Development of Optical Window Material Database for Spaceflight Environments

NASA's Mission

As a result of the severity associated with the failure of windowpanes on crewed vehicles and habitats, materials that exceed the optical and structural properties of current windows must be tested so potential replacement candidates can be selected for upcoming missions.

GRC Task

JSC Task

LaRC Task (Performed in this Lab)

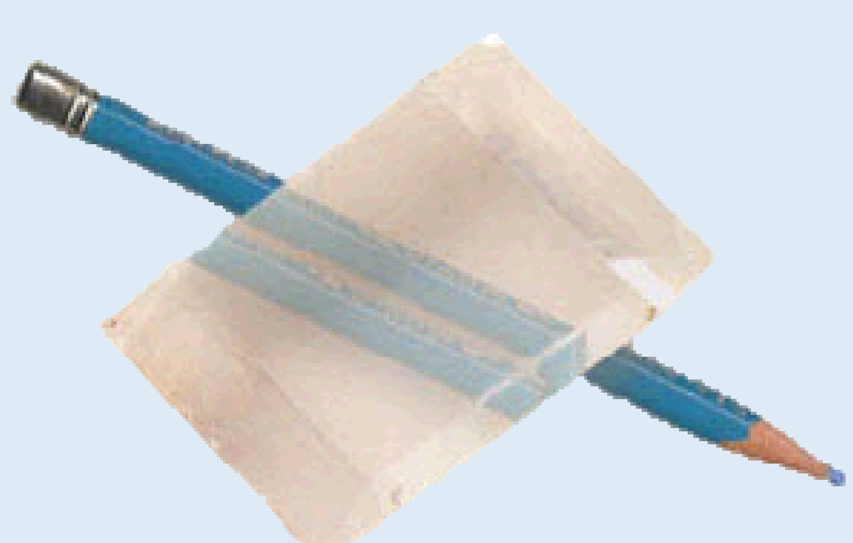
JSC/MSFC Task

Mechanical	Thermal	Optical	Environmental
Density	Thermal Expansion	Transmittance	Flammability
Fracture Toughness	Thermal Conductivity	Striae	Toxicity
Slow Crack Growth	Thermal Shock	Haze and Clarity	Atomic Oxygen Stability
Modulus of Elasticity	Thermal Environmental Tolerance/Exposure	Optical Wedge	Vacuum Stability
Modulus of Rupture		Color Balance	UV Stability
Hardness		Homogeneity	Humidity Stability
Impact tolerance (low and hypervelocity) / Residual Strength		Wavefront Quality	Temperature dependant Creep
		Birefringence	Thermal Vacuum Stability
		Imagery Quality	Ionizing Radiation Tolerance

Methods

Birefringence

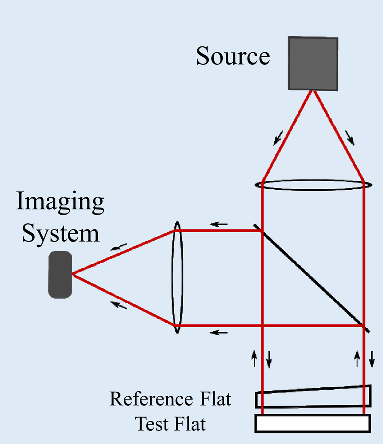
- Measured using the Exicor 150 AT instrument. Birefringence plots refined in MATLAB..
- Cause: Varying indices of refraction across a pane with two parallel sides.
- Effects: The appearance of two images from one object.



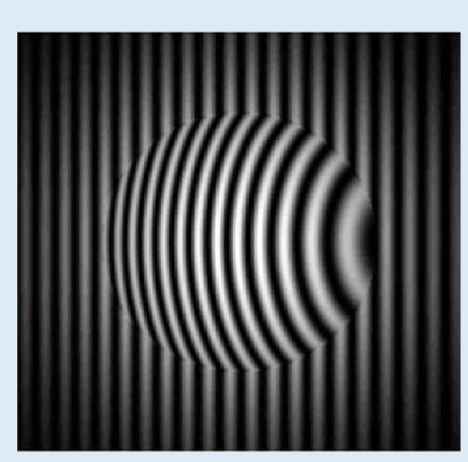
Birefringence in a Calcite Crystal

Wavefront Quality

- Measured through an optical system using a Fizeau interferometer.
- Cause: Light travels through material at different speeds due to the inhomogeneity of the material.
- Effect: Fringes produced by constructive and destructive interference.



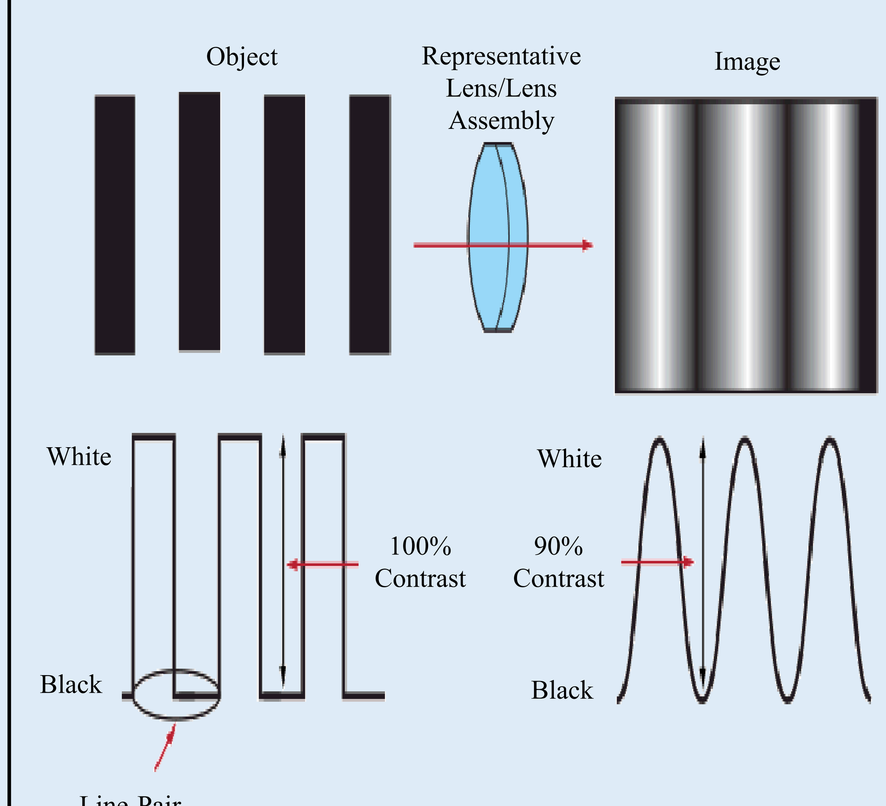
Fizeau Interferometer



Fringes Produce by an Optic Material

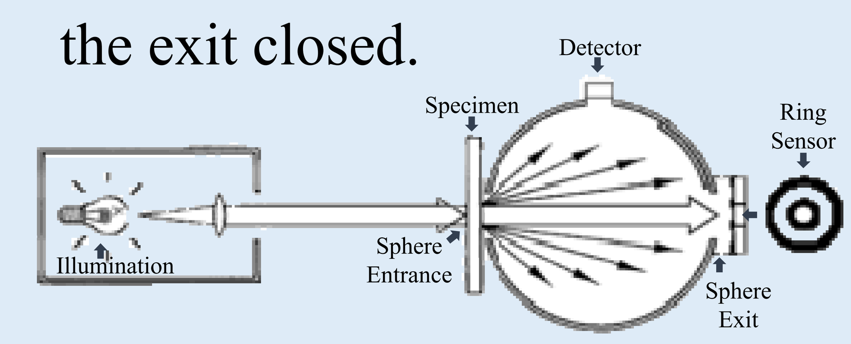
MTF

- Measured using Mathematica and/or Imatest software.
- Relates special frequency to visibility of contrast.
- MTF50 is typically the most sought-after value.
- The MTF50 value represents the special frequency at which 50% of the contrast is visible.



Haze, Clarity, and Transmittance

- Measured using a BYK Haze Meter
- The haze meter must be setup with a calibrated haze standard. All measurements are compared to this standard to distinguish the effect of the optical material.
- Haze: Percentage of transmitted light that deviates from the incident beam direction by angles greater than 2.5°
- Clarity: Percentage of transmitted light intensity that deviates from the incident beam by angles less than 2.5°
- Transmittance is measured with the exit closed.

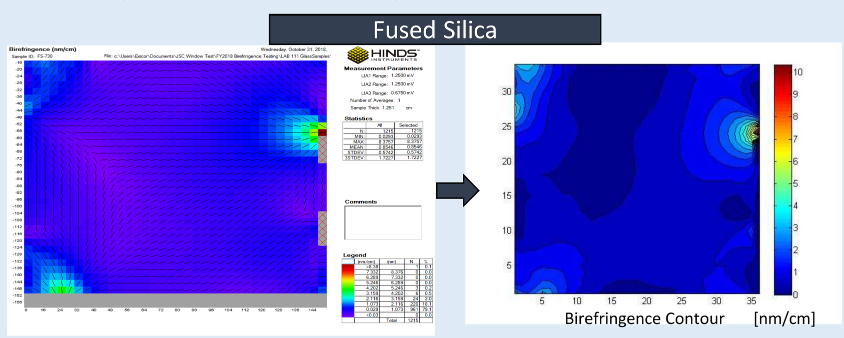


Results

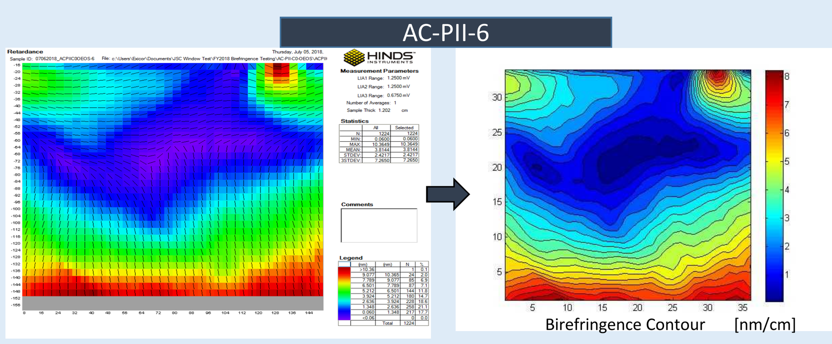
Birefringence

- Birefringence map across the whole pane for each material was measured with a scanning step of 4 mm
- Higher stress-induced birefringence values are attributed to fabrication and manufacturing processes
- Compared to PMMA, PC panes has higher birefringence variation

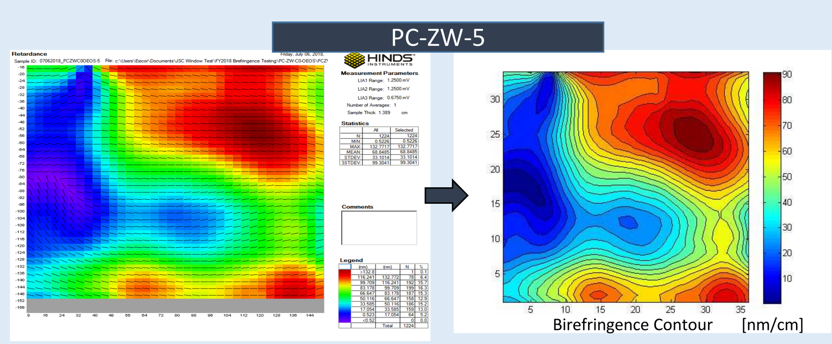
Fused Silica



AC-PII-6



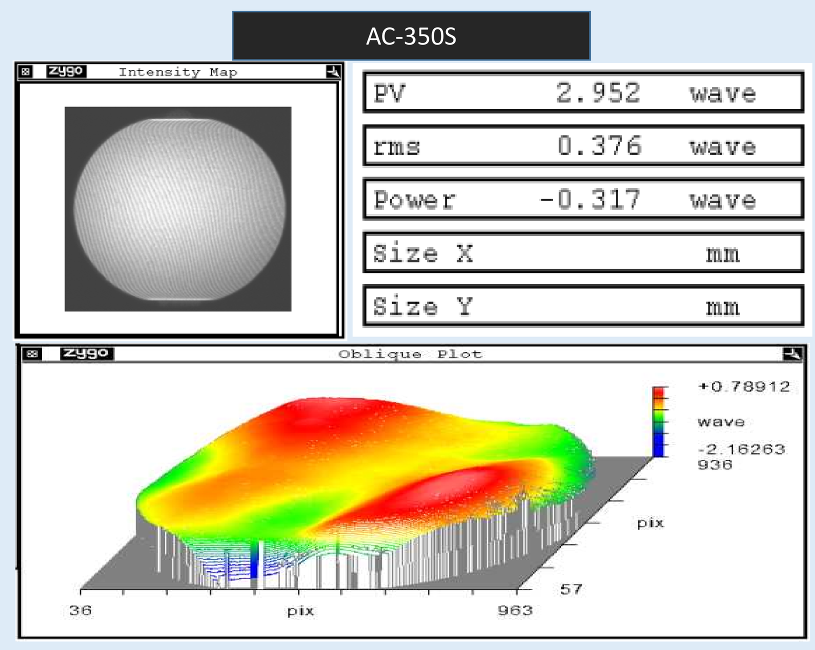
PC-ZW-5



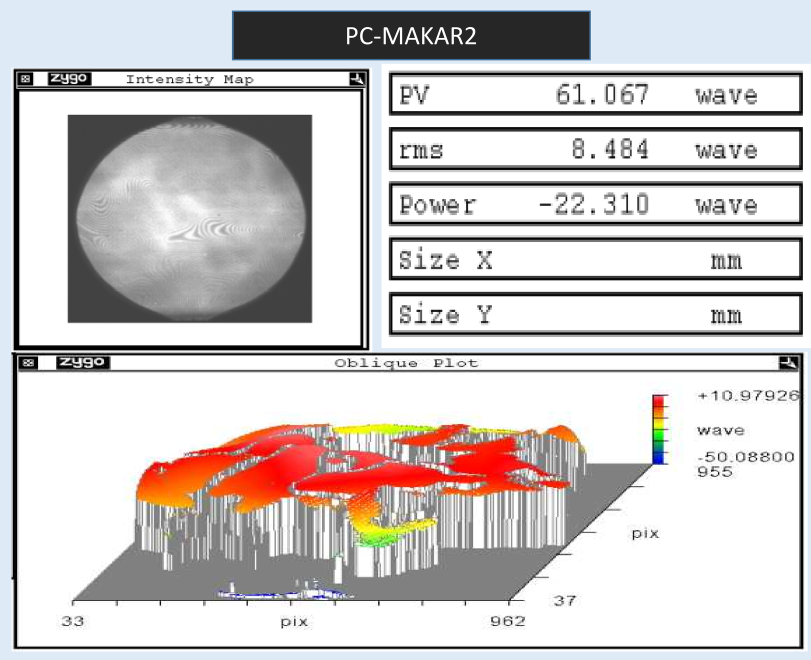
Wavefront Quality

- To quantify the wavefront performance, Peak to Valley and rms values of the transmitting wavefront are measured.

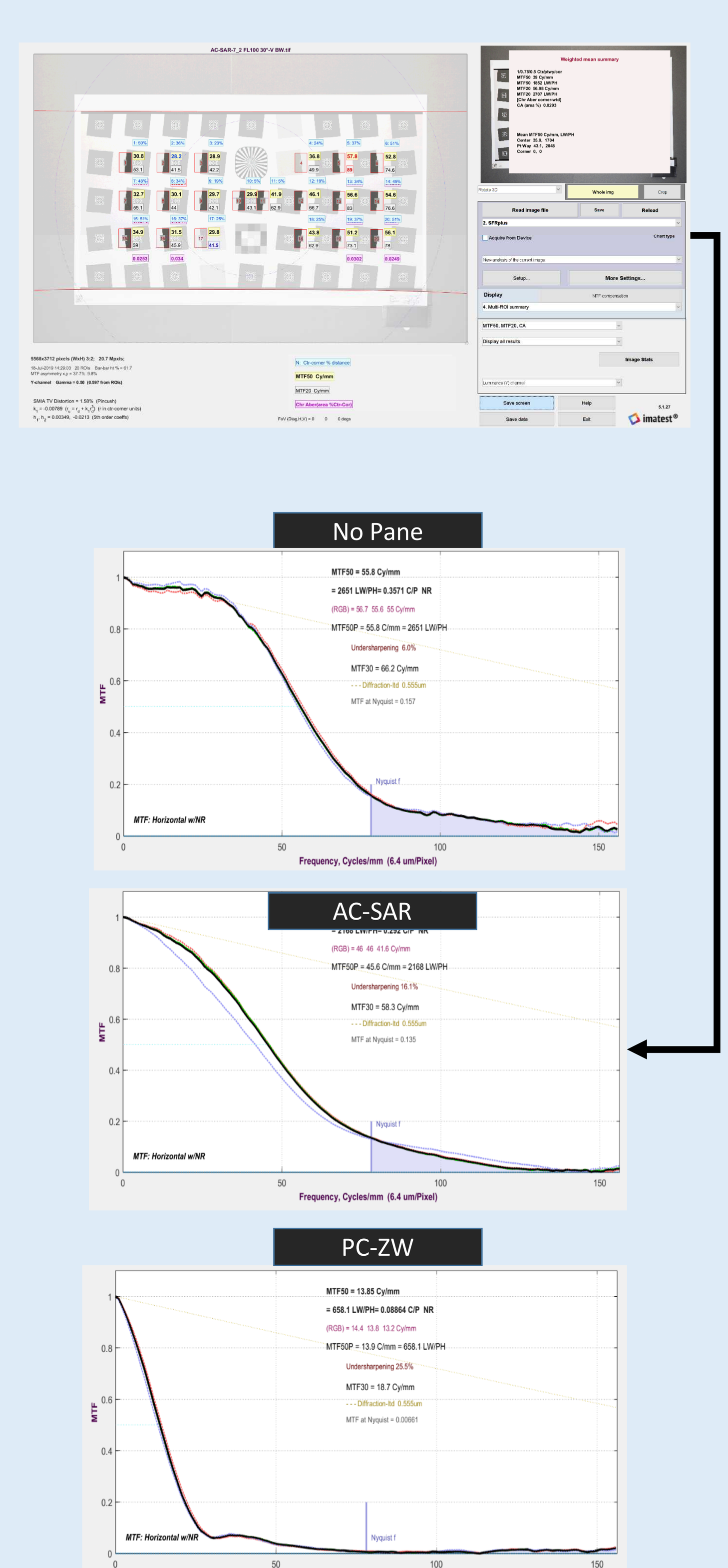
AC-350S



PC-MAKAR2



MTF50



Haze, Clarity, and Transmittance

- The haze, clarity, and luminous transmittance values of each pane were calculated from the average of nine points of measurement.
- Coating of the optical pane plays an important role to define the effective values of these parameters.

	Hazemeter Measurement [%]		
	Haze	Transmittance	Clarity
AC-GKN350C-C0-OEOS-1	1.8	92.1	99.6
AC-GKN350C-C0-OEOS-2	1.7	92.1	99.6
AC-GKN350C-C0-OEOS-3	2.3	92	99.5
AC-GKN350C-C0-OEOS-4	2.3	92.1	99.6
AC-GKN350C-C0-OEOS-5	2.9	91.9	99.6
AC-GKN350C-C0-OEOS-6	2.5	92	99.5
AC-GKN350C-C0-OEOS-7	2.2	91.9	99.6
AC-GKN350C-C0-OEOS-8	2.2	91.9	99.6
AC-GKN350C-C0-OEOS-9	2.2	91.8	99.6

	Hazemeter Measurement [%]		
	Haze	Transmittance	Clarity
PC-Z-C0-OEOS-1	1.5	82.7	99
PC-Z-C0-OEOS-2	1.4	82.7	98.9
PC-Z-C0-OEOS-3	1.5	82.7	99
PC-Z-C0-OEOS-4	1.6	82.9	99
PC-Z-C0-OEOS-5	1.6	83.1	98.8
PC-Z-C0-OEOS-6	1.6	83	98.6
PC-Z-C0-OEOS-7	1.5	83.1	98.7
PC-Z-C0-OEOS-8	1.6	83.1	99
PC-Z-C0-OEOS-9	1.5	83	98.8

Example Chart Made with AC-SAR Measurements

PM-SP-6-6-0.5-015: Luminous Transmittance/Haze/Clarity

T	93.6	T	94.2	T	94.0
H	1.04	H	1.18	H	1.12
C	99.6	C	99.6	C	99.5
T	94.2	T	94.2	T	94.2
H	1.05	H	1.19	H	0.97
C	99.6	C	99.5	C	99.5
T	94.3	T	94.3	T	94.1
H	1.10	H	1.24	H	1.16
C	99.6	C	99.5	C	99.5

	Transmittance	Haze	Clarity
Average	94.1	1.1	99.5
STD	0.2	0.1	0.1

STEM TAKES FLIGHT

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VIRGINIA SPACE GRANT CONSORTIUM

Project Summary

The NASA AES NextSTEP Project has, as one of its goals, the development of a comprehensive optical window material database that can be used by designers of crewed vehicles and habitats. Johnson Space Center has requested Langley's help in supporting optical metrology testing of window specimens to measure and analyze various optical parameters to assess the quality of the materials for aerospace applications.

Introduction

Due to window malfunction/failure being classified as critical 1, meaning that malfunctions will result in loss of life, vehicle, or habitat, a need has been established for transparent window material that surpasses the bar that has been set regarding the optical and structural properties of current windowpanes. For missions such as Apollo and ISS, fused silica has been our go-to specimen for windows, however the weight penalty and its brittleness is undeniable. If these windows could be replaced by a cost-effective plastic-based material, such as polycarbonate, which has a specific density of $1.20\frac{g}{cm^3}$ in comparison to fused silica's $2.20\frac{g}{cm^3}$, the weight of panes used in habitats and spacecraft can nearly be cut in half. Since the plastic based materials are typically more durable as well, penalties on design as a result of windowpane redundancies can be reduced, and thus allow more structural options for the designers of crewed habitat and spacecraft.

In order to aid in this mission, I have been tasked to create a user-friendly database to consolidate, organize, report, and analyze metrology data for various optical parameters while utilizing programs such as MATLAB, Mathematica, LabVIEW, and Zygo, for data acquisition. Measurements are taken through various types of windowpane material, at different angles, to further compare with data collected through a windowless or baseline condition. These comparisons can provide insight about how well light transmits through a material, and its homogeneity, which can impact how sharp an image or object is perceived when viewed through the specimen. Since sources of light, such as lasers and white light, are used for measurement purposes across all fields of engineering, if these materials are used as a medium, and this information is not known, inaccurate data can be accumulated and thus give rise to misleading results.

Goals

- Create a user-friendly database for various optical parameters that can be used by the designers of crewed vehicles and habitats.
- Assemble a versatile multi-axial linear stage for upcoming measurements.

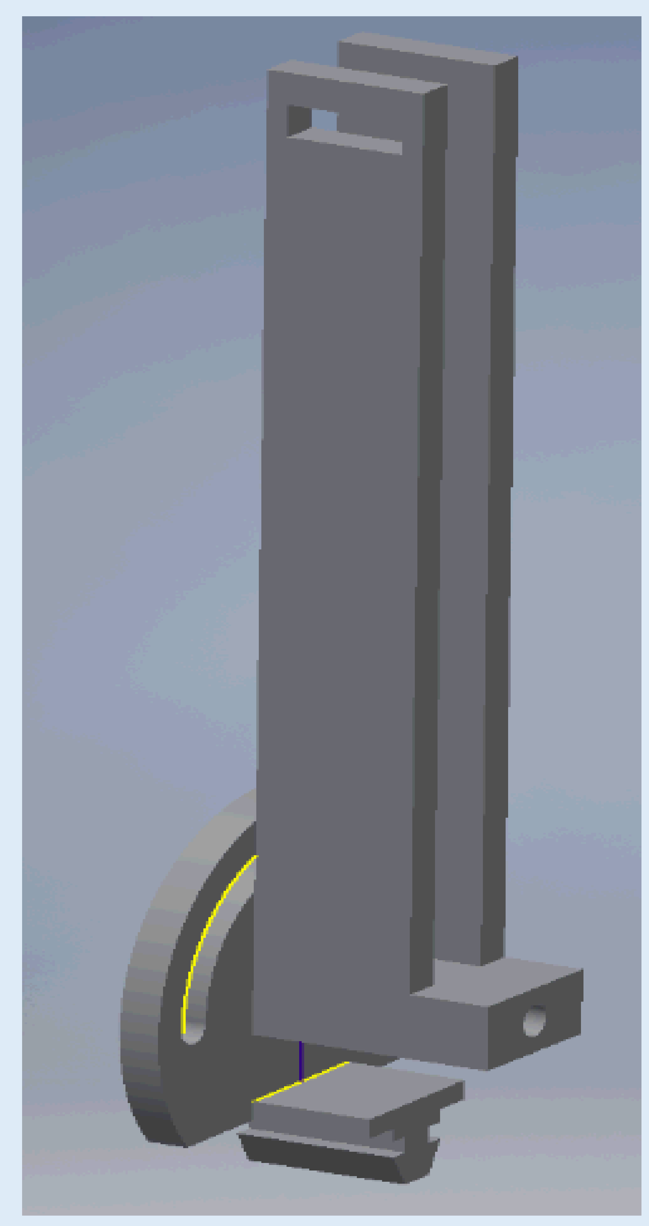
Resources

1) Concepts in Light and Optics – Optical Specifications – Plano Optics. (n.d.). Retrieved from https://escooptics.com/blogs/news/concepts-in-light-and-optics-optical-specifications-plano-optics
2) Fizeau interferometer. (2017, November 08). Retrieved from https://en.wikipedia.org/wiki/Fizeau_interferometer
3) Introduction to Modulation Transfer Function: Edmund Optics. (n.d.). Retrieved from https://www.edmundoptics.com/resources/application-notes/optics/introduction-to-modulation- transfer-function/
4) Optical Birefringence. (n.d.). Retrieved from https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/birefringence/
5) Tedjojuwono, K. K., Clark, N., & Humphreys, W. M., Jr. (n.d.). *Optical Characterization of Window Materials for Aerospace Applications*. NASA Langley Research Center, Hampton, VA.

Multi-Axial Linear Stage

<u>Multi Step Process</u>

Wire
Program
3D Model
Assemble
Troubleshoot
Refine



Future Research

- Continue acquiring and analyzing data regarding the eight optical properties assigned to LARC with the selection of new pane materials, such that the database can be expanded to cover wider variety of material and potential customers.
- Refine the program and 3-D modeled parts used for the multi-axial linear stage to allow it to be utilized in different instrumentation systems and maximize the efficiency of adjustments.

Conclusion

Each material that has currently been tested has its own strengths and weaknesses, and this information is used to form foundation for acceptance criteria for the selection of window materials for future aerospace vehicle and habitat designs. The database is in its final stages of completion, however it will be expanded as additional data is acquired for other available candidate optical window materials.

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