# A Method for Rapidly Assessing Jet Fuel compatibility with Non-Metallic Materials Project 088

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### **Project 088 Phase I**

### A Method for Rapidly Assessing Jet ASSESSING

#### **University of Dayton Research Institute**

PI: John Graham, Ph.D. and Gina Roesch, Ph.D.

PM: Theodore Johnson, FAA

Cost Share Partner(s): Global Bioenergies, Boeing, GE Aviation, NRC

Canada, Lanzatech, Neste, Shell and IHI

### **Research Approach:**

This project will build on over 20 years of prior work with the material compatibility of alternative aviation fuels. Key elements of the proposed effort include developing a clear understanding of the link between fuel composition and material compatibility and defining specific requirements for a drop-in SATF. This program combines elements of fuel chemistry, material science, and materials engineering to provide computational and physical tools to accelerate the development and certification of drop-in SAFs using small volumes of fuel (<250 mL) and materials (milligrams).

#### **Objective:**

The objective of this project is to develop a method for rapidly assessing the compatibility of candidate synthetic aviation turbine fuels (SATFs) with various non-metallic materials.

#### **Project Benefits:**

The proposed program will provide a screening tool to:

- Lower the cost of jet fuel compatibility with non-metallic materials.
- Speed the development and certification of candidate SATFs.
- Provide a simplified means of evaluating material compatibility.
- Utilize very small amounts of fuel and materials.

#### **Major Accomplishments (to date):**

- 12 test fuels have been selected and analyzed from a sample of 93 different fuels across the CONUS.
- Testing is complete for 36 of 36 materials for all 6 technical tasks.
- Data reporting is in progress.

#### **Future Work / Schedule:**

- Produce and submit a final report.
- Continue progress on experimental portion of Phase II.

### **Introduction**

₩ D4054 – 23

- D4054 is the current process of certifying a synthetic aviation turbine fuel (SATF).
- A key part of D4054 qualification is material compatibility.
  - Pre-screening with 3 O-ring materials in Tier II.
  - Complete suite of materials (seals, sealants, foams, adhesives, etc.) evaluated in Tier III.
- The original draft of this evaluation was written for JP-8, and the reference data sets are out of date.

### The goal of Project 88 Phase I:

To create a modernized and complete prescreening method for SATF compatibility with the D4054 Annex A3 material list.

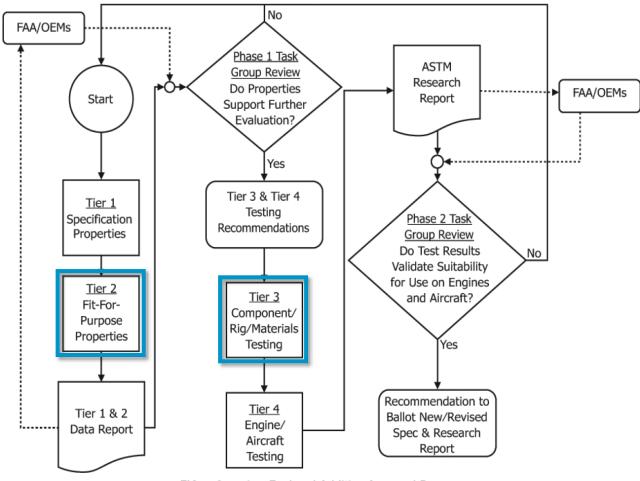


FIG. 1 Overview Fuel and Additive Approval Process

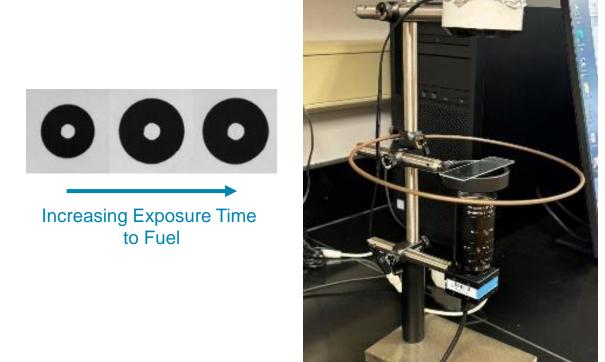




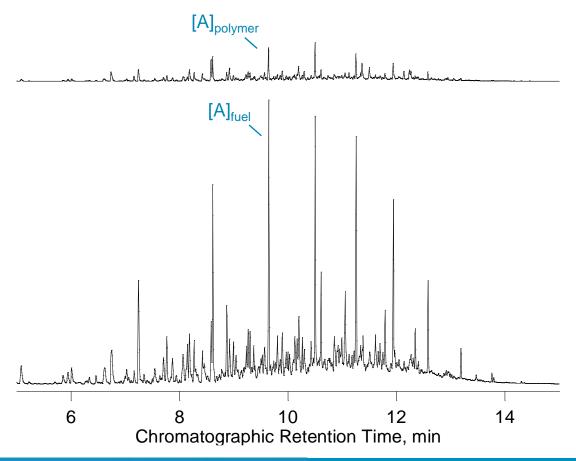
### **Experimental Techniques – Volume Swell and Absorbed Fuel Analysis**

Given that volume swell captures the overall exchange between a material and fuel, it was chosen as the representative physical property for this prescreening method. In addition to the volume swell, gas chromatography mass spectrometry was used to quantify the exchange.

#### **Optical Dilatometry: Volume Swell**



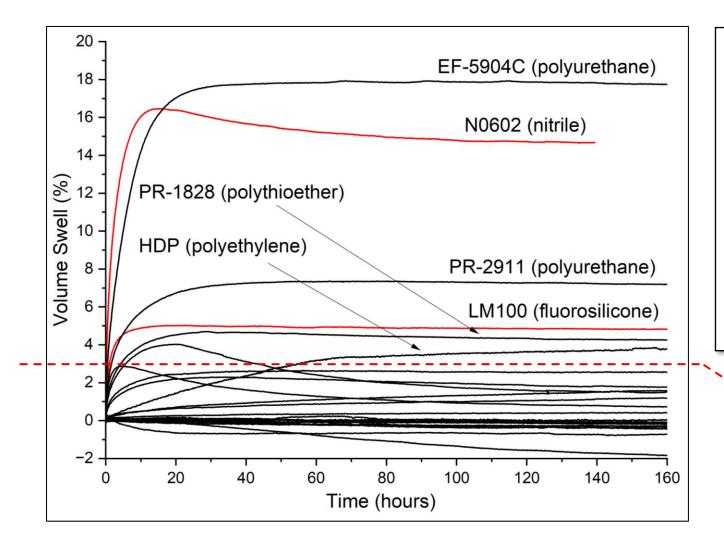
#### **Gas Chromatograph Mass Spectrometry: Partition Coefficients**







### **Major Conclusions: Few Materials Readily Respond to Fuel**



- 1. All 36 materials reach equilibrium or near equilibrium after being exposed to fuel for 160 hours.
- 2. Most of the 36 materials show very little response to fuel.

Project 88's Definition of Fuel Response:
Any material that swells less than 3% in total volume swell. 3% volume swell can be back calculated to a 1% change in linear swell, which is not expected to cause leaks at critical seals.

3% Volume Swell ≈ 1% Linear Swell





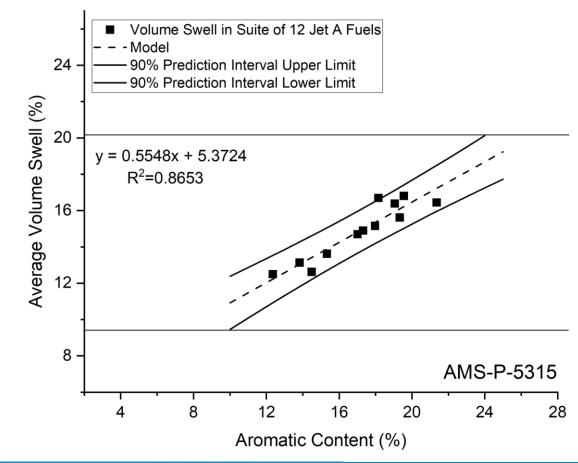
### **Experimental Application – the Single Variable Model**

Given the community's general interest in the aromatic content of fuels, a single variable model correlating the measured volume swell to the aromatic content of the fuel was developed.

### **Key variables include:**

- 1. Slope: average response of the material to the aromatic content of Jet A fuels.
- 2. Intercept: the volume swell extrapolated to 0% aromatics.
- 3. Coefficient of Determination (R2): strength of correlation between the aromatic content of the fuels and the swell of the material.
- 4. 90% Prediction Interval: statistical prediction of the swell for 90% of all Jet A fuels with 10-25% aromatics.

Task 5 Model Output Parameter	AMS5315
Slope (%/%)	0.555
Intercept (%)	5.37
R <sup>2</sup>	0.865
Lower Limit of 90% Prediction Interval (%)	9.5
Upper Limit of 90% Prediction Interval (%)	20.8





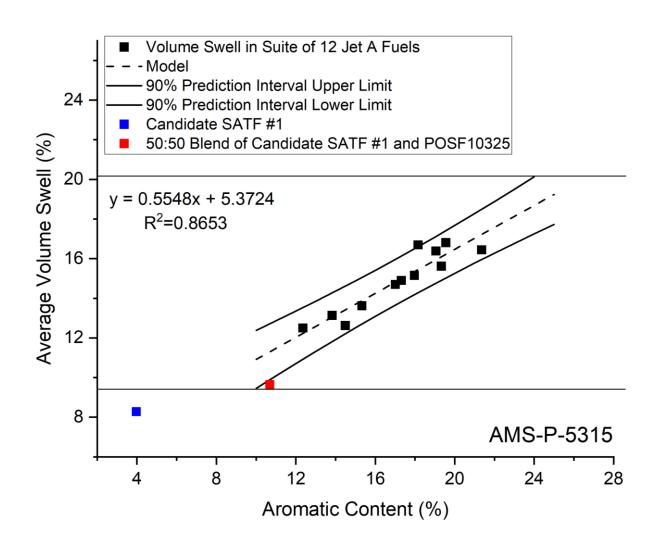


#### Experiments Needed:

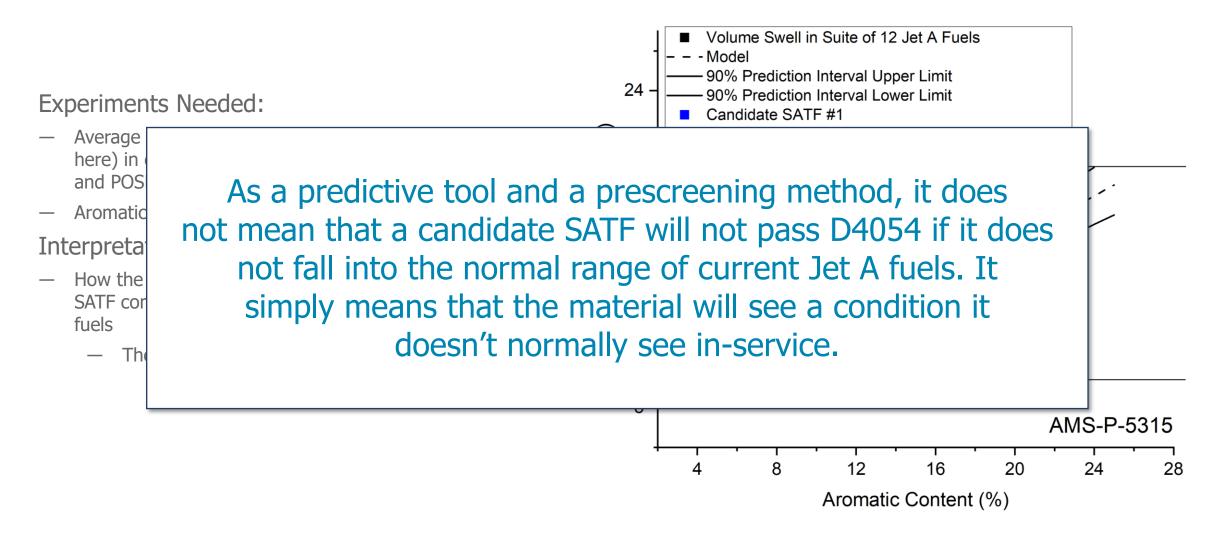
- Average volume swell of material (AMS-P-5315 shown here) in candidate SATF (blue) and 50:50 blend of SATF and POSF 10325 (red)
- Aromatic content of the candidate SATF

### Interpretation:

- How the swell of the selected material in the candidate SATF compares to 90% of all current, in-service Jet A fuels
  - The value of the prediction interval





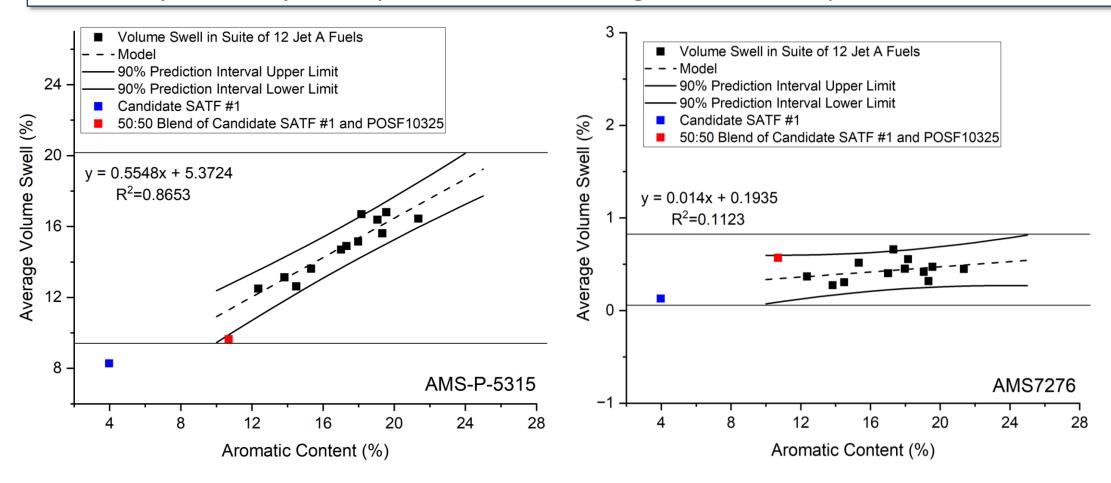






AMS-P-5315 (nitrile) does not respond within the normal range of Jet A for Candidate SATF #1.

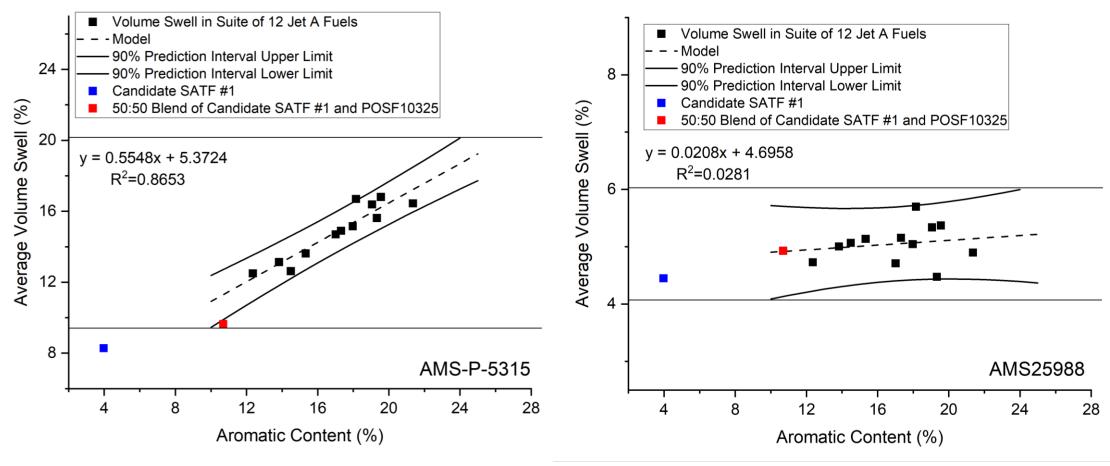
AMS7276 (fluorocarbon) does respond within the normal range for Jet A when exposed to Candidate SATF #1.







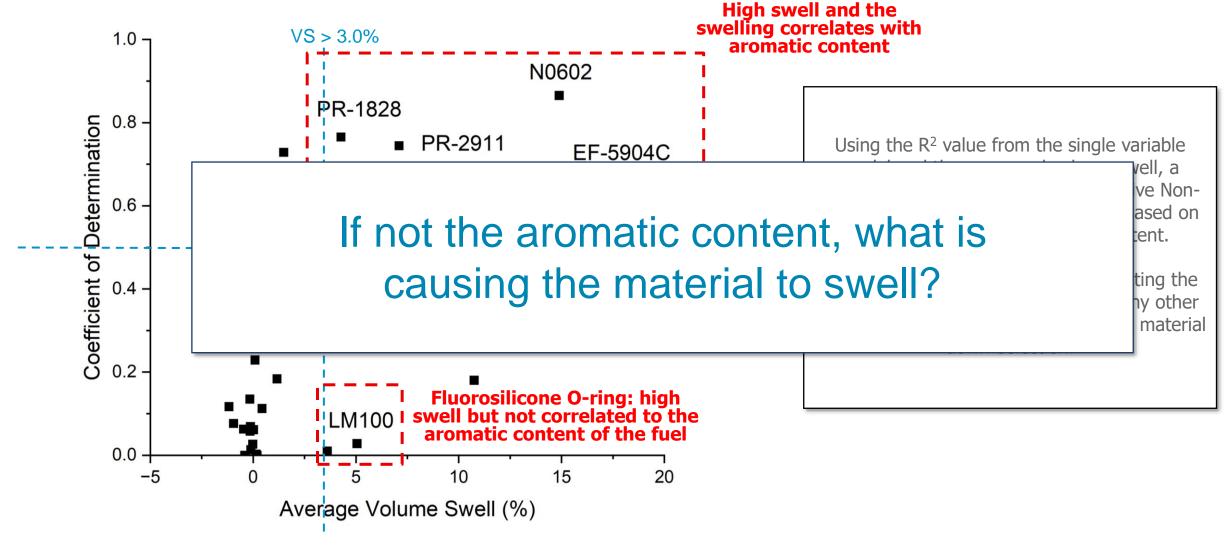
AMS-P-5315 (nitrile) does not respond within the normal range of Jet A for Candidate SATF #1. AMS25988 (fluorosilicone) does respond within the normal range for Jet A when exposed to Candidate SATF #1.







### **Another Way to Use the Single Variable Model**







### **Correlating Swell to the Entire Fuel Composition**

The multivariate model consists of the sum of all the class fractions identified in the hydrocarbon type analysis (HTA) of each Jet A fuel:

$$Volume Swell = \sum_{i=1}^{n} k_i A_i + \mathcal{E}$$

where  $k_i$  is the regression coefficient for factor i,  $A_i$  is the scalar for factor i, and E is the model residual.

Factor, k <sub>i</sub>	Class Fraction or Other Assignment	Expected Volume Swell Trend	
4	Total Aromatics	Total Aromatics Increased swell	
2	Alkyl Benzenes	Increased swell	
3	Cycloaromatics	Similar to alkyl benzenes?	
4	Diaromatics	Increased swell	
5	<del>n,i-Paraffins</del>	Decreased swell	
6	Cycloparaffins	Cycloparaffins Increased swell	
7	Mean Molecular Weight	Decreased swell	
8	Other	Variable	

Using the volume swell of each material and the known fuel composition, a multivariate model that includes the contribution of each class fraction to the overall volume swell was created.

However, the as-proposed model turned out to be over constrained, resulting in model coefficients that lacked physical meaning.

To increase the degrees of freedom, an intermediate model was created.





### **Example Model Coefficients: Nitrile vs. Fluorosilicone**

A Reminder: The single variable model describes the swelling character of nitrile O-rings very well.

Single Variable Model Output	Nitrile O-ring Model Variables	Fluorosilicone O-ring Model Variables
Slope (%/%)	0.555	0.021
Intercept (%)	5.37	4.70
R <sup>2</sup>	0.865	0.028
Lower Limit of 90% Prediction Interval (%)	9.5	4.09
Upper Limit of 90% Prediction Interval (%)	20.8	6.06

By including select class fractions, the multivariate model does a far superior job of describing the observed swelling behavior of fluorosilicone O-rings.

Factor, k <sub>i</sub>	Class Fraction or Other Assignment	Nitrile O-ring Intermediate Model Coefficient	Fluorosilicone O-ring Intermediate Model Coefficient
1	Alkyl Benzenes	0.698	0.210
2	Cycloaromatics	0.386	-0.124
3	Diaromatics	0.250	-0.093
4	Cycloparaffins	0.081	0.034
5	Intercept	1.974	2.270
6	R <sup>2</sup>	0.919	0.498





### **Summary**

- Phase I data acquisition and analysis is complete.
- Report writing is in progress.

### **Next Steps**

- Phase II of Project 088 has been approved and funded.
- The experimental portion is already in progress.





### **Project 088 Phase II**



### **Fuel Compatibility with non-Metallic Materials**

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#### **Research Approach:**

Phase II will be a targeted investigation of how selected O-ring seals respond to fuel switching under representative service conditions. Briefly, the sealing pressure of selected seals will be examined in near real-time as they are switched from a Jet A conditioning fuel to selected low-swell test fuels. This will be performed using instrumented model O-ring seals and examples of actual flight hardware in the form of flexible fuel couplings. These component-level tests will be accompanied by performance predictions based on volume swell tests that will be performed under similar fuel-switching conditions.

#### **Objective:**

Directly measure the sealing pressure of model O-ring seals as the fuel is switched from a Jet A to selected test fuels. This data sets will be compared to tests using flexible fuel couplings and predictions based on volume swell measurements.

#### **Project Benefits:**

The proposed program will:

- Examine the behavior of O-ring seals during a Jet A to SAF (synthetic aviation fuel) switch.
- Compare the results obtained with instrumented O-ring seals with examples of actual flight hardware.
- Compare the observed performance with the behavior predicted from the volume swell data.

#### **Major Accomplishments (to date):**

- Reviewed prior work conducted for DLA and AFRL.
- Identified the specific O-ring materials and fuels to be used.
- Began volume swell for all candidate fuels (Task 2).
- Started long-term compression set testing for Jet A (Task 3).
- Experimentally determined the sealing pressure of dry source O-ring materials (Task 4).

#### **Future Work / Schedule:**

- Begin long-term compression set testing for neat HEFA and SATF blend.
- Setup the fuel lines for experimental testing of the sealing pressure of fuel-wetted O-rings.

### **Project 088 Phase II**

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### **Fuel Compatibility with non-Metallic Materials**

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**Research Approa** 

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**Objective:** 

Directly measure the sealing pressure of model O-ring seals as the fuel is switched from a Jet A to selected test fuels. This data sets will be compared to tests using flexible fuel couplings and predictions based on volume swell measurements.

**Project Benefits:** 

Volume swell is a measure of the physical response of an O-ring (Phase I), but the sealing pressure of an O-ring is the primary metric that determines in-service performance (Phase II).

a Jet A to SAF

O-ring seals with

behavior predicted

be used.

(Task 3).

dry source O-ring

materials (Task 4).

#### **Future Work / Schedule:**

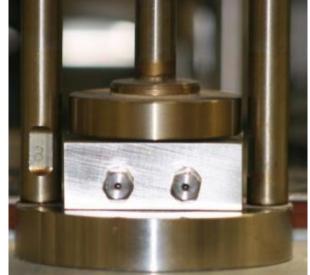
- Begin long-term compression set testing for neat HEFA and SATF blend.
- Setup the fuel lines for experimental testing of the sealing pressure of fuel-wetted O-rinas.

### **Measuring the Sealing Force and the Area of Contact**

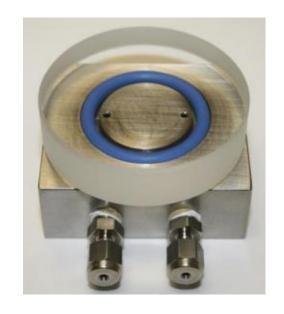
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To measure the sealing force, a compression stress relaxometer (CSR) is fitted with a gland and fuel lines. The force applied is recorded over time.





To measure the area over which force is applied, a replica O-ring gland is placed beneath a window with optical access as increasing compression is applied.





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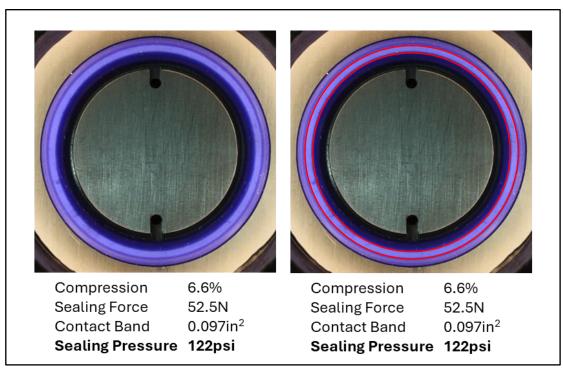


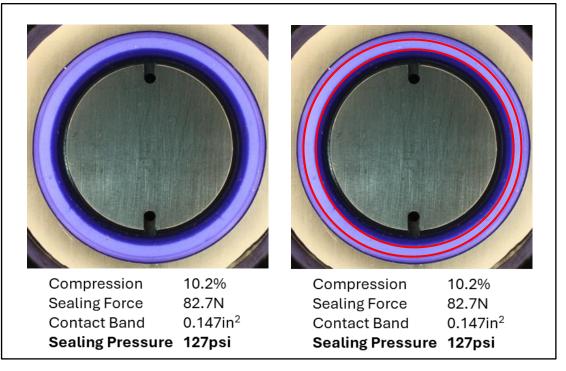


### **Identifying the Contact Band**

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Identifying the contact band using an optical access window allows for the calculation of sealing pressure, which is the force applied divided by the area of the contact band.





The left side of each figure shows unaltered images. The right side of each figure highlights the change in the area of the contact band as the compression is increased from 7% to 10%.

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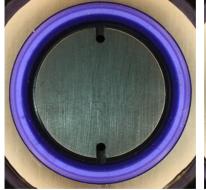




## The Sealing Pressure as a Function of O-ring Compression on Dry, Source O-rings

#### Calculated Sealing Pressure vs Compression 400 AMS5315 - AMS25988 350 - - AMS7276 ----- AMS7287 300 - - - 60 psi Sealing Pressure, psi 250 200 150 100 50 20 25 10 Compression, %

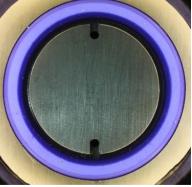
#### Sample Images of AMS25988 O-ring



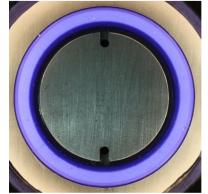
Compression 6.6%
Sealing Force 52.5N
Contact Band 0.097in²
Sealing Pressure 122psi



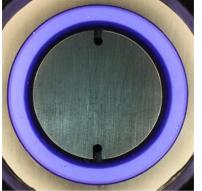
Compression 10.2%
Sealing Force 82.7N
Contact Band 0.147in²
Sealing Pressure 127psi



Compression 13.8%
Sealing Force 121.5N
Contact Band 0.194in²
Sealing Pressure 141psi



Compression 17.4%
Sealing Force 179.8N
Contact Band 0.238in<sup>2</sup>
Sealing Pressure 170psi



Compression 21.0%
Sealing Force 272.2N
Contact Band 0.281in<sup>2</sup>
Sealing Pressure 218psi



Compression 24.6%
Sealing Force 417.4N
Contact Band 0.320in<sup>2</sup>
Sealing Pressure 293psi

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### **Acknowledgements**

- 1. Federal Aviation Administration
- 2. ASCENT the Aviation Sustainability Center
- 3. Cost Share Partners...
  - Global Bioenergies, The Boeing Company, GE Aviation, NRC Canada, Lanzatech, Neste, Shell, and IHI

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