressed with block, stainless steel, etc.

Category 4: Complex

Hydro-formed with limited additional features such as joggles, closed angles over 100 degrees, and tight radii. Fairly thick, non-malleable. Small tolerance band. Requires multiple form blocks, return flange, titanium, CNC bent pneudraulic tubing, etc.



Category 5: Highly Complex

Hydro-formed sheet metal components with multiple complex features as listed in Category 4, as well as additions such as stiffening beads, lightening holes, etc. Composite tooling and Additively Manufactured tooling

34

Additive Manufacturing

Sheet Metal Tooling

Form Blocks for hydroforming presses, FDM Polycarbonate, TRL 9

Form-Fit-Function/ Rapid Prototyping

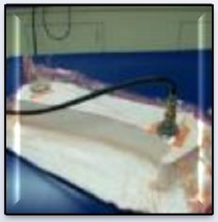
Model Verification, Fit-Up in Aircraft, FDM PC & ABS, TRL 9

Shop Tooling

Guides, Jigs, Fixtures, Work Aids, Visualization Aids, Chemical milling templates, FDM PC & ABS, TRL 9

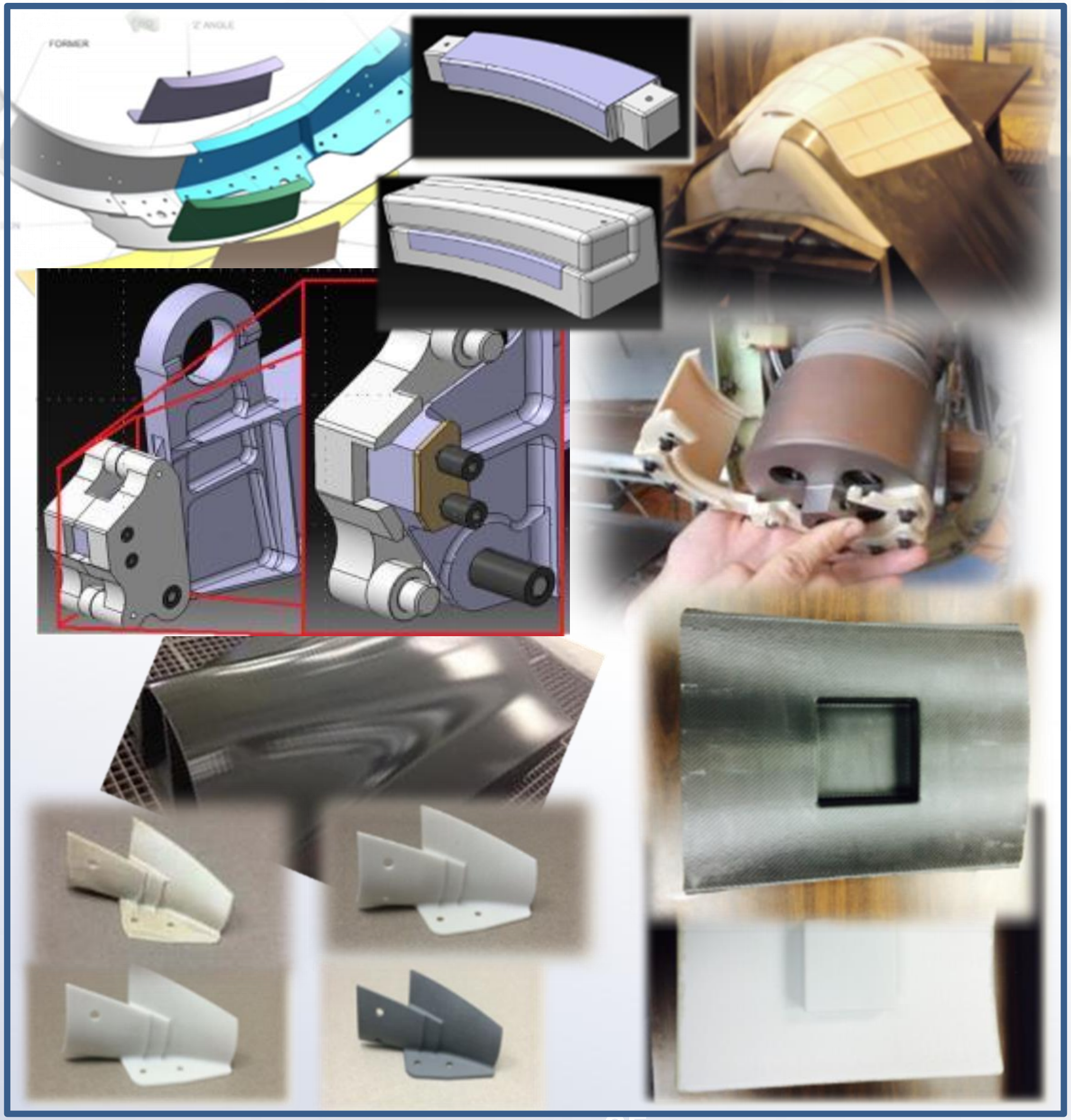
Composite Tooling

R&D Work - CTE of AM Materials, PFP Reversal Tools, FDM & BAAM System, PPSF / In Autoclave, TRL 6-7



On-Aircraft End-Use Parts

NON CRITICAL PARTS.: Near Term Work in Progress, FDM or SLS, TRL 6-7 FLIGHT CRITICAL PARTS: NAVAIR AM Demonstration Project, Longer Term: EOS Metal Powder Bed, TRL 1-6 (depending on process and material)



Direct Digital Manufacturing

Focus: Additive Manufacturing

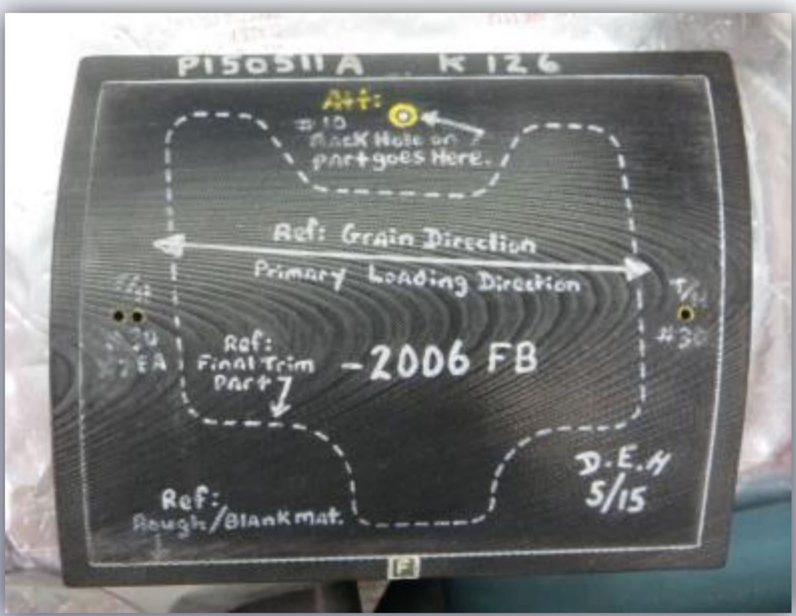
Additive Manufacturing

Synergizes well with laser scanning, providing a rapid, cost-effective way to manufacture custom, complex, organically shaped parts, and support equipment using little or no technical data

Department	Activity	Activity	Location	State	Company	Model	Process	Materials
DoD	NAVAIR	FRC East	MCAS Cherry Point	NC	Stratasys	Fortus 900mc	Fused Deposition Modeling	ABS, PC, Ultem, PPSF
DoD	NAVAIR	FRC East	MCAS Cherry Point	NC	Stratasys	Dimension SST	Fused Deposition Modeling	ABS
DoD	NAVAIR	FRC East	MCAS Cherry Point	NC	Stratasys	Fortus 400mc	Fused Deposition Modeling	ABS, PC, Ultem, PPSF
DoD	NAVAIR	FRC Southeast	NAS Jacksonville	FL	Z-Corp	Spectrum Z510	Jetted Binder	Zp150 Powder, Zb60 Binder
DoD	NAVAIR	FRC Southeast	NAS Jacksonville	FL	Stratasys	Fortus 400mc and 450	Fused Deposition Modeling	ABS, PC, Ultem, PPSF, ABS-M30
DoD	NAVAIR	FRC Southeast	NAS Jacksonville	FL	Stratasys	Fortus 900mc	Fused Deposition Modeling	Ultem 9085, Nylon
DoD	NAVAIR	FRC Southeast	NAS Jacksonville	FL	Keystone	Modified Sciaky	Electron Beam	Metals (multiple)
DoD	NAVAIR	FRC Southeast	NAS Jacksonville	FL	Stratasys	Uprint SE	Fused Deposition Modeling	ABS
DoD	NAVAIR	FRC Southwest	NAS North Island	CA	3D Systems	iPro 8000	StereoLithography	Accura 25
DoD	NAVAIR	FRC Southwest	NAS North Island	CA	3D Systems	sPro 60 HD	Selective Laser Sintering	Duraform PA
DoD	NAVAIR	FRC Southwest	NAS North Island	CA	Stratasys	Dimension SST	Fused Deposition Modeling	ABS
DoD	NAVAIR	FRC Southwest	NAS North Island	CA	Stratasys	Fortus 400mc	Fused Deposition Modeling	Ultem, PC, PC-ABS, ABS-M30

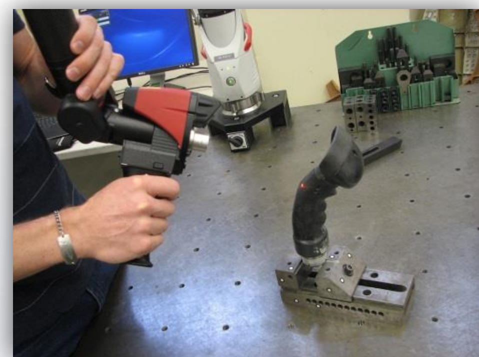
F-18 3D Printed Tooling

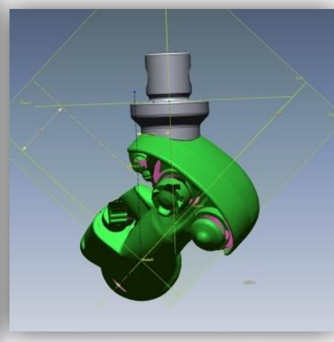
- All required tooling including the form block, chem. mill trim template, and check templates were created on the Fortus 400mc.
- New tooling can be printed quickly when the existing tooling is damaged now that the design has been verified.
- The combination of the 3D printer and chemical milling allows the brackets to be manufactured correctly and without defects.



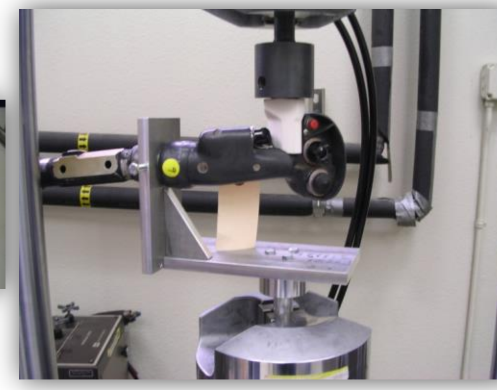
Additive Manufacturing

Combining AM with laser scanning and reverse engineering

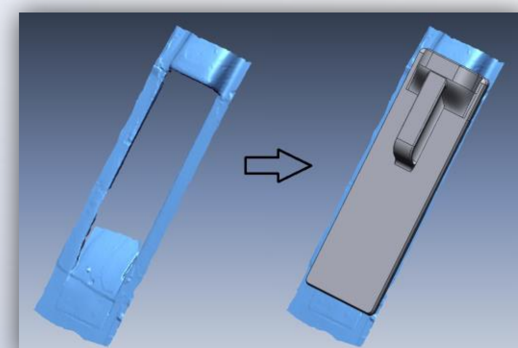




Engineering Investigation Test Apparatus Parts



Laser Scanning → Solid Modeling → 3D Printing



Aircraft Masking for PMB

Additive Manufacturing

Problem:

Unable to mate a custom drill to an OTS holding apparatus.

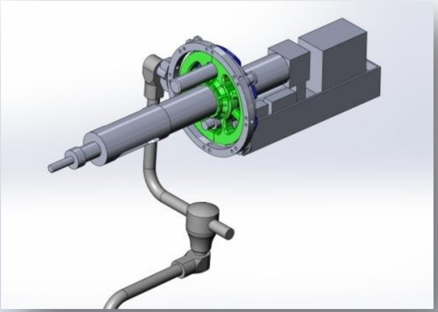
Solution:

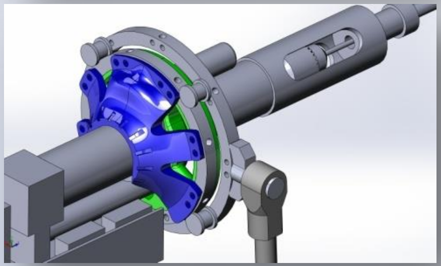
Laser scan the drill and the apparatus and design a fixture.

End-use 3D printed parts were delivered in 4 business days.

Benefits of AM vs Traditional MFG:

- Rapid solution delivery
- Low cost
- Design freedom





EEC Holding Fixture

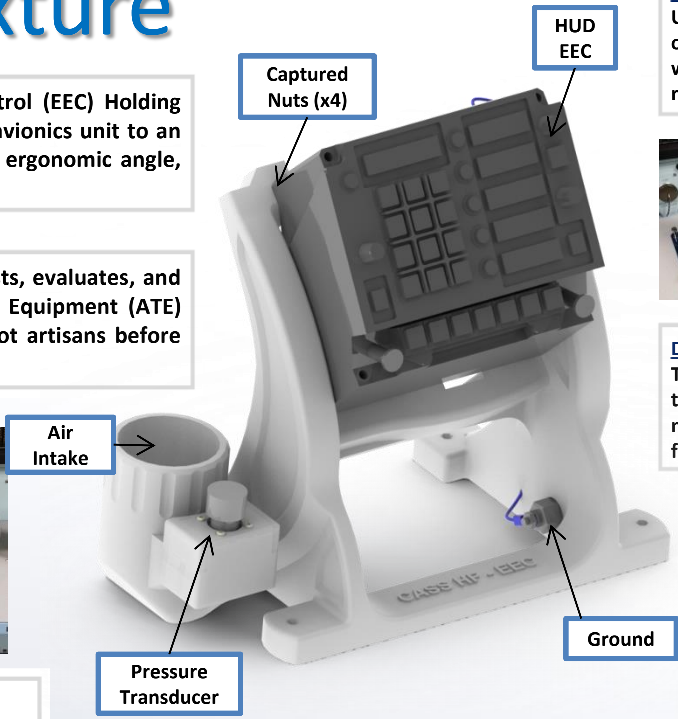
What Is It?

The Heads Up Display (HUD) Electronic Equipment Control (EEC) Holding Fixture is a piece of support equipment that secures an avionics unit to an avionics test bench. It is designed to hold the EEC at an ergonomic angle, provide airflow to its internals, and electrically ground it.

Who Uses It?

The CASS TPS Development Team designs, integrates, tests, evaluates, and supports the production and fielding of Automatic Test Equipment (ATE) hardware and software used by the warfighter and depot artisans before turning it over to the respective FST for ISE support.

Image courtesy of Guy Newton

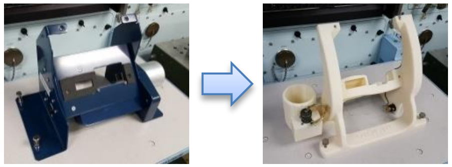


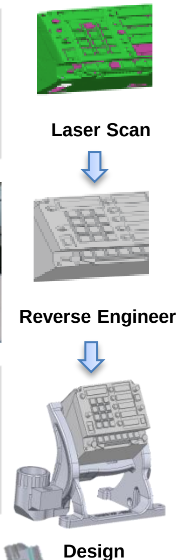
Consolidated Automated Support System (CASS)

Provides electrical inputs into the avionics under test and evaluates the responses for a pass or fail condition

Reverse Engineering Process

Using laser scan data of the EEC and 2D prints of the existing fixture, an enhanced version was designed that is optimized for 3D printing rather than traditional manufacturing.



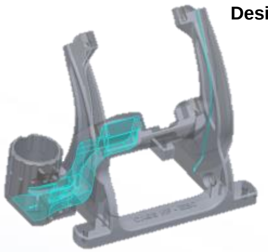


Design for Additive Manufacturing

The fixture was designed to minimize build time by removing the necessity for support material wherever possible. This design also focused on reducing assembly part count.

Image courtesy of Stratasys

Stratasys Fortus 400MC
Fused Deposition Modeling
Material: ABS-M30



Internal passages that don't require support material

Business Case

- Reduced development time through rapid design/prototype/test cycles
- Reduced logistics costs due to production on demand capability
- Significantly reduced production cost and schedule due to manufacturing simplification

	Traditional Manufacturing	Additive Manufacturing	Savings
Development Time (NRE)			
- Calendar (Months)	24	1	23 Months
- Labor (Hours)	1000	56	944 Hours
Labor Cost	$100,000 (avg. $100/hr)	$4200 ($75/hr)	$96K
Production Costs	$60K (3 prototypes, 2 FAT)	$1000 (1 prototype, 1 FAT)	$59K
Production Schedule	180 Days (all prototypes)	2 Days	178 Days
Replacement Cost (/part)	$15K-$50K (est.)	$500	$15K-$50K (est.)
Replacement Schedule	1-2 Years (est.)	2-7 Days	1-2 Years

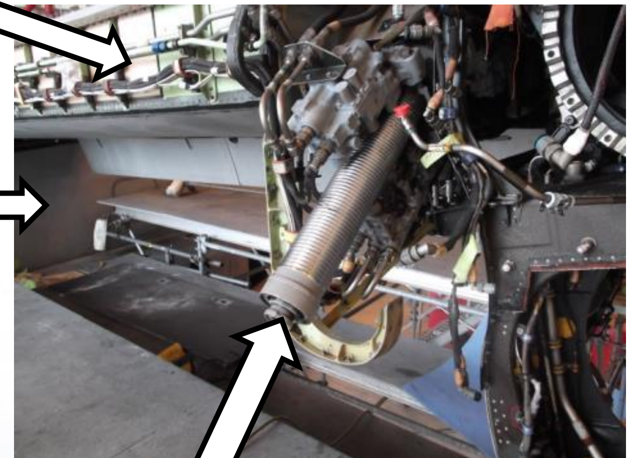
Project Future

- This proof of concept is a significant step forward in the adoption of additive manufacturing by our CASS Development Team.
- The goal is for future designs to fully utilize Design for AM concepts and AM technologies for production.

V-22 Support Equipment

Wing

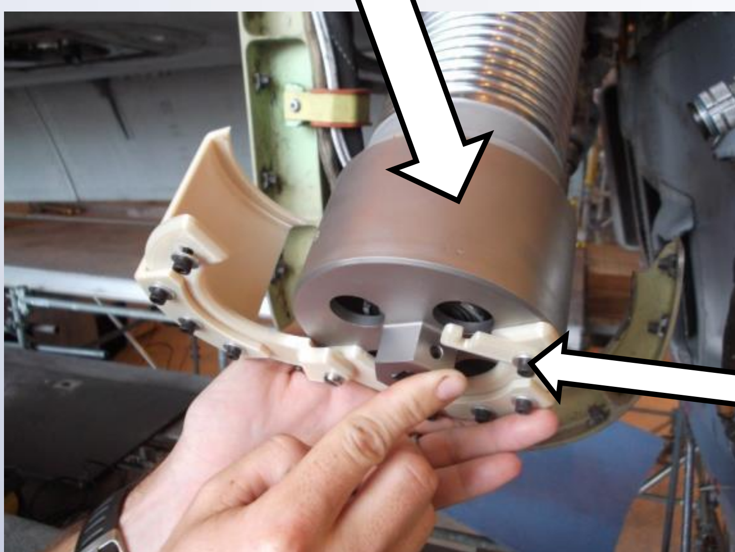
Fuselage



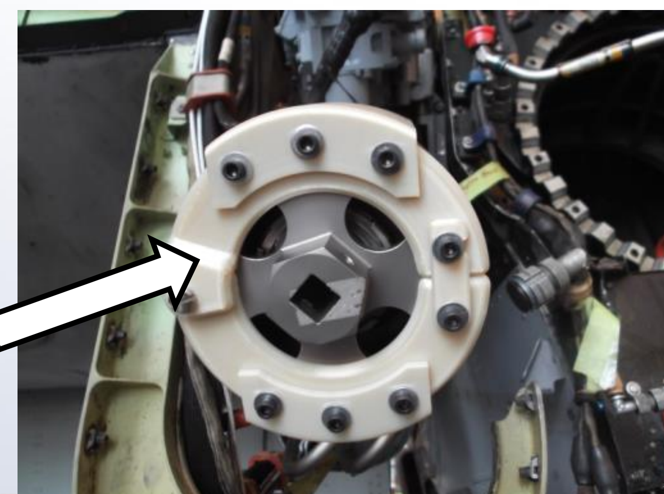
Nacelle

Tilt-Axis actuation screw

Socket to manually rotate nacelle while in hangar. Not captive – tends to slip off



Socket Retention Tool



Large Stretch Press Die

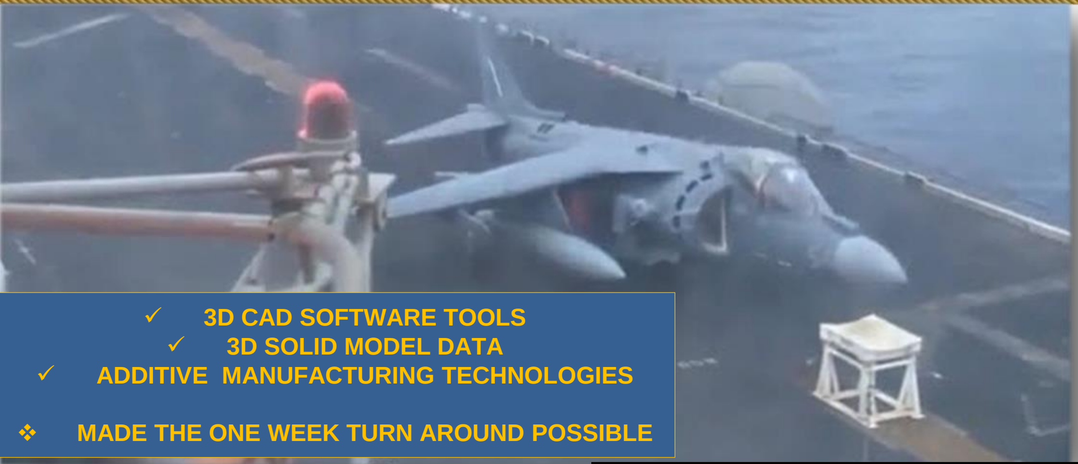
What Is It?

Large scale sheet metal forming die for use in the stretch forming press. Tools for this process are traditionally sand cast from molten Kirksite, a Zinc/Aluminum alloy. This tool is a ¼" thick polycarbonate shell which has been back-filled with plaster.

Who Uses It?

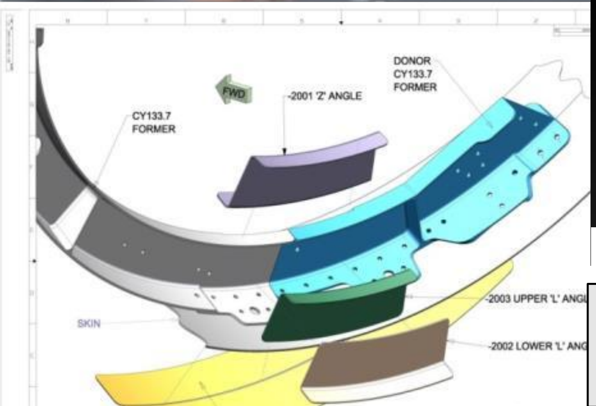
Depot Artisans known as Pattern Makers digitally design, additively manufacture, and traditionally use these types of tools.

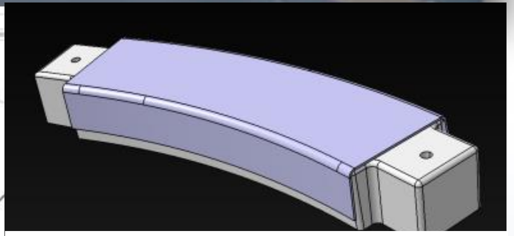
Additive Manufacturing



✓ 3D CAD SOFTWARE TOOLS
✓ 3D SOLID MODEL DATA
✓ ADDITIVE MANUFACTURING TECHNOLOGIES

❖ MADE THE ONE WEEK TURN AROUND POSSIBLE



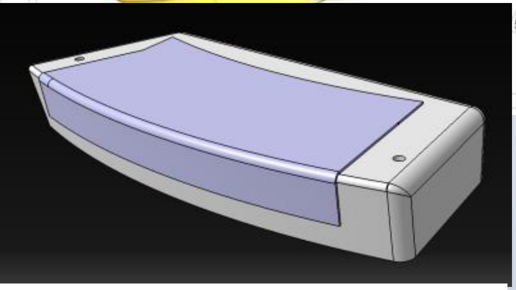


L Angle Block Tool & Part

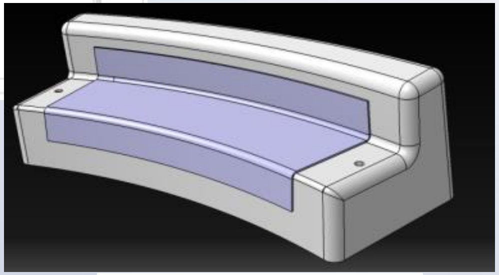
Part Forming
- Form two Channels
- Cut the channels to form L Angle parts
- Polycarbonate, FORTUS 900mc

TIME-LINE

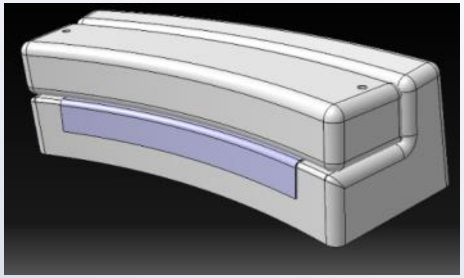
- 07 JUNE 14
  - Loss of Nose Landing Gear
  - Controlled Hard Landing
- 07 – 25 JUNE 14
  - Damage Assessment & Repair Strategy
  - FST Structural Analysis
  - OEM CAD Solid Modeling
- *25 JUNE (Wednesday)*
  - *Receive OEM solid model of damaged frame*
  - *Begin repair & tool design*
- *26 JUNE (Thursday)*
  - *Form block designs complete*
  - *Begin AM builds at ~1700*
- *27 JUNE (Friday)*
  - *Design & produce flat patterns*
  - *AM tool build parts complete*
- 28 JUNE (Saturday)
  - Form C, L & Z doublers using rubber & bladder presses
  - Begin heat treat
- 30 JUNE (Monday)
  - Paint 1st set
  - Manufacture 2nd set backup parts
  - Heat treat 2nd set on second shift
- 01 JULY (Tuesday)
  - Paint 2nd set
- 02 JULY (Wednesday)
  - Deliver finished parts to FST



Z Block Stage 1



Z Block Stage 2



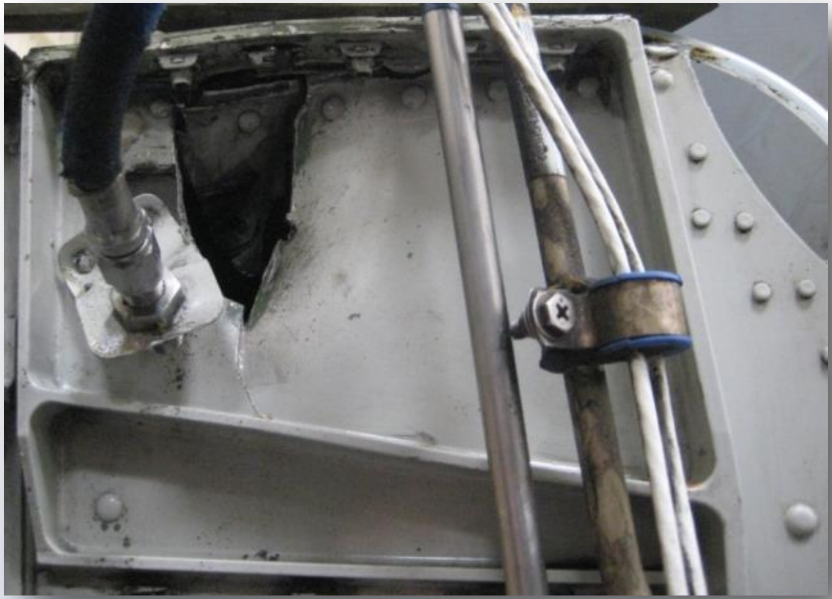
Z Block Stage 2 with Cover

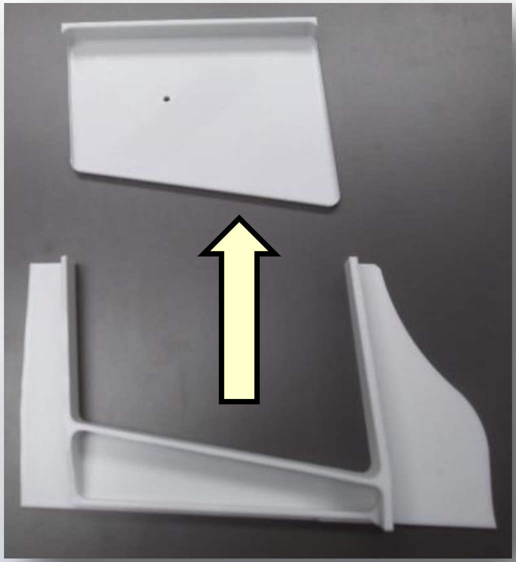
Part Forming Form upper lip using Stage 1 block
- Reverse part and place in Stage 2 block
- Attach cover block
- Form lower lip
- Polycarbonate, FORTUS 400mc

SHOP TOOLING (VISUAL AID)

UH-1Y Bathtub Fitting Repair

- **Rotor Brake failure caused catastrophic damage to web and upper flange**





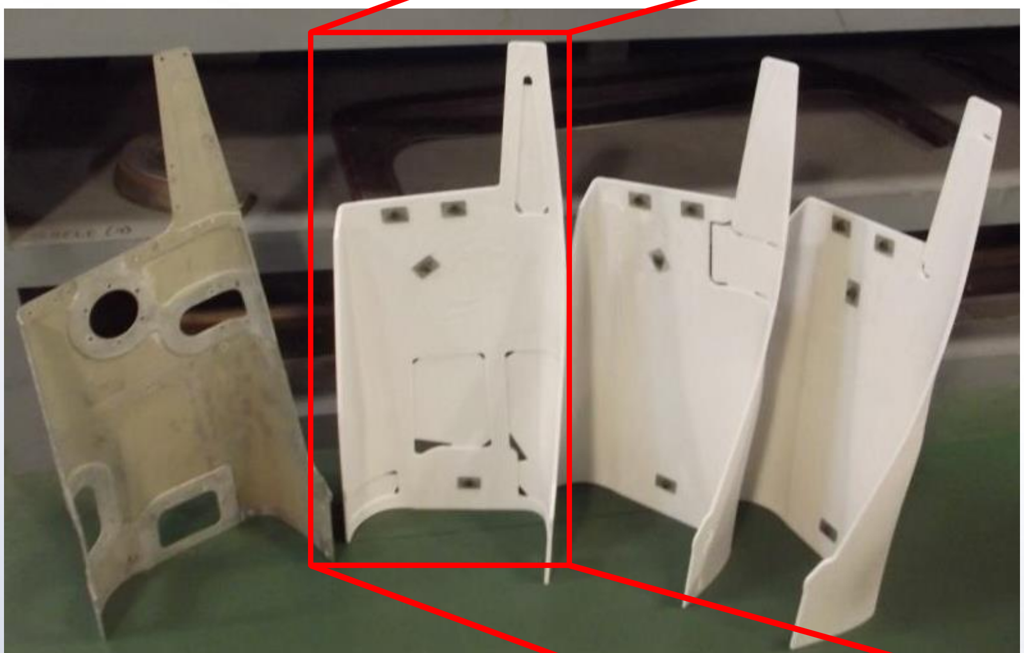
Section to remove

Repair Fitting

Difficult to depict cut lines for material removal Web, upper contoured flange, and fillet radii in pocket must be removed

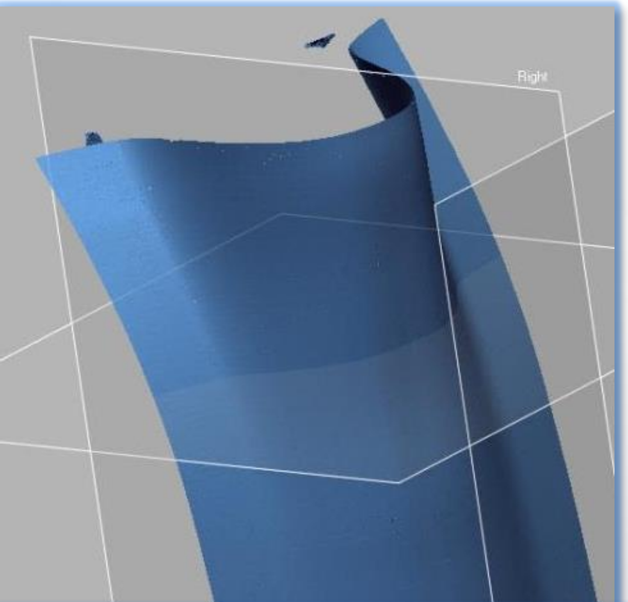
Additive Manufacturing

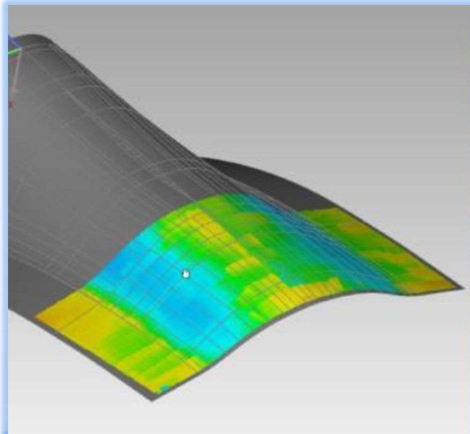
Chemical Milling Template For AV-8 Bullet Fairing Skin

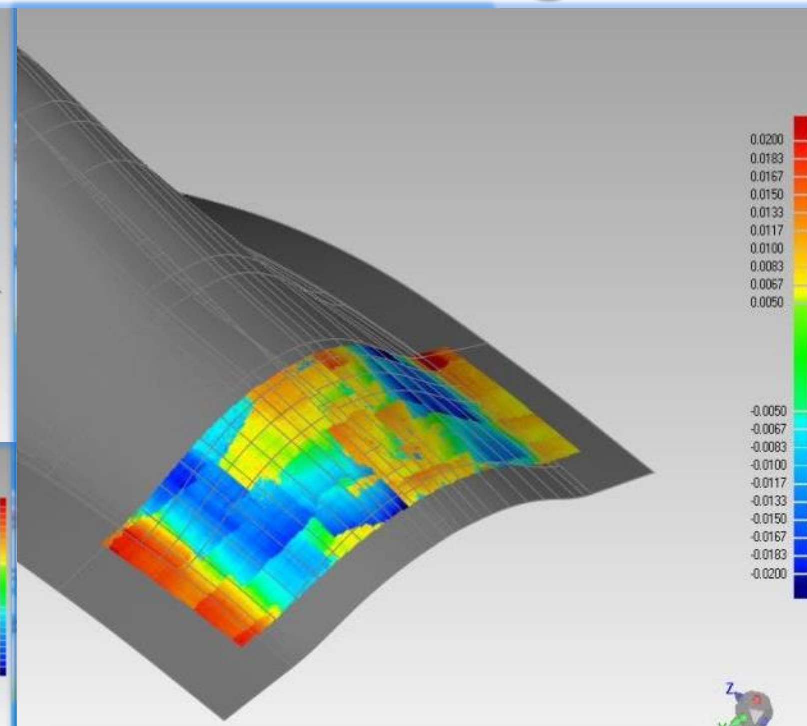


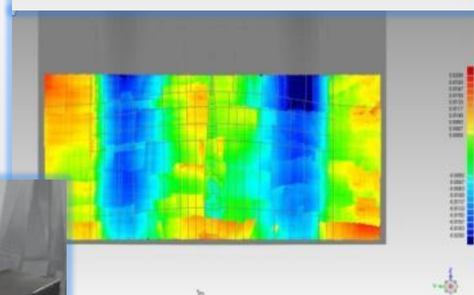
- Pockets were **reverse engineered** with FARO scanner
- Savings of hundreds of man-hours per each unit over traditional, hand layup methods

Medium Scale Polymer Autoclave Tooling Trial



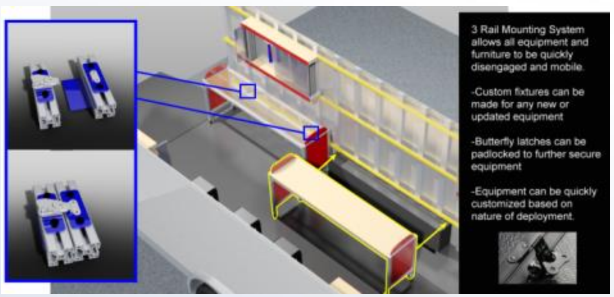


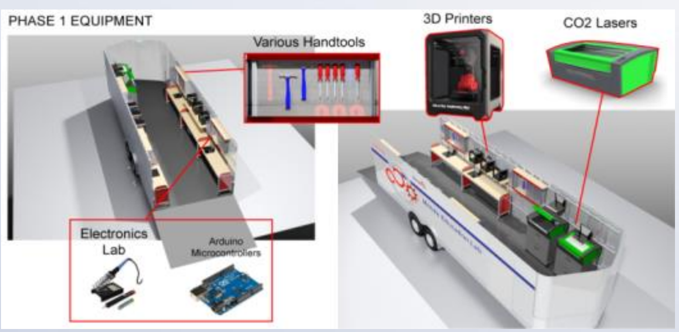




FAB LAB - WHAT IS IT?

- Mobile Lab - A platform to train O & I Level Maintainers, Artisans and others in 3D Design & Digital Manufacturing (Additive & Subtractive)
- Workforce Development
  - **Educate & Engage O & I Level personnel, artisans and others in a risk tolerant setting to use 3D CAD design and digital manufacturing tools (additive & subtractive) to take their own ideas from concept to prototype in support of an improved maintenance and operating environment.**
    - **Bottom-up vs. top-down solutions**
- DARPA (MENTOR) & ONR Funding
- One On-Site Lab (Operational)
  - NAVSEA MARMC, Norfolk, VA
- Three Mobile Labs
  - NAVAIR FRCE, Cherry Point, NC
  - NAVSEA SERMC, Mayport, FL
  - NAVSEA SWRMC, San Diego, CA
- Contractors
  - Bennett Aerospace, Cary, NC (Prime)
  - Tech Shop, San Jose, CA (Sub to build & equip the Mobile Labs and to provide training)





Trailer Details:
- 10 x 35 foot bumper pull Trailer
- Wired for external power 110/240V
- Light fixtures & outlets (surge protected)
- Internal network wiring with external Ethernet jack
- Air Compressor
- Adjustable locking rail system for customizing layout.

Equipment Proposed:
- 10 Laptop PC's (with open source 3D CAD)
- 3D Scanner
- 3 Consumer grade 3D Printers (FDM)
- 2 Table Top CNC Mills
- 1 Laser Cutter & Engraver
- 1 CNC Router
- 1 Bench Mount Drill Press
- 1 Vacuum Former
- Misc. Hand and Power Tools
- Shop Supplies, Spare Parts & Initial Stock of Raw Material

Thank You

Price, R. David

FRCSW Reverse Engineering Lab

Richard.d.price2@navy.mil

(619) 545-6995

Renstrom, Michael

FRCSE F/A-18 Manufacturing Project Lead

michael.renstrom@navy.mil

(904) 790-6251

Reynolds, Justin

FRCE MBD Lead

Justin.d.reynolds@navy.mil

(252) 464-8383