# Kevlar® 49/Epoxy COPV Aging Evaluation

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**Abstract**

NASA initiated an effort to determine if the aging of Kevlar® 49/Epoxy composite overwrapped pressure vessels (COPV) affected their performance. This study briefly reviews the history and certification of composite pressure vessels employed on NASA Orbiters. Tests to evaluate overwrap tensile strength changes compared 30 year old samples from Orbiter vessels to new Kevlar/Epoxy pressure vessel materials. Other tests include transverse compression and thermal analyses (glass transition and moduli). Results from these tests do not indicate a noticeable effect due to aging of the overwrap materials.

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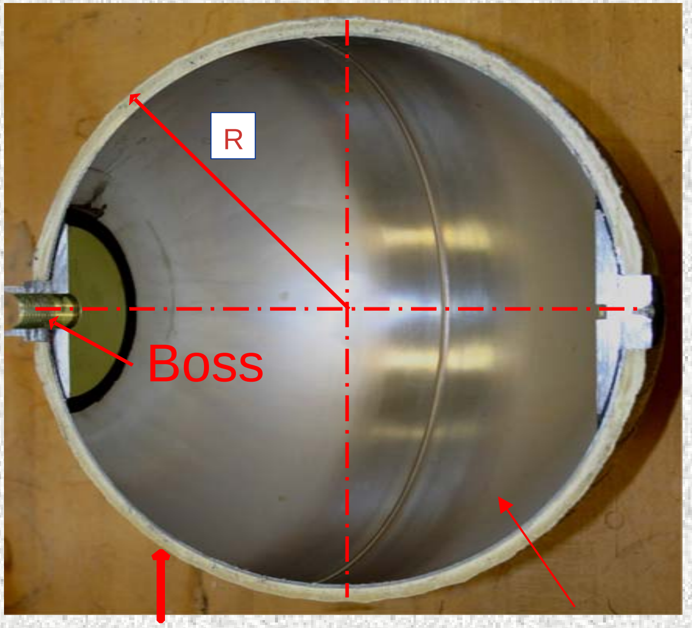
## Aging Aircraft 2008

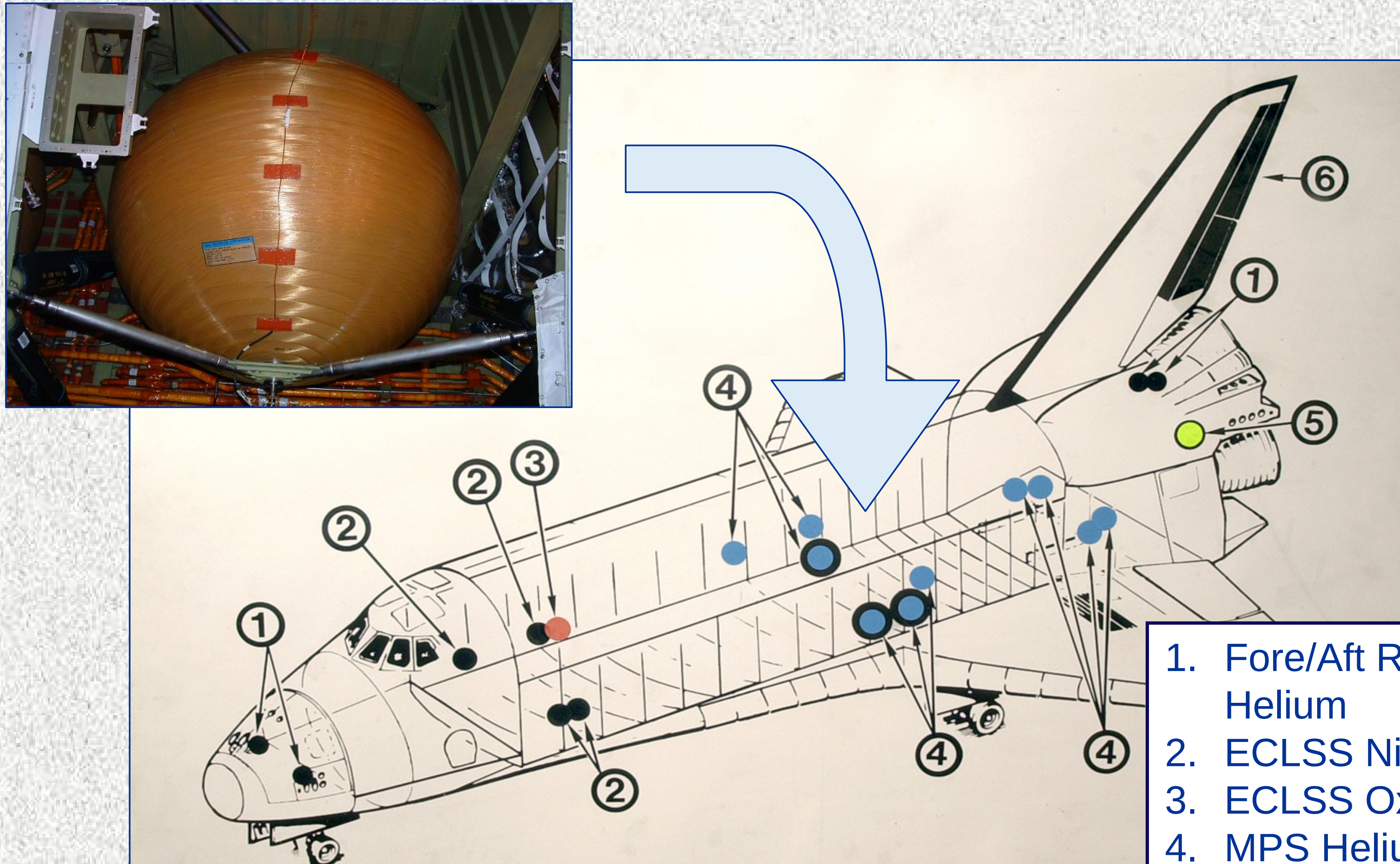
# COPV Design

Composite overwrapped pressure vessels

- NASA in 1970s
- Lighter weight
- Basic configuration
  - Boss
  - Composite overwrap
  - Metallic liner
- Safety is key factor



# Orbiter Systems




1. Fore/Aft RCS Helium
2. ECLSS Nitrogen
3. ECLSS Oxygen
4. MPS Helium
5. OMS Helium

# COPV Design

- Liner
  - Pressure-tight
  - Metal or plastic
  - Permeation barrier
  - Leak-before-burst (LBB)
  - Failure can be catastrophic

# COPV Design

- Composite overwrap
  - Fiber & resin
  - E- or S-glass, Kevlar® 49, Carbon, Spectra
  - Epoxy matrix
  - Encapsulates liner
  - Provide strength
  - Failures result in catastrophic high energy releases

# COPV Materials Age-Life

- Issues:
  - Aging of Orbiter COPV nonmetallic materials may compromise overwrap structural integrity (fiber, resin & coating)
  - Materials data is insufficient to completely bound problem
    - Required existing certification deviation each SSP flight
- Concern:
  - Aging effects could result in degradation of composite structural integrity resulting in premature burst failure during service
- Objective:
  - Test plan that addresses material age life in support of COPV flight rationale development
- Status:
  - A per-flight Cert Dev required but *no near-term* COPV age-life concerns
  - Pressurization controls improved
  - Pad clears at launch – 4 Days
  - COPV stress rupture testing initiated

# Material-Age Life Recertification

- Initial Age-Life Tests in 1980s found no age-life issues
  - 10 year old samples
    - Fiber = Kevlar® 49
    - Matrix Resin = LRF-092
  - Test data not saved
  - Better tests today

- Limited Data: Orbiter COPV data packs were not readily available (fiber tensile strength, liner volume)

- Project Office relies on literature searches for Kevlar/epoxy: *Orbiter fleet is ~ oldest application for Kevlar/epoxy composite*

# Coupon Testing

## Why do coupon tests?

- Burst test representing single point failure not rigorous measure of aging
- NDI provides inherently qualitative, not quantitative, data
- Establish baseline for age life
  - Recertification overwrap age testing in 1988/89 was inconclusive
  - No baseline for aging was established

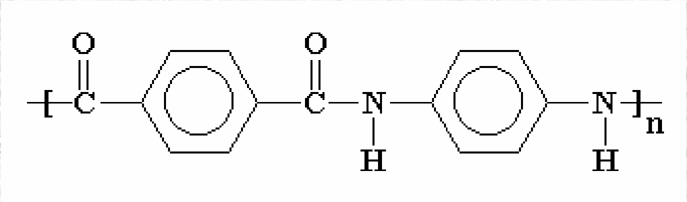
*No correlation between burst strength and stress rupture*

- Not for single fibers, strands or vessels
- Strength distribution of fibers = same for virgin material & fiber exposed to static loads
- Bottom line: failure mechanism for stress rupture is not known

# Overwrap Coupon Testing

## – Composite testing

- *Strand tests—tensile/creep (most common)*
- Stress rupture—strands
- *Transverse compression—squish*
- *Dynamic mechanical analysis—stiffness*
- *Coefficient of thermal expansion—soft or brittle*
- *Glass transition temperature (Tg) —glass-to-rubbery transition*
- Micrographic analysis—fiber/resin morphology
- Raman spectroscopy—residual stress



Kevlar®

## – Liner tests

- Tensile strength & stiffness (boss, membrane, equatorial)
- Fatigue changes & micrographic analyses

# COPV Aging Test Matrix

| Composite Test | Purpose | Samples |
|---|---|---|
| Transverse Compressive | Through thickness stiffness changes | Composite coupons S/N 011, S/N 029, New GD Tanks |
| Dynamic Mechanical Analysis (DMA) | - Tg (Age life changes)<br>- Stiffness Changes | Composite Coupons |
| Coefficient of Thermal Expansion (CTE) | Fiber Age-life changes | Composite Coupons |
| Thermal Mechanical Analysis (TMA) | - Composite age-life changes<br>- Tg | Composite Coupons |
| Tensile Strength | Fiber age-life changes | Strand Filaments |

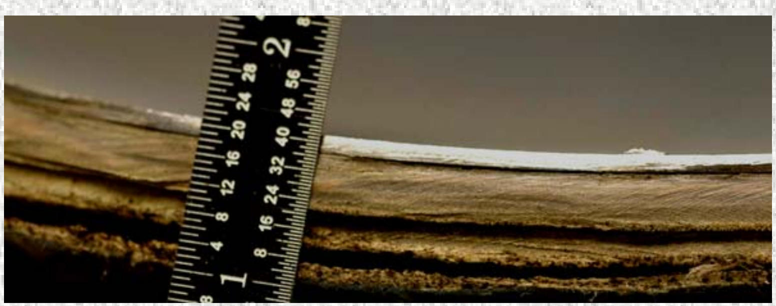
# COPV Coupon Specimens

**<u>Aged Material</u>**

- S/N 029 – Low Residual Volume Vessel
- S/N 011 – High Residual Volume & Burst Vessel

**<u>New Material</u>**

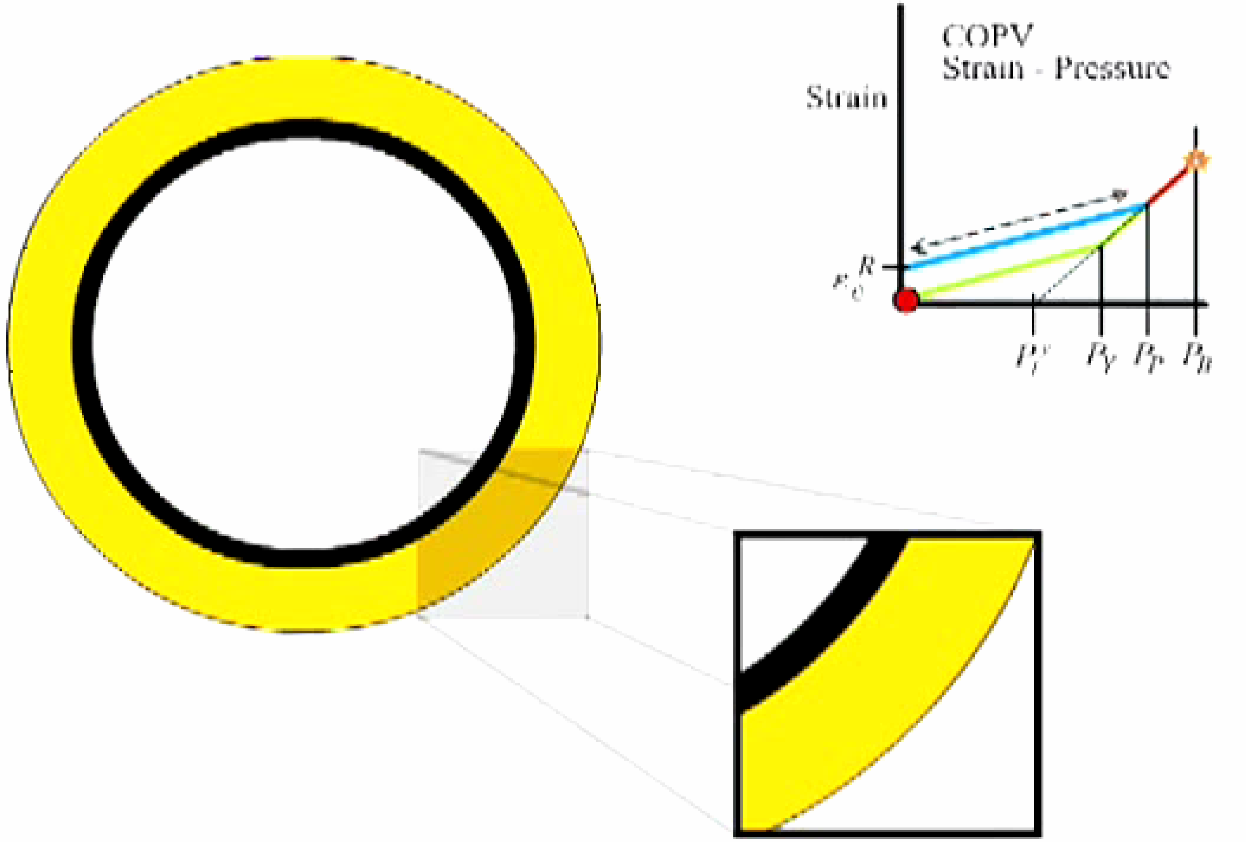
- 10” Fleet Leader – New Vessel
- New Cured Strand – 2 spools



S/N 029 Cross-section
- Ti 6/4 Liner
- Composite Overwrap

Apparent Residual Stress

# COPV Proof Process Affects Overwrap Stress




$P_l^y$ - Liner Pressure Share Equivalent to Flow Stress of a Perfectly Plastic Liner

$P_Y$ - Vessel Pressure that Initiates Plastic Flow in the Liner

$P_P$ - Vessel Proof Sizing Pressure

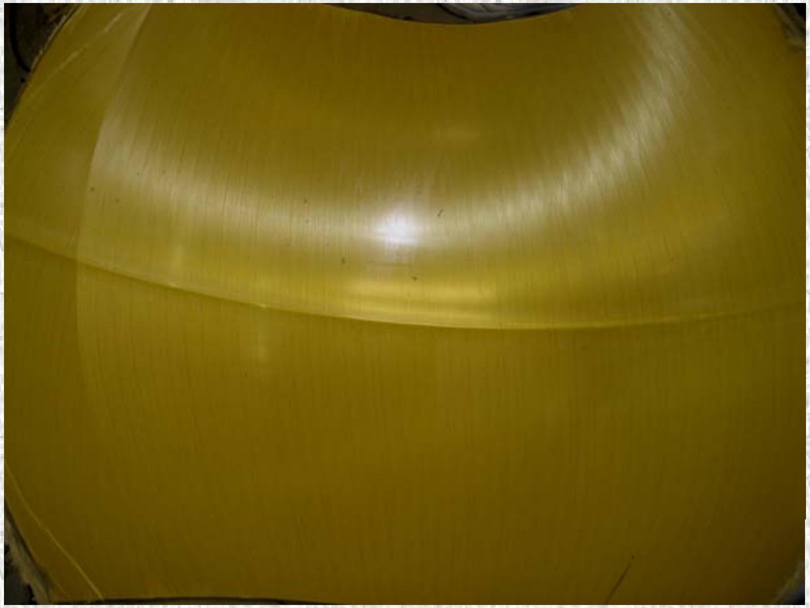
$P_B$ - Vessel Burst Pressure

$\varepsilon_c^R$ - Residual Strain Due to Proof Sizing

# COPV Kevlar/Epoxy Testing

- S/N 029 Columbia OV-102 COPV ~ 25 yrs old
  - Survived reentry
  - Composite Interior Provided Good Samples
  - Manufactured by Brunswick Composites (GD)

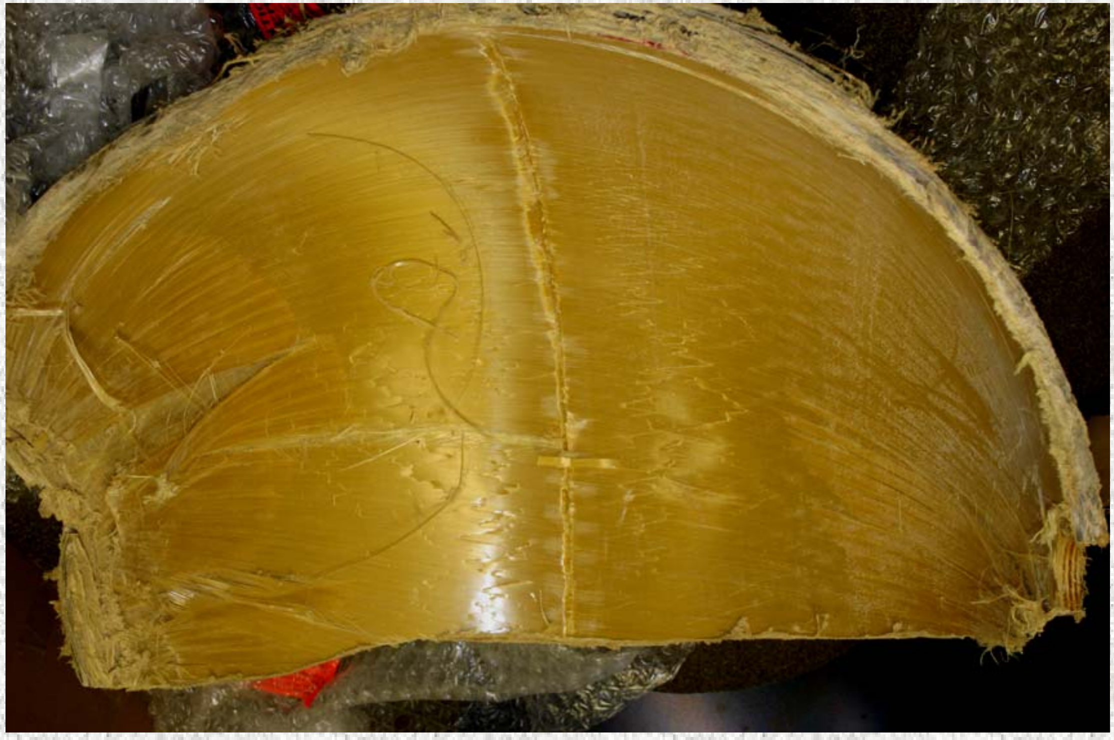
**Columbia OV-102 COPV (40 inch)**
**Model S/N 029 Damaged Outer Shell**



**Columbia S/N 029**
**Inside View After Sectioning**

# COPV Kevlar/Epoxy Testing

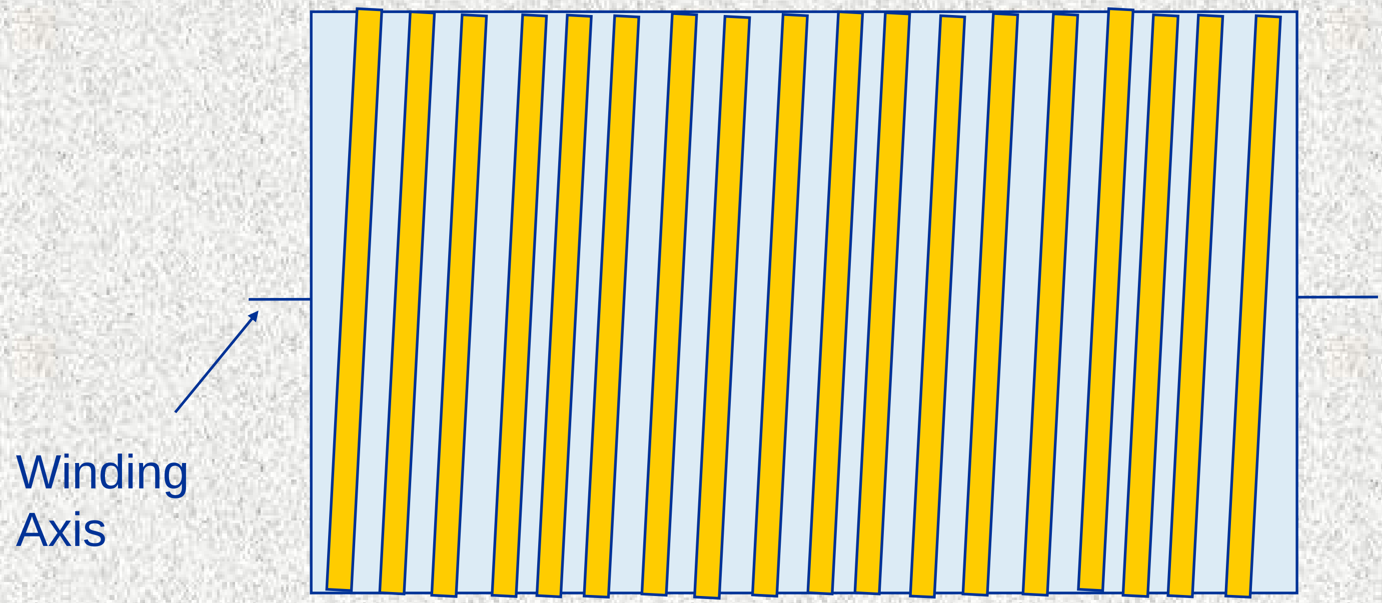
- S/N 011 COPV ~ 25 yr old (40 inch)
  - Kevlar® 49/LRF-092 composite overwrap
  - Not exposed to space environment
  - Extensive pressure cycling



# COPV Kevlar/Epoxy Testing

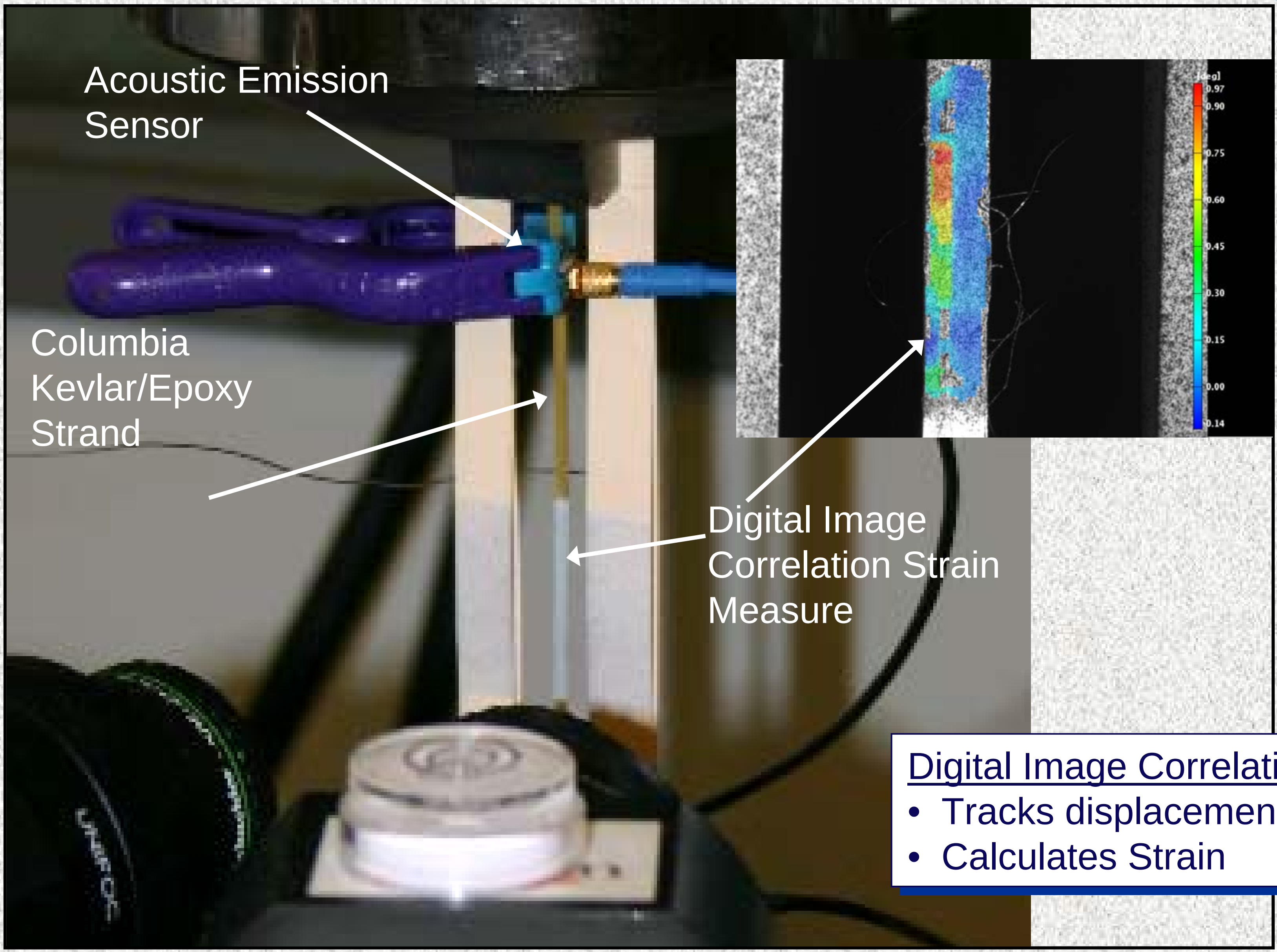
- New 10 inch Kevlar® 49/LRF-092 COPV (390 $in^3$)
- Manufacturer is General Dynamics – Lincoln Composites
- Same fiber and epoxy as Orbiter COPV S/N 029 and 011

# Kevlar® 49/LRF-092 Strand Processing



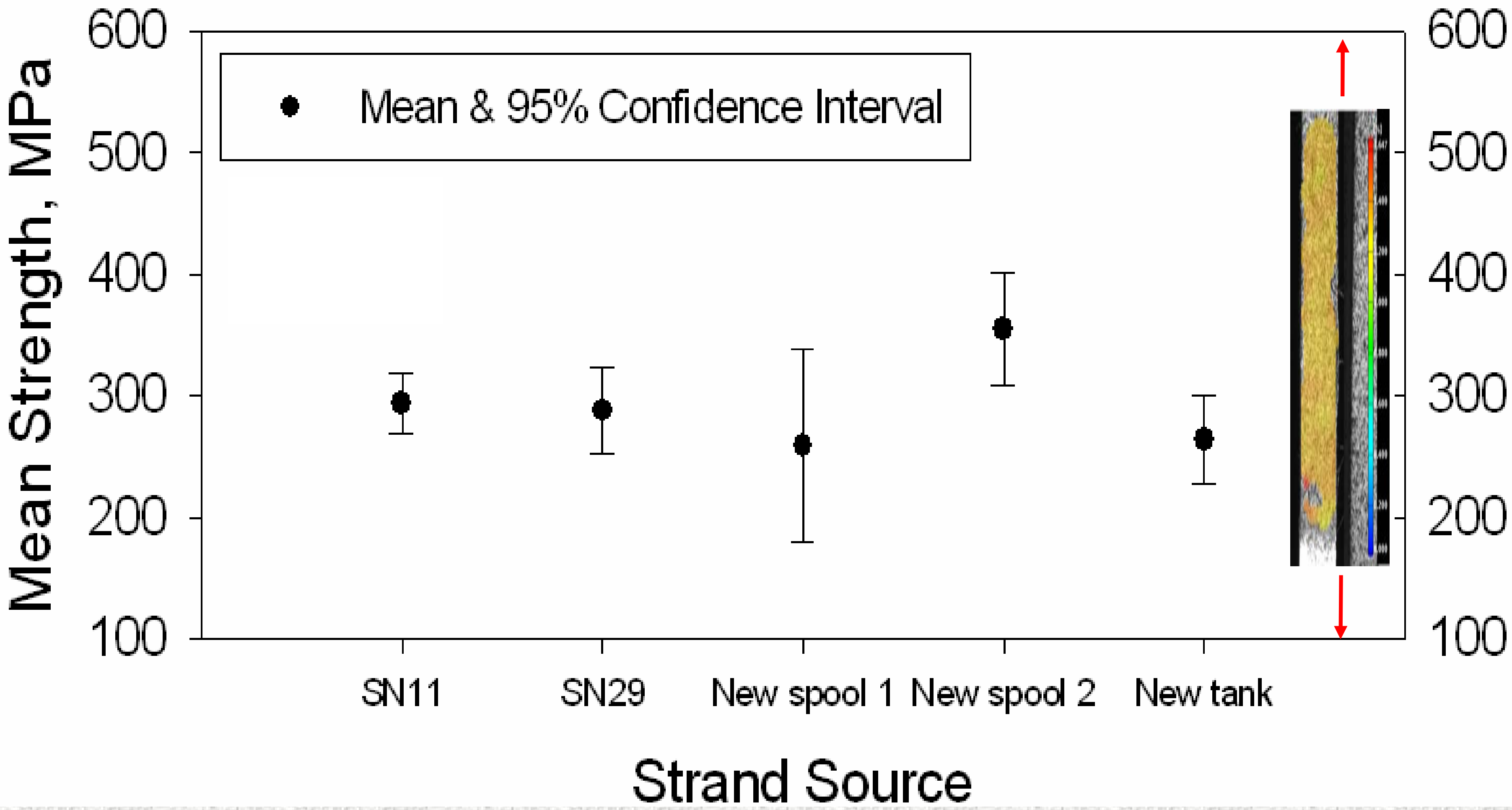

- Kevlar® 49/LRF-092 spools purchased from GD
- Strand Cured at 150 $^{o}$C/1hr
- Strand curing develops strains similar to COPV cure
- Less than 1yr old

# Strand Tensile Tests



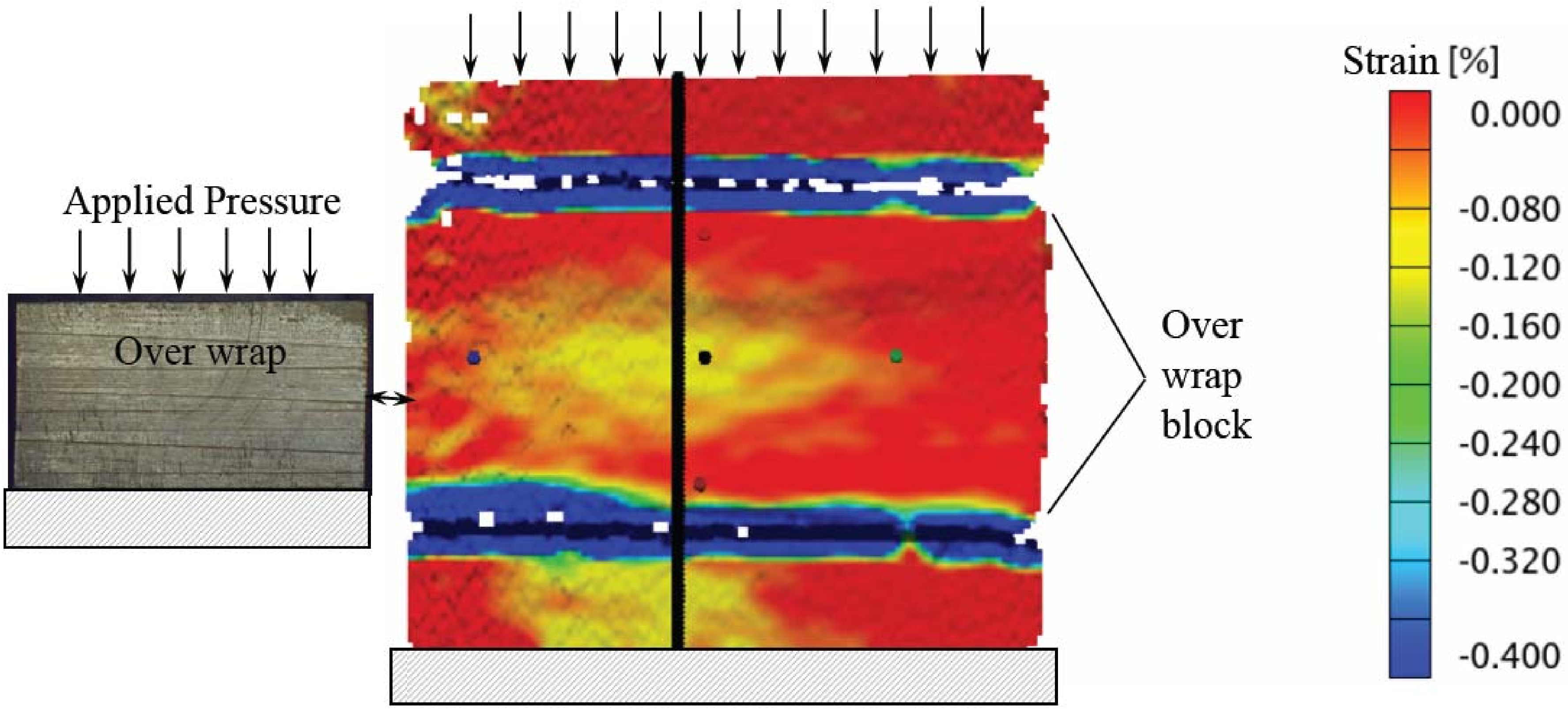

<u>Digital Image Correlation</u>
- Tracks displacement
- Calculates Strain

# Tensile Strength



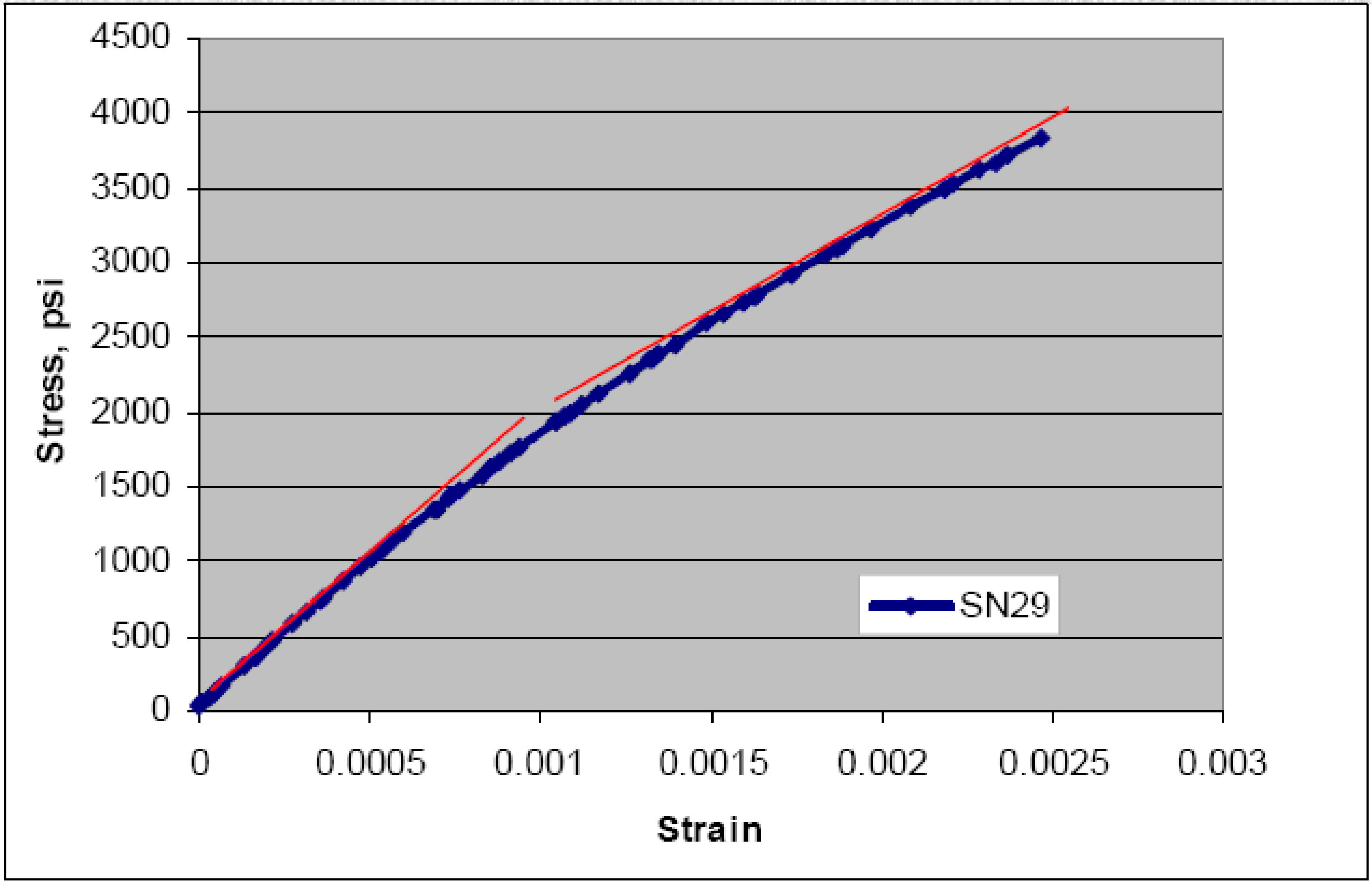

No Significant Difference in Tensile Strengths

# Transverse Compression Tests




- Digital Image Correlation Strain Measurement
- Three Composite Overwrap Specimens Stacked
- Difficult to control sample bulging

# Transverse Compression S/N 029




- Young's modulus = 1.8 msi below 0.1% strain/1.3 msi above 0.1% strain
- Poisson's ratio = 0.27

# Thermal Analysis

## Glass Transition Temperature – S/N 029 and New 10" COPV

| S/N029 | | 1st Drying | 2nd Drying |
|---|---|---|---|
| TMA | Inner | 101 ± 7 | 115 ± 1 ºC |
| | Middle | 104 ± 8 | 121 ± 3 ºC |
| | Outer | 100 ± 4 | 121 ± 1 ºC |
| DMA | Outer | 112 ± 4 | 118 ± 2 ºC |
| | Inner | 101 ± 1 | 107 ± 1 ºC |
| New 10"COPV | | | |
| TMA | Middle | --- | 117 ± 4 ºC |

- Drying Affects Glass Transition Temperature (Tg)
- No Significant Difference in Unaged and Aged Composite Overwrap Tg

# Summary and Conclusions

- Tensile strengths for unaged and aged composite strands shows no significant difference
  - Differences in COPV residual volumes not detected in tensile strength tests
  - COPV manufacturing and operation environmental difference not apparent through tensile tests
- Thermal Analyses for unaged and aged composites shows no significant differences in Tg
  - Aged Composite Tg are comparable General Dynamics reported values in 1978
- Columbia (OV-102) COPV S/N029 composite interior
  - Pristine appearance despite reentry after accident
- Future Work
  - Full-Scale COPV stress rupture underway
  - Raman Spectroscopy: useful composite overwrap strain measurements