Synopsis of the Article:

“Contamination effects and requirements derivation for the James Webb Space Telescope”

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Proc. of SPIE Vol. 7069, 70690J (2008)

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OPTI-521: Introductory Optomechanical Engineering, 2016

Overview of the Article

This article discusses the purpose, derivation methodology and contamination control requirements which have been levied on the the James Webb Space Telescope (JWST) to maximize the system sensitivity for space science. Due to the signal to noise sensitivity of the science goals associated with JWST, the contamination requirements (captured as Percent Area Coverage or PAC) are analyzed for the major subsystems to guide the development of contamination control measures. This paper summarizes detailed analysis of the JWST system performance requirements and the acceptable levels of contamination by which will degrade system performance while maintaining mission objectives.

Purpose of this Synopsis:

The purpose of this report is to summarize the article “Contamination effects and requirements derivation for the James Webb Space Telescope”. The reader will gain a brief understanding of the contamination concerns facing optical systems and the considerations facing optomechanical designers when designing a sensitive system. While the purpose of this report is to summarize the contamination control concerns and requirements levied on the JWST, it is recommended that the reader reviews “Contamination Control Engineering Design Guidelines for the Aerospace Community”, A.C. Tribble, SPIE Vol. 2864, for a more general approach to contamination control for aerospace optical systems. As a general guideline, this report will follow the format of the original paper and summarize the contents. Figures from the paper are only referenced in this synopsis.

1 Introduction:

The James Webb Space Telescope is an 18 piece segmented primary mirror telescope which is home to 4 instruments. JWST’s mission is to detect the signatures of the early universe using interferometric and infrared (IR) to near-infrared (NIR) instruments. However, such detections require highly sensitive instruments that will degrade with system contamination. The most vulnerable to contamination are the primary mirror segments and any other exposed optics. The optics are susceptible to molecular and particulate contamination while the instruments are influenced by stray light from the thermal environment (especially in the IR) and the same woes as the exposed optics. These sources of contamination lead to requirements on thermal cooling of specific optical areas and an Assembly, Integration and Test (AI&T) approach to limit the influence on the end of life (EOL) system performance.

2 JWST Requirements:

There are three main requirements governing the contamination control for JWST. System sensitivity is the top level requirement which flows into requirements on stray light and system transmission. Each of these requirements are described in more detail in the sections below. Like any optical system, the requirements levied on the system performance will impact the physical design and implementation of the system.

3 The Sensitivity Requirement (MR-51):

The sensitivity of the system dictates the integration time of the instruments. Figure (3) of the paper is a table of the different instrument bandpasses and the required sensitivity to reach mission performance. The sensitivities of each of the bandpasses gives the engineers insight into the level of contamination acceptable for each system for the life of the mission. To mitigate any threat to sensitivity, one dial available to account for contamination is increasing the integration time of the system. However, careful consideration is given to increasing integration times since this can increase signal to noise ratios and impact mission planning. For example: the system would need 15 days for 1 observation instead of 10 for a single filter, greatly reducing the science capability of the intended mission life of 10 years.

4 The Stray Light Requirement:

Stray light is the undesired spectral radiance caused in part by contamination from particulates. Other sources include the surface roughness of the optic and the mechanical design of the system (in this case, where thermal cooling may be needed). To control one of the main sources of stray light that would end up impacting sensitivity, the size and distribution of particles were modeled using IEST-STD-CC1246D (the updated contamination standards document from the military standard: MIL-STD-1246). The particulate designation is modeled for fallout and residual particulate from post clearnings. Figure (7) tabilizes the transmission levels for different assumptions on the Percent Area Coverage under various illumination conditions. From this table, the level of PAC assigned to each optics is chosen. In this case, the primary mirror was given a PAC level of 1.5% and secondary mirror given a PAC level of 0.5%. The tertiary and fold mirrors being given 0.5% (tight requirements, especially for the primary and secondary, but feasible). Additional cleanliness levels for the primary mirrors would be complex, costly and incur additional unnecessary risk to the hardware.

5 The Transmission Requirement (MR-211):

Ultimately, the goal of JWST is to get the right photons and a particular number of them to reach the detector for science. Transmission of a photon from the source to the detector will be impacted by multiple sources of degradation including: dust, particulates, obscurations, coating imperfections, space debri, etc. Optical components with critical and sensitive coatings can be impacted by outgassing of surrounding materials and water absorption. Figure (12) tabelizes the percent transmission for each wavelength or bandpass of interest. One wavelength in particular (3.1 um) is absorbed by water which also happens to be a critical science observing wavelength, so an allocation on the thickness and polarization effects are captured as a requirement to control the influence from ice/water. Contamination on coated optics also reduces transmission by impacting the behavior of the coating, whereby a requirement on the non-volatile residue (NVR) is levied. Finally, in Figure (18) the complete end to end performance of the end of life system is budgeted with the parameters described for NVR's and PAC's where the system is marginally not meeting the required transmission levels with the tight contamination program.

Summary:

When designing an optical system it is important to consider the conditions under which the system will be used. Not all systems require the complex approach to contamination control like the James Webb Space Telescope, but it is important to consider design and materials used. Materials can outgas, a poor mechanical design can leach stray light into the optical path and the system may be susceptible to thermal environments and moisture. Understanding the degree to which the system is sensitive to contamination will bring insight into the complexity and cost of the Assembly, Integration and Testing portions of hardware. The JWST system has tight contamination requirements and slim margins for error but will ultimately lead to very interesting answers about the beginnings of our universe.

References:

Eve Wooldridge and Jonathan Arenberg, "Contamination effects and requirements derivation for the James Webb Space Telescope", Proc. of SPIE Vol. 7069, 70690J, (2008)

A. C. Tribble, "Contamination Control Engineering Design Guidelines for the Aerospace Community", Proc. SPIE Vol. 2864