Program Update

FAA Continuous Lower Energy, Emissions and Noise (CLEEN) Program

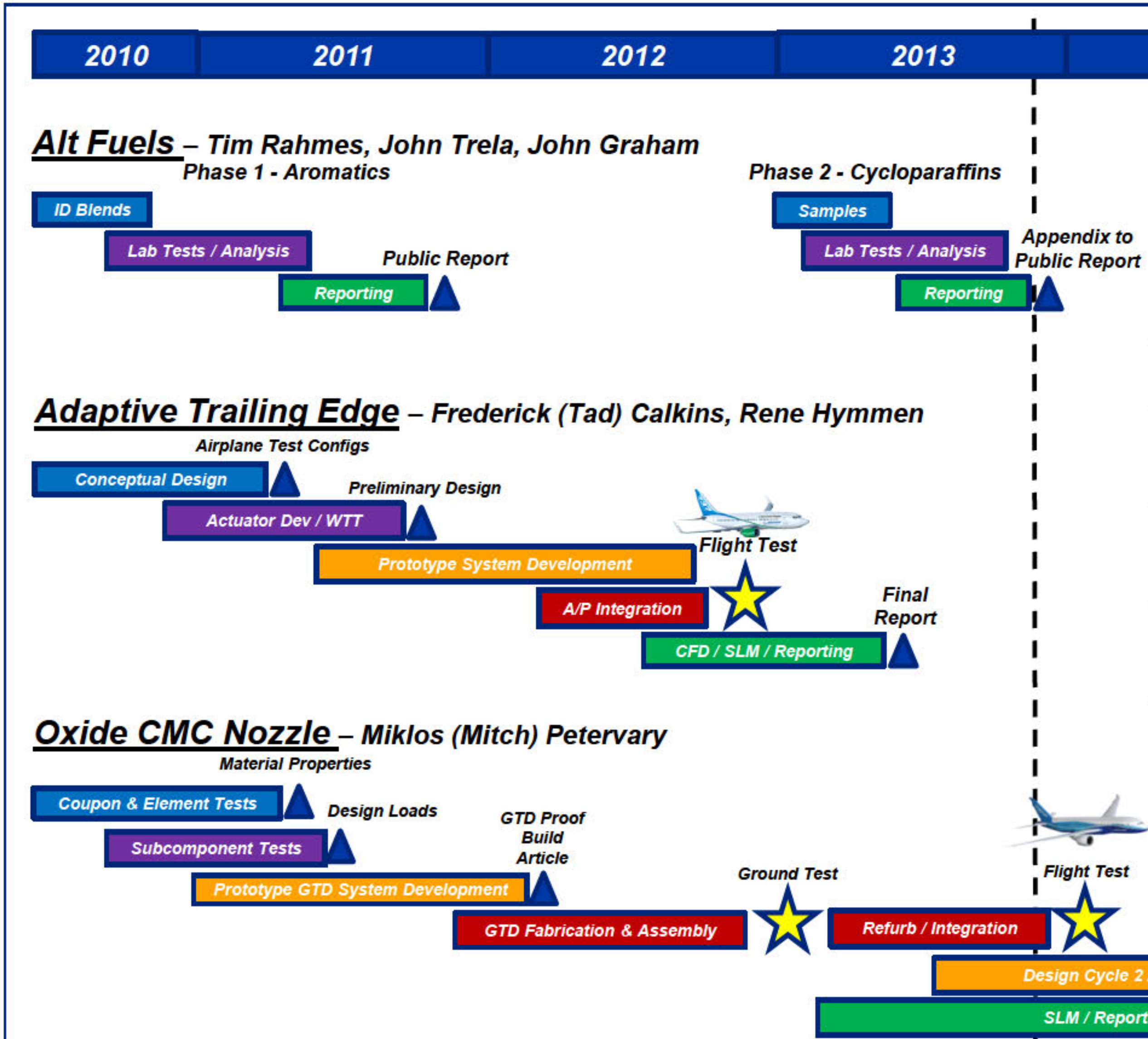
Craig Wilsey, Program Manager
CLEEN Consortium, Public Session
Atlanta, GA
November 20, 2013

Approved for Public Release

Agenda

- Boeing CLEEN Technologies
- Adaptive Trailing Edges
- CMC Nozzle
- Alternative Fuels

Boeing CLEEN Technologies



Technology		Goal Impact
Fuel system material swell & fuel absorption		Alt Fuels
Adaptable Trailing Edges		Fuel-burn Noise
Ceramic Matrix Composite Acoustic Nozzle		Fuel-burn Noise

Adaptive Trailing Edges

Rene Hymmen, IPT Lead
F. T. Calkins, Principle Investigator
J. Larssen, Noise Lead
T. Sclafani, HS Aero Lead
D. Lacy, LS Aero Lead
S. Bieniawski, controls Lead
J. Mabe, Actuation Lead
B. Griffiths, Test Lead

Adaptive Trailing Edge

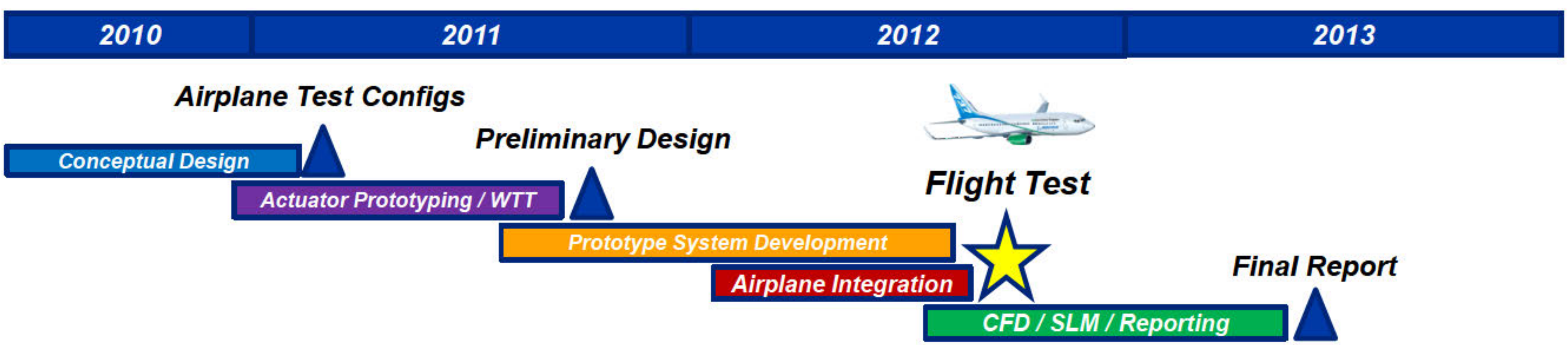
Objective:

- Develop and demonstrate a prototype adaptive trailing edge system capable of tailoring wing performance to reduce noise and fuel burn at different flight regimes

Work Statement:

- Conduct technology survey, CFD analysis and wind tunnel testing to predict potential performance and define demo system architecture
- Evaluate airplane-level performance impacts of ATE system through CFD models and ground testing
- Develop and integrate prototype ATE system into airplane and demonstrate actuation and control system in flight (TRL 7)

Potential Transition: New and Derivative Airplanes



ATE Flight Test Configurations

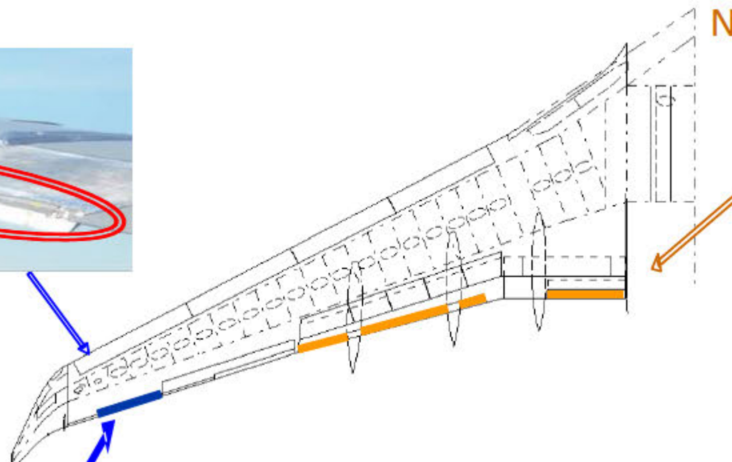
Actuated Mini Plane Flap

30 deg up to 60 deg down

Inboard, Outboard Flap

Non-Actuated Mini Split Flap Wedge

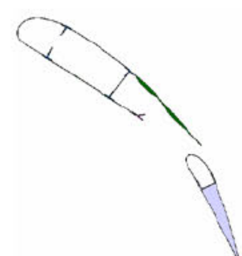
2% Chord, 60 Deg wedge



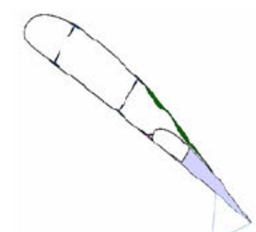
Actuated Mini Split Flap

Faired to 60 deg down

Double-Slotted Flap Baseline



Single-Slotted Flap with Wedge (simulated MSF)



Aft flaps pinned in stowed position within main flaps to replicate single-slotted flaps for MSF testing

MSF modeled as a fixed wedge bonded to flap lower surface at its TE

Flight Test

Objectives

- Test 6 configurations (MSF, MPF, Wedges)
- Generate aero and loads data for high and low speed flight conditions
- Generate community noise data for take off and approach
- Demonstrate closed loop feedback control of mini-flap
- Test single slotted flap and simulated mini-split-flap at low speed
- Simulate mini flap system failure modes

Airplane instrumentation

- Pressure belts
- Accelerometers
- Thermocouples
- Strain Gages
- Kulites
- Flow Cones

Ground instrumentation

- Ground Weather Station
- Community Noise Certification Microphone array
- Phased Array

ATE Flight Test completed Sept '12
Glasgow, MT

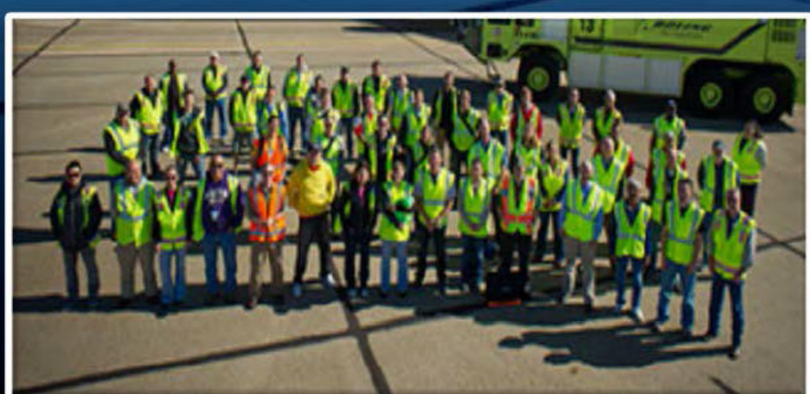


Photo: Bob Ferguson

ATE Accomplishments

- ✓ Technology Survey, System Design
- ✓ Low Speed Wind Tunnel Test
- ✓ Prototype System Developed, Tested
- ✓ Airplane Integration & Ground Test (TRL 6)
- ✓ Flight Test Completed / Report (TRL 7)
- ✓ Post Test Analysis / SLM Completed
- ✓ Final Report Delivered

CMC Acoustic Exhaust

M. Petervary, Principle Investigator
C. Frankel, Development Lead
B. Smith, Ground Test Integrator
T. Pinney, Design Lead
W. Keith, Analysis Lead
E. Tong, Dynamics
L. Lehman, M&P Lead

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CMC Acoustic Nozzle

NextGEN CLEEN

Objective:

- Demonstrate material system that can enable lighter, quieter, more efficient engines
- Design, fabricate and demonstrate an acoustic ceramic matrix composite (CMC) primary exhaust system

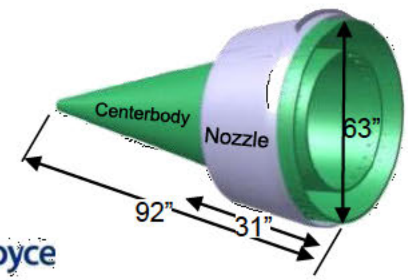
Work Statement:

- Conduct Coupon, element & subcomponent testing, establish design loads, validate design tools / methods
- Conduct Proof of Concept Build at full scale
- Test Prototype system in ground demonstration (TRL 6)
- Demonstrate prototype system in flight (TRL 7)

ATK

ALBANY Engineered Composites

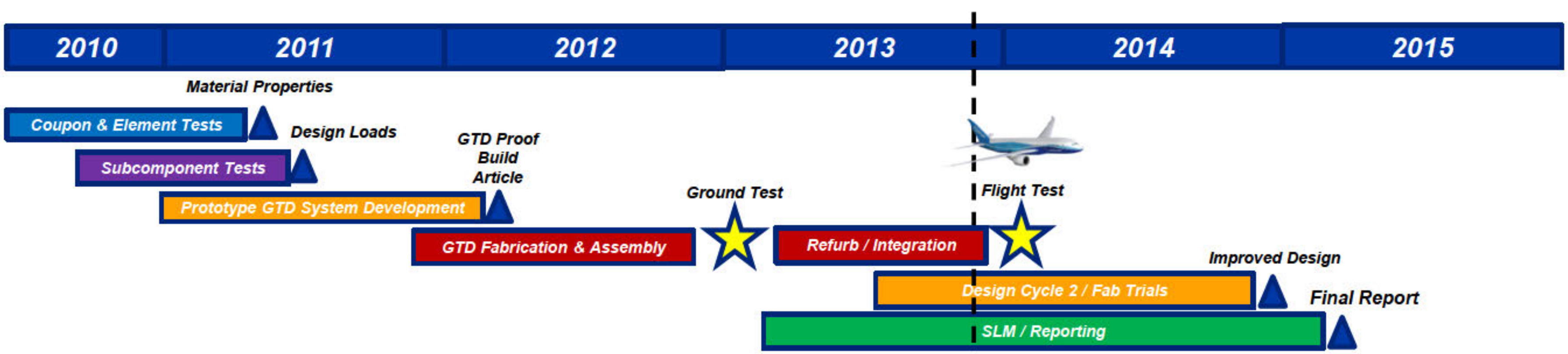
Rolls-Royce



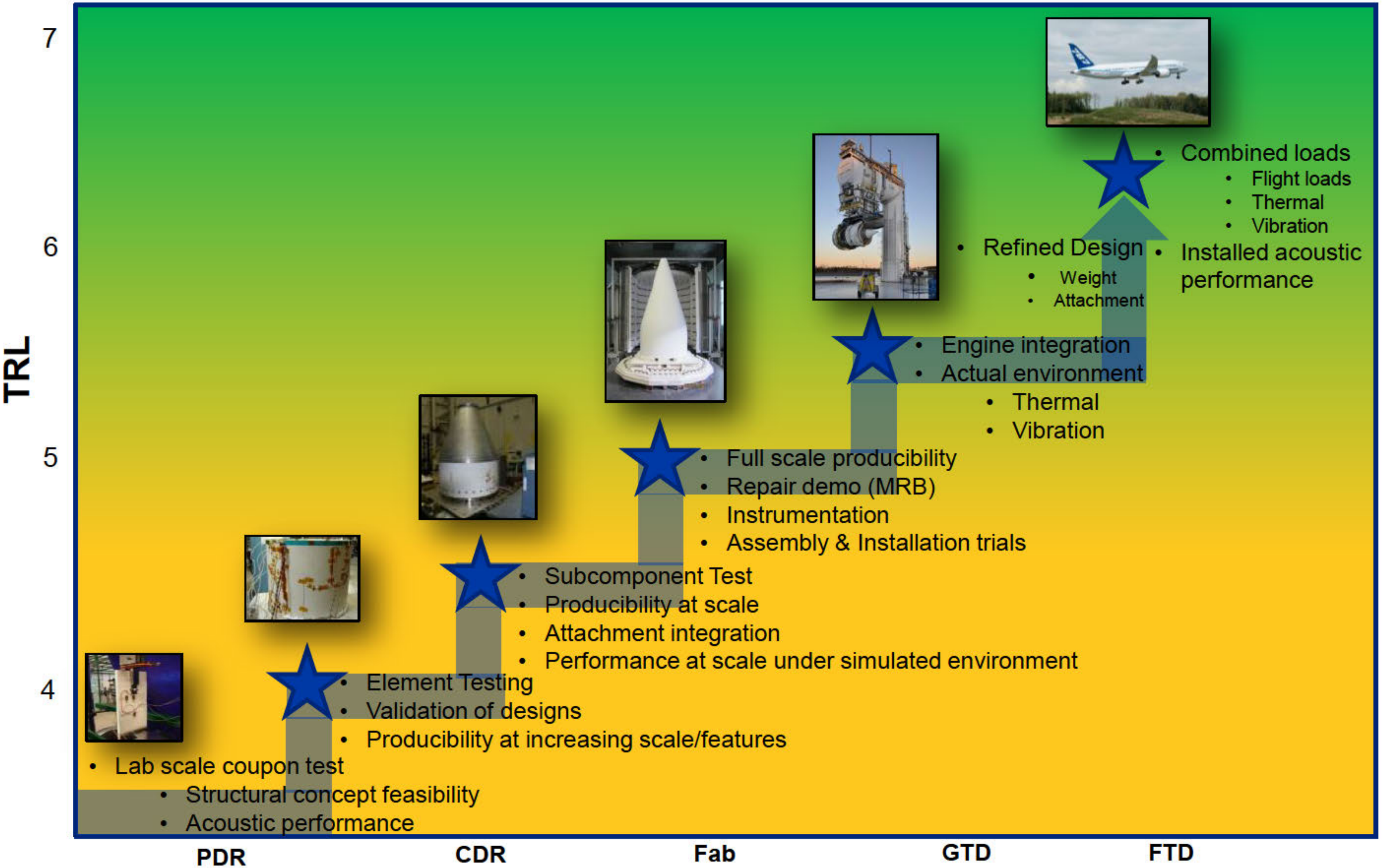
Baseline Material: 2D N610/AS Oxide CMC

Baseline Demonstration Engine: Rolls Royce Trent 1000

Potential Transition: Future Products and Derivatives



Building Block Approach



Ground Test 1Q13

Objectives

- Verify structural integrity of exhaust system and attachment hardware
    - steady-state & transient loads
- Validate/correlate temperature predictions
- Demonstrate installation on Trent 1000 engine
- Accumulate engine run time & cycles to qualify for FT

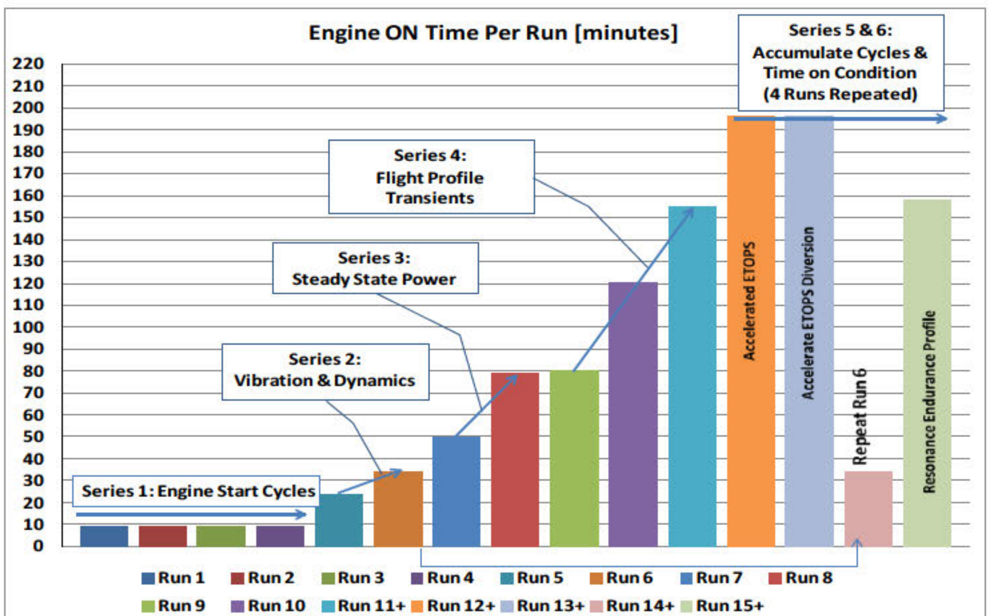
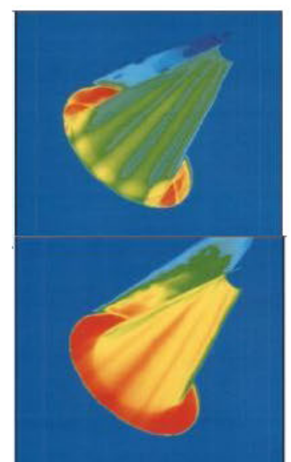
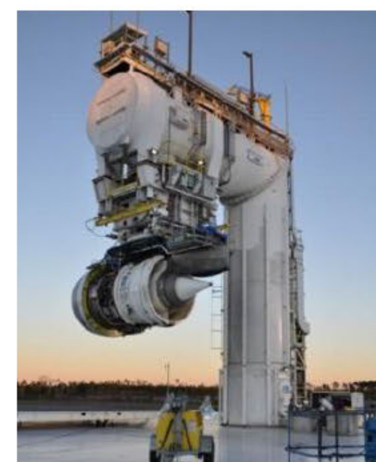


Photo Courtesy Rolls Royce





CMC Nozzle Ground Test completed Feb '13

RR Test Facility Stennis, MS

- 4.5 weeks of powered testing
- 38 runs, 75 hrs on condition
- All objectives met or exceeded

Data Acquired (125+ channels)

- Thermal (on and off body)
- Loads, Stress
- Dynamics (on and off body)
- Repair techniques

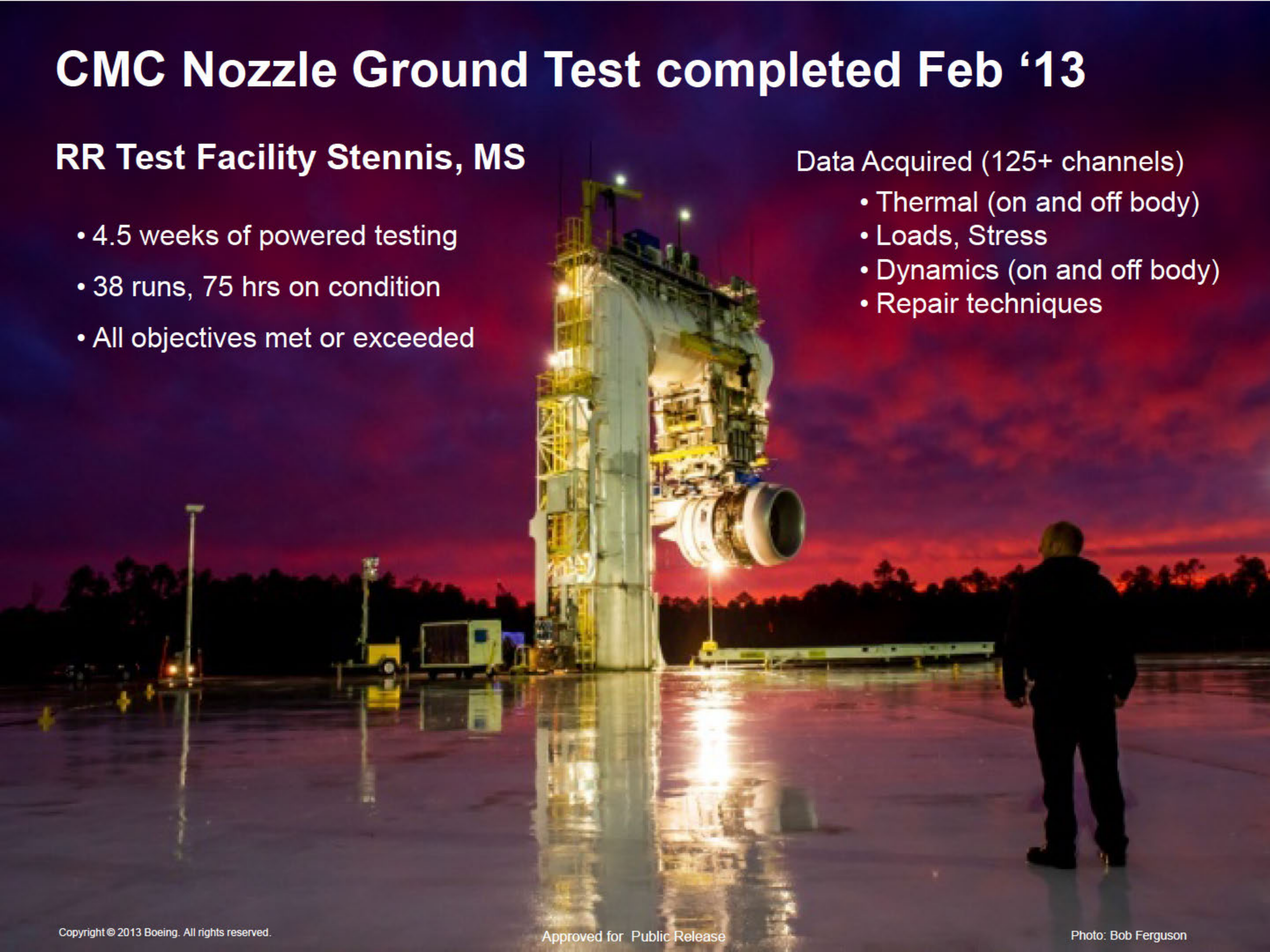


Photo: Bob Ferguson

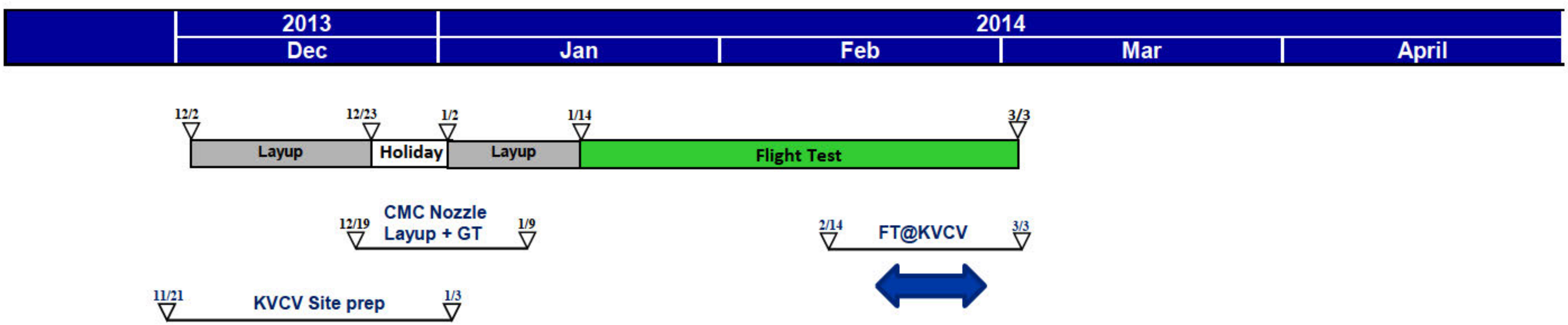
Preparing for Flight Test 1Q14

Objectives

- **Verify structural performance in flight**
  - Combined thermal/structural in-flight loads
  - Flight g-loads & vibrations
  - T/R deployment loads
- **Evaluate acoustic performance comparatively against baseline titanium acoustic exhaust.**
- **Accumulate as many flight hours on CMC exhaust system as possible**

Flight Test Planning

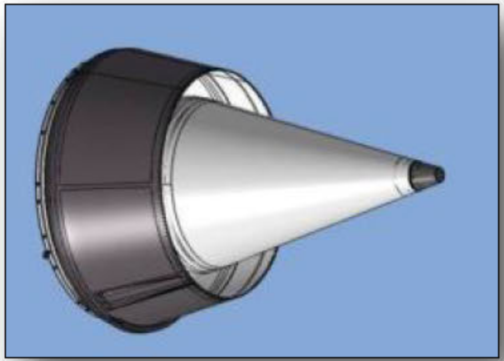
- **Preparing to receive flight test aircraft**
- **Detailed Test Plans are complete for CMC Nozzle**
  - Community Noise
  - Up and Away testing
  - Endurance – accumulation of flight hours
- **Reviewing multiple test schedule scenarios with program**
  - Specific Test Start date being defined
- **Preparing Victorville, CA site for remote testing**

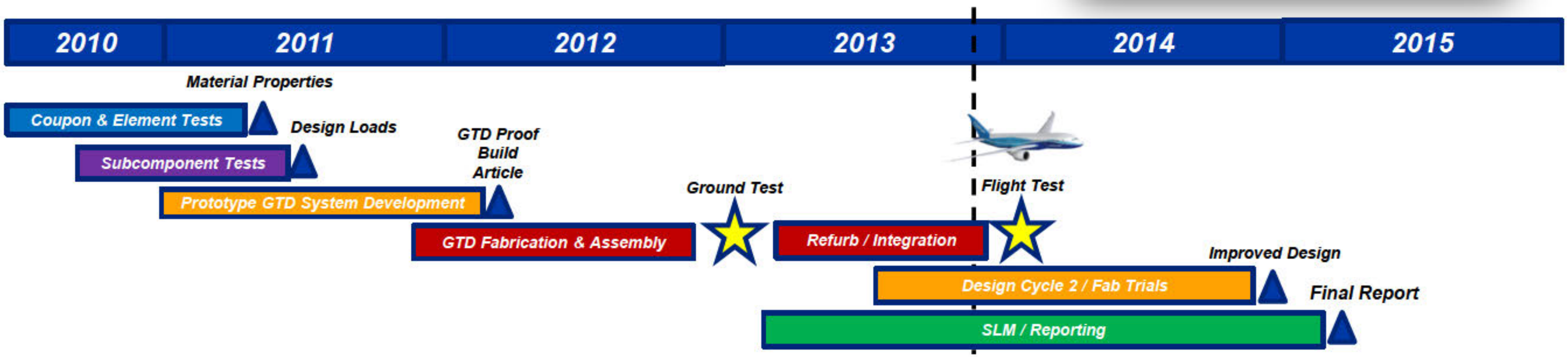


CMC Exhaust Readied for Flight Test

CMC Nozzle Accomplishments

- ✓ Coupon, Joint & Acoustic Element Tests
- ✓ Subcomponent Test
- ✓ Successful Proof of Concept Build
- ✓ Repair Demonstration
- ✓ Ground Test (TRL 6)
- ✓ Flight Test Planning
- ✓ Hardware Refurbishment
- Flight Test 1Q14 (TRL 7)
- 2nd Design/Fabrication Cycle





CMC Nozzle Team

Boeing

Craig Frankel, Project Lead
Brian Smith, Ground Test Lead
T Pinney, Design Lead
Leanne Lehman, M&P Lead
Patrick Mobers, M&P
Bill Keith, Analysis Lead
Edward Tong, Dynamics
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Albany Engineered Composites

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ATK/COIC

Steve Atmur, Vijay Parthasarathy,
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NASA

Mike Jones, Dennis Fox
Doug Kiser, Joe Grady

Rolls-Royce

Dave Bull, Charlie Harrison,
Andy Brown, Martin Flanders & the
entire Stennis Team

Alternative Fuels – Seal Swell

Evaluating the Impact of SPK Fuels and Fuel Blends on Non-metallic Materials used in Commercial Aircraft Fuel Systems
Addendum: Cycloparaffins

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Steven A. Millett
Jean Ray
William L. Vannice

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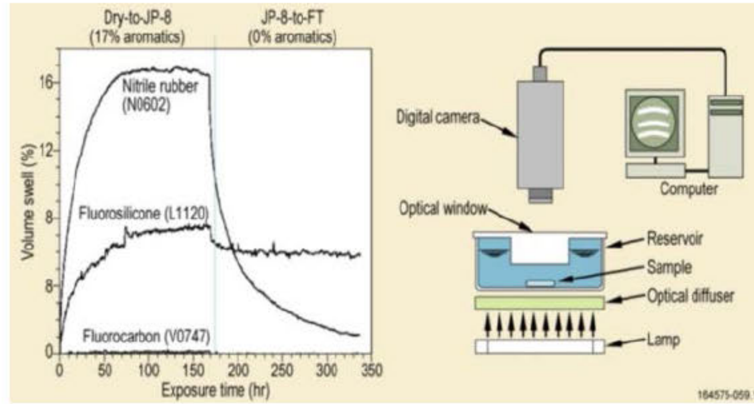
Alternative Fuels Testing

Objectives:

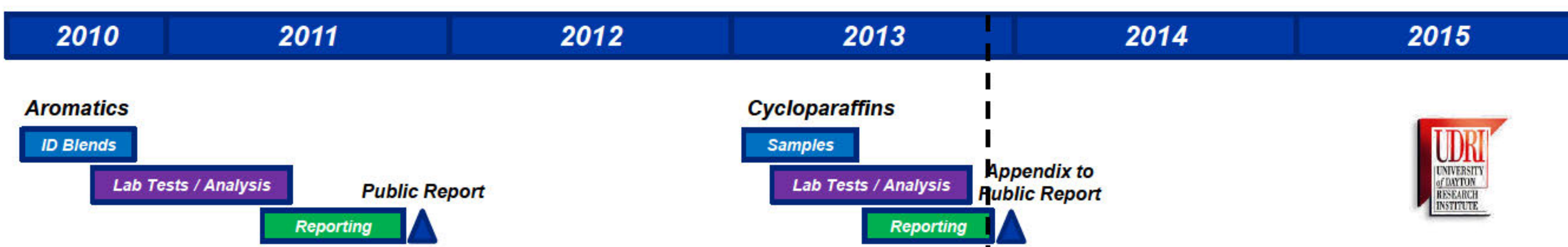
- Evaluate the impact of SPK Fuels and Fuel Blends on Non-metallic Materials used in Commercial Aircraft Fuel Systems
- Generate data to help industry determine effects of the type and concentration of Aromatic and Cycloparaffins on material properties (e.g. seal swell)
- Help enable alternative fuel blends greater than 50% content



Work Statement:

- Select sample fuel blends for analysis
- Measure composition of fuel absorbed by materials for variety of fuels/blends. Establish statistical bounds for behaviour of typical fuel system material
- Conduct volume swell test for common components such as O-rings, sealants and coatings
- Produce Public Report

Potential Transition: Support to "Drop-In" renewable fuel replacement strategies



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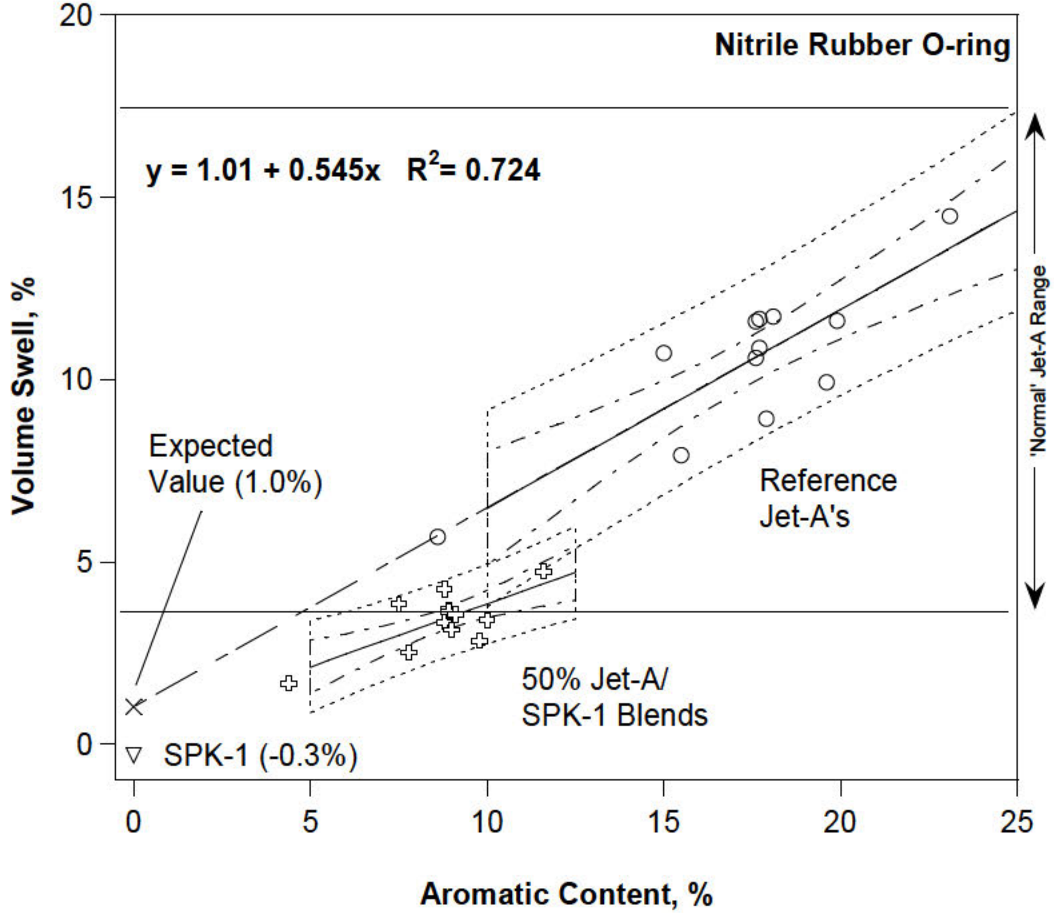
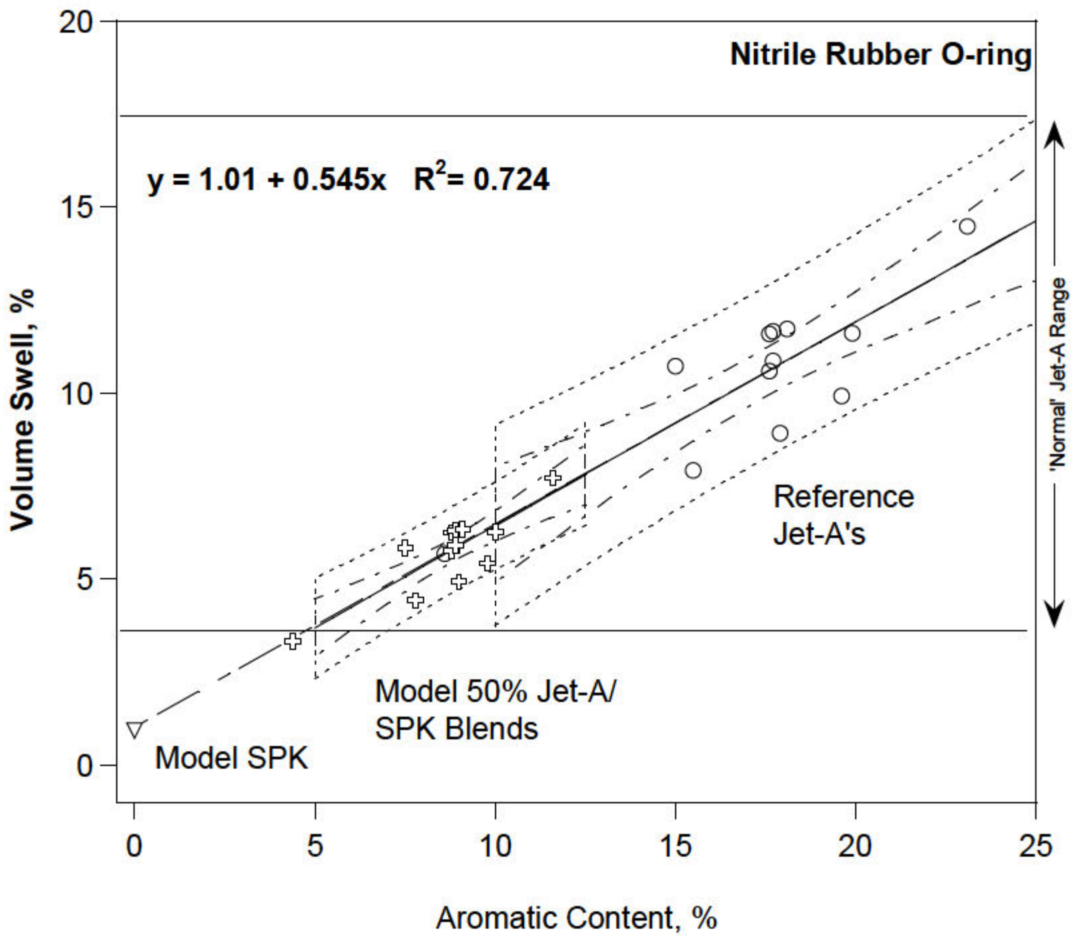
Aromatic Study Example Results

NextGEN CLEEN



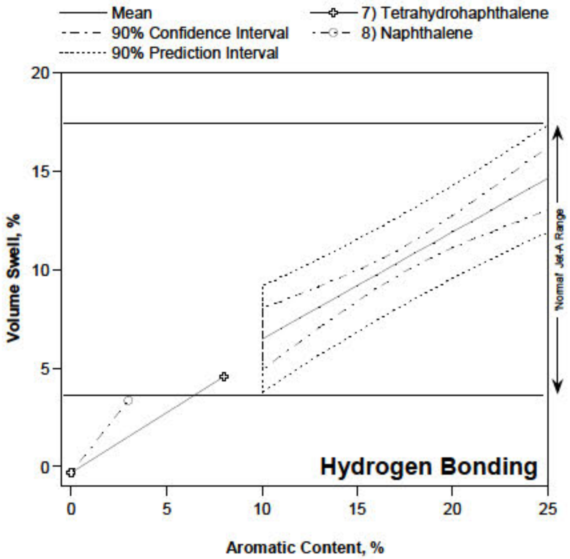
Neat SPK fuels tend to under-swell polymers as compared to the expected value for a fuel with 0% aromatics.

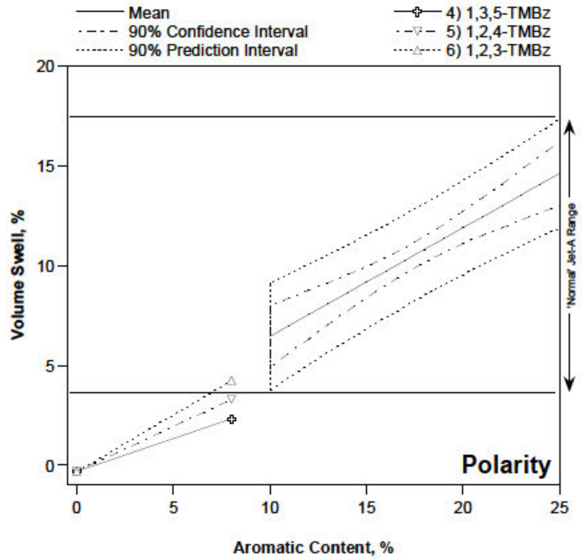
Model Fuel Blends w/ Improved Blending Stock

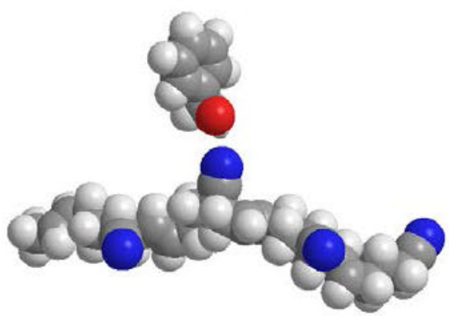


If an SPK could be produced that matches, or exceeds, the expected value, the volume swell of the SPK blends could be greatly improved.

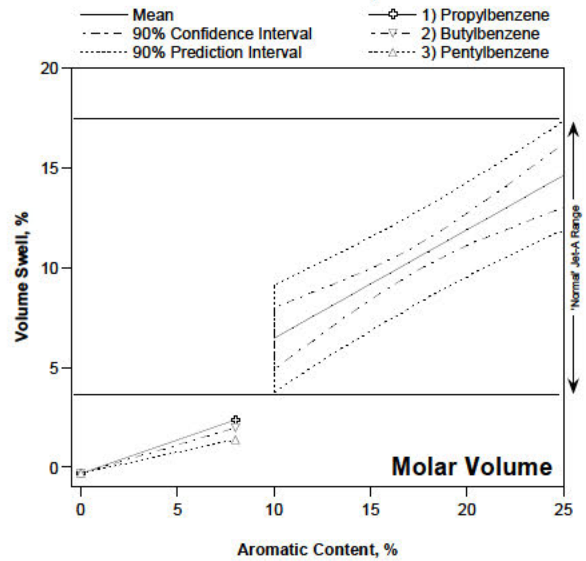
Aromatic Study: Example Results







Nitrile Rubber



It was found that the strength of interaction between specific components of the fuel and polymeric materials is the result of a complex series of fuel-fuel, polymer-polymer, and polymer-fuel interactions.

Generally, however, it was found that volume swell tends to increase as the polarity and hydrogen bonding of the fuel components increase and as their molar volume decreases

These rules apply to ***all*** fuel components including the alkanes, aromatics, and fuel additives

This formed the foundation for understanding a specific peculiarity we noticed in the volume swell of many alternative fuels

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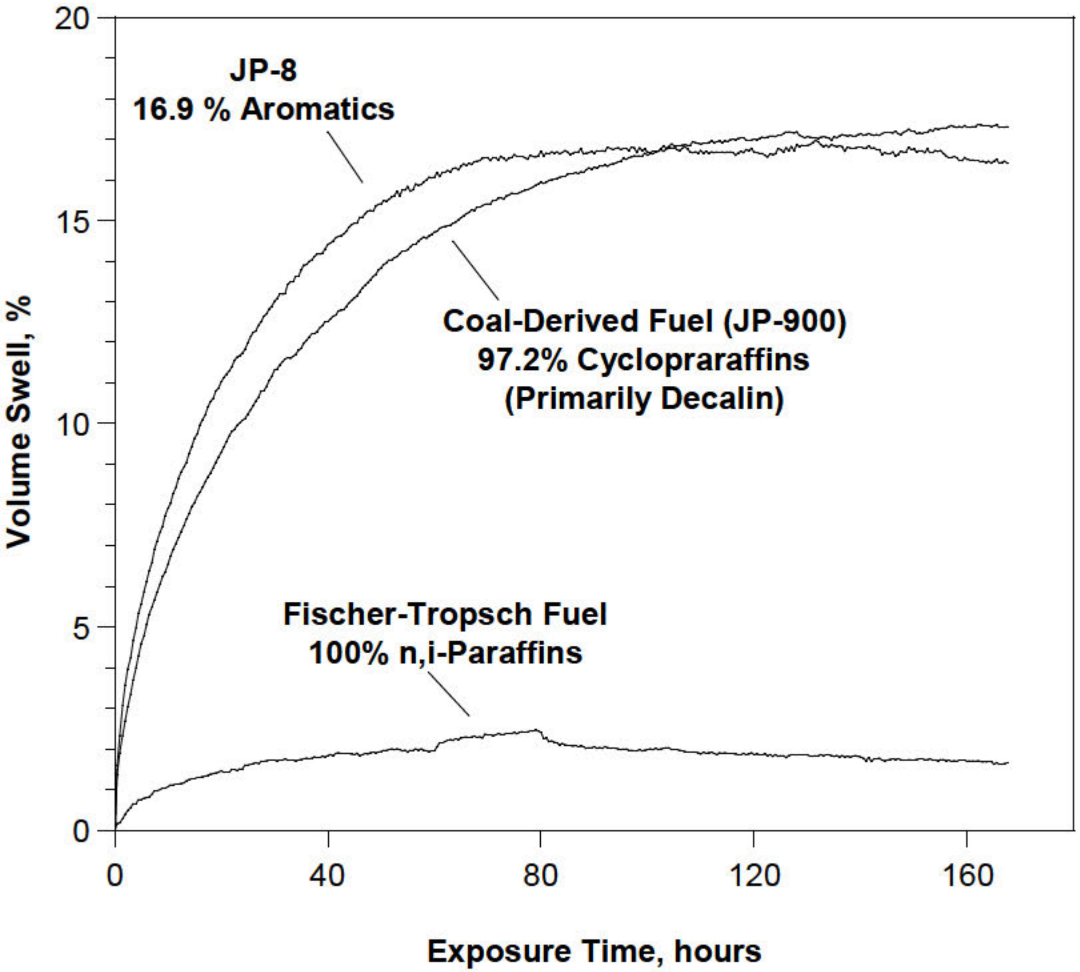
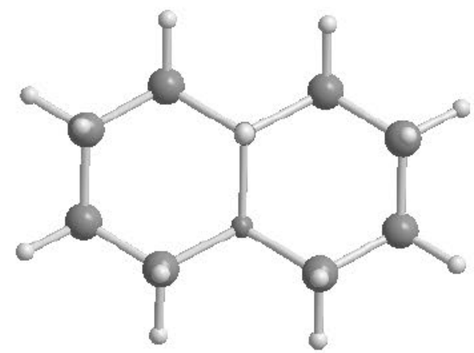
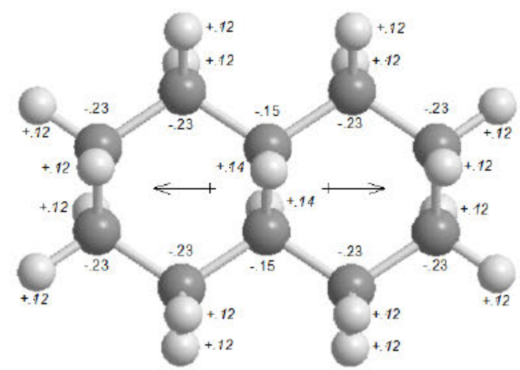
Jet Fuel (JP-900) Derived From Liquefied Coal





Molar Volume

n-Decane	Cyclodecane	Decalin
195 mL/mol	161 mL/mol	157 mL/mol



Charge Distribution

Limited Conformations (?)

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Approach

- Measure the volume swell of selected materials in an example synthetic paraffinic kerosene (SPK) with 0% aromatics dosed with a series of cycloparaffins selected to isolate specific molecular characteristics
- Obtain supporting data in the form of an analysis of the absorbed fuel to measure the solubility of the selected cycloparaffins
- Demonstrate the effectiveness of at least one selected cycloparaffin by measuring the volume swell of a set of 50% SPK/Jet-A fuel blends where the SPK blending stock is prepared with and without the selected cycloparaffin

Volume Swell by Optical Dilatometry

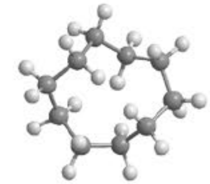
Analysis of Absorbed fuel by GC-MS

Selected Molecular Characteristics

Ring Size

Cyclohexane

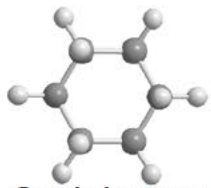
Cyclooctane



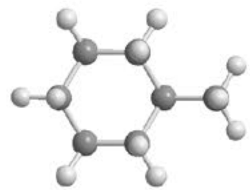
Cyclodecane

Cyclododecane

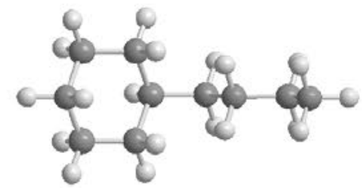
Molar Volume



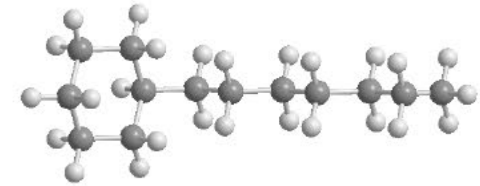
Cyclohexane



Methylcyclohexane



Butylcyclohexane

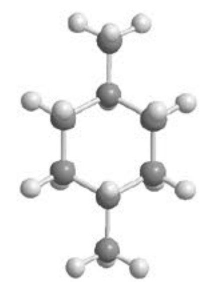


Heptylcyclohexane

Substitution Pattern

1,2 dimethylcyclohexane

1,3 dimethylcyclohexane

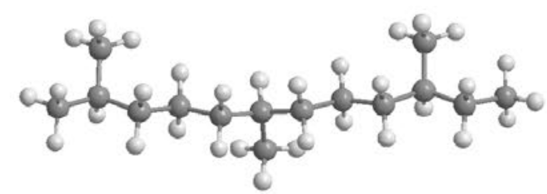


1,4 dimethylcyclohexane

Multiple Rings

Decalin

Adamantane (5%)



Farnesane (2,6,10-Trimethyldodecane)

Test Materials

Component	Material	Sample ID
O-Rings	Nitrile Rubber	N0602
	Extracted Nitrile Rubber*	N0602e
	Fluorosilicone	L1120
	Low Temp Fluorocarbon	V0835
Sealants	Lightweight Polysulfide	PR 1776
	Polythioether	PR 1828
Coatings	Epoxy	BMS 10-20
	Epoxy	BMS 10-123
Films	Nylon (6,6)	Nylon
	Kapton	Kapton

* Nitrile rubber with its plasticizer extracted.

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Reference & Test Fuels

NextGEN CLEEN

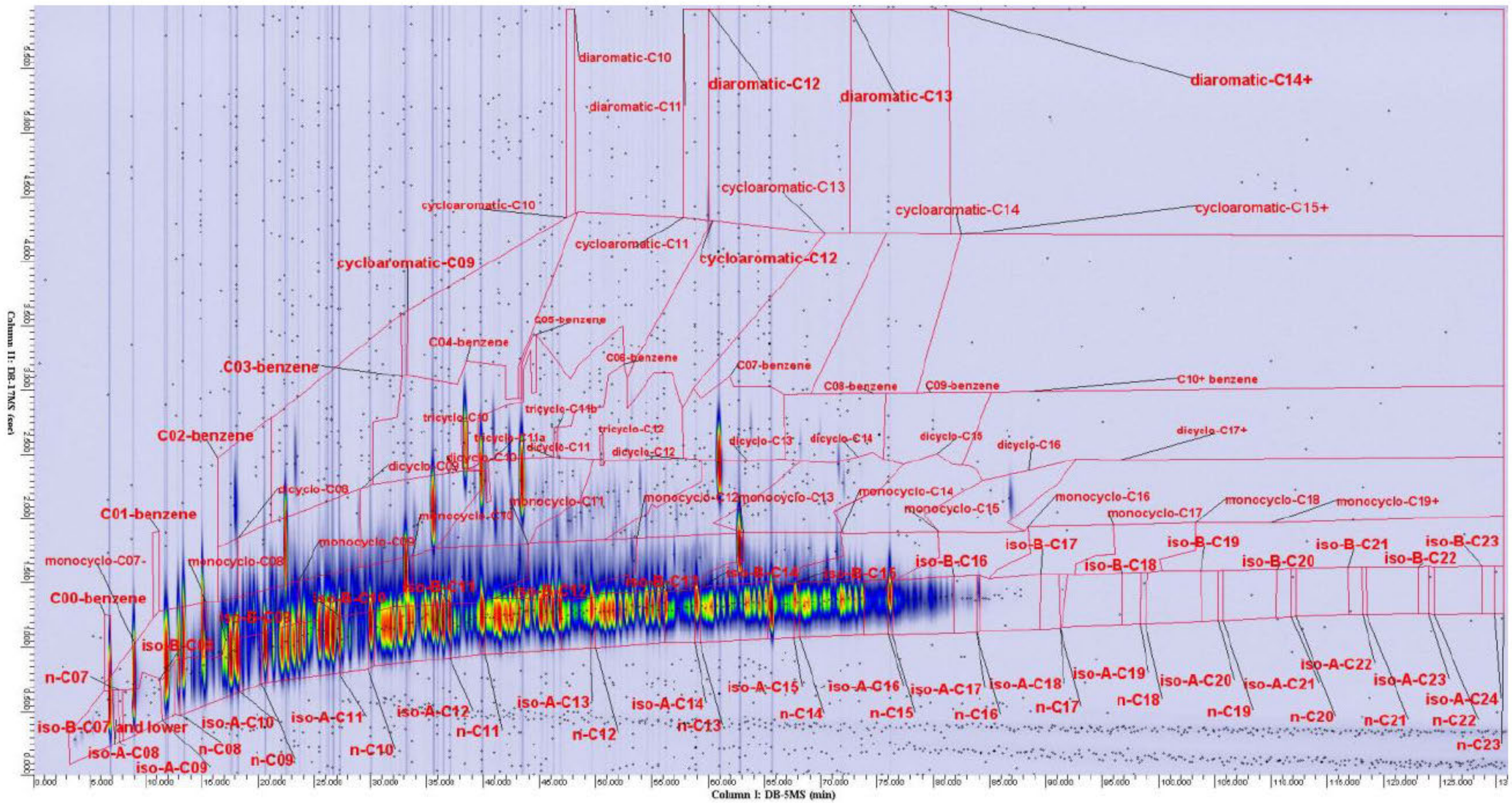
Fuel	ID	Aromatics	Naphthalenes	Cycloparaffins	Notes
Jet-A	SRI-1	8.7%	0.2%	n.a.	Clay-treated JP-8
	4597	15.0%	1.9%	28%	Jet-A
	5245	15.5%	0.2%	30%	Jet-A
	3166	17.6%	2.5%	38%	Jet-A
	4598	17.6%	1.4%	n.a.	Jet-A
	4600	17.7%	1.3%	29%	Jet-A
	4658	17.7%	1.3%	30%	Jet-A
	4626	17.9%	0.6%	23%	Jet-A
	5661	18.1%	0.6%	40%	Jet-A
	4877	19.6%	0.4%	25%	Jet-A
	4599	19.9%	1.4%	29%	Jet-A
	3602	23.1%	1.1%	38%	Jet-A
Average		17.4%	1.1%	31%	Average Jet-A
SPK	SPK-1	0.0%	0.0%	2%	Jatropha

12 reference Jet-A fuels with 8.7%-23.1% aromatics and 23%-40% cycloparaffins

1 SPK blending stock (Jatropha) with 0% aromatics and 2% cycloparaffins

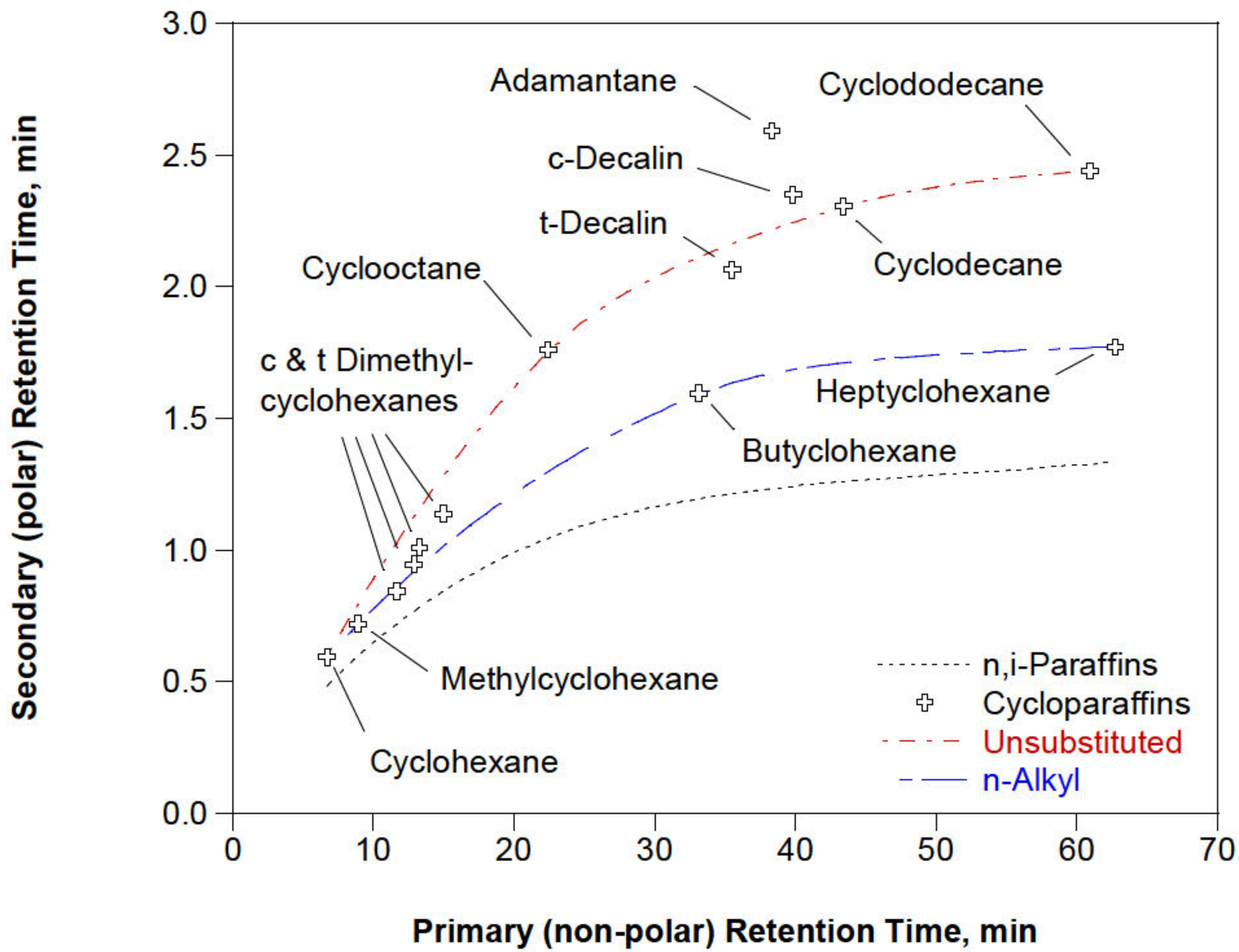
30% v/v was selected as the concentration of the cycloparaffins in the SPK

Selected Cycloparaffins GC x GC Analysis



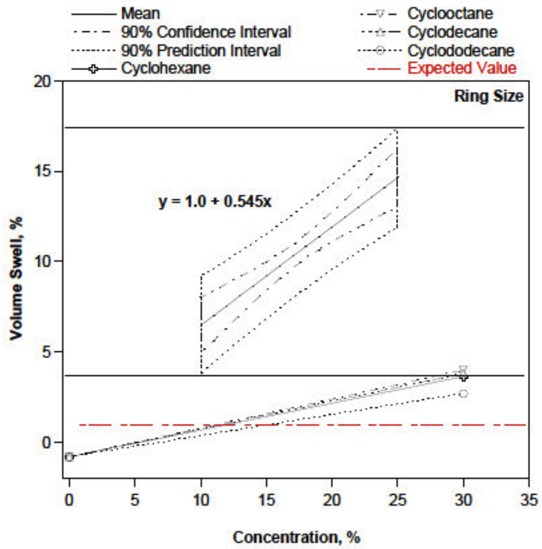
GC x GC analysis of SPK-1 blended with each of the selected cycloparaffins

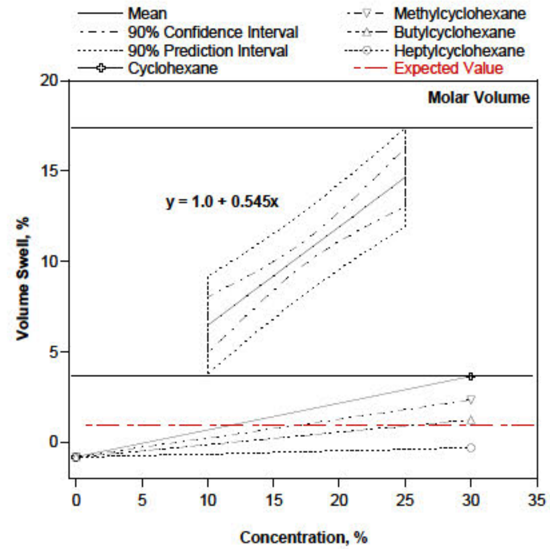
Selected Cycloparaffins GC x GC Analysis

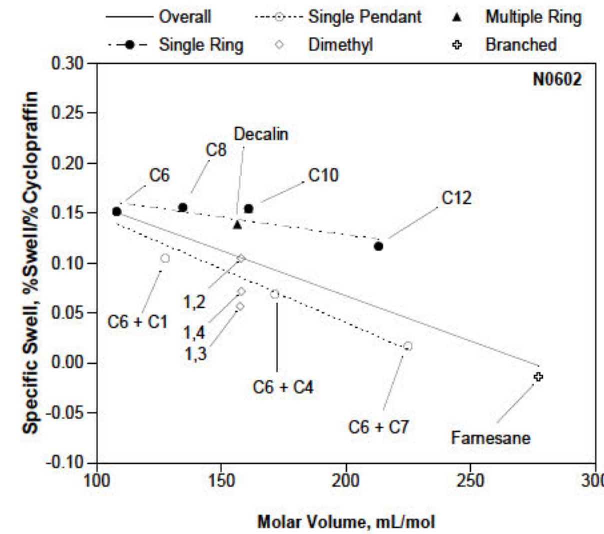


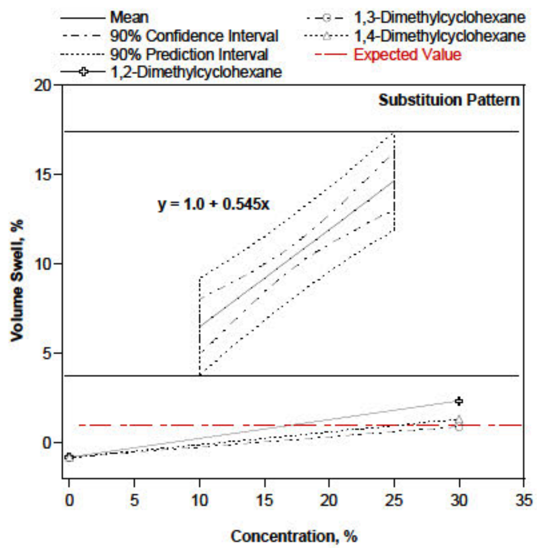
GC x GC analysis of SPK-1 blended with each of the selected cycloparaffins

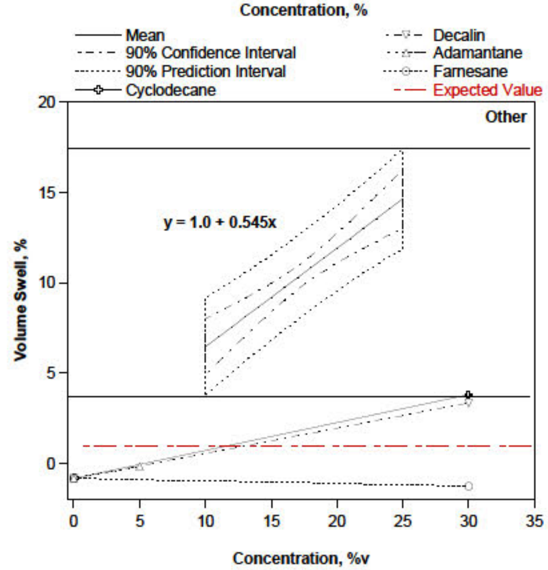
O-rings
N0602 Nitrile Rubber

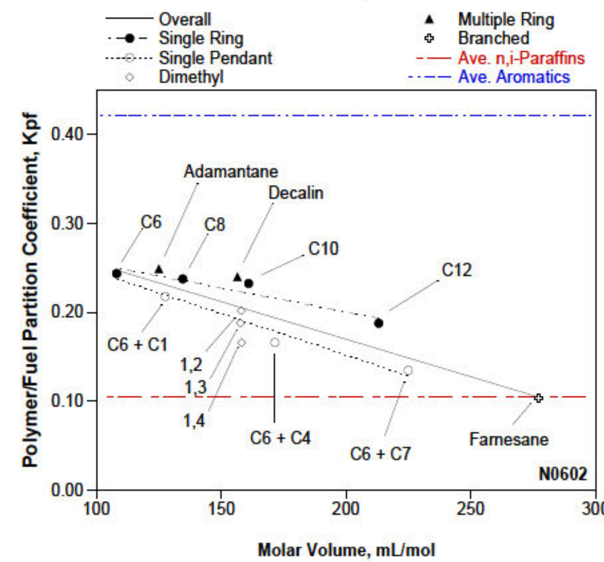




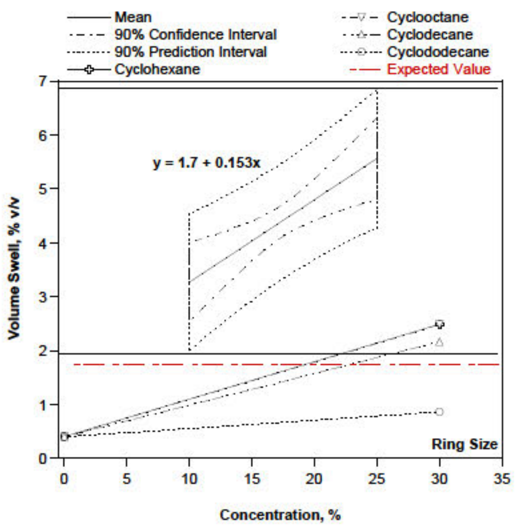


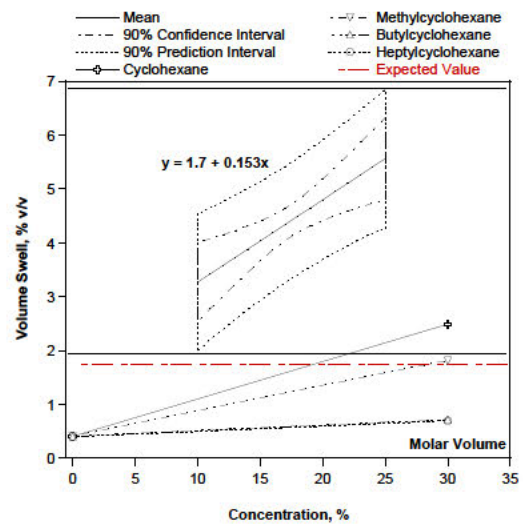


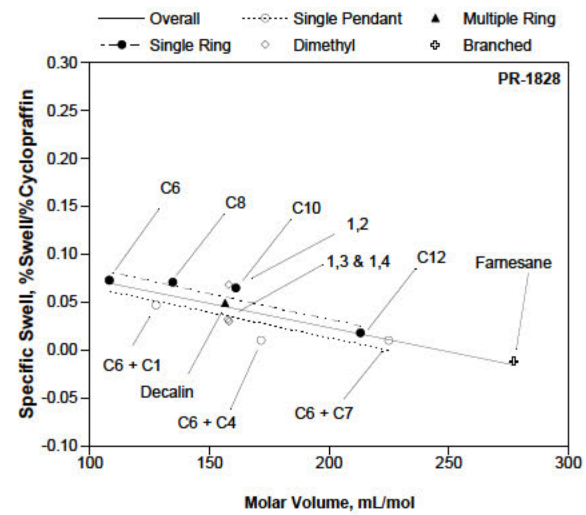


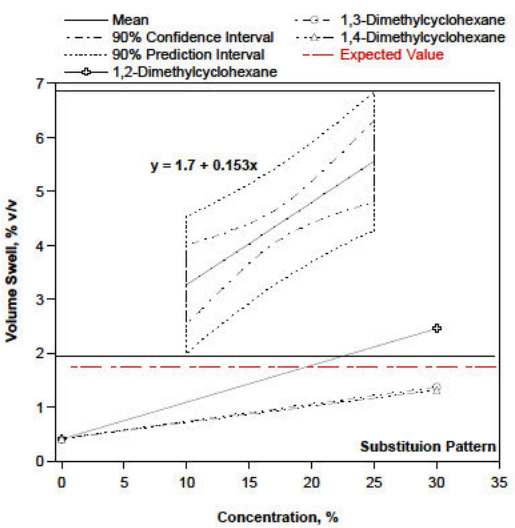


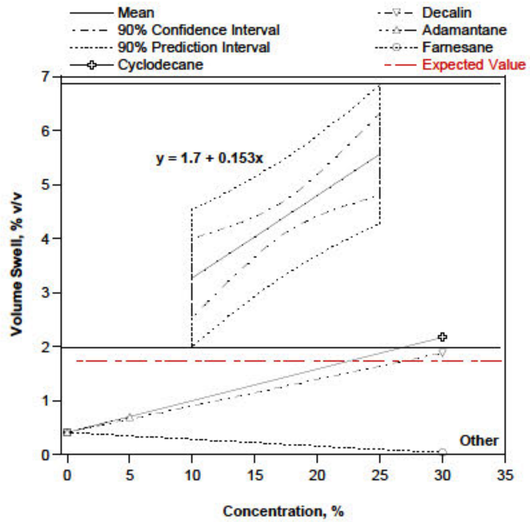
Sealants: PR-1828 Polythioether

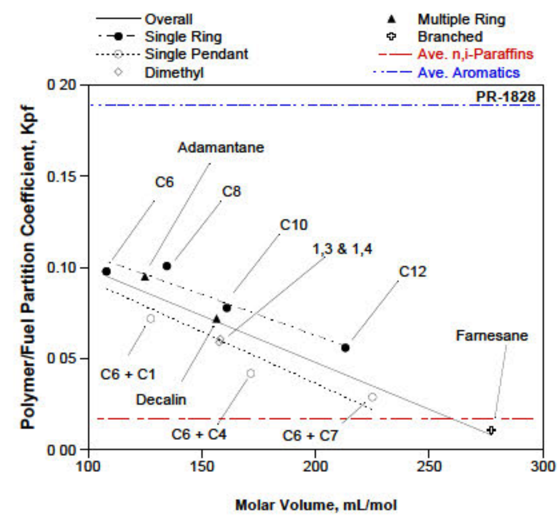




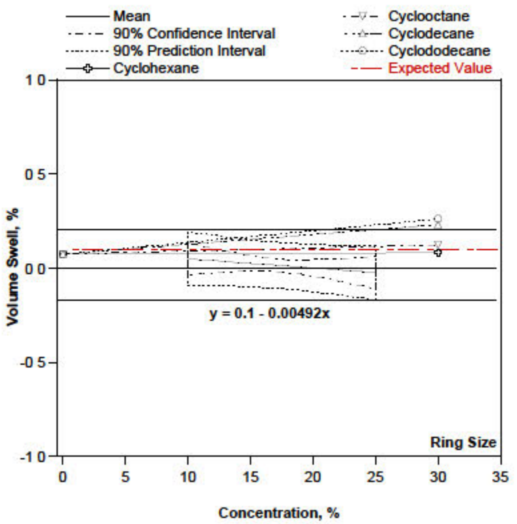


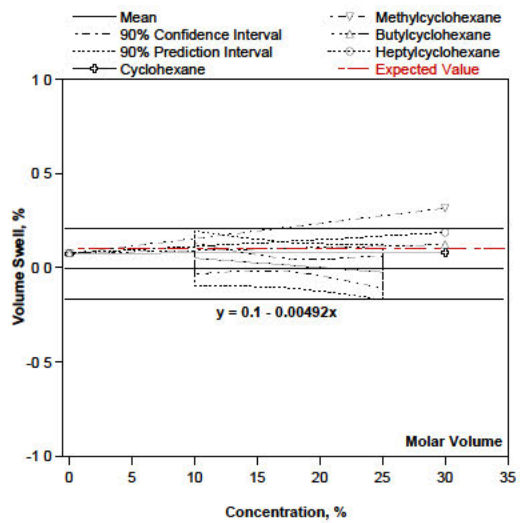


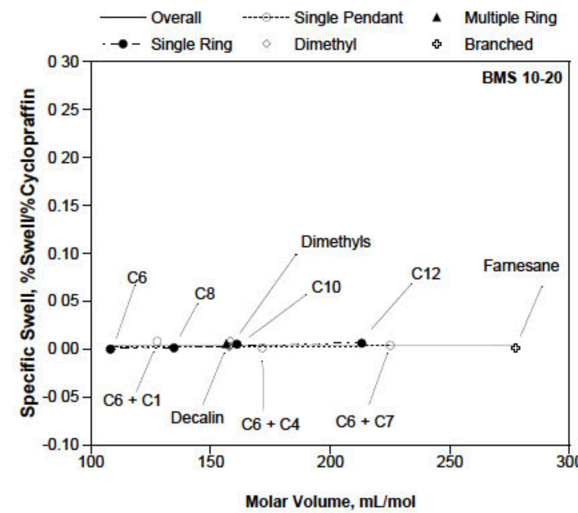


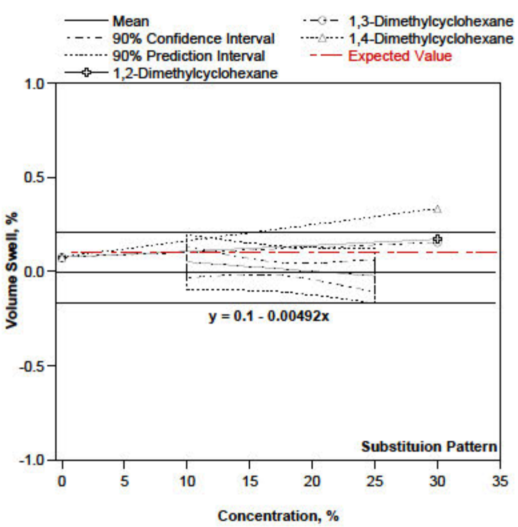


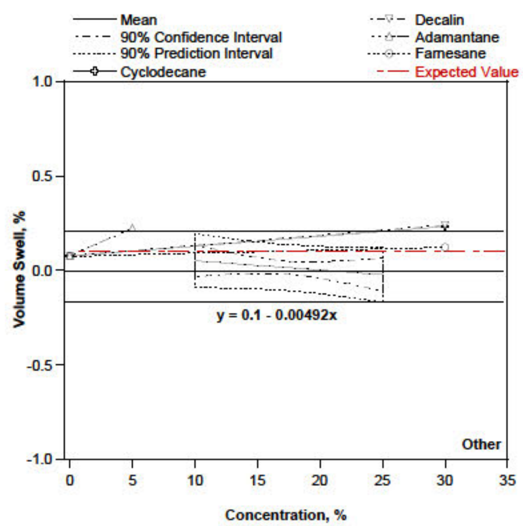
Coatings: BMS 10-20 Epoxy

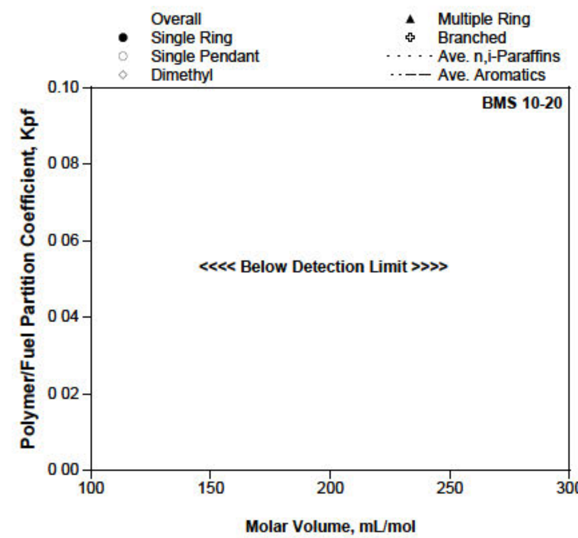






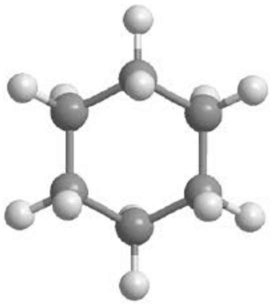
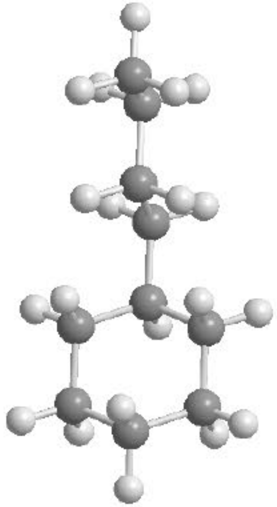
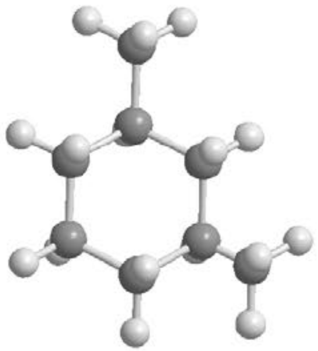
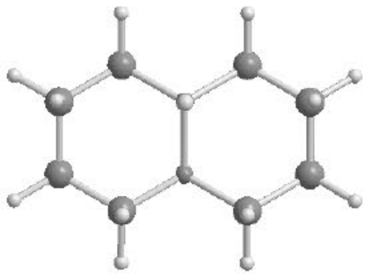






Summary

- Cycloparaffins obey the same basic rules as other fuel components
- Volume swell increases as polarity increases and as molar volume decreases (cycloparaffins do not exhibit any hydrogen bonding character)
- Molar volume appears to be the main factor influencing the performance of cycloparaffins
- Non-substituted cycloparaffins show a modest increase in activity as compared to substituted rings
- The volume swell is weakly influenced by the substitution position with the 1,2 substitution pattern being the preferred configuration

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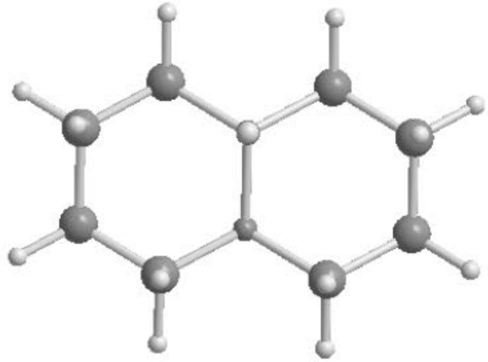
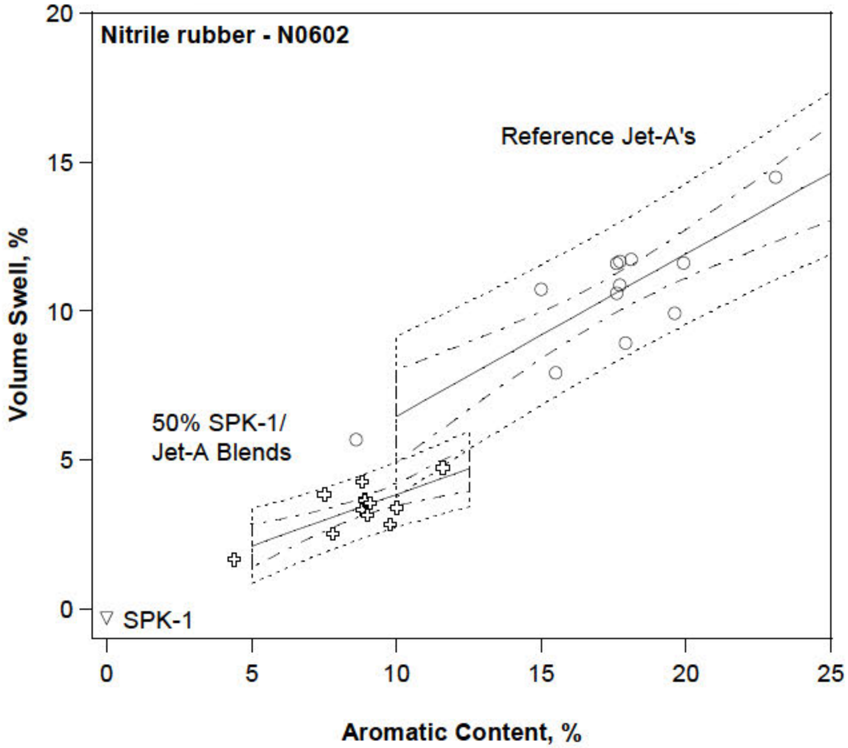
Selected Cycloparaffin - Decalin

- Decalin showed good overall performance, though not exceptionally high
- Decalin lies well within the boiling range of Jet-A
- Decalin has shown good performance characteristics as a major fuel component (JP-900)
- It has been demonstrated that decalin can be produced from non-petroleum sources (coal)
- Decalin is readily available in high purity and at a relatively low cost as an analytical chemical
- Decalin has the added benefit of bringing significant density to the fuel making it easier to meet the density specification

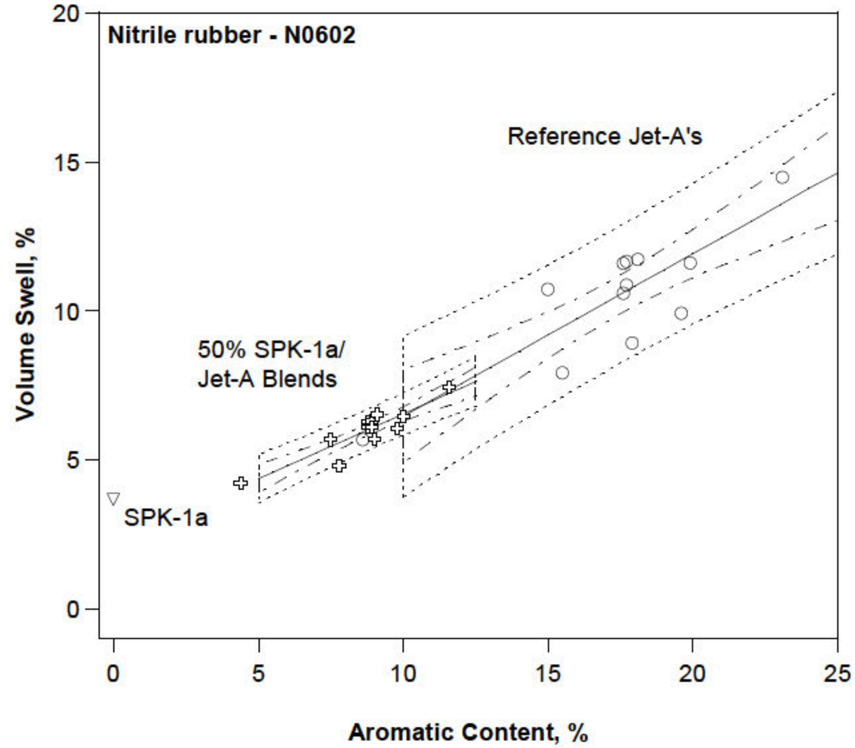


O-rings: N0602 Nitrile Rubber

Neat SPK-1 Blending Stock



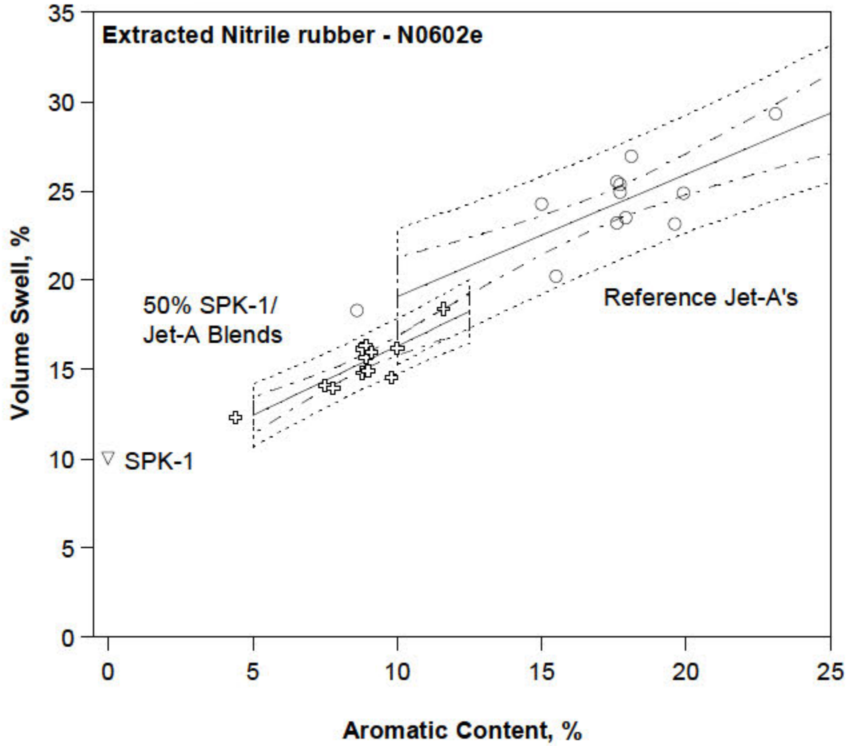
Neat SPK-1 with 30% v/v Decalin



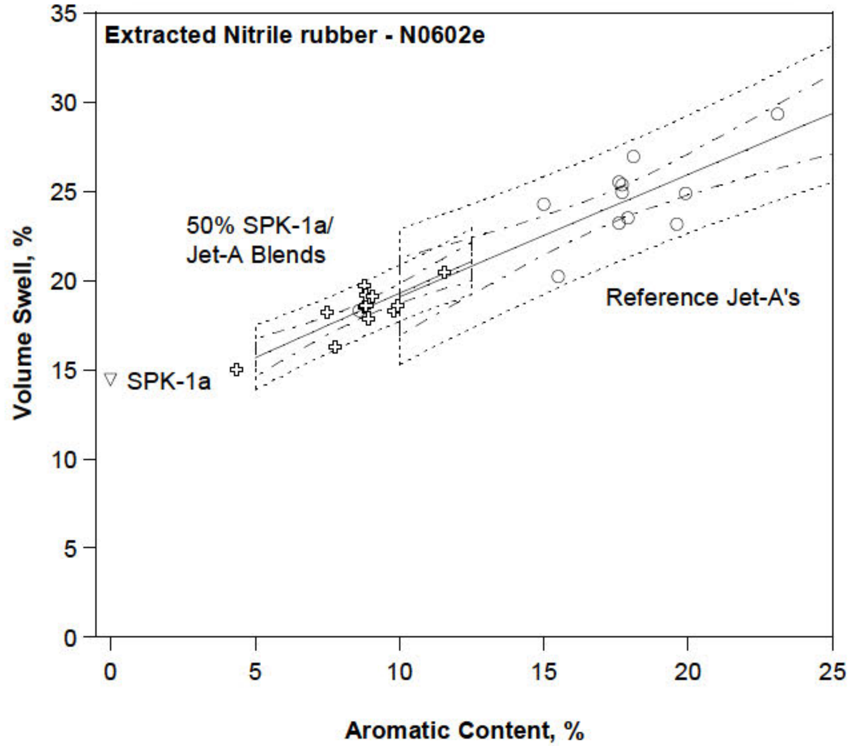
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	44%	97%
50% SPK w/ 8% Aro.	23%	100%

O-rings: N0602e Extracted Nitrile Rubber

Neat SPK-1 Blending Stock



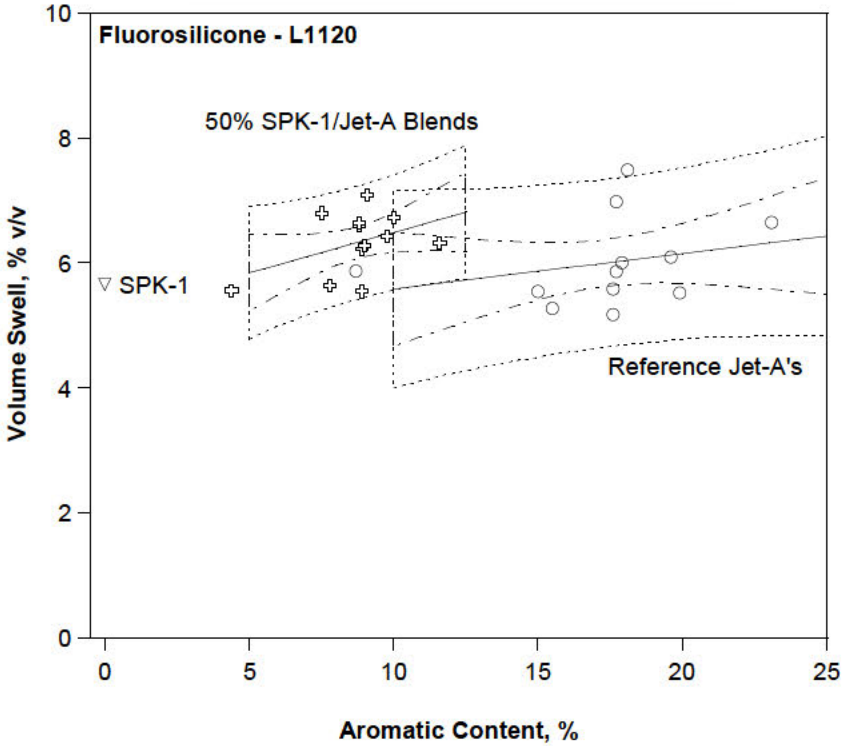
Neat SPK-1 with 30% v/v Decalin



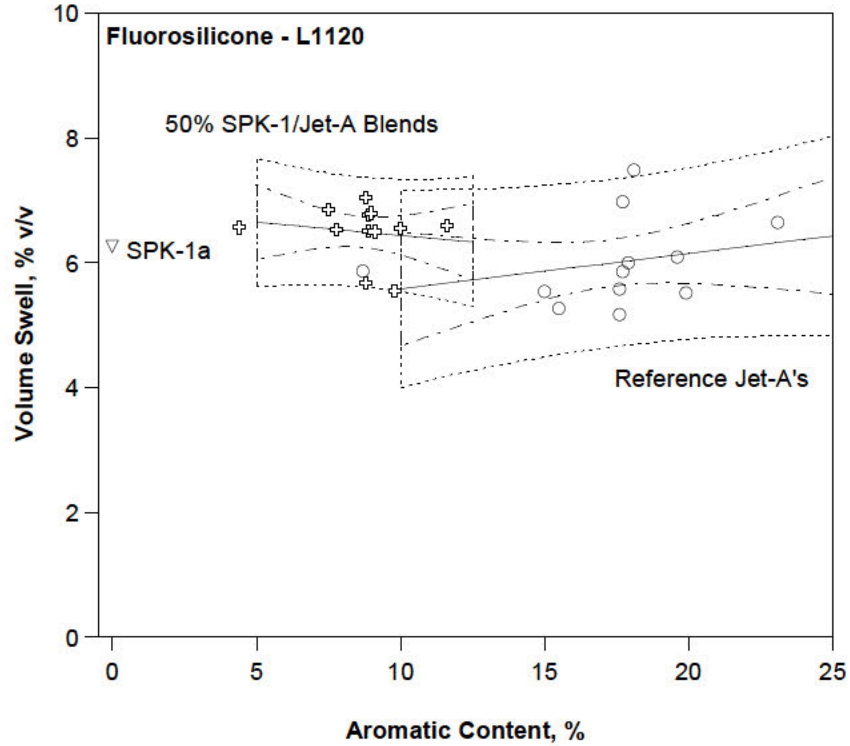
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	51%	85%
50% SPK w/ 8% Aro.	34%	100%

O-rings: L1120 Fluorosilicone

Neat SPK-1 Blending Stock



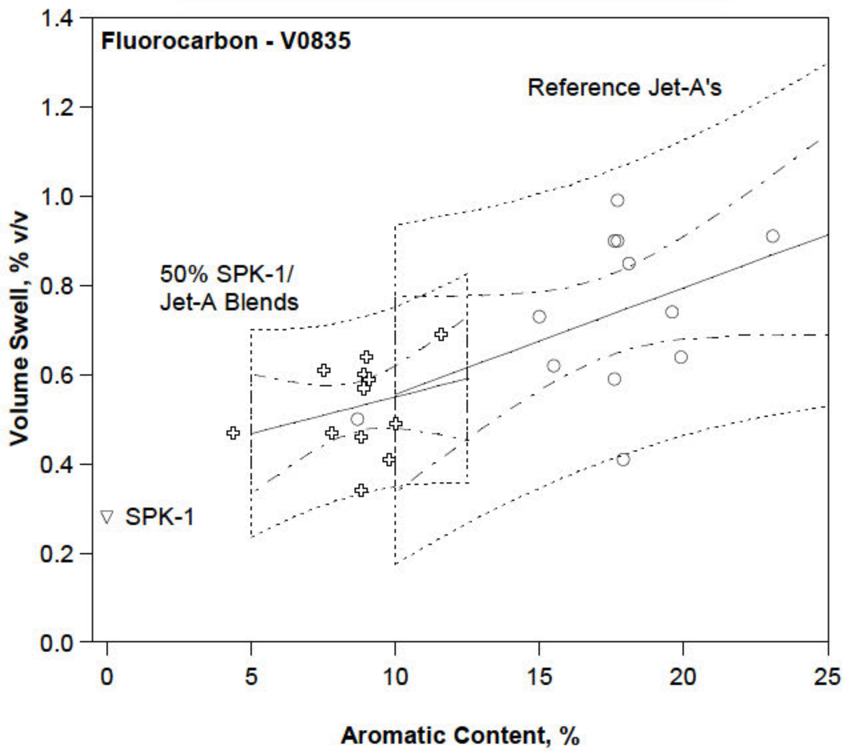
Neat SPK-1 with 30% v/v Decalin



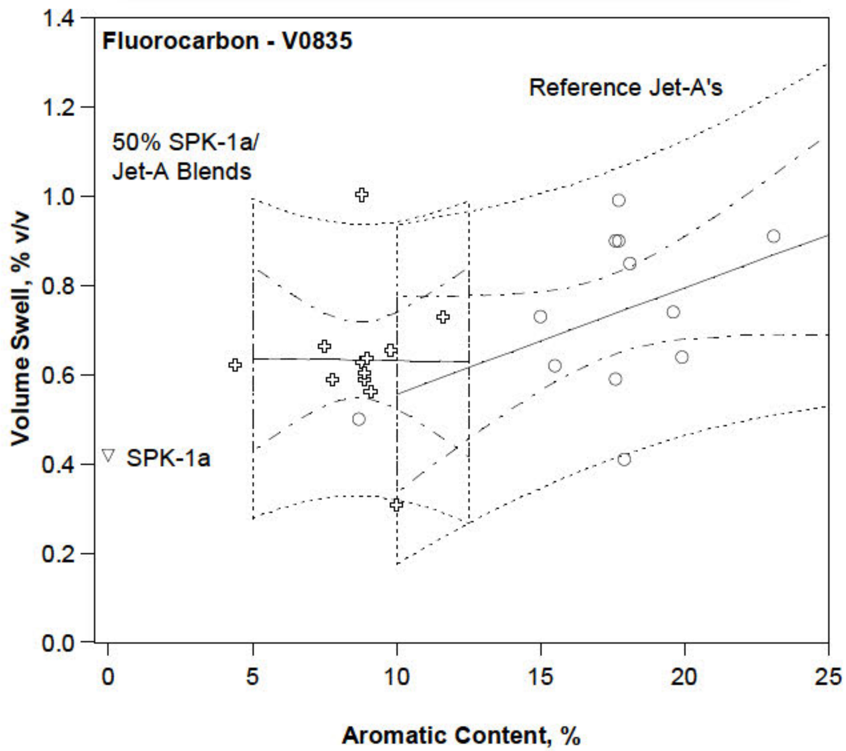
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	100%	100%
50% SPK w/ 8% Aro.	100%	100%

O-rings: V0835 Fluorocarbon

Neat SPK-1 Blending Stock



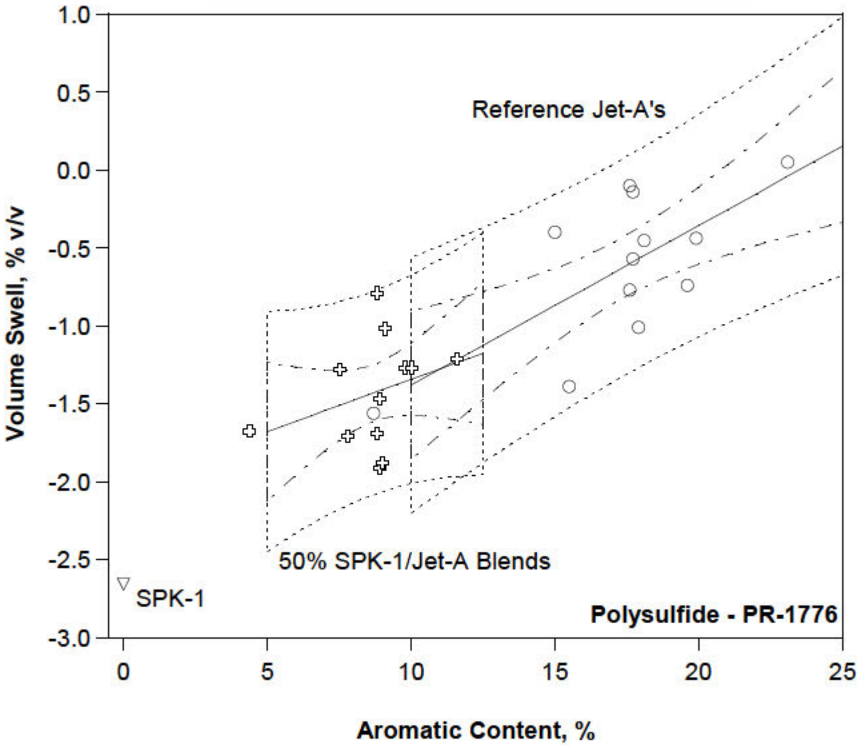
Neat SPK-1 with 30% v/v Decalin



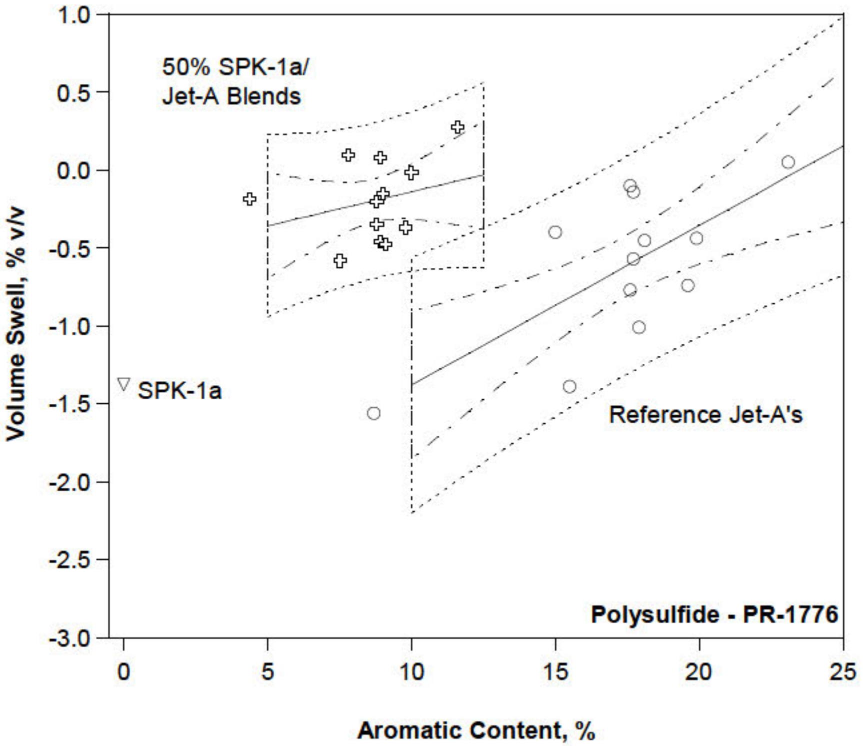
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	100%	100%
50% SPK w/ 8% Aro.	100%	100%

Sealants: PR-1776 Polysulfide

Neat SPK-1 Blending Stock



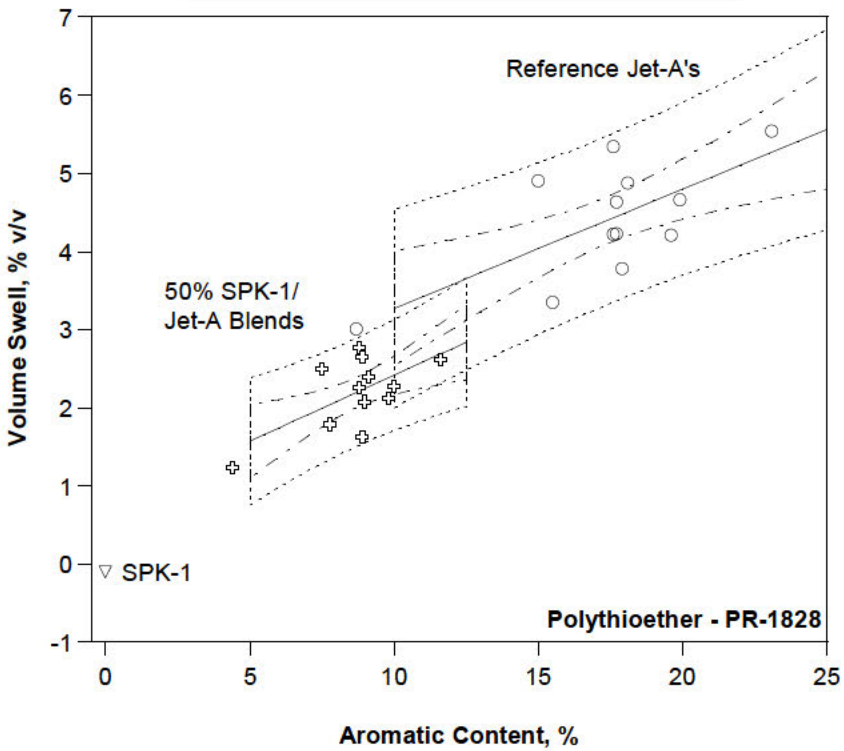
Neat SPK-1 with 30% v/v Decalin



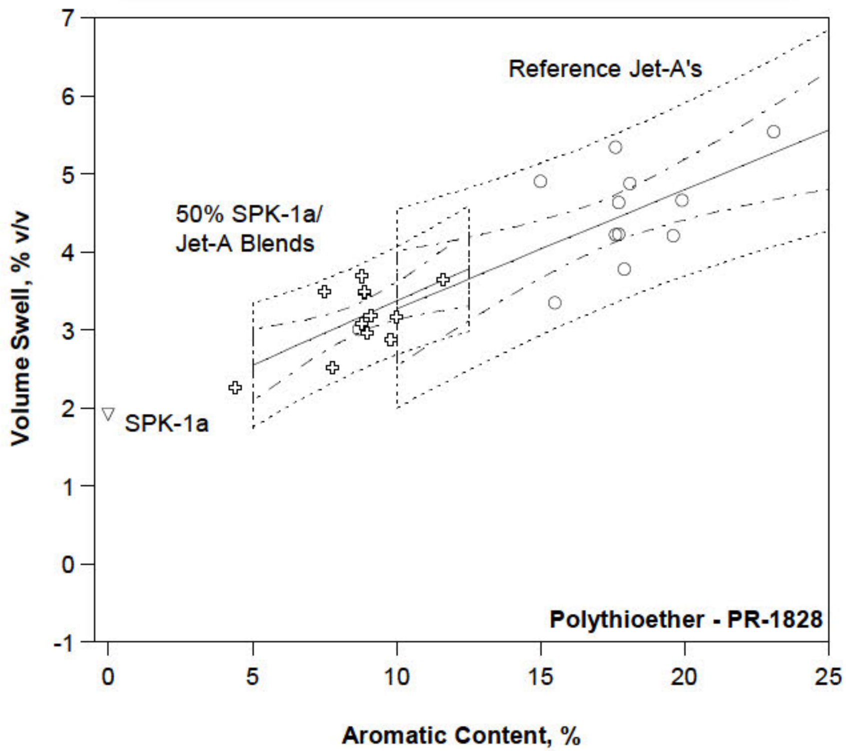
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	88%	100%
50% SPK w/ 8% Aro.	100%	100%

Sealants: PR-1828 Polythioether

Neat SPK-1 Blending Stock



Neat SPK-1 with 30% v/v Decalin



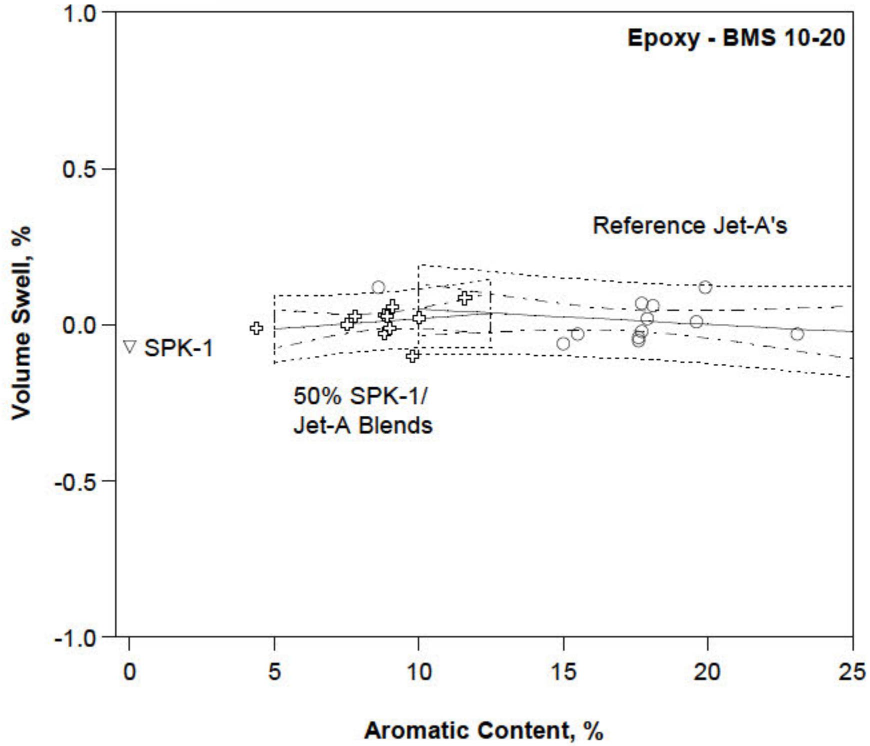
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	57%	91%
50% SPK w/ 8% Aro.	56%	100%

BOEING

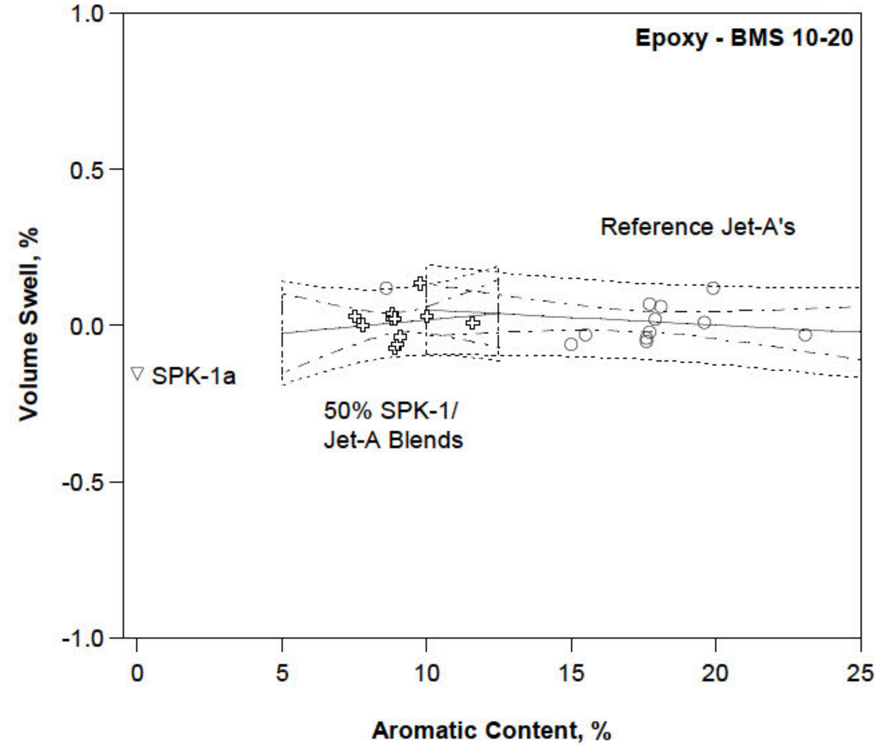
Coatings: BMS 10-20 Epoxy

NextGEN CLEEN

Neat SPK-1 Blending Stock



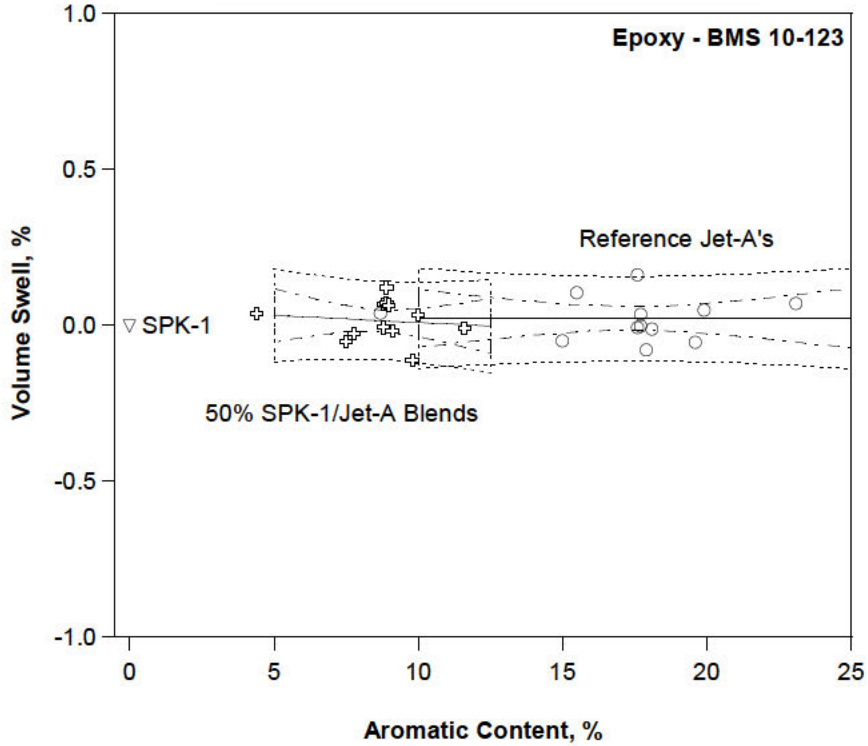
Neat SPK-1 with 30% v/v Decalin



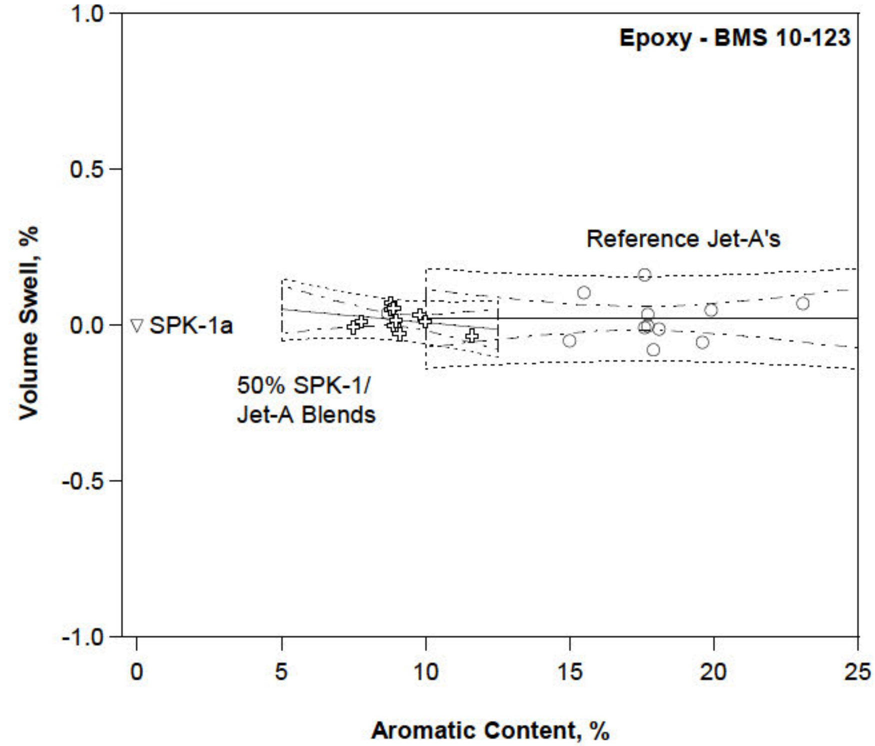
Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	100%	95%
50% SPK w/ 8% Aro.	100%	100%

Coatings: BMS 10-123 Epoxy

Neat SPK-1 Blending Stock



Neat SPK-1 with 30% v/v Decalin



Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	96%	100%
50% SPK w/ 8% Aro.	100%	100%

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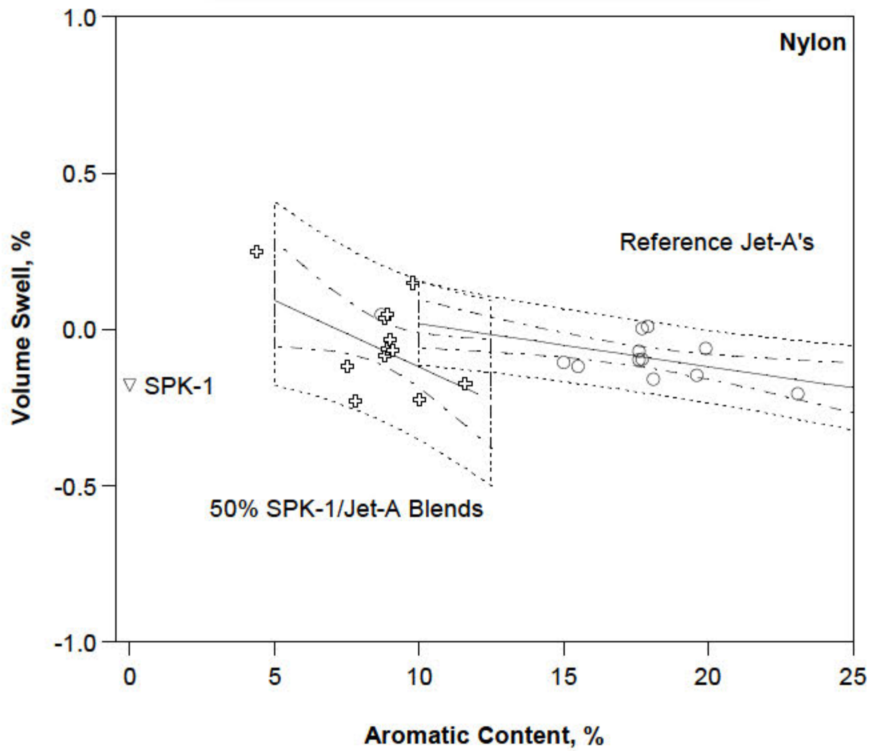
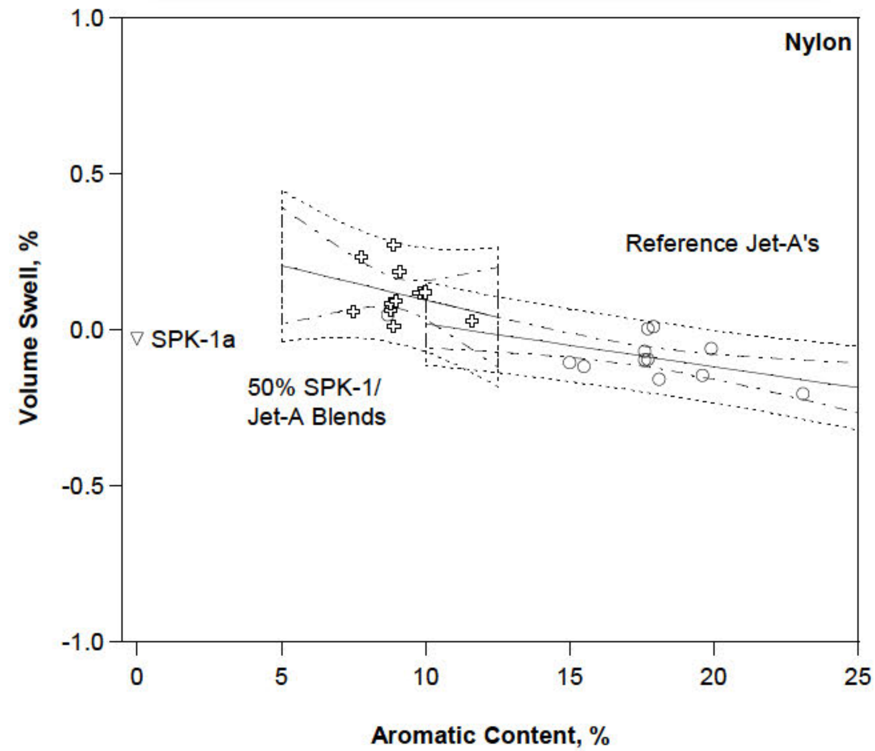
Films: Nylon (6,6)

Neat SPK-1 Blending Stock

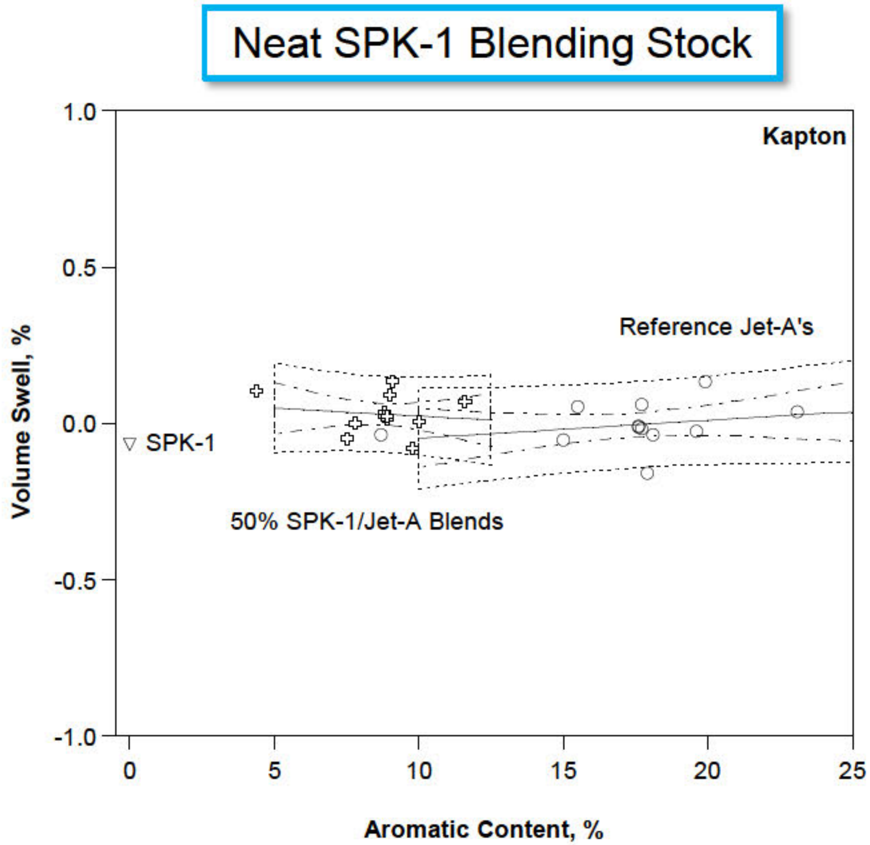


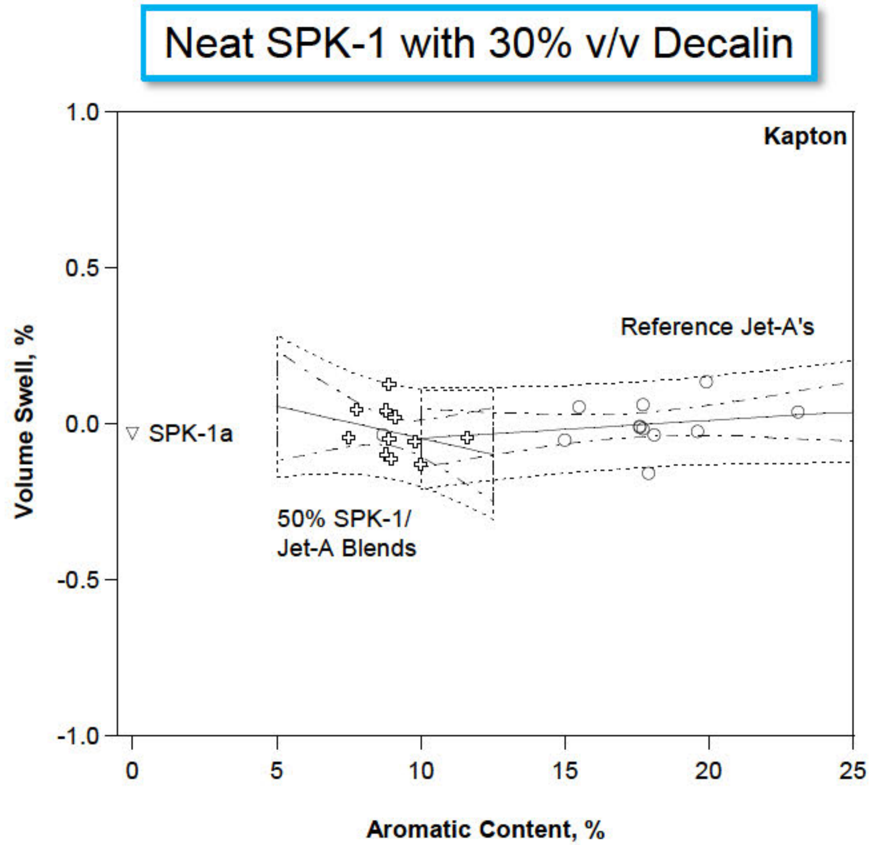
Neat SPK-1 with 30% v/v Decalin



Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	80%	100%
50% SPK w/ 8% Aro.	100%	100%

Films: Kapton





Fuel	Overlap 90% PI	
	SPK-1	SPK-1a
50% SPK w/ 5%-12.5% Aro.	100%	84%
50% SPK w/ 8% Aro.	100%	100%

Conclusions

- Cycloparaffins obey the same basic rules as other fuel components
- Volume swell increases as polarity increases and as molar volume decreases (cycloparaffins do not exhibit any hydrogen bonding character)
- Molar volume appears to be the main factor influencing the performance of cycloparaffins
- The addition of decalin at 30% to the SPK used here greatly improved the material compatibility of the 50% fuel blends used in this study
- The overall results suggest that it may be possible to develop a fuel that is high in cycloparaffins with very low, or even zero, aromatic content

Alt Fuels Team

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University of Dayton Research Institute

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The Boeing Company

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Summary

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Summary

NextGEN CLEEN

Adaptive Trailing Edges

- ✓ *Project SOW Completed*
- ✓ *Final Report delivered to FAA*
- ✓ *Technology ownership transferred to Boeing transition team*

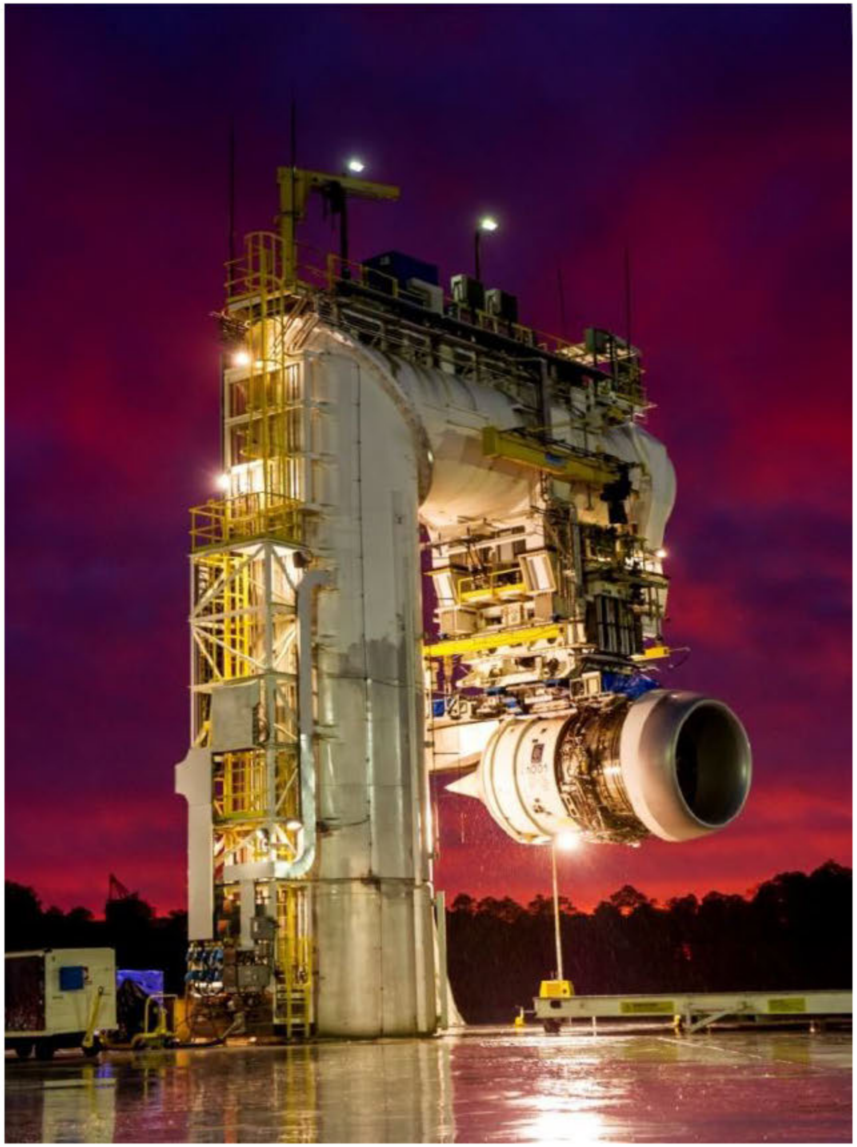
CMC Nozzle

- ✓ *First full-scale proof build completed*
- ✓ *Ground Test Completed*
- ✓ *Exhaust hardware refurbished, ready for Flight Test*
- *Flight Demo planned for 1Q14, team and CMC hardware are ready*
- *2nd Design Cycle started*

Alt Fuels

- ✓ *Testing & Analyses completed*
- *Updated Public Report to be released in 1Q14*

Thank you



Photos: Bob Ferguson