N89-12885

LASER ANEMOMETRY: A STATUS REPORT

Mark P. Wernet, Richard G. Seasholtz, Donald H. Weikle, and Lawrence G. Oberle
NASA Lewis Research Center
Cleveland, Ohio

A laser anemometer system is being developed for the warm turbine facility as part of the HOST program. The system will be built using results obtained from our analytical and experimental research program. A status report of the laser anemometry applications research effort will be presented.

SUMMARY OF LASER ANEMOMETER STATUS FOR WARM TURBINE FACILITY

The designs for the turbine casing, the windows, and the positioning system have been completed. A block diagram of the laser anemometer system, signal processing scheme, and computer system is shown in figure 1. The status of these components is as follows:

Optics. - The optics will use an f/2.5 diffraction-limited final focusing lens. This fast lens was selected to allow the collection of the maximum amount of scattered light. It also will allow measurements close to surfaces by using large aperture masks. The primary optical design will be a single color laser fringe design (LFA). The use of a second color is being considered to provide simultaneous two-component measurements, if required. Both designs will include provision for rotation of the sample volume so that both the axial and circumferential velocity component can be measured. The four-spot time-of-flight anemometer system (TOFA) will be evaluated for use in hot, high-speed flows. If it proves superior to the LFA, the TOFA will be used.

Because of the aberration caused by the curved windows (0.250 and 0.3752 in. thick), it will be necessary to use compensating optics. Without compensation, the two beams will not, in general, cross and no measurements would be possible. The correction scheme consists of using a cylindrical lens and actuator which act as a zoom lens element.

Positioning system. - The optics will be mounted on a custom-designed optical table attached to a three-axis linear positioning system. In addition, the viewing direction will be determined by a mirror mounted on a two-axis goniometer, and the sample volume orientation by an image rotator. These six axes are adjusted by a controller that is interfaced to the system computer.

Seed injection system. - Because of the high-temperature flow environment, a solid seed material will be used. A fluidized-bed seeder generator has been purchased. The seed material will be alumina or another refractory material such as titanium dioxide. An identical seed generator has been successfully used in the NASA Lewis open jet burner. The seed injection will be through an 0.125-in. o.d. diameter tube. The tube position will be determined by an actuator controlled by the system computer. The seed injection mechanism is part of the casing design. One alternative approach that is being investigated is the injection of titanium tetrachloride vapor into the gas stream. Titanium tetrachloride reacts with water vapor to form small titanium dioxide particles and hydrochloric acid.

Window cleaning. - One anticipated problem is maintaining optically clean windows. It is expected that during operation the windows will be coated with seed material and, perhaps, by combustion products and/or lubricating oil. The following steps have been taken to alleviate this problem: First, provision has been made in the design of the window frame for the injection of purge gas to prevent the accumulation of contaminants on the windows. These purge holes can also be used to inject a cleaning solution during operation. Finally, an access window has been located so that the windows can be cleaned without removing them from the rig.

Data acquisition. - The data acquisition and experiment control will be handled through the system computer, PDP 11/44. The signal processor for the LFA is a counter processor. (The TOFA uses a custom-designed processor.) Each velocity measurement will result in three quantities being sent via a DMA channel to the PDP 11/44: (1) the velocity, (2) the time between the current velocity measurement to the previous measurement, and (3) the rotor position as determined by an electronic shaft angle encoder (ref. 1). A custom signal preprocessor will be used to allow computer control of a number of functions, including the selection of filters, selection of the PMT high voltage, selection of the gain of the signal amplifier, and monitoring of the PMT current.

Software. - The software needed to control the system and to acquire the data is a major part of the project. It will determine both the quality of the data and the efficiency of taking the data. The general goals of the system are

(1) To obtain axial and circumferential components of the velocity and turbulence intensity through the measurement region (which includes both the stator and the rotor)
(2) To determine the accuracy of these data
(3) To obtain a complete survey at one flow condition in a 4-hour test run
(4) To obtain estimates of the turbulence scale
(5) To have operating procedures simple enough so the system can be used by the facility engineers without extensive training.

SEEDING WITH TITANIUM TETRACHLORIDE

The reaction of $TiCl_4$ with water to form TiO_2 is being investigated to form seed particles for hot-section applications. Titanium tetrachloride reacts with water in air as shown:

$$TiCl_4 + 2H_2O \Rightarrow TiO_2 + 4HCl$$

The technique being used for forming particles in the open jet burner uses a dry air carrier for the $TiCl_4$ gas. Moist air is generated by running a separate line of air through a water bubbler. The $TiCl_4$ gas and moist air are then mixed 1 in. from the entrance to the hot section by a concentric injector with the $TiCl_4$ stream in the center. The TiO_2 particles are formed in the gas stream before it enters the burner. The moist air surrounding the $TiCl_4$ gas tube keeps the tube free of accumulated TiO_2 and HCl.

In the initial tests run, data rates of 20 kHz were achieved. Data indicated that the particles were small ($\leq$1 μm), but the size was not measured. Current tests are being conducted to obtain samples of the TiO_2 from the burner exit. SEM photographs will be taken to determine of the TiO_2 particle size.

Some advantages of using $TiCl_4$ are (1) large number density of particles, (2) small size, (3) generated where needed, and (4) constant rate of generation.

Some disadvantages are (1) toxic liquid and gas, (2) large amount of HCl to neutralize, and (3) necessary use of special container materials (glass, ceramic, or stainless steel)

FOUR-SPOT TIME-OF-FLIGHT LASER ANEMOMETER

The four-spot time-of-flight laser anemometer system (TOFA) is a hybrid system, designed specifically for use in high-speed, turbulent flows near walls or surfaces. These are the anticipated conditions inside the warm turbine facility. The performance of the TOFA in low-speed flows (< Mach 0.3) was reported in the 1985 HOST Workshop (ref. 3). In early 1986 the new high-speed ECL version of the signal processor, capable of measurements greater than Mach 2, was received from Case Western Reserve University. An interface for the new signal processor to the system computer has been completed and initial tests of the processor have shown good performance up to Mach 1.3. A test was also conducted to determine additional performance characteristics of the system.

The TOFA sample volume contains approximately half the illuminated area of a typical LFA. The higher light flux in the probe volume enables the TOFA to measure smaller particles than an LFA. Detection of smaller particles is desirable because they follow the flow more accurately. A particle velocity lag experiment was conducted to determine range of particle diameters detectable by the TOFA.

In the particle velocity lag experiment, the velocity of particles entrained in the flow are measured downstream of a sonic nozzle. The gas accelerates through the nozzle, reaching Mach 1 at the exit. Particles greater in diameter than approximately 0.3 μm will lag behind the gas velocity at the nozzle exit. The amount of velocity lag is proportional to the particle diameter. The gas velocity can be calculated from the plenum temperature and the pressure drop across the nozzle. Since the laser anemometer can only measure the velocity of the particles entrained in the flow, the particle lag velocity is directly obtained. The measured particle velocity histograms are converted to particle diameter histograms. The mean particle diameter and standard deviation are then determined from the particle diameter histograms.

The seed particles used in the experiment were diagnostic latex spheres of 0.5- and 0.8-μm diameter, with a specific gravity of 1.05. A LFA cannot measure particles less than approximately 0.7 μm in diameter. The results of the particle lag experiment are shown in the table below and the corresponding velocity histograms are shown in figures 2 and 3.

Seed particle diameter, mm	Measured particle diameter, mm	Standard deviation of mean diameter, mm
0.50	0.54	0.20
.80	.82	.14

The spread in the histograms is caused by both error in the measurement and agglomeration of the seed particles. The estimates of the mean particle diameter are biased to higher values than the true particle diameters because of these effects. The results from the analysis show that the TOFA system can detect particles down to at least 0.5 μm in diameter.

CORRECTION OPTIC FOR CURVED TURBINE WINDOW

The turbine casing for the warm turbine facility has been refabricated with an optical access window. The window, which is curved to match the inner radius of the turbine casing, will minimize disturbance to the flow. The disadvantage of using a curved window is its astigmatic aberration. The curved window acts as a lens with uneven powers in the horizontal and vertical planes. An alternative approach and previously the only approach, is to use planar windows (ref. 5). This minimizes the astigmatic aberrations, but disturbs the flow field.

The laser anemometer system for the warm turbine will initially be a one component system with an image rotator. Rotation of the probe volume through various angles permits the measurement of the axial and circumferential velocity components. Rotating the probe volume through the turbine window causes varying degrees of image distortion. A solution to this problem is to preaberrate the image before it passes through the turbine window. This correction optic must also have continuous compensation throughout the survey range of the probe volume.

A lens design software package was purchased, and a correction optic for the warm turbine window was designed. The correction optic will be zoomed in and out as the three-axis table is moved to position the probe volume (figs. 4 and 5). The corrector has been optimized for normal incidence to the turbine window. The astigmatic errors in the image formation can be reduced through the use of the correction optic.

REFERENCES

1. Powell, J.A.; Strazisar, A.J.; and Seasholtz, R.G.: Efficient Laser Anemometer for Intra-Rotor Flow Mapping in Turbomachinery, Trans. ASME, vol. 103, pp. 424-429, Apr. 1981.
2. Seasholtz, R.G.; Oberle, L.G.; and Weikle, D.H.: Laser Anemometers of Hot-Section Applications. Turbine Engine Hot Section Technology - 1984. NASA CP-2339, pp. 59-69, 1984.
3. Wernet, M.P.: The Four Spot Time-of-Flight Laser Anemometer. Turbine Engine Hot Section Technology - 1985, NASA CP-2405, pp. 67-75, 1985.
4. Wernet, M.P.; and Edwards, R.V.: Implementation of a New Type of Time-of-Flight Laser Anemometer, Appl. Opt., vol. 25, pp. 644-648, Mar. 1986.
5. Schodl, R.: Laser-Two-Focus Velocimetry, AGARD Conference paper no. CPP-399, pp. 7.1-7.30, 1986.

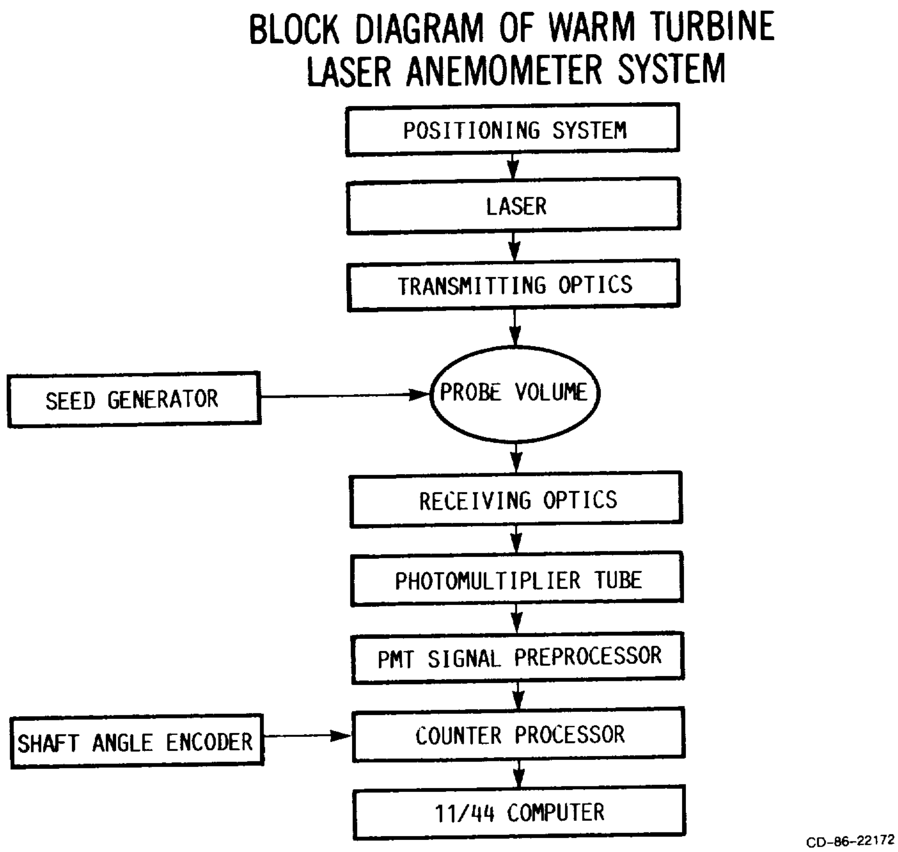
BLOCK DIAGRAM OF WARM TURBINE
LASER ANEMOMETER SYSTEM
POSITIONING SYSTEM
LASER
TRANSMITTING OPTICS
SEED GENERATOR
PROBE VOLUME
RECEIVING OPTICS
PHOTOMULTIPLIER TUBE
PMT SIGNAL PREPROCESSOR
SHAFT ANGLE ENCODER
COUNTER PROCESSOR
11/44 COMPUTER
CD-86-22172

Figure 1

PARTICLE-LAG VELOCITY HISTOGRAM

0.5-μM SEED PARTICLES; TAKEN 200 μM FROM NOZZLE EXIT; CRITICAL VELOCITY, 315 M/SEC

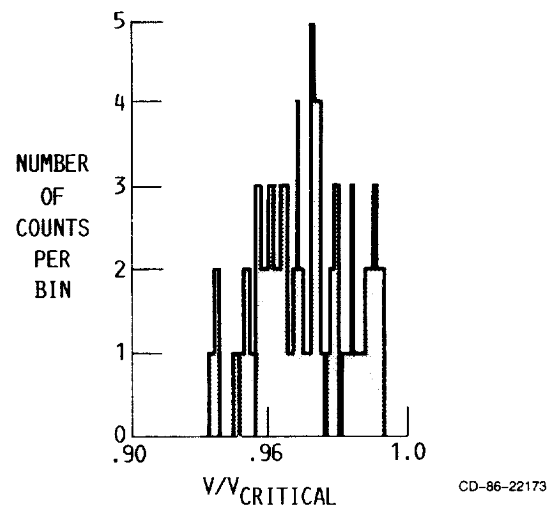

Figure 2

PARTICLE-LAG VELOCITY HISTOGRAM

0.8-μM SEED PARTICLES; TAKEN 200 μM FROM NOZZLE EXIT; CRITICAL VELOCITY, 315 M/SEC

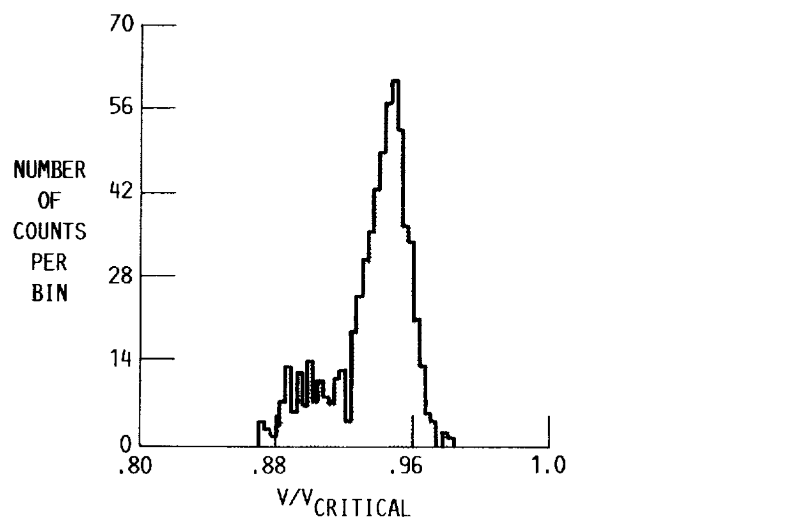

Figure 3

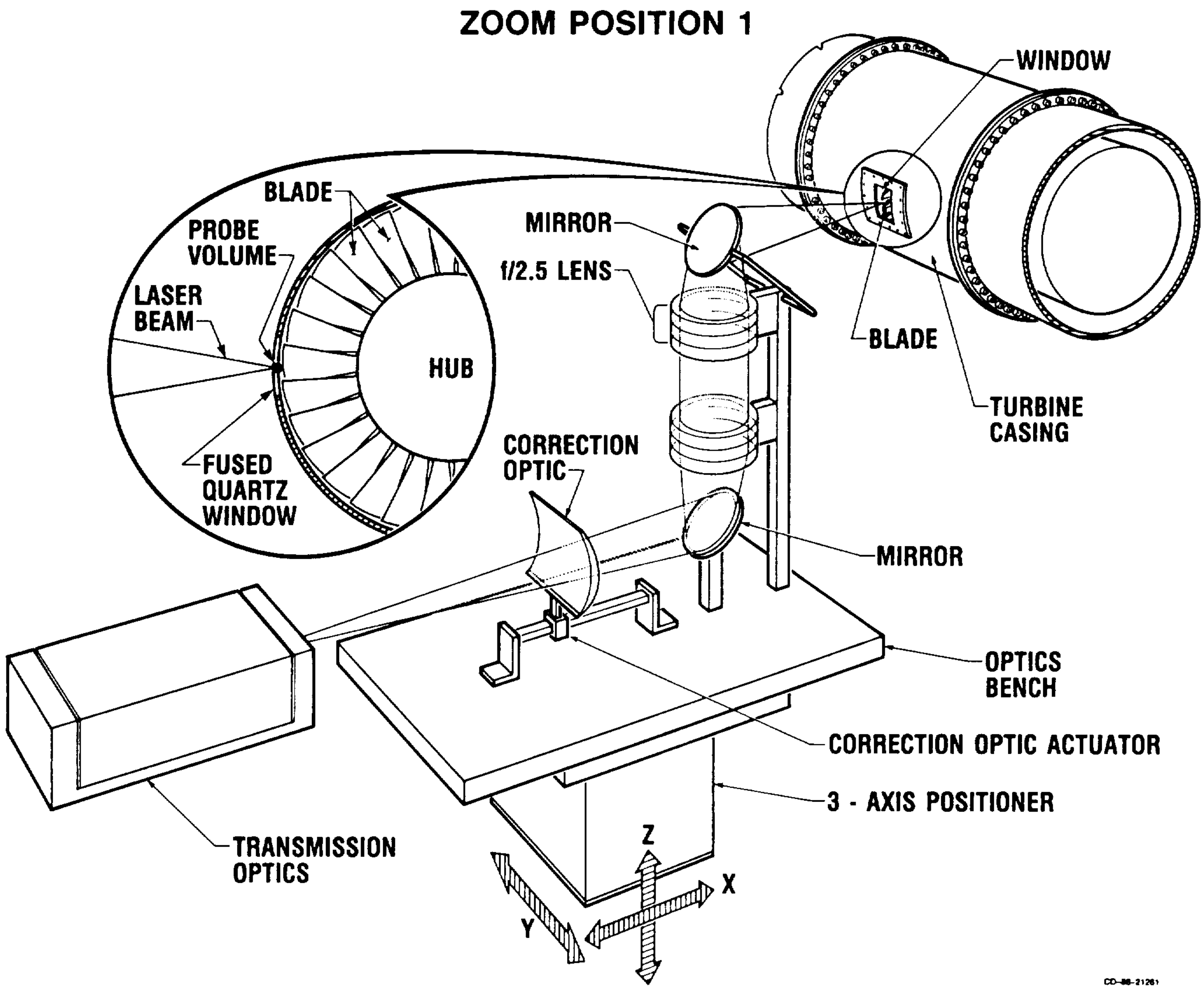
ZOOM POSITION 1
WINDOW
BLADE
PROBE
VOLUME
LASER
BEAM
HUB
FUSED
QUARTZ
WINDOW
MIRROR
f/2.5 LENS
BLADE
TURBINE
CASING
CORRECTION
OPTIC
MIRROR
OPTICS
BENCH
CORRECTION OPTIC ACTUATOR
3 - AXIS POSITIONER
TRANSMISSION
OPTICS
Z
X
Y

Figure 4

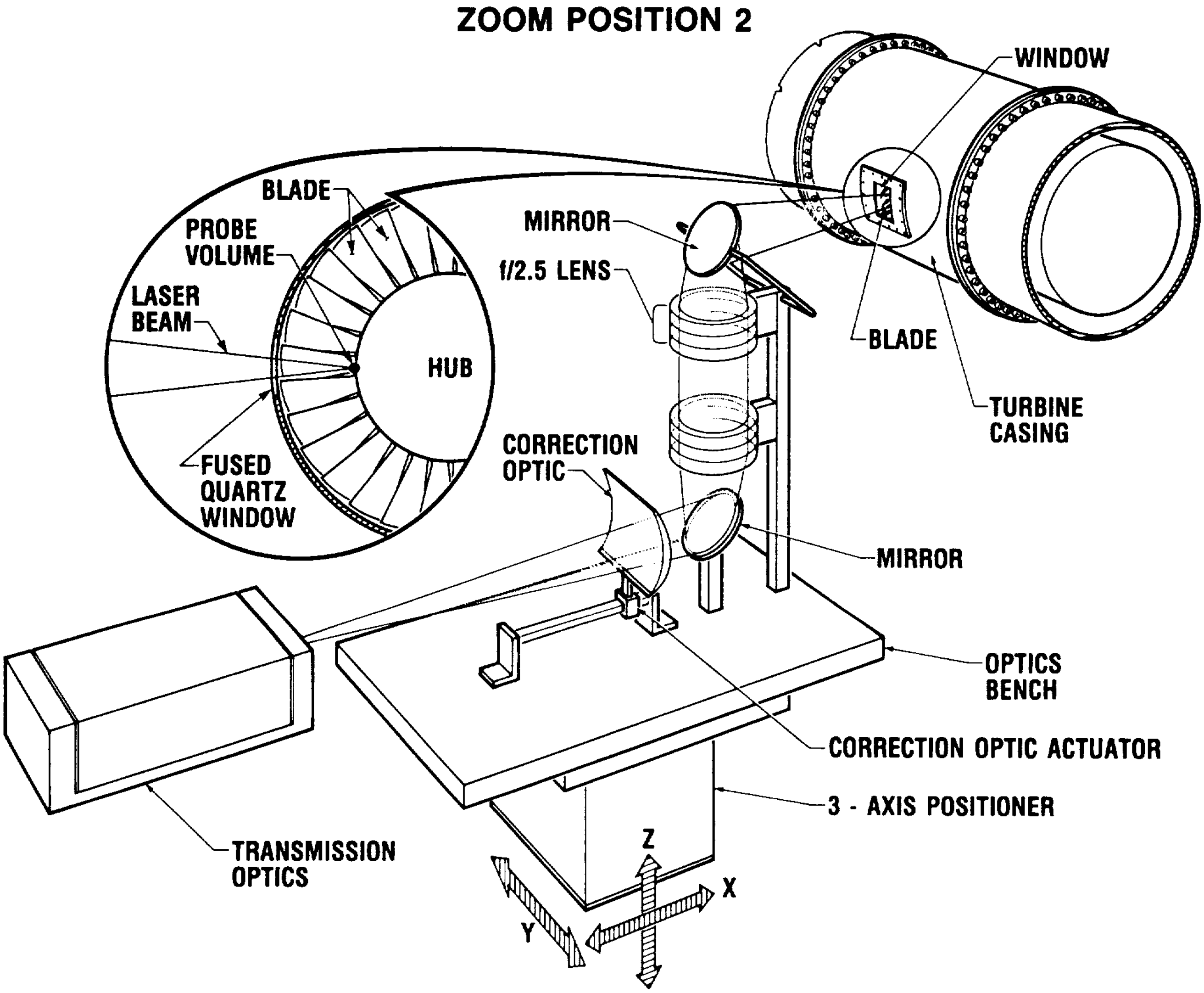
ZOOM POSITION 2
WINDOW
BLADE
PROBE VOLUME
LASER BEAM
HUB
FUSED QUARTZ WINDOW
MIRROR
f/2.5 LENS
BLADE
TURBINE CASING
CORRECTION OPTIC
MIRROR
OPTICS BENCH
CORRECTION OPTIC ACTUATOR
3 - AXIS POSITIONER
TRANSMISSION OPTICS
Z
X
Y

Figure 5