University of Colorado
Department of Aerospace Engineering Sciences
Senior Projects – ASEN 4018

COMPASS
Conceptual Design Document

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1 Information

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2 Project Description

2.1 Project Purpose

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 angular rate of 64 deg/s in yaw, pitch, and roll and 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.

2.2 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, angular rate/position or plunge height, 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 1 below outlines the above through a system functional block diagram.

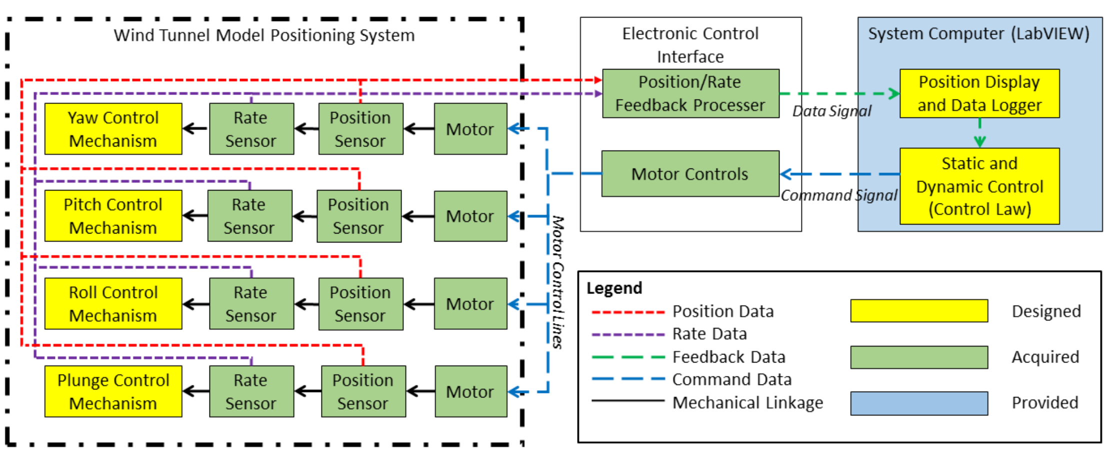

Figure 1. Functional Block Diagram for Wind Tunnel Model Positioning System

2.3 CONOPS

The model positioning system will be able to accurately control the orientation of an object in the wind tunnel both statically and dynamically by following the process displayed in Figure 2 below in the concept of operations. It includes the model positioning hardware integrated with both the wind tunnel and a computer to control movements and positions through LabVIEW. The four ranges of motion displayed are roll, pitch, yaw and plunge. In Step 2 of the CONOPS static position means that the system will be capable of moving to a specific position defined by the four ranges of motion input into the computer and hold that position with a wind tunnel produced flow moving over the model and positioning system. Dynamic position command refers to the hardware's capability to perform a motion based on an input rate and position profile in a wind tunnel produced flow. This includes one range motion and potentially coupling up to all four ranges of motions. The user will produce this motion with an initial and final position input in LabVIEW. The system will be able to report the position over time and write it to a file via LabVIEW.

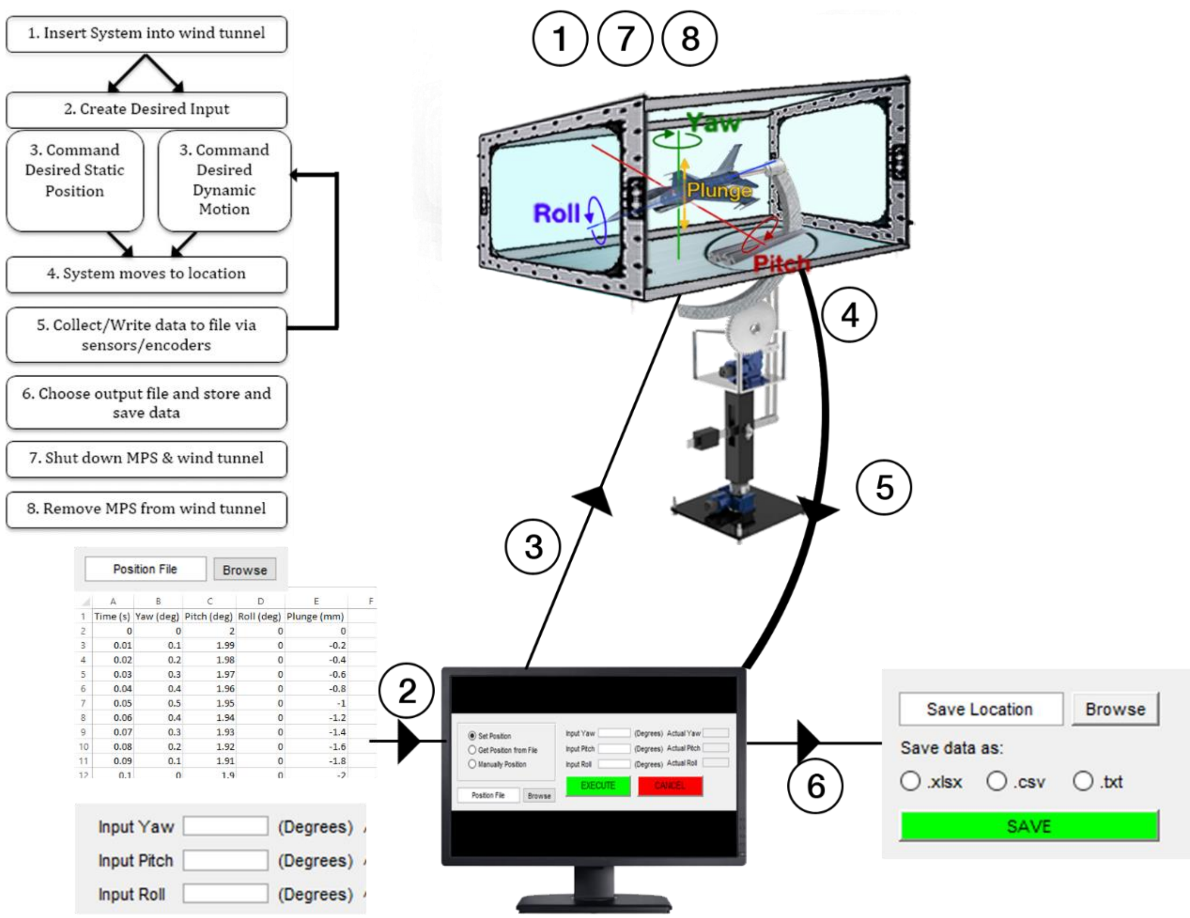

Figure 2. Concept of operations for COMPASS system

2.4 Functional Requirements

In order to lead COMPASS to fulfilling design requirements, functional requirements have been established. These functional requirements are divided into three categories based on system needs. **FR 1** discusses the positioning of the model, **FR 2** discusses how the software and hardware shall interface with COMPASS at required specifications, and **FR 3** discusses integration of COMPASS with the wind tunnel itself.

FR 1 COMPASS shall be able to position the model.
FR 2 COMPASS software shall interface with the user and the hardware such that models can be positioned at the required range and rate.
FR 3 COMPASS shall be integrated with the wind tunnel test section.

3 Design Requirements

FR 1 COMPASS shall be able to position the model.

DR 1.1 The positioning system shall have the ranges defined in **DR 1.1.1** through **1.1.4**.
Motivation: The intent is to ensure the wind tunnel and/or model are undamaged if an angle that is too large is input.
V&V: Successful verification of **DR 1.1.1** through **1.1.4**.

DR 1.1.1 The pitch range of the model shall be ±30° minimum.
Motivation: The intent is to give enough range in pitch to simulate real world situations.
V&V: Test – With an input of ±30° pitch, using a digital protractor, the angle shall be checked.

DR 1.1.2 The yaw range of the model shall be ±30° minimum.
Motivation: The intent is to give enough range in yaw to simulate real world situations.
V&V: Test – With an input of ±30° yaw, using a digital protractor, the angle shall be checked.

DR 1.1.3 The roll range of the model shall be ±45° minimum.
Motivation: The intent is to give enough range in roll to simulate real world situations.
V&V: Test – With an input of ±45° roll, using a digital protractor, the angle shall be checked

DR 1.1.4 The plunge range of the model shall be ±10 cm minimum.
Motivation: The intent is to give enough range in plunge to simulate real world situations.
V&V: Test – With an input of ±10 cm, using calipers, the range of motion shall be checked.

DR 1.1.5 The position and rate of the model given from the sensors shall check if they stay within specified ranges.
Motivation: The intent is that the input position and rate shall be able to be verified from sensor data.
V&V: Successful verification of **DR 1.1.5.1** through **1.1.5.2**.

DR 1.1.5.1 The input position shall be given from sensor data, explained more in **DR 2.2**.
Motivation: The intent is the input position shall be able to be verified to within 0.1°.
V&V: Inspection – When a 1° pitch/roll/yaw, or 5mm plunge, is input, a digital protractor or similar instrument is used to insure that the position changed 1° or 5 mm, with tolerances given below in **DR 1.1.5.1.1** through **1.1.5.1.4**.

DR 1.1.5.1.1 The accuracy for pitch is within ±0.1°.
Motivation: The intent is to ensure the model is positioned as close to the user's desired position as possible.
V&V: Test – After a given movement, a digital protractor will be used to ensure accuracy.

DR 1.1.5.1.2 The accuracy for yaw is within ±0.1°.
Motivation: The intent is to ensure the model is positioned as close to the user's desired position as possible.
V&V: Test – After a given movement, a digital protractor will be used to ensure accuracy.

DR 1.1.5.1.3 The accuracy for roll is within ±0.5°.

Motivation: The intent is to ensure the model is positioned as close to the user's desired position as possible.
V&V: Test – After a given movement, a digital protractor will be used to ensure accuracy.

DR 1.1.5.1.4 The accuracy for plunge within ±0.5mm.
Motivation: The intent is to ensure the model is positioned as close to the user's desired position as possible.
V&V: Test – After a given movement, a digital protractor will be used to ensure accuracy.

DR 1.1.5.2 The positioning system shall be capable of moving at 64 deg/s.
Motivation: The intent is that the input rate shall be able to be verified to within 1 deg/s.
V&V: Test – When a 5° pitch/roll/yaw, or 2.5cm plunge, is input, the movement shall be timed and the rate shall be calculated to ensure that it meets the 64 Hz minimum.

DR 1.2 The position of the system shall be given from sensor data for both static and dynamic cases.
Motivation: The intent is that the model is positioned correctly whether it is static or undergoing dynamic motion.
V&V: Successful verification of **DR 1.2.1** and **1.2.2**.

DR 1.2.1 The system shall have 4 Degrees of Freedom.
Motivation: The intent is to be able to have 4 Degrees of Freedom: roll, pitch, yaw, plunge.
V&V: Demonstration – The system shall be moved to prove that 4 Degrees of Freedom are allowed.

DR 1.2.1.1 The motors shall be able to resist the load applied on a NACA 0012 airfoil, suggested by Professor Farnsworth.
Motivation: The intent is that the motors shall be able to move the model when the wind tunnel is not operating, and when the wind tunnel is operating and applying force to the model.
V&V: Test – Apply torque to the model to ensure the motors shall withstand it.

DR 1.2.1.2 The linkages of gears and motors shall very minimal slippage.
Motivation: The intent is to ensure that there shall be no large slips between gears or the motors breaking off during testing.
V&V: Test – The gears shall be tested to ensure correct meshing between gears and the motors shall have force applied to them to ensure they stay connected to the system.

DR 1.2.1.2.1 The slippages shall be no more than 0.05° for pitch, yaw, or roll and 0.1 mm for plunge.
Motivation: The intent is to ensure any slips that happen do not impede testing.
V&V: Test – The gears and motors shall be tested with applied loads.

DR 1.2.2 When the model is in motion, the minimum rate shall be up to 64 deg/s.
Motivation: The intent is that when the model is in motion, it shall move at 64 deg/s – allowing for real world simulations to be performed.
V&V: Test – Calculate the rate from acquired time stamps and position readings.

FR 2 COMPASS software shall interface with the user and the hardware such that models can be positioned at the required range and rate.

DR 2.1 The LabVIEW user interface shall facilitate the user's operation of the COMPASS machinery.
Motivation: The intent is to ensure the user can easily and effectively use the COMPASS system.
V&V: Validation of **DR 2.1.1** through **2.1.4**.

DR 2.1.1 Implementation of the COMPASS LabVIEW software shall run independently of the pre-existing wind tunnel LabVIEW interface.

Motivation: The intent is to operate as independently as possible from the wind tunnel software. Neither should need to be present for the operation of the other.

V&V: Demonstration - The COMPASS and wind tunnel will be capable of operation separately from one another.

DR 2.1.2 The COMPASS LabVIEW software shall accommodate user input commands of static position values.

Motivation: The intent is for the user to be able to either set a constant position for testing, or actively control the position during testing.

V&V: Testing - Static and user input positions shall be achieved and measured at the required accuracies and rates as defined in **DR 1.3.1.** and **1.3.2**.

DR 2.1.3 The COMPASS LabVIEW software shall accommodate a user selected file of positions versus time at a given interval; this is to be input in a specified format.

Motivation: The intent is for the system to dynamically control the model. The user should be able to control the model through any series of motions within the range and rate capabilities of the system.

V&V: Testing – Dynamic control shall be achieved and measured at the required accuracies and rates as defined in **DR 1.3.1** and **1.3.2**.

DR 2.1.4 The COMPASS LabVIEW software shall be user-friendly.

Motivation: The intent is for COMPASS to be intuitive and simple to operate through the LabVIEW user interface since the software and hardware will be completely new to users.

V&V: Testing – A focus study shall be performed with the customer to determine ease of use and provide feedback.

DR 2.2 COMPASS shall incorporate position feedback in order to control the system via the control law as well as to display the position to the user and save to file.

Motivation: Control law will be the most accurate and efficient method of controlling the position of the system. Accurate feedback is also necessary for effective flow field analysis.

V&V: Validation of **DR 2.2.1** through **2.2.3**.

DR 2.2.1 The linear plunge feedback sensors shall be calibrated to measure plunge within 0.25mm.

Motivation: The accuracies given above are half of the required accuracy for the positioning and orienting capabilities of the system. The feedback shall be within this range to verify the actual position satisfies those requirements.

V&V: Testing - Physical measurements, either with rudimentary materials or with an optical measuring system, shall be taken to compare the feedback sensor readings.

DR 2.2.2 The angular feedback sensors shall be calibrated to measure angles within 0.05°.

Motivation: The accuracies given above are half of the required accuracy for the positioning and orienting capabilities of the system. The feedback shall be within this range to verify the actual position satisfies those requirements.

V&V: Testing Physical measurements, either with rudimentary materials or with an optical measuring system, shall be taken to compare the feedback sensor readings.

DR 2.2.3 The feedback data shall be displayed in real-time as well as write to file.

Motivation: The intent is to be able to monitor the position in real-time as well as choose the file type and location for the data to be saved to.

V&V: Demonstration – The user interface shall display the model position in real-time, as well as allow the user to choose the file type and location.

DR 2.2.4 The data acquisition system shall sample model position via the feedback sensors at 1280 Hz.

Motivation: The intent is to sample the position at a rate which can accurately reflect the actual position. The system is required to position the model at 64 deg/sec. To accurately read positions at a 0.1° accuracy, the sensors shall sample at a 0.05° resolution at the full 64 deg/sec. This results in an absolute minimum of 1280 Hz.

V&V: Inspection – The number of samples taken over a given period of time can be used to determine the sampling rate.

DR 2.3 COMPASS shall incorporate safety within the software to determine if the commanded static or dynamic position is within the capabilities of the COMPASS hardware.

Motivation: The intent is to protect the system from the user. If the user mistypes an input value or the input file intends to position and orient the model to a position or at a rate outside of the capacities of the hardware, the system should not attempt to carry out that command.

V&V: Testing – The software shall stop execution of the command and notify the user if the input commands or file would command the system to operate outside of its capabilities.

DR 2.4 COMPASS shall couple motion for the different degrees of freedom to result in smooth, realistic motion.

Motivation: The intent is to simulate the model's motion as realistically as possible in order to properly analyze the flow fields. The model should achieve the desired position with couple motion in multiple degrees of freedom such as a coordinated turn.

V&V: Testing – Verification of **DR 2.4.1**

DR 2.4.1 COMPASS software shall determine the rate at which to move in each degree in order to achieve the desired position at the same time.

Motivation: The intent is to simulate the aircraft motion as realistically as possible.

V&V: All degrees of freedom of the model shall achieve the commanded position at the same time in dynamic testing.

FR 3 COMPASS shall be integrated with the wind tunnel test section.

DR 3.1 COMPASS shall prevent damage to itself and the wind tunnel in the event of a power failure.

Motivation: The prevention of damage to the wind tunnel and the COMPASS hardware is critical due to the cost of both systems.

V&V: Requirement verified in section **DR 3.1.1** through **3.1.2**

DR 3.1.1 In the event of a power outage the system shall prevent any movement of the hardware therefore not allowing the positioning system or model to touch the test section walls or rest of the wind tunnel.

Motivation: With motors and moving parts built into COMPASS, the prevention of movement through a mechanical safety is crucial when power to the system is lost.

V&V: Test – Cutting power to COMPASS in an open space and observing how the system behaves with safety measures installed.

DR 3.1.2 COMPASS's mechanical linkages shall be designed with a safety factor so COMPASS does not break in the wind tunnel under a load.

Motivation: A hardware failure could result in an expensive model or piece of COMPASS breaking off and causing significant damage to the wind tunnel or model positioning hardware.

V&V: Test – Apply small initial loads to the model positioning system outside of the wind tunnel that would simulate the torques a model in the wind tunnel shall put on COMPASS.

DR 3.2 The installation/assimilation of the model positioning system shall not impede the basic functions of the wind tunnel.

Motivation: The intent is to provide an efficient positioning system without restricting experiment capability.

V&V: Requirement verified in **DR 3.2.1** through **3.2.3**

DR 3.2.1 The COMPASS hardware in the test section shall not block more than 10% of the total cross sectional area.

Motivation: The intent is to not restrict or disrupt the flow in the wind tunnel.

V&V: Inspection – The max cross sectional area will be measured and compared to the total cross sectional area of the wind tunnel.

DR 3.2.2 COMPASS will not allow any flow to leave the test section at the point of integration.

Motivation: The intent is to install the hardware so that the wind tunnel flow does not leave the test section through any gap in the physical connections.
V&V: Test – Run a low speed flow with the COMPASS hardware in the test section and the use of a simple wind speed detection object, such as a light string, at all points of integration.

DR 3.2.3 The hardware shall be installed and removed from the test section without risk of damaging the wind tunnel if done properly.

Motivation: The intent is to minimize the risk of unnecessary damage to the wind tunnel and COMPASS.
V&V: Test – Come up with a set of instructions that can be followed easily and repeated for setup and removal of the COMPASS hardware that do not harm the wind tunnel or positioning system.

4 Key Design Options Considered

In order to properly examine the available design options for the COMPASS system, the design requirements for the system must be considered. Four main areas of design were considered to fulfill the design requirements. These four areas were the pointing structure, software, hardware, and sensors. The software and hardware categories specifically address the need for the system to interface with both user and the wind tunnel. These areas and how they break down to specific categories is shown as a design tree in Figure 3. The pointing area first specifies that the structure will be mounted on the floor. From there, two main options for mounting were considered. The first was the sting and the second was strut. Both of these methods were further broken down into two categories each to examine different designs. Software was broken into three categories, but the software to be used for controls was the main concern. Hardware included the electrical interface between the software and the motors as well as the motors themselves. Electrical was examined to see if a commercial off-the-shelf (COTS) or custom system would be more viable. The motor design options included all electrical motors, but this was divided up into different motor types with the goal of finding a type of motor that directly satisfy the requirements. The last area of sensors was addressed specifically as sensors will be important for the pointing requirements of the system. Four separate types of sensors were examined in this area. Each design option was considered by establishing a basic list of pros and cons for comparison. Final design options were then selected using a trade study outline in Section 5 of this document.

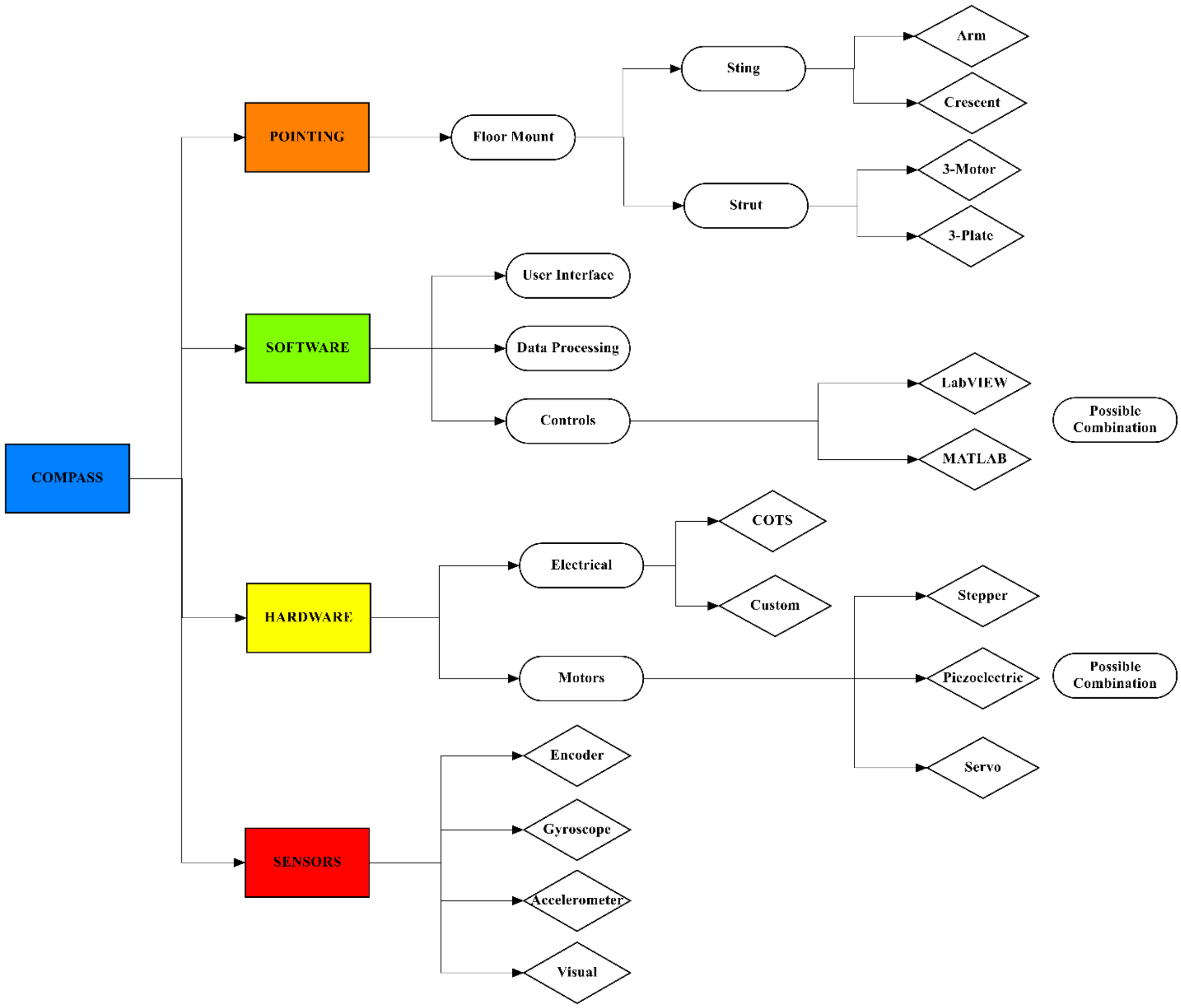

Figure 3. COMPASS Design Tree

4.1 Pointing Structure

COMPASS will use a pointing system to fulfill **DR 1.1.1** through **DR 1.1.4**, which state COMPASS's specific range requirements in roll, pitch, yaw, and plunge for the model. The pointing aspect of the system will be responsible for positioning the model with minimum ranges of ±30 deg in pitch and roll, ±45 deg in yaw, and ±10 cm in plunge. Some of these systems can position the model in plunge but others require modification for movement in the z-axis. The two main positioning types are categorized by the interface with the model, either a sting mount or strut mount.

The pointing system will be floor mounted per the restrictions of the testing section of the wind tunnel. This will allow much of the weight of the system to be supported by a structure and the floor rather than the test section structure itself. This design will mostly likely require the system to be installed in two parts as to clear the test section and its supporting frame. This will satisfy the request of the customer that the sides and other elements of the tunnel not be altered as per **FR 3** and specifically **DR 3.2**.

4.1.1 Sting

The sting interface is the most common in wind tunnel systems due to its minimal impact on the flow field around the model. The mount connects to the rear of the model in place of the vertical surface or out the back such that the sting aligns with the model's geometric center. This mount type is typically used with a sting balance which slides in between the model and the mount to calculate the forces and moments. The sting balance is more universal when switching between models.

4.1.1.1 Arm

The sting arm is a relatively low cost solution because it relies on lever arms to pitch the model. Each of these arms can be simple beams which leads to easy manufacturing. Since this system is practical for pitch and plunge, a turntable would be added for the yaw component. Roll would also have to be added using devices such as a roller head which are designed to work with the sting setup.[1] Plunge is easily added by moving the mast or the whole array up and down relative to the test section.[2] An example of how this system is set up is illustrated in Figure 4 and a list of the pros and cons of such a system are displayed in Table 1.

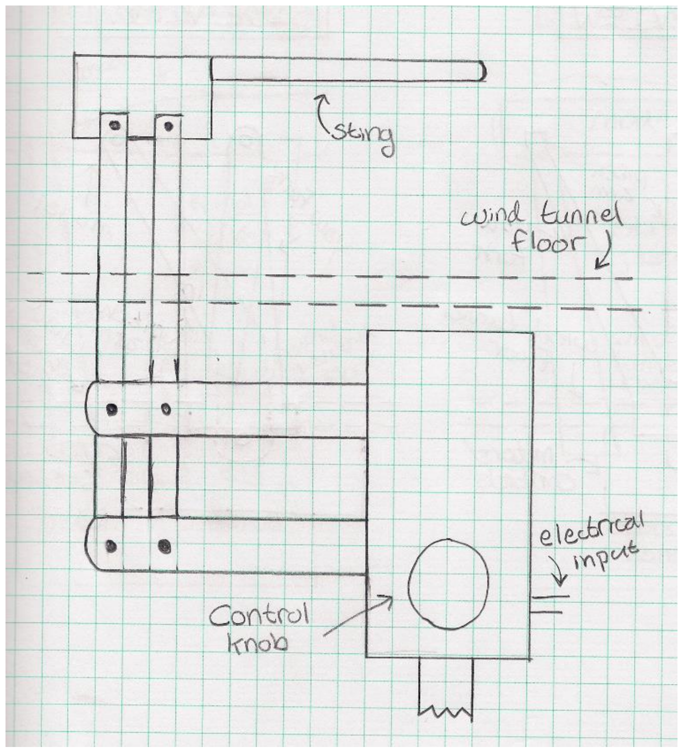

Figure 4. Sting arm sketch

Table 1. Pros and Cons of Sting Arm.

Pros	Cons	Unknown
Common model interface Easy manufacturing Easy roll/yaw modifications Lightweight	Limited pitch Needs modification for roll/yaw Rotation affects translation	Loading capabilities

4.1.1.2 Crescent

The crescent sting is slightly more complicated than the arm because it uses a circular rail to pitch the model. The rail system can circle below or above the model and then be set onto a turntable for yaw motion. This system by itself does not have a roll component but it is compatible with a roll head.[3] The circular design of the pitch and yaw controls ensure that the model will stay centered relative to the pitching point. Plunge is only achievable by moving the whole system up and down in the wind tunnel.[4] This configuration is shown in Figure 5 and its pros and cons are shown in Table 2.

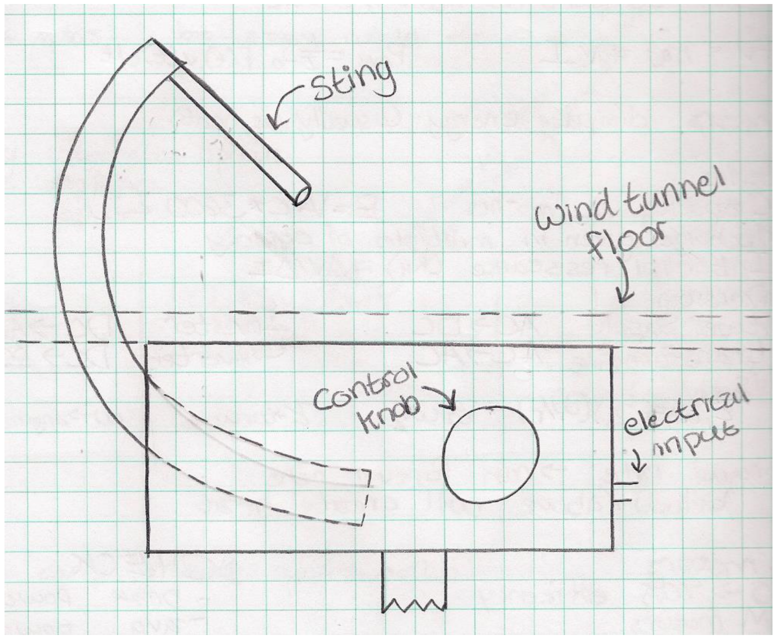

Figure 5. Crescent Sting sketch.

Table 2. Pros and Cons of Crescent Sting.

Pros	Cons	Unknown
Common model interface Medium difficulty manufacturing Easy roll modifications Easy yaw incorporation Lightweight Uncoupled translation and rotation	Limited pitch Needs modification for roll Translation requires translation of whole system	Loading capabilities

4.1.2 Strut

This system uses one or more struts to hold the model aloft in the wind tunnel. At least three struts must be used to allow movement in three or more directions. The strut interface is less widely used due to the effect on the flow by the struts. However with more struts a higher load can be applied to the system.

4.1.2.1 Three Plate

The three plate struts change the position height of each strut to achieve a pitch and roll for the model. However the roll angle is always small for this system because the struts are fixed to the floor of the wind tunnel and thus cannot move closer as the aircraft rolls. Pitch is less restricted and only depends on the distance from the front strut to the rear struts.[5] Yaw motions are accomplished by mounting the system on a turntable at the base of the wind tunnel, to turn the struts and model. The aircraft can also be moved in plunge by decreasing or increasing the length of each strut by the same amount.[6] An illustration of this concept is shown in Figure 6 along with a lift of pros and cons in Table 3.

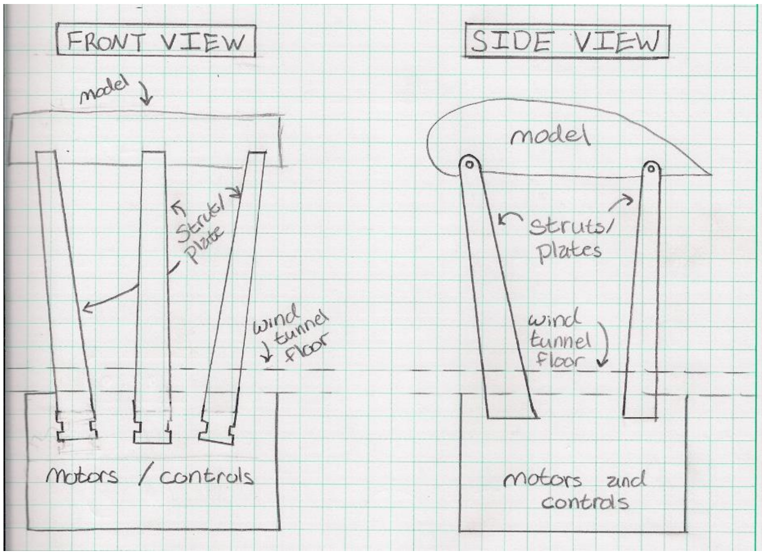

Figure 6. Three Strut Plate sketch.

Table 3. Pros and Cons of Three Plate Strut

Pros	Cons	Unknown
Can handle very heavy loading Medium skill manufacturing Good pitch control	Model interface must be built into specimen Limited roll capabilities Flow interference Complicated modification for yaw turntable	None

4.1.2.2 Three Motor

Lever arms are used in the three motor set up. Two fixed arms hold one section of the plane while a pitch arm rotates to pitch the model up or down. This range is determined by the distance between the pitch arm and fixed arms connection points with the model. All arms meet at the floor of the tunnel where they connect to a base which is typically allowed to turn and provide yaw. This system has no roll capabilities because of the fixed arms. Manufacturing this system is much less complicated however because there are fewer moving parts and more rigidity.[7] Figure 7 shows an example of this system and Table 4 lists its pros and cons.

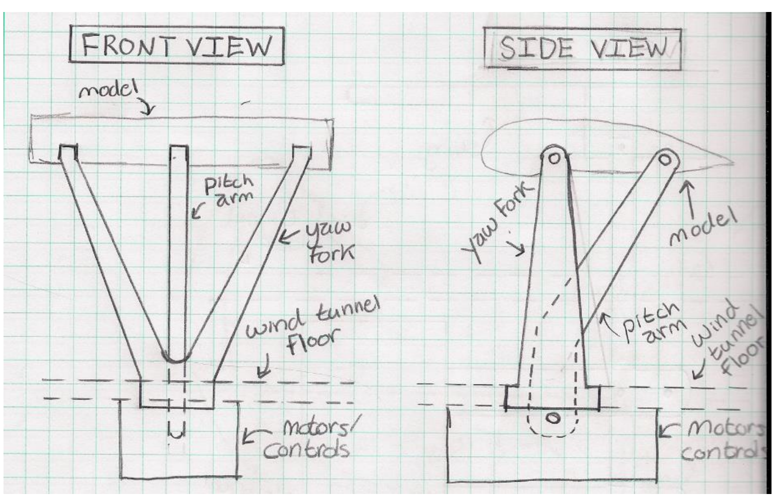

Figure 7. Three Strut Motor sketch.

Table 4. Pros and Cons of Three Motor Strut.

Pros	Cons	Unknown
Can handle very heavy loading Easy manufacturing Pitch control medium range Simple yaw control	Model interface must be built into specimen No roll capabilities Flow interference	Motor requirements

With the research conducted into each positioning system, basic system capabilities were found. These system capabilities are outlined below in Table 5. The capabilities show that the strut structures have a limited range of movement when compared to the sting structures. However, each of these structures would require modifications to achieve movement in all degrees of freedom as specified by **DR 1.2.1**.

Table 5. General capabilities of each system based on design research

	Sting Arm	**Sting Crescent**	**Strut 3 Motor**	**Strut 3 Plate**
Range				
Yaw	Turntable Needed	~70 deg	~40 deg	Turntable Needed
Pitch	~25 deg	~60 deg	~60 deg	~30 deg
Roll	Modification	Modification	~0 deg	~10 deg
Plunge/Side	Yes /No	No /No	No/No	Minimal /No
Loading	Medium	Medium	High	High
Size				
Overall	Small to Medium	Small to Large	Medium to Large	Medium to Large
SA / flow	Minimal surface area behind flow	Minimal surface area behind flow	Large surface area in flow	Large surface area in flow
Data collection device	Sting balance	Sting balance	Load cells/strain gauges	Load cells/ strain gauges

4.2 Software

The main software needs of COMPASS focus largely on the control of the system per **FR 2.** This control includes the user interface as well as position feedback, or control law. The goal of the user interface is for any user of the wind tunnel to be able to easily set the position or motion of the COMPASS system. The goal of the control law is to successfully execute the commands of the user.

4.2.1 Controls

The controls elements of the design stem from **FR 2**, which states that COMPASS shall interface with the user as per **DR 2.1** as well as incorporate position feedback via control law, display position, and save the data, as per **DR 2.2**.

4.2.1.1 User Interface

In order to interface with the user, LabVIEW will be the best option due to its ability for custom graphical user interfaces (GUIs) (**DR 2.1.1**). Using LabVIEW will also allow for more familiarity with past users, as the previous wind tunnel's software used LabVIEW. Many users will already be familiar with it, and no further software learning will be necessary, unlike MATLAB which may be unfamiliar to users.[8]

Table 6. User Interface Pros & Cons

	Pros	**Cons**
LabVIEW	More user familiarity Already in use by Wind Tunnel Low-Cost	Licensing Long start-up time
MATLAB	Free/cheap for educational purposes	Many users might be unfamiliar Expensive on its own

4.2.1.2 Position Feedback/Control Law

In order to incorporate feedback via control law, the software shall need to be able to model the inputs and perform calculations (**DR 2.2.1, 2.2.2, & 2.2.4**). The software must also be able to save and output the data to a file (**DR 2.2.3**). Both LabVIEW and MATLAB have large storage libraries and programming capabilities, but both have some drawbacks. LabVIEW is slow for calculations and has some limited capabilities due to the need for certain required files. MATLAB has some confusing syntax initially and is slow at importing and exporting data.[9]

Table 7. Position Feedback Pros & Cons

	Pros	**Cons**
LabVIEW	Large data storage libraries Parallel loop programming	Slow calculations Limited capabilities
MATLAB	Control Law/Simulink Large data storage libraries Quick calculations Can interface with other programs well Functions to increase productivity	Syntax can be confusing at first Slow to import/export data to other programs

After looking over the pros and cons between MATLAB and LabVIEW, the best option is to use a combination of both. LabVIEW will be used for the user interface due to current user familiarity. MATLAB will be used for modeling and calculations due to its ability to perform quick control law calculations through Simulink and numerical computing. Though importing and exporting to and from MATLAB can be slow, it will be better for computing than LabVIEW.

4.3 Hardware

The hardware elements of the COMPASS design have been derived from **FR 1**, which states COMPASS shall be able to position the model. Specifically, this includes the Motors and Electrical Interface to address the position and rate requirements as well as load resistance laid out in **DR 1.2**. It should be mentioned that a combination of the following elements could be used. As such, some elements have been evaluated based upon possible placement. For example, Motors may be evaluated upon which degree of freedom they have been assigned to control. This has been done because the loads each degree of freedom will see will most likely differ.

4.3.1 Electrical

COMPASS will require a great deal of communication with a lab station. The electrical hardware within the system will need to gather position and angular rate data as well as store it and send position commands back to COMPASS in order to control its movement. The sensors and motors within COMPASS will likely require analog to digital conversion (ADC) and data acquisition (DAQ). For this reason two options for electrical hardware have been considered; the first being commercial off-the-shelf (COTS) electrical hardware. This hardware usually includes DAQ, ADC and DAC abilities. These systems come with prebuilt circuit boards with well-defined specs and in some cases even software that makes it extremely easy to interface with a lab station. This would greatly decrease the amount of man hours needed to learn the system and implement it into

COMPASS. In addition to the ease of use, COTS hardware is easy to obtain. The ITLL owns and rents out many DAQ systems. These systems could be rented or purchased from the ITLL at a lower cost than off of the shelf. However, if the team decides to purchase directly from the supplier, there are numerous systems out there that can successfully fulfill the needs of COMPASS. Having a prebuilt, well-defined piece of hardware will reduce scheduling risks and will simplify the electrical integration of COMPASS.

Some COTS DAQ systems can be extremely expensive. For instance, National Instruments charges \$1,648 for a 400 V_{rms} analog input module.[10] The price of the electrical hardware will continue to rise as the entire system is put together. There are other cheaper alternatives out there; however you sacrifice quality for price. As the system gets more complex, the budget becomes more of a constraint. Although having a prebuilt system is extremely convenient, it could leave a huge dent in the budget. Pre-built systems also take some understanding away from the group. The circuitry is pre-assembled and therefore the group assumes it will work without truly understanding what is going on behind the scenes. If the circuit needs to be repaired or altered, the team would need to spend additional man hours figuring out how it works and how it can be safely altered without damaging the hardware or its functionality. The electrical hardware would be also constrained to what is available on the market. The exact needs of COMPASS may not be met perfectly by any one system on the market. Sacrifices may need to be made, either in the budget or elsewhere to accommodate for the prebuilt electrical hardware. The pros and cons of using COTS electrical hardware within COMPASS are shown in Table 8.

Table 8. COTS Electrical Hardware Pros & Cons

Pros	**Cons**	**Unknown**
Interface with LabVIEW is simple. Fewer man hours needed to learn/implement. Hardware may be available through the ITLL. Well defined system specs.	Can be quite expensive. Miss out on learning associated with creating the system ourselves. Limited to what is available off the shelf.	None

The second option available in regard to electrical hardware is a custom built control board. In essence, the team would assemble their own board capable of DAQ, ADC and DAC. The board would provide all of the same capabilities as a COTS unit, but it would be custom tailored to COMPASS's needs. Due to the fact that it was designed and manufactured by the team, they would fully understand its capabilities and limitations. Any alteration or repairs would require little man hours because of the deep understanding of the system at a fundamental level. In addition to this deep understanding, a custom control board could be inexpensive, as the team would need to purchase only fundamental components but the assembly and design would be done completely in house. That being said, the design and manufacturing of this board would require a huge amount of work. On top of that, the team may lack the technical skills needed to design or manufacture such a system. With such a complex piece of hardware, this could put a huge strain on scheduling and could potentially push back the development of the entire project. As with the COTS electrical hardware, the pros and cons of a custom built control board are shown in Table 9.

Table 9. Custom Control Board Pros & Cons

Pros	**Cons**	**Unknown**
Custom tailored to the needs of COMPASS. Team would fully understand the abilities and limitations of the DAQ system. Inexpensive.	Number of man hours needed to design/manufacture would be large. Team may lack experience needed to manufacture the system. Hardware/software development could be very difficult.	None

4.3.2 Motors

The key options considered for motors for the control of COMPASS include all electrical motors. The types of electric motors included in this study are Stepper Motors, Piezoelectric Motors, and Servo Motors. Other modes of actuation, such as pneumatics, have not been considered due to familiarity. It has been reasoned that working with electric motors would be more feasible in terms of time and available resources.

4.3.2.1 Stepper Motors

Stepper motors are brushless DC motors that rotate incrementally by converting input pulses that move the shaft by a fixed angle. These motors contain a large number of poles that allow for the motor to rotate between each pole, precisely and accurately. This allows for the motor to run in an open loop - without any feedback elements for position control.[11]

Table 10 illustrates the pros and cons of stepper motors. One of the best advantages for stepper motors is their ability to run in an open loop, thus not requiring any feedback elements. Operating in this way, the design and application of the motors would not be as expensive nor as complicated. The stepper motor has a particular disadvantage in regards to loss of torque while running at speeds past 50 Hz. This affects the ability to meet the requirements for angular rate as defined by **DR 1.1.5.2**. This deficiency is compounded with the application of microstepping since the motor torque is reduced up to 30%. Microstepping would be needed to achieve the required pointing resolution detailed in **DR 1.2.1.1.**

Table 10. Stepper Motor Pros and Cons

Pros	Cons	Unknown
Less complex and cheaper if run as open loop system[12] Capable of high torque at low speeds[13] Capable of holding a position completely still[13] System is more reliable overall with no brushes and if run without feedback elements[13]	Not capable of running at speeds past 50 Hz without significant losses in torque[11] Not efficient in power consumption, and thus have a smaller power to weight ratio[12] Overheating can occur for continuous use past speeds of 25 Hz[12] Can skip steps, or slip, if the motor stalls Torque experiences exponential decay when motor microstepping[14]	Would need microstepping to reach required resolution specified in **DR 1.2.1.1**

4.3.2.2 Piezoelectric Motors

The basic principle behind the mechanics of piezoelectric motors is that the piezoelectric materials change shape when voltage is applied. This classification of motors takes advantage of these material properties to make linear actuators and rotary motors. In the case of the linear actuator, ceramic piezoelectric motors "walk" along the actuator to move it.[15] This can be considered to be very similar to stepping in the rotary motors. The stepping function allows piezoelectric motors to operate in a fashion very similar to stepper motors, but piezoelectric motors are capable of higher resolution. Resolutions as small as single micrometer have been achieved.[15] The linear actuators were not considered as options because, in general, their range of movement is limited to around 10cm. This is unfortunate since the linear actuators are capable of 40N of force. Rotary motors have full revolution movement and can be selected and geared as necessary to fulfill the requirements of COMPASS.

Table 11 below outlines the pros and cons of piezoelectric motors. The high precision while maintaining torque at high angular velocities is attractive, but the motors are expensive. The other attractive element of these motors is their size. They can be very small, but this generally means they cannot deliver the necessary torque to the control mechanism. There are piezoelectric motors available with high torque values, but selection is limited in this area and prices begin to reach $1000 per motor.[16] It is also unknown whether or not the motors would need additional equipment for control. It has been indicated that this is not the case but will need to be explored if the motors are selected. As mentioned earlier, each motor was evaluated in each degree of freedom. The results are shown in Table 11.

Table 11. Piezoelectric Motor Pros and Cons

Pros	Cons	Unknown
Capable of micrometer precision which means high resolution for system Capable of maintain torque at high angular velocities Small profile, or volume	Limited selection with high torque Motors are expensive	Control may require extra hardware provided by motor suppliers

4.3.2.3 Servo Motors

A basic servo motor is an AC or DC motor running in a closed loop control system, thus requiring feedback elements. These motors convert electrical current to mechanical energy, where the current can be varied by a servo amplifier. Small servo motors are used by hobbyists in radio-controlled airplanes and robots. They allow for precise and responsive control. Simple control circuits can be implemented on DC motors to create servo motors.[17]

Table 12 below lists the advantages and disadvantages with servo motors. A primary advantage of using servo motors is their ability to hold torque across varying speeds. Servo motors are capable of retaining their rated torque to about 90% at high speeds, thus allowing COMPASS to meet the speed requirements of **DR 1.1.5.2** without sacrificing torque.[18] The advantage of using an integrated control law could also be a drawback - the requirement of feedback elements means that not only does the hardware design become more complex and expensive, the resolution in positioning that the servo motors can achieve is dependent on the minimum resolution of the feedback elements.[11] Therefore meeting the pointing requirement of **DR 1.2.1.1** is dependent on the precision of feedback elements.

Table 12. Servo Motor Pros and Cons

Pros	Cons	Unknown
Integrated control law High torque available Capable of maintaining torque at high speeds (50 - 100 Hz)[11] Power efficient - consumes power when commanded[11]	Industrial motors large High torque motors expensive Following errors can occur from motor being driven by error signal[11]	Capable of high resolution - dependent on precision of feedback elements[19] Require low friction and correct gear ratio to retain torque at low speeds[18] Holding a position is dependent on minimum resolution of feedback elements[19]

4.4 Sensors

The trade space was intended to be open to a wide range of sensors. These can be seen in the design tree in Figure 3. However, it became obvious through research that encoders would be the only reasonably feasible option for obtaining the position and rate of the system. Visual sensors can be extremely accurate but would be hard to implement within the wind tunnel. Gyroscopes and accelerometers would be difficult to implement on the system, and the velocity and position would need to be inferred from the output of these sensors. This is not ideal as errors can easily build up in the system. Therefore, it was decided that the system would use rotary encoders for position and angular rate. The key comparisons were then conducted between absolute encoders and incremental encoders.

4.4.1 Rotary Encoders

A rotary encoder is also known as a shaft encoder. It is a mechanical device that can take position and velocity and convert it to a digital or analog code that can be fed back to a computer where the data can then be converted back into a position or velocity.[20] Rotary encoders have many uses including controls and robotics. Each of these encoders have specific advantages that could help COMPASS perform to the design requirements illustrated above. The two prevalent types of encoders are absolute and incremental.

4.4.1.1 Absolute Encoders

An absolute encoder gives the exact angular position of a shaft. For optical absolute encoders, this is established by assigning each position a unique binary signal. The internal sensor reads this signal and can send the exact position of the shaft back to the controller. Velocity of the shaft can be inferred from these sensors by deriving the position data over a given period of time. Table 13 below provides the pros and cons of absolute encoders.

Table 13: Absolute Encoder Pros & Cons

Pros	Cons	Unknown
Can determine current position Cutting power to the system does not affect measurements when power is restored	More complicated signals to decode. Cannot give information about motion. Microprocessor needed for signal conversion	Exact cost for high accuracy Which specific type is best: optical, mechanical, magnetic

4.4.1.2 Incremental Encoders

Incremental encoders deduct information about the velocity of the shaft from position increments in the sensor. Much like a hall effect sensor, the encoder produces a signal every time one of these increments passes a certain position. The velocity of the shaft is inferred by how many of these increments were received over a given time. Although used in many applications to find position from a known starting point, this encoder can be used to find velocity. The pros and cons of incremental encoders are shown in Table 14.

Table 14: Incremental Encoder Pros & Cons

Pros	Cons	Unknown
Can easily determine motion from output signal Can determine both position and velocity Extremely accurate Less expensive than absolute Up to 10,000 data increments (27 position points per degree)	Only provides data when being rotated Microprocessor needed for signal conversion	Which specific type is best: optical, mechanical, magnetic Hollow or solid shaft

4.5 Additional Considerations

4.5.1 Torque and Axial Loads

With the pointing and angular requirements outlined in **DR 1.2.1.1** and **DR 1.2.2**, the system must maintain these requirements when aerodynamically loaded. A NACA 0012 airfoil with chord of 0.1m and a span of 0.5m made of solid Aluminum 6061 on a 0.25m sting was used to estimate torque and axial loads for the sting and strut positioning system, respectively. The axial load is currently estimated to be about 10.8N, and the torque load is currently estimated to be about 3.265N-m while not under load. While under aerodynamic load, the torque is estimated to be about 8.299N-m. With proper gearing and robust motors, these torque values are feasible to reach. However, cost of the motors will need to be considered, and it is possible that a maximum model weight be defined for COMPASS as to avoid excessive loading.

4.5.2 Power Requirements

The project would prefer to have an uniform system, and this would lead the project towards procuring mostly COTS parts for the electrical interface. This is due to the current implementation of LabVIEW and a National Instruments (NI) DAQ Chassis in the wind tunnel. Custom parts may be difficult to interface with these components, and a uniform system NI components would be easier to maintain. However, the motors may require a large amount of power in order to actuate the system. This would possibly force the system to have a separate interface for supplying power to the motors. This system could be custom as only power will need to be supplied to the motors.

5 Trade Study Process and Results

5.1 Pointing Structure Trade

The trade study for the pointing structure consisted of four main categories. These four categories being: size, range, loading and manufacturability. A more in depth description of each be found below. Manufacturability was found to be the most important aspect of the pointing configuration. This was due to the fact that if a system is not easily manufacturable, it may not be worth the effort of trying to make it work in the first place. Reducing complexity in the system benefits the entire project. The second most important category was determined to be range. Certain types of pointing configurations provide a wider range of available angles in roll pitch and yaw. The chosen system will need to adequately fulfill the requirements outlined in **DR 1.1.1** through **1.1.4**. Loading was the next most important category. COMPASS will encounter different stress loadings depending on the geometry of the model as well as its orientation with respect to the oncoming flow. The pointing configuration will need to be able to handle these loadings without issue. The least important category for the pointing configurations is size. Depending on the configuration, the structure will block a certain amount of the test section. The goal is to keep this blockage to a minimum.

5.1.1 Trade Elements

5.1.1.1 Size

This category was selected for analysis based on the blockage requirement outlined by **DR 3.2.1.** The different design options each have some cross-sectional area that is blocking the flow within the tunnel. The goal is to have system where this is a minimum. Even though it is important to have this element at a minimum, it is the least important element because **DR 3.2.1** is hard requirement of the system, and this element evaluates the ease of achieving that design requirement.

5.1.1.2 Range

This category was selected for analysis based on the minimum range requirements listed in **DR 1.1**. The research conducted into each design option revealed that certain degrees of freedom are more restricted than others depending on the design and setup. The design restrictions would have to be overcome with modifications in order for the minimum ranges to be achieved in all degrees of freedom. To that end, this trade element evaluates the feasibility of achieving minimum range requirements with each design.

5.1.1.3 Loading

This category was selected for analysis based on the requirements under **DR 1.2.1.1** and **DR 1.2.1.2**. The COMPASS pointing system must be able to resist loads both under and not under aerodynamic loading. Some of the loading will be held by the motors, but it is also important for the structure to be able to resist the loads as well. As such, this elements addresses the feasibility of each design resisting aerodynamic loading with a model.

5.1.1.4 Manufacturability

This category was selected as the pointing structure will need to be machined and assembled by the team. Some components will be easier to machine than others, but those components may be included in a design that is difficult to assemble. Some designs may also require less total parts. For example, the 3-strut system needs three separate holding mechanisms to interface with the model while a sting only needs one or two parts. Although these structures may be slightly more difficult to machine, systems with less parts would be have greater manufacturability in terms of tolerance. Each part in each of these systems would require relatively high tolerance, and less parts to manufacture at this tolerances is desirable.

Table 15. Trade Matrix for Pointing Configuration

	Weight	Sting Arm	Sting Crescent	3-Strut Motor	3-Strut Plate
Size	10%	10	10	5	5
Range	30%	8	9	4	5
Loading	20%	6	6	8	7
Manufacturability	40%	7	9	7	6
Total	100%	7.4	8.5	6.1	5.8

5.2 Motor Design Trade

5.2.1 Trade Elements

For the motor design trade, five categories were considered for the study: stall/max torque, resolution, angular rate, cost, and size. Descriptions of each of these categories can be found below. Power consumption of the motors was not considered although the motors may draw a large amount of current under certain conditions. The primary concern for the motors is meeting the design requirements for pointing and load resistance outlined in **DR 1.2.1.1** and **DR 1.2.2.** To this end, stall/max torque, resolution, angular rate were weighted the heaviest. Cost was discovered to be an issue through research, but it did not receive a higher weighting due to deciding that full project success was the priority.

5.2.1.1 Stall/Max Torque

The stall/max torque category was examined in this trade study because this torque determines what the motors need to be capable of sustaining during wind tunnel flow. Sustaining a torque under aerodynamic load will be critical in satisfying the pointing requirements of **DR 1.2.1.1**. Considerations were made with regard to what torque the different motors can hold at varying speeds. The degree to which COMPASS is able to position under maximum torque load across varying speeds is indicated by larger numbers in this category. Since stepper motors degrade in torque capability at high speeds and servo motors function in the converse fashion, this category was similar across the three types.

5.2.1.2 Resolution

The resolution category was considered in this trade study to examine which motor provided the resolution sufficient to meet the requirements of **DR 1.2.1.1.** Larger numbers in this category correspond with to what degree each type of motor is capable of meeting the resolution requirements. Some aspects of this category were indeterminate, since the choice of feedback elements affect to what level of resolution servo motors can obtain.

5.2.1.3 Angular Rate

The aspect of angular rate was examined in order to sort out which motor is capable of meeting the **DR 1.1.5.2** design requirement of 64 deg/sec angular rate. Better ratings in this category show to what extent the motor is capable of meeting this requirement.

5.2.1.4 Cost

Cost was added as category for the trade study based upon research into the motors. Many motors are relatively cheap, but the motors that can directly meet the requirements of COMPASS outlined in **DR 1.2.1.1** and **DR 1.2.2** will cost at least $500 each. In the case of the piezoelectric motors, the cost can be as great as $1000 per motor. Although not weighted heavily compared to stall/max torque, resolution, and angular rate, cost will become a constraint on the final selection for motors.

5.2.1.5 Size

This category addresses the total volume the motor occupies. Part of the conceptual design is to have the motor actuating roll to be in the test section itself. To satisfy **DR 3.2.1,** the test section must not block more than 10% of the cross-sectional area of the wind tunnel. The size of the motor must be minimal in order for it to be installed in the test section. However, size is not weighted heavily since many motor options are small in size. The other degrees of freedom, yaw, pitch, and plunge, will be actuated externally from the system and, therefore, do not require a size requirement as stringent as that of roll.

5.2.2 Trade Study

In Table 16 shown below, the scale used for the trade study ranged from 1 to 10 with 10 being the most favorable. Weighting was assigned in terms of their perceived importance to the project within the motor trade space. The items are ranked from most important to least important. The specific weight assigned to each category is shown in the column next to each category. As discussed earlier, stall/max torque and resolution were seen as the most important and assigned a weight of 25% each. Angular rate and cost were the next most important elements and were weighted at 20% each. The final element, size, was weighted at 10%.

Table 16. Trade Matrix for Electric Motors

	Weight	Stepper Motor	Piezoelectric Motor	Servo Motor
Stall/Max Torque	25%	8	8	7
Resolution	25%	6	10	9
Angular Rate	20%	5	6	8
Cost	20%	8	2	5
Size	10%	8	8	6
Total	100%	6.9	6.9	7.2

From Table 16, it is reasonable to assume that the trade study did not have a conclusive result. The stepper motor and piezoelectric motor had the same results while the servo motor had only a slightly better result. Due to this issue, a second trade study was conducted. This trade study is shown below in Table 17. The study was simple in comparison to others conducted in this document, but it served the purpose of narrowing the trade space. The objective of this trade study was to examine the feasibility of using a certain motor to actuate a particular degree of freedom. The metric used for this study was a yes/no, or 1/0. For example, a servo motor may not be feasible to use for roll due to its relatively larger size. Therefore, the motor was given a 0 for roll, and this result can be seen in Table 17.

Table 17. Motors with Position Feasibility Matrix

	Stepper Motor	Piezoelectric Motor	Servo Motor
Pitch	1	0	1
Roll	1	1	0
Yaw	1	1	1
Plunge	0	0	1
Total	3	2	3

6 Selection of Baseline Design

6.1 Pointing Structure Baseline Design

The second most optimal pointing structure baseline design was the sting arm. The greatest detriment to it was the loading capability. This structure would rely completely on the capacity of the motors for load resistance, while the struts provide more structural support. The manufacturability was its next worst characteristic. In addition to precise calculations necessary to determine the conversion from arm motion to angle, there are many moving parts – each of which requiring precise machining, as well as difficulty in designing the interfaces between each part. It scored the maximum for size, as all the pieces within the wind tunnel are downstream of the model, so the flow would not be interrupted by the positioning system.

The optimal pointing structure baseline design was determined to be the sting crescent. This configuration also scored the maximum on size. The crescent body and any attached motors would be completely behind the test model so the flow would not be interrupted. Similarly to the sting arm, the positioning would rely entirely on the motors for load resistance. The predominant factors that led to the success of the sting crescent were the manufacturability and range. The sting arm interfacing would likely limit the pitch range of the system due to the additional interfacing. The sting crescent would be able to pitch as far as the length of the crescent allows. The sting crescent would also require significantly fewer moving parts, resulting in much less interface design and machining.

Both of the strut configurations fell short when it came to the trade study. The manufacturability of the strut configuration was one of its strong suits. In theory it is quite simple in comparison with the sting, with the three strut plate being slightly more complex. The big downside to the strut configuration is the range limitations. It is harder to achieve the range of angles needed with a strut than it is with a sting. The struts had a better rating than the sting when it came to loading, but this category had a much smaller impact than the categories discussed previously. As for loading, both the strut and sting configurations were pretty even across the board with the 3 strut motor being slightly better than the rest. The last category where the strut configuration really suffered was size. Both strut configurations would take up a large amount of the test section and could possibly disrupt the air flow within the test section, causing inaccurate measurements. For this reason the strut configuration scored very poorly. After the pointing structure trade study was completed, it was apparent the 3 strut systems were inferior to the sting for COMPASS's application.

6.2 Hardware Baseline Design

6.2.1 Motors

Following the motor trade study, the results were similar and did not indicate any clear choice. This did not prevent a decision to be made to eliminate piezoelectric motors a design option. This decision was made for two reasons: 1) the motor can only feasibly be applied to two different degrees of freedom and 2) the motor has a much higher cost compared to the other two options. Reason 1 still allows for the use of a combination of stepper and servo motors, but the elimination of piezoelectric limits the trade space and simplifies the overall design to only two motor types.

The decision to use a combination of servo and stepper motors was the most attractive option. These motors are relatively cheap in comparison to the piezoelectric motors but still have the ability to deliver the necessary torque and resolution. With cost and budget constraints becoming a larger issue as component selection narrows, this characteristic of the motors may be critical. The motors also come in a range of sizes allowing a combination of the motors to fulfill the requirements of each degree of freedom. For example, it may not be feasible to use a servo motor to control roll due to possible size constraints, but a stepper motor could fit within the same position. Servo and stepper motors have heritage here at the University of Colorado at Boulder and in the ITLL. Being able to easily learn and implement control of the motors in a timely manner will be important to this project. Servo and stepper motors allow this since faculty and lab staff have experience with these motors and their respective drivers.

Piezoelectric motors are an attractive option when dealing with the pointing requirements of the system. However, the motors necessary for this system may run in excess of $1000 per motor. This is not a viable budget option as the budget may only expand by a relatively small amount. It may be possible in the future to afford these motors with a larger budget, but they currently have been decided to not be an option for design. Another reason for eliminating piezoelectric motors as an option was control. Custom drivers and controllers or third party COTS parts can be implemented for control, yet it appeared many suppliers recommended using their own controllers to take full advantage of the motor. This would incur extra costs and pose a potential problem for interfacing between the controllers, electrical interface, and software VI.

Servo and stepper motors were selected to actuate each of the degrees of freedom for the COMPASS system. This decision was made based on cost, ease of implementation, and familiarity with each motor type. Specific motors have yet to be selected for each degree of freedom, but once further analysis of the system has been conducted, it will be clear which motors would be appropriate for each degree of freedom.

6.2.2 Electrical Hardware

After considering the two possible electrical hardware options, the better decision is a COTS unit. In particular, a system manufactured by National Instruments. This uniformity will greatly simplify the interaction between COMPASS and the lab station because both the DAQ system and LabVIEW are made by National Instruments. If the power requirements of the motors require a separate power system, a custom power supply will be made to work in conjunction with the NI DAQ. Although this custom board will increase man hours, the uniformity of the DAQ and LabVIEW will make up for the time that would be spent with a fully custom electrical hardware system.

A completely custom system would require far too many man hours to implement. Both the design and manufacturing would have to be done in house, whereas a COTS system is ready when purchased. Software would also have to be developed for a custom system, which would increase the man hours even more. Although a custom system may reduce the impact on the budget greatly, the disadvantages far outweigh the advantages.

6.2.3 Sensors

After looking at the pros and cons of both absolute and incremental encoders, it was decided that both encoders will be needed for the COMPASS hardware. Both encoders have certain advantages that make them viable options for being integrated with COMPASS. The absolute encoder is very accurate at determining the current position of the system, while the incremental encoder is great at determining motion when the system is moving. Since the incremental encoder can only read data while the system is moving, the absolute encoder is the better choice for positional readings only. The absolute encoder also holds its measurement if the power is cut. This means that in the event of a power failure the encoder will be able to return an accurate position once power is restored. Since absolute encoders do not track motion, an incremental encoder is needed to determine the rate at which COMPASS moves. Both sensors can be configured two different ways with the COMPASS hardware. The encoders can be integrated with the rotating axle of the motor or around the axle. These types of encoders are referred to as solid and hollow shaft encoders. It is yet to be decided which will be used based on current design; this choice will come later to determine which is better for COMPASS integration.

6.3 Software Baseline Design

After researching LabVIEW and MATLAB software options, the best decision for COMPASS is to use a combination of both: LabVIEW shall be used as the user interface and control law for COMPASS, while MATLAB shall be used for any necessary modeling and simulation of the system. LabVIEW's user interface is neater and easier to follow than MATLAB's. MATLAB's numerical computing abilities make it a necessity for modeling and computing for COMPASS.

LabVIEW shall be used as the main controller for COMPASS. Any commands or controls shall be implemented within LabVIEW. Control calculations shall be done in MATLAB to model and verify the correct control commands are being sent from LabVIEW to COMPASS. For example, the user will upload a series of commands to MATLAB to evaluate the feasibility; these commands can then be input into the LabVIEW VI.

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