Introduction

The James Webb Space Telescope (JWST) is an infrared space telescope that will reside in an orbit about 1.5 million km from the Earth, and it is scheduled for launch in 2016. The JWST will have a 6.5 meter diameter primary mirror made of beryllium and a sun-shield the size of a tennis court. Once the space telescope reaches its orbit, it will address its science goals which are grouped into four themes: first light and reionization, the assembly of galaxies, the birth of stars and protoplanetary systems, and planetary systems and the origins of life.

The JWST has an optical train that consists of the Optical Telescope Element (OTE), and the Integrated Science Instrument Module (ISIM). The ISIM contains four science instruments: the near infrared spectrograph, the near infrared camera, the mid infrared instrument, and the fine guidance sensor. These components will allow the JWST to accomplish its science objectives. When these science instruments are integrated onto ISIM at NASA's Goddard Space Flight Center (GSFC), the assembly becomes the ISIM Element. This element has a common orthogonal coordinate system, called the V-coordinate system (VCS), which consists of the coordinates V_1, V_2 and V_3. The whole element is assembled at ambient cleanroom conditions using theodolites, photogrammetry, and laser radar and laser tracker metrology for mechanical alignment.

Since the JWST will operate at cryogenic temperatures on orbit, temperature-induced alignment changes during environmental testing at GSFC are measured using photogrammetry (PG) for the bare structure.

To test the optical performance of the science instruments of the ISIM Element, the OTE SIMulator (OSIM) will be used. This is a high-fidelity, cryogenic telescope simulator that features a ~1.5 meter diameter powered primary mirror, and it will enable measurement of focus, pupil shear, and wavefront error. It will receive alignment feedback from custom sensors built into OSIM.

Once the ISIM Element reaches its cryogenic operating temperature at GSFC, it will undergo repeated cryogenic vacuum tests to verify that the science instruments share a common focus and a common pupil.

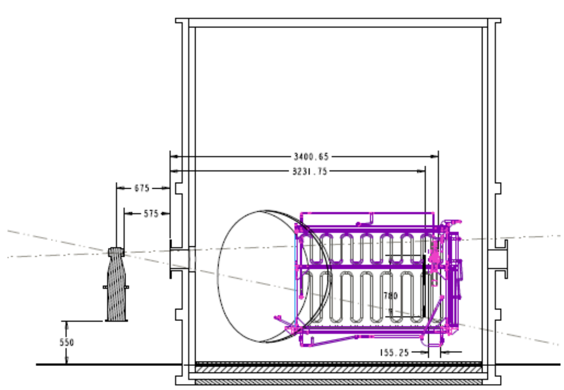
Before any of this can be accomplished, several tests need to be done regarding alignment and calibration, where ISIM and OSIM will require assistance of various fixtures, in order to properly align each subsystem.

The alignment of the ISIM element starts at a specific location: ISIM has six kinematic mount (KM) interface points, spherical balls, which fit into six spherical sockets on the OTE backplane support frame (BSF). The average location of the center of these balls/sockets is called the average interface point (AIP). It is important to know that the ISIM structure meets its alignment requirements at its operating temperature (37K), since it controls the common-path component of the science instruments alignment. This is because the ISIM structure is made of an invar and graphite-epoxy composite, which has a very low coefficient of thermal expansion (CTE), allowing the ISIM structure to just about keep its ambient dimensions at cryogenic conditions. The science instruments are made of different materials than the ISIM, and CTE mismatch is balanced by flexures at the ISIM-science instrument interface.

The OTE-BSF is simulated with a fixture called the ISIM test platform (ITP). This fixture is designed so that the interface is the same as the interface of the OTE-BSF. In other words, instead of the ISIM-to-OTE interface, there is the ISIM-to-ITP interface. Mounted to the ITP is the Master Alignment Target Fixture (MATF), which is used to align OSIM during system level ISIM element testing. Another fixture is the ISIM Alignment Target

Fixture (IATF), which is attached to the top deck ($-V_1$) of the ISIM structure. To verify that all of these parts are properly aligned, laser radars, laser trackers and theodolites are used to measure laser tracker and laser radar targets and optical cubes on the ISIM, IATF, ITP, and MATF. After the locations of these targets are measured, they are replaced with PG targets. They first undergo an ambient photogrammetry scan and are later used during cryogenic tests.

When the MATF and IATF fixtures are calibrated, their alignment/metrology targets will be measured through a glass window on a vacuum chamber port. This is due to the fact that the targets must work at cryogenic temperatures, but laser radars and laser trackers are not made to work in that environment, requiring isolation at ambient conditions. To meet this requirement, the laser tracker and laser radar will have to collect the data through a glass window. It is important to understand, and moreover, to measure and model how the presence of this window modifies the apparent position of the targets, so that any offset may be understood and removed from the data if necessary. Figure 1 represents a schematic of an instrument looking through the window of a cryogenic chamber, similar to what the actual calibration test will look like.



<u>Figure 1</u>: Thermal-vacuum test chamber with metrology instrument measuring through the window.

Before measuring the window effect it is important to understand how the instruments (laser radar and laser tracker) work. Measuring the instrument's resolution is vital to determine the quality of the measurement, and to know how much detail we will be able to resolve; we are also interested in comparing one instrument to the other. It is also fundamental to establish if there is a difference between targets. Each instrument has its own set of targets and it is possible that some can be resolved better than others. Therefore, this thesis will report the capacity of the instruments to resolve micrometer shifts, the similarity among targets, and the difference between the measurements collected with the laser radar and those collected with the laser tracker.

The window effect will be discussed in Chapters 3 and 4, after obtaining a better understanding of the instrument's capabilities. These last chapters will explain in detail the effect of the window and how the window itself changes the apparent position of the measured targets. The distance between the instrument and the targets will be approximately 2.5 meters, because the chamber size is already known and so is the volume of the structure that will contain the MATF and the IATF. We will use this same distance for the tests performed throughout this thesis so that the results will be comparable to the actual test.

Measuring the window offset will help us determine the absolute position of the targets. Nonetheless, measuring the resolution of the instruments and the agreement between them at a micrometer level is also important, as we mentioned previously.

Therefore, the general objective of this thesis is to measure the offset introduced by the window in two directions, perpendicular and parallel (transverse and axial) to the measuring beam, and compare the measured shifts with those determined by an optical design software simulation (Zemax). If these models agree, the offsets become constant in respect to the window.

The specific objectives are to:

- Understand the apparent target position caused by refraction through the window.
- Create a ray trace model with Zemax, accurately predicting the apparent position of a target due to the glass window at ambient conditions.
- Measure, using a laser tracker and a laser radar at ambient conditions, the apparent distortion of different targets through the glass window and compare the results to the Zemax model values (model validation).
- Verify each instrument's resolution (capability to discern micrometers) by intentionally displacing the targets a small, known amount without the window.
- Measure singular target types, and compare each instrument's ability to differentiate distinct features by best fitting the measurements of distinct targets.
- Determine instrumental agreement by best fitting data measured with the laser tracker and with the data measured with the laser radar.

To accomplish the aforementioned objectives, in Chapter 1 we will compare both instruments to validate that they each have the same measuring capacities. In Chapter 2 we will quantify the laser radar's resolution, and compare two different targets measured by this instrument to verify if both can be equally as reliable. In Chapter 3 we will explain the physical effect the window, also called plane parallel plate, has on the observed targets. Finally, in Chapter 4 we will utilize the understanding of how the instruments work (explained in the first two chapters) and the theory presented in Chapter 3 to better interpret the results of the experimental arrangements. This final chapter will explain the experimental setup in detail, measuring with and without the window. Therefore, in Chapter 4 we will conclude this thesis by comparing the numerical model used to predict the apparent targets shifts to the measured target shifts to ultimately discuss the agreement or disagreement between the models.

It is important to mention that this thesis only presents a first approach to develop a correction model for a window; future testing will require vacuum and cryogenic conditions. These changing setups will make the window behave in an unusual manner, possibly changing the window shape and distribution. These specific conditions will make the tests and simulations more complete, complex and more interesting.