# SOME NTF LASER VELOCIMETER
# INSTALLATION AND OPERATION
# CONSIDERATIONS

W. W. Hunter, Jr.
L. R. Gartrell
W. C. Honaker

NASA Langley Research Center
Hampton, Virginia

# INTRODUCTION

Installation and effective utilization of a laser velocimeter system in the National Transonic Facility (NTF) has been advocated by a variety of technical panels (ref. 1) . The purpose of these panels is to make recommendations to ensure maximum research information is realized from this unique modern facility. Throughout the NTF's development high priority program requirements have continued to push consideration of a laser velocimeter system into the future. A need exists to measure and monitor flow field angularity during the calibration and shakedown of the NTF; providing a near term requirement for laser velocimetry.

Two velocimeter techniques were considered as possible candidates to meet this flow field angularity measurement requirement. The two approaches considered were the "fringe" laser Doppler velocimeter and the "two spot" laser transit anemometer. The purpose of this paper is to present the performance and system considerations in selecting the "two-spot" approach.

## REQUIREMENT

The initial requirement was to make a non-intrusive measurement of flow field angularity at a point on the centerline displaced some distance upstream of a potential model location. The angle range and required resolution were estimated to be 0.2 and 0.01 degrees, respectively. Maximum velocity for design considerations was 250 m/sec. Spatial resolution was not initially specified, other than it should be small compared with model and flow field scale so that a two-dimensional measurement in the plane perpendicular, coincident, and parallel to tunnel centerline would not be significantly in error due to a three-dimensional flow field.

## VELOCIMETER TECHNIQUES

Two velocimeter techniques were considered as potential candidates for achieving the flow field angularity measurements. The first was the "fringe" laser Doppler velocimeter, (LDV). A great deal of experience has been obtained with this approach at Langley and the literature is rich with papers describing many experimental applications and system performance details (refs. 2 and 3). That is, many velocity flow field measurements have been conducted with the LDV but not with high resolution precise angularity measurements. The second candidate considered was the "two-spot" laser transit anemometer, (LTA). This approach has not been as extensively used as the LDV technique but literature does contain experimental applications and system performance details (refs. 4 and 5). Again, a lack of high resolution, high precision angularity measurements is noted for the LTA.

### REQUIREMENT

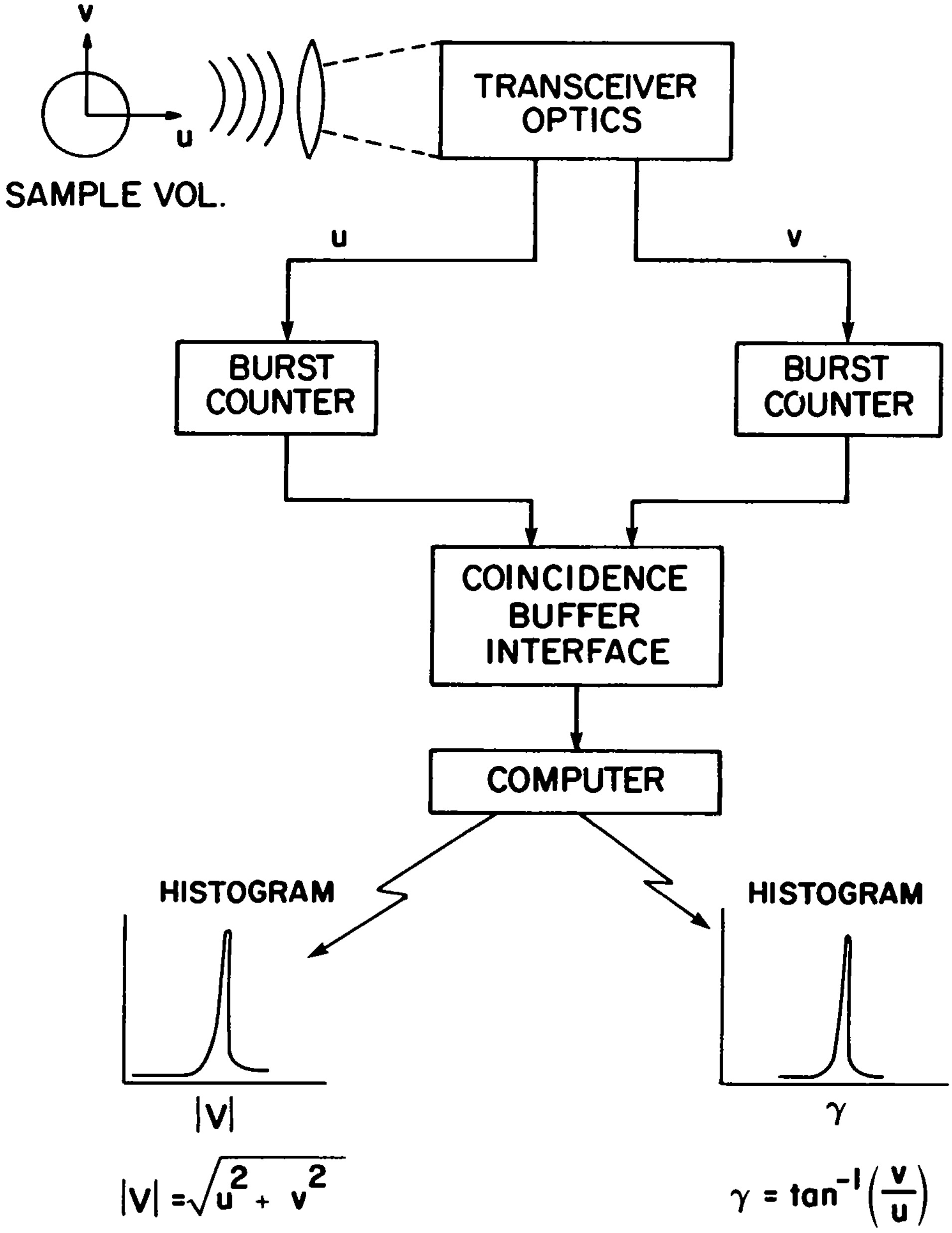
MEASURE FLOW FIELD ANGULARITY WITH AN ACCURACY OF 0.01 DEGREE NON-INTRUSIVELY

### APPROACHES CONSIDERED

- o LASER DOPPLER VELOCIMETER (LDV)
- o LASER TRANSIT ANEMOMETER (LTA)

## LDV FUNCTIONAL DIAGRAM

The approach considered for the measurement of the flow field angularity in a perpendicular plane parallel and coincident with the tunnel centerline was to require simultaneous two-velocity component measurements, u and v. The imposition of the condition of coincident measurements allows for the separation and measurement of the mean flow field velocity magnitude and angularity and their respective higher order statistical moments.



# LASER DOPPLER VELOCIMETER COORDINATE SYSTEM

Fundamentals of the "fringe" laser Doppler velocimeter are well known and numerous articles and conferences have explored its capabilities and limitations. Conceptually the technique is embodied in this simple expression:

$$f_D = \frac{2V \sin \theta/2}{\lambda}$$

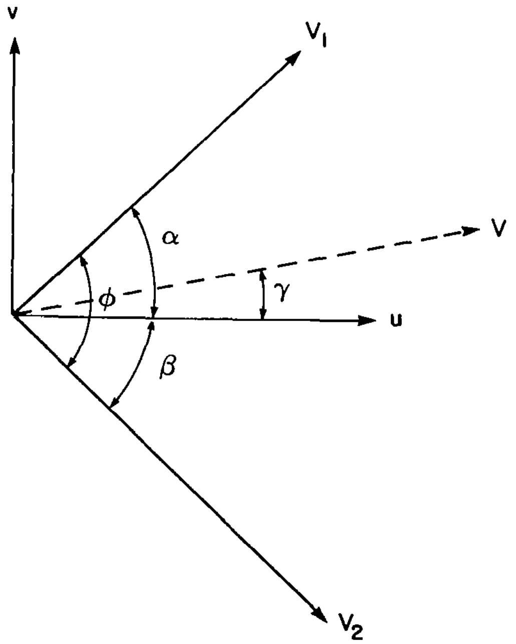
The Doppler frequency, $f_D$, is related to the velocity component, V, in the plane of two laser beams which cross with an angle $\theta$ and whose wavelength is $\lambda$.

The Coordinate system shown below and the following expressions permit the development of the relations between the measured values and the two-dimensional flow field magnitude and angle:

$$V_1 = V \cos (\alpha-\gamma)$$
$$V_2 = V \cos (\phi-\alpha+\gamma)$$
$$\beta = \phi-\alpha$$

The flow field angularity is given by:

$$\gamma = \tan^{-1} \left[\frac{V_1 \cos (\phi-\alpha) - V_2 \cos \alpha}{V_1 \sin (\phi-\alpha) + V_2 \sin \alpha}\right]$$



## ESTIMATE OF THE ALLOWED SYSTEM UNCERTAINTIES

To achieve an estimate of the uncertainty to be expected in the measurement of $\gamma$ or to achieve an estimate of the uncertainties that can be tolerated in the parameters $V_1$, $V_2$, $\phi$, and $\alpha$, an analysis based on the propogation of errors was performed (ref. 6). For the specific case indicated and the assumptions that the uncertainties in the quantities $V_1$, $V_2$, $\phi$ and $\alpha$ are independent and the velocity, V, of the scattering particulate is constant during the measurement transition the following expression for the standard deviation, $\sigma$, or variance, $\sigma^2$, of the flow angle, $\gamma$, and velocity were derived. Note the potentially significant amplification of the variance of the cross beam angle, $\theta$, by the cotangent squared term.

FOR CASE

$$\phi = 90^\circ$$

$$\alpha = 45^\circ$$

THEN

$$V_2 \cong V_2$$

$$\sigma_{V_1} \cong \sigma_{V_2}$$

AND ASSUMING

$$\sigma_\alpha \cong \sigma_\phi$$

$$\sigma_\gamma = \left[ \frac{\sigma_V{}^2}{2V^2} + \frac{5\sigma_\phi{}^2}{4} \right]^{1/2}$$

WHERE

$$\frac{\sigma_V{}^2}{V^2} = \left[ \frac{\sigma_{fD}{}^2}{fD^2} + \frac{\mathrm{COT}^2 \ \theta/2}{4} \ \sigma_\theta{}^2 \right]$$

## RESULT OF UNCERTAINTY ANALYSIS

Assuming that the angles, $\theta$, and $\phi$ can be determined with equal precision and noting that the cotangent squared term dominates the case considered, the contribution to the uncertainty by the detected Doppler frequency was neglected. To achieve the flow angle, $\gamma$, uncertainty of 0.01 degree requires that the uncertainty in the cross beam angle be restricted to no more than 1.3 seconds of arc.

$$\sigma_\gamma = \left[ \frac{\sigma_{fD}^{\,2}}{2fD^2} + \frac{\mathrm{COT}^2\ \theta/2\ \sigma_\theta^{\,2}}{8} + \frac{5}{4}\sigma_\phi^{\,2} \right]^{1/2}$$

ASSUMING $\sigma_\theta = \sigma_\phi \equiv \sigma_<$

AND NEGLECTING $\sigma_{fD}^{\,2}/2fD^2$

$$\sigma_< = \frac{\sigma_\gamma}{\left[ \frac{\mathrm{COT}^2\ \theta/2}{8} + \frac{5}{4} \right]^{1/2}}$$

REQUIRE: $\sigma_\gamma \leqslant 0.01^\circ$ OR $1.74 \times 10^{-4}$ RAD.

AND LET: $\theta = 1.5^\circ$

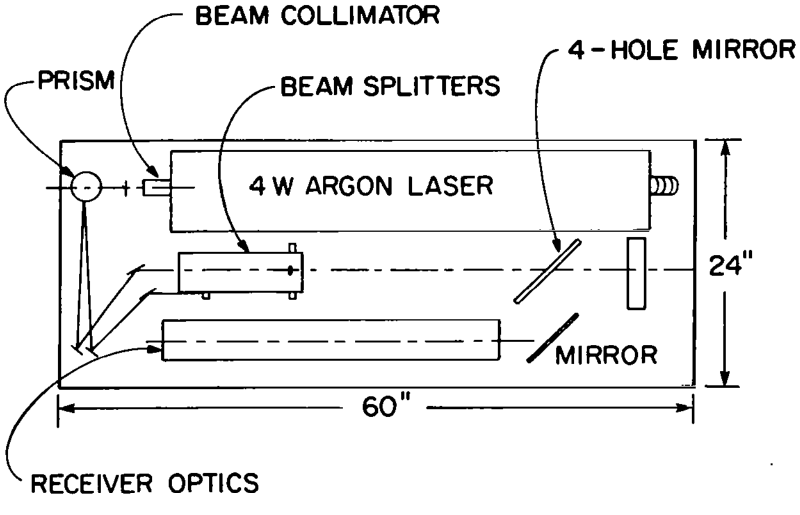
THE ALLOWED UNCERTAINTY OF $\sigma_<$ IS

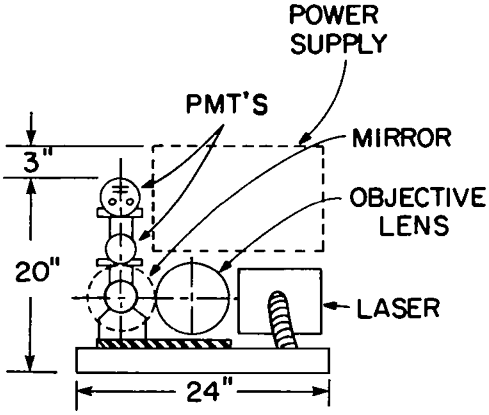
$6.44 \times 10^{-6}$ RAD. OR 1.3 SECONDS

# LDV LASER/OPTICS CONFIGURATION

The only optical access to the NTF test section is through ports in the side walls. There are no optical ports in the plenum vessel wall, so installation of any velocimeter system would have to be in the plenum chamber. Any optical package installed in the plenum chamber must have the proper enclosure to protect it from the high pressures and cryogenic temperatures. A schematic diagram of a LDV system configuration and the minimum internal dimensions for the protective enclosure are shown below. Installation of this configuration and its enclosure would be very difficult.

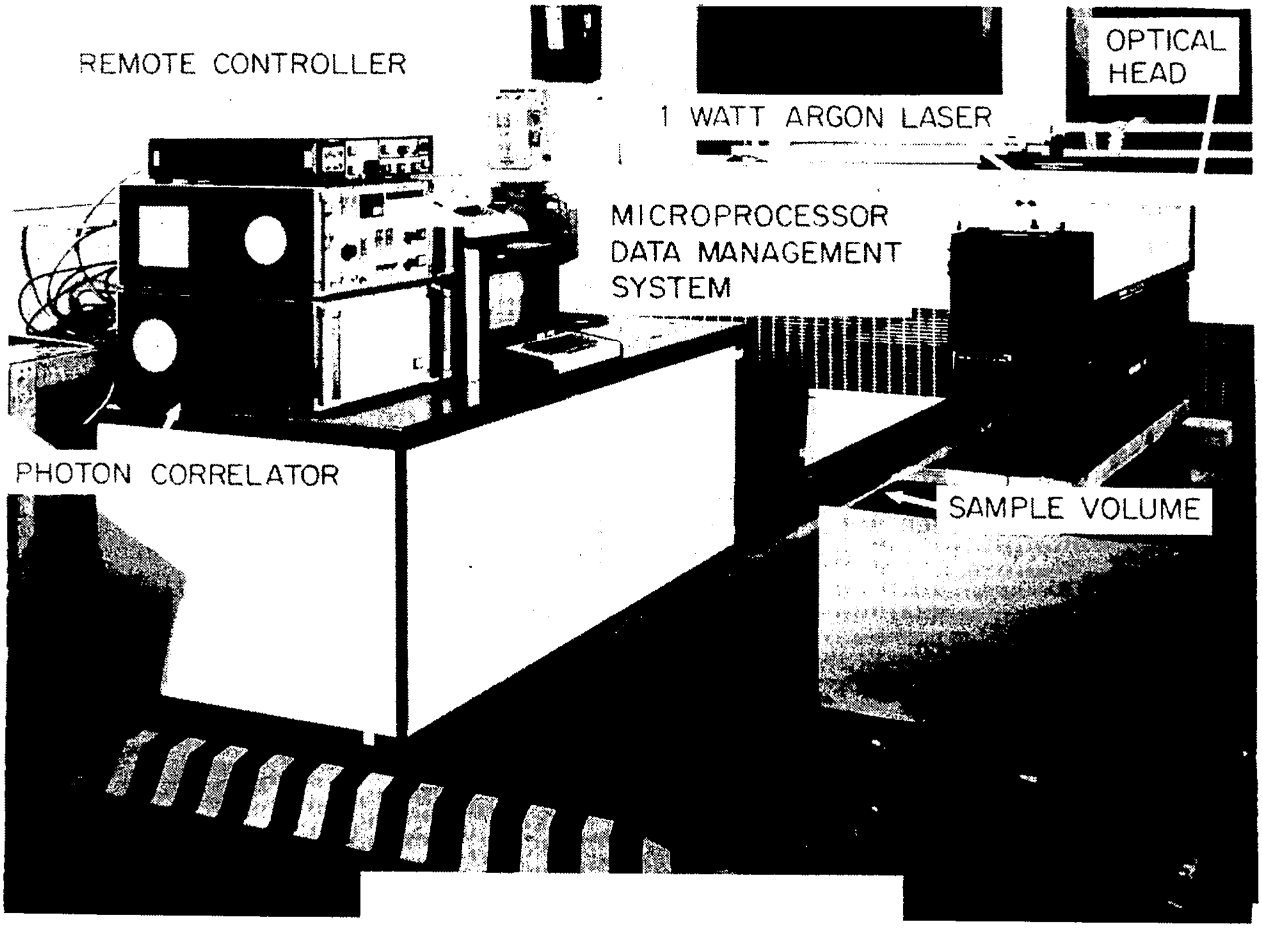
Consideration of equipment and installation cost plus the inability to ensure that once a system has been aligned to the required precision at ambient conditions that this alignment would hold at the high pressures and cryogenic temperatures it was decided to consider another approach. This approach was the laser transit anemometer.





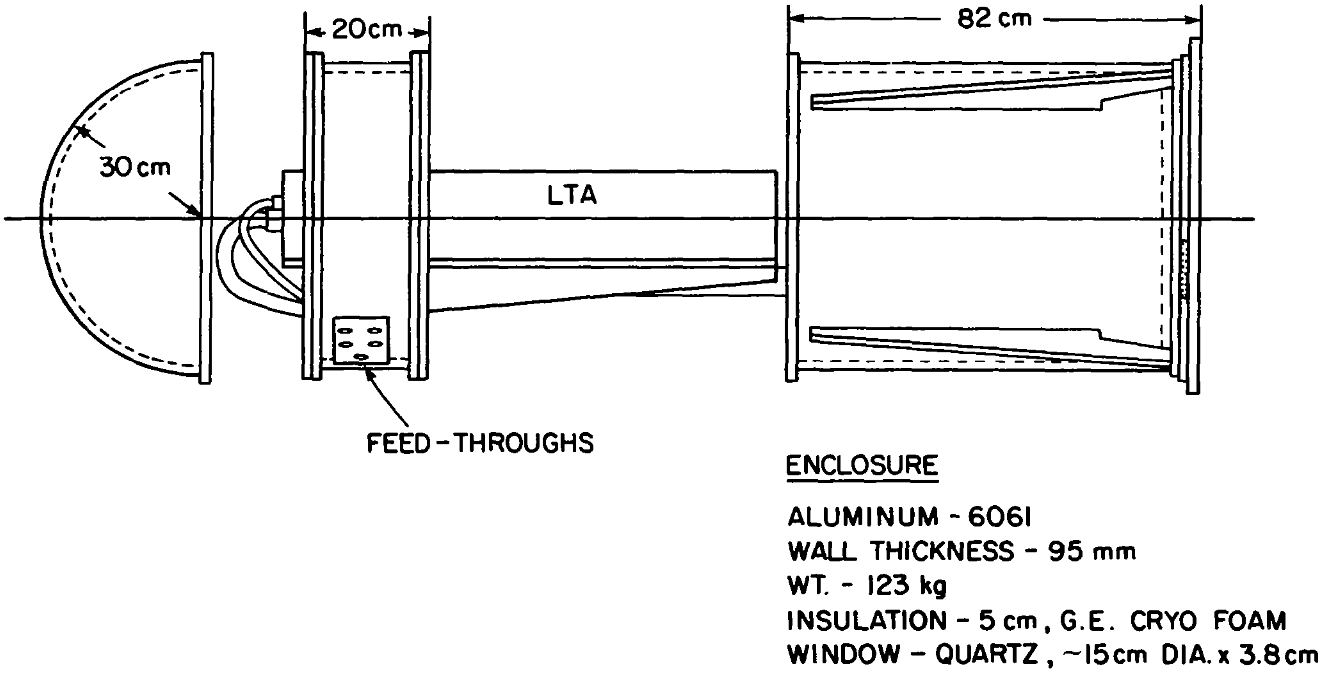
## LASER TRANSIT ANEMOMETER

Langley's laser transit anemometer system (LTA) is a Spectron Development Laboratories, Inc., model 104 which is equipped with a one-watt cw argon-ion laser and a 100mm diameter objective lens. An attribute of this system that the fringe velocimeter does not have is its compact laser/optics package.



## LTA ENCLOSURE

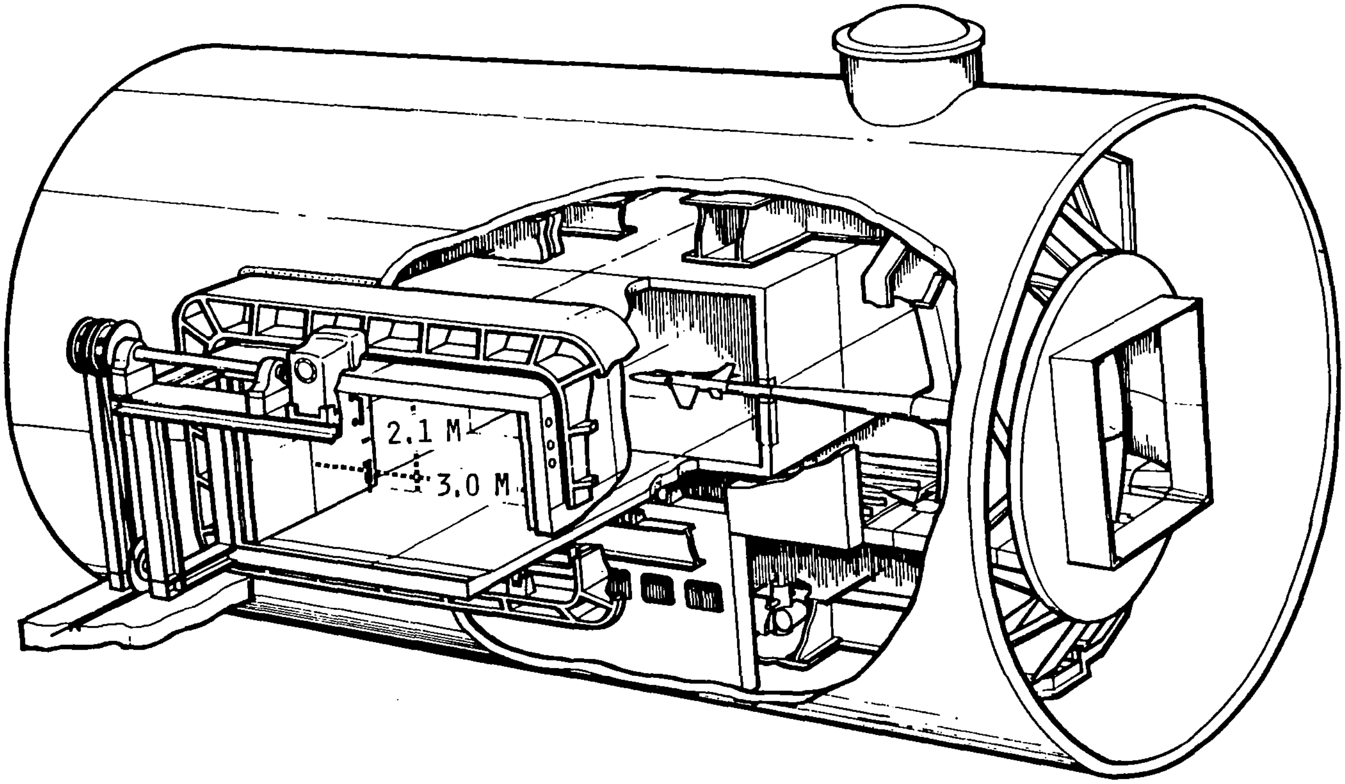
Because of the limited optical access and the necessity to achieve the minimum optical path length, consideration was given to mounting the LTA laser/optics package on the tunnel test section wall. This creates an operational problem. The side walls of the test section retract into the floor area of the plenum vessel to allow access to the test section. Any device mounted to either side wall must not obstruct side wall operations, i.e., must clear structures about the wall or be easily removed. To provide sufficient clearance the LTA laser/optics package enclosure was designed so that it can be easily disassembled.



# MODEL ACCESS SYSTEM

An additional operational problem exists. To achieve access to the test section for disassembling of the LTA enclosure, a tunnel warm-up period of five hours is required. Operationally, to reduce this excessive warm-up time the use of portable enclosures is planned which can be installed through the plenum side wall into the test section permitting access to the test models. With this procedure, tunnel warm-up and subsequent cool-down periods are reduced to half-hour periods. These enclosures also require clear access and side walls must be free for retraction.

The preceding operational problems have not been resolved at this time. An additional installation problem is the provision of water for laser thermal control. It is a paradox, i.e., with the enormous amount of cooling gas present, that efforts must be made to maintain ambient conditions for the optics and at the same time provide cooling water for the laser. Obviously, it is highly desirable to decouple the laser from the optics package and transmit the laser radiation to the optics by some means such as fiber optics. This problem is being pursued.



## CONCLUDING COMMENTS

At the present time, the ability to achieve flow field angularity measurements with an absolute 0.01 degree accuracy appears, at best, very difficult. But, because of the unique installation and operation requirements presented by the NTF an entry with a laser velocimeter is necessary to obtain the experience to achieve optimum performance capability. Also, because the present existing velocimeter systems are capable of obtaining state-of-the-art velocity measurements it appears to be appropriate to recommend the installation of a system in NTF. This initial entry should be accomplished at a minimum cost. Based on the preceeding considerations it was decided to recommend the use of an existing "two-spot" system for the initial tests. The LTA "two-spot" system has a compact laser/optics package which should keep the initial installation cost to a minimum plus the system is capable of comparable performance with a larger LDV "fringe" system. If it is decided a "fringe" system would be more appropriate at a later time, the experienced gained with the "two-spot" and related performance data should be applicable or can be related with a minimum of effort.

THE RESULTS OF THIS STUDY, 0.3 M TCT LDV AND LTA TESTS AND OTHER EFFORTS HAVE NOT REVEALED ANY FUNDAMENTAL PROBLEMS THAT WOULD SUGGEST THAT LASER VELOCIMETRY IS NOT A VIABLE DIAGNOSTIC TECHNIQUE FOR NTF. HOWEVER, THERE ARE A NUMBER OF ENGINEERING PROBLEMS THAT NEED TO BE SOLVED, E.G.,:

1) AN INSTALLATION SCHEME THAT IS COMPATIBLE WITH THE PLANNED TUNNEL OPERATION PROCEDURES

2) MEANS TO SIMPLIFY THE INSTALLATION, FOR EXAMPLE, RELOCATION OF THE LASER OUTSIDE OF THE TUNNEL AND REMOTE FROM THE OPTICS PACKAGE (FIBER OPTICS?)

3) AN EFFICIENT SEEDING TECHNIQUE AND RELATED SYSTEM SO THAT POINT MEASUREMENT TIME IS ON THE ORDER OF A SECOND

4) DEVELOP HARDWARE AND TECHNIQUES TO ACHIEVE THE 0.01 DEGREE ACCURACY GOAL

# SYMBOLS

$f$ - frequency, Hertz

$u$ - reference direction

$v$ - reference direction, normal to $u$

$V$ - velocity magnitude, meters per second

$\alpha$ - angle between velocity component $V_1$ and reference direction $u$, radians

$\beta$ - angle between velocity component $V_2$ and reference direction $u$, radians

$\gamma$ - flow field angularity with respect to reference direction $u$, radians

$\Delta$ - finite difference

$\phi$ - angle between velocity components $V_1$ and $V_2$, radians

$\theta$ - laser cross beam angle, radians

$\lambda$ - laser radiation wavelength, meters

$\sigma$ - standard deviation

$\sigma^2$ - variance

<u>Subscripts</u>

D - Doppler

1, 2 - velocity components

$\sphericalangle$ - angle

# REFERENCES

1. McKenney, L. W.; and Baals, D. D., eds.: Proceedings of the Workshop on High Reynolds Number Research. NASA 2183, 1981.

2. Thompson, H. D.; and Stevenson, W. H., eds.: Laser Velocimetry and Particle Sizing. Hemisphere Publishing Corp., C. 1979.

3. Eckert, E. R. G.; ed.: Proceedings of the Minnesota Symposium on Laser Anemometry. Continuing Education and Extension, University of Minnesota, Jan. 1976.

4. Mayo, W. T., Jr.; and Smart, A. E.; eds.: Proceedings from the 4th International Conference on Photon Correlation Techniques in Fluid Mechanics. Stanford, University, Aug. 1980.

5. Ross, M. M.: Transit Laser Anemometry Data Reduction for Flow In Industrial Turbo Machinery. Optica Acta, Vol. 27, No. 4, pp. 511-528 (1980).

6. Pugh, Emerson M.; and Winslow, George H.: The Analysis of Physical Measurements. Addison-Wesley, 1966.