# UPDATE ON THE DEVELOPMENT AND CAPABILITIES OF UNIQUE STRUCTURAL SEAL TEST RIGS

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## Update on the Development and Capabilities of Unique Structural Seal Test Rigs

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**2002 NASA Seals/Secondary Air Flow System Workshop**
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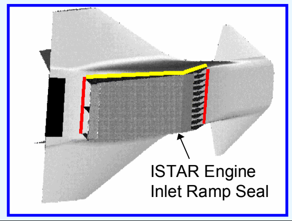
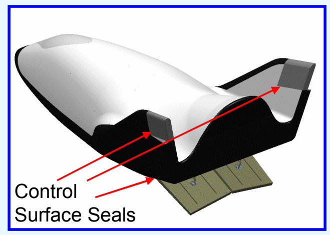
## Structural Seal Objectives and Background

- **Goal:** Develop high temperature, long life, control and propulsion system seals with the aid of appropriate test/analysis methods
- **Areas of Development**
  - ➢ Propulsion System Seals
    - 3rd Generation Reusable Launch Vehicle
      - ▪ ISTAR Engine (RBCC)
  - ➢ Control Surface Seals
    - 3rd Generation Reusable Launch Vehicle
      - ▪ X-38 / Crew Return Vehicle
      - ▪ X-37 / Space Maneuver Vehicle




**ISTAR Engine**
(P&W/Aerojet/Boeing/Rocketdyne)




**X-38 CRV**

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High temperature structural seals are necessary in many aerospace and aeronautical applications to minimize any detrimental effects originating from undesired leakage. The NASA Glenn Research Center has been and continues to be a pioneer in the development and evaluation of these types of seals. The current focus for the development of structural seals is for the 3rd Generation Reusable Launch Vehicle (RLV), which is scheduled to replace the current space shuttle system by 2025. Specific areas of development under this program include seals for propulsion systems (such as the hypersonic air-breathing ISTAR engine concept based upon Rocket Based Combined Cycle technology) and control surface seals for spacecraft including the autonomous rescue X-38 Crew Return Vehicle and the X-37 Space Maneuver Vehicle.

## Performance Criteria for High Temperature Seals

**Primary Role of High Temperature Structural Seals:**

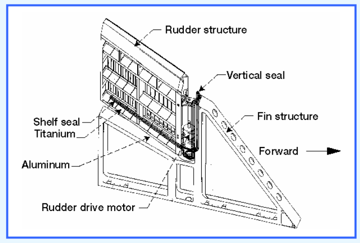
- Minimize leakage
  - Propulsion System Seals: Prevent unburned fuel from leaking into backside cavities
  - Control Surface Seals: Block excessive heat flow

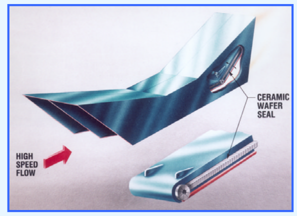
✓ Good insulatory properties → block heat flow

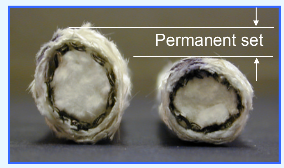
✓ Good flexibility → conform to complex airframe and propulsion system geometries

✓ Good resiliency → maintain contact with opposing surfaces under dynamic conditions and over many cycles

✓ Good wear resistance → maintain seal continuity under dynamic conditions and over many cycles



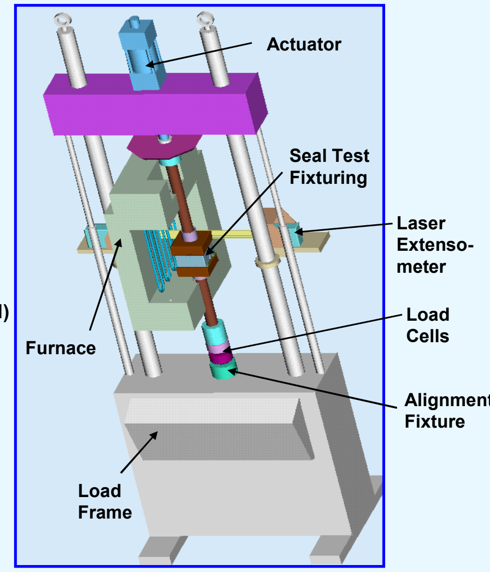



The primary role of structural seals is to minimize the leakage of elevated temperature fluids and/or gases. These hot fluids or gases could damage or destroy critical flight components if not properly sealed, and could result in loss of the aircraft or even loss of life. As an example, consider the potential failure of the rudder/fin seal in the X-38 craft which could severely damage the rudder drive motor and render the craft nearly inoperable. In order to function properly, structural seals must meet or exceed certain performance criteria, including good insulatory properties, excellent flexibility, consistent and effective resiliency, and superior wear resistance. The primary focus of this presentation is on the development of testing rigs to evaluate these last two properties.

## Hot Compression / Scrub Seal Testing Rig Overview

### System Components

- **MTS Model 318.25 Servohydraulic Load Frame**
  - 55 kip load frame
  - 3.3 kip, 6 in. stroke actuator
  - 500 lb, 3300 lb load cells
  - 5.5 kip alignment fixture
  - 11 gpm HPU
  - Dual servovalves (1 gpm, 15 gpm)
  - TestStar IIs controller
- **ATS Series 3350 Custom Box Air Furnace**
  - Temperatures up to 3000°F (14.5 kW)
  - Kanthal Super 33 $MoSi_2$ heating elements
  - Large working volume (9” W x 14” D x 18” H)
  - Front and back loading doors & top port
  - Adjustable laser alignment fixturing and shield
- **Beta LaserMike Intelliscan 50 Extensometer**
  - Non-contact Class II laser extensometer
  - 0 in. – 2 in. measurement range
  - ±0.25 mil accuracy
  - 1000 scans/s
  - Hot object filter

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One of the rigs that the NASA Glenn Research Center is assembling for the structural seals area will consist of three main components: an MTS servohydraulic load frame, an ATS high temperature air furnace, and a Beta LaserMike non-contact laser extensometer. The rig will permit independent (i.e. non-simultaneous) testing of both seal resiliency characteristics (compression test) and seal wear performance (scrub test) at temperatures up to 3000 °F (1650 °C). This one-of-a-kind equipment will have many unique capabilities for testing of numerous seal configurations, including dual load cells (with multi-ranging capabilities) for accurate measurement of load application, dual servovalves to permit precise testing at multiple stroke rates, a large capacity high temperature air furnace, and a non-contact laser extensometer system to accurately measure displacements.

## Hot Compression Rig Details

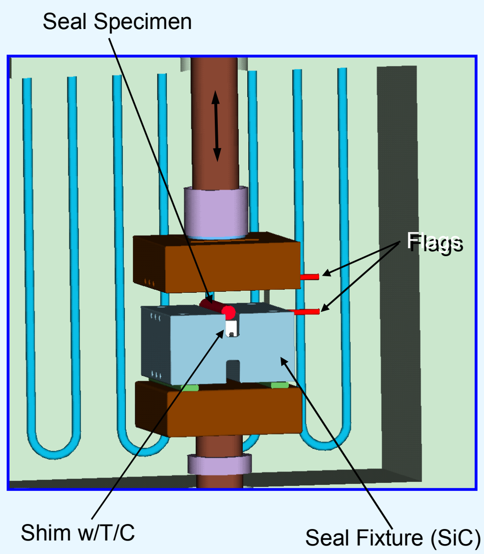
### Purpose

New rig will permit measurement of seal load vs. linear compression, preload, & stiffness for various test conditions:

- Temperature
- Compression level
- Loading rate
- Load cycling vs. stress relaxation

### Capabilities

- ✓ Temperatures up to 3000°F (1650°C)
- ✓ Loads up to 3300 lbs
- ✓ Stroke rates from 0.001 in/s to 8.0 in/s
- ✓ Seal lengths up to 4 in.
- ✓ Seal diameters up to 2 in.
- ✓ Variety of loading waveforms
  - Cycling (sine wave, sawtooth, user-defined profiles)
  - Stress relaxation

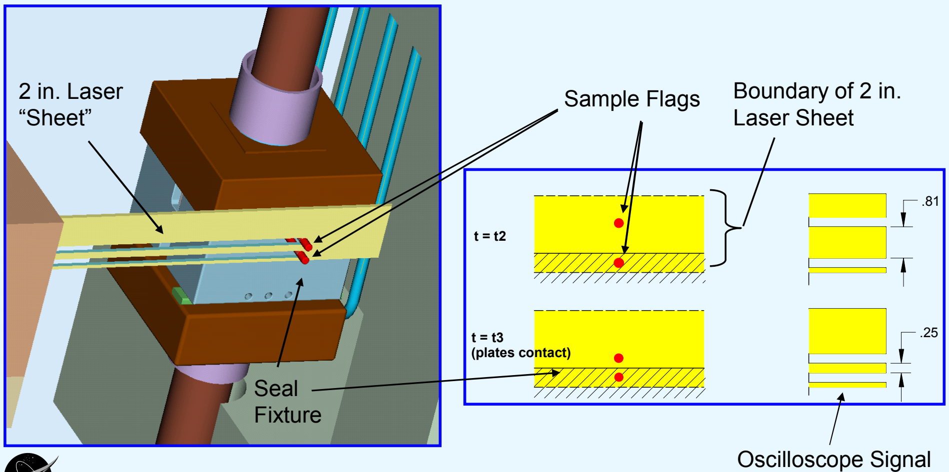





One of the primary tests to be conducted with the new rig will be high temperature (up to 3000°F) compression tests to assess seal resiliency. These evaluations will be carried out by employing a number of user-defined parameters including temperature, loading rate, amount of compression, and mode of application (single load application vs. cycling). The setup will consist of upper and lower SiC platens which compress a seal specimen residing in the groove of a seal holder. Small pins (called sample flags) will be inserted into both the upper platen and seal fixture and will be used in concert with the laser extensometer system previously mentioned to accurately measure compression level as a function of time.

## Hot Compression Rig Details: Laser Extensometer

- Laser extensometer will permit very accurate, high temperature, non-contact measurements of seal compression level
- Total displacement = Flag gap (t) – Flag gap ($t_0$)

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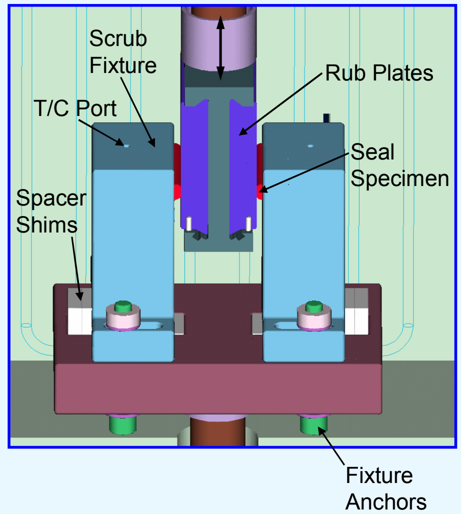
The laser extensometer system (Beta LaserMike Intelliscan 50) essentially consists of a transmitter and receiver. A small motor inside the transmitter unit spins a mirror at high speed as laser light is emitted and causes a laser "sheet" to be transmitted. This sheet of laser light is detected by the receiver unit. Blockage of any part of the laser sheet results in dark areas as seen by the receiver unit. For the current setup, small SiC flags (rods) attached to the upper platen and sample fixture will be used to block part of the laser sheet. As the sample platen moves downward (compresses the seal specimen), the gap of light between the two flags will change and the displacement at any time *t* can be determined.

## Hot Scrub Rig Details

### Purpose

New rig will permit measurement of wear rates and frictional loads for various test conditions:
- Temperature
- Compression level
- Stroke rate and number of cycles
- Rub surface conditions (material, roughness, surface profile)




### Capabilities

- ✓ Temperatures up to 3000°F (1650°C)
- ✓ Loads up to 3300 lbs
- ✓ 3 in. stroke at rates from 0.001 in/s to 8.0 in/s
- ✓ Seal lengths up to 4 in.
- ✓ Seal diameters up to 2 in.
- ✓ Gaps from 0 in. to 0.625 in.
- ✓ Variety of cyclic loading waveforms (sine wave, sawtooth, user-defined profiles)
- ✓ Pre- & post-scrub flow testing



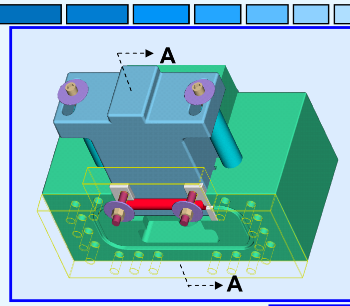
A second setup using the same MTS rig will be used to assess high temperature wear characteristics of structural seal candidates. In this setup, a SiC seal holder containing a seal specimen will flank each side of a scrubbing saber assembly. The seal holders will be held in place through combination of a novel high temperature anchoring system and spacer shims. A load cell mounted at the bottom of the lower platen will permit monitoring of the friction loads. Numerous combinations of testing parameters will be possible with this test setup, including various temperature ranges, seal compression levels, scrubbing rates and profiles, etc. This design will also facilitate post-scrubbing flow tests, as described on the following slide.

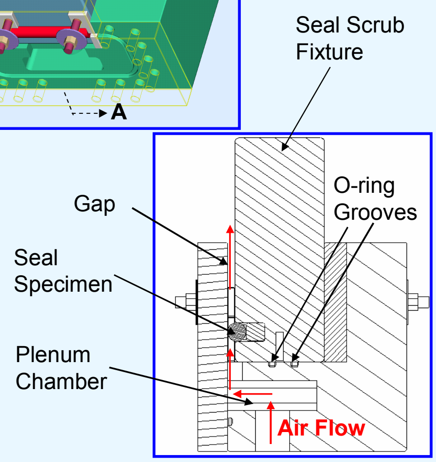
## Hot Scrub Rig Details: Pre- and Post-Scrub Flow Testing

**Purpose**

Ambient flow fixture permits pre- and post-scrub flow evaluations of candidate seals

- Flow testing at 3000°F prohibitively expensive and complicated
- Design minimizes damage due to secondary handling (seal undisturbed between scrub test and flow test)
- Modular design facilitates testing of multiple seal configurations under different testing conditions
  - Test gases: air
  - Flow rates: 0 – 3000 slpm
  - Pressures: 0 – 120 psi
  - Gap settings: 0 – 1 in.




Section A-A

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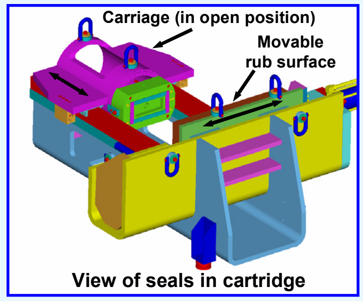
Room temperature leakage tests will also be performed on seal candidates using the same seal holder described for the high temperature scrubbing test. This design will allow a specimen which has just completed a scrubbing evaluation to be “dropped into” this flow fixture, thereby minimizing damage of the seal due to secondary handling. Seal leakage as a function of wear damage can then be easily evaluated.

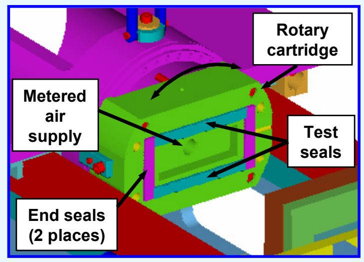
## Ambient Scrub & Flow Testing Rig Overview

**Purpose**

Combined seal flow and scrub tests will be performed in new ambient test rig. Flow rates through seals will be measured for various test conditions:

- Scrub/cycle damage
- Compression level
- Gap size
- Rub surface conditions (material, surface roughness, surface profile)
- Scrub direction (e.g., transverse vs. wiping)



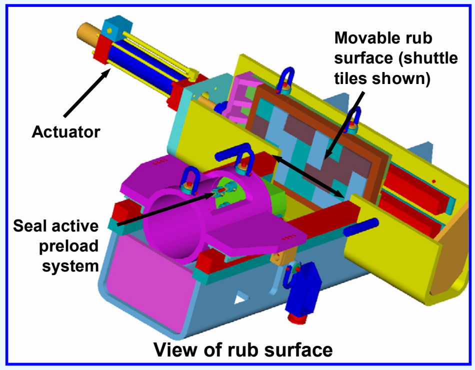



A second rig being design at the NASA Glenn Research Center will permit simultaneous evaluation of room temperature leakage as a function of seal wear. For this rig, a carriage containing a rotation-adjustable seal cartridge will be placed such that the seal specimens are in contact with a scrubbing surface. A servohydraulic actuator would then cycle the scrub surface across the seals via a user-defined cycling profile. A number of different test parameters can be adjusted to mimic actual service environments, including compression level, rub surface conditions, and orientation of the seal with respect to the scrubbing direction.

## Ambient Scrub & Flow Testing Rig Overview (cont.)

### Capabilities

- ✓ Multiple seal geometries/configurations
- ✓ Seal lengths up to 8 in.
- ✓ Scrub rates up to 12 in/s
- ✓ Scrub loads up to 10 kip (frictional loads)
- ✓ Stroke up to 12 in.
- ✓ Active (pneumatic) or passive (Belleville washers) seal preload monitoring system
- ✓ Multiple scrub directions (cartridge can be rotated)
- ✓ Variety of rub surface conditions
- ✓ Test gas: air
- ✓ Flow rates up to 3000 slpm
- ✓ Pressures range: 0 – 120 psi

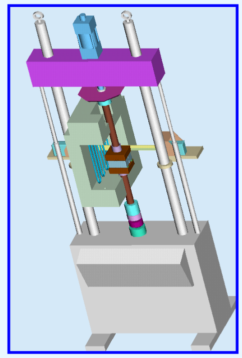




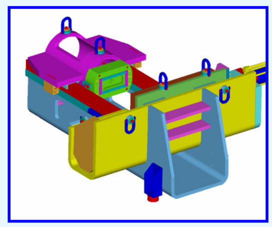

The scrub and flow rig being designed at NASA GRC will have numerous capabilities, including different seal configurations, multiple scrubbing speeds/profiles, measurement of frictional loads, user-controlled seal preloading, etc. These capabilities and the modularity of the design will permit evaluation of numerous seal candidates.

## Update as of 10/2002

- **Hot Compression/Scrub Rig**
  - LaserMike received (8/2001)
  - Load frame received (10/2001)
  - Furnace received (1/2002)
  - High temp. SiC fixturing
    - » Designs complete
    - » Compression fixturing received (9/2002)
    - » Scrub fixturing ordered *(11/2002 est. delivery)*
  - Linear Static Flow Fixture (II) ordered *(10/2002 est. delivery)*



- **Ambient Scrub & Flow Rig**
  - HPU received (11/2001)
  - Rig received (9/2002)



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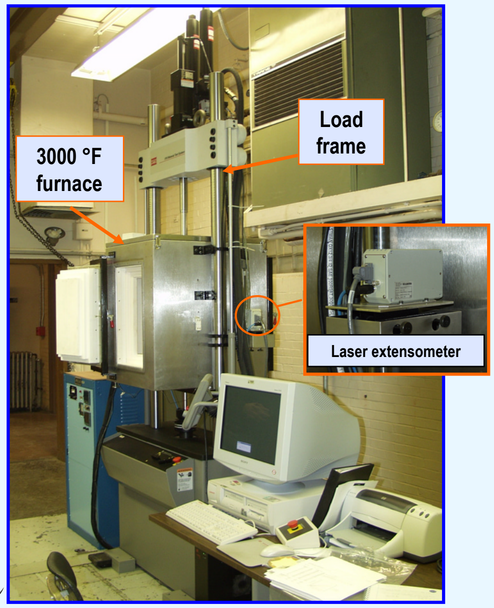
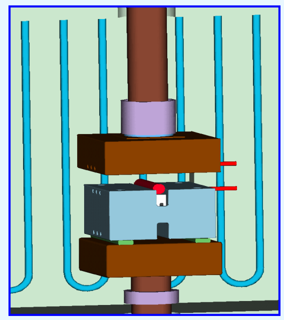
Most of the major components for these state-of-the-art test rigs were acquired by the fall of 2002. Both rigs are currently in the final stages of buildup and integration and will be tested and debugged over the next few months. Seal testing is scheduled to commence in FY03.

## Hot Compression Rig Setup

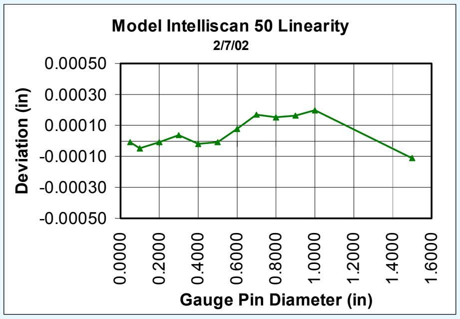


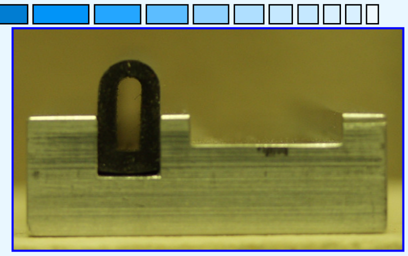



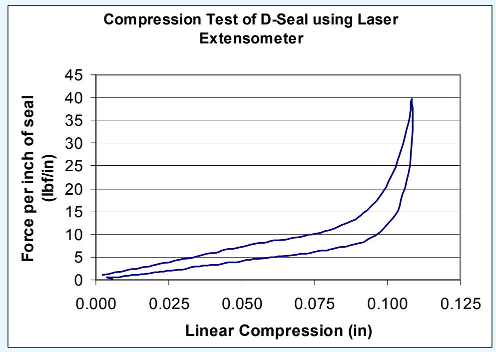


The Hot Compression / Scrub rig is shown on the left with most of the major components installed. The exception is that the high temperature test fixturing was not installed at the time of this picture. The SiC compression fixturing was received and installed in late September of 2002 and is shown in the upper right corner along with the original conceptual schematic in the lower right corner. The SiC scrub fixturing is expected to be delivered in November of 2002.

## Testing Results with Laser Extensometer






- ✓ **Accurate to <0.00025 in**
- ✓ **Linked (DAQ) with MTS controller**

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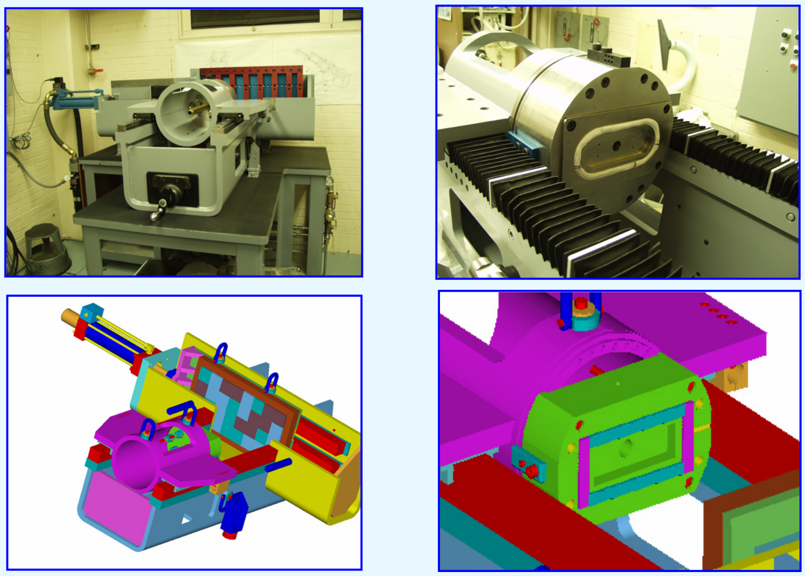
The Laser Extensometer is a key component for the accurate testing of the next generation of high temperature seals. Results of the check out of the laser received by NASA GRC demonstrated excellent accuracy (down to 0.25 mil). A typical test plot conducted on a D-seal in the compression rig at room temperature is shown in the bottom right corner.

## Ambient Scrub & Flow Rig



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The Ambient Scrub and Flow Rig was received and installed with it's initial build in mid-October 2002. The test rig with the single rope seal holder is shown in the top photographs. For comparison, the conceptual schematics (with the wafer seal holder) are also shown.

## Conclusions and Timeline

- NASA GRC is developing and acquiring several unique high temperature seal test rigs to evaluate current and future seal designs
  - Hot Compression / Scrub Rig
  - Ambient Simultaneous Scrub & Flow Rig
  - Proposed initial seal fixture configurations:
    - X-38 rope seals (0.62 in. diam)
    - Ceramic wafer seals (1 in. x 0.5 in. x 0.25 in.)
    - Other seal configurations to be machined at a later date
    - Custom configurations as mutually arranged

| | Hot Compression Rig | Hot Scrub Rig | Ambient Scrub & Flow Rig |
|---|---|---|---|
| Fabrication Complete | Q3 FY02 | Q4 FY02 | Q1 FY03 |
| Installation Complete | Q4 FY02 | Q1 FY03 | Q2 FY03 |
| Checkout Complete | Q1 FY03 | Q2 FY03 | Q3 FY03 |
| Ready for Tests | Q2 FY03 | Q3 FY03 | Q4 FY03 |



NASA Glenn's structural seal research capabilities are in the process of being significantly upgraded. The acquisition of an integrated hot compression / scrub rig and an ambient simultaneous scrub and flow rig will drastically enhance the evaluation and development of current and future high temperature structural seals.

## Additional Information

- Points of Contact

| | | |
|---|---|---|
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- Reminder (for those that are already signed up)

  Tour of NASA Seal Test Facilities    Today, 2:45 pm – 4:15 pm