University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Wind Tunnel Model Positioning System

Approvals

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1.0 Problem or Need

Within the field of aerospace engineering, the ability to simulate and validate flow fields around a scale model is crucial. This is generally accomplished through the use of low speed wind tunnels. A wind tunnel allows the user to observe flow fields and measure loads on a test specimen, as well as various aerodynamic properties of a body through static and dynamic positioning. Static positioning refers to constant position and angular orientation with respect to time, while dynamic positioning refers to varying position and angular orientation with time in three dimensional space.

Currently, the University of Colorado at Boulder (UCB) has a low speed educational wind tunnel located in the Integrated Teaching and Learning Laboratory (ITLL). Testing within this facility occurs as part of the Aerospace Engineering Sciences (AES) undergraduate curriculum at UCB, during the sophomore and junior years. The wind tunnel is continuously used throughout the year for these classes leaving little time for research projects. In the fall of 2015, AES at UCB will bring online a new wind tunnel for research. To extend the aerodynamic testing capabilities of the new wind tunnel, a model positioning system is needed that can accurately orient test articles with respect to the air flow. This positioning system requires four degrees of freedom including pitch, yaw, roll, and plunge with respective pointing accuracies of 0.1°, 0.1°, 0.5°, and 0.5 mm. The system must be capable of electrical manipulation through a LabVIEW virtual interface. The required angular rate for all degrees of freedom is defined by achieving maximum frequency of 64 Hz with a 1° displacement in yaw, pitch, and roll and 1 mm displacement in plunge. Remaining requirements include: (1) the ability to integrate with a future load and moment measuring system, (2) integrate within the current test section and have less than 10% total cross-sectional blockage with a model included, and (3) have a failsafe for power failure scenarios.

The installation of the new wind tunnel and the design and development of a custom model positioning system will introduce significant new capabilities within the AES Department here are at UCB. This equipment will benefit both undergraduate and graduate students in research and has the potential to foster future collaborations between the university and the aerospace industry. With the wind tunnel position system, static and dynamic research of wind tunnel models can be easily accomplished with the resources at the university. The overall benefits of a fully functional system in conjunction with a new wind tunnel are considerable.

2.0 Previous problems/solutions

There are two primary pre-existing configurations of mechanical positioning systems used in wind tunnels today. These include: (1) strut and (2) sting mount systems.

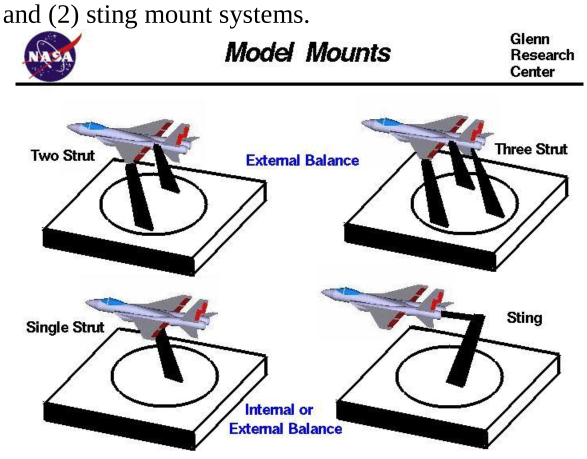

Figure 1. Typical mechanical positioning systems [4]

Some techniques use 3 struts while others use only one or two, as seen in Figure 1. These systems can typically achieve most yaw and pitch orientations, but roll is more limited. Different configurations of the struts provide different levels of capability. These levels of capability can include the degree of financial expense, complexity, structural rigidity, and flow interference. [4]

Another method is the sting mount system which is pictured in the lower right hand corner of Figure 1. This method utilizes one arm attached to the model which is connected to the rest of the test section. A sting mount minimizes the effect of the mounting system on the flow field since the sting lies mostly behind the model.[4]

In more rare cases, teams have developed systems using lever arms and three degree of freedom counter balances to achieve up to five degrees of freedom. These degrees of freedom being: pitch, yaw, roll, plunge, and side-to-side motions.[5] Tracks are also an option for moving the model in x, y, and z coordinates.

Similar testing to the envisioned performance has used angles of attack for 0- 16 degrees for airfoils with 0.1° precision, confirmed by the sting mount system motors and enoders.[2] It is fairly uncommon to use angles higher than this because airfoils may tend to stall at high static angles of attack. Other experiments performed by our customer have used mounts designed to oscillate at 75-120Hz frequencies to match the time it takes for one particle in the flow to cross from tip to tail. These also incorporated a 6 degree of freedom wall mount load cell.[3] These measuring systems are common in the field and might have to be incorporated into future designs.

Research into control systems used in model positioning systems yielded two types of control loops for position control – move-pause and continuous movement. Either controller drives the motors to position the model until the position feedback matches the commanded value. The primary components of a closed-loop control system include a servoamplifier, an engineering unit display microcomputer (EUD), programmable controller, feedback elements and the electrical components needed to select model orientation. The feedback elements that can be used to inform the control system of the model positioning at any point in time are either linear potentiometers or digital rotary encoders. Both of these elements have their advantages and disadvantages in regards to wiring space available or external effects such as temperature. Potentiometers are desirable when wiring space is of a concern, and encoders are less subject to temperature effects. Either element is driven by zero-backlash gears to meet the required high resolution of movement. The rate at which the model reaches the commanded position is determined by the servoamplifier that outputs the required voltage to the motor that drives the mechanism at the commanded rate. The required voltage that determines this rate is affected by both the specifications of the motor used, model weight and resultant torques acting on the model during active flow in the wind tunnel. Velocity feedback is performed by an instrument like a tachometer or derived from sampling the counter electromotive forces during periods of non-drive of the electric motors.[1]

In order to confidently achieve the required high levels of precision, sufficient calibration will be done to ensure accuracy. In the series of mechanical and electrical linkages that will be necessary, any amount of loss of precision can be lost and must be either eliminated or accounted for with thorough calibration. Through research, a few methods of calibration were found. The first method dealt with the calibration and uncertainty analysis of a wind tunnel.[7] The calibration itself was completed by using an interaction matrix. This interaction matrix is a coefficient matrix composed of systems of equations relating the side force, drag and yawing moment experienced by a model within the test section. This coefficient matrix was then used to find a best fit fifth order polynomial. This polynomial is the basis for the calibration. For a given value read by the sensor, the true calibrated result is related to this value through the use of the fifth order function. Although this system was a calibration for the side force, drag and yawing moment, it could still be an applicable method for determining the calibrations needed for the wind tunnel positioning system.

Another process of calibration that was investigated uses a digital-to-analog converter (DAC) for position commands and a EUD microcomputer. By comparing data acquired by feedback elements – which provide what the actual positioning of the model should be – and simulated data generated from the commanded position and rate inputs, the commanded control of the model can be verified. The simulation is accomplished by the EUD microcomputer. It can then calculate the unit position and movement rates needed to position the model to where it is commanded in the form of conversion constants. This data is then sent to the DAQ. The conversion constants are used to convert the binary values from the DAQ to the voltages necessary to drive the motors to the commanded position. This process is automated and performed by the facility computer. This method allows for simultaneous checkout of the model as it is being positioned.[1]

There also exists more rudimentary methods of verification. These measurements are as simple as using a digital protractor to measure the angle in pitch, or motion capture software along with nodes or markers to measure the angular rates of the system. These more rudimentary methods of verification may be more useful for this project due to their simplicity and availability.

In all of these cases listed above, there have been both electrically and manually actuated control mechanisms. Our project is similar to these cases in that we need to develop a positioning system, with the exception that our design solution does not require the measurement of forces on the test specimen. Therefore our positioning system must incorporate the appropriate modularity to include the equipment that performs these measurements. The solutions given above mirror what our project aims to accomplish in regard to functional requirements, with the main difference being a more limited financial constraint.

3.0 Specific Objectives:

Table 1. Levels of requirements for wind tunnel model positioning system

Categories:	Position/Angular Accuracy	Range (min)	Testing Expectations	DoF	Frequency Oscillation
Level 1:	Pitch: +/- 0.1° Yaw: +/- 0.1°	Pitch: +/- 30° Yaw: +/- 30°	0 m/s (No Wind)	Pitch Yaw	f = 0 Hz (Hold Static)
Level 2:	Roll: +/- 0.5°	Roll: +/- 45°	" "	Roll	f = 64 Hz
Level 3:	Plunge: +/- 0.5mm	Plunge: +/- 10 cm	30-45 m/s (Average Testing Speed)	Plunge	" "

4.0 Functional Requirements

4.1 Concept of Operations for Model Positioning System (CONOPS for MPS)

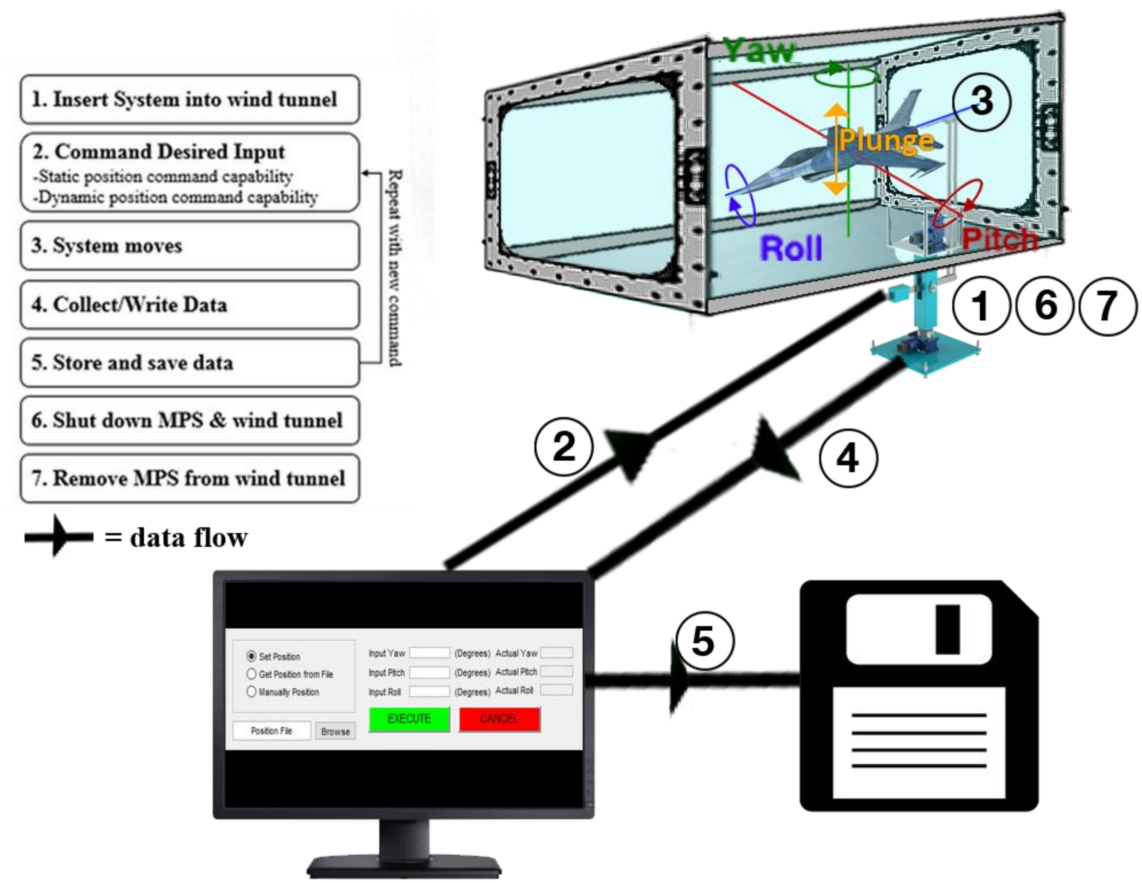

Figure 2. CONOPS for complete wind tunnel system

4.2 Functional Block Diagram

With the model positioning system installed in the wind tunnel, the user will give the positioning system a series of commands using a LabVIEW virtual interface (VI). The user will have the ability to set static positions or have the system perform specified dynamic movements. These commands will be fed to a closed-loop feedback control system. Within this control system, the software within LabVIEW will command the individual motors for yaw, pitch, roll, and plunge to the specified positions. For dynamic movement, the motors will be commanded to perform a specified path of discrete positions to follow in time at various rates and ranges for each degree of freedom. This is accomplished using an Electronic Control Interface between the motors and LabVIEW VI control. Position and rate sensors will measure the position and rate of the motors and transmit this data back to the Electronic Control Interface. The Electronic Control Interface converts this information, if needed, and sends it to the VI for display and data logging. This data is also sent to the closed-loop feedback controller system until the system achieves the commanded position or rates. Figure 3 below outlines the above through a system functional block diagram.

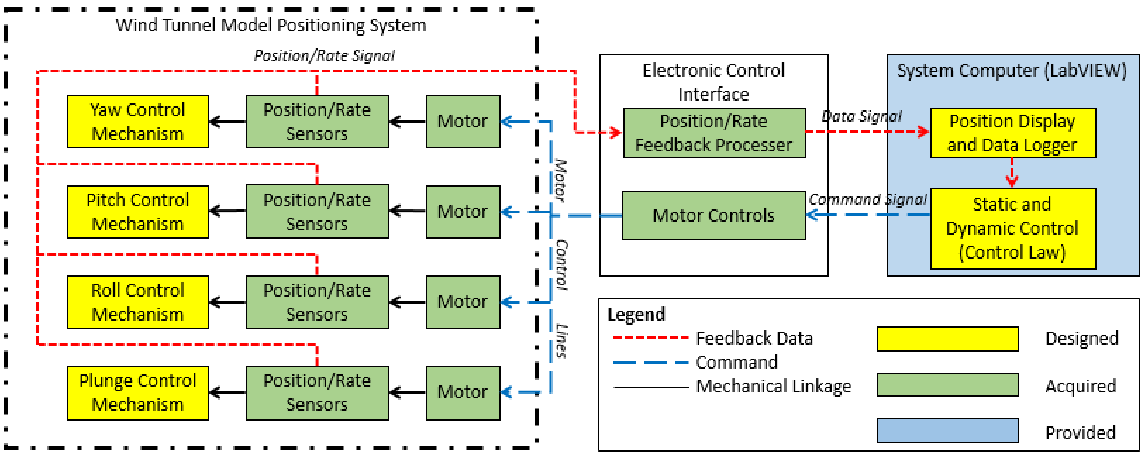

Figure 3. Functional Block Diagram for Wind Tunnel Model Positioning System

5.0 Critical Project Elements

CPE.1 DAQ and Motor Costs: Based on initial research, the use of a DAQ would require acquiring modules for the final system, and these modules are costly. Motors fitting project requirements and initial torque requirements also appear to be costly.
CPE.2 Access to Wind Tunnel: Access to the wind tunnel is needed to acquire and maintain an accurate image of the interface area, and this access is limited throughout the academic year. The wind tunnel is currently scheduled for delivery on September 21st and being operational by October 8th.
CPE.3 Load Resistance: The system must maintain positioning accuracy while subject to loading. This includes the aerodynamic forces the system is subject to as well as the weight of the installed model and aerodynamics forces the model is subject to.
CPE.4 Mechanical Linkages: Motors will need to interface with the position control mechanisms and may require gearing to achieve the required pointing accuracies. These links in the system must have a high tolerance to keep the degradation of accuracy to a minimum.
CPE.5 LabVIEW Software: It is required that the user be able to interface with the system via a LabVIEW VI. The LabVIEW VI will need the ability to control the positioning system as well as record and store the position of each degree of freedom with time.
CPE.6 Pointing Accuracy: The pointing requirements for each degree of freedom may require difficult to design hardware in order to achieve.
CPE.7 System Validation: The pointing requirements for each degree of freedom may require validation methods with high resolution and difficult to design or use.

6.0 Team Skills and Interests

Critical Project Element	Team Member(s) Associated skills/interests
DAQ and Motor Cost	Mandy: Handled large budgets in the past. Ryan: Kept extensive budget records for spending.
Access to Wind Tunnel	Mandy: Organizational skills. Kristian: Point of contact with Prof. Farnsworth.
Load Resistance	Brandon: Knowledge of structures and aerodynamics. Ryan: Knowledge of structures and aerodynamics.
Mechanical Linkages	Kristian: Background in SolidWorks and willing to learn more. Brandon: Background in SolidWorks and willing to learn more in addition to machine work. Ryan: Background in SolidWorks and machining. Willing to learn more.
LabVIEW Software	Mandy: Some background in LabVIEW and willing to learn more. Kyle: Some background in LabVIEW and willing to learn more. Ryan: Some background in LabVIEW and willing to learn more. Alex: Willing to learn about LabVIEW. Nick: Willing to learn about LabVIEW.
Pointing Accuracy	Nick: Software background. Alex: Electronics background. Anna: Electronics background.
System Validation	Kyle: CAD background. Nick: Software background. Anna: Electronics background and willing to learn more. Brandon: Software background and Mechanical background.

7.0 Resources

Critical Project Element	Resource/Source
DAQ and Motor Cost	ITLL Equipment - DAQ modules and motors need to be acquired from suppliers. DAQ modules can be borrowed for testing from ITLL. EEF - Additional funds can be sought through Engineering Excellence Fund for DAQ modules and motors.
Access to Wind Tunnel	Prof. Farnsworth and Matt Rhode- Interfacing with for delivery/assembly dates. We will also interface with them to gain access to the tunnel to examine test section.
Load Resistance	Matt Rhode - Can verify designs and drawings for positioning system. He can also help check basic calculations for loading of the system. ITLL Workshops - ITLL holds SolidWorks workshops
Mechanical Linkages	Matt Rhode - Has knowledge of mechanical systems and can help with properly linking and gearing the system ITLL Workshops - ITLL holds SolidWorks workshops
LabVIEW Software	Dan Godrick - Leads LabVIEW software workshops and is responsible for the National Instruments DAQ equipment at the ITLL Trudy Schwartz - Has experience with implementing LabVIEW VI's for experimentation and control Prof. Farnsworth – Has experience with writing and implementing LabVIEW VI’s for experimentation and control.
Pointing Accuracy	Matt Rhode - In conjunction with mechanical linkages, Matt can help with making sure gearing is correct and tolerances within the gearing is met. Bobby Hodgkinson - Has knowledge of motors and motor control.
System Validation	Prof. Farnsworth - Previous knowledge and experience with wind tunnels and associated positioning systems.

Sources

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