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Epitrochoid Power-Law Nozzle
Rapid Prototype Build/Test Project

Mr. Eric J. Paulson-Vehicle Analyst
Rocket Propulsion Division
Combustion devices Branch
Systems Analysis Group

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Epitrochoid Power-Law Nozzle Build/Test Overview

• **Who:**
  – **PM:** Eric Paulson RQRC Systems Analysis Group
  – Partners: Dr. Shelley, Lancaster University Center

• **What:** 6-month Rapid Prototype Build/Test $N_2$ cold flow prototype of Epitrochoid Power-law Nozzle (EPN)

• **Where:** Lancaster University Center (LUC)

• **Why:**
  – Demo initial proof of concept for new 3D multiple plume nozzle
  – Demo new cold flow nozzle manufacture/test approach

• **Cost:** To Be Determined (TBD)
Economics of Decreasing Annual Rocket Engine Production

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Epitrochoid Power-Law Nozzle Build/Test
Build on SpaceX Multiengine Approach

Engines: Merlin 1D on Falcon 9 v1.1 (Photo SpaceX)

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• Falcon 9 launch video here
Epitrochoid Power-Law Nozzle Build/Test
A Type of Radially Lobed Nozzle

Lobed Nozzle Extension for Better Gas Dynamic Incorporation of Modular Thrust Cells Exhaust

- Implementation Requires a Parametric Design of Lobed Shape
- Epitrochoid Planar Curve Fits the Bill

Parameterized by $R_1$, $R_2$, $k$, and $d$

- $R_1$: primary circle radius
- $R_2$: secondary circle radius
- $k$: ratio of $R_1/R_2$
- $d$: normalized generating parameter

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A power-law relationship for R1 primary circle radius as function of x defines a semi-infinite surface from x=0 plane. Adding $x_{\text{min}}$ & $x_{\text{max}}$ bounds creates a diverging radially lobed nozzle extension shape.
Typical Nozzle Test Article Costs

• Multiple nozzle cold-flow testing using traditional manufacture would be prohibitive
  
  — Typically 1-3 test articles tested over 8 week test period in cold-flow facility
  
  — Currently: $30-100k manufacturing cost per metallic test nozzle depending on complexity
  
  — $30k for mechanical design of test article

• NASA-MSFC Rapid Prototyping Demo costs: $3-5K for in-house manufacture & process development, per nozzle

Manufacturing cost reduction of 90-95% per nozzle test article
NASA-MSFC Lessons
New Material Requires New Design Approach

• Weaker than metal
  — distribute flange loads
• Thermal insulator instead of conductor
  — account for thermal gradients
• Avoid multipart designs with lots seals:
  — build in the passages
  — “Cartridge” test article and housing

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• Objectives

  ─ Develop extremely cheap and fast method to build experimental test nozzles
  ─ Develop extremely cheap and fast test rig to bench-level sea-level cold flow test
  ─ Develop cheap/fast method to build lobed Epitrochoid Power-law (EP) nozzle extension
  ─ Demo proof-of-concept cold flow testing of the EP nozzle
Takeaway Questions
Why is This Innovative

• Some related work occurring in industry: metallic additive mfgr demoed/used for small thrust cells, propellant injectors and valve housings

• Cold flow nozzles are being built same way as they were in 1960.
  — EP nozzle: a new way to utilize features of high performance engines advances and the economies of scale of the multi-engine approach of SpaceX Falcon 9
  — Rapid Prototype cold flow testing:
    • Enable order-of-magnitude cost reduction for build
    • Enable extremely rapid, affordable design exploration for 3D classes of nozzles

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Takeaway Questions
What is Success?

• Lots of off ramps to declare success
  – Feasible new quick/cheap cold flow test design approach (criteria=better than current approach with usable wall pressure data)
  – Feasible to build axisymmetric cold flow nozzle test articles using plastic-based inexpensive rapid additive manufacturing
  – Feasible to rapid prototype lobed nozzle extension
  – Feasible lobed nozzle extension
  • Criteria=demo proof-of-concept for stable full-flowing lobed nozzle at sea level

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Why Choose to Work This Project?

• Fame, glory, and the accolades of your peers…

• Opportunity to legitimately call yourself a rocket engineer

• Chance to work on something cutting edge
  – No other teams in US working on low cost cold-flow test nozzle designs currently
  – The lobed epitrochoid power-law nozzle concept is new and original: you’re looking at the inventor

• Opportunity to publish/present the initial results for what may continue into a bigger program

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