NASA/JPL STUDY ON OPTICAL IMAGING INTERFEROMETRY IN SPACE

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ABSTRACT

By the early 1990's the Hubble Space Telescope will have produced spectacular new astronomical images. Ground based high resolution optical interferometric imaging will have matured significantly and its limitations will have become clearer. These developments will increase tremendously the astronomical community's interest in and advocacy for the next generation high resolution optical imaging instrument in space. Studies initiated in the late 1980's into the technological problems associated with practical spacecraft implementations of some of the concepts proposed at this meeting will enable the Space Agencies to respond positively to the community's heightened interest a few years later. In this paper we briefly outline the plans we have for such a study under NASA funding.

Keywords: Space Interferometry, Optical Interferometry

1. INTRODUCTION AND APPROACH

Several recent conferences (Corsica 1984, Cambridge, USA 1985, and others) have seen extensive discussions on the many possible conceptual designs of interferometric imaging missions, and have identified the science opportunities accessible to each. In addition in the U. S., Perkin-Elmer and Marshall Space Flight Center technology studies have been done on some aspects of the practical implementation problems of an interferometer in space. A goal of the ongoing JPL effort is to further press beyond the conceptualization and initial study phases and begin to examine in detail the problems associated with making images in the UV-visible-near IR region from data acquired by collecting elements supported by a moving, rotating structure in space subject to thermal, gravitational, drag and other external influences, and to its own internal perturbations from control systems, etc. Conceptualization will certainly have to continue but we believe that in-depth studies of a few (probably two) different functional concepts would contribute to the identification of critical or accommodating technologies. The immediate goal is to identify those technology gaps which must be bridged in order that an instrument can fly in the reasonably near term.

Although it will almost certainly evolve considerably, the approach that we currently have in mind can be summarized as follows:

1. Develop several candidate functional system configurations.

2. Generate the requirements on the structural, optical and controls subsystems needed to insure that each configuration is capable of producing high resolution images of astronomical sources.

3. Develop state-of-the-art designs for the structural, optical and controls subsystems of the configuration in 1.

4. Compare the capabilities of the current best possible designs in 3. with the requirements found in 2. above. This comparison will almost certainly require the development of new software study tools, and the laboratory measurement of the mechanical performance of advanced-concept structural joints and other members.

5. From this comparison formulate a long term program to develop the critical and accommodating technologies.

2. OVERALL INSTRUMENT MORPHOLOGY

Primarily from launch stowage and on-orbit deployment consideration, we are slightly biased toward an intensive study of a VLA-like wye configuration as shown in Figure 1, and as suggested by others (Norrdham, this meeting, and Bender et al, this meeting as examples). Such a configuration could fly as 3 or 4 parallel "arrows" in the shuttle "quiver" with a central instrument package occupying a few meter region at one end of the bay. The structural arms and the internal optics in each arm could be fully assembled on the ground, although deployable trusses and simple optical assembly to allow smaller launch packaging could also be considered. The mode of mating the arms to the central package (i.e., types of joints, likely subsequent motions, optical alignment, etc.) and the raising of the mast if needed obviously must be considered in some detail. We will discuss the structural modelling problem further below.

It may be most convenient and efficient, and at the same time very educational, to examine the various methods of combining the light within the single structural framework of the wye. We may find that structural motion considerations force us to abandon the wye in favor of a more rigid triangle or a tetrahedron or Burke's bicycle wheel. But the wye configuration with the mast and guy wires may provide adequate structural control while perhaps avoiding the higher frequency effects in the more rigid structures.

3. OPTICAL DESIGN

For the purpose of conducting specific studies we would ideally like to choose optical designs which span the space of reasonable possibilities so that our study finds all the relevant technology gaps that currently exist. The two generic designs that we will attempt to study in some detail are a COSMIC-like (although 2-D) direct imager or phased array with a beam combining telescope, and an amplitude and phase map maker such as OASIS. Variations on these two themes using fibers instead of mirrors will also be considered.

For the 2-D COSMIC, estimates of the structural modes developed as part of the study (see below) will be used to establish requirements on the rates, amplitudes, degrees of freedom, etc. that the active path length compensation system must satisfy. Such tolerances have not been established before because the full structural characteristics were not known. Since the overall spacecraft orientation will be slowly varying within allowable limits (measured presumably either by one of the collecting elements as in the Marshall study or by one of the baselines) the internal control system must be able to respond to allow long integrations. This raises the idea of nested control systems; a coarse one using something like momentum wheels to control the overall orientation to a few arcseconds, and a fine one to compensate for both the remaining orientation error and the internal structural effects.

The second generic type of optical setup to be considered would be the OASIS coherent array approach in which fringe amplitudes and phases from the various baselines are individually measured and an image is constructed in the computer from these fourier components. In this design equality of path length through all baselines is not demanded but stability of the phase relationships during an integration is required. The use of wide field (0.5 deg) reference objects has been raised as a possible solution to both the fringe stabilization and phasing problems. We would like to investigate the wide field optical design possibilities. All approaches to this problem seem to involve considerable optical system complexity, and if an elegant, simple solution cannot be found then predictions that the imaging interferometer is a gigabuck class project may be correct. Questions to be investigated include whether at least partial reference object coherence can be achieved in spite of aberrations, how the required extra delay lines can be properly phased, whether the reference fringe motions provide enough information to allow the science fringes to be frozen on the detectors, and what optical component motions must occur to allow this to happen. There will certainly be other questions depending on the particfular design chosen. All of this again would be studied under the assumption that the optics is embedded in a structure which is constantly moving, and drifting in pointing.

Connes (this meeting) has pointed out the advantages of using fibers to transfer the light from the collectors to the detectors. Since the advantages appear great we would like, resources permitting, to study the effects of using fibers in at least one of the configurations discussed above. The logical choice appears to be the phased array in which the narrow field restriction imposed by the fibers is not a problem. However, guiding the telescope output to the fiber input in the face of the structural vibrations and rotations may be a significant difficulty in any configuration.

4. STRUCTURAL CONFIGURATIONS

The requirement for the development of conventional space structures for short wavelength sensors far exceeds the current state-of-the-art capability. A new generation of structures is required that will reconfigure and maintain precise geometry without human intervention when subject to internal and environmental forces. Additionally the requirement to estimate the micron and submicron mechanical performance of the underlying structural members of an optical interferometer in space is beyond the state-of-the-art. No study tools exist with which to make reliable estimates of the amplitudes and rates of the structural motions at the level required to fully understand the implications for optical and control system design. Progress in the area of identifying and quantifying the technological gaps will require a combination of theoretical and laboratory measurement work on several different types of structural components, and the incorporation of these results into the large finite element codes which are used currently for predicting larger amplitude effects. Initial estimates of submicron structural behavior may be obtainable with near term modifications to the existing codes before the more detailed analysis is done but this approach has not been assessed yet either. In any case the structural behavior in response to a variety of external and internal stimuli must be understood or at least bounded before the optical and controls systems can be fully specified (but the internal stimuli are caused by elements of the controls systems, etc; the whole problem is obviously iterative in nature).

5. CONTROLS AND SYSTEMS CONSIDERATIONS

A few final thoughts:

The requirements on the coarse attitude control of the spacecraft may be set by the need to keep the light beams from drifting off small optical elements used for fine pointing which are internal to the instrument. The attitude control error signals will originate in the optical system. The design of the optics and controls systems will depend heavily on the design of the supporting structure. The fundamental point is that since the optics and controls will be spread over the entire structure, the analysis of the imaging interferometer must be done from a systems point of view if the design is to be optimized.

An overall view of the process of assessing the ability of such an instrument to make images of a desired quality is shown in Figure 2. Although this may be an idealized process and one whose software elements may take a long time to build, the goal of having a tool which can enable assessment of the effects of instrument imperfections or errors on the final achievable image quality would seem to be a highly desirable one. The construction of such a tool in some form is a goal of our study.

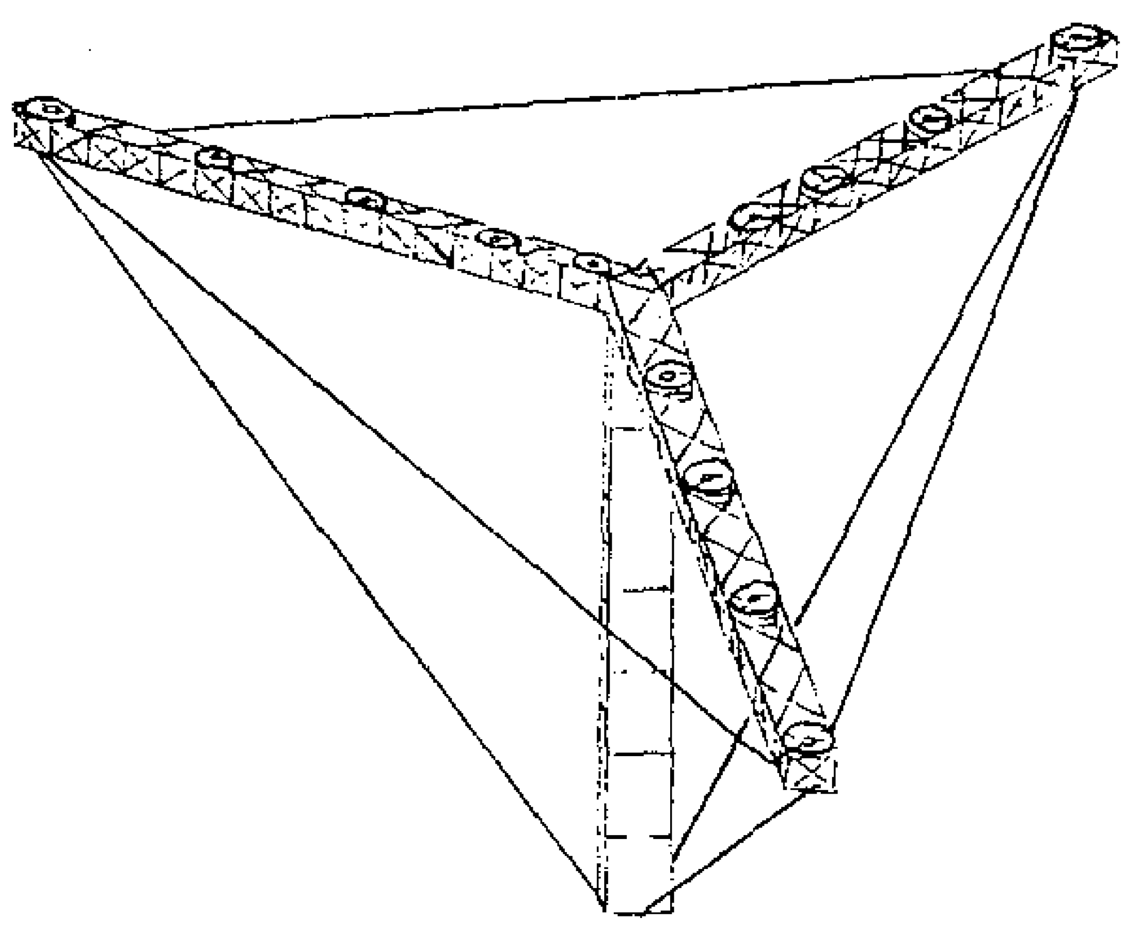

Figure 1.

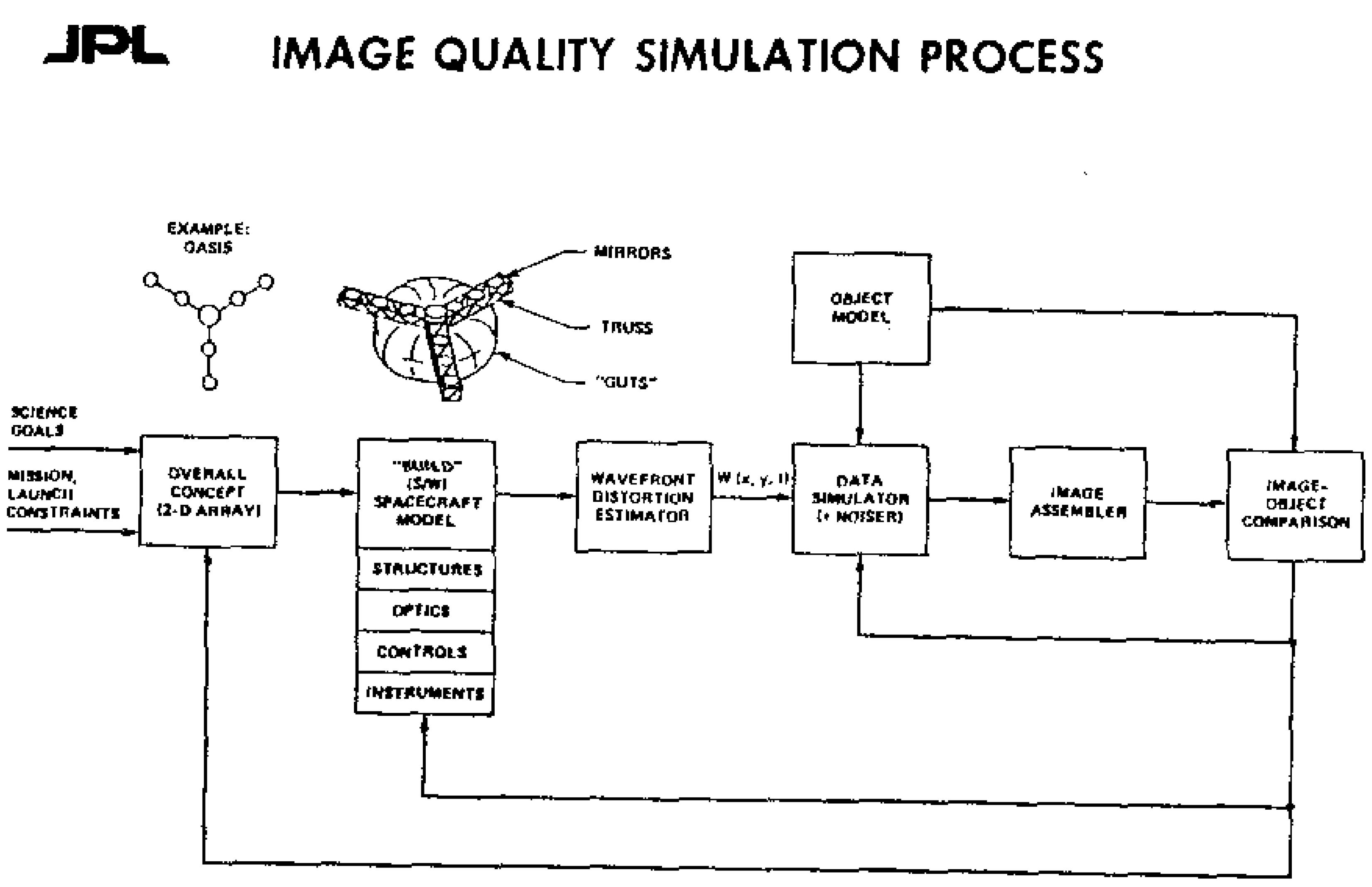

Figure 2.