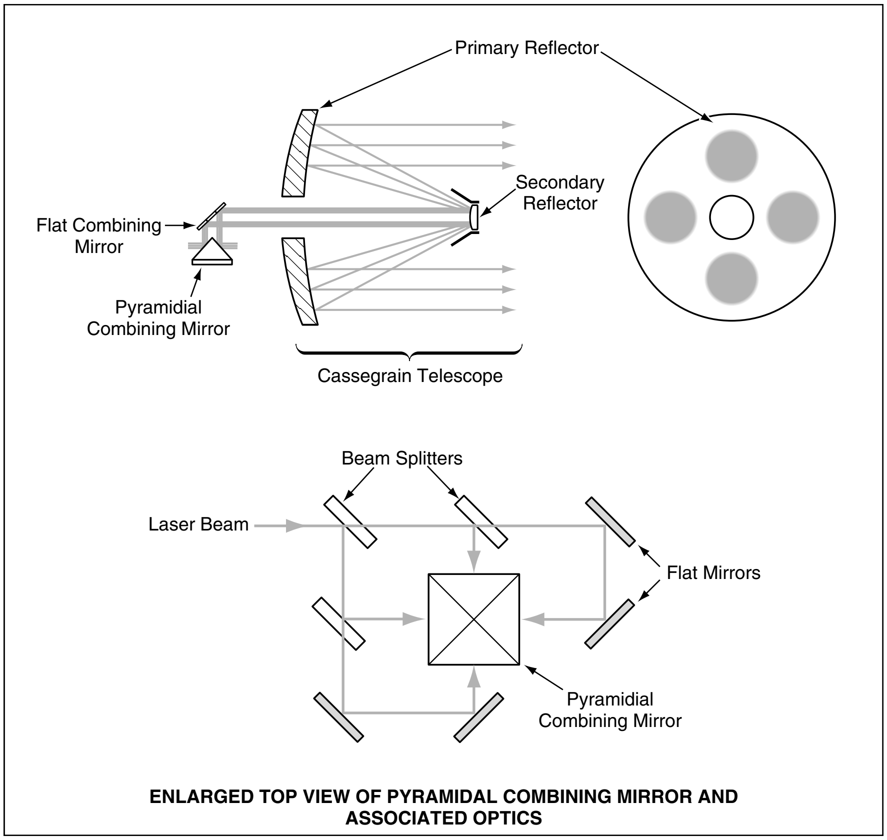


Figure 2. The **Laser Beam Would Be Split** in four and then recombined in such a manner as to illuminate the primary mirror in four unobscured subapertures.

would slice the laser beam into two or more beams that would have sector-of-circle cross sections, and that would be arranged symmetrically about the optical axis in unobscured off-axis positions. The difference between the axicon device and the prism beam slicer is that instead of a conical rear surface, the prism beam slicer would have an even number of flat rear surfaces in a pyramidal configuration at the same angle as that of the conical surface in the axicon device. If the number of pyramidal surfaces were made infinite, the prism beam splitter would revert to the axicon device.

The second technique now proposed would be a combination of the subaperture-illumination technique with a beam-splitting/beam-combining technique. As shown in Figure 2, the laser beam would be split into four beams that would be made to impinge on four faces of a pyramidal combining mirror and then further reflected by a flat combining mirror to generate four beams that would be parallel to the optical axis and would strike the primary mirror at unobscured off-axis positions 90° apart.

*This work was done by Hamid Hemmati and Norman Page of Caltech for* **NASA's Jet Propulsion Laboratory***. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to*

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# Aligning Three Off-Axis Mirrors With Help of a DOE

Precise lithographic fabrication would solve a large part of the alignment problem.

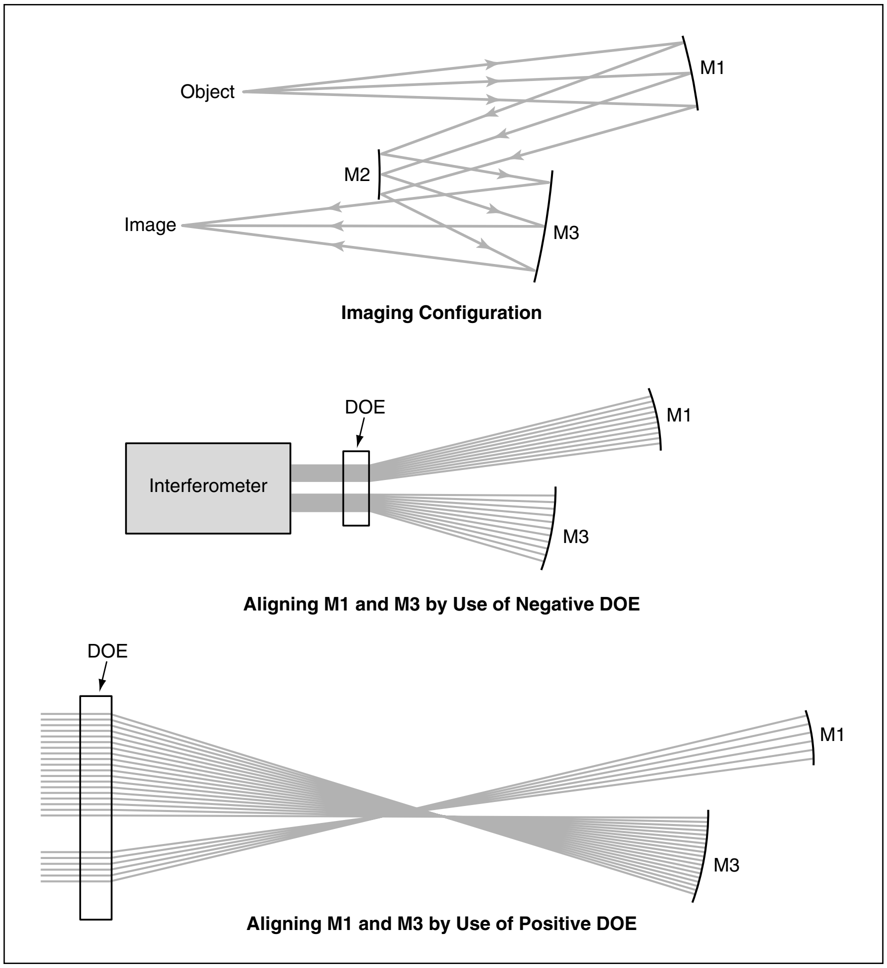
*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed method based on the use of a special-purpose diffractive optical element (DOE) would simplify (relative to prior methods) the alignment of three off-axis mirrors that constitute an imaging optical system. The method would exploit the fact that a DOE can be fabricated lithographically with high accuracy by electron-beam lithography in a thin film of poly(methyl methacrylate). The method would effectively transfer much of the problem of obtaining the needed accuracy from the mechanical-mirror-alignment domain to the lithographic domain. Unlike other methods that depend on specific symmetries (e.g., sphericity and/or concentricity), this method is expected to apply with equal ease and accuracy to mirrors of any configuration — including aspherical, decentered mirrors.

Assuming that one of the mirrors of a general three-mirror imaging optical system can serve as a reference for the alignment of the other two mirrors, such a system has 12 degrees of freedom in alignment. In the proposed method, one would use an interferometer in combination with a DOE to effect precise and relatively rapid and easy alignment of two of the mirrors with respect to each other, thus reducing the alignment task to that of the six degrees of freedom of the remaining mirror.

The figure depicts a representative three-mirror off-axis imaging system, wherein the primary and tertiary mirrors (M1 and M3, respectively) are concave and the secondary mirror (M2) is convex. The DOE for aligning this system would be fabricated on the right surface of an optical flat and could be made to have either negative or positive focusing power, depending on the requirements of the specific application. The DOE could be designed to be placed at any convenient distance from M1 and M3 — again, depending on the application.

The DOE would be illuminated with light coming from the left, generated by an interferometer. First, assuming the optical flat is of high quality, the plane of the DOE would be aligned perpendicular to the collimated beam by use of light reflected from the left face of the optical flat. The DOE would comprise two independent areas: one dedicated to M1, the other to M3. The portions of the collimated beam passing through those areas would be diffracted towards the corresponding mirrors. A mask, not shown in the figure, could be used to prevent light from




**Three Mirrors Would Be Aligned** with a DOE and, hence, with each other, in a sequence of interferometric procedures that would involve no more than six degrees of freedom of adjustment at one time.

passing through the rest of the area of the optical flat. Light rays reflected from M1 and M3 would retrace their paths through the DOE and would propagate leftward to the interferometer.

One would adjust the position and orientation of each of M1 and M3 in an effort to minimize the number of fringes in its portion of the interferogram. Such adjustments are commonplace in interferometry and can be performed easily. Once these adjustments were complete, M1 and M3 would be in alignment with the DOE and, hence, with each other.

With M1 and M3 thus fixed, one could align M2 by performing similar adjustments on M2 while observing the interferogram of the entire optical system in double pass, as is standard practice. For this purpose, it is necessary to generate an object beam with sufficient accuracy. For an infinitely distant object, it would suffice to remove the DOE and rotate the assembly of M1, M2, and M3 by a prescribed amount that can be easily calculated. The collimated beam from the interferometer would then act as object beam. For an object at a finite distance, one would place a focusing lens in front of the interferometer to generate a spherical wavefront, which could then be made to pass through a pinhole that could be fabricated at an otherwise unoccupied area of the DOE. The position of the pinhole could be known with high accuracy, inasmuch as it would be controlled during fabrication of the DOE.

By virtue of the precisely known geometric relationships between (1) the position of the pinhole and the rest of the DOE and (2) the DOE and the mirrors, the geometric relationship between the position of the pinhole and the object would thus also be known. The whole assembly could then be translated to the required coordinates, making it possible to use the interferometer beam as the object beam for final testing and alignment.

*This work was done by Pantazis Mouroulis and Daniel Wilson of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com***.

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# Calibrating Laser Gas Measurements by Use of Natural $CO_2$

Every spectral scan includes a calibration line.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

An improved method of calibration has been devised for instruments that utilize tunable lasers to measure the absorption spectra of atmospheric gases in order to determine the relative abundances of the gases. In this method, $CO_2$ in the atmosphere is used as a natural calibration standard. Unlike in one prior calibration method, it is not necessary to perform calibration measurements in advance of use of the instrument and to risk deterioration of accuracy with time during use. Unlike in another prior calibration method, it is not necessary to include a calibration gas standard (and the attendant additional hardware) in the instrument and to interrupt the acquisition of atmospheric data to perform calibration measurements.

In the operation of an instrument of this type, the beam from a tunable diode laser or a tunable quantum-cascade laser is directed along a path through the atmosphere, the laser is made to scan in wavelength over an infrared spectral region that contains one or two absorption spectral lines of a gas of interest, and the transmission (and, thereby, the absorption) of the beam is measured. The concentration of the gas of interest can then be calculated from the observed depth of the absorption line(s), given the temperature, pressure, and path length.

$CO_2$ is nearly ideal as a natural calibration gas for the following reasons: $CO_2$ has numerous rotation/vibration infrared spectral lines, many of which are near absorption lines of other gases. The concentration of $CO_2$ relative to the concentrations of the major constituents of the atmosphere is well