Channel Wall Nozzle Manufacturing and Hot-Fire Testing using a Laser Wire Direct Closeout Technique for Liquid Rocket Engines

July 11, 2018
AIAA-2018-4860

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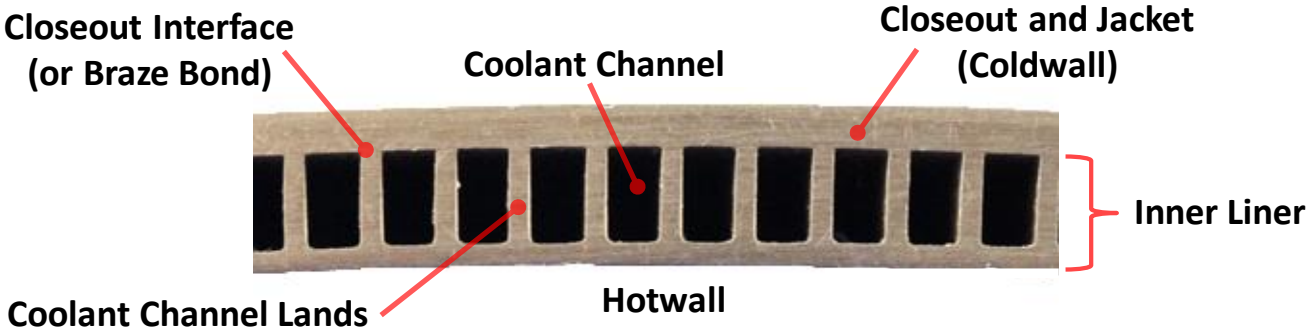
Motivation for Channel Wall Nozzle (CWN) Technology

- Channel wall nozzles have been evaluated as a cost savings technology for current and future missions for a variety of engine programs
- NASA has evaluated and worked with vendors and contractors on fabrication of “traditional” large scale channel wall nozzles (CWN) on several programs over the last few decades
- Recent CWN manufacturing technology has been limited based on minimal investments and scale to mature technology
  - Current State of the art focused on brazing technology
  - GKN (formally Volvo) evolved the laser welded sandwich wall technology
  - Other domestic technology has limited public data available

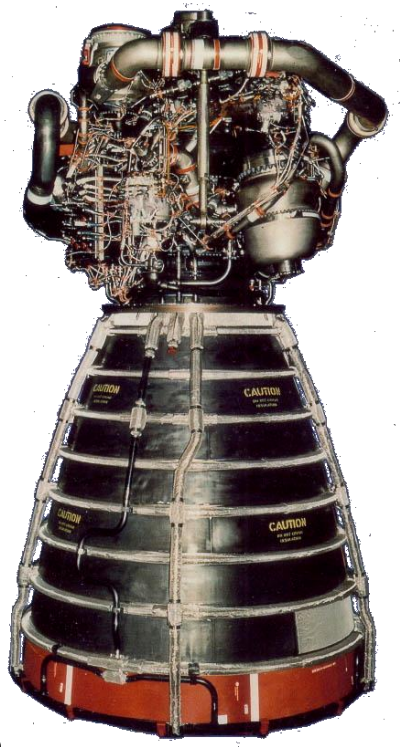
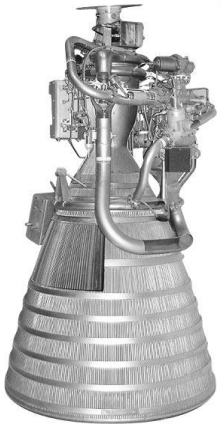
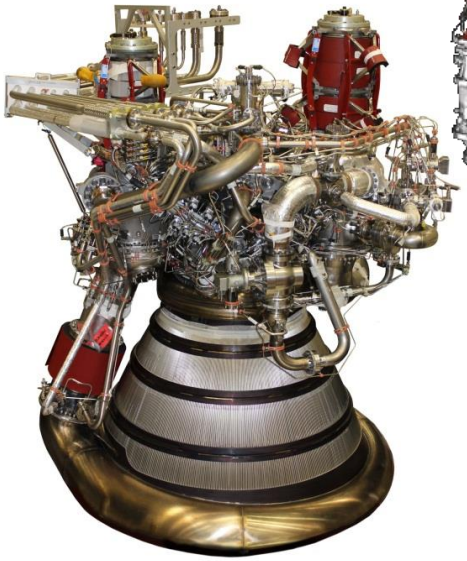
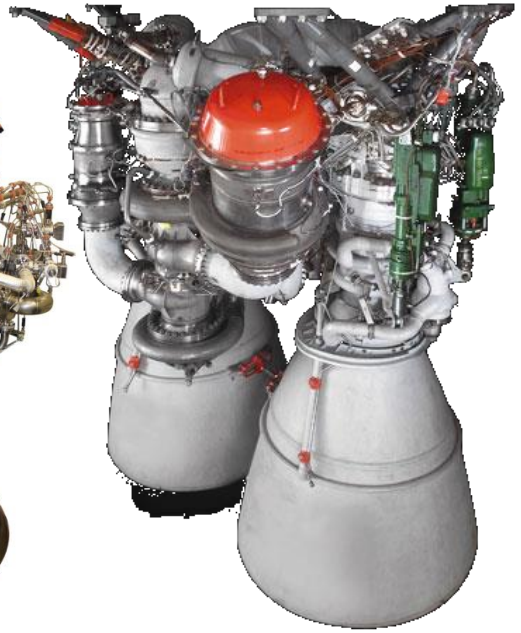


Goal: Evaluate alternate manufacturing techniques to reduce fabrication cycle (and subsequent costs) and improve performance for large scale channel wall nozzles

What about using Selective Laser Melting for Nozzles?

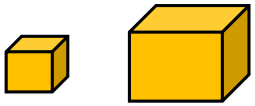
Although new additive manufacturing machines are being introduced, current state of the art is limited in size…

Engine

SSME/RS-25	RL-10A-4	J-2X, Regen Only	RD-180
			
90″	46″	70″	56″

Nozzle Exit Dia.

SLM Build Boxes



10x10x10 (inches)

15.5x24x19

Ref: Gradl, P.R., Brandsmeier, W. Alberts, D., Walker, B., Schneider, J.A. Manufacturing Process Developments for Large Scale Regeneratively-cooled Channel Wall Rocket Nozzles Paper presented at 63nd JANNAF Propulsion Meeting/9th Liquid Propulsion Subcommittee, December 5-9, 2016. Phoenix, AZ.

Overview of Techniques

Liner Fabrication

- Forging
- Spin Forming
- Shear Forming
- Powder Metallurgy
- Freeform AM Deposition
  - Powder-based Laser
  - Wire-based Laser
  - Arc-based Wire
- Multi-Piece SLM
- Platelets
- Explosive Forming
- Coldspray
- Casting
- Vacuum Plasma Spray

Channel Forming/Slotting

- Slitting Saw
- End Milling
- Water Jet Milling
- Electro or Photochemical
- Plunge EDM
- Multi-Piece SLM
- Platelets
- Freeform AM Deposition

Channel Closeout and Jackets

- Pressure Assisted Braze
- Standard Atmosphere Braze
- Multi-Piece SLM
- Vacuum Plasma Spray
- Electroplating
- Coldspray
- Freeform AM Deposition
  - Wire-based Laser
  - Powder-based Laser
  - Arc-based Wire
- Explosive Bonding
- Ultrasonic
- Laser Welding
- Diffusion Bonding
- Platelets
- Casting
- Composite Overwrap

Manifold Application

- Wrought and Machined
- Freeform AM Deposition
  - Wire-based Laser
  - Powder-based Laser
  - Arc-based Wire
- Multi-Piece SLM
- Platelets
- Casting
- Molded Composites

Ref: Gradl, P. "Rapid Fabrication Techniques for Liquid Rocket Channel Wall Nozzles". AIAA-2016-4771, Paper presented at 52nd AIAA/SAE/ASEE Joint Propulsion Conference, July 27, 2016. Salt Lake City, UT.

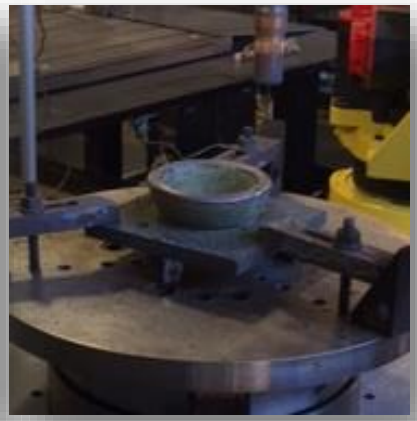
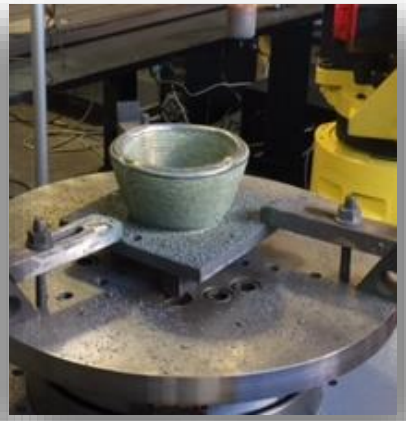
Deposition Techniques for Forming Liner

Directed Energy Deposition (DED)

Liner Fabrication

Arc-based Deposition
Metal Direct Digital Manufacturing (MDDM)

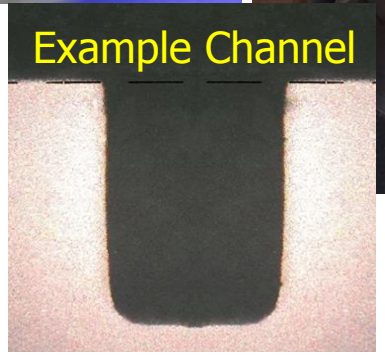
- Provides high deposition rate (20+ lbs/hr) using wire-based arc welding techniques; near net shape deposition


Water Jet Milling

Channel Forming/Slotting

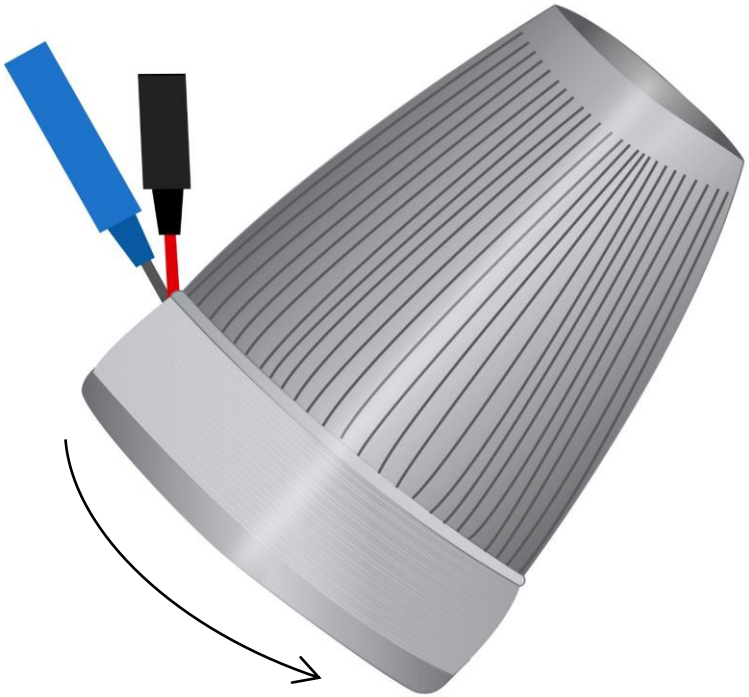
- Abrasive blind Water Jet Milling technique to form coolant channels (*akin to slotting*)
  - Low load technique, reduced wall thicknesses
  - Allows for easy milling of difficult materials in a variety of geometries
  - Current development to “mimic” features of slotting

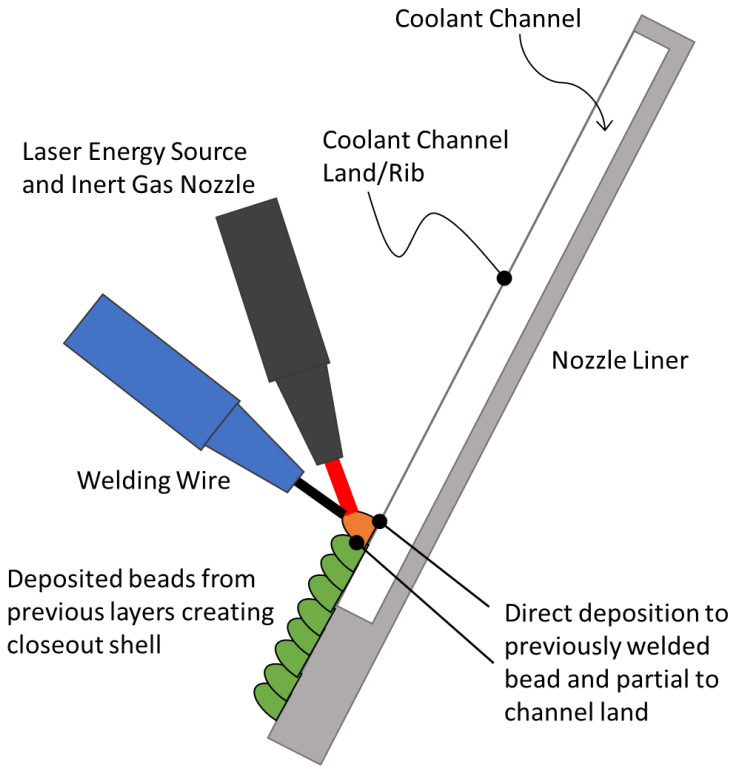


- Ability to hold +/- 0.001” in subscale applications
- Rougher surface finish that traditional machining, but acceptable during hot-fire and flow testing

Closeout – Laser Wire Direct Closeout

- Laser Wire Direct Closeout (LWDC) is an additive technique that locally bonds a wire to the channel ribs and provides a structural jacket in place
  - Freeform welding process without need for filler
- Uses laser energy source and off-axis wire
- Complete bond at ribs and previously deposited layers
- No material “drop-thru” into channels

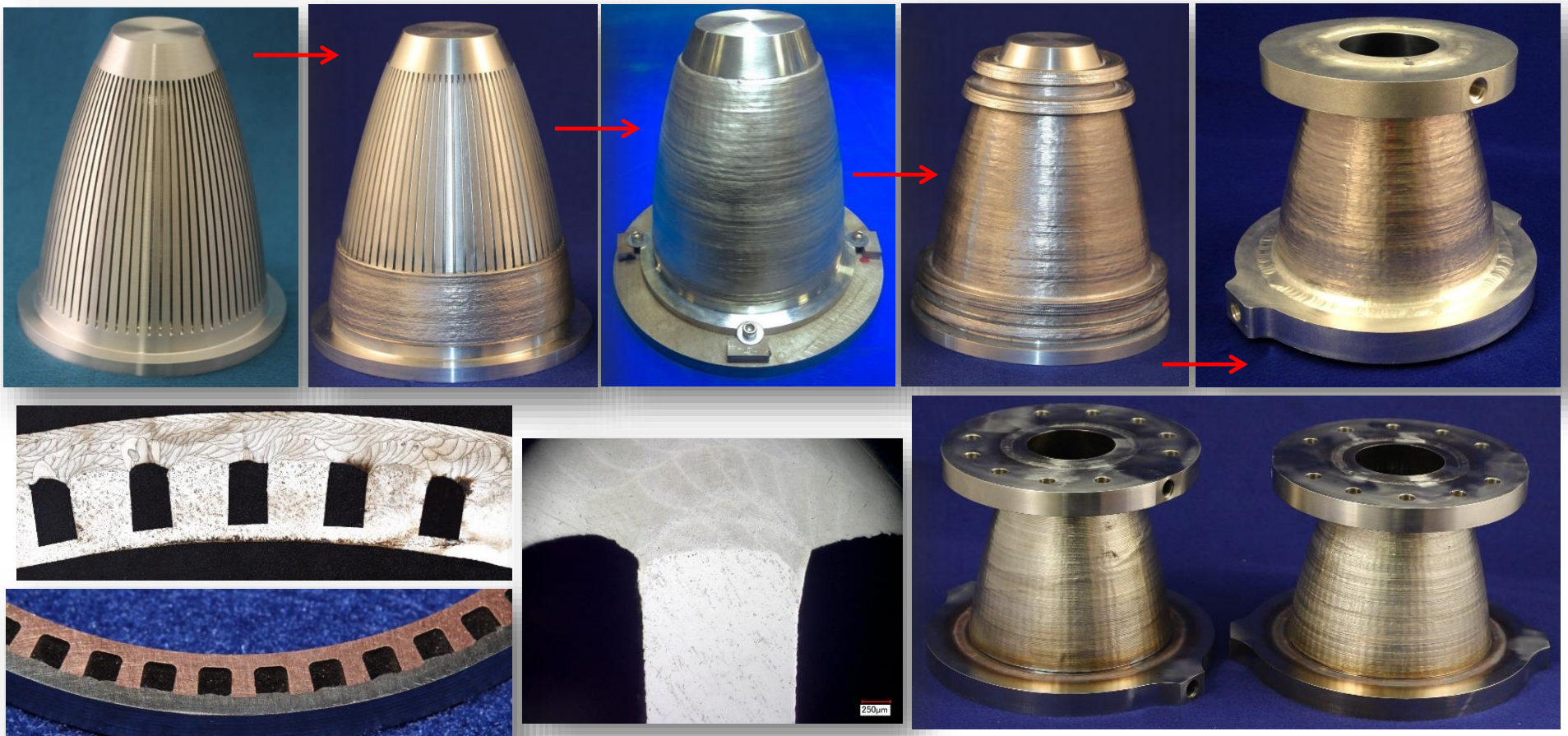




Closeout – Laser Wire Direct Closeout

Channel Closeout and Jackets

- Demonstrated on a variety of materials including Inco 625, SS347, Bimetallic (Cu-Inco), Al-6061
- Allows for interim starts-stops and real-time inspection



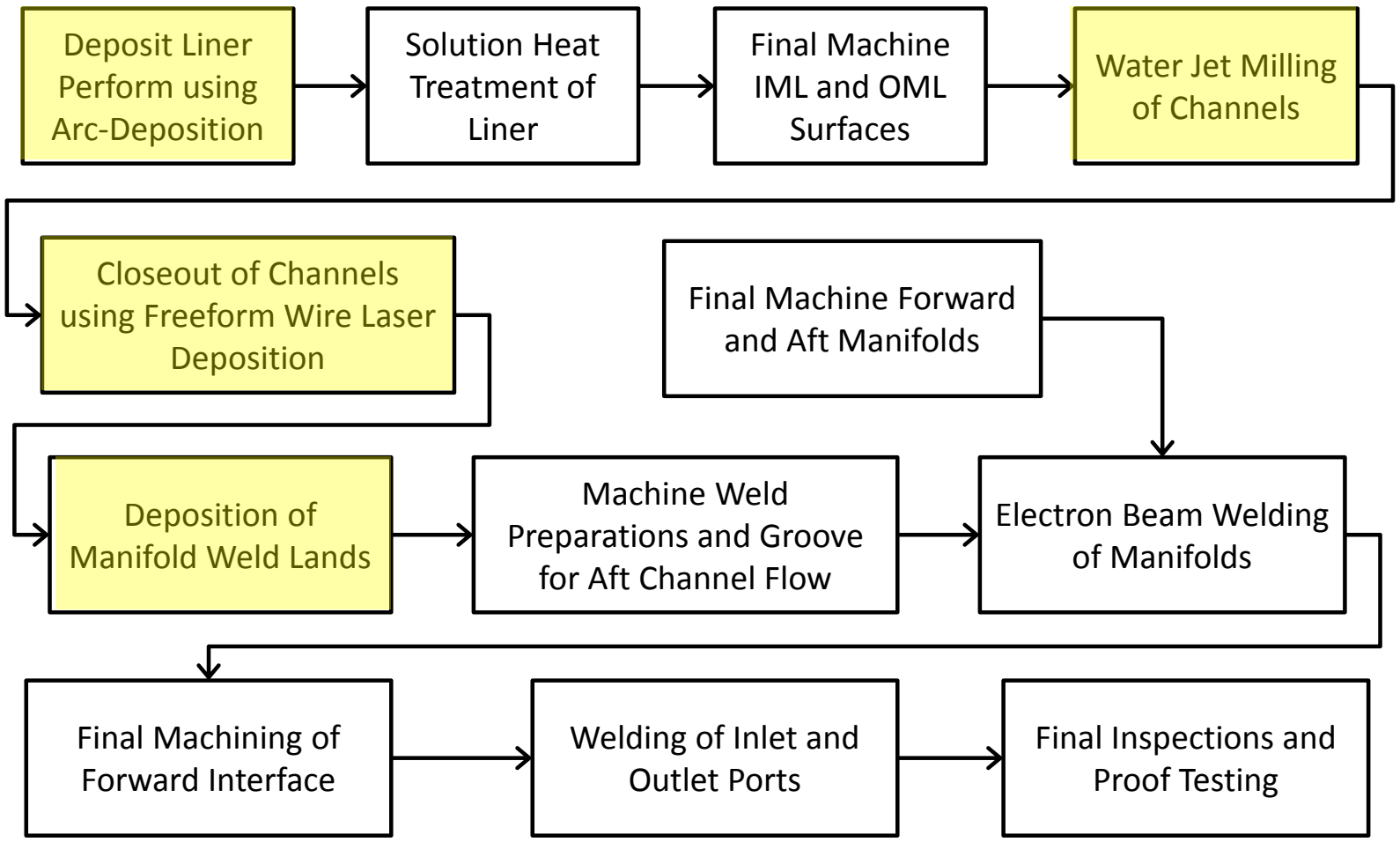
CWN Techniques Hot-fire Tested

Nozzle #1
CRES 347 Forging
Water Jet Milled Channels
SS247 Laser Wire Direct Closeout (LWDC)

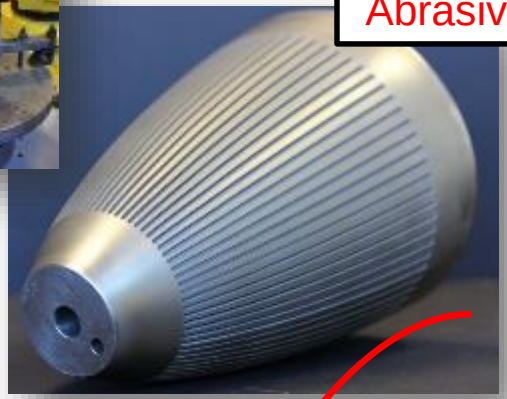
Nozzle #2
Inconel 625 Arc-Deposited Liner
Water Jet Milled Channels, Thin-wall
Inco 625 Laser Wire Direct Closeout (LWDC)

Fabrication Process for LWDC Nozzles

- Process for fabrication of Inco 625 Nozzle #2 shown
- Near net-shape deposition of liner and LWDC closeout significantly reduced machining required

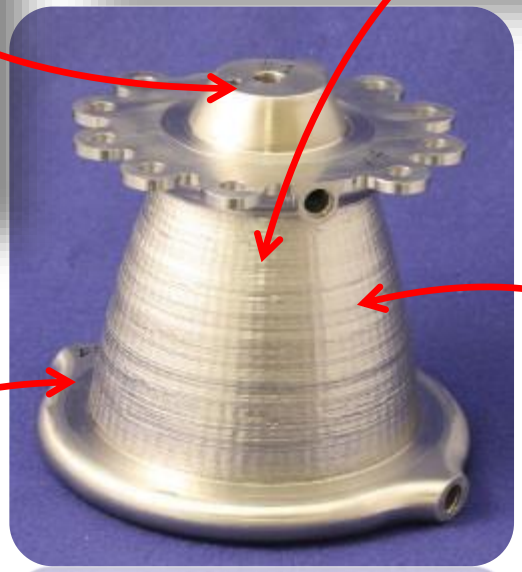


Nozzle #2 – Inco 625 LWDC



Abrasive Water Jet Milling

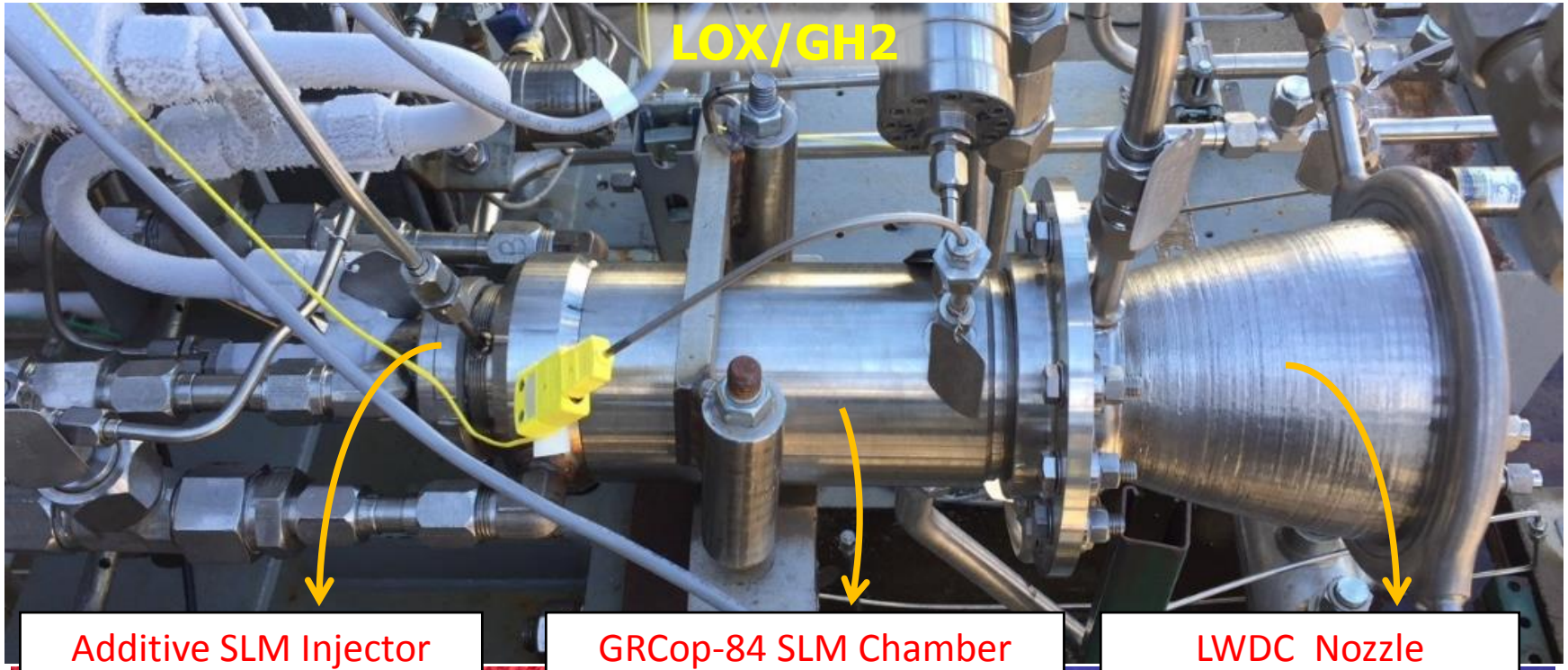
Liner Formed using Arc-Deposition Additive



Traditionally machined manifolds

Laser Wire Direct Closeout

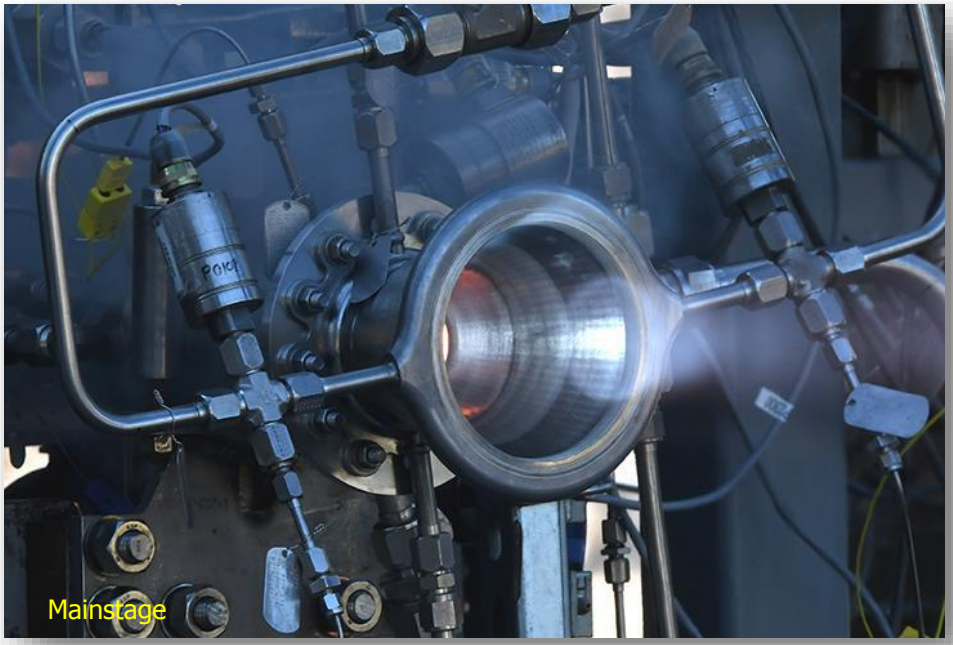
CWN Supporting Test Hardware
All-Additive Thrust Chamber Assembly



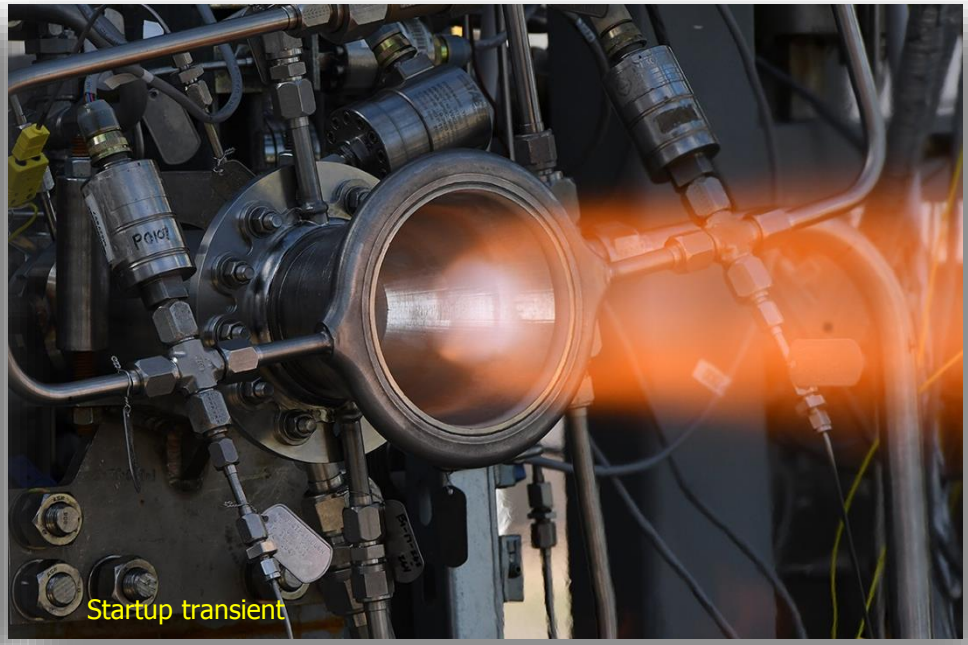
Hot-Fire Testing of LWDC and DED Nozzles

- Completed hot-fire testing at MSFC TS115, November 2017 *(PH034)*
- LOX/GH2, Pc=800 psig and MR = 5.6 – 6.7 (1,200-1,500 lb_f thrust)
- Completed 13 hot-fire tests

Nozzle Identifier and Technique	Starts	Accumulated Time (seconds)
Nozzle #1 - LWDC SS347	4	160
Nozzle #2 - LWDC Inco 625, Fully AM	9	880



Nozzle #1 - SS347

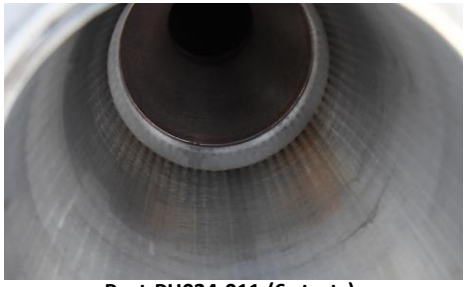


Nozzle #2 - Inco 625, Fully Additive

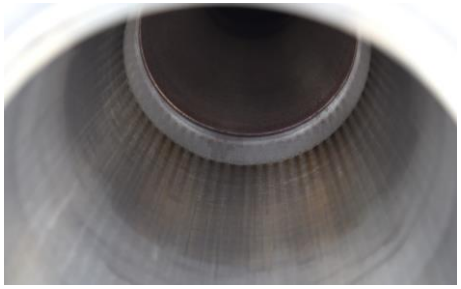
Results of Hot-fire Testing

- ✓ No issues observed with arc-based deposited liner, material behaved as-expected at elevated temperatures and strain ranges
- ✓ Pressure-drop measured during hot-fire testing using water jet milled channels met predictions
- ✓ LWDC closeout performed as-expected during startup and steady state hot-fire loads

Post-PH034-009 (4 starts)



Post-PH034-011 (6 starts)

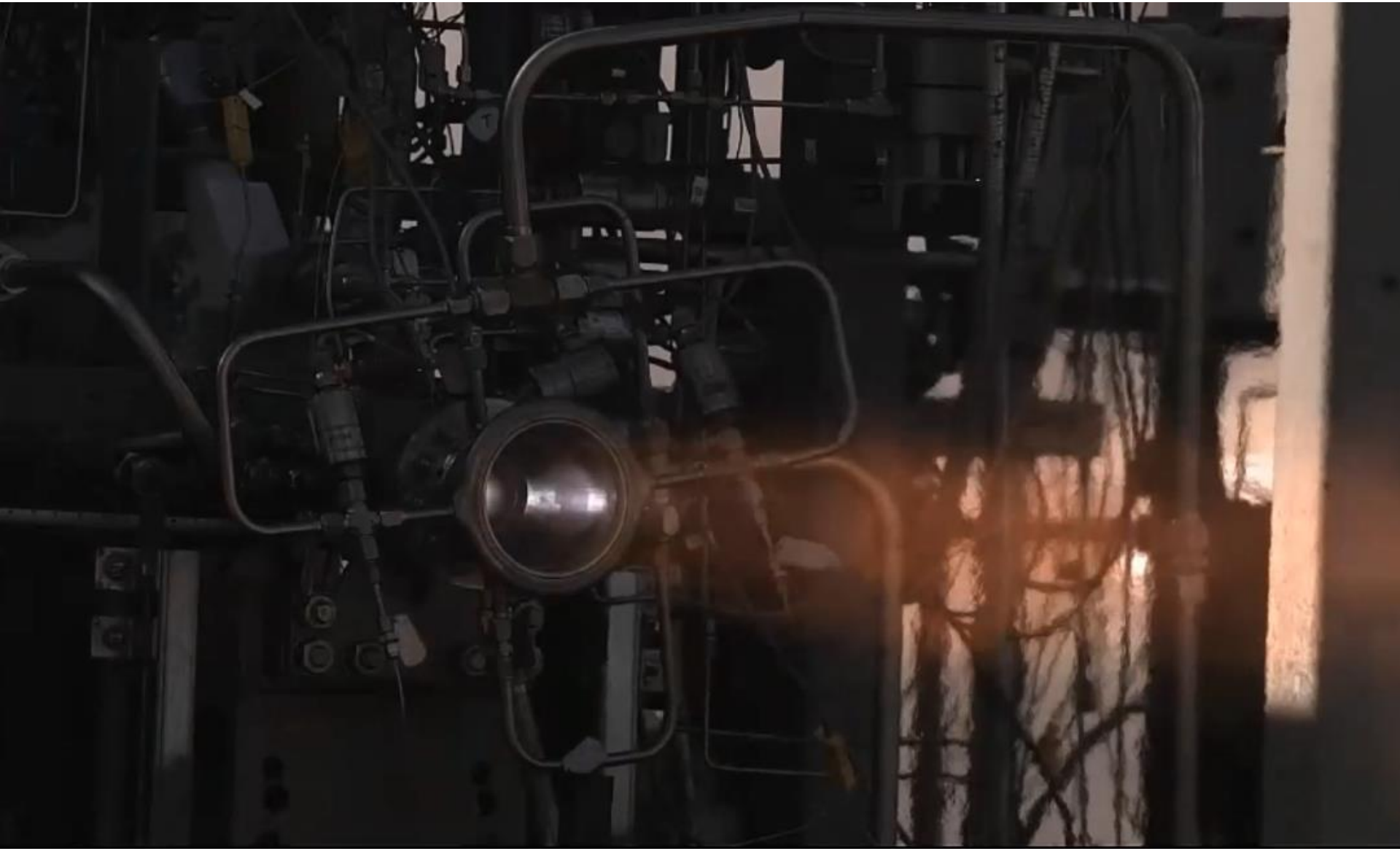


Post-PH034-014 (9 starts), 6 o'clock

Post-PH034-014 (9 starts), 12 o'clock

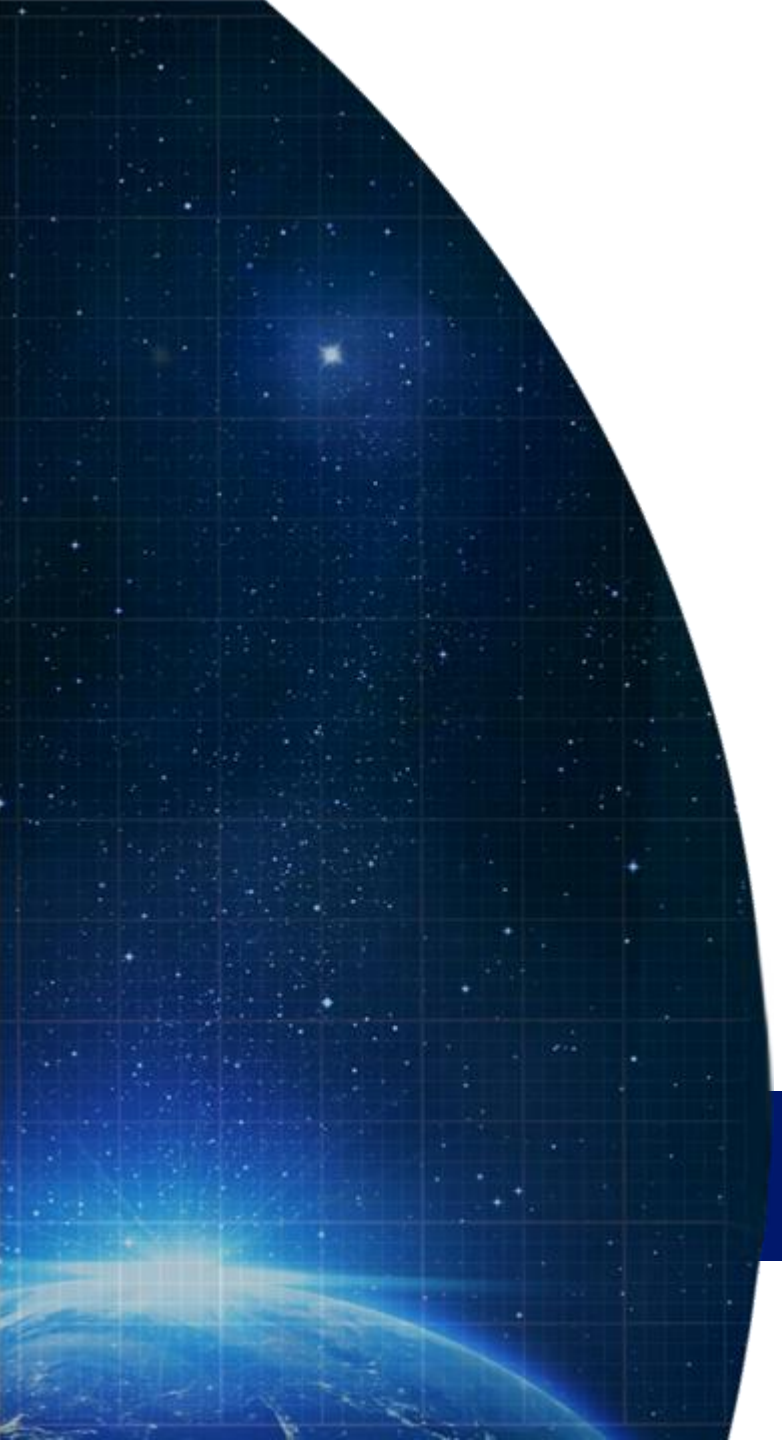
Nozzle #2, LWDC with Arc-based Additive Liner

Video of Hot-Fire Test



Conclusions

- New manufacturing technologies have been developed and advanced for use in channel wall nozzle applications
  - **Deposition techniques offer alternatives for rapid forming liners**
    - Material properties confirmed in mechanical test and hot-fire
  - **Water Jet Milling offers an alternative to slotting for difficult to machine materials**
    - Met pressure drop expectations
  - **Laser Wire Direct Closeout (LWDC) offers a new method for closeout of nozzle and chambers**
    - Demonstrated subscale hardware and process for fabrication
- NASA is continuing to invest in these technologies through Project Funding, IRAD, Space Act Agreements, SBIR/STTR programs and fabricating larger-scale hardware for testing
- The process is continued to be scaled up and hardware being developed
- Alternate materials being investigated including bimetallic hardware
- Data on techniques and vendors available to industry



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Acknowledgments

- Cynthia Sprader
- Test Crew at TS115
- Bryant Walker – Keystone
- Albert Hammeke – Laser Tech
- Dan Alberts – Ormond
- Judy Schneider – UAH
- Dave Brasher – HEMI
- Joe Sims – ASRC Federal
- ProCAM
- Ken Cooper
- Jim Lydon
- Zach Jones
- Omar Mireles
- Dave Ellis
- Bob Carter
- Brad Lerch
- Ian Locci
- Jeff Clounch
- Craig Wood
- Steve Wofford
- Carol Jacobs (retired)
- Mike Shadoan
- John Fikes
- Jim Turner
- Gregg Jones
- Chris Protz
- Chance Garcia
- Jessica Wood

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