

UCRL-JC-120767

PREPRINT

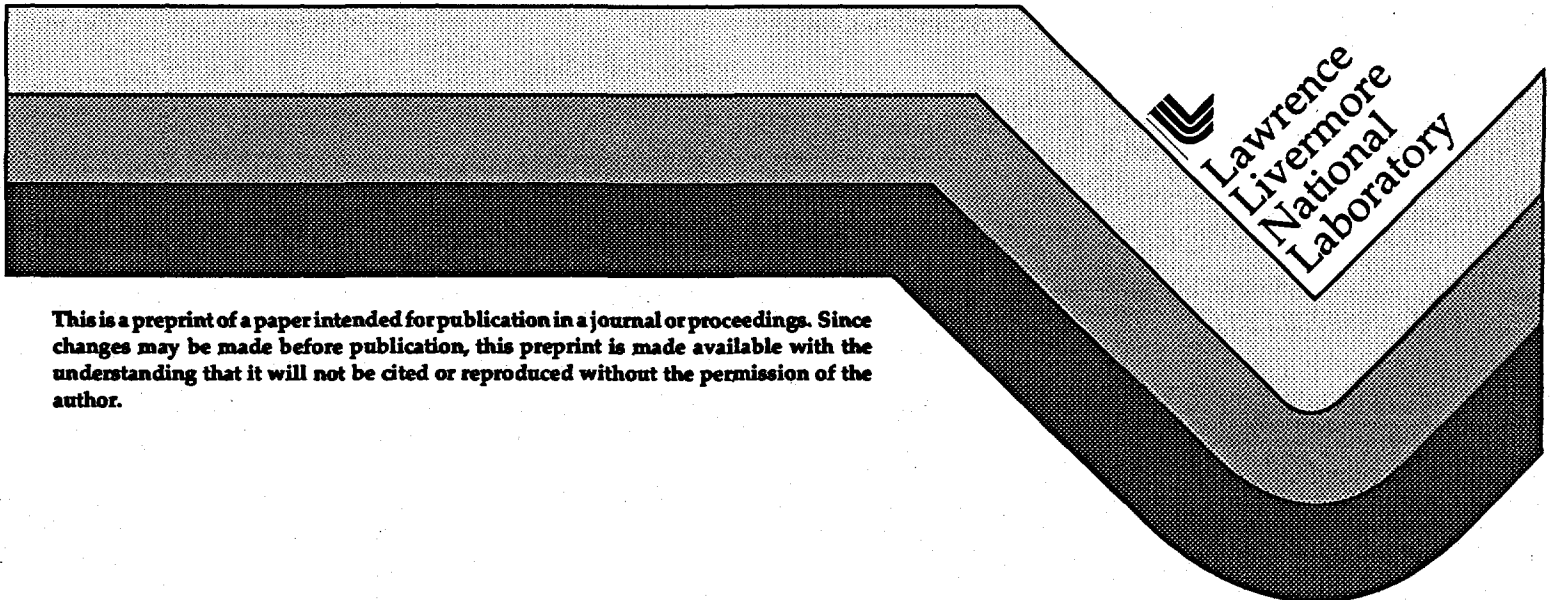
CONF-9507174--1

**A Database of Wavefront Measurements for: Laser System
Modeling, Optical Component Development and
Fabrication Process Qualification**

**C. R. Wolfe
J. K. Lawson
D. M. Aikens
R. E. English**

**This paper was prepared for submittal to the
Interferometry VII Applications
Tucson, AZ
July 14, 1995**

April 12, 1995



This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER *ds*
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A database of wavefront measurements for: laser system modeling, optical component development and fabrication process qualification

by

C. R. Wolfe, J. K. Lawson, D. M. Aikens and R. E. English

Lawrence Livermore National Laboratory, L-487

P. O. Box 5508

Livermore Ca., 94550

1.0 Introduction

In the second half of the 1990's, LLNL and others anticipate designing and beginning construction of the National Ignition Facility (NIF). The NIF will be capable of producing the worlds first laboratory scale fusion ignition and burn reaction by imploding a small target. The NIF will utilize approximately 192 simultaneous laser beams for this purpose. The laser will be capable of producing a shaped energy pulse of at least 1.8 million joules (MJ) with peak power of at least 500 trillion watts (TW). In total, the facility will require more than 7,000 large optical components. The performance of a high power laser of this kind can be seriously degraded by the presence of low amplitude, periodic modulations in the surface and transmitted wavefronts of the optics used. At high peak power, these phase modulations can convert into large intensity modulations by non-linear optical processes. This in turn can lead to loss in energy on target via many well known mechanisms. In some cases laser damage to the optics downstream of the source of the phase modulation can occur.

The database described here contains wavefront phase maps of early prototype optical components for the NIF. It has only recently become possible to map the wavefront of these large aperture components with high spatial resolution. Modern large aperture static fringe and phase shifting interferometers equipped with large area solid state detectors have made this possible. In a series of measurements with these instruments, wide spatial bandwidth can be detected in the wavefront.

The wavefront data is written as an electronic file. This simplifies use, transfer and storage. When used for computation, these phase maps and can be first manipulated (i.e. to generate an ensemble of phase maps from measured data) or input directly as individual surfaces or components into optical design and system optimization codes. The electronic format also greatly improves communication between remote test instruments and centralized analysis computers. The ability to transfer this data via LANs and over the Internet will be essential to timely, cost effective, monitoring of fabrication processes and acceptance testing of optical components for the NIF.

2.0 Purpose of the database

This database will provide both technical and administrative information to the NIF Project. As such, it will play a key role in the NIF Quality Assurance Plan for optical components. From the optical engineering perspective the data will provide:

- i. raw wavefront information for beam propagation modeling, laser system design and optimization,
- ii. metrology data for optical component specifications,
- iii. a baseline to characterize optical fabrication processes, and
- iv. acceptance test criteria applicable during the production of optical components.

From the administrative point-of-view the database will:

- i. satisfy DOE project management guidance for engineering data control, and
- ii. provide the quantitative basis for supplier qualification for the procurement process.

2.1 System design

The NIF laser design is the most demanding ever attempted by the inertial confinement fusion (ICF) community. The principles of geometrical optics (refraction) are sufficient at the conceptual design stage but consideration of diffraction and non-linear optical effects become essential in the detailed design. This is necessary because the NIF is a high intensity, coherent, narrow bandwidth optical system; beam propagation is dominated by these effects. Detailed computational modeling of beam propagation requires that the optical components be represented by measured data from actual materials and surfaces. This data is available as reflected and/or transmitted wavefronts (i.e. phase maps) of the fabricated parts. With this data on the optical components, designers and modelers can vary the design in a meaningful way, to perform "what if" experiments as part of design optimization (using codes such as PROP92). This design optimization process also includes feedback to suppliers so that system performance and cost is managed properly.

The NIF Project has completed the conceptual design phase and plans to begin the first phase (Title 1) of detailed engineering design in fiscal year 1996. The detailed design phase is planned to continue for several years as we refine the design and develop new low cost fabrication techniques for optical components in partnership with qualified suppliers.

2.2 Input to specifications for optical components

Wavefront data is used by designers and computational analysts to calculate modulation in the NIF aperture at various locations along the beam path. The process of detailed simulation consists of placing the correct number of optical components at their mechanical separations, as is done in a ray trace

code simulation. Measured wavefront phase map data is used rather than simple analytical representations of ideal optics. Then, if desired, the frequency spectrum or Power Spectral Density (PSD) of the measured wavefronts can be varied and the resultant beam modulation can be calculated incorporating the effects of geometrical optics, diffraction and non-linear effects. The results of this process will be used to derive initial specifications for components (i.e.; frequency spectra or PSDs). These specifications are the starting point for discussions with suppliers of optical materials and fabricators of finished components.

Wavefront data can be measured across a relatively broad range of spatial wavelength using modern instrumentation, as described below. The performance of the NIF laser system is limited by different optical mechanisms depending on the position along the beam path. These mechanisms can result in loss or optical damage depending on the scale length of features in the wavefront. For specification of optical components the wavefront will be partitioned into three regimes:

- I. short scale, or "micro roughness", having scale lengths $< 120 \mu\text{m}$
- ii. mid-spatial scale, with scale lengths from 0.12 to 33 mm, and
- iii. long scale, or conventional "optical figure/curvature", having scale lengths $> 33 \text{ mm}$.

Specifications will be developed separately for each regime.

2.3 Characterization of fabrication processes

A primary goal of the optical development program over the next several years is to develop low cost fabrication process for materials and finished components. Parts fabricated in this program will be tested at LLNL and/or by the supplier. This information will be used to guide new process development as well as to control quality as process costs are reduced.

2.4 Acceptance test criteria and supplier qualification

The optical engineering design and optimization process described in Sec 2.1 and 2.2 are planned to continue for several years. The current NIF Project schedule calls for pilot production to begin in FY '97, followed by the start of full production in FY '98. Data obtained from components fabricated during our development program will be used to qualify those processes for production of NIF optics.

In addition, this campaign of design, fabrication and testing will yield acceptance test procedures and a thorough knowledge of potential supplier capabilities. A list of suppliers qualified to bid on NIF optics production will be compiled by the NIF Project and used for procurement and subcontract administration purposes.

3.0 Database description:

The data base contains electronic files of wavefront phase maps from the following components:

- i. laser slabs,
- ii. KDP and KD*P crystals,
- iii. lenses,
- iv. polarizers,
- v. mirrors,
- vi. beamsplitters,
- vii. windows and
- viii. blanks of advanced optical materials

Transmitted wavefronts are predominantly measured at use angle. Reflected wavefronts are measured at normal incidence for substrates, at the use angle if coated. Example phase maps are included as figures 1 - 3. Our database currently contains approximately 200 files and is being added to constantly as new parts are tested.

Once the data on a new component is analyzed and determined to be of interest to the NIF design team, the files are transmitted to the NIF modeling group. These data files are in Unix binary format and are located on a LAN file server that can be accessed by members of the group. Supplier and fabrication process identification is kept separate from the phase map data. This ensures the protection of proprietary supplier information. In addition backup electronic copies of all measured parts (whether or not they are used for modeling) are kept in the NIF QA file on floppy disk.

Many instruments have been used to compile the data. They include phase measuring and static fringe interferometers and interference microscopes. Data has been obtained from the following organizations:

- i. Lawrence Livermore National Laboratory
- ii. Laboratory for Laser Energetics, Univ. of Rochester
- iii. Centre D'Etudes de Limeil - Valenton, France (CEL-V)
- iv. optical component suppliers of lenses, blanks, crystals and finished flats.

4.0 General description of measurement techniques

Optical components up to 400 mm x 750 mm are required by the NIF. Most of the largest (rectangular) components are used at high incident angles and have use apertures of approximately 400 x 400 mm. These parts has been measured using state-of-the-art commercial phase shifting or static fringe interferometers at a wavelength of 6328 Å. Most of the data have been

obtained from Fizeau interferometers, the exception is some data on lenses that was measured with a LUPI (Laser Unequal Path Interferometer) due to the long focal length. Transmitted wavefront measurements were made at the use angle and at near normal incidence. Reflected wavefront measurements were made at near normal incidence on uncoated parts. Coated parts were measured at use angle and use wavelength. Parts that have been measured include: laser slabs, windows, KDP crystals and lenses.

The spatial bandwidth resolution of an interferometer is dependent on the size of the detector array and the test aperture. The theoretical dependence of spatial bandwidth vs. aperture diameter and detector size is illustrated in figure 4. Full aperture measurements are made with either 45 or 80 cm aperture static fringe interferometers. The object of these measurements is to characterize the long wavelength features, the "optical figure or curvature." The spatial resolution limit of these measurements is approximately 33mm. Characterization of the "mid-spatial wavelength regime" (0.12 - 33.0 mm) usually is performed in two sequential sub-aperture measurements at the same position on the part (i.e. 150 and 15 mm). Phase shifting interferometers are used for this purpose. "Micro roughness" measurements that resolve wavefront features with wavelength < 0.12 mm, are made with interference microscopes or optical surface profilers.

The mid-spatial wavelength regime (0.12 to 33 mm) of the wavefront for large aperture NIF optical components has not been well characterized in the past. Regular repetitive wavefront structure has been observed in many components in this regimes during the course of this work. The P-V magnitude of these structures are typically from $\lambda/100$ to $\lambda/20$. at 6328 Å. Previously unobserved structure has been detected in optical materials and on the surfaces of finished parts. We believe the sources of these structures are small index of refraction or fabrication errors that are well within previous specifications for the parts. It remains to be seen whether or not future design requirements will dictate reduction of the magnitude of these features.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

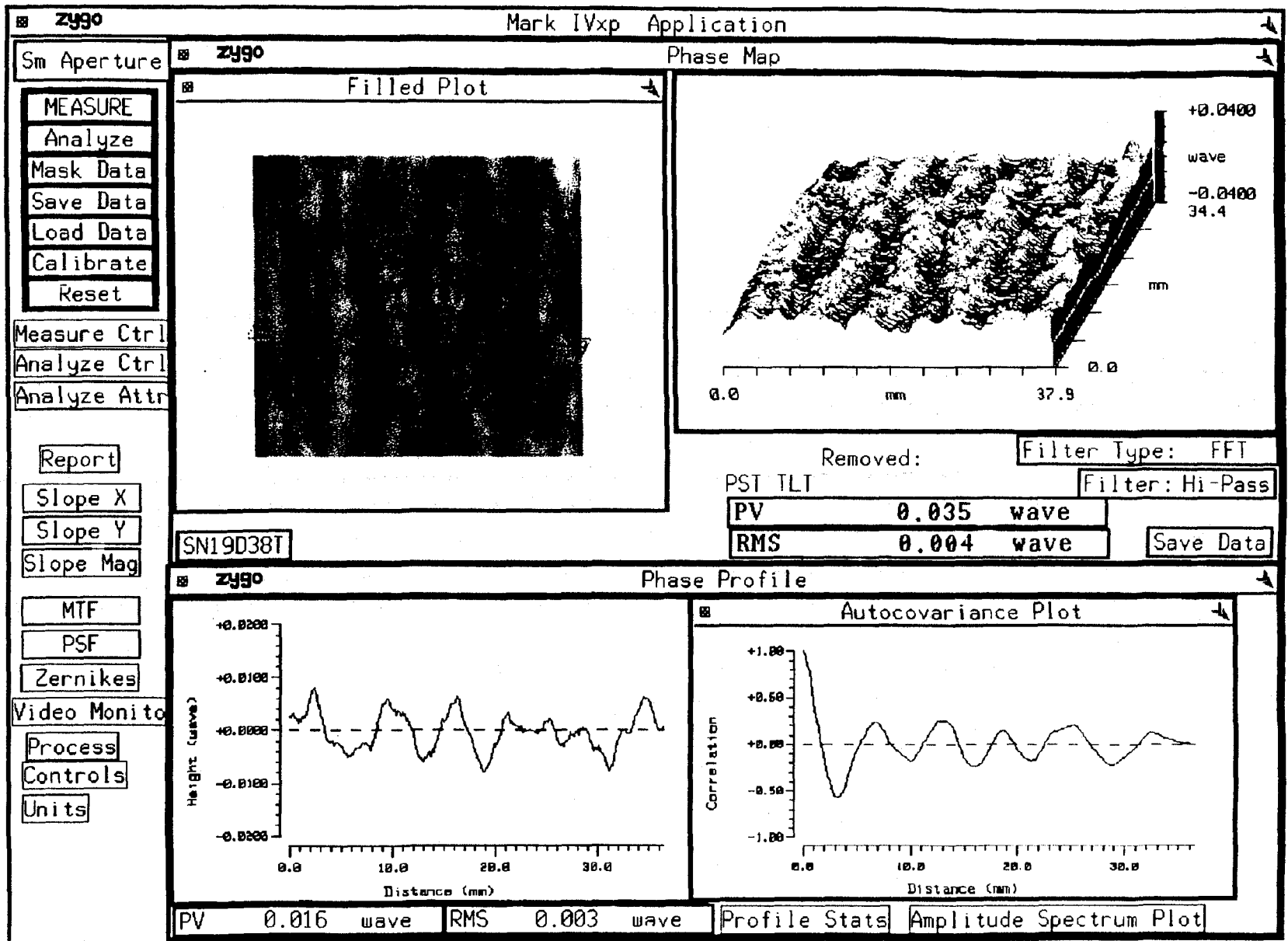


Figure 1: Transmitted wavefront phase map of an optical window ($\lambda = 6328 \text{ \AA}$)

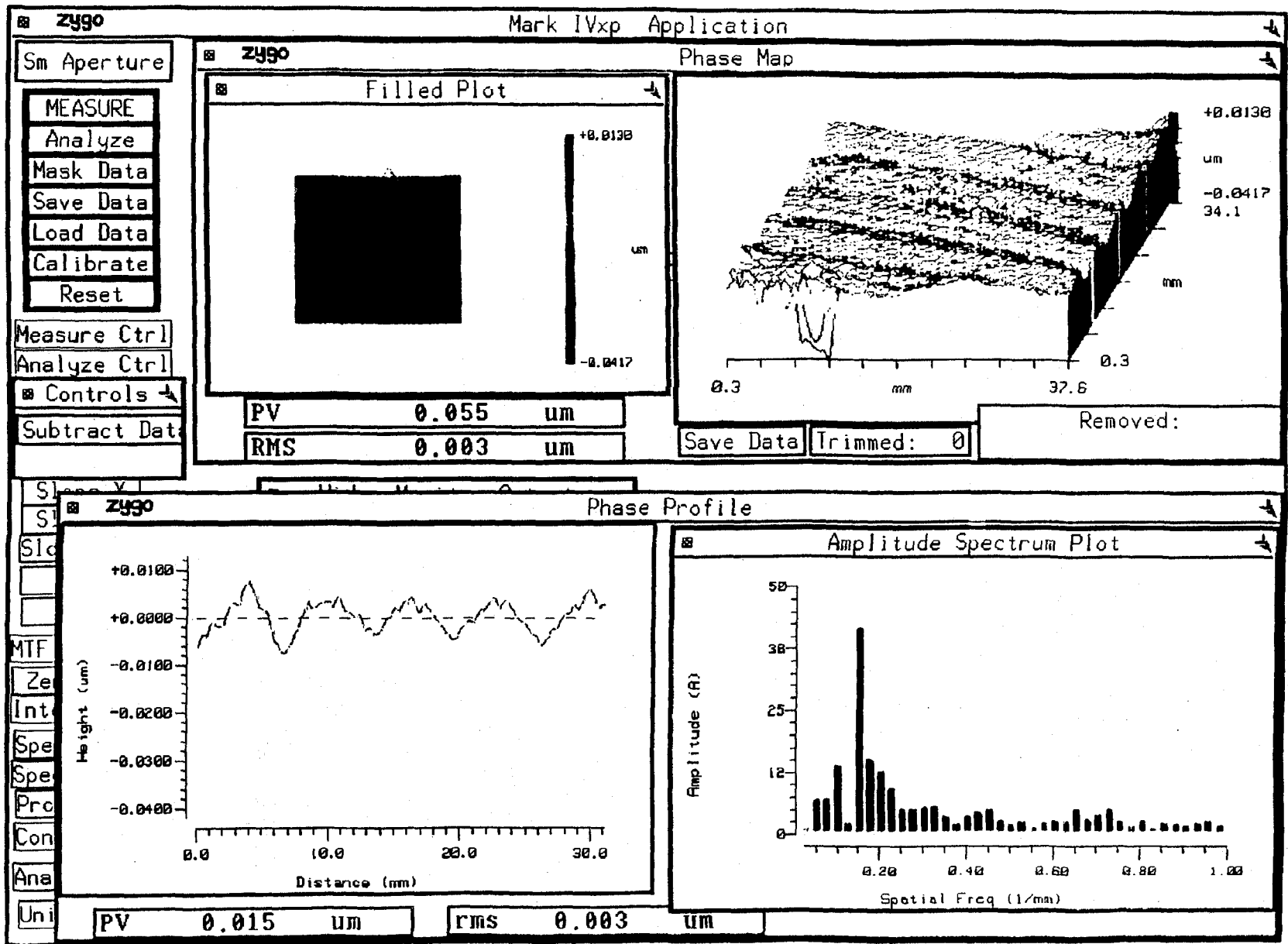


Figure 2: Reflected wavefront phase map of a diamond turned surface, ($\lambda = 6328 \text{ \AA}$)

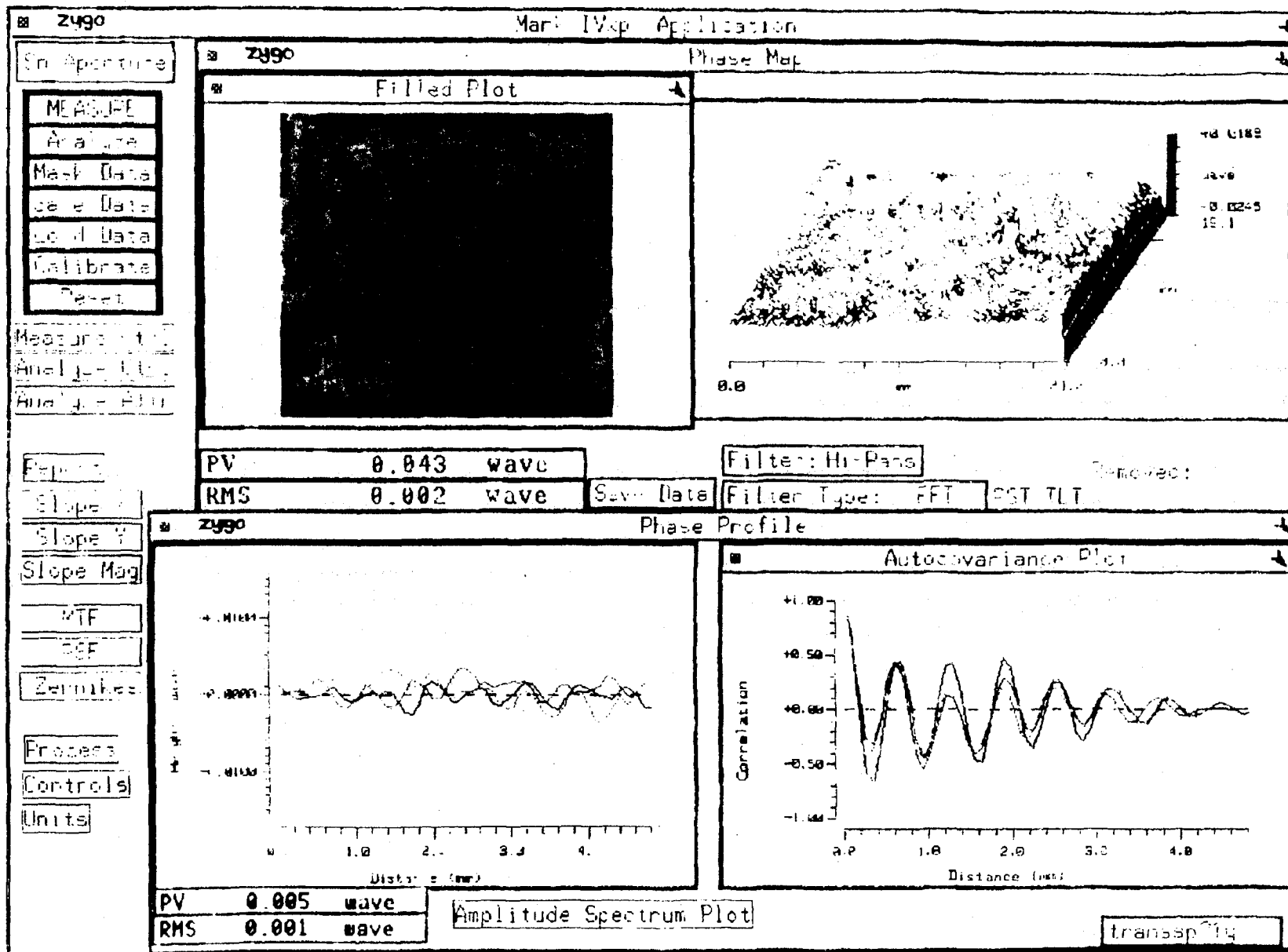
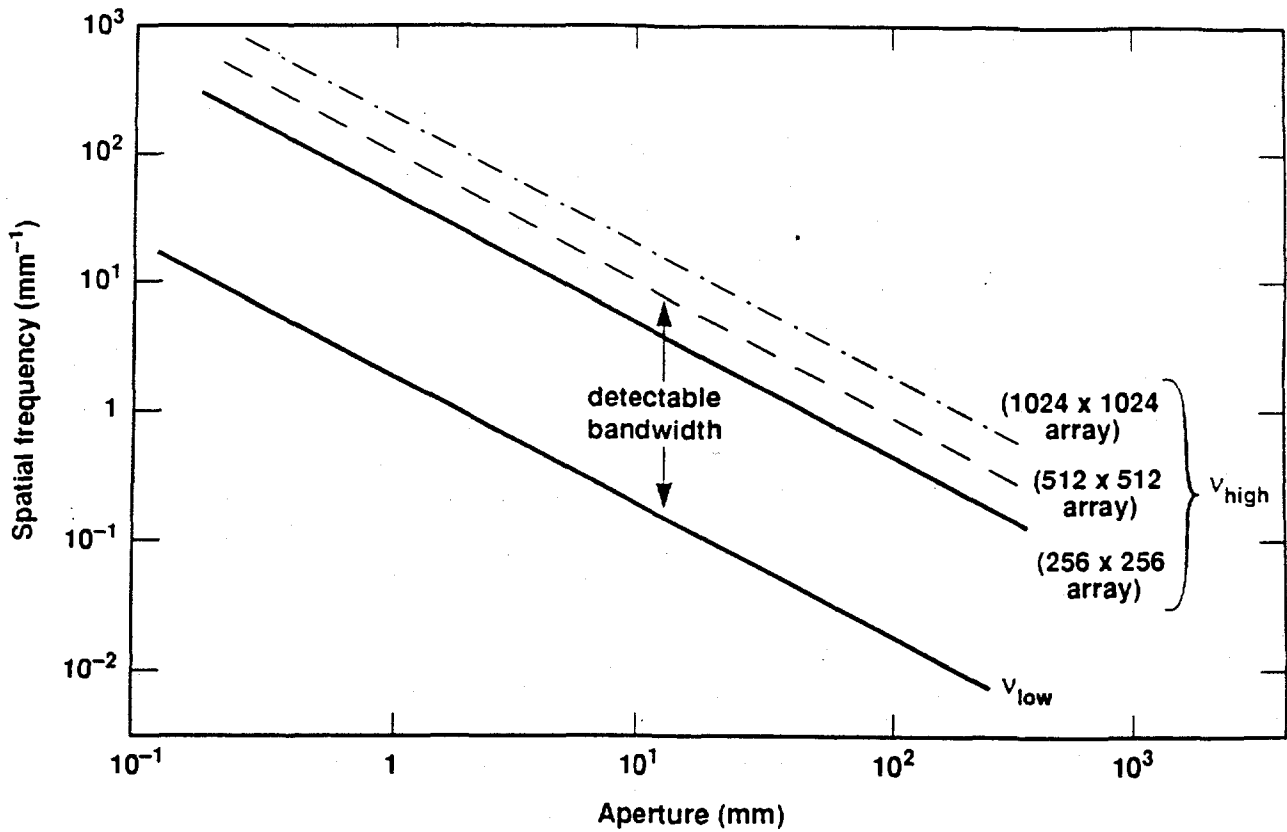


Figure 3: Transmitted wavefront phase map of a spatial filter lens, ($\lambda = 6328 \text{ \AA}$)



70-39-0894-3318pb01

Figure 4: Dependence of spatial bandwidth on aperture diameter and detector size (illustrative)