NSRP | National Shipbuilding Research Program

Pulsed Laser Comparison Tool: Update

June 26, 2026

Dr. Melissa Klingenberg and Mr. Steve Brown – Penn State ARL
Mr. James Brooks – Newport News Shipbuilding

NATIONAL SHIPBUILDING RESEARCH PROGRAM™
Taking Shipbuilding and Repair to the Next Level

Today's Presentation

- Issues
- Goal & Objectives
- NSRP Tasking Update
- Next Steps
- Proposed Timeline
- Acknowledgements
- Questions

Issues

- To avoid health and safety concerns and excessive material removal caused by conventional paint removal tools, shipyards (SYs) are pursuing laser ablation (LA).
- Initial investigations were conducted in mid-to-late 2000s.
    - Did not immediately lead to approval for use.
    - Recent (2017-19) projects addressed widely varying applications.
        - Steel applications = corrosion and coating removal on subs to surface ships.
        - Aluminum applications = corrosion and coating removal on subs to surface ships; passivation.
    - ONR ManTech "LA of Pre-construction Primer on HSLA Steels" provided data leading to LA approval for use on many steels if post-LA blast/grind/etc. is conducted.
        - Identified 100s of parameters dominating material degradation and optimized stripping rate.
        - Created process map for in-line 1kW pulsed fiber laser based on laser variables dominating material characteristics and removal rate/completeness.
- SYs want hand-held (HH) LA tools for other applications, but requires costly testing due to no direct transition from in-line LA to HH LA tools.
    - Different peak energies, processing variables, spot sizes, scan speeds/shapes = different energy densities and material effects.

Goal and Objectives

- Goal:
  - Develop pulsed laser comparison tool (processing map overlays) to enable SYs to:
    - Shorten the duration and expenses associated with qualifying alternate LA systems for similar applications.
    - Leverage data already developed.
- Objectives:
  - Identify high priority laser systems-of-interest for shipyard use
    - Hand held and automated
  - Review dominant factors influencing strip rate, completeness of stripping, and degradation to materials.
  - Determine best methods to compare systems
    - Identify best variables to include in developing a comparative processing tool/map.
  - Develop processing tool/map based on previous data and new testing conducted under this project.
  - Gain support from Technical Warrant Holders
    - Work to better understand TWH requirements for LA use on ship steel.

Task 1: Project Management

- Develop Project Plan – Submitted May 1, 2025
- Produced Quarterly Reports
  - Submitted QTRLY 1 - June 19, 2025
  - Submitted QTRLY 2 – September 19, 2025
  - Submitted QTRLY 3 – December 29, 2025
  - Submitted QTRLY 4 – March 19, 2026
- Generated required briefing materials
  - Produced kick-off briefing – May 2, 2025
  - Presented at SPC panel meeting – September 9, 2025
  - Presenting at SPC panel meeting – June 2, 2026
  - Leverage project findings toward broad-scale shipyard implementation of LA technologies - ongoing
- Collaborate with MIB to leverage plans for LA implementation across SYs - ongoing

Task 6: Complete Final Report

- Compile project activities, findings, results/recommendations into a Final Report - Submitted
  - Testing requirements
  - Executed testing and logged data
  - Analysis of testing results
  - Development of process maps
  - Indication of ability to overlay process parameter maps of different LA systems to achieve similar material conditions.

Task 2: Select Laser Systems to Trial - **Completed**

	NNS Interest	MIB Interest?	NSRP Funding & Schedule Permitting	Selected for NSRP		
	GC Laser 1000	**Adapt Laser Systems CL 1000**	**P-Laser QF1000**	**GC Laser 500X**	**Adapt Laser Systems CL500**	**P-Laser QFC100**
Partners / Specs →	1kW, pulsed fiber	1 kW, pulsed Nd:YAG	1 kW, pulsed fiber	500W, pulsed fiber	500 W, pulsed fiber	100 W, pulsed fiber
HII-NNS	#2: awaiting delivery for fast clad removal	Significant data already available	#3: comparison to GC and Adapt?	#1: received from MIB, rust and PCP removal	Significant data already available	#4: Interest for use in small/tight areas
GDBIW*	N/A	#3/4	N/A	#1/2	#3/4	#1/2
HII-Ingalls	No Preference					
Penn State ARL	#4 – NNS interest	#5 – MIB interest and procured for SYs	#6 – relatively unknown for applications and not easily accessible	#1 – use for small and large ships; MIB procured for SYs	#3 – scales to CL1000 (MIB), and available in house	#2 – represents constrained space use (small ships)

Future Studies?

* No preference, but ordered due to use in ManTech project interest areas

Comparison to IPG Photonics 1 kW pulsed fiber laser + Scan Lab Intelliweld Scanner

Task 3: Identify Targeted Materials/Conditions for Testing - **Completed**

			Possible Crossover to ManTech	Possible consideration for follow-on activities		Selected for NSRP
	Availability dependent		Coatings			Condition
	MIL-PRF-23236 Type 6 Epoxy – Off-White	**IOZ PCP - Green**	**MIL-PRF-23236 Type 6 Epoxy – Buff**	**Polysiloxane - Gray**	**Powder coat - Gray**	**No to slightly weathered (light corrosion possible)**
Partner/comment	New NNS primer	Previously Tested NNS PCP		GDBIW input		Coating system dependent
HII-NNS	#1 – hardest to remove (color)	#2 – leverage previous data	#3: Use dk gray with oxide red top coat	Not interested – not used on carrier	Not interested – not used on carrier	#1
GDBIW*	No interest noted	No interest noted	#1	#2/3	#2/3	No input
HII-Ingalls	#1 – uses this on HSLA 100		No input			No Input

Reduced Use – limited quantities

No interest from NNS

- *Selected HSLA 100 Steel substrates due to sufficient quantities available in required timeframe.*
- *Selected Off White epoxy due to similarity to buff (BIW) and availability in required timeframe; very little weathering on specimens due to recency of sample production.*

Task 3: Identify Targeted Testing - **Completed**

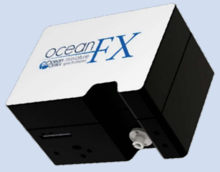
- TWH input for suggested testing for qualification purposes:
  - SEM microscopy (top and cross-section) to determine damage and completeness of stripping.
    - Optical microscopy was completed for all tests and incorporated into ML dataset
    - SEM was not performed, since correlation to ML "predictors" could not be mapped within the cost/time constraints
    - Should additional funds become available outside of this project, SEM and other possible testing could be conducted to provide confirmation on material properties.
  - X-ray Diffraction Stress Analysis
    - Eliminated for this project due to time and funding constraints and need to focus on mapping tool examination.
    - Should additional funds become available outside of this project, this and other possible testing could be conducted to provide confirmation on material properties.
  - Profilometry – was considered to be optional by TWH, but technical team determined need to discern between beam types and resulting effects on the surface.
  - Key focus was to reduce overall testing requirements to qualify like LA systems for use in similar applications.

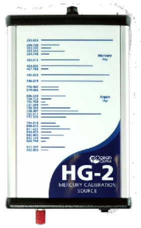
Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

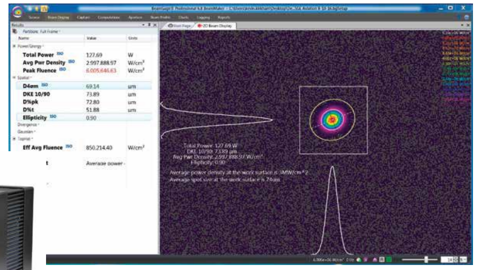
- Determine if process variables permit energy density overlay between lasers (e.g., YLPN-1 kW comparison to QFC100, GC500X, and CL500).
- Identify secondary defining parameter in removal and resulting material conditions.
- Original plan:
  - Identify laser parameters – variable and fixed each laser being trialed.
  - Sample parameters to narrow in on conditions closely approximating successful IPG Photonics conditions
  - Conduct measurements (see next slides)
    - Stand-off distance (depth of focus tolerance)
    - Laser wavelength, energy and power (peak and average)
    - Spot size/geometry and overlap
    - Scanning frequency, duration, trajectories
    - Sample interactions (appearance, ablation depth, temperature)

Task 4: Identify Dominating Parameters Through Testing - Incomplete

Parameter	Equipment
Wavelength verification (nm) – Primary & **Process/Sample Interactions** - Secondary (reflected/emitted spectra; extra data related to surface condition pre-post ablation)	**Spectrometer(s):** • OO Ocean FX (249 – 576 nm) • OO USB2000+ (474 – 1134 nm) **Calibration Sources:** • OO Hg-2 (wavelength) • OO DH-3+ (intensity)
Pulse Frequency Verification (Hz) – Primary & **Pulse Duration Verification** (ns) - Primary	**Photodiode:** • Newport (818-BB-21) **Oscilloscope:** • Tektronix TDS 3052B
Beam Profile – primary measurement - Primary (spatial intensity distribution)	**Beam Profiler:** • Ophir BeamCheck Challenges Experienced
Scanning Trajectory confirmation – TBD (Extra data: trace scan paths, velocities, etc.)	**Cameras:** • uEye 5120 RE (high dynamic range) • Phantom 1310 (high-speed)
Spot Size (um) - Primary & **Ablation Depth** (um) - Primary	**Profilometer:** • Keyence V6000 or V7000
Process/Sample Interactions – Secondary (substrate heating)	**IR Camera:** • Optris Xi 400





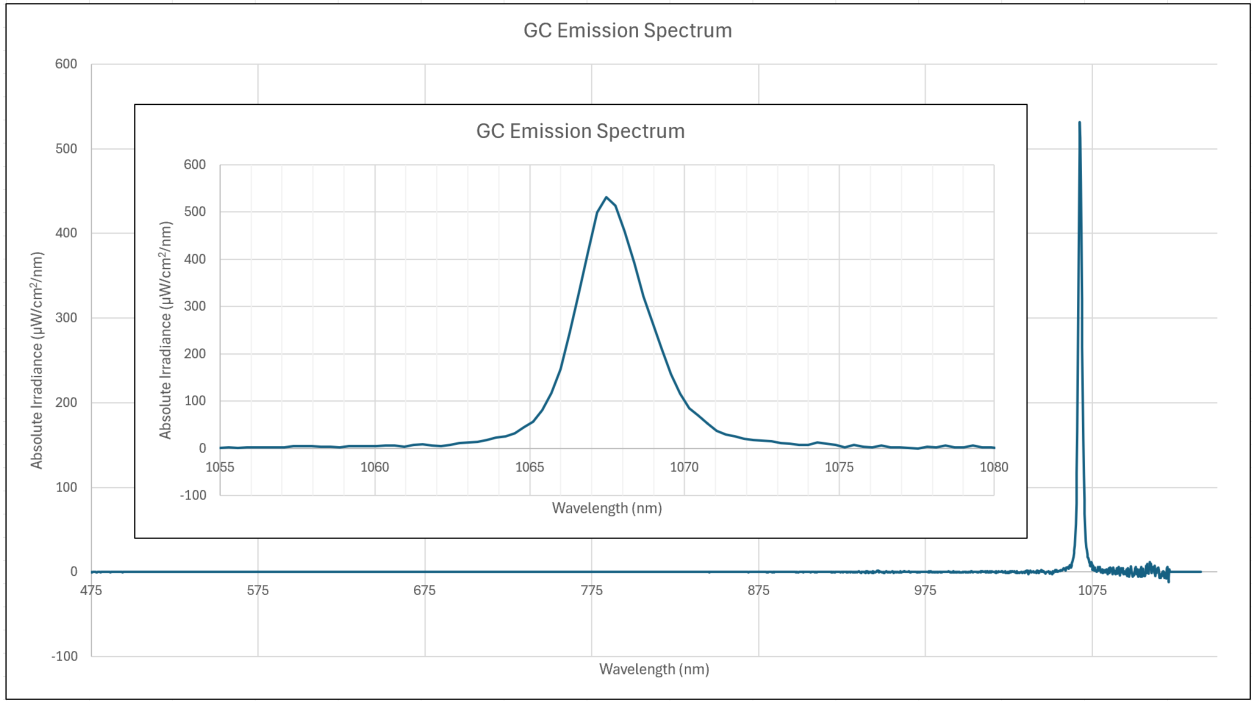



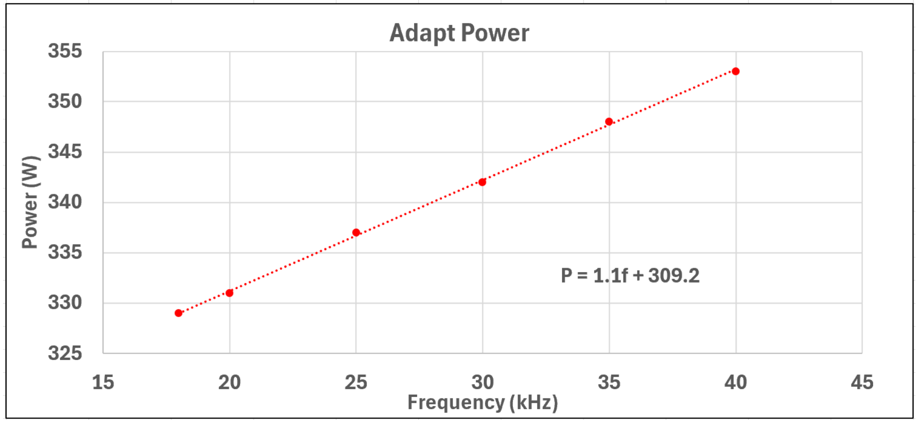

Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

- A *Laser Ablation Process Recipe Framework* identified >50 parameters of interest to characterize an LA process:
  - Some that were directly measured include:
    - Wavelength
    - Average power
    - Pulse duration and frequency
    - Waist diameter
  - Some that were indirectly measured include:
    - Local hit cadence (timing between pulses at a specific location on the substrate)
    - Process-dependent material properties (e.g., emissivity)
  - Some non-measured parameters include:
    - Standoff (operator position not tracked)
    - Polarization

Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

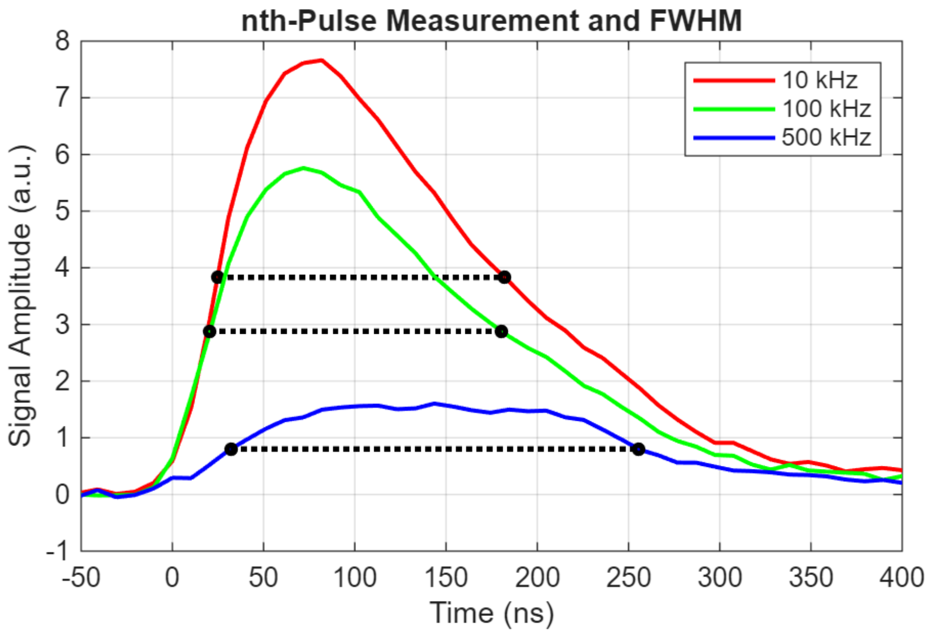
- Wavelength:
  - All four LA systems have nearly the same central wavelength and spectral bandwidth
    - Adapt : 1067.6 ± 0.6 nm
    - GC : 1067.5 ± 1.3 nm
    - IPG : 1068.0 ± 1.8 nm
    - P-Laser : 1068.1 ± 2.3 nm
- Average power:
  - Results varied, with mixed dependencies on other parameters, e.g., pulse duration and frequency
  - Each laser reached highest average power at its highest output frequency
  - Transmission losses were up to 30%

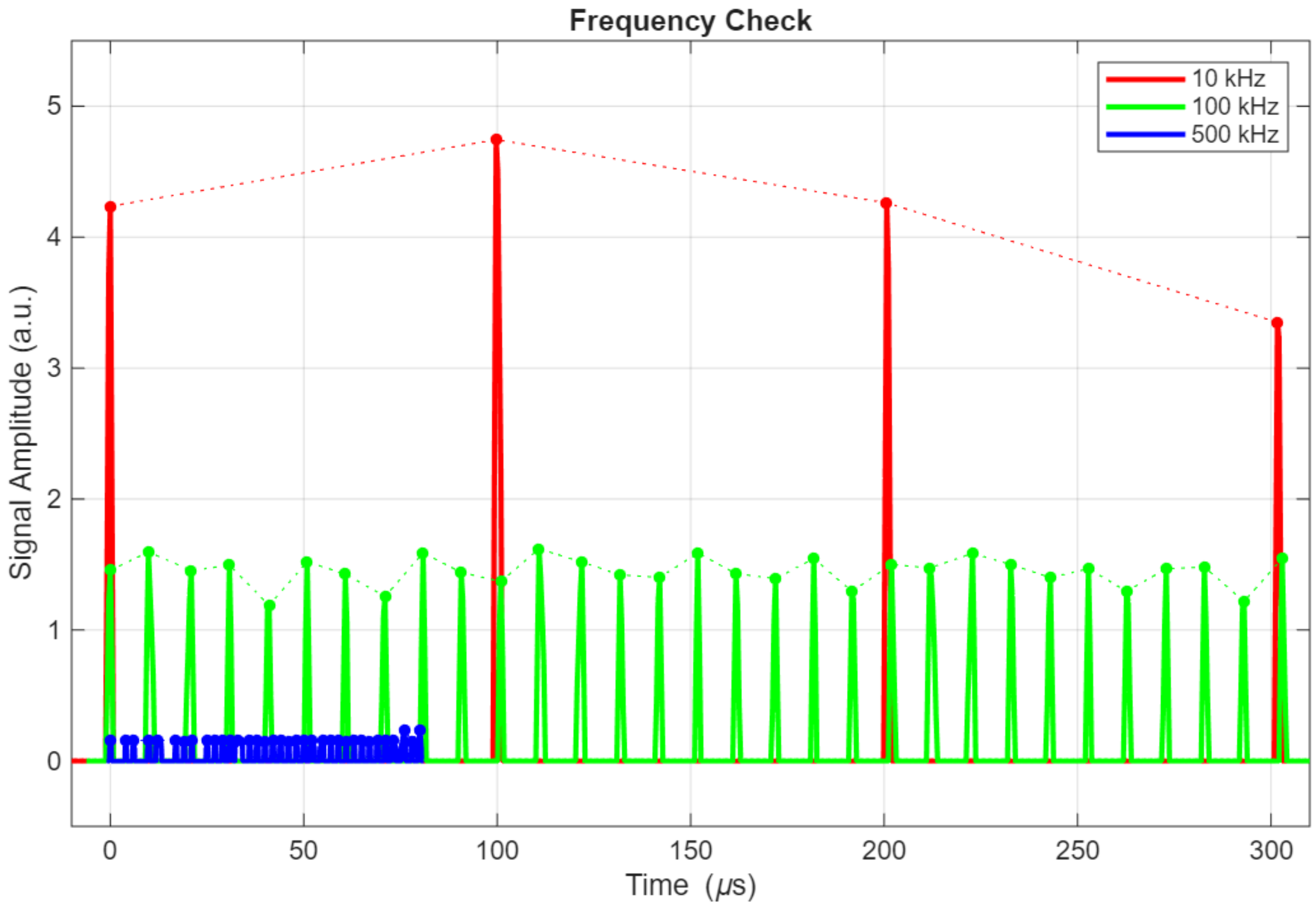




Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

- Pulse duration:
  - Varied significantly from reported values
- Frequency:
  - Tracked more closely with expected values

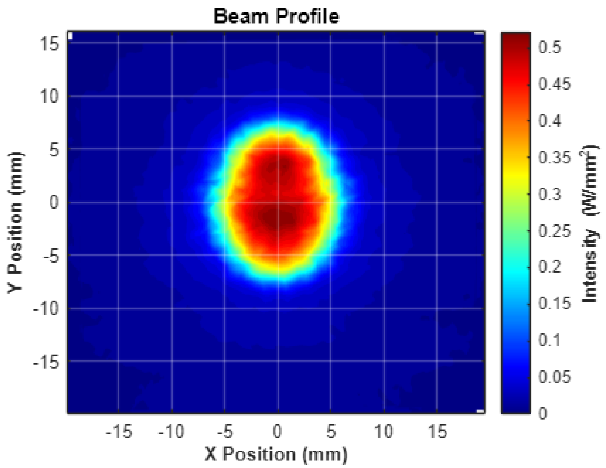


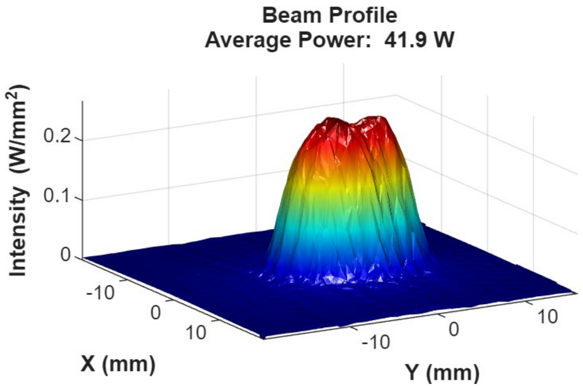


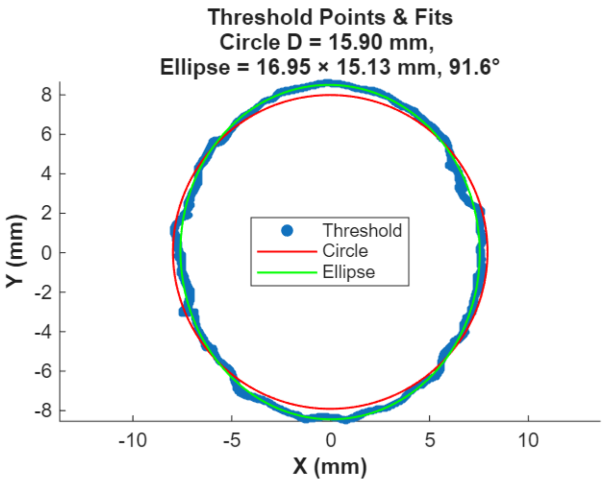
(P-Laser pulse duration and frequency plots)

Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

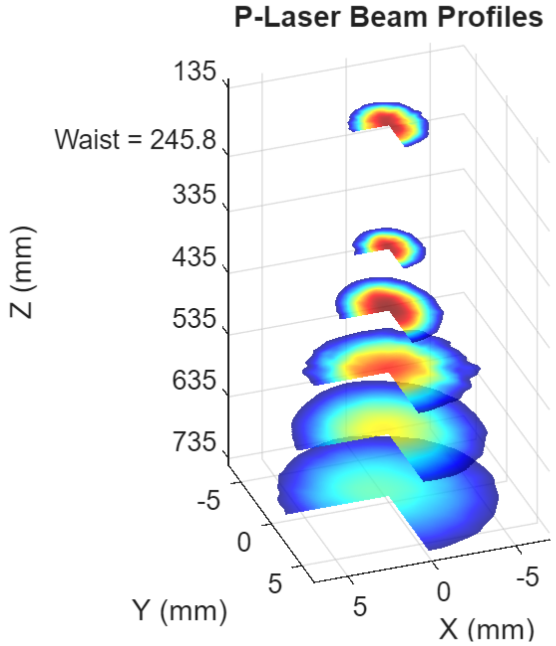
- Beam profile → waist diameter):
  - Qualitatively-measured due to equipment malfunction



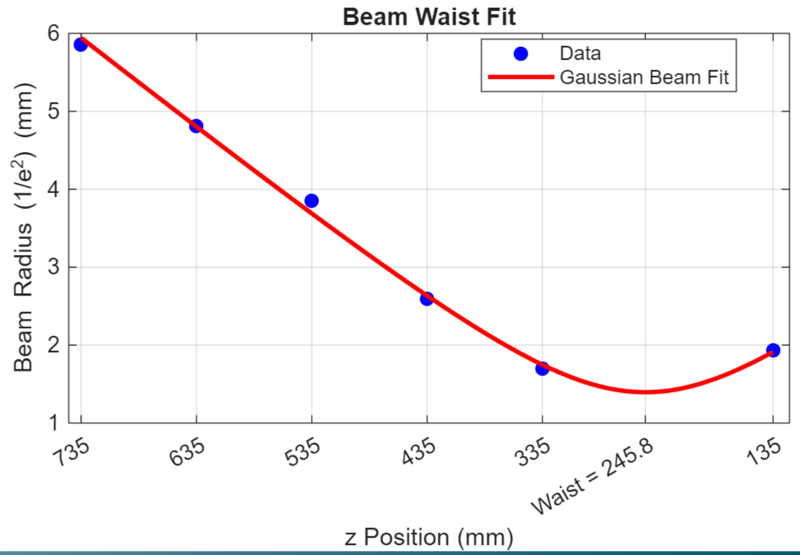




(IPG plots)

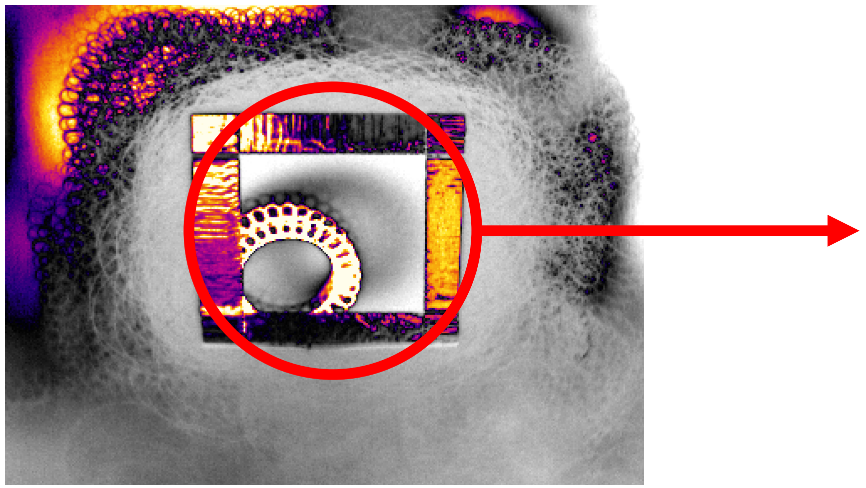


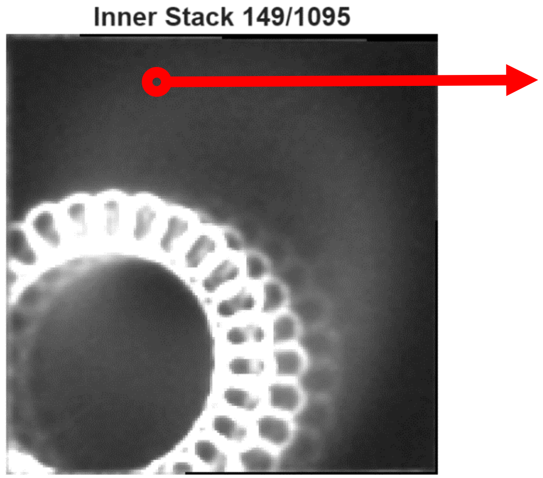
(P-Laser plots)

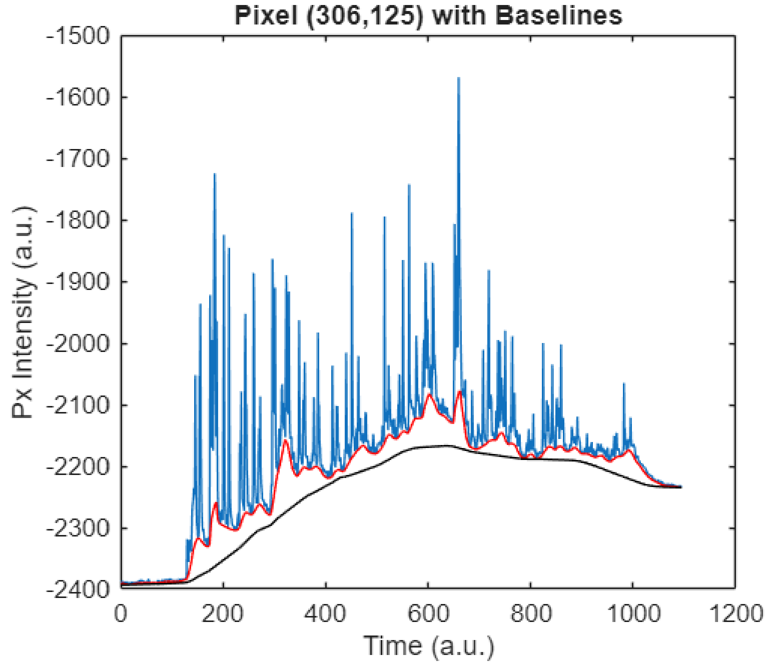


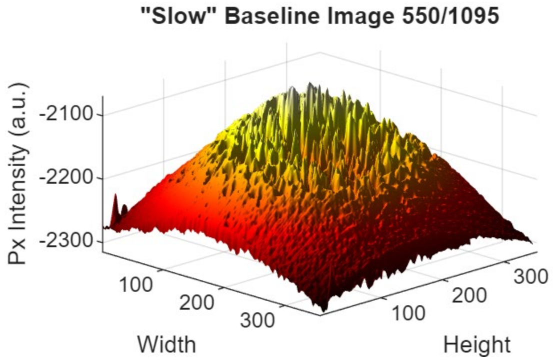
Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

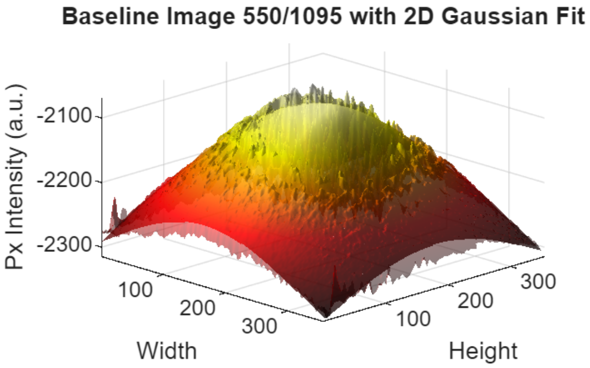
- IR Video → Local Hit Cadence, Emissivity:
  - Indirect measurements, characterized by statistical quantities

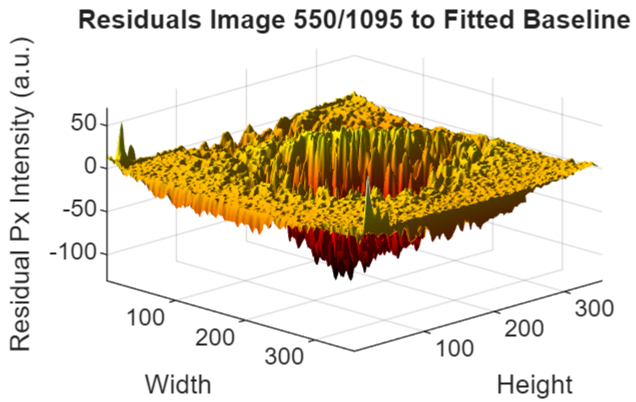








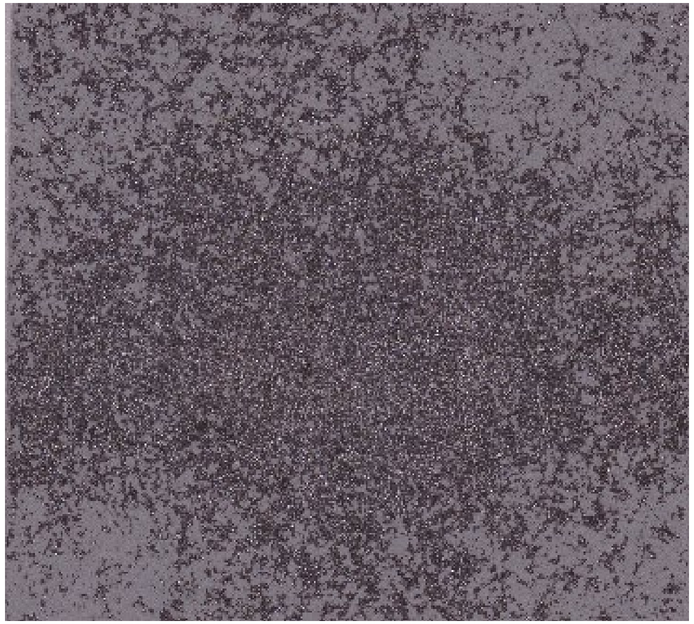




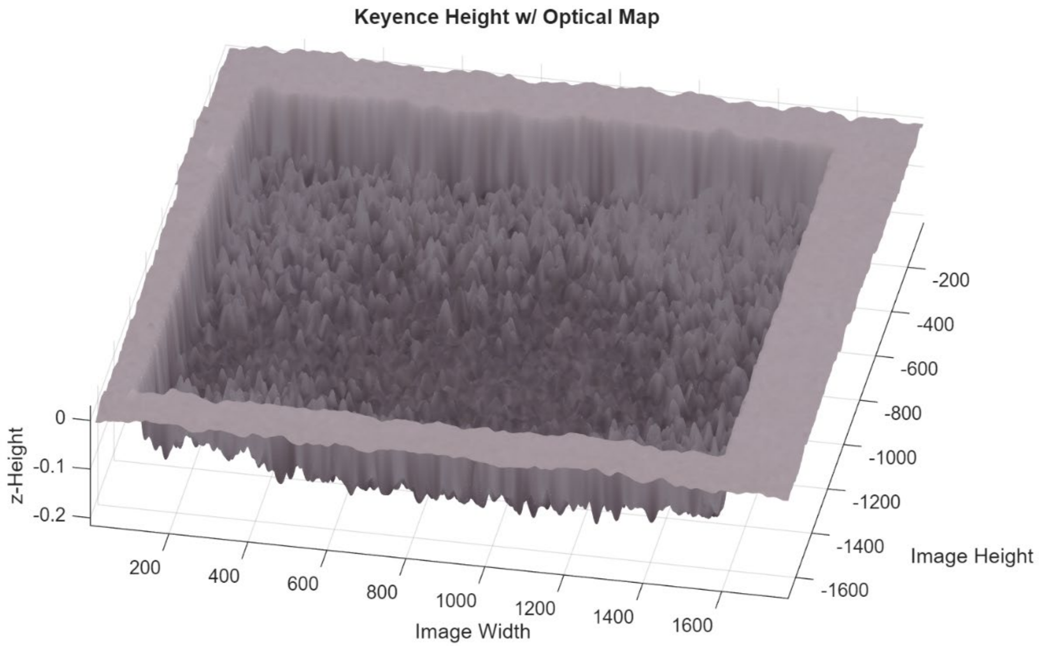
Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

- Intended to reveal dominant parameters through analysis of stripping action/rate and surface characteristics combined with examination of process and beam data to be analyzed for all trials under Task 5.
  - Performed selected characterization (surface microscopy and profilometry) to determine stripping completeness and base material condition (e.g., damage) similarities/differences in stripping completeness and substrate damage or lack thereof, as well as, surface profile

Microscopic image (25X) of representative samples



Profilometry map of representative samples



Task 4: Identify Dominating Parameters Through Testing - **Incomplete**

- Found that ablation depth and (surface) color depend most heavily on:
  - Laser equipment (peak power)
  - Substrate location (area-based ablation region, geometry, etc., from operator’s perspective)
  - Material (emissivity)
  - Process (local hit cadence)
- Concerns include:
  - Equipment dependency on spot diameter was expected, but not found (e.g., not “peak power density”)
  - Substrate ~location identifies inherent biases to handheld operation, but also diminishes predictability of current PLCT / ML model
  - Material ~emissivity (as indirectly measured) is also tied to a result of ablation; provision is needed to redefine corresponding predictor
  - Process ~cadence needs further assessment for effective mapping

Task 4: Identify Dominating Parameters Through Testing - Incomplete

- Breadth of characterization/testing had to be modified due to budget and time constraints, as well as measurement data having limited utility.
    - XRD was removed from testing plan due to approach change. Team is focusing on discriminating between parameters of lasers to produce similar surfaces when stripping.
        - Selection of white epoxy coating system on HSLA 100 steel rendered baseline data from LA of PCP on HSLA steels void for this project. There is no useful to link to previous fatigue data should XRD data be generated for these specimens.
    - Targeted wide array of parameters was expected to open the aperture for comparison between disparate laser system and associated capabilities.
        - Intent: Test theory on dominating parameters for removal and damage or no damage in substrates and examine multi-process overlays.
        - Realized: Subset of ML database was retained for testing, and it predicted as-expected (<60% accurate)
    - Future expansion of investigation is still desired, but need to focus on obtaining sufficient, high quality, measurement data to ensure that mapping overlays are even possible.
        - Handheld dependency must be addressed (e.g., via convolutional neural network, CNN-based model)

Task 5: Overlay Maps and Correlate Characterization Data - Incomplete

- Generate process maps for evaluated lasers – partially completed
  - Reviewed limited characterization/ test data against process data; only used optical microscopy and profilometry with thermal camera data.
  - Completed compilation of measured data for machine learning (ML) assessment to help determine dominating parameters
    - Measurements (during and following LA processing) produced extensive data (~200 GB) that had to be interpreted and distilled by physics-driven algorithms and statistical processes before inclusion in the master ML training dataset.
    - Summarization of individual LA test data was computationally-heavy, requiring many hours of iterative processing.
    - ML training datasets included ~500k unique observations, each with ~100s features and multiple responses. Team summarized parameters to get statistical features on the measurements.
  - All summarized datasets were fed into a single, master dataset used to train the ML models. The best model was used to identify which variables most affect the response, and generate "maps" to compare equipment-specific parameter spaces
- Overlaying process maps between LA systems – Not accomplished; insufficient data and time remaining in project
  - Many errors were discovered in the master dataset due to various inconsistencies. These were meticulously investigated and all were corrected (to our knowledge)
  - Strong dependency on substrate location was not managed (e.g., via CNN-based modeling)
  - Recommendations identified for next steps, if desired.
  - Project findings reported, as-is.
  - Recommending possible expanded project with SIB, NNS (and BIW and HII-Ingalls, if available), TWHs.

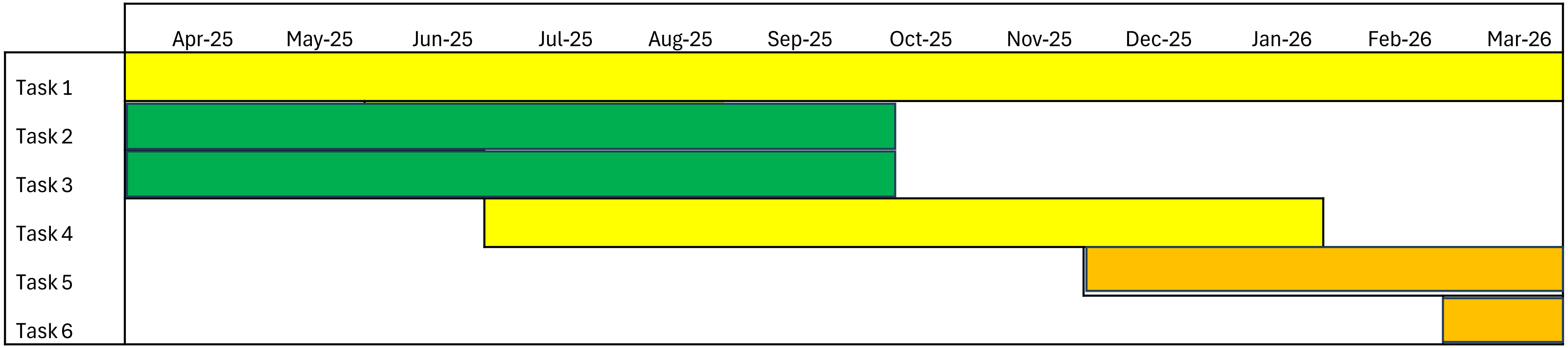
Summary

- Team requires additional data and time to develop process overlay maps due to:
    - **Unexpected equipment problems.** We'd like to complete the current analysis (using existing "independent observations")
        - Obtain previously desired "predictors" (spot diameter, beam profile, Rayleigh range) & "responses" (residual stress)
    - **Insufficient testing on "green" PCP.** Would like to conduct additional LA testing on "green" substrates to bridge current mapping thereto (and the prior ONR ManTech-funded effort, *LA of PCP from HSLA Steels)*
        - "Optional" NSRP testing on "green" PCP was/is strongly desired. Too few tests were conducted to adequately label (thus, classify) and use the results.
    - **Unforeseen technical challenges.** Believe the dataset already produced has value that we were unable to fully extract.
        - Forced manual-processing, e.g., significantly increased the time/labor requirement to produce the ML dataset. We'd like to continue working with the ~same data/PLCT (notwithstanding the bullets above) to extend its usefulness.
- Team recommends additional funding for new equipment:
    - **Beam profiler.** A combination of (new) OEM equipment and revised custom hardware will characterize the beams.
    - **X-ray diffraction.** Adding surface residual stress to the ablation result will improve predictive performance.
    - **IR camera(s).** Advanced features will enhance contrasts of different materials and programmatic performance.

Timeline

- *PULSED-LASER COMPARISON TOOL* — *Est. Schedule*
  - Task 1: Program Management — Month 1-12
  - ~~Task 2: Select Laser Systems to Trial — Month 1-5~~
  - ~~Task 3: Identify Targeted Testing — Month 2-5~~
  - Task 4: Identify Dominating Parameters Through Testing — Month 5-12
  - Task 5: Overlay Maps and Correlate Characterization Data — Month 11-17
  - Task 6: Complete Final Report — Month 18

Extended, but completed Project



Next Steps

- Near-Term Milestones to be Addressed
  - Complete Final Briefing as of this presentation
- Technical Progress to be Accomplished
  - Done
- Risk Reduction Items that <u>Were Not</u> Addressed
  - Developing sufficient data with existing funds.
  - Intended to leverage existing processing data generated under ManTech Project, but specimens were not the same as those used in that project. General knowledge has been utilized but still was insufficient for developing processing maps.
  - Need additional data from beam profiler and SEM data.
  - Ensure usefulness of data generated for SY implementation activities.
    - Leverage developed data for future NSRP or SIB activities, if funded.
- Technical Progress Suggested for Future Accomplishments
  - Complete characterization of specimens (cross-sections) from each laser trial across energy regimes.
  - Continue processing mammoth dataset using ML models, including additional programming for improved useage.
  - Conduct additional processing trials at laser vendor facilities using their equipment with ability to stop laser, measure beam size and profile without worrying about warranty violations.
  - Generate additional, required "mapping" data and develop processing maps of utility.

Acknowledgements: NSRP Team

- NSRP Panels, Program Managers and Administrators
  - Mr. Colin Dunlop – Former NSRP Program Manager, NAVSEA
  - Mr. Mark Smitherman – Program Administrator NSRP
  - Mr. Conlan Hsu – NSRP Surface and Coatings Preparation Chair
  - Ms. Angel Zepeda - NSRP Surface and Coatings Preparation Vice Chair
  - Mr. Kevin Roossinck – NSRP Welding Chair
  - Mr. Cody Whitely – NSRP Welding Vice Chair
  - Mr. Peter Radzicki– NSRP Planning, Production, Processes, and Facilities (PPPF) Chair
  - Mr. Brian Tapajna - NSRP PPPF Vice Chair
  - Ms. Kristen Walkup – NSRP Sustainment Chair
  - Mr. Kaipo Crowell – NSRP Sustainment Vice Chair
- NSRP Executive Control Board Members
  - Mr. Chris Orlowski – Chair, Austal USA
  - Ms. Zoe Cawlfield – Vice Chair, GD - NASSCO
  - Mr. John Kooienga - Treasurer, HII – Ingalls Shipbuilding
  - Mr. Luke Lyndaker – Member, GD Bath Iron Works
  - Mr. Danielle Perera – Member, General Dynamics (GD) Electric Boat
  - Mr. Travis Carter – Member, BAE Systems
  - Mr. Cengiz Atam – Member, Fincantieri Marinette Marine
  - Mr. Jonathan Sherman – Member, HII-Newport News Shipbuilding

<u>NSRP Project Team</u>

- Newport News Shipbuilding – Active Participant
  - Mr. James Brooks – NNS Technical Lead
  - Ms. Tammy Rossi – NNS NSRP Manager
  - Mr. Elmer Dickens – NNS NSRP POC
- General Dynamics Bath Iron Works - Participant
  - Mr. Gregg Buczkowski – BIW Technical Lead
  - Mr. Andy Blackman – BIW NSRP Manager
- Huntington Ingalls Shipbuilding (HII) - Participant
  - Ms. Haley McGee – HII Technical Lead
  - Ms. Ambre Cauley – HII NSRP Manager
- Penn State Applied Research Laboratory
  - Dr. Melissa Klingenberg – Principal Investigator (PI)
  - Mr. Stephen Brown – Co-PI
  - Mr. David Rearick – Co-PI
- ATI
  - Mr. Nick Laney – Project Manager

Acknowledgements: ONR, SIB, & NSRP

ONR ManTech Team Members

- ONR: Mr. Paul Huang – iMAST Program Officer
- PMS 379: Mr. Russell Knowles – (retired) PEO Aircraft Carriers
- NAVSEA Technical Authorities: NAVSEA 05
  - Mr. John McGrorey – TWH, Metallic Hull Materials, Welding and Fabrication Processes Used in Surface Ship Structures
  - Mr. Chris Rodgers – TWH, Structural Integrity – Aircraft Carriers and Large Deck Amphibious Ships
  - Mr. Yunusa Balogun – Eng. Mgr/Materials Engineer
- NSWC-CD
  - Mr. Maxmilian Kinsey – supported John McGrorey
  - Mr. Natburut Panyavuthilert – supported Christopher Rodgers
- Institute for Manufacturing and Sustainment Technologies
  - Mr. Chris Ligetti – Program Director, Penn State ARL
  - Dr. Dan Finke – Technical Director, Penn State ARL

ONR ManTech Team Members

- Newport News Shipbuilding
  - Ms. Tammy Rossi – NNS ManTech Manager
  - Mr. James Brooks – NNS Project Lead
  - Mr. Mike Cunneen – NNS Lead Mfg. Engineer

SIB Members and Affiliates:

- Submarine Industrial Base Laser Ablation /Coatings Removal Leads
  - Mr. Ryan Blondino – Industrial Base Acceleration (IBA)
  - Mr. Alex Tafreshi – MIB, IBA, Coatings Removal PM
  - Mr. Deniz Ferrin – IMF PMG WA

NSRP
NATIONAL SHIPBUILDING RESEARCH PROGRAM™
Taking Shipbuilding and Repair to the Next Level