

Hyperspectral Sensor

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LONG-TERM GOALS

The goal of the Hyperspectral Imager for the Coastal Ocean (HICO) program is to demonstrate the utility of maritime imaging for Naval applications in the littoral ocean from a space borne platform. The coastal ocean is a dark target and visible and Near Infrared light is the only part of the electromagnetic spectrum that penetrates water and can be used to directly sense the water and seafloor properties. Analysis has shown that maritime hyperspectral imaging is the only remote sensing technique that is able to deconvolve the complicated coastal scene (Lee and Carder, 2002). The spectral content of hyperspectral data can give information on the depth and characteristics of the seafloor and undersea objects. This can be of great utility for the identification of objects and the avoidance of false alarms.

The Navy's "Sea Strike" mission requires precise knowledge and modeling of the littoral battlespace in denied areas of the globe. The emphasis on littoral tactics for precise amphibious assault, special forces insertion and mine warfare drive the need for improved capability. Space borne maritime hyperspectral imagery and its derived products such as bathymetry, bottom type, water clarity and beach traffic will be used to demonstrate the effectiveness of using hyperspectral data for characterizing the littoral battlefield.

The HICO program will demonstrate the use of space borne hyperspectral methods to detect submerged objects, the retrieval of environmental data products of value to Naval forces, and the development of coupled physical and bio-optical models of coastal ocean sites globally.

OBJECTIVES

NOVASOL's objective for the HICO program is to design and build a spectrometer that will meet the requirements for imaging the littoral region of the world's oceans while mounted on the structure of the International Space Station. The system is designed to meet a set of key requirements specifically derived in order to optimize the performance of the hyperspectral system from a space borne platform. NOVASOL is responsible for the design of the spectrometer and the collecting telescope that is mounted to the front of the spectrometer.

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A hyperspectral imager records a contiguous spectrum of the light leaving each pixel in the scene, and this spectral information is exploited during data processing and product retrieval. Therefore, a hyperspectral imager must contain a telescope to collect light from the scene, a spectrally dispersive element, a focal plane array to convert the dispersed light to an electrical signal, data collection and storage electronics, and a system controller and power supply. The performance requirements for maritime hyperspectral imaging, based on NRL experience (Davis and Carder, 1997; Davis, et al., 2002), are summarized in Table 1.

Table 1. Key performance parameters for the HICO maritime hyperspectral imager. The system has been designed to meet the set of requirements in Table 1. Pre-launch calibration and characterization will be completed to demonstrate that capability.

Parameter	Requirement for Maritime Hyperspectral Imaging from Space	Rationale
Off-nadir pointing	+/-30 deg (Goal +70/-45 deg)	To increase scene access frequency
Spectral Range	Minimum 400 to 860 nm (Goal 380-1000 nm)	water-penetrating wavelengths and NIR for atmospheric correction
Spectral Channel Width	10 nm (goal 5 nm)	Sufficient resolution to resolve spectral features
Signal to Noise Ratio	> 200 to 1 for a 5% surface albedo scene	Provides adequate residual SNR after atmospheric removal
Polarization Sensitivity	< 5% (< 2% goal)	Sensor response to be insensitive to polarization of scene light
Ground Sample Distance	100 meters ($\pm$ 20%)	Comparable to scale of coastal features
Scene Size	Thousands of square kilometers	To encompass the scale of coastal dynamics
MTF	>0.35 at Nyquist spatial frequency of 0.5 cycles/pixel	To assure that the recorded signal is coming from the sampled GSD
Saturation	Shall not saturate when viewing a 95% albedo cloud	To be able to image dark ocean next to bright clouds
Spectral stray light	< 1% albedo error	To assure that the true spectrum is recorded
Long term stability	+/- 0.5% after calibration of the data	To assure a consistent data set over time for change detection
Jitter	< 0.5 pixel (highly dependent on spacecraft vibrations)	To assure that the image is not distorted during the collection period.
MTF	>0.35 at Nyquist spatial frequency of 0.5 cycles/pixel	To assure that the recorded signal is coming from the sampled GSD

To provide high quality data, the last six parameters listed in Table 1 will be measured to evaluate system performance. These parameters will be measured and the performance accepted as measured. Any problems that are identified will be corrected to the extent possible in the processing software. This is the approach used with PHILLS (Davis, et al., 2002) which has resulted in high quality data.

Table 2. The final specifications for the spectrometer and lens. These requirements will ensure the system will meet the program requirements specified in Tables 1.

Lens	Specification	Requirement
	Focal length	60 mm ($\pm 3\%$)
	FOV	7.6 degrees (i.e., ± 3.8 degrees)
	f-number	2.5 – 2.8 (set final value after assembly)
	Spectral range	0.38 – 1.0 μ
	Optical spot size	$< 7 \mu$ rms diameter
	Lateral color	$< 20\%$ of a 16 μ pixel = 3 μ
	Throughput	$\geq 90\%$ for all wavelengths
	Vignetting	none
Spectrometer	Spectral range and dispersion	0.38 – 1.0 μ over 4 mm ³
	Blaze wavelength	500 nm
	Slit width	16 μ
	Slit length	8.2 mm (= 16 $\mu \times 512$ pixels)
	f-number	2.5
	Final optical spot size	$< 10 \mu$ rms diameter (includes effect of lens)
	Spectral smile	< 2 nm of wavelength = 0.8 pixels = 12 μ
	Keystone	$< 20\%$ of a 16 μ pixel = 3 μ (includes effect of lens)
	Throughput	$\geq 50\%$ for all wavelengths in 0.4 – 0.76 μ band
		$\geq 30\%$ for 0.76 – 1 μ band
	Polarization sensitivity	$\leq 5\%$ (includes fold mirror)
	0-order beam dump	yes (reduces stray light)
	Stray light	no specific requirement, as low as possible

APPROACH

The HICO hyperspectral imaging system supplied by NOVASOL includes the telescope lens, the spectrometer and camera with the focal plane and electronics. NOVASOL is responsible for the design of the lens and spectrometer and NRL will supply the camera and order sorting filter that will be attached to the camera.

The spectrometer design is based on an Offner optical design which was chosen due to the extremely low distortion properties of an Offner based system, specifically for both keystone and smile. An Offner design also provides high quality imaging at a low F number while allowing for a compact mechanical package. A high efficiency grating with an expected efficiency of 75% at the peak wavelength of 500 nm has been designed into the spectrometer. The grating is being procured from Bach Research. Bach Research was founded by Bernie Bach and his sons, Erich and Kurt Bach. Collectively Bach Research employees have over 120 years experience in optical fabrication, optical coatings, diffraction gratings, and optical testing.

The telescope lens was custom designed by NOVASOL in order to meet the field of view, f number, vignetted and throughput requirements. The lens has a telecentric focus at the slit (chief rays are parallel to the optical axis) and has chromatic correction over the entire wavelength range of 380 nm to 1000nm. The optical design of the lens and spectrometer was performed by Chris Warren and Dave Breitwieser. Chris Warren is a Principal Optical Engineer with over 25 years experience in the optics industry. His work experience includes optical design, testing of optical systems and hardware development of hyperspectral and multispectral imaging systems. Mr. Warren designed the Short Wave Infrared (SWIR) spectrometers for the Diamond and Ironhorse projects at NRL. Dave Breitwieser is a Senior Optical Engineer at NOVASOL. Mr. Breitwieser has over 17 years of optical engineering experience, 11 of which has been in the design, build, testing and characterization of remote sensing systems and hyperspectral imagers.

Since the spectrometer and telescope must survive a rocket launch and deployment on the outer structure of the International Space Station, the mechanical design is designed to be robust and contain only materials that are currently approved by NASA. The spectrometer and lens will be designed to be hermetically sealed so that dry nitrogen gas can be inserted into the system. The mechanical design is being performed by Ed Galicki. Mr. Galicki is a senior designer who designed the SWIR hyperspectral systems for NRL on the Diamond and Ironhorse projects. He also designed the ARCHER hyperspectral units, 17 of which are currently deployed on Civil Air Patrol aircraft nationwide. The mechanical design effort includes Chris Warren and Arleen Velasco. Ms. Velasco is a senior engineer who has over 12 years experience in manufacturing, testing and calibrating hyperspectral instruments. She has over 25 years experience in the production of military imaging systems including instruments built for space programs.

WORK COMPLETED

Throughout the year NRL has been working on finalizing the requirements for the HICO spectrometer, lens and camera. NOVASOL has cooperated and worked with NRL while NRL was deciding on the final system specifications. In that process, NOVASOL designed an f/2.8 with large spectral dispersion requirement (8 mm) and a custom telescope lens for that system. NOVASOL also designed an F/2.5 spectrometer and lens for the 8 mm dispersion system. In the middle of the year NRL made a final decision to use an F/2.5 system with a reduced dispersion requirement, 4 mm. A third and final design of the spectrometer and telescope lens is completed and meets the final specifications given by NRL in June 2007. The final design is an F/2.5 system that meets the requirements listed in the Objectives section of this report.

The mechanical design of the spectrometer is largely impacted by the decision as to how the system will be sealed so that it can operate properly in a space environment. Due to the time schedule requested by NRL for the final unit, NOVASOL started the mechanical design with the assumption that the spectrometer would be independently sealed from the camera, with NRL designing a sealed enclosure for the camera itself. NOVASOL recently received a request from NRL that the spectrometer be open to the environment of the camera. NOVASOL is altering the design to accommodate this request. The mechanical design – assuming no additional change requests by NRL – will be completed within 6 weeks. The mechanical design includes individual part drawing as well as assembly and interface drawings.

Due to the long lead time of the Bach grating, NOVASOL initiated a purchase order with BACH so that Bach can proceed while NOVASOL completes the mechanical design.

The following figures 1 through 6 show the optical and mechanical layout of the spectrometer and telescope lens.

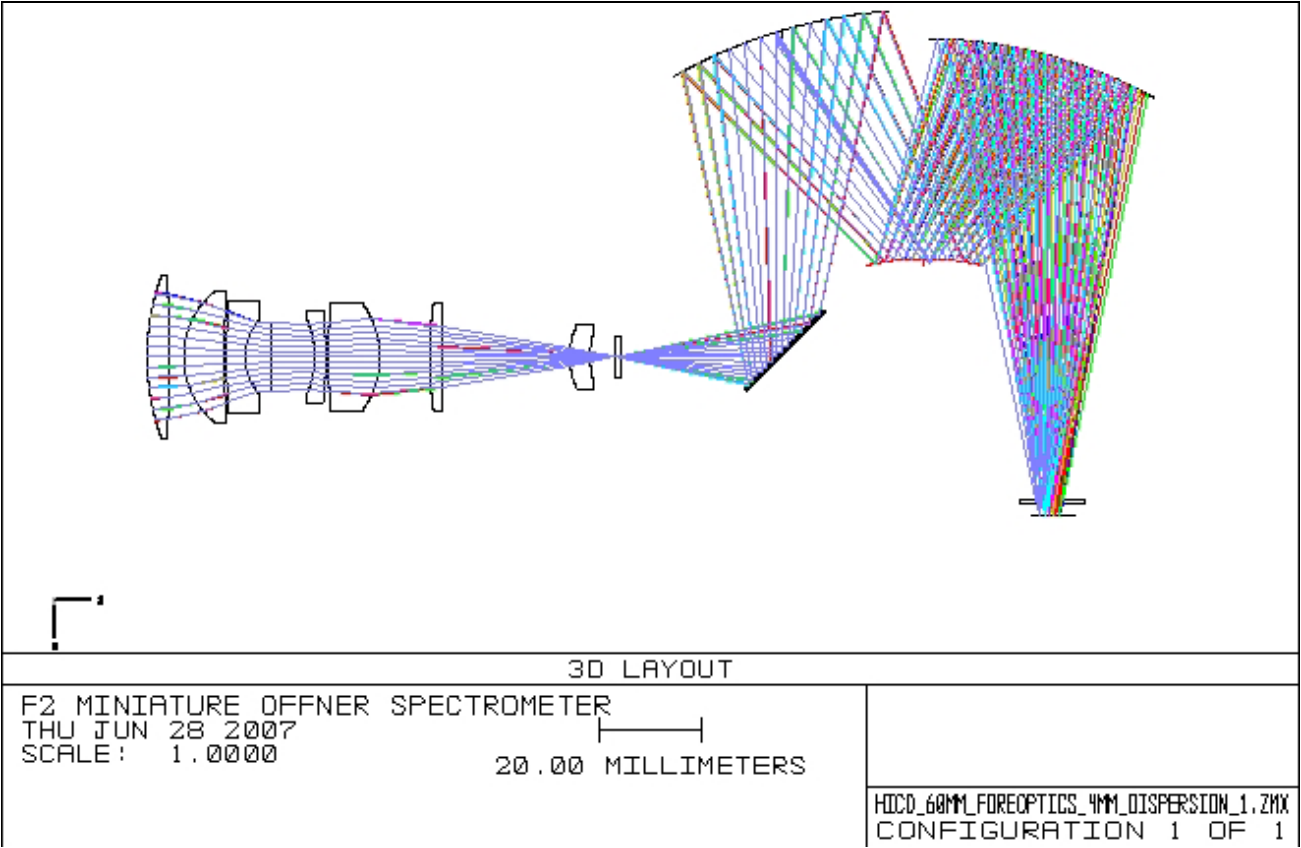


Figure 1 - Optical Design Layout of telescope lens and spectrometer for HICO F/2.5, 4 mm dispersion, and 7.6 Degree Field of View

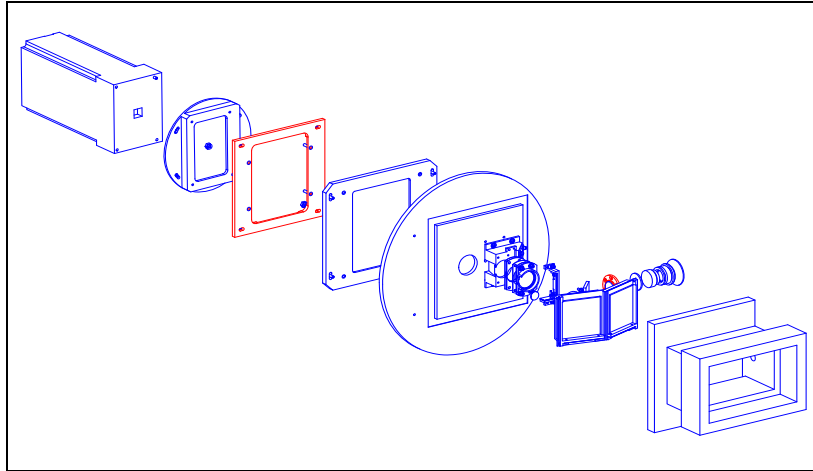


Figure 2 – Mechanical Layout of Spectrometer starting right to left, housing, optics, camera sealing plate, camera adjustment plates and camera

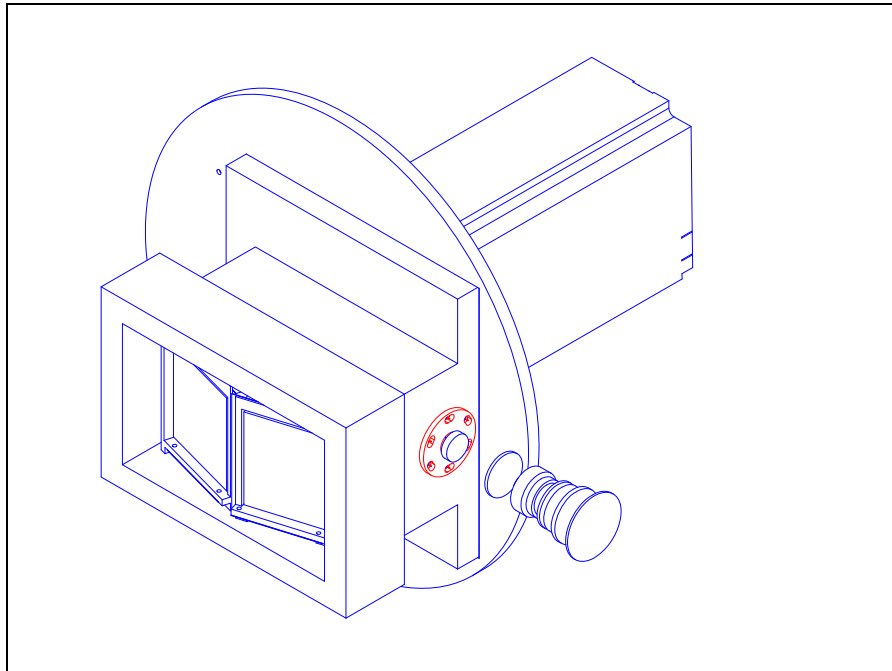


Figure 3 - drawing showing assembled spectrometer mated to camera. The end cover is removed so that the spherical mirrors can be seen inside the spectrometer. The lens assembly, which is on the right side of the drawing, is shown without a mechanical barrel.

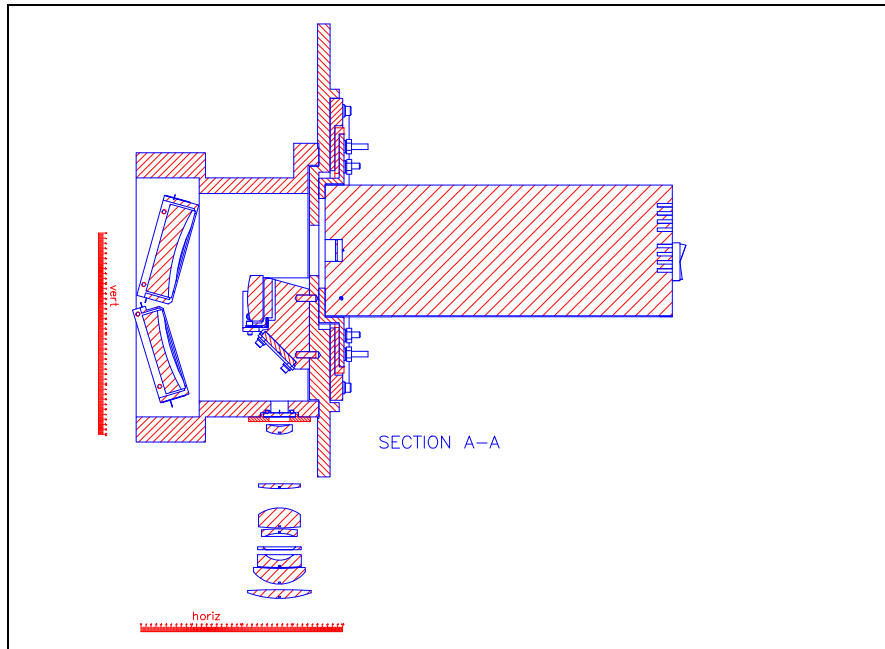


Figure 4 – Side view of the spectrometer showing position of optical elements in relation ship to the camera. The telescope lens is shown without a mechanical barrel.

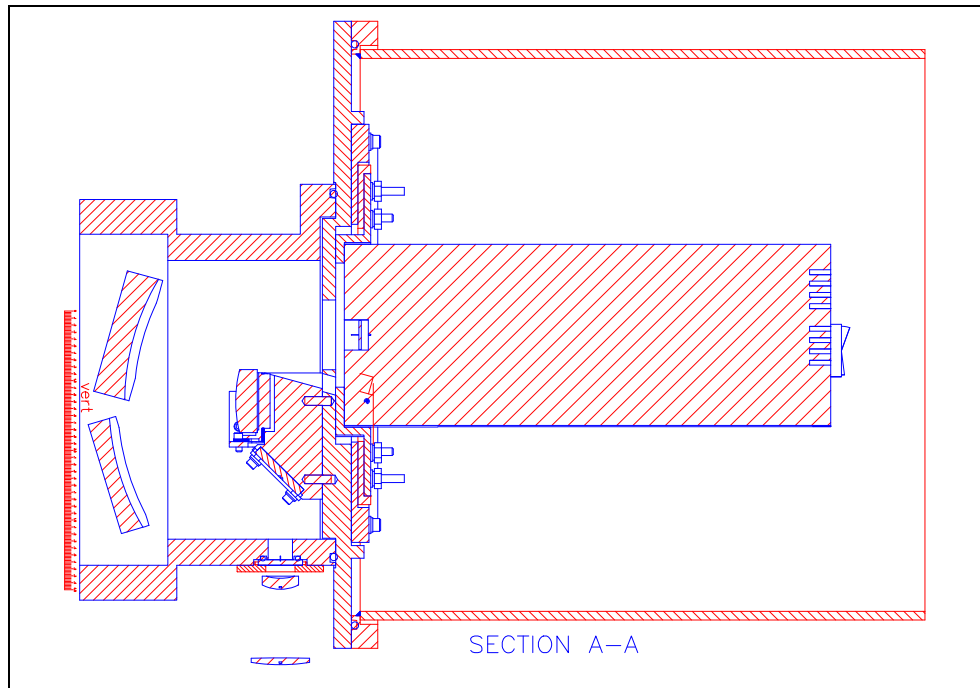


Figure 5 - Section view of spectrometer showing the outer barrel that seals to the spectrometer and encompasses the camera.

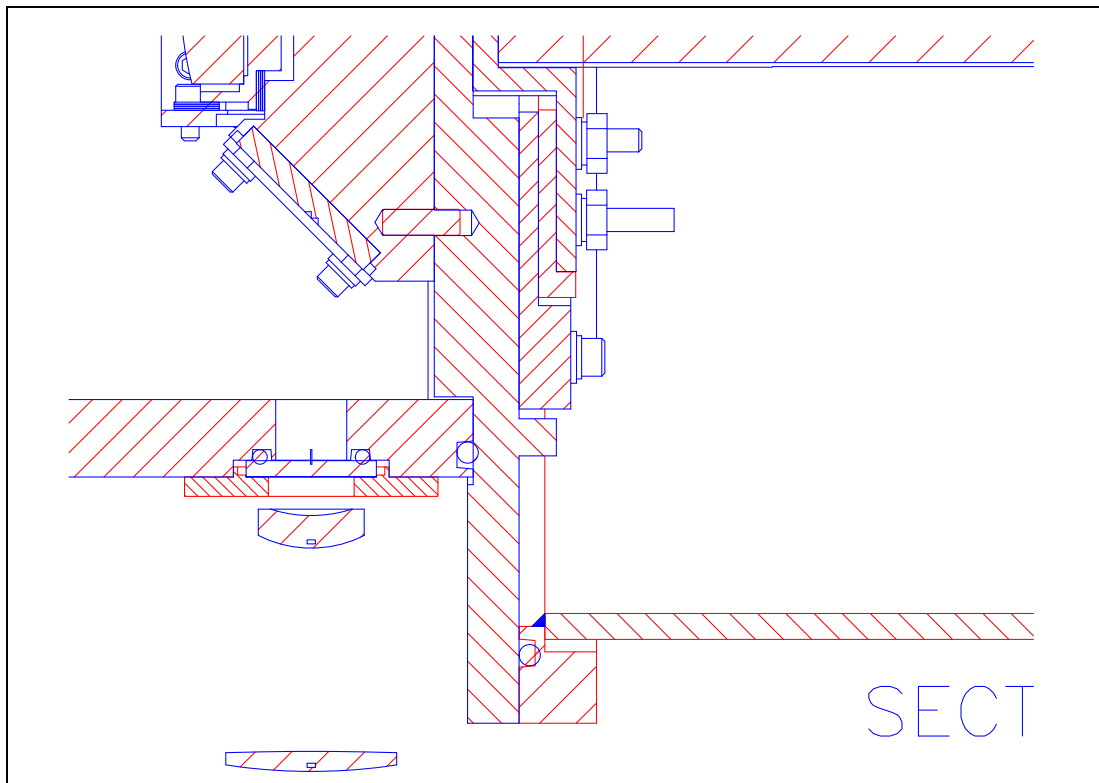


Figure 6 - Detail of the o-rings and mechanics that provide the ability to hermetically seal the camera and spectrograph into one volume.

RESULTS

NOVASOL has completed the design of a high performance hyperspectral imager and telescope lens assembly that will be space worthy and meet or exceed the NRL specifications for the HICO program. The high efficiency grating will enhance the throughput of the overall system and significantly improve the SNR of the system. The mechanical design is rugged and capable of surviving the launch into space and the deployment onto the International Space Station.

IMPACT/APPLICATIONS

This space grade hyperspectral imager can be used for other space and aircraft applications. It will be rugged, environmentally sealed and space ready. Depending on the application, the spectrometer can also accommodate other lenses with field of views of up to 40 degrees. The design also allows for other cameras with similar focal planes, 512 x 512, with 16 micron pixels. While this spectrometer is designed specifically for a Naval application, other applications for this system might include studies of land use and land cover, vegetation type, vegetation stress and health and crop yield.

TRANSITIONS

n/a

RELATED PROJECTS

None.

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