ORAN W. NICKS LOW SPEED WIND TUNNEL

FACILITY HANDBOOK

AEROSPACE ENGINEERING DIVISION

TEXAS A&M UNIVERSITY

COLLEGE STATION, TEXAS

SEPTEMBER 2000

TEXAS ENGINEERING
EXPERIMENT STATION

Oran Wesley Nicks

Oran W. Nicks came to Texas A&M University in 1980. He served as the Director of the Low Speed Wind Tunnel and a TEES Research Engineer until 1996, when he retired to start a new personal project. Building his own glider. Mr. Nicks also organized and directed the Space Research Center and was the first chair of the Texas Space Grant Consortium, serving from 1989 to 1993.

Mr. Nicks was the author of two books, "This Island Earth" and "Far Travelers – The Exploring Machines", as well as 75 technical papers and special publications. He was a three-time recipient of NASA's Exceptional Service Medal, and was also awarded the Distinguished Service Medal and Outstanding Leadership Medal. Mr. Nicks held five patents and was a commercial pilot with instrument and glider ratings, as well as a certified instructor. Mr. Nicks passed away in 1998.

INTRODUCTION

This handbook was prepared to acquaint potential users with the capabilities of Oran W. Nicks Low Speed Wind Tunnel at Texas A&M University. The facility is available to all industry, governmental agencies, educational institutions and private individuals. Two methods of providing wind tunnel services are in general use. Most common is a fixed priced rental rate per occupancy hour based on single shift operation and normally handled by purchase order. The rental rate includes facility use, supervisory and operating crew, and the use of standard and auxiliary equipment. An occupancy hour is defined as one during which the facility is completely dedicated to a customer. There is no charge for time lost due to malfunctioning of tunnel equipment. The second method is that in which wind tunnel testing is included as a portion of an overall study or research project where tunnel charges are estimated and negotiated for funding under a research contract or grant through the Texas Engineering Experiment Station or other University system part.

The tunnel is used for both basic and applied air flow research and development, and also provides laboratory instructional aid for students of various departments of the University. A wide variety of aerodynamic tests have been performed at the facility on aircraft and aircraft components, helicopters, space vehicles, ground vehicles, bicycles, offshore platforms, buildings and structures. During these tests, a variety of information has been obtained, including static and dynamic force and moment measurements, dynamic measurements, flow field studies with multi-hole probes or hotwires, surface pressure measurements, and flow visualization using smoke or surface treatments. The facility also has available a high pressure air system to provide auxiliary air for jet simulation or powered model testing, and a motor generator variable frequency electric drive system for rotor and propeller testing.

The results from the tests are used in a multitude of projects including; determination of stability and control characteristics for aerodynamic vehicles, fuel economy of ground vehicles, drag and overturning moments of offshore structures; wind engineering studies on buildings and offshore structures, helicopter rotor dynamics, wind-powered energy generation; environmental tests.

The wind tunnel is operated by the Aerospace Engineering Division of the Texas Engineering Experiment Station, the research arm of the Texas A&M University College of Engineering. The facility staff consists of seven (7) full-time personnel, several co-op student workers and part-time student workers.

Included in this handbook are detailed descriptions of the facility, its performance and operational characteristics. Also described are available instrumentation, data recording equipment, methods of data management and presentation, and information on available support equipment and services.

Admission to the Texas A&M University System and any of its sponsored programs is open to qualified individuals regardless of race, color, religion, sex, national origin or educationally unrelated handicaps. An open invitation is extended for all interested persons to visit the wind tunnel facility and/or to confer with operating personnel. For further information relating to visits, test scheduling and rental rates, please contact:

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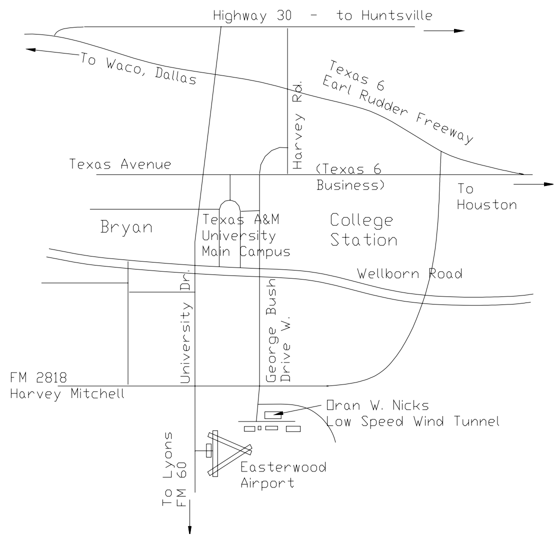
DESCRIPTION OF FACILITY

Location

The Oran W. Nicks Low Speed Wind Tunnel at Texas A&M University is a self-contained facility located two miles west of the University main campus at College Station, Texas. It is adjacent to the University-owned and operated Easterwood Airport, served by regional airlines with convenient flight connections to most major air carriers at Dallas and Houston. The area is served by rail, air and motor freight. *Figure 1* is an area map showing the location; *Figure 2* is an aerial photograph of the facility.



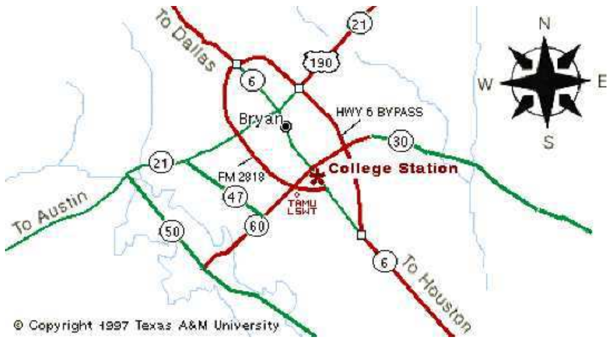


Figure 1. Location of the Oran W. Nicks Low Speed Wind Tunnel Facility.

Figure 2. Aerial photograph of the Oran W. Nicks Low Speed Wind Tunnel Facility.

General

The wind tunnel is the closed circuit, single return type having a rectangular test section ten feet wide and seven feet high. The test section portion of the tunnel is housed in a two-story building. Building, tunnel, external balance, and drive motor all have independent foundations to reduce the transmission of vibrations among them. The external balance room, storage space, conference room, office space, an electronics/instrumentation lab, and the model transfer area make up the lower floor of the building. An eight-foot by twelve-foot door provides access to the transfer area and a one ton monorail hoist facilitates the transport of large models from transfer area to the test set-up area.

Space is provided on the second floor for an administrative reception area, engineering offices for wind tunnel staff and customer engineers and representatives, the tunnel control room, model and test set-up area and the tunnel test section. A one ton monorail hoist permits ready transport of models between set-up room and test section. The test area is serviced by 120 and 240 volt 60 Hz. AC. power, 220 volt, 60 Hz., 3 phase AC. power, 28 volt DC. power, water and compressed air. An adjacent building in the northwest, houses a small machine shop. The shop has a 12 foot by 10 foot door access to the pathway, to a 30 ft by 40 ft building used for shipping, receiving and storage of models and hardware. A forklift is used to load and unload of shipments and transfer to and from buildings including the ready room area. Southeast of the tunnel is the compressor building which houses two 150 HP, 3500 PSI compressors, a high pressure storage tank and a motor generator electric drive system for tests involving powered models.

Tunnel Circuit

Figure 3 presents a line drawing of the second floor of the building and a plan view of the wind tunnel circuit. Total circuit length at the centerline is 396 feet. From the power section at the exit of the diffuser around to the entrance of the contraction section, the tunnel cross section is circular and of steel plate construction. The maximum diameter of 30 feet occurs in the settling chamber. Turning vanes are installed at each corner of the circuit. A single screen is located at the settling chamber entrance and a double screen just upstream of the contraction section to improve dynamic pressure uniformity and to reduce flow turbulence level.

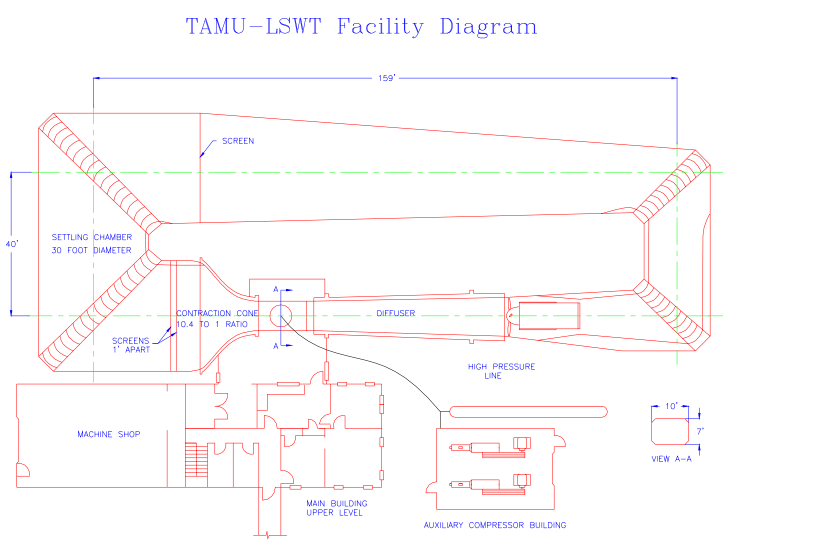


Figure 3. Low Speed Wind Tunnel Circuit.

The contraction section which acts as a transition piece from circular to rectangular cross section is of reinforced concrete construction. Contraction ratio is 10.4 to 1 in a length of 30 feet. Diffusion takes place immediately downstream of the test section in a concrete diffuser which also returns the flow to a circular section. The horizontal expansion angle is 1.43 degrees and the vertical 3.38 degrees in an overall length of 46.5 feet.

Power Section

The 12-1/2 foot diameter, four-blade Curtiss Electric propeller driven at a constant 900 RPM by a 1250 kVA synchronous electric motor provides the air flow in the wind tunnel. The propeller blades are from a standard B-29 airplane made of solid aluminum with the tips cut off about 1.5 feet. Blade tips are inset into the tunnel wall to minimize tip interference effects *(Figure 4)*. Any desired test section dynamic pressure between zero and 100 pounds per square foot can be obtained by proper propeller blade pitch angle positioning. The propeller pitch angle is change using a 28 Volt DC electric drive. Motor starting is accomplished by an automatic motor control unit which allows synchronous speed to be achieved in about 10 seconds. Propeller pitch actuation and tunnel response are sufficiently rapid to allow setting of test section dynamic pressure within one minute.

Figure 4. Oran W. Nicks Low Speed Wind Tunnel Propeller

Test Section

The rectangular test section is 7 feet high, 10 feet wide and 16 feet long, fabricated of structural steel lined with marine plywood *(Figure 5)*. The corners have 12 inch fillets which house fluorescent lamps to provide sufficient light to work and for photographic purposes. Cross sectional area of the test section is 68 square feet. Three inch wide vertical venting slots in the sidewalls at the test section exit maintain near atmospheric static pressure and the sidewalls diverging about 1-inch in 12-feet to account for boundary layer growth. A top door 8 feet wide by 10 feet long provides easy installation of assembled models while a 34 inch wide by 80 inch high side door aft of the test section allows access for personnel and smaller pieces of equipment. Sixty-five square feet of plated glass windows assure adequate visual access to a model undergoing testing and provide opportunity for model photography from many angles. A turntable seven feet in diameter built into the test section floor rotates with the external balance but is isolated from the balance and has a separate, but synchronous drive system.

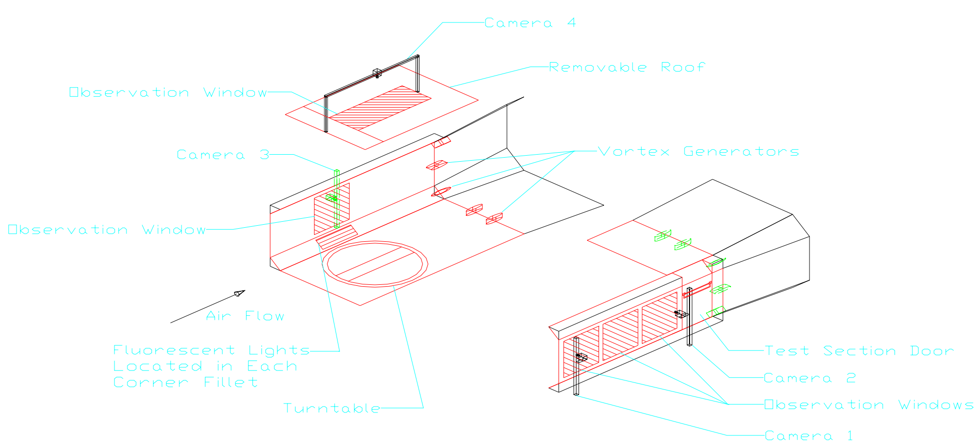


Figure 5. Test Section Layout.

Control Room

Figure 6. Control Room.

The wind tunnel control room (*Figure 6*), houses the operator's control console, auxiliary systems control console, video recording equipment, online display terminal and run sequence display. The wind tunnel operators' control console is located adjacent to the test section and is placed so that the operator has a full view of the model during testing. All switches, controls and instruments required for motor starting, setting the test section velocity, positioning the model attitude and regulating the high pressure air system or the motor generator set are on the console within easy reach. Video monitors provide close-up views of the test section and model. Immediately to the right of the operator is the data acquisition position. To the left of the operator, the high pressure air system and the motor generator set can be controlled and monitored during operation. The graphical online data display is located next to the auxiliary control console, also in the same section, a printer for data outputs and recording equipment for the camera system are located. The camera system and recording equipment can be used for extended recording of the test operation or for flow visualization. The screen in the wall is used to display the run sequence in order to have a single point of reference for test engineers, model technicians and wind tunnel operator and personnel. *Figures 7-10* are photographs of the control area sections. The low noise level and ample floor space in the control room provide a comfortable working area for the test crew.

Figure 7. Control Console.

Figure 8. Auxiliary Systems Controls.

Figure 9. On-line Data Display.

Figure 10. Run Schedule Display.

Customer Engineering and Work Space

The customer engineering area, is adjacent to the control room, if has approximately 200 ft^2 of space and includes the computer for the run sequence display and a computer with access to the test data files. Table and desk space for customer computers and data analysis is ample and the room can accommodate 4 people comfortably. A conference room is available in the ground floor of the building for conference calls with the company management or other engineers during the test period. The conference room is isolated from the main traffic areas and provides a low noise level and a speaker phone. The room is also equipped with a video player and television that can be used to review test information.

Machine Shop Support

The wind tunnel has a 1200 square foot machine shop with the basic equipment to support the tests and its operations. The shop is attached to the north side of the main building and provides work tables for model assembly and/or work *(Figure 11*). The shop equipment includes; two mills, a lathe, band saw, Mig and Tig welders, 2X3 granite surface tables, disk sander, grinder and wood working equipment. The tunnel can also have extra machine shop support by the TEES machine shop located less than 10 minutes away. Most model changes and/or modifications can be accomplished in house, by either the wind tunnel staff or customer model support personnel. A 10 ft X 12 ft door provides access to the shop and it also serves as the model access to the wind tunnel building.

Figure 11. Machine shop.

Model Shipping and Receiving

A 1200 square foot building north of the machine shop and attached with a concrete walkway serves as the model shipping, receiving and storage for the wind tunnel. The building has two 10 ft X 10 ft doors in opposite ends of the building to allow for shipping and receiving and for access to the main tunnel building. Shipments can be sent or received by any size truck and can be unloaded with the forklift from the loading dock. Shipping boxes can be moved to and from the main building with either a forklift or pallet cart. The fork lift can move the model boxes from the storage building up to the ready room, or hoists in both the ready room and model transfer area in the main building can move equipment if the forklift is not practical.

Tunnel Cooling

When required by weather conditions, cooling water is sprayed over the entire top surface of the steel portions of the wind tunnel to provide evaporative cooling. Water not evaporated runs down the sides to a catch basin and pumped for re-circulation. This system can maintain the test section air temperature at not more than ten degrees above outside temperature. Testing through the hot summer months has never been interrupted because of cooling requirements.

External Balance Model Support Systems

Model support or mounting systems vary widely depending upon the objectives of a given test program. For tests requiring the acquisition of force and moment data, a balance system will be required and the model must be mounted in a manner to transmit all aerodynamic loads to the balance. The majority of testing at the Texas A&M tunnel involves models mounted on the external balance located immediately below the test section.

There are three main methods of supporting aerodynamic models on the external balance: three strut, two strut and single strut supports:

The three strut system is comprised of two main struts which may be spaced laterally from 9 to 66 inches apart plus a pitch strut with a variable location between 18 and 42 inches aft (or forward) of the main struts *(Figure 12)*. The purpose of the pitch strut is to rotate the model about the trunnion of the main struts. The trunnion point is normally set at 42" above the test section floor and corresponds to the moment resolving center of the external balance. The pitch strut can be used as a tail strut or a nose strut *(Figure 13*). Fairings and dummy struts are available to allow tare and interference measurements *(Figure 14)*. The image system simplifies assessment of mounting system effects so that they can be subtracted from the test data. The image system for the three strut mounting system does not allow for beta changes. This is due to a lack of a turntable in the roof.

Figure 12. Three strut mount.

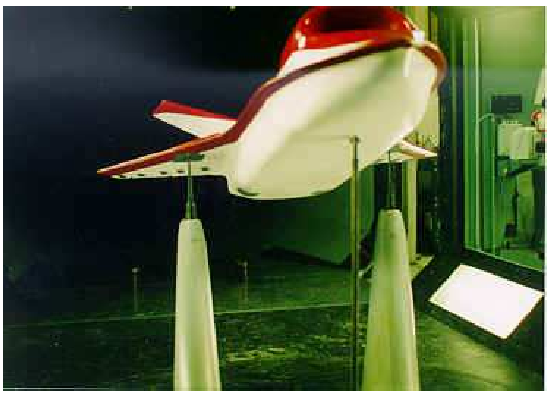


Figure 13. Three strut mount with nose strut.

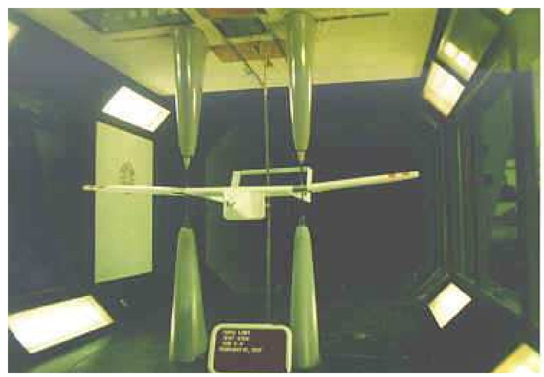


Figure 14. Image system for three strut mount.

The two-strut system uses a single main strut in conjunction with the pitch strut. *Figure 15* shows an example of the two-strut system. It should be noted that for this type of support system, the main strut must take all lateral and rolling loads as the pitch strut has little lateral stiffness. Tare and interference effects can also be determined with this setup using an image system *(Figure 16).*

Figure 15. Two strut mount.

Figure 16. Two strut mount with image system.

Yaw angles changes with the image system are possible by cutting the dummy strut ½ in short of the roof, to allow the movement side to side. The main strut is always placed in the center of the turntable, therefore, rotation does not produce and lateral movement.

The single strut support system makes use of one main strut in the testing of models with internal pitch mechanisms, or for models which do not require pitch changes. Figures 17 show a model mounted on a single strut with an internal pitch mechanism, Figure 18 shows the same configuration with the addition of the image system.

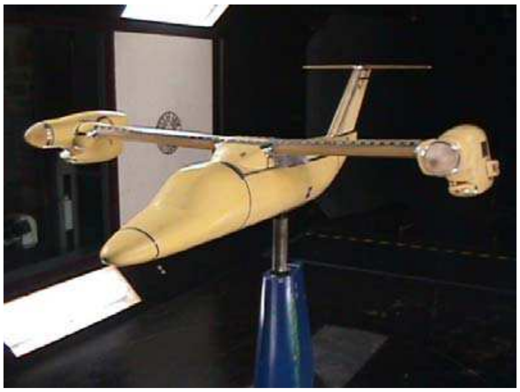


Figure 17. Single strut with internal pitch mechanism.

Figure 18. Image system with a single strut

An internal pitching mechanism is available for use by customers who wish to use a single strut support system and are able to design their model to fit around the mechanism box. Design loads for this device are:

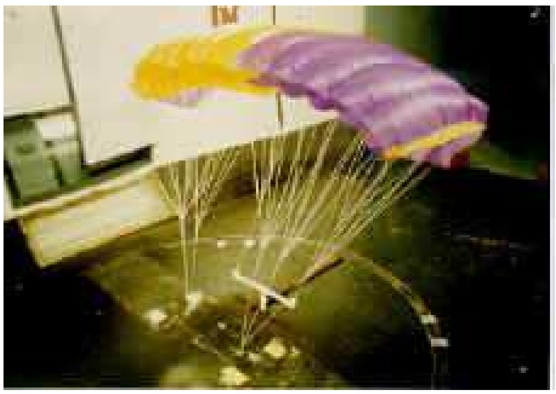
Lift, side, drag force	± 500 lbs.
Pitching moment	± 50 lb. ft.
Rolling & yawing moment	± 100 lb. ft.
Pitching range	± 40º
Pitching speed	1.5º/Sec.

Complements of windshield fairings are available for the various strut mounting systems. A variety of struts are also available or they can be manufactures for the specific need. The balance clamping system and main struts are flexible in order to allow for most requirements.

The above mounts are designed and used primarily by aircraft testing, the use of low speed wind tunnels has increased for a wide variety for tests outside of the aircraft industry. The wind velocity regime and test section size, make it possible to perform tests on most objects exposed to wind, either in full scale or models of different scales. The ability to control and sustain a certain condition, allows test for wind engineering on buildings, offshore structures and housing materials. Automotive industry has also learned to use the wind tunnels to reduce aerodynamic resistance in their designs and therefore increase the fuel economy.

Mounting configurations for these tests vary as much as the objects being tested. Most of this models/objects are attached to the external balance with the purpose of measuring the forces and moments due to wind. Special mounting systems have been developed for specific customers. The semisubmersible oil rigs are attached to the balance with a single strut below the floor that can be rotated independently from the balance turntable. The model mounting system also allows the heel angle to be changed manually therefore allowing testing of the models at any attitude. The truck models are tested using a beam mounted to the external balance using both of the clamps. The beam allows for a variety of mounting interface systems, including through the wheel systems.

The following group of pictures illustrate a sample of some of the variety of test that have been performed at the facility.

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Internal Balance Model Support Systems

Three sting mounting systems are currently available for testing models using internal strain gage balances mounted on a single axial support. A large sting mount which adapts to an adjustable knuckle *(Figure 19)*. This can be used with a sting sized for a 2 inch balance, or a 1.25 inch balance can be used with the small sting and a sting extension to adapt to the knuckle (*Figure 20*). The models can be oriented with either wings horizontal or wings vertical. Most airplane models are mounted with wings vertical in order to change the pitch angle using the test section turntable, and yaw can be combined with pitch by adjusting the knuckle. This system can also be used for missile testing for which the roll angle is changed manually by rotating the sting about the knuckle attachment point. There are two knuckles available. The angle range for the knuckles is -5º to +25º increments of 5º or -10º to +30º with increments of 1º.

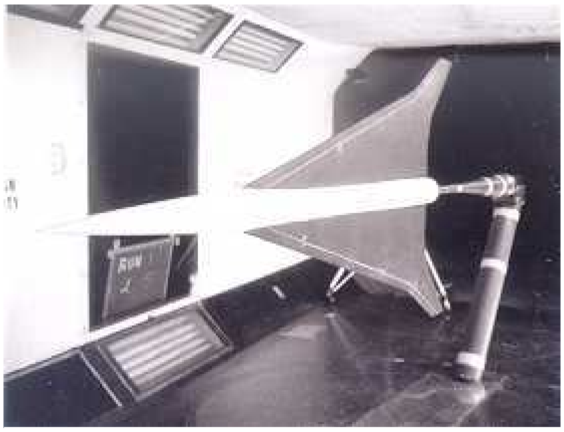


Figure 19. Large sting mount with the 2" sting.

Figure 20. Large sting mount with 1.5" sting.

Figure 21 shows the small sting mounting system for the 1.25 inch balance. Offset angles for this knuckle can be set from –1º to +30º, the angle setting is infinite due to the screw type adjustment. This system as the large sting mount system uses the external balance turntable to change one of the attitude angles and the knuckle to change the other. One advantage of this system is that the model position shift due to the changes of attitude is not as large as it is with the large sting mount system since the pivot arm is not as large. The one disadvantage is that it can only be used with small models and loads.

Figure 21. Small sting mount system.

Figure 22 shows the small sting mount being used for a missile test. The single strut mount was selected for this test to incorporate the internal balance load measurements and the high pressure air supply in the model. The air supply was used to simulate thrusters in the nose of the model.

Figure 22. Missile with the small sting mount.

The third system is a computer control pitch mechanism called the High Attitude Robotic Sting (HARS) mounted to the external balance turntable to obtain yaw angle changes, thus allowing the attitude of the model to be changed remotely *(Figures 23&24)* for both pitch and yaw conditions.

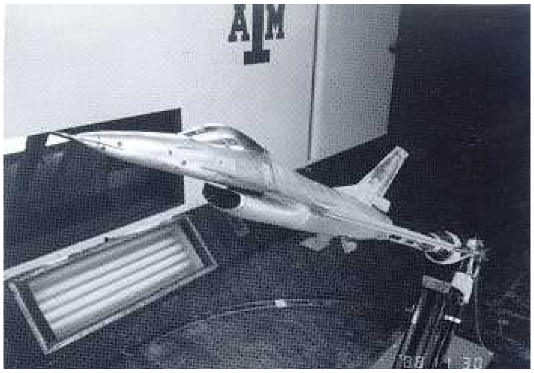


Figure 23. HARS at normal angle of attack.

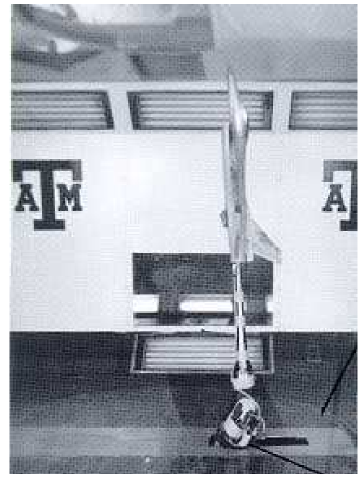


Figure 24. HARS at high angle of attack.

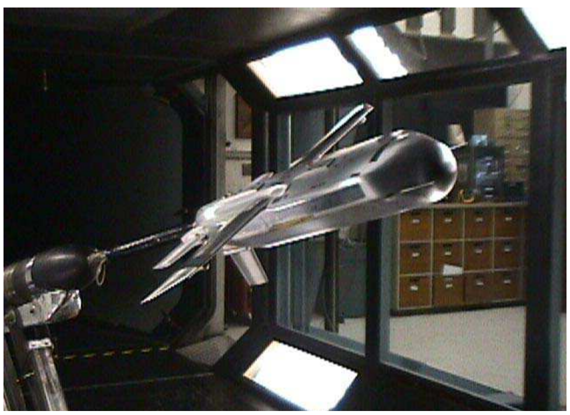


Figure 25. HARS with pitch, yaw and roll control.

The angle of attack range with this system is -10º to 88º and the yaw range is -30º to 45º. The system also can be used with a roll motor, allowing the changes of any of the three attitude angles to be changed remotely. The roll angle changes are only limited by the wiring, but normally can be changed 0º to 180º with no problem (*Figure 25*). The roll motor is especially useful during testing of missiles where the variable angle is normally the roll.

Ground Effects Support Systems

For studies requiring ground effects and the use of the external balance, with a model using a three strut mount system, the variable height struts can be used (*Figure 26*). The struts are adjustable from 32" above the ground down to the allowable model design minimum height. For customers requiring a ground plane, it can be used with a single strut set-up *(Figure 27)*. Modification of the ground board may be performed for other set-ups if necessary and possible. A disadvantage of the ground plane is the time

Figure 26. Variable height three strut mount.

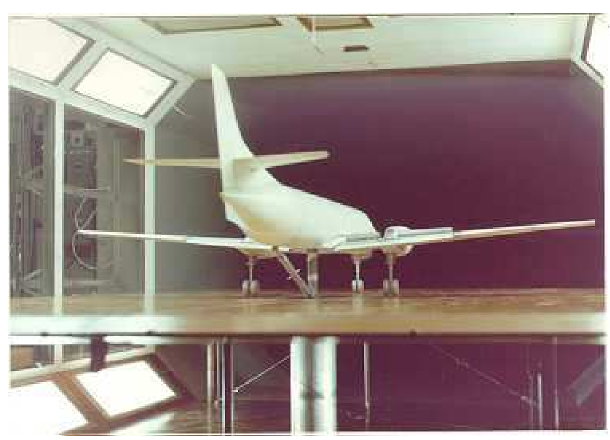


Figure 27. Ground plane with single strut mount.

required for set-up, adjustment and test section re-calibrations before testing can begin.. The ground plane adjustable set-up can obtain a range of 12" to 28" from the floor. The facility has performed comparison tests of the boundary layer comparison with a ground plane and the test section floor. The results showed little or no change in the boundary layer thickness using the ground plane. A simple explanation is that the boundary layer growth in both the test section floor and the ground plane start at the same point and the they have the same distance to develop. The design of the TAMU wind tunnel has the contraction cone ending at the start of the test section, which is also the point where the leading edge of the ground plane begins. Because of these results, the TAMU LSWT encourages to use the use the test section floor instead of the ground plane.

Vehicle testing is done in ground effects. Truck testing is routinely performed at the facility using the test section floor and turntable to provide average drag coefficient data as required by the SAE procedures. The flexibility of the balance attachment system, makes it possible to have a variety of mounting system for the trucks including wheel mounting. With the typical scale used for truck testing (1/8), the suggested model position in the test section to reduce pressure differential effects is accomplished both in front of the model and behind the model. The balance size does not limit the Reynolds number and therefore a typical test Reynolds number for trucks is 1.77 million per foot. *Figure 28* shows a typical truck model in the test section.

Figure 28. Typical truck model configuration.

The HARS sting system can also be used for ground effects. *Figure 29* shows the HARS in a ground effect configuration with a bent sting. The bent sting was used to obtain the required angle of attack and height to span ratio. The geometry of the straight sting and the HARS movement have a small sets of condition that can be achieved during ground effect testing. The bent sting increases the possible combination of angles and heights for the test. The ground clearance is dependent on the sting, angle of attack and model configuration.

For test programs not requiring the acquisition of balance data, models may be mounted directly to the walls or floor of the test section, to the turntable, to the balance struts with the balance locked, or to a ground plane.

Figure 29. HARS used for ground effects testing.

Wind Gradient Tailoring

For wind engineering tests, the test section wind gradient can be tailored to produce velocity and turbulence profiles approximating the geostrophic wind required for the specific test. *Figure 30* shows one of the profile generators. The profile is changed by moving the rods to increase or decrease blockage and therefore producing a change in the flow energy through the fence. Screens, blocks and/or spikes are other blockage methods used to control the shape and turbulence intensity of the boundary layer profile.

Figure 30. Boundary layer fence.

For testing of offshore platforms (*Figure 31*), the profiles can be set to any specific power law requirements, but do not set any specific requirements regarding turbulence intensity. Profiles for buildings do require some correlation of turbulence intensity and therefore blocks and screens are used to increase the control of the turbulence intensity along with the mean profile shape. *Figure 32* shows a building test setup which includes rods, blocks and screens. Test data requirements for these type of tests can include force and moment data, surface pressure measurements, flow evaluation in specific or problematic areas and or flow dispersion.

Figure 31. Offshore platform set-up.

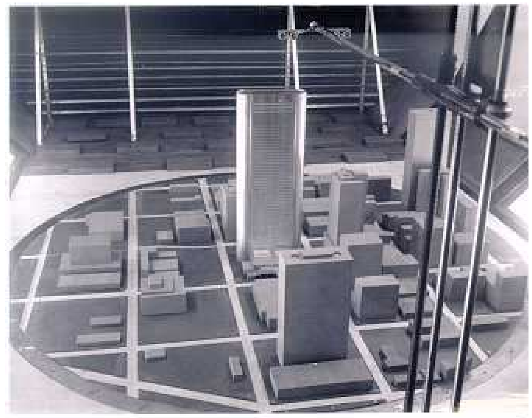
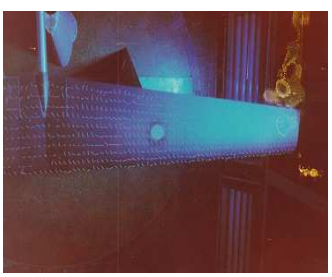


Figure 32. Building test with boundary layer profile

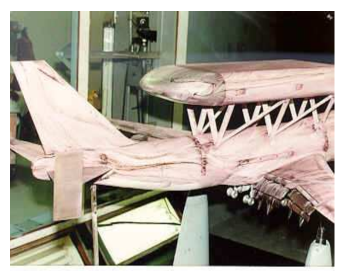
Flow Visualization

Several methods of flow visualization are available ranging from simple yarn tufts to fluorescent oil dyes (*Figure 33*). Mini tufts as small as 0.0019 inches in diameter together with an Ultraviolet strobe light are used when it is desirable that flow visualization has minimum interference with force and moment measurements. Fluorescent oils and ultraviolet lights have been used successfully for studying laminar flow transition and other surface phenomena. Sublimation techniques with tempera and kerosene allow viewing surface flow conditions for one single point. Pressure sensitive paint has also been used but it is still under development by a variety of companies. Tufts made with yard are a inexpensive but effective of flow visualization, and at low speeds, smoke wands are available for examining local flow regions.



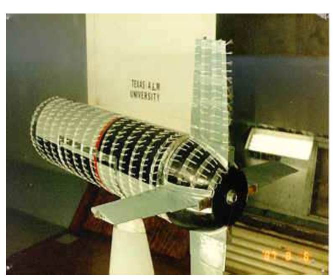
Mini tufts

Fluorescent paints and oil



Tempera and kerosene

Pressure sensitive paint



Yarn tufts

Smoke wand

Figure 33. Flow visualization techniques.

Flow Surveys

A traversing mechanism is available for flow surveys in the test section. The mechanism protrudes the ceiling at the rear of the test section (*Figure 34*). The arm has a travel distance of 36 inches in the z direction and 80 inches in the y direction. Several arm extensions and adapters are available or can be modified to meet most flow survey requirements. The mechanism is automated and can complete a grid with 500 points in one hour. Times are subject to grid size and data acquisition time requirements. Five and seven hole probes are available for flow surveys requiring all of the flow characteristics. Total pressure probes and rakes are also available for surveys requiring only total pressure measurements. One, two and three hot wire probes are also available if the flow surveys required dynamic data, along with the flow characteristics. *Figure 35* shows several samples of the traversing mechanism past uses. The first picture shows the set up for surveying the space shuttle wake during landing. The next picture shows the mechanism being used to defined the boundary layer profile formed by the boundary layer system and the last one shows the survey of the airfoil wake with a single probe to define the drag of a 2-D wing section.

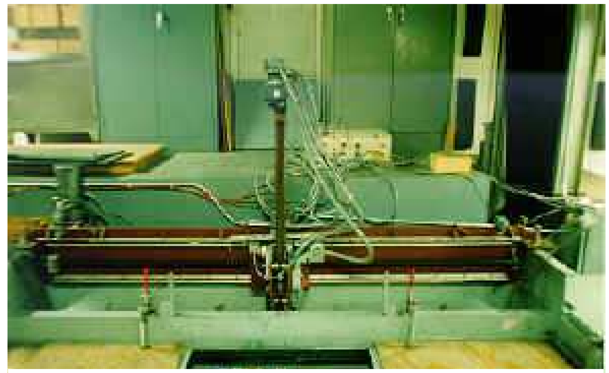


Figure 34. Traversing mechanism location.

Figure 35. Traversing mechanism uses.

High Speed Video System

A one camera high speed video system is available for use at the facility. The system a Motion Corder Analyzer SR-1000C by Kodak can record up to a speed of 1,000 frames per second and has a couple of different data formats for data storage. The amount of storage time is dependent of the recording speed, resolution and number of frames captured. The system has a maximum resolution of 512 x 480 at a speed of 250 frames per second and a minimum speed of 30 frames per second. The system minimum resolution is 128 x 34. The data is stored in memory for immediate viewing or for post processing. The camera used with the system includes a 12.5x75 zoom lens. *Figure 36* presents a set up that used the video system.

Figure 36. NASA X-38 drop model set-up.

Auxiliary Air System

An auxiliary high pressure air system provides a permanent capability for testing of turboprop or jet powered models. The system has also been use in special nozzle testing and inlet testing or for other applications requiring or using high pressure air. An example of a turboprop powered model and an inlet test with an ejector is shown in *Figure 37.*

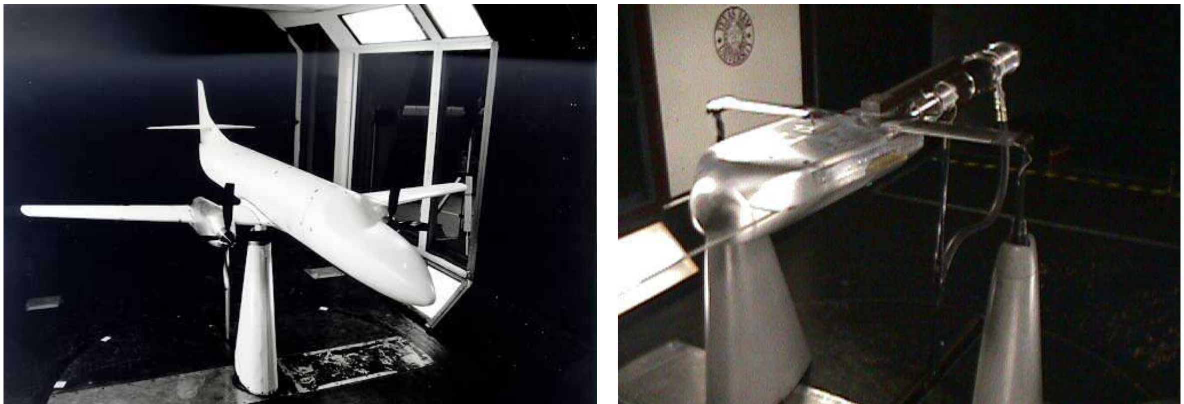


Figure 37. Turbo fan and inlet test model.

Two, four-stage Chicago Pneumatic TCB-4 compressors that were formerly installed in a NASA rocket vehicle test facility, has been located in a building adjacent to the Wind Tunnel, *Figure 38*. These units are powered by two 150 HP electric motor drives and are rated to provide 250 standard cubic ft./min. air flow at 3,500 PSI, *Figure 39*. Air is pumped through inter-coolers, filters and regulators to an A.D. Smith high pressure tank having 822 cubic ft. of storage volume, operating at pressures up to 2,300 PSI, *Figure 40* and located in the east side of the compressor building.

Figure 38. Compressor Building.

Figure 39. Chicago Pneumatic Compressors.

Figure 40. High pressure air storage tank.

Air is piped from the compressor-tank system into the wind tunnel balance room at pressures up to 750 PSIG. A Daniel Model 2271 flow computer is used to provide continuous and instantaneous solutions of the general flow equations. The system accuracy is ± 0.1% of full scale. Flow rate, totalized flow, pressures, and temperatures can be exhibited digitally with LED displays. This flow computer system, along with accurately controlled flow valves, allows the setting of model flow rates and the measurement of flow conditions.

A Chromalox 80 kW heater is used for providing proper input-output model airflow temperatures. The control unit is a solid state system that allows the selection of desired temperatures and closed loop control to ± .02%. The heater can provide temperatures up to 800º F for a mass flow rate of 2 lbs./sec.

A bridge system of opposing tanks and flexible hoses is used to bring air through the external balance into the model without drag or thrust tare effects. Final filtering of the air before the model is provided by 10 microns stainless steel filter.

Experience has shown that typical wind tunnel run schedules can be maintained at airflow rates up to 2.0 pounds per second with normal periods of pumping during model changes. Figure 38 presents a chart to approximate the running time vs. the required mass flow rate. This clean, heated air is ideally suited for driving air turbine units of turboprop models or for producing jet thrust simulations. It can also be employed in research modes for inlet design, thrust vectoring, aerodynamic camber changing, or for boundary layer control.

Schematics of the overall system and a typical mounting setup are provided in the Appendix.

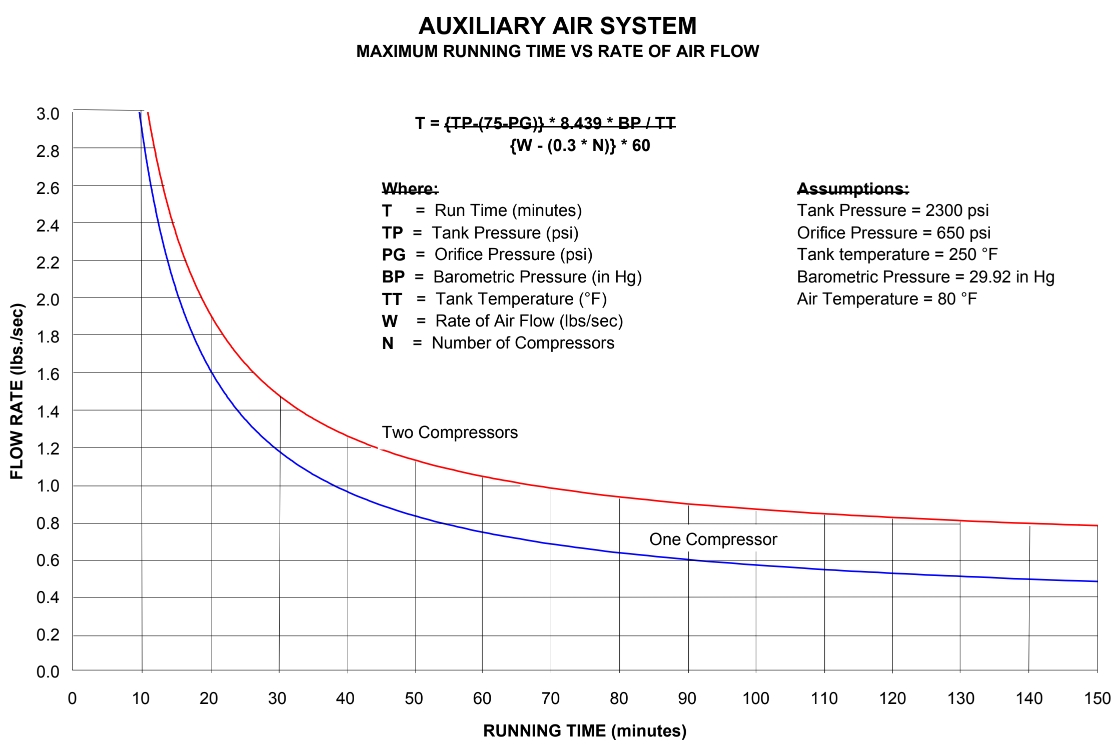


Figure 38. Compressor running time approximation chart.

Electric Drive System

The electrical drive system is especially suited to propeller or rotor research. Both sting and strut mounts may be accommodated to acquire force and moment data, along with flow surveys or other data requirements. *Figure 41* shows a counter-rotating turboprop model with an electric motor drive using a sting mount. This mount system allowed the use of an internal balance for force measurements and the external balance turntable for yaw angle changes. *Figure 42* shows a helicopter rotor using the three strut mount to allow pitch and yaw angle changes. A single strut mount with a simulated fairing is presented in *Figure 43,* the propeller in this setup can be set up in either a pusher or standard configurations.

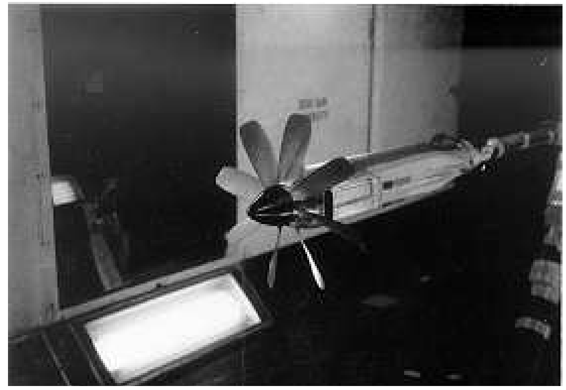


Figure 41. Counter rotating propeller.

Figure 42. Helicopter rotor w/three strut mount.

Figure 43. Propeller test with single strut mount.

Figure 44 shows the electric drive system that is capable of powering three phase AC motors as large as 75 horsepower. A motor generator (MG) set consisting of 150 horsepower DC motor and a variable frequency AC generator provide from 0 to 600 volts AC and a maximum of 180 amps AC, with a variable generator output frequency range of 0-450 Hertz. Model drive motors are available for propeller or rotor system testing.

A solid-state control system allows full range operation of the MG set from the control room, and is able to maintain a given generator output voltage/frequency ratio over the operating frequency or speed range of the generator. The voltage/frequency ratio is adjustable from 0.8 E/F to 1.2 E/F. The remote control system uses feedback to maintain speeds.

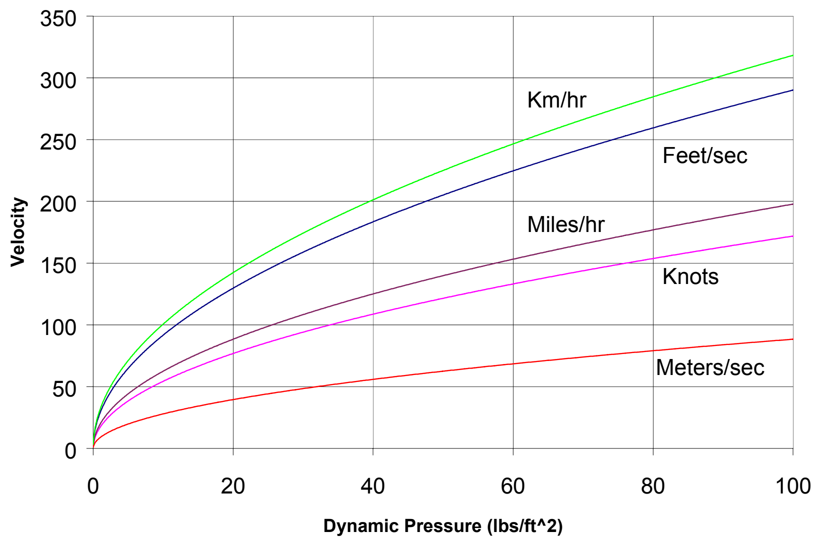
Figure 44. Electric drive system.

Testing Regime

With the test section empty, the Texas A&M Oran W. Nicks Low Speed Wind Tunnel is capable of producing wind velocities up to 300 feet per second at approximately atmospheric static pressure. This corresponds to a test dynamic pressure (q) of 100 pounds per square foot (lbs/ft^2) in accordance with the relationship:

$q = 1/2\,\rho\,V^2$ Where ρ = air density, slugs/ft^3 (standard conditions 0.0023769)

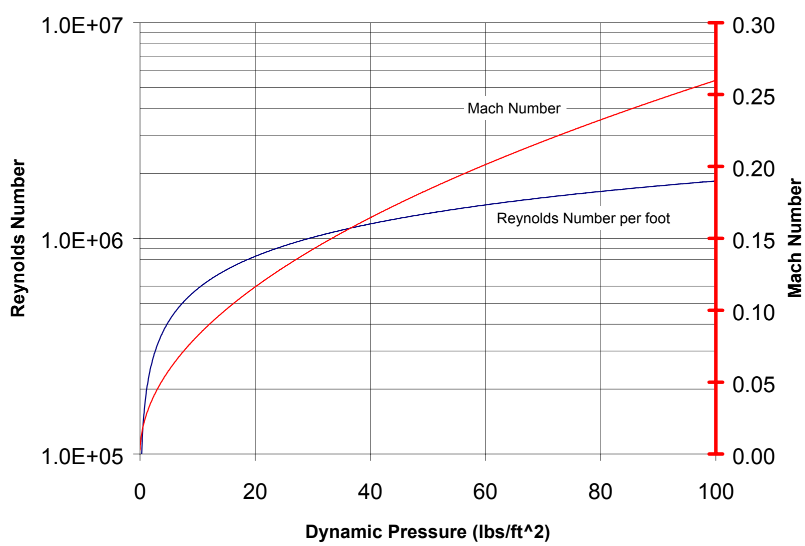
V = air velocity, ft/sec



Maximum test Reynolds number, Re, is 1.844 X 10^6 per foot at standard conditions (Temperature 59° F) where Reynolds number is defined by:

$$R_e = \frac{\rho V d}{\mu}$$

Where μ = absolute viscosity of air, lbs sec/ft^2 (std. cond. 3.7373x10^{-7})



Flow Quality

Flow quality in the test section was evaluated at dynamic pressures of 30, 50, 80 and 100 pounds per square foot. Representative results of this calibration are as follows:

Dynamic Pressure Variation			$\pm$ 0.4%
Flow Angularity			$\pm$ 0.25°
Static Pressure Gradient			0
Turbulence Factor			1.10
Turbulence Intensity			under 1%
Boundary Layer Thickness	Entry		1.5 inches
	Exit		3.5 inches

A mapping of the dynamic pressure variation is presented in *Figure 45*.

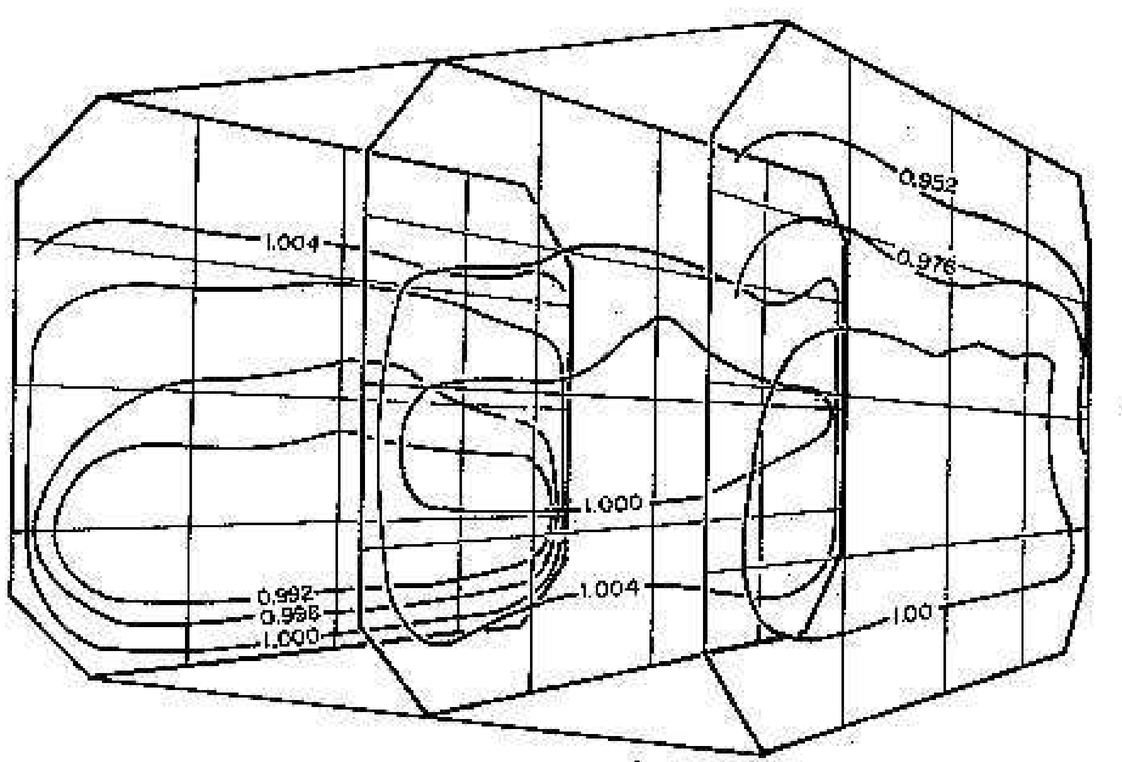


Figure 45. Variation of dynamic pressure in an empty test section.

Velocity Measurement and Control

Tunnel flow is controlled and measured in terms of dynamic pressure (q) rather than in terms of velocity. Test section dynamic pressure is determined by a Druck pressure transducer which indicates tunnel set q in pounds per square foot using static pressures sensed by piezometer rings and carried to the transducer through pressure tubing. The high pressure piezometer ring is located in the settling chamber and the low pressure ring is just upstream of the test section entrance. The dynamic pressure resolution is $\pm$ .05 pounds per square foot. The actual or calibrated dynamic pressure is obtained by using a previously obtained calibration between the set dynamic pressure and the dynamic pressure measured at the center of the empty test section.

Dynamic pressure is controlled by varying the propeller blade pitch angle and is infinitely variable between zero and 100 pounds per square foot. Except for very low dynamic pressures (q<1), tunnel q setting can generally be achieved and held steady in less than one minute from start.

INSTRUMENTATION AND DATA MANAGEMENT

External Balance System

Figure 46. External balance

The external balance located on the first floor of the building directly beneath the test section *(Figure 46)* is a Dynametrics Incorporated, six component, pyramidal, virtual center, electro-mechanical balance which resolves all aerodynamic forces acting upon the test model in three orthogonal forces and their associated moments. These components are measured along and about a system of wind oriented axes having their origin at the balance resolving center. The balance center corresponds to the geometric center of the test section (42" from the floor, 60" from the side walls and at the center of the turntable). The forces and moments are transmitted to the individual null beam systems via flexors. The null beam system outputs location via digital encoders to the electronic counters in the control room. The counters display the balance outputs in pounds or foot pounds and do not require any other calibration. The balance system includes a turntable, which is matched in movement by an upper turntable in the floor of the test section using synchronous motors. The balance turntable incorporates a clamping system and a pitch arm to allow a variety of model mounting options as described in previous sections. The upper turntable includes two channels to allow mounting strut protrusions . The model positions in pitch and yaw attitudes are also transmitted to the control room via encoders and displayed to electronic counters. The data acquisition system obtains all its information from the external balance through the digital outputs of the counters.

Balance components are linear and repeatable within 0.10%. Attitude and load capacities are:

Component	Range	Accuracy	Resolution
Pitch	-35º to +35º	± 0.05º	0.01º
Yaw	-120º to + 190º	± 0.05º	0.01º
Lift Force	-1000 to + 3000 lbs.	± 0.10 lb. Or 0.1 % of Applied Load	0.01 lb.
Drag Force	-1000 to +1000 lbs.	± 0.10 lb. Or 0.1 % of Applied Load	0.01 lb.
Side Force	-1000 to +1000 lbs.	± 0.10 lb. Or 0.1 % of Applied Load.	0.01 lb.
Pitching Moment	-2000 to +2000 ft-lbs.	± 0.10 ft-lb. Or 0.1 % of Applied Load	0.01 ft-lb.
Yawing Moment	-1000 to +1000 ft-lbs.	± 0.10 ft-lb. Or 0.1 % of Applied Load	0.01 ft-lb.
Rolling Moment	-2000 to +2000 ft-lbs.	± 0.10 ft-lb. Or 0.1 % of Applied Load	0.01 ft-lb.

Internal Balance

The wind tunnel has three internal balances in its inventory. Two balances were manufactured by Task and the third one is a NASA Langley balance. The balances have up to date calibrations and are re-calibrated as it is anticipated or deemed necessary by the wind tunnel staff. Customer may request a new calibration to be performed, if this is the case, calibration cost will be responsibility of the customer. Time for re-calibrations is normally 4-6 weeks.

1.25" Dia.	Task Mark XIII	Task Mark X
N1	500 Lbs.	100 Lbs.
N2	500 Lbs.	100 Lbs.
Axial	150 Lbs.	60 Lbs.
Rolling Moment	800 In-lbs.	120 In-lbs.
S1	500 Lbs.	50 Lbs.
S2	500 Lbs.	50 Lbs.

1.75" Dia.	NASA 711-A
Normal	500 Lbs.
Side	350 Lbs.
Axial	500 Lbs.
Rolling Moment	720 In-lbs.
PM	4,200 In-lbs.
YM	2,100 In-lbs.

The customer can provide their own balance, in this case, the facility is prepared to handle any balance or strain gage, given the type, calibration matrix and procedures for data reduction.

Electronic Signal Conditioning and Other Hardware

Twelve (12) channels of strain gage conditioners (HP-75000) and ten (10) channels of amplifiers (Vishay 2120) are available for strain gage and/or other electronic signals. Sixteen (16) channels of Analog to Digital interface (HP-75000) exist to provide inputs to the computer in digital form at rates up to 100 kHz. All A-D conversions are made with 16 bit converters. Three hot-wire constant temperature anemometers (TSI 1053-B) with variable decade resistors (TSI 1056) and required power supply (TSI 1051-10) are also available together with one, two or three wire probes for measuring flow characteristics.

Sixteen (16) Digital to Analog channels are also available and can be used to supply outputs to customer equipment or control hardware requiring DC voltage for operation.

Pressure System

A PSI 8400 pressure system processor for electronic pressure scanners is available with a $\pm$ 5 psi calibration unit and interface for up to 16 scanners. The PSI system has the advantage of obtaining pressure data with individual transducers at each port, therefore speeding up the data acquisition. At this time, the wind tunnel has 80 ports (2 scanners) with 1 psi transducers, 32 ports (1 scanner) with 20" H_2O (0.72 psi) transducers and 160 ports (5 scanners) with 5 psi transducers. The system only adds a couple of seconds per data point to the data acquisition time. Call the wind tunnel for information for an up-to-date available number of ports and pressure ranges.

The old scanivalve mechanical system with up to 288 ports (6 heads) is still available for pressure measurements in models. A range of transducers are available, as well as the controllers and processors necessary to control and input information to the computer. This system uses one transducer per head and therefore time for the pressure to fill the tube and movement from one port to the next is required. Approximate time for typical data acquisition is 1.5 minutes per point.

Data Acquisition

A stand-alone data acquisition and analysis system is in use at the Oran W. Nicks Low Speed Wind Tunnel @ Texas A&M University. The computer system is built around network of PC computers. The data acquisition system is built around a HP-75000 system with 16 A-D channels, 12 strain gage conditioner channels and 64 D-D channels, a PSI 8400 pressure system with a $\pm$ 5 psi pressure calibration unit and the capability of taking data from up to 16 scanners. The data acquisition computer uses IEEE interface and all the programs and data are stored in the network drive, printers and graphic displays are connected directly to the computer for direct output and on-line monitoring of the data. The network server includes two 8 GB hard disks set up as mirroring for backup purposes, a tape backup system used for daily backup of the data throughout the test period and achieved purposes after every test. The server as well as 70% of the desktop computers have auxiliary power supplies which can keep power for up to 25 minutes in case of power failures.

This combination of equipment and appropriate software provides a capability for the acquisition and analysis of force and moment data from either internal or external balance systems or combinations thereof. A number of programs are available to incorporate all of the customary corrections applied to aircraft model testing including tare, alignment and interference data. The presentation of data in coefficient form resolved to several appropriate axes, is immediately available. On-line plotting capabilities provide direct comparisons of test data. In some cases, customers will have special requirements concerning data collection or reduction; software can usually be tailored to meet these individual needs given ample notice. Software programs also exist for pressure tests involving several hundred pressure measurements. In addition to obtaining raw data, pressures are readily computed into coefficient form.

Data Reduction

The standard external balance force and moment data reduction process reduces data to coefficient form and applies corrections to remove unwanted effects due to test conditions and techniques. Data is first reduced to coefficient form by dividing by dynamic pressure and a characteristic area for forces and area and length for moments. Data are collected with all moments resolved about the balance center , which corresponds to the center of the test section. The moments can be transferred to a model center, a point usually specified dimensionally by the Principal Investigator. The reduced data can be readily transferred to two other axis systems-stability axis and body axis. Force and moment data can then be presented as data tables:

Wind axis, Balance center
Wind axis, Model center
Stability axis, Model center
Body axis, Model center

Data in final form, includes corrections for static weight tare, buoyancy, blockage, strut tare, interference, alignment and wall presence.

- Static weight tare corrections simply remove the effects of the model, balance turntable and pitch mechanism weight and its distribution from the data. A wind-off run is made to determine weight effects and they are subtracted from the raw data before any other corrections are made.
- Buoyancy corrections account for the thrust effects caused by a static pressure gradient within the test section.
- When correcting data for blockage, two blockage effects on dynamic pressures must be taken into account. The first of these is due to the effect of the solid model and support systems and the second is due to the model wake which effectively add to the blockage volume. These volumes reduce the effective area for the flow around the model. Reducing the cross-sectional area around the model increases local flow velocities and changes the pressure distribution in the vicinity of the model.
- Strut tare and interference corrections are an approximate means of eliminating the effects of the model support struts. Strut tares are forces and moments resulting from direct exposure of the support system to the flow while interference is a result of the disturbance of the pressure fields on the model caused by the presence of the support system. The alignment correction provides for a means of accounting for any flow inclination or curvature of flow in the test section. In addition, the alignment correction is used to insure that the lift and drag directions on the balance system are mutually perpendicular.
- Wall corrections account for an alteration to normal flow pattern caused by the confinement of the flow by the walls of the test section. C_D, C_{pm} and angle of attack are all corrected for wall effects.

Data is supplied to the customer in electronic format. There are a variety of formats, which include Floppies, Zip disks, PC CD or transferred by FTTP. With the changes of formats and data transfer methods, the facility staff normally works with the customer to supply the data in a format that is mutually convenient.

Special Instrumentation

Other types of sensors and recording equipment are available for testing programs having unique requirements. Nominal charges may be applied for the use of special equipment, including the costs of consumable supplies.

Special instruments available include the following:

VHS Video Recording and Play Equipment
Camera-35mm Pentax, Polaroid (Instant Prints), Digital camera.
Lighting Equipment-Stroboscopic and Ultraviolet
Inclinometer (Shaevitz, and Digital)
Anemometer Probes-hot wire, pressure
Transducers-(PSI, Validyne and other)
Pressure Standard-Ruska DDR 6000 (0-5 PSI), + 5 PSI
Water Manometers
Scanivalves-Scanco Type D and S
Integrating Digital Voltmeter (Hewlett-Packard)
Oscilloscope-HP 54501A Digitizing 100 MHz
Telescoping Vernier Height Gauge
Frequency Counter-HP 5332 A Frequency Counter
Timer-Counter-HP 5326 B (0-100 MHz) DMM
Pivot Balance-0-20 kg, 1 g Resolution
Square Wave Generator-HP Model E01 211 AR
Smoke Generator-Various Wands

A variety of small boundary layer rakes is available for surveying floor or wall boundary layer conditions. Five and Seven hole probes are also available to use

Auxiliary Support Service and Equipment

An added advantage of a university-connected wind tunnel is the ready access to a human resource pool of technical expertise. Day-to-day informal information exchange is the norm. Teams of technical experts from varying disciplines can be formed to solve a wide variety of problems using the wind tunnel and other facilities as data gathering tools. For example, a major wind engineering study might require specialists in aeronautical engineering, structural analysis, architecture, civil engineering, environmental design, mechanical engineering and computer sciences. Because the University is a non-profit organization, additional charges for technical assistance are nominal and include only labor and overhead costs.

A full range of wind tunnel model building service is offered by the TAMU Testing, Machining and Repair Facility, another division of the Texas Engineering Experiment Station. Complete design by experienced model engineers, fabrication from customer supplied drawings, instrumentation of customer models, or just minor last minute modifications are among the services available.

The location and self-containment of the Texas A&M Wind Tunnel allow complete security control for tests involving proprietary information. Any degree of access limitation may be applied as the customer dictates and security guards could be made available if required by the security level. Charges for security levels besides the standard proprietary information will apply and can be quoted as needed. For classified tests, the facility will have to obtain a site and personnel clearances. This can be done in a per project basis and costs vary depending on the level required. Sufficient advance notice is required to arrange and complete the process.

GENERAL REQUIREMENTS

Models

Unless designed purposely to provide dynamic data, wind tunnel models should be strong and stiff to avoid unwanted deflections or risks of model failure. Weight is not generally a concern for wind tunnel models; it is customary to use a design factor of safety of four (4) to insure adequate margins for unexpected conditions. A model design stress report, or other evidence of suitable structural integrity, is required before beginning a test. The wind tunnel staff will be glad to review plans, analyses, or actual hardware prior to the test date.

Pretest Inputs

To correctly reduce and analyze test data, it is necessary that accurate dimensional information for the model and reference areas and lengths to be used for computing coefficients, be provided by the test sponsor. These data, along with a preliminary run schedule and requirements for data reduction format, are requested two weeks before the test if possible to allow wind tunnel personnel to prepare software programs and test equipment in advance. Equipment supplied by the customer and that is to be connected to the facility data acquisition equipment, would be also requested to be at the facility at least to weeks in advance. This time will allow the staff to assure compatibility of the systems.

Test Planning and Scheduling

Because of the nature of research work, flexibility and cooperation between the wind tunnel staff and user representatives are primary considerations. However, a reasonable amount of pre-planning is essential to a smooth running, efficient test program. Some considerations for proper planning and scheduling are offered as a guide to users.

Tests should be scheduled as far in advance as practical with at least a tentative date of entry and test length set. Users are strongly urged to send their representatives to College Station for a pre-test conference at least two weeks before the start of a test. Such a conference can do a great deal toward clearing up “communication gaps” and attending to the “nuts and bolts” details that will avoid costly delays on the entry day. It is advisable for the user to prepare a pre-test report outlining the purpose and scope of the test, model specifications and load estimates, a tentative run schedule, special equipment requirements and desired data and reporting.

Contractual and financial matters pertaining to wind tunnel operations performed on a job order basis are handled directly by the wind tunnel staff and the Aerospace Engineering Division of TEES, research grants and contracts, are generally administered by the Texas Engineering Experiment Station (TEES). Normally the user’s issuance of a purchase order to TEES for the initial cost estimate will be acknowledged as meeting the requirement for test authorization. Special contracts may be drawn if the circumstances of a particular test program require them or if the customer prefer to operate on such a basis. Confidentiality agreements and terms and conditions for purchase orders or contractual terms are reviewed and agreed by TEES authorized personnel.

Wind Tunnel Scheduling Policy

Requests for wind tunnel test time should be made as far in advance as possible. Schedules are maintained and updated as necessary for use by the wind tunnel staff. Two categories of scheduling are used – tentative and firm. The facility follows the holiday schedule set by the University.

Tentative Schedule

The wind tunnel may be scheduled on a tentative basis for four weeks or less in any twelve month period by telephone, followed by a letter of confirmation and approval by return mail. A request for tentative scheduling involving more than four weeks in any twelve month period must be accompanied by a purchase order and an advance payment for 50% of the time requested. Cancellation by the customer will require forfeiture of the advance, unless the facility is able to reschedule the time with other customers.

Approved tentative schedules will reserve the time as requested until four weeks prior to the tentative occupancy start date, at which time a purchase order is required to convert the schedule to firm status. If a purchase order has not been received four weeks prior to the tentative occupancy date, the facility has the right to reschedule the time for other users.

The facility reserves the right to adjust tentative schedules to accommodate firm schedules or unforeseen schedule problems due to equipment failure; however, customers having tentative schedules will be given first option to change to firm schedules, or to reschedule.

Firm Schedule

Firm Schedules require the customer to guarantee use of the wind tunnel for the period of time requested. Firm scheduling may be requested earlier than the four weeks prior to occupancy date if desired. Cancellation of a firm schedule by the customer requires a payment of 50% of the scheduled time unless the facility is able to reschedule the time with other customers.

TERMS AND CONDITIONS

7 x 10 Foot Oran W. Nicks Low Speed Wind Tunnel

1. Basic rate is $350 per occupancy hour. Occupancy is based on an eight (8) hour day, five (5) day week. Occupancy starts with test section preparation for model installation and ends with model removal and test section restoration. Changes to the basic rate can be made if the test requires minimum equipment or supervision. These changes will be provided or proposed as requested.

2. The basic occupancy rate includes the following:
   a. Wind Tunnel rental.
   b. Data reduction - incorporates calibration factors: up to three copies of data in coefficient form.
   c. A test report explaining the nature of the test, test conditions, data reduction methods used and factors important to data interpretation.
   d. Personnel to operate the wind tunnel and associated equipment.
   e. Personnel to help install and remove model, and assist with model changes, instrumentation checkout.
   f. Still photographs obtained during the test for recording purposes.

3. For tests involving internal strain gage balances, the basic rate plus an additional charge of $50 per hour is required. For multiple balances, the single balance rate will increase by $25 per hour, per each additional balance.

4. For tests involving electronic pressure scanners, the basic rate plus an additional charge of $50 per hour is required.

5. For test involving the use of auxiliary air or electrical drive systems, the basic rate plus an additional charge of $100 per occupancy hour is required.

6. For tests requiring the use of hotwire anemometry, the basic rate plus an additional charge of $50 per occupancy hour should be used.

7. For tests requiring the use of High Speed Camera system, the basic rate plus an additional charge of $30 per occupancy hour should be used.

8. For tests requiring the use bicycle mount system, the basic rate plus an additional charge of $30 per occupancy hour should be used.

9. Additional Wind Tunnel services available, charges can vary and depend on the tasks and proposals. Specific costs will be provided on request:
   a. Special computing, analysis, data preparation, or supervision of facility during non-working hours ($40/man hour).
   b. Overtime operation - for time exceeding the normal operating schedule, only if possibility and need is approved, ($110/Hr above the hourly tunnel rate).
   c. Engineering services ($70/Hr, travel or Principal Investigator or support)
   d. Test support services ($35/Hr, Technician, $11/Hr, Student)
   e. Operation of High Pressure air system for Turbo Machinery Laboratory ($40/Hr.)

10. Additional facilities and equipment are also available, rates provided on request:
   a. Complete machine shop with experienced machinist-model makers for model design, construction, modification, and repair.
   b. Computing services.
   c. Electronic instrumentation equipment.
   d. Printing, copy machines.
   e. Photographic equipment, 35-mm still, Polaroid, videotape.
   f. Additional security.

11. Special consultation; University facilities and research engineers are available for help on technical problems. Rates provided on request.

12. Materials and purchases made by the University for the customer will be invoiced to the customer at actual cost.

13. The customer will assume repair expenses to the facility or equipment in the event of model failure and/or customer negligence.

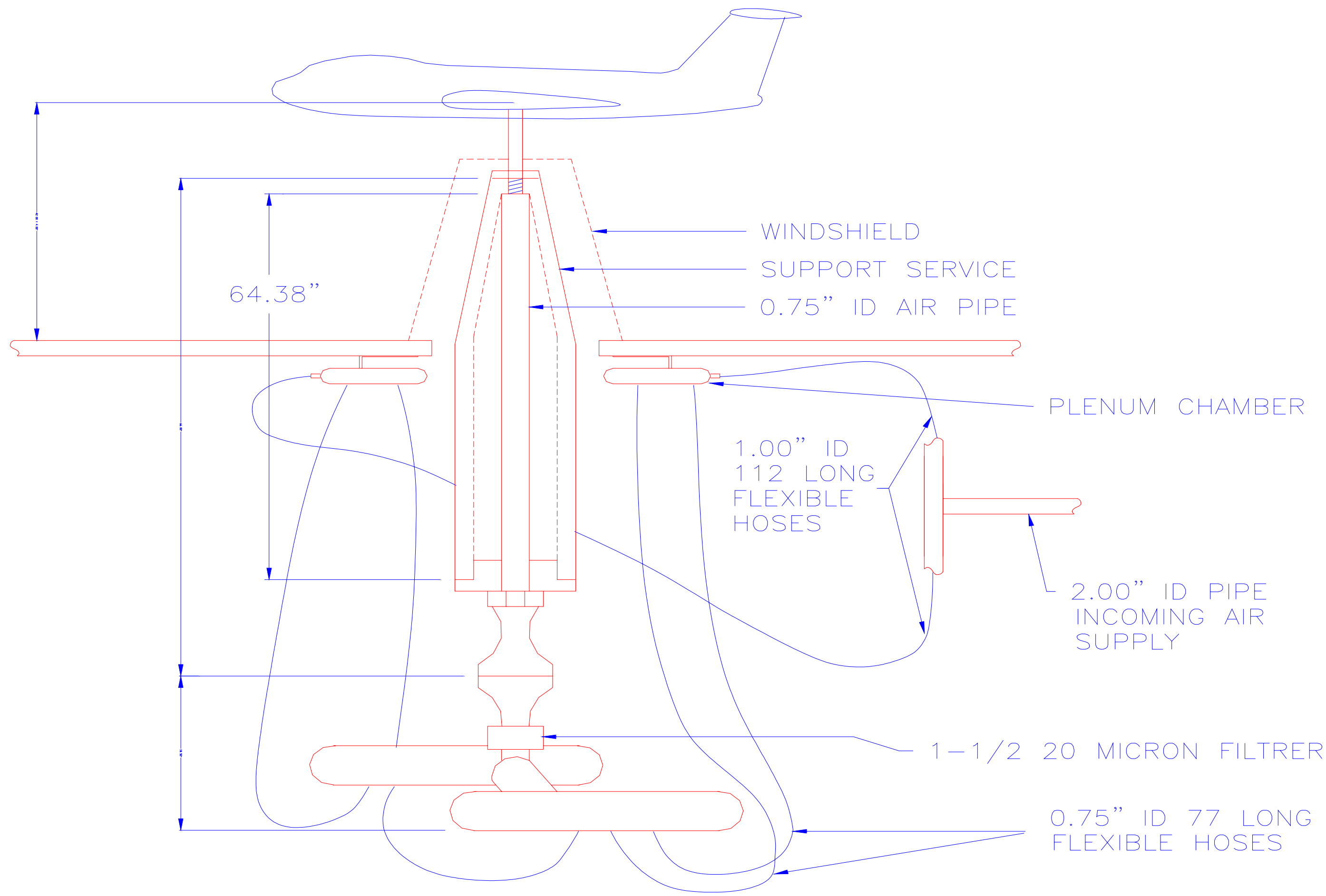
Occupancy rate is subject to change without notice. Always contact the tunnel staff for latest quotation.

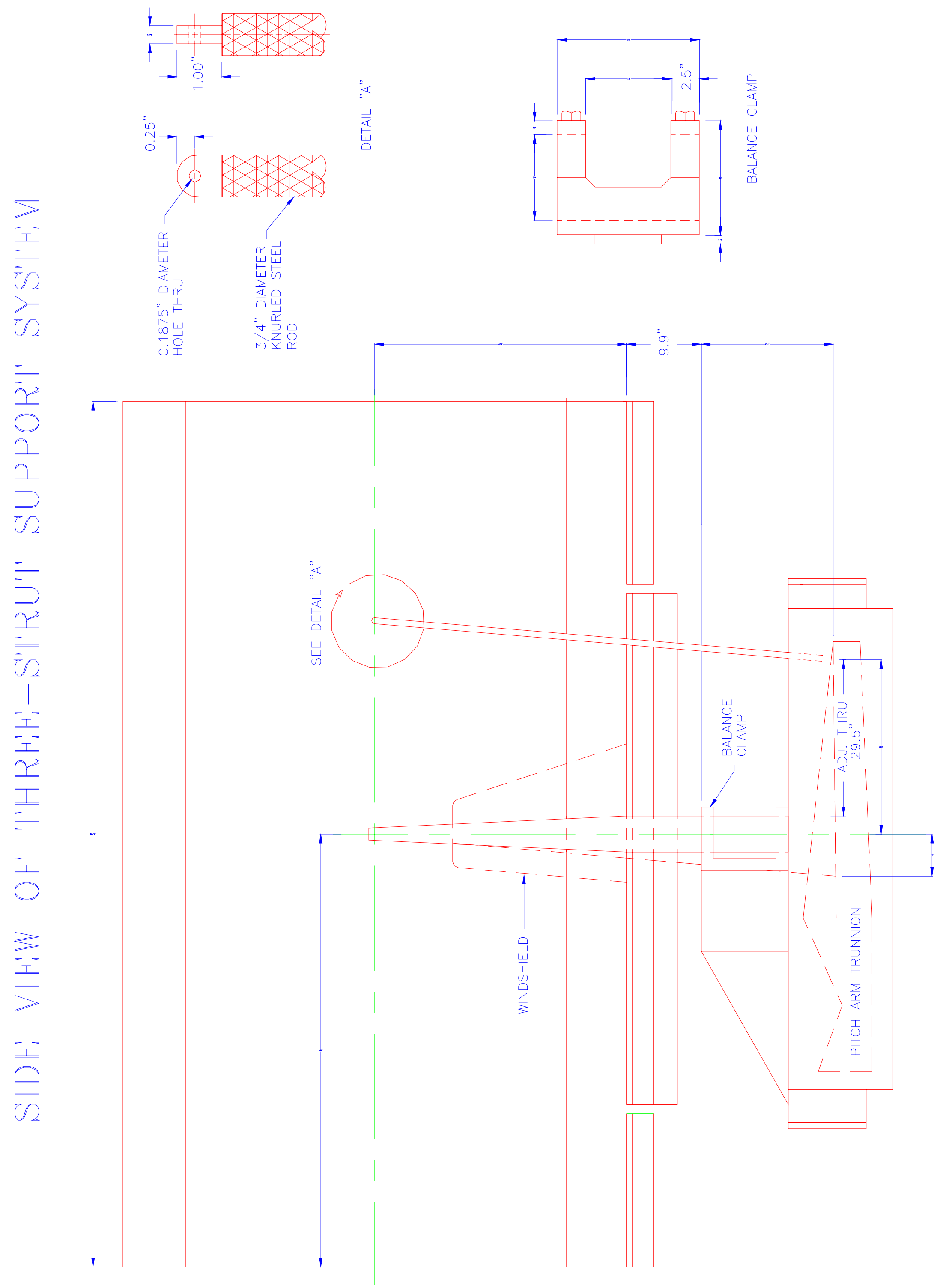
APPENDIX

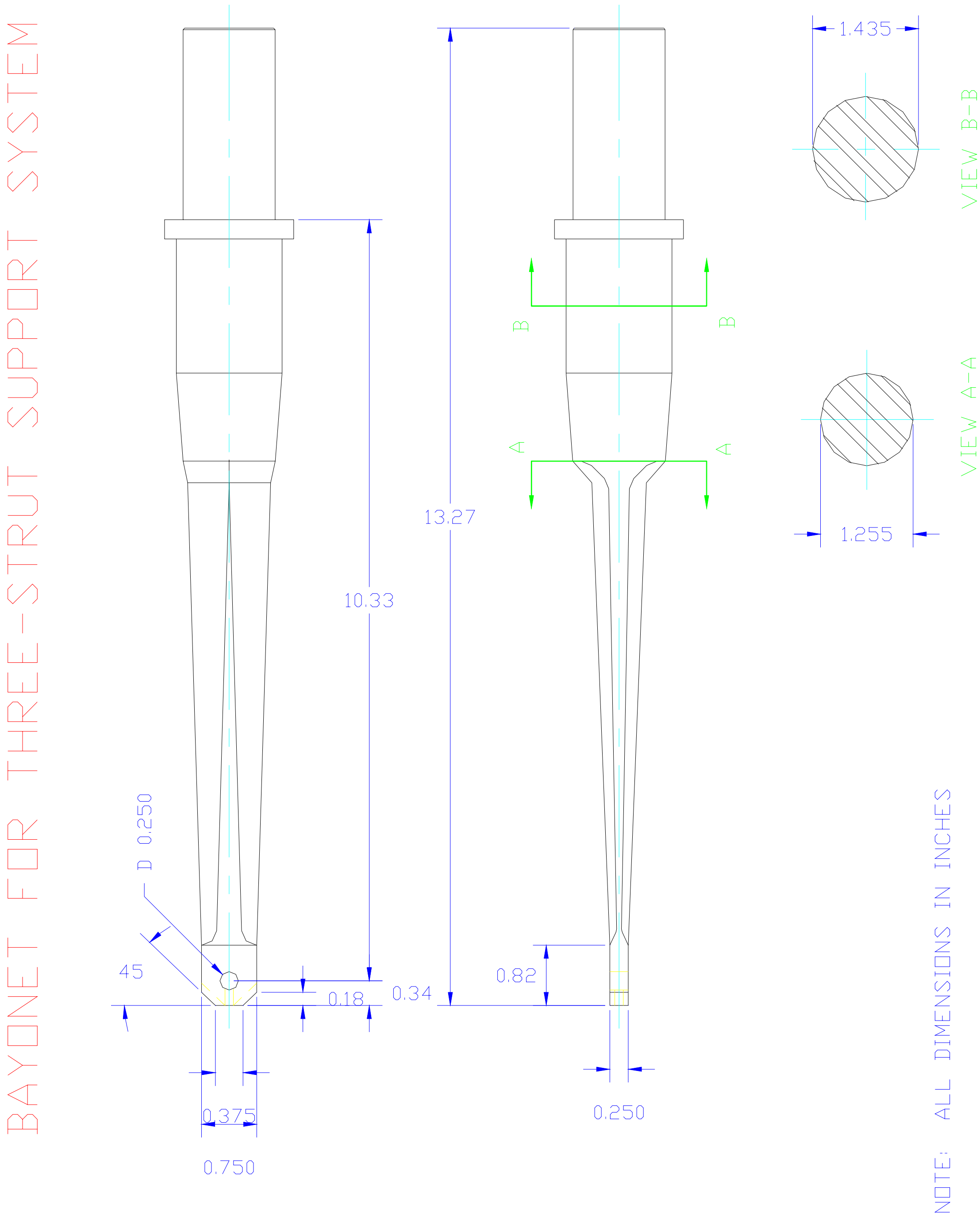
Included in this section are reference drawings of standard mounting provisions. These drawings may help to adapt existing models and equipment or the design of a new model to be used at this facility. While these drawings are suitable for reference, it is recommended that wind tunnel personnel be consulted before final design of an installation.

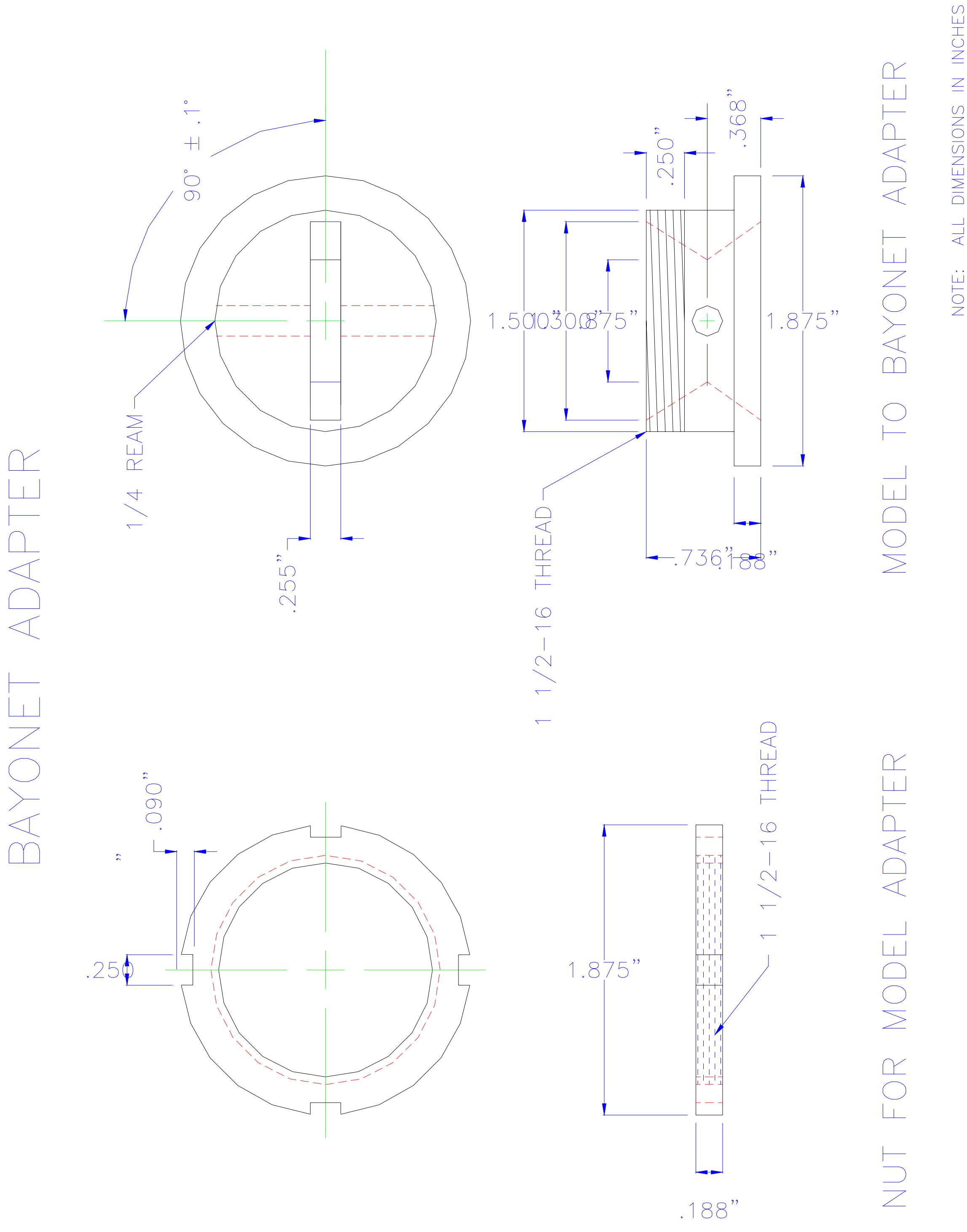
As deflections are normally undesirable, it is important that models and supports be as stiff as possible; all pin connections should be reamed fit to minimize play between parts.

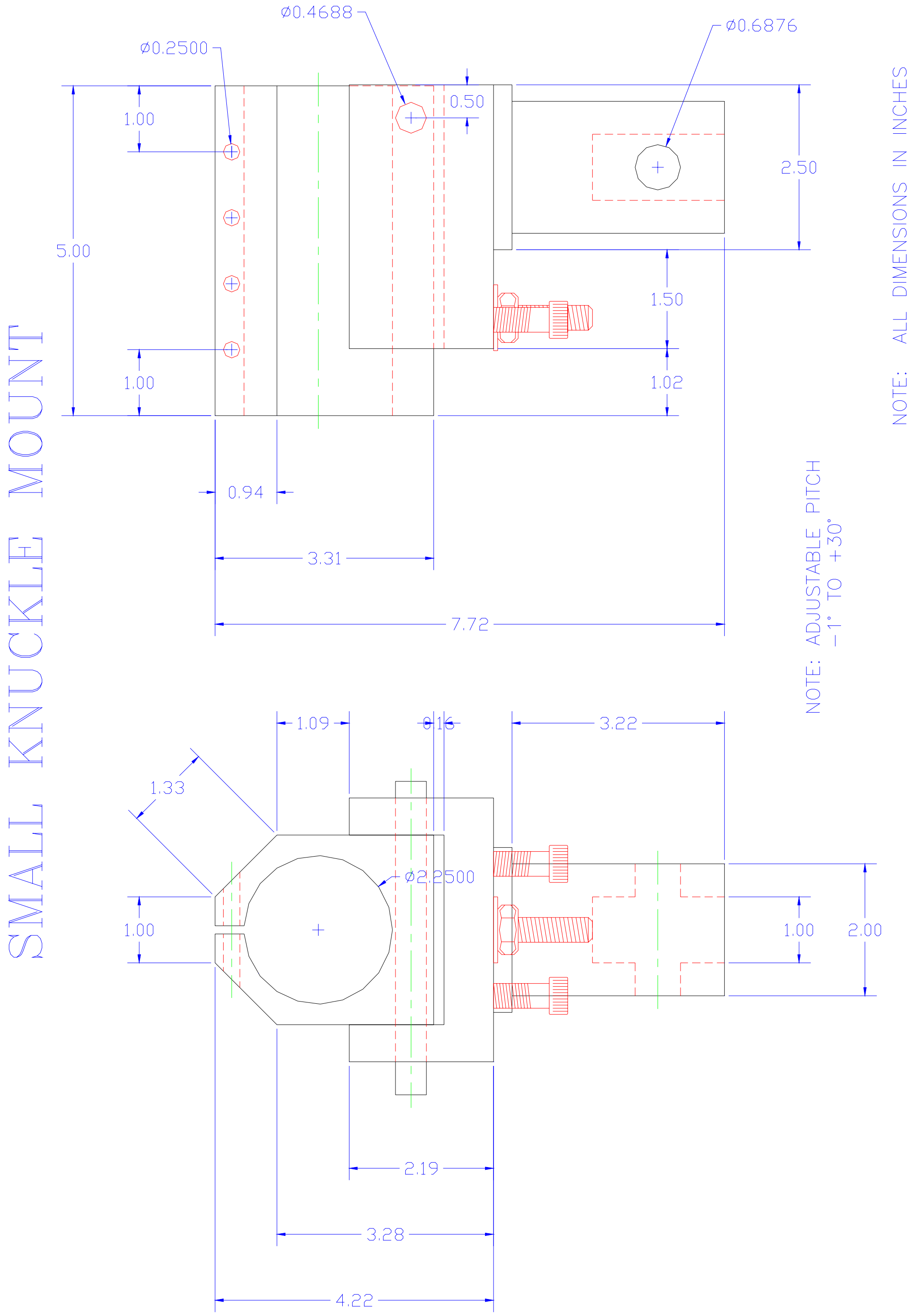
SCHEMATIC OF HIGH PRESSURE AIR SYSTEM MOUNTING TO TUNNEL TEST SECTION

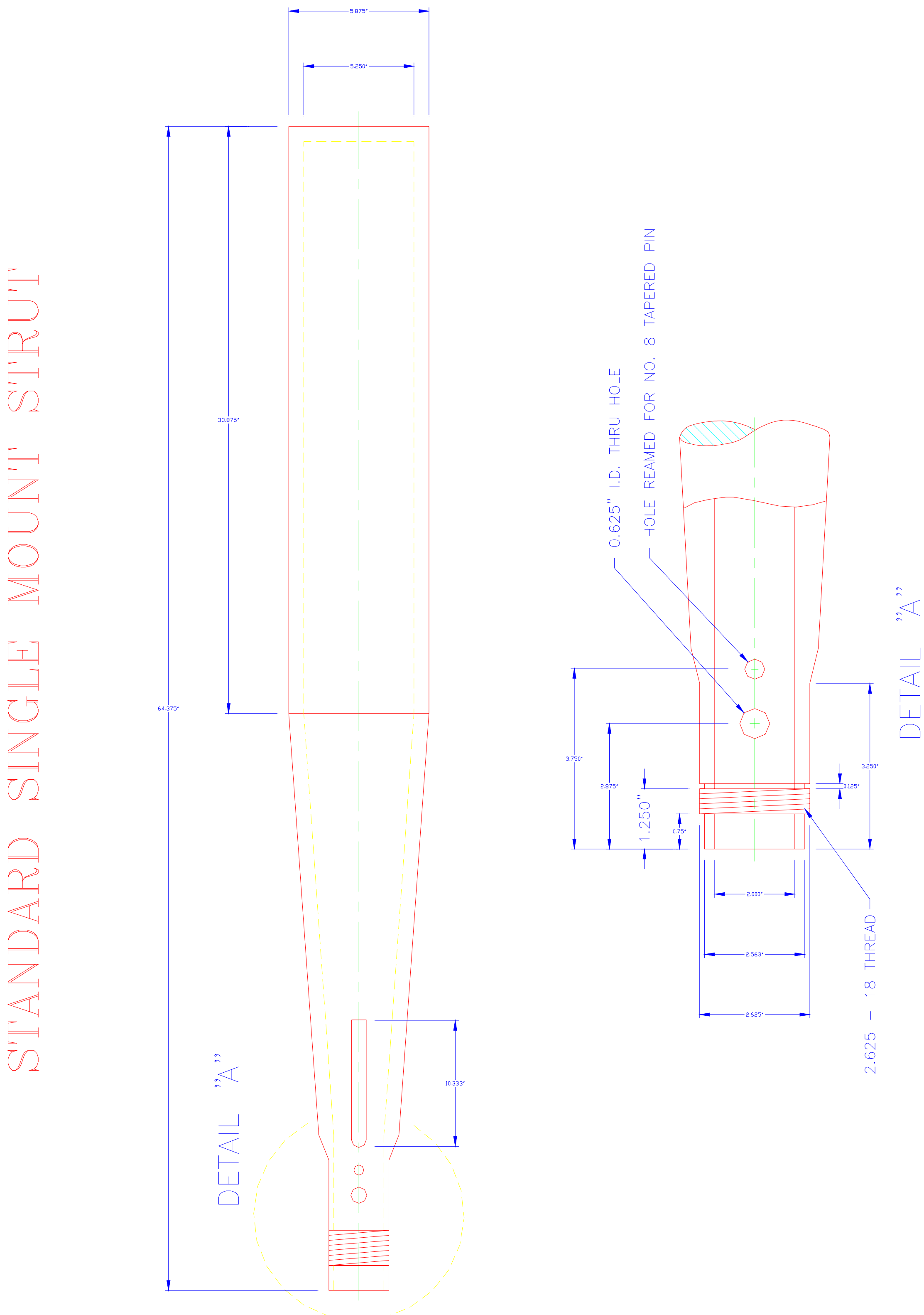


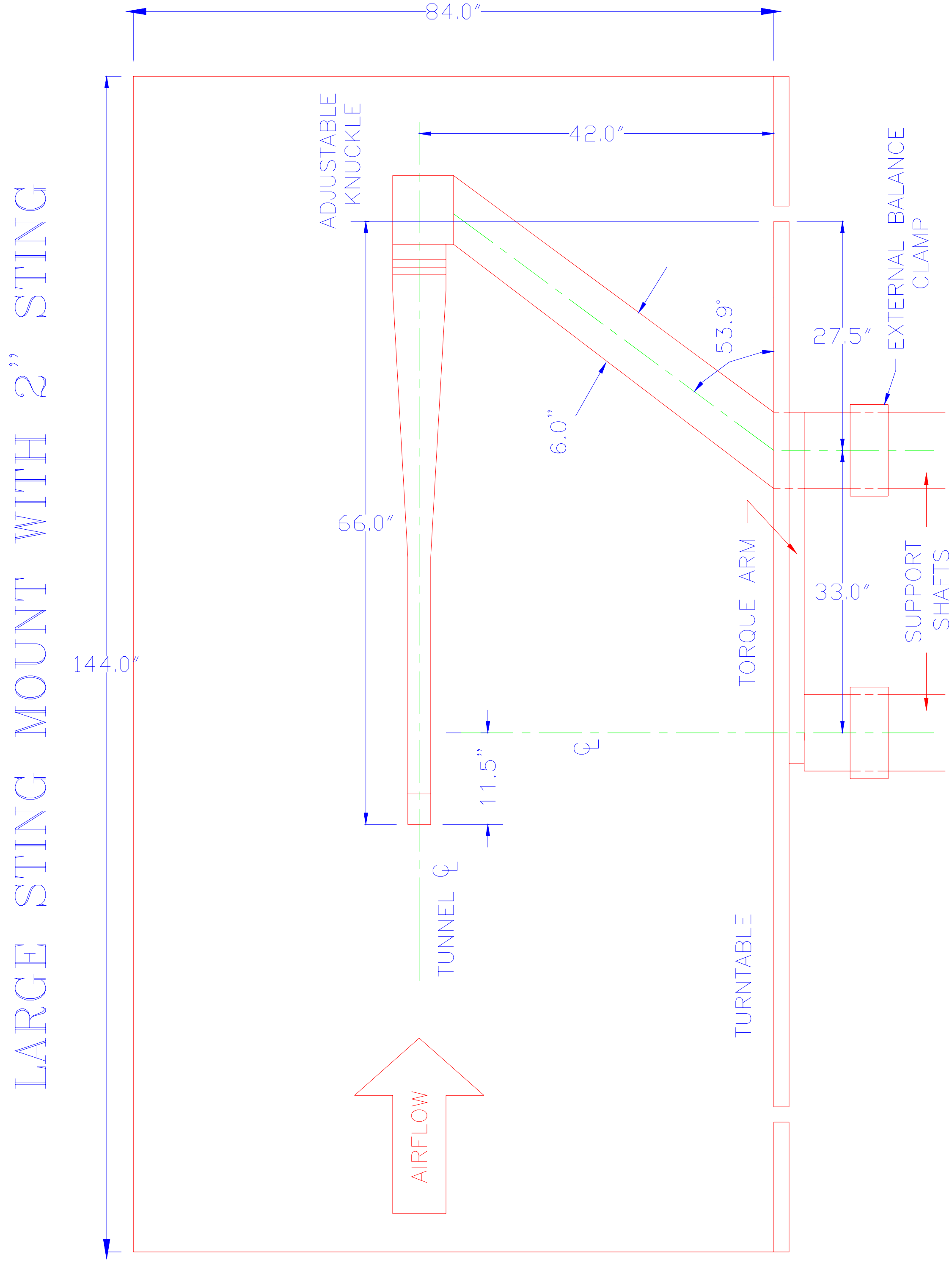

SIDE VIEW OF THREE-STRUT SUPPORT SYSTEM
0.25"
1.00"
0.1875" DIAMETER
HOLE THRU
3/4" DIAMETER
KNURLED STEEL
ROD
DETAIL "A"
2.5"
BALANCE CLAMP
9.9"
SEE DETAIL "A"
BALANCE
CLAMP
ADJ. THRU
29.5"
WINDSHIELD
PITCH ARM TRUNNION

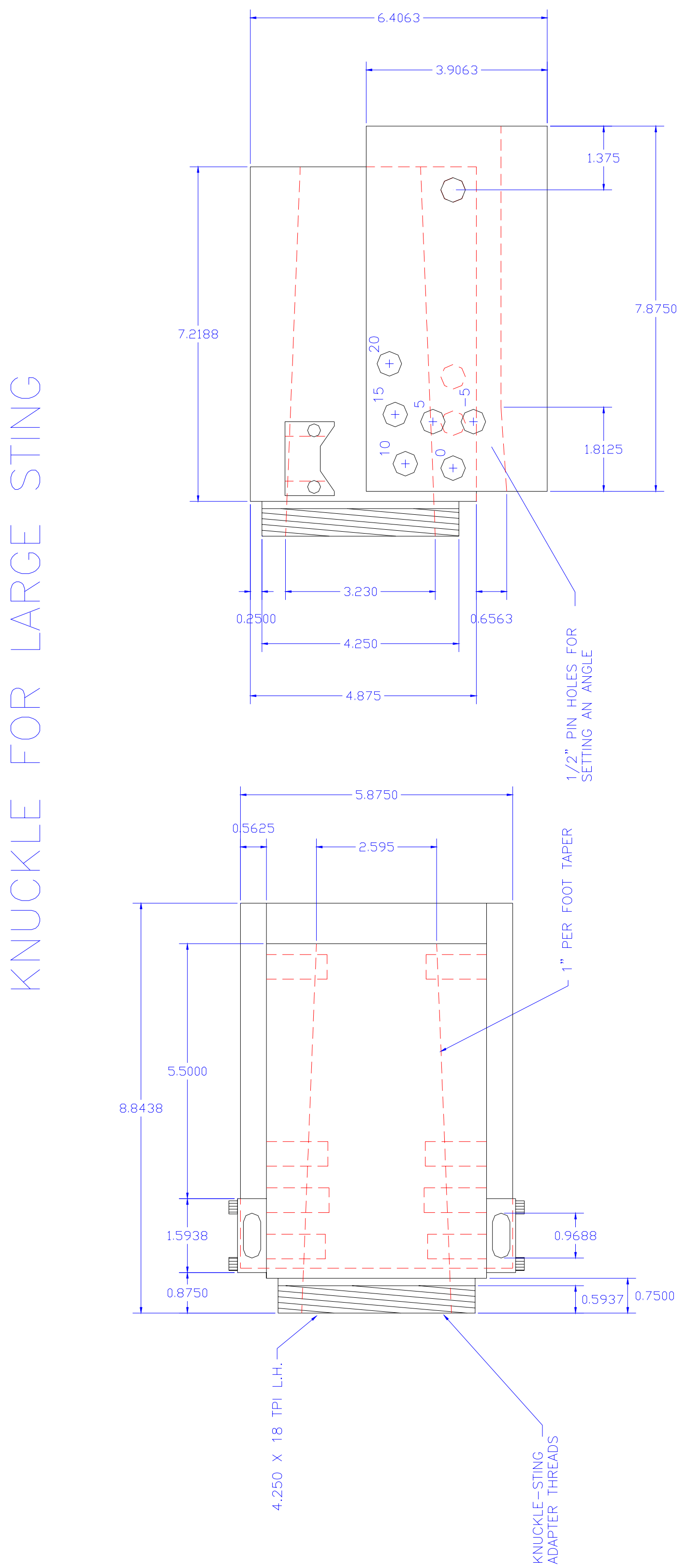

BAYONET FOR THREE-STRUT SUPPORT SYSTEM
1.435
VIEW B-B
VIEW A-A
1.255
B
B
A
A
13.27
10.33
D 0.250
45
0.18
0.34
0.82
0.375
0.750
0.250
NOTE: ALL DIMENSIONS IN INCHES

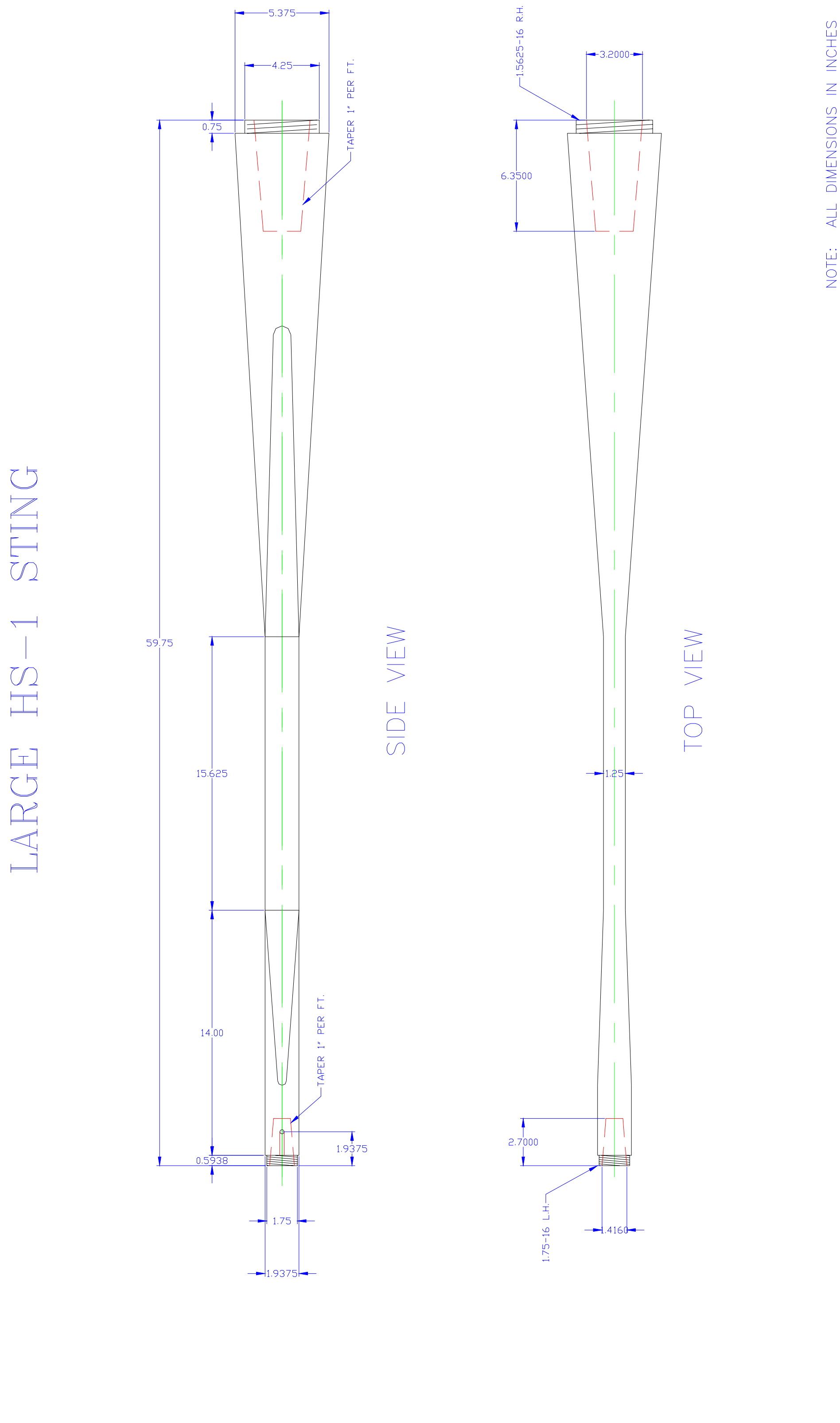

BAYONET ADAPTER
MODEL TO BAYONET ADAPTER
NUT FOR MODEL ADAPTER
NOTE: ALL DIMENSIONS IN INCHES
90° ± .1°
1/4 REAM
.255"
1 1/2-16 THREAD
.250"
.368"
1.875"
.736"
.188"
.090"
.250
1.875"
1 1/2-16 THREAD
.188"


SMALL KNUCKLE MOUNT
NOTE: ALL DIMENSIONS IN INCHES
NOTE: ADJUSTABLE PITCH
-1° TO +30°
ø0.2500
ø0.4688
ø0.6876
ø2.2500
0.50
1.00
5.00
1.00
2.50
1.50
1.02
0.94
3.31
7.72
1.09
0.16
3.22
1.33
1.00
1.00
2.00
2.19
3.28
4.22

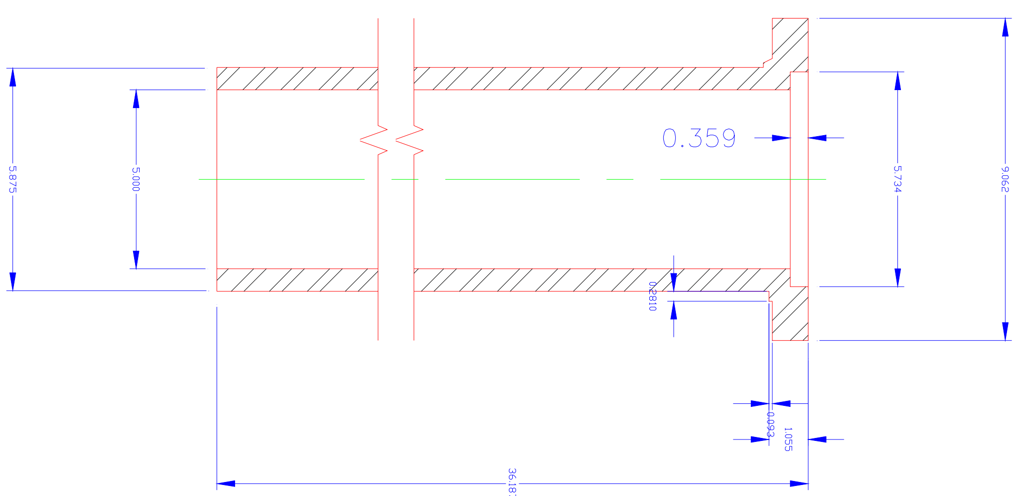

STANDARD SINGLE MOUNT STRUT
DETAIL "A"
5.875"
5.250"
33.875"
64.375"
10.333"
0.625" I.D. THRU HOLE
HOLE REAMED FOR NO. 8 TAPERED PIN
3.750"
2.875"
1.250"
0.75"
0.125"
3.250"
2.000"
2.563"
2.625"
2.625 - 18 THREAD
DETAIL "A"

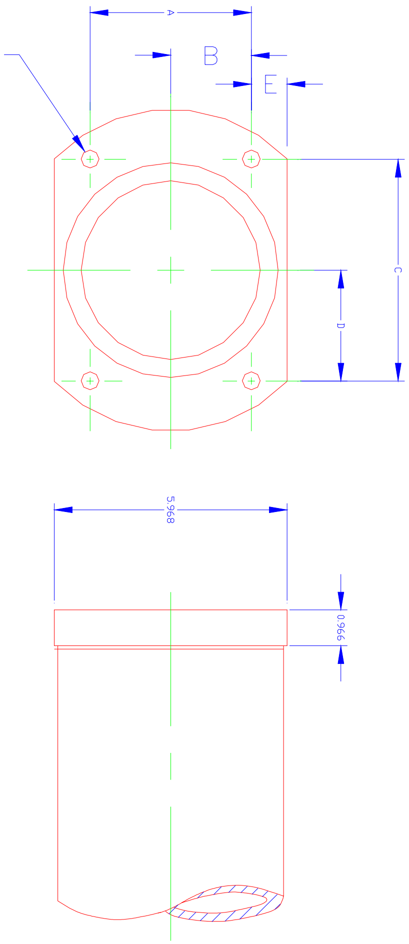

LARGE STING MOUNT WITH 2" STING
84.0"
144.0"
42.0"
ADJUSTABLE KNUCKLE
EXTERNAL BALANCE CLAMP
27.5"
53.9°
6.0"
66.0"
33.0"
TORQUE ARM
SUPPORT SHAFTS
11.5"
TUNNEL ℄
℄
TURNTABLE
AIRFLOW


KNUCKLE FOR LARGE STING
6.4063
3.9063
1.375
7.8750
7.2188
1.8125
20
15
10
5
0
-5
3.230
0.2500
0.6563
4.250
4.875
1/2" PIN HOLES FOR SETTING AN ANGLE
5.8750
0.5625
2.595
1" PER FOOT TAPER
8.8438
5.5000
1.5938
0.8750
0.9688
0.5937
0.7500
4.250 X 18 TPI L.H.
KNUCKLE-STING ADAPTER THREADS


LARGE HS-1 STING
SIDE VIEW
TOP VIEW
NOTE: ALL DIMENSIONS IN INCHES
5.375
4.25
0.75
TAPER 1" PER FT.
59.75
15.625
14.00
TAPER 1" PER FT.
0.5938
1.9375
1.75
1.9375
1.5625-16 R.H.
3.2000
6.3500
1.25
2.7000
1.75-16 L.H.
1.4160

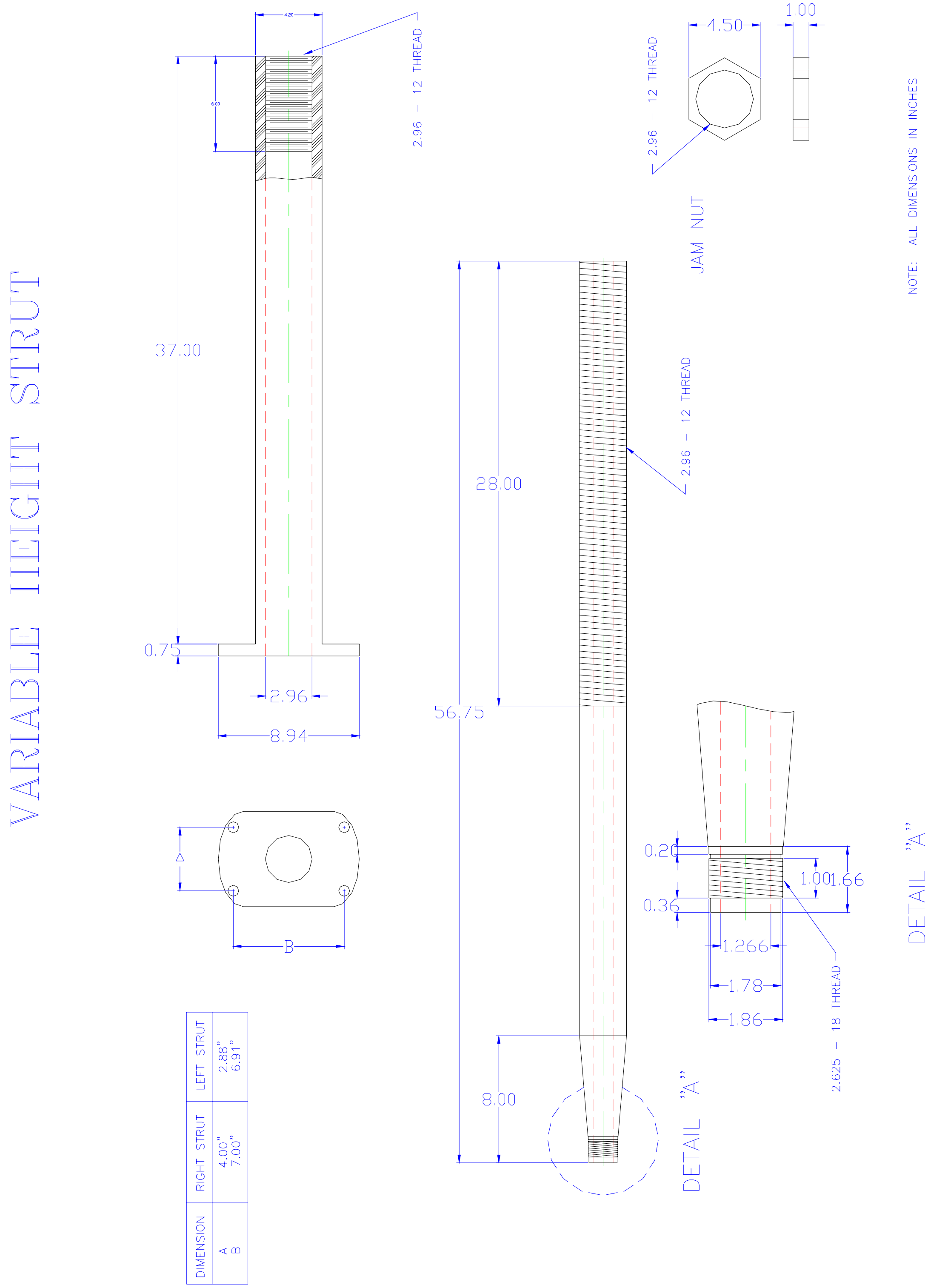
BASE MOUNT SUPPORTS





DIMENSION	RIGHT STRUT	LEFT STRUT
A	4.000	2.875
B	2.000	1.437
C	7.000	6.906
D	3.500	3.453
E	0.937	1.511

NOTE: ALL DIMENSIONS IN INCHES



DIMENSION	RIGHT STRUT	LEFT STRUT
A	4.00"	2.88"
B	7.00"	6.91"