Advanced Suit Team
JSC – EC5

Establishing Standardized Test Methods for Evaluating Space Suit Gloves

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Outline

- Introduction to the Project
- Spacesuit Standardized Testing History
- Lunar Glove Fabric Evaluation Plan
    - Literature Review of Previous Work
    - Defining Characteristics of “Better” Materials for the Lunar Environment
    - Standardized Tests for Evaluating Candidate Materials
    - Standardized Test Development: Tumbler Abrasion
        - Rotational Tumbler Exploratory Testing
        - Rotational Tumbler Validation Testing
    - Cryogenic Flex Testing
    - Alternative Material Candidate Selection
    - Combined Test Procedure
- Candidate Fabric Test Results
    - Pre-Screen Cryo Crack Testing
    - Tumbler Test Results
- Discussion of Results
- Conclusion and Future Work

Image Credit: NASA

Introduction

Background:

- Current Phase VI gloves are designed and certified for LEO
- Artemis environment is drastically different
  - Dust
  - Cut hazards
  - Thermal Extremes
- NASA and Vendors have a need to develop more durable gloves

Image Credit: NASA

Problems Addressed in this Effort:

NASA has undertaken an effort to address three key obstacles to producing a space suit glove that is sufficiently durable to meet the needs of the Artemis mission. These obstacles include:

1. No consistent/standardized testing defined to evaluate the durability of gloves for the extreme lunar environments

2. No baseline lunar performance data on the Phase VI gloves from which to compare new design

3. Current glove fabrics are unlikely to be sufficient to meet Lunar requirements.

Space Suit Standardized Testing History

- ASTM/ANSI tests exist for characterizing the properties of fabrics, coatings, films, seams
- Space suit designs have relied on these material level tests in conjunction with more complex system level tests
- Lack of an agreed upon standardized test procedure for Lunar Gloves

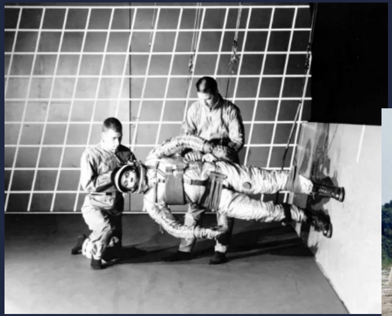


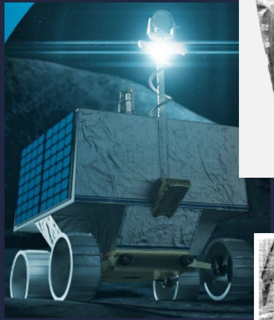
Image Credit: NASA

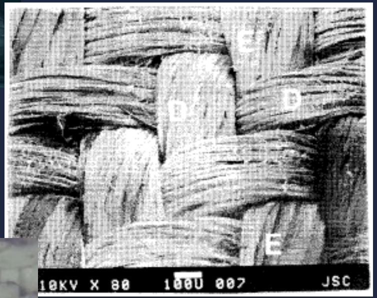
Lunar Glove Fabric Evaluation Plan

- System level testing is costly and takes time
- Risk can be reduced by developing a vetting process at the fabric level
- Steps followed to developing the plan:
  - Reviewed literature of previous work
  - Defined characteristics/requirements of “better” materials
  - Devised a series of standardized tests for evaluating candidate glove fabrics
  - Conducted market research to identify alternative COTs materials
  - Evaluated alternative materials

Lessons Learned from Previous Work

- Include reference fabrics to compare durability
  - Teflon (Apollo) and Ortho Fabric (EMU)
- Fabric down select and test method from VIPER Rover seemed practical
  - Pre and post exposure testing for strength comparison
- Use SEM/optical observations to broadly characterize fiber and coating wear
- Include the base fibers of Vectran, Gore-Tex (Teflon) and Kevlar
- Choose fabrics with a flat (plain) weave rather than textured (twill) weave
- Include coatings (dust resistance, puncture resistance, cut resistance)
- Refine the Tumbler Abrasion Test Method
  - Create easy to define metrics
  - Setup the test in a way to minimize disturbance
  - Setup the test in a way to minimize variables
  - A standardized test requires consistent and repeatable results
  - Combine with other fabric strength measurement tests (cut, tear, puncture, tensile)





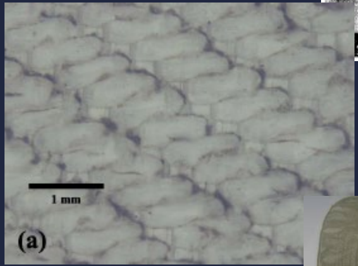


Image Credit: NASA

Defining Characteristics of “Better” Materials

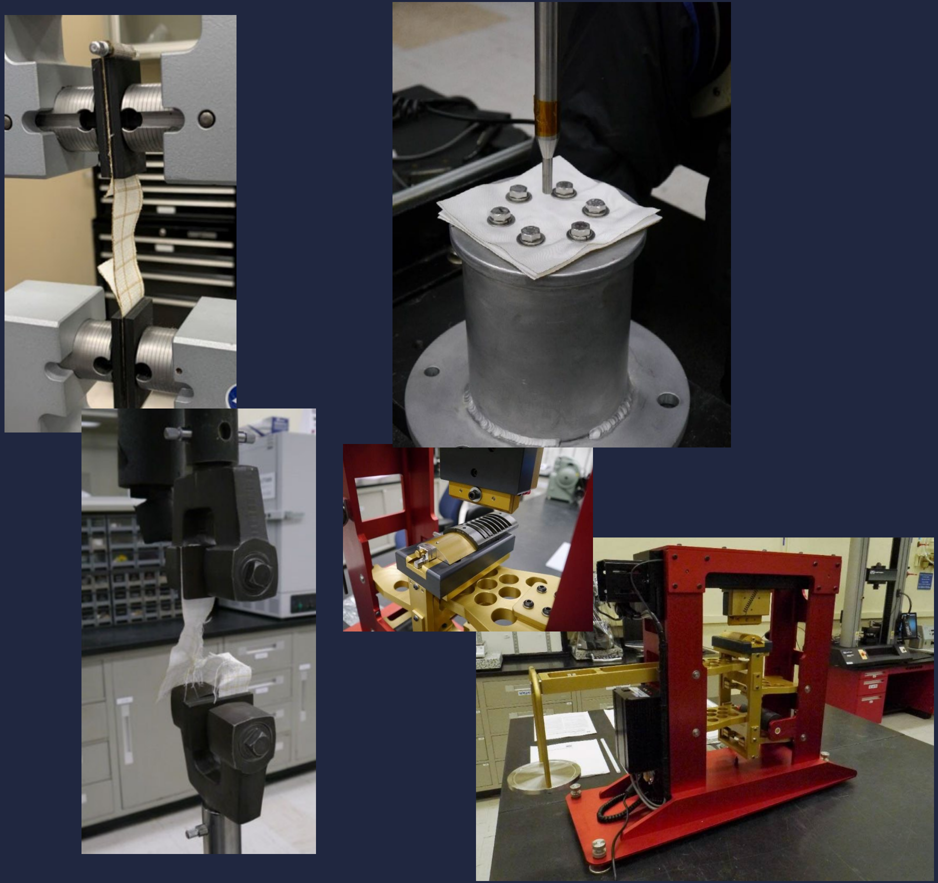
- Differences in environments

	ISS	Lunar South Pole
Wear Environment	Relatively pristine, low dust	Fine abrasive regolith, sharp rocks
Thermal Environment	144K to 433K (-200F to +320F) Incidental 100K (-280F)	8 hours: 100K to 350K (-280F to 170F) 2 hours: 48K (-390F)
Activities to be Performed	Grasping handrails, translation, moving objects	Heavy activity, high impact tools, frequent handling of “dirty” materials

- Material specification sheet for vendors

Attribute	Requirement/Guideline
Thermal Range	8 hours: 100K to 350K (-280F to 170F) 2 hours: 48K (-390F)
Abrasion Resistance	High (i.e., in a Taber test withstand wear from 150 grit garnet sandpaper)
Cut Resistance	Min rating of ANSI A2 (Ortho); A5 or higher is ideal
Strength	Min strength of 500 lbf tensile (Ortho) for cut/abrasion fabrics
Off gassing/volatiles	Low
UV Resistance	High
Stiffness	Low
Shedding capability	Low

Standardized Tests for Evaluating Fabrics



Tensile strength test (upper left). Tear strength test (lower left). Puncture strength test (upper right). Cut resistance test (two in lower right). Image Credit: NASA

<u>Existing Tests Selected</u>

- Tensile Strength (ASTM D5035)
- Puncture Strength (ASTM F1342)
- Tear Strength (ASTM D2261)
- Cut Resistance (ASTM F2992)
- Thermal Conductivity (ASTM C 177)
- Abrasion Resistance (ASMT D4966)
- Emissivity (ASTM C1371)
- Air Permeability (ASTM D737)
- Stiffness (ASTM D1388)

<u>Custom Tests Selected and Refined in this Effort</u>

- Tumbler Abrasion (NASA Design)
- Cryo Flex Test (NASA Design)

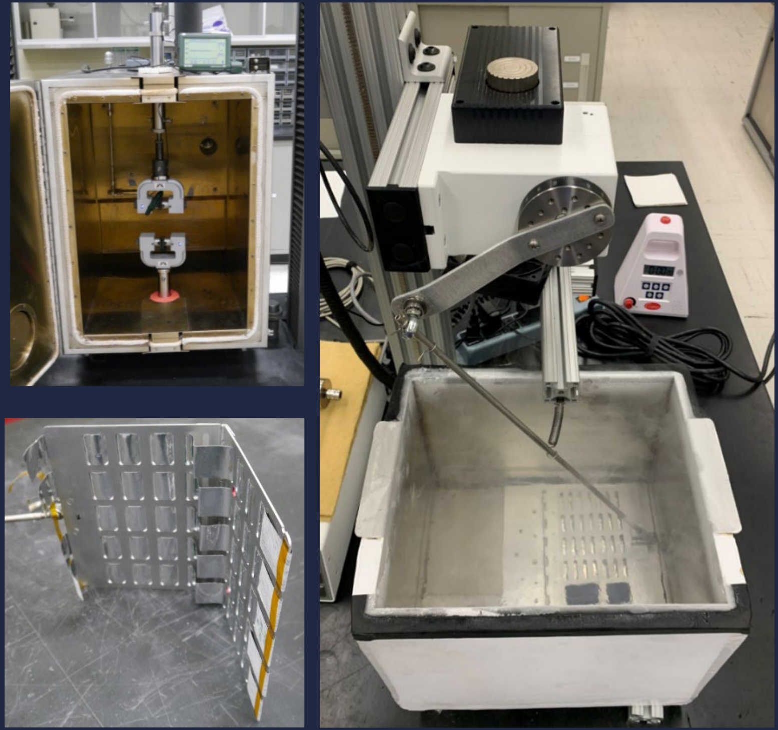
Standardized Test Development: Tumbler

- ASTM representatives were included on the team and bring insight from industry and experience in fabric testing; they document the new standard
- Emphasis on establishing a defined procedure for
  - Preparation of fabric panels
  - Quantifying metrics
  - Cleaning the fabric to prepare it for post abrasion strength testing
- Enhancements were made to improve functionality of test
  - Longer fabric panels are captured in 6 removeable frames
  - Tumbler frames with clear, polycarbonate windows for viewing dust penetration/holes
- Exploratory Testing - Controllable variables were identified and defined
  - Type/quantity of lunar simulant and rock media defined
  - Speed of rotation of tumbler
  - Duration of the test
- Validation Testing - Consistency and Repeatability
  - Performed using Ortho Fabric, Cotton, and Kevlar as reference fabrics

Tumbler apparatus (upper left). Commercially available tumbler media (upper right). Tumbler with dust shown migrating through material (lower left). Tumbler with panel removed to show internals of tumbler after tumbling with Lunar regolith simulant and tumbler media (lower right). Image Credit: NASA

Cryogenic Exposure Testing

- Determine if fabrics degrade from exposure to cryogenic temperatures
  - Not commonly tested
- Limited research available to understand total effect
- Three separate tests included to compare LN2 effects
  - Pre-screen pass-or-fail fold test
    - Completed on a subset fabrics – all fabrics “passed”
  - Instron strength testing with LN2 chamber (tensile, tear, puncture)
    - Not completed due to technical issues
  - NASA developed LN2 folding apparatus with post tensile test
    - Completed on a subset of fabrics



Instron strength test apparatus in LN2 chamber (upper left). Folding apparatus (lower left). LN2 bath with folding apparatus motor and interfaces (right). Image Credit: NASA

Alternative Material Candidate Selection

- COTs fabrics procured and included in Test Series

	Fabric Tested	Type	Category	Coating	Construction	Thickness (in)	Weight (oz/yd^2)	Reason for Inclusion
100	Ortho	116	Reference	N/A	2 layer plain weave	0.024	14.40	*Baseline fabric used on EMU TMG*
XX	Cotton (Lot 1)	Staple	Reference	N/A	plain weave	0.0118	5.20	*Low strength fabric used for validation testing*
XX	Cotton (Lot 2)	Staple	Reference	N/A	plain weave	0.011	4.50	*Low strength fabric used for validation testing*
107	JPS Kevlar	775 KM2 Plus	Cut/Abrasion	N/A	plain weave	0.011	6.81	*High MMOD protection; used in other NASA vehicles and military armor*
113	Turtleskin	T9-1094	Cut/Abrasion	N/A	plain weave	0.008	3.00	*Light weight cut resistant fabric; Turtleskin patches are used on Ph VI glove*
122	Teflon	T-162	Cut/Abrasion	N/A	plain weave	0.008	9.30	*Used on Apollo suit and EMU gloves*
111	Coated Woven Vectran	2241*	Cut/Abrasion	STF	plain weave	0.013	6.70	*Shear thickening fluid provides enhanced MMOD, puncture and dust resistance*
110	Uncoated Woven Vectran	2241	Cut/Abrasion	N/A	plain weave	0.013	5.60	*Included as comparison for coated version of fabric*
109	Uncoated Vectran Ortho	2340	Cut/Abrasion	N/A	2 layer plain weave	0.027	14.50	*Included as comparison for coated version of fabric*
112	Coated Vectran Ortho	2340*	Cut/Abrasion	STF	2 layer plain weave	0.027	16.80	*Shear thickening fluid provides enhanced MMOD, puncture and dust resistance*

Shear Thickening Fluid (STF)/ Super Hydrophobic Coating

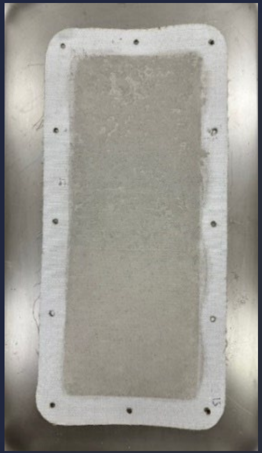
Alternative Material Candidate Selection

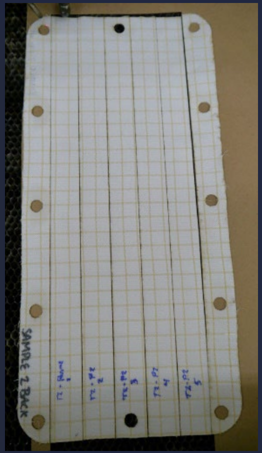
- Fabrics of interest but not included in Test Series

	Fabric Tested	Type	Category	Coating	Construction	Weight (oz/yd^2)	Reason for Inclusion
101	PTFE Felt	PTFENF900S	Thermal	N/A	non woven	26.54	*Used on xEMU EPG around protruding hardware to create a dust seal*
102	Hybrid Shield Thermal Array (single sided)	NSM-HS-TA	Thermal	Elastomer pillars	composite	N/R	*Used on prototype HPEG glove; high temp resistance; flexible fiberglass substrate with elastomer pillars*
103	Hybrid Shield Thermal Array (double sided)	NSM-HS-TA	Thermal	Elastomer pillars	composite	N/R	*Used on prototype HPEG glove; high temp resistance; flexible fiberglass substrate with elastomer pillars*
104	Nomex Nano	Glide Ice	Dust	N/A	composite	6.50	*Nomex nano is used for smoke particle filtration in firefighter garments*
105	Dunmore	TR01447	Cut/Abrasion	Stanet	laminate	7.87	*Fabric selected for VIPER rover suspension cover; VDA/Kapton/Kevlar*
106	Dunmore	Cryoshield	Thermal	aluminum	non woven	N/R	*Vendor recommended; used for storage of liquid gas*
108	UPT Treated Tyvek	1070D	Dust	ALD-TiO2	spun	2.00	*Dust barrier with coating to enhance UV and abrasion resistance*
114	Turtleskin	T9-1391	Cut/Abrasion	N/A	plain weave	5.50	*Light weight cut resistant fabric; a version of Turtleskin is used on Ph VI glove*
115	Mid-Mountain Material	Amatex CF-19	Cut/Abrasion	ceramic	woven	N/R	*Vendor recommended; high strength; high temp range; good flexibility*
116	Superfabric	600d	Cut/Abrasion	guard plates	woven	N/R	*Used in TMG Evolution Task and xEMU kneepads; high op temp; flexible*
117	Sefar Architecture	EL-55-TO	Cut/Abrasion	N/A	woven	N/R	*Fabric evaluated for VIPER rover suspension cover; PTFE fabric; UV resistant*
118	Sefar Architecture	EL-30-T1-UV	Cut/Abrasion	N/A	woven	N/R	*Fabric evaluated for VIPER rover suspension cover*
119	Sefar Architecture	IA-40-CL	Cut/Abrasion	N/A	woven	N/R	*Fabric evaluated for VIPER rover suspension cover*
120	Sefar Architecture	4T40HF	Cut/Abrasion	ePTFE	woven	N/R	*Fabric evaluated for VIPER rover suspension cover*
121	Superfabric	700192	Cut/Abrasion	guard plates	woven	N/R	*Used in TMG Evolution Task and xEMU kneepads; high op temp; flexible*
123	Teflon	T-164	Baseline	N/A	plain weave	9.00	*Used on Apollo suit and EMU gloves*
124	Cormatex	Silica Fiber Felt	Thermal	N/A	non woven	21.53	*Vendor recommended*
125	Cormatex	Basalt Fiber Felt	Thermal	N/A	non woven	10.32	*Vendor recommended*
126	Cormatex	Glass Fiber Felt	Thermal	N/A	non woven	30.97	*Vendor recommended*

Candidate Fabric Test Results

- The fabric test plan is extensive and only a subset was completed for this effort
- Pre-screen cryo crack testing
  - All fabrics “passed” visual inspection
- Abrasion Exposure (Tumbler Test)
  - Baseline data gathered (tensile, tear, cut, puncture, thickness, mass, air permeability, stiffness
  - Panels of fabric were abraded for 8 hours using lunar simulant and rocks
  - Post abrasion strength data collected





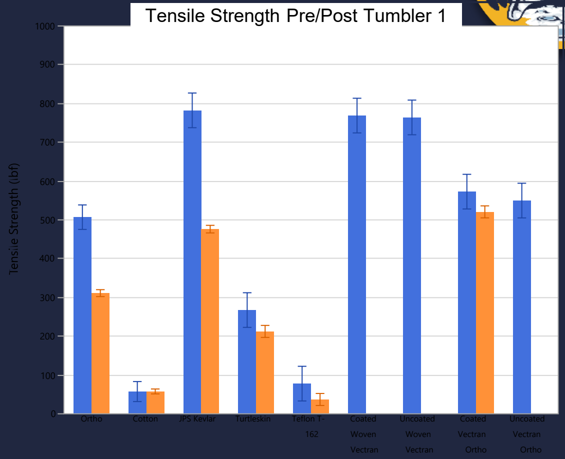
Fabric panel showing remaining lunar simulant after being removed from tumbler (left); Fabric panel showing strips cut for tensile testing (right) Image Credit: NASA

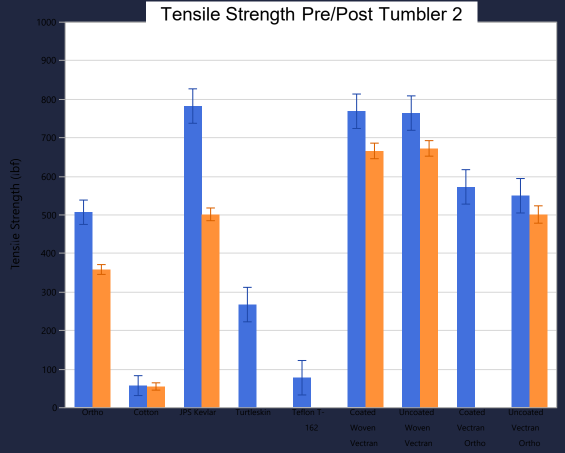
Candidate Fabric Test Results

Tensile Results

- What is the variability of the tumbler abrasion test?
- Fabrics were run in 2 unique tumbler drums
- P-Value analysis is being conducted to determine 95% confidence interval of results
- Initial analysis to determine if mean tensile strength is determined by fabric type

- Hypothesis 0: The mean tensile strength is equivalent for all fabrics
- Hypothesis 1: The mean tensile strength is not equivalent for all fabrics





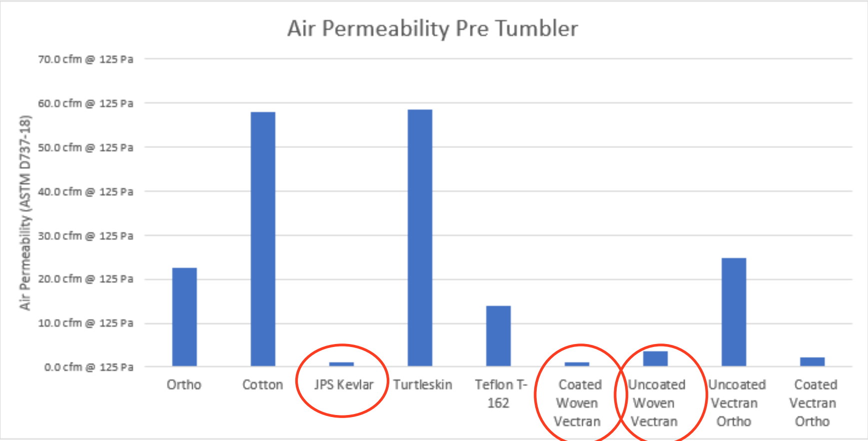
Conclusions:

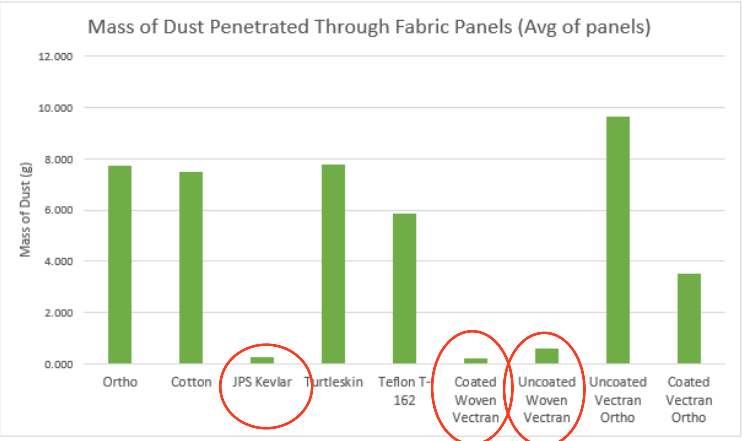
- Baseline: Kevlar, Coated Woven Vectran, Uncoated Woven Vectran > Coated Vectran Ortho, Uncoated Vectran Ortho, Ortho > Turtleskin > Teflon T-162 and Cotton
- Tumbler 1: Coated Vectran Ortho > Kevlar > Ortho> Turtleskin > Cotton and Teflon T-162
- Tumbler 2: Uncoated Woven Vectran, Coated Woven Vectran > Kevlar, Uncoated Vectran Ortho > Ortho > Cotton

Candidate Fabric Test Results

Air Permeability and Dust Penetration Analysis

- Correlation found between fabrics with ***low*** air permeability/plain weave and amount of dust penetrated
  - Kevlar, Uncoated and Coated Woven Vectran
- Correlation not as strong for fabrics with high air permeability
  - Ortho Fabric, Turtleskin, Teflon, Uncoated Vectran Ortho Fabric





Discussion of Results

- Pre-screen cryo test not aggressive enough or visual observation is not enough to detect damage
- Tumbler test has some variation which must be investigated in order to compare fabrics
- Thickness and mass measurements were not good metrics to use for down select
- Air permeability test does indicate a fabrics dust resistance as long as it is low; particle penetration test should be considered
- Cryo flex test yielded unexpected results (increase in strength on several fabrics) and warrants further investigation
- Not included: UV, AO, Vacuum, Charge dissipation, MMOD, combined environmental effects

Discussion of Results

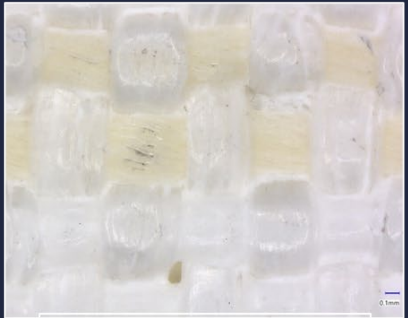
- Microscopy on tumbled fabrics

100X Uncoated Vectran Ortho Pre-Tumbler

100X Uncoated Vectran Ortho Post-Tumbler

100X Uncoated Woven Vectran Pre-Tumbler

100X Uncoated Woven Vectran Post-Tumbler



100X Coated Vectran Ortho Pre-Tumbler

100X Coated Vectran Ortho Post-Tumbler

100X Coated Woven Vectran Pre-Tumbler

100X Coated Woven Vectran Post-Tumbler

Conclusion and Forward Work

- Top contender:
  - STF/SH Coated Woven Vectran (tight, plain weave, coating, high strength, abrasion resistant fiber) but need to investigate UV concerns
- This effort helped to vet a process for NASA’s ability to test glove fabrics and identified deficiencies
- The fabric test plan is extensive and only a subset was completed
- Task 2 and 3 are focused on establishing standardized tests for glove thermal and cut testing

ADVANCED SUIT TEAM

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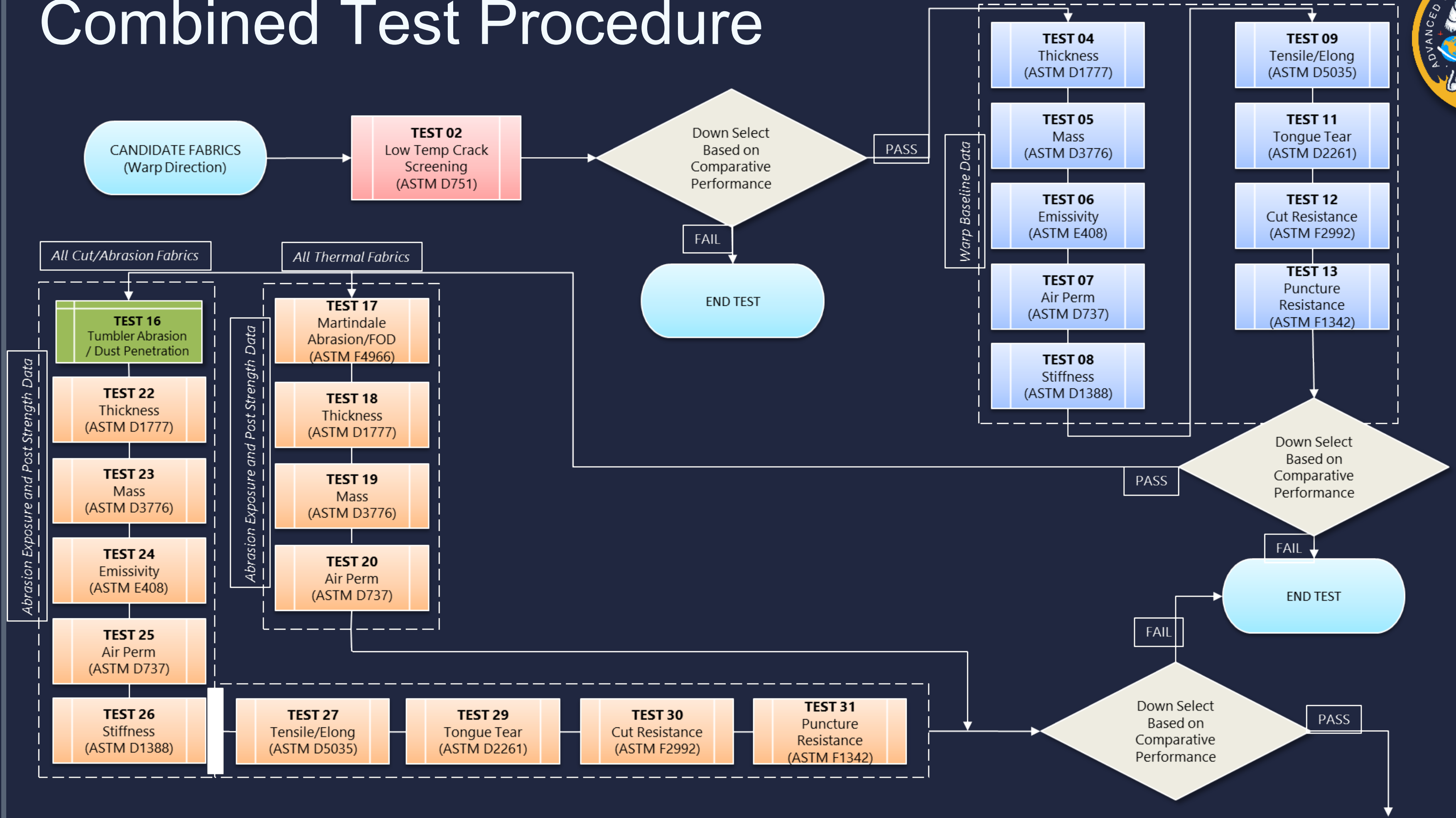
Backup Slides

Combined Test Procedure



Combined Test Procedure