NAVSEA
WARFARE CENTERS
Philadelphia

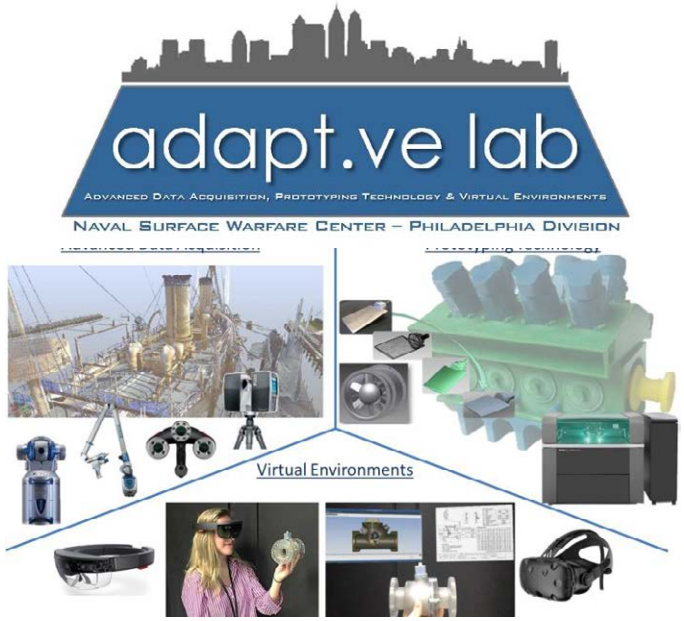
NAVAL SURFACE WARFARE CENTER
PHILADELPHIA DIVISION

Additive Manufacturing Applications at the Naval Surface Warfare Center-Philadelphia Division

Philip Greiner

RAPID 2017

10 May 2017



Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Outline

- NSWCPD Overview
- ADAPT.VE Lab Overview
- NSWCPD AM Applications
  - Biofouling Scanning/Printing
  - Seal Whiskers 3D Printing
  - Rogowski Coil Test Fixture
  - Teletype Cartridge Obsolescence
  - LPD17 Handle
- Summary

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

NSWC Philadelphia Division

- Philadelphia Warfare Center has a central focus on Naval Machinery
- Develop superior technical products and expertise by capitalizing on NSWCPD's multiple laboratories and full-scale test sites
- Vision: Shape the Navy's future by continuously expanding machinery systems and advantages through technical dominance.

"Powering Today's Fleet, Innovating Tomorrow's"

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

ADAPT.VE Lab

- Advanced Data Acquisition

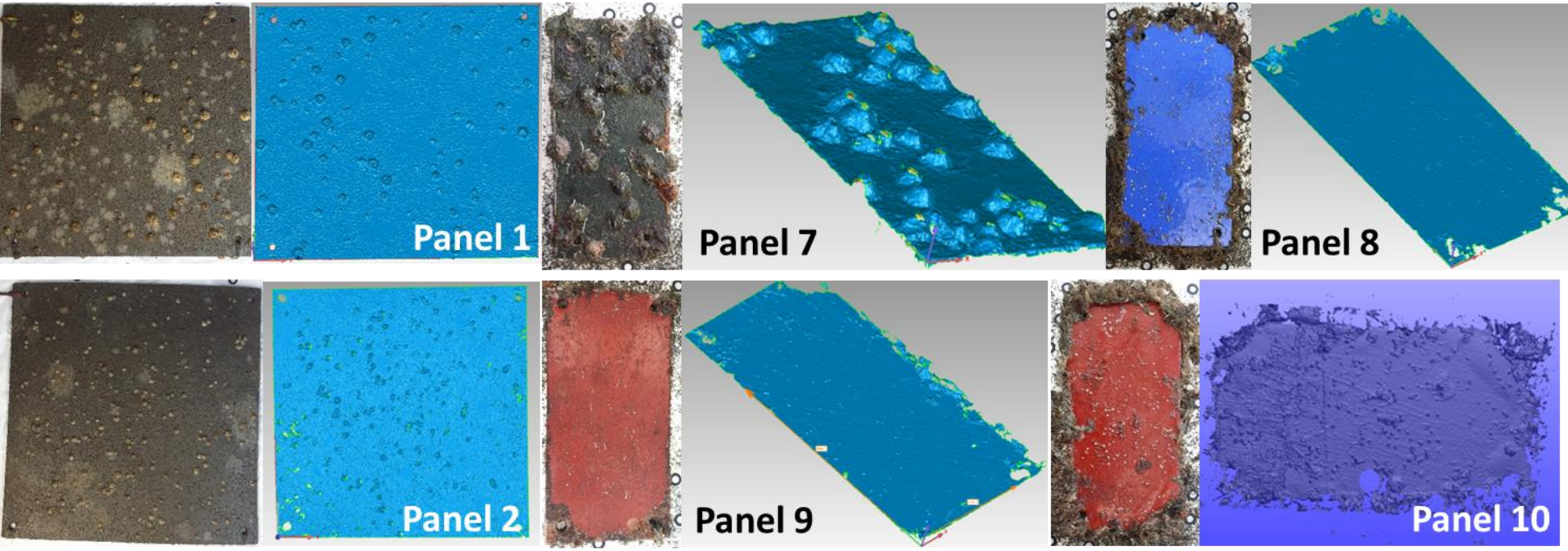
- Prototyping Technology

- Virtual Environments

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Biofouling

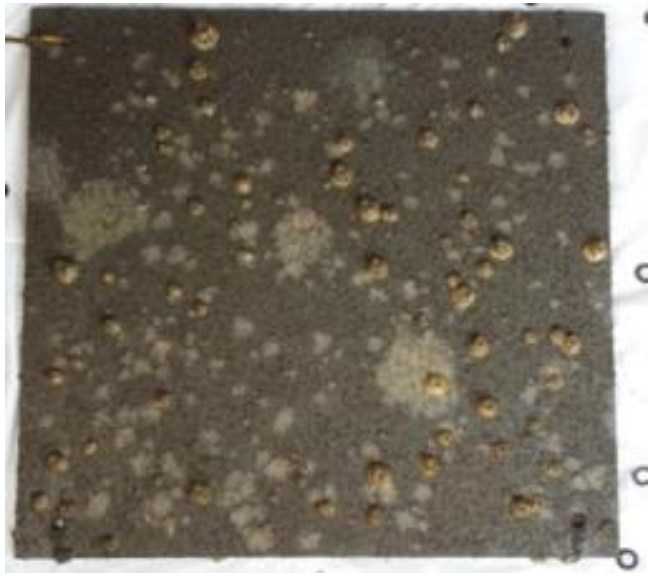


- Laser scan biofouled panels to capture geometries of biofouling organisms to quantify roughness characteristics and to 3D print panels for hydrodynamic testing

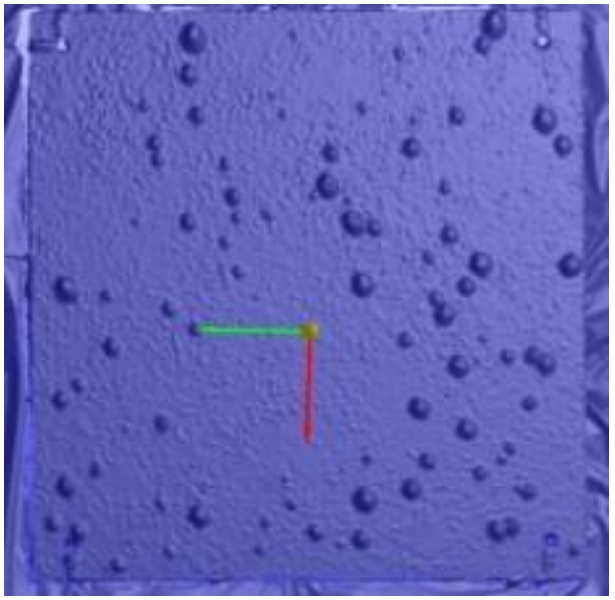
Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

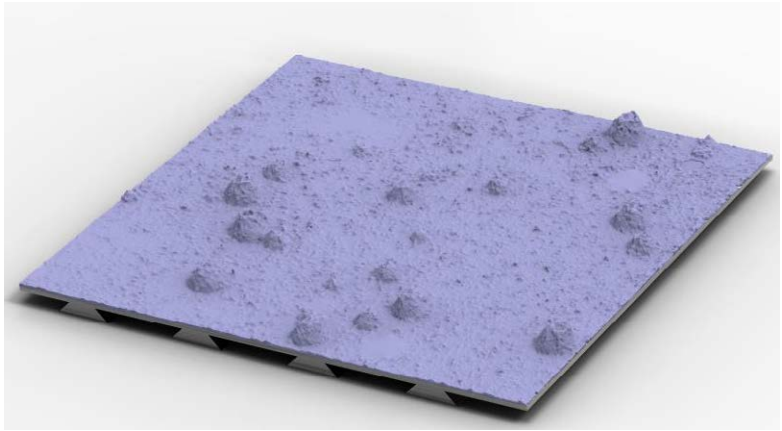
Biofouling 3D Printing



1. Biofouling panel representing ship hull. Barnacles, encrusting bryozoan, and biofilm among biofouling organisms present.



2. Biofouling panel scan data captured using the Creaform MAXScan



3. 3D Model created from scan data and combined with a dovetail 3D model for 3D printing.

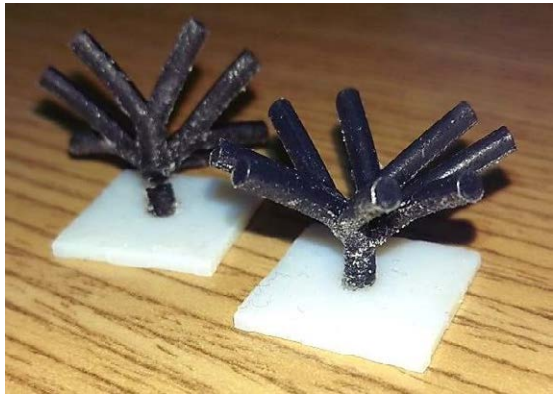
4. 3D Printed on Objet350 Connex3 for use in channel flow test chamber

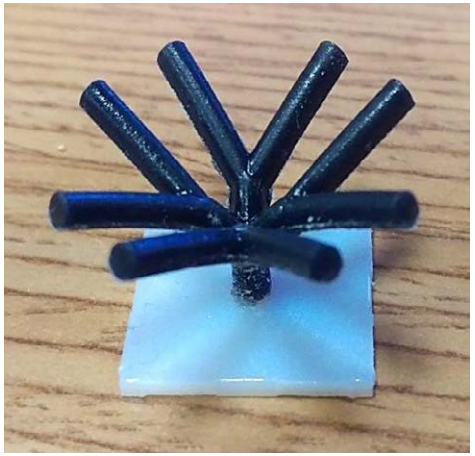
Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Biofouling Future Work

- Investigate ability to print soft fouling on the Objet350 Connex3 to mimic deflection characteristics in moving water
- 3D Print fouling rating ‘cheat sheets’ for Navy Divers to assist in assessment of fouling intensity on ship hulls





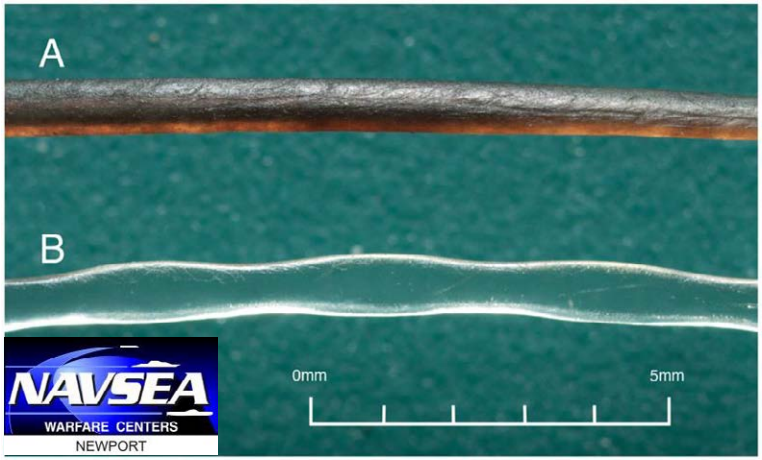
Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Seal Whiskers

- Proposal: Use whiskers as a sensory receptor for underwater detection of objects.
- 3D print representative seal whiskers using varying combinations of flexible and rigid materials to best mimic actual seal whiskers characteristics in water.

Live Seal Whisker Array



Close-up of a Sea Lion (top) and Seal (bottom) Whisker

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Seal Whiskers 3D Printing

- Objet350 Connex3 3D printer used to print varying flexibility
- Whiskers are a combination of TangoBlack+ and VeroWhitePlus
- NUWC NWPT determined 60-100% rigidity may best mimic real seal whisker—testing is underway

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Seal Whiskers Future Work

- Design for AM will enhance seal whiskers' interface with sensory equipment
- Scanning of a seal head will determine the whisker array

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Rogowski Coil Test Fixture

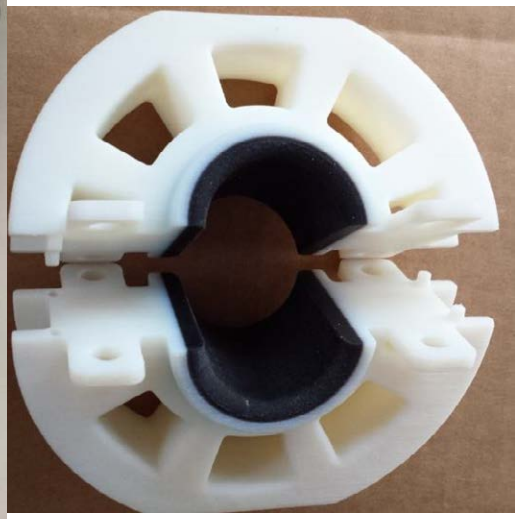
- Electromagnetic field test requires a Rogowski coil sensor to sit concentric to the cable whose EM field it is reading
- Fixture needed within a 2 week turnaround time, making procurement of a fixture or tooling impossible

Distribution Statement A. Distribution unlimited. Approved for Public Release.

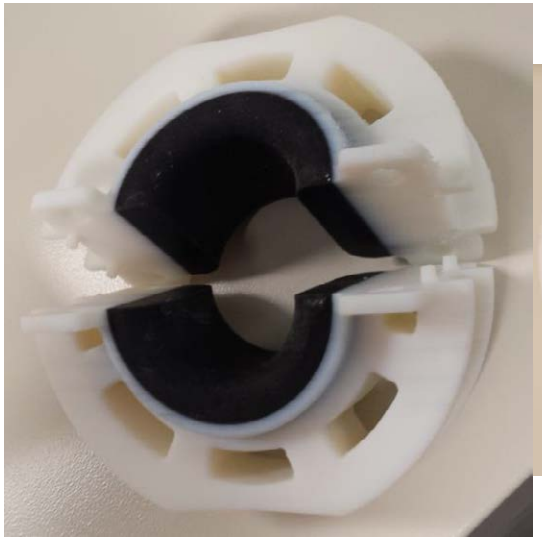
Rogowski Coil Test Fixture

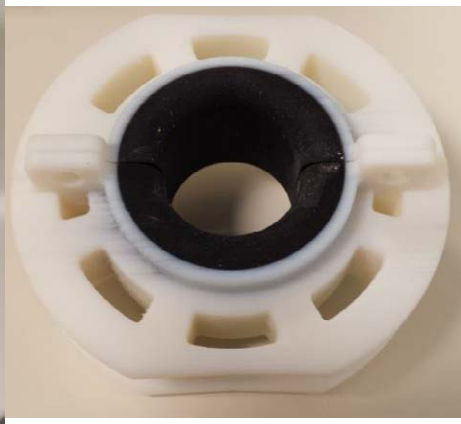
- Two-piece design created in-house in 2 days
- Compression fit desired at interface between fixture and cable
  - Objet350 Connex3 flexible material capability enabled compression fit without risking damage to the high voltage cable
- Design was iterated 3 times to optimize the compression fit

First design iteration.



Second design iteration.





Final Design

Distribution Statement A. Distribution unlimited. Approved for Public Release.

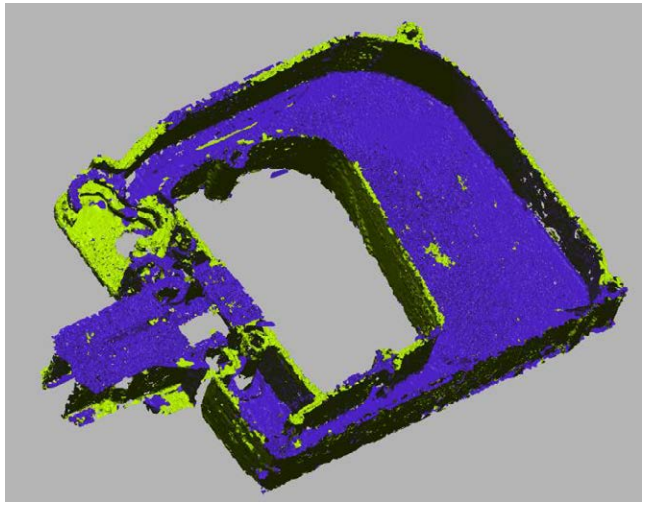
NAVSEA
WARFARE CENTERS
Philadelphia

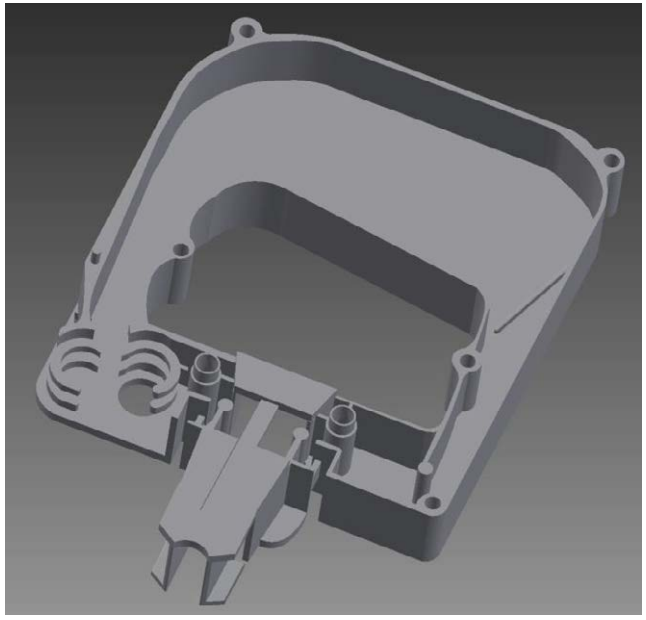
Teletype Cartridge

- Obsolete Teletype Cartridge with no supporting documentation had OEM unable to reproduce
- Exhausted most of reserves and need new cartridges to support the Fleet

Distribution Statement A. Distribution unlimited. Approved for Public Release.

Teletype Cartridge Reverse Engineering



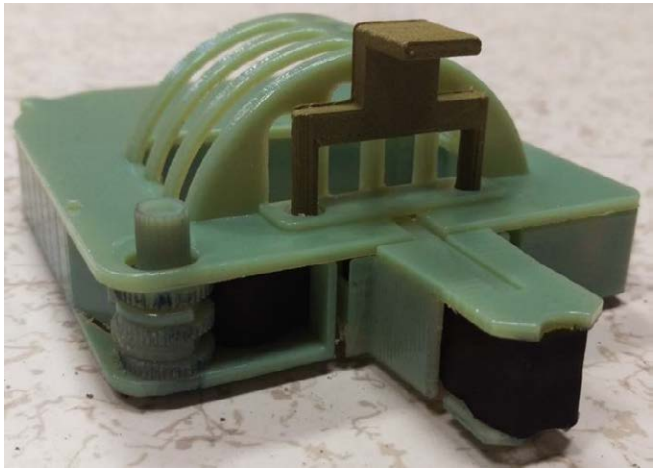


- Laser scan teletype cartridge to create 3D model
  - Equipment used: Faro Edge Arm with ScanArm attachment
- All five pieces laser scanned and 3D modeled in Geomagic® Design X™ to import into 3D printer

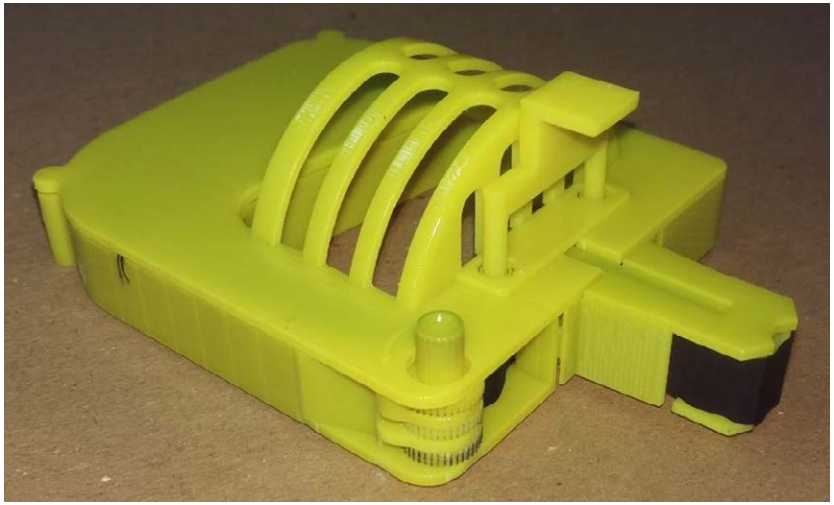
Distribution Statement A. Distribution unlimited. Approved for Public Release.

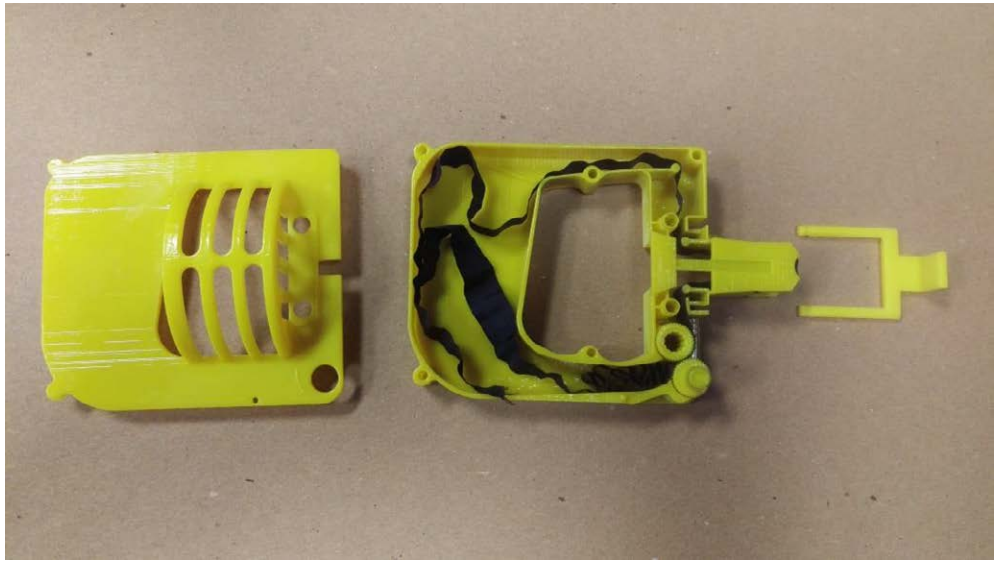
NAVSEA
WARFARE CENTERS
Philadelphia

Teletype Cartridge 3D Printing



First iteration of teletype cartridge printed on the Objet350 Connex3 with additional components printed on the LulzBot Taz 6





Final version of teletype cartridge printed entirely on the Objet350 Connex3 due to the fidelity requirements of various pieces

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

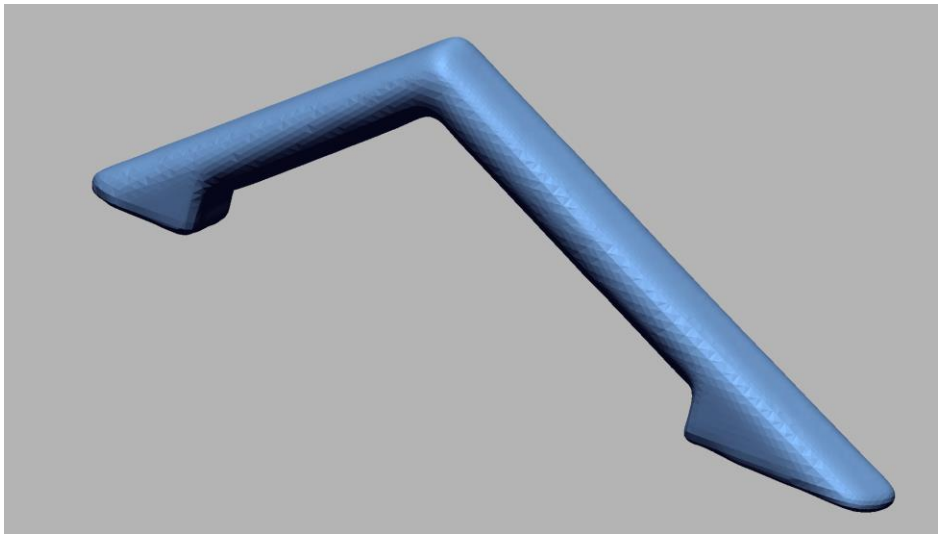
LPD17 Handle

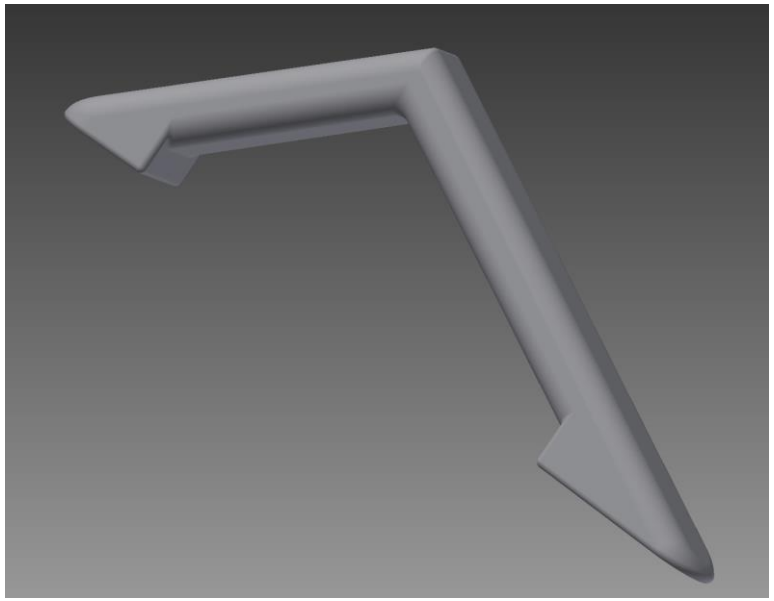
- LPD17 electrical panel handle is a common failure point
- Handle is not being used as intended during the original design– sailors are using it for support to enter/exit a nearby access hatch
- Individual handle procurement is not possible without buying the entire electrical panel

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

LPD17 Handle Reverse Engineering





- LPD17 Handle was laser scanned to develop the 3D model
  - Equipment Used: Faro Edge Arm with ScanArm attachment
- Laser scans post-processed in Geomagic® Design X™ and saved as an STL for 3D printing.

Distribution Statement A. Distribution unlimited. Approved for Public Release.

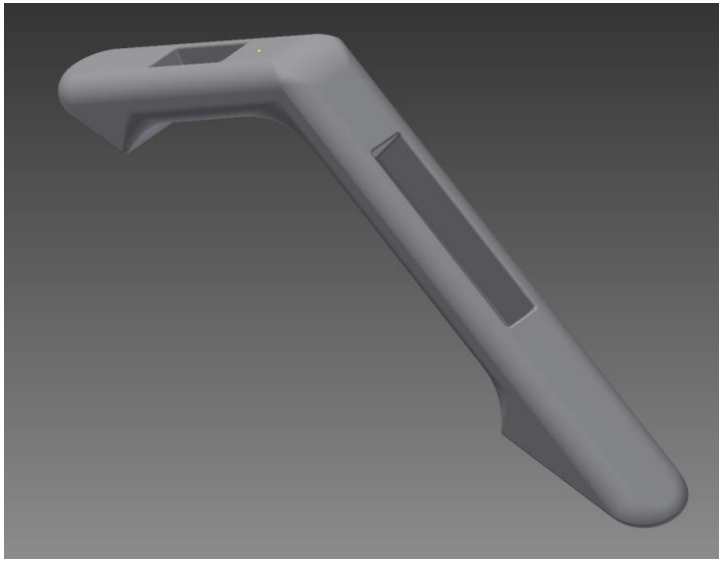
NAVSEA
WARFARE CENTERS
Philadelphia

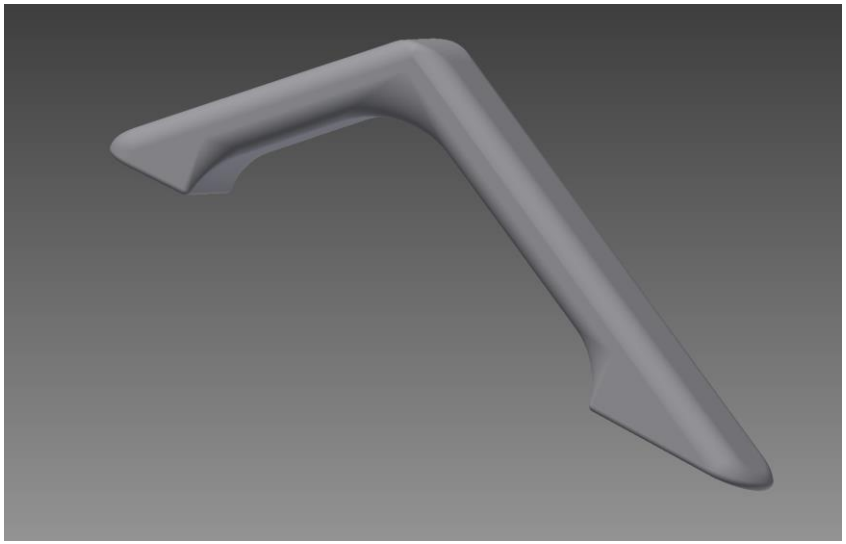
LPD17 Handle 3D Printing

- LPD17 Handle has been 3D printed on the Objet350 Connex3 printer
- Initial prints are using VeroBlackPlus rigid material
- Laser scanning of 3D printed part for GD&T
- Future prints may require Digital ABS material for mechanical strength requirements

Distribution Statement A. Distribution unlimited. Approved for Public Release.

LPD17 Handle Future Work





- Use topology optimization software to optimize the handle design to support the increased loads experienced during underway conditions
- Consider various metal coating methods to enhance 3D printed model mechanical properties

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Summary

- NSWCPD is the Navy's primary Warfare Center for machinery systems expertise.
- NSWCPD is exploring AM in various application areas
  - Test jigs/fixtures
  - Obsolete parts
  - Concept models
  - Training aids
- NSWCPD AM focus areas are complimented with laser metrology and virtual/augmented reality

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Points of Contact

Biofouling	Seal Whiskers	Rogowski Coil Fixture	Teletype Cartridge	LPD17 Handle
Scott Storms NSWCPD 215.897.8220 scott.storms@navy.mil	Christin Murphy NUWC Newport 401.832.5753 christin.murphy@navy.mil	Scott Storms NSWCPD 215.897.8220 scott.storms@navy.mil	Patrick Violante NSWCPD 215.897.7779 patrick.violante@navy.mil	Phil Greiner NSWCPD 215.897.2094 philip.greiner@navy.mil

Distribution Statement A. Distribution unlimited. Approved for Public Release.

QUESTIONS

Distribution Statement A. Distribution unlimited. Approved for Public Release.

NAVSEA
WARFARE CENTERS
Philadelphia

Laser Scanning Equipment

Point Scanner

Uses: Precision Alignments, Reverse Engineering, Large Part Q/A

Accuracy:
+/- 0.002” @ 30 Ft.,
+/- 0.005” @ 100 Ft.

ARM w/ LLP Scanner

Uses: Reverse Engineering, Q/A, Validations

Accuracy:
Touch Probe
+/- 0.0011” @ 8 Ft.
Laser Line Probe (LLP)
+/- 0.0014” @ 0.5 Ft.

Large Scale Scanner

Uses: Large Room Scans, Shipchecks, Spatial Arrangements, & A/I Validation

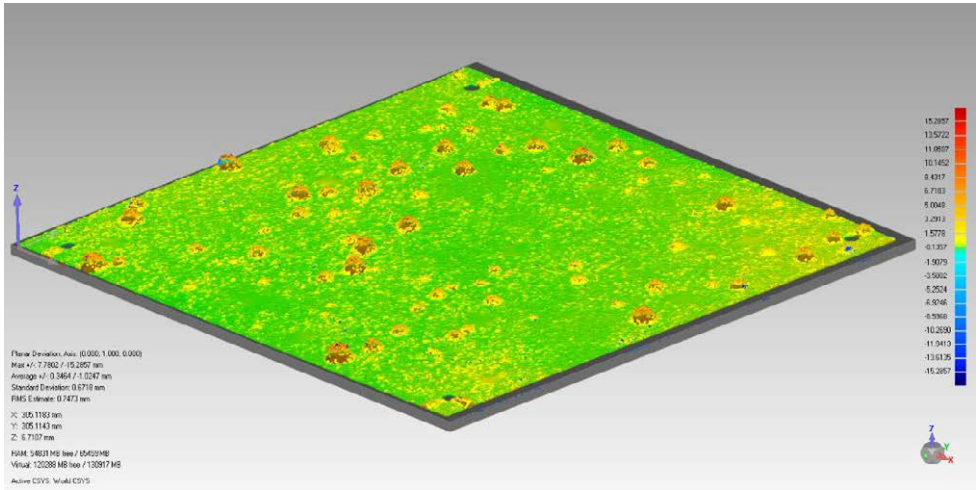
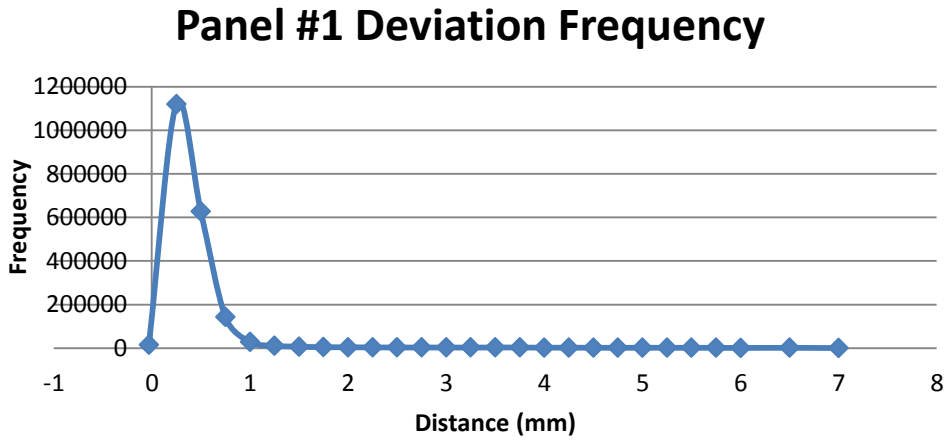
Accuracy: +/- 0.125”

Portable Probe Scanner

Uses: Reverse Engineering, Q/A, Validations

Accuracy: +/- 0.002” at 0.5 Ft.

Distribution Statement A. Distribution unlimited. Approved for Public Release.

Biofouling Deviation Analysis

Calculation	Result
Average [mm]	0.3273
Standard Deviation [mm]	0.6713
RMSE [mm]	0.7468
Kurtosis	88.32
Skewness	0.1345
Total Points Sampled	2,000,000