Testing & Validation Plan

Introduction

This document details the testing needed to confirm that the product lives up to the evaluation criteria in the agreed upon project specification (amended in this document).

First, the revised design objectives and evaluation criteria will be stated, with a summary of how the objectives have been met. On the following pages, the testing procedure for each design objective will be described.

Design Objectives & Evaluation Criteria

Design Objective	**Evaluation Criteria**	**How was it achieved?**
Mechanical Strength	Materials used must be in accordance with FSAE rules.	FEA, calcs, minimum components and p.o.f.
Ease of Manufacture	How well the system uses the minimal number of parts, and assembly complexity, thereby increasing efficiency, accuracy, and overall product quality and reliability.	Sheet metal design that can be cut and bend into shape.
Lightweight	Must fit under the vehicular mass limit of 300kg. (Attempt to keep it as light as possible without sacrificing mechanical integrity.)	Weight is not unreasonably large (insignificant according to UTSMA).
Modular	Must be able to dismount and remount it onto different vehicles (iterations) without damaging the components.	Only the angle of wedge needs to be redesigned.
Disengageable	The autonomous steering system must be designed for easy disengagement, allowing manual control of the car via the steering wheel.	Motor is backdrivable.
Ergonomic	Must allow template from FSAE to pass through.	Template from FSAE can pass through CAD assembly.
Safety	“T.1.3.3 All moving suspension and steering components and other sharp edges inside the cockpit between the front hoop and a vertical plane 100 mm rearward of the pedals, must be shielded with solid material. […]	Casing around moving components.

	T.1.3.4 Covers over suspension and steering components must be removable to allow inspection of the mounting points.” – Formula SAE Rules 2024	
Control	Must be able to track position and velocity references within sufficient accuracy (of 6 degrees).	Motor can be controlled using CubeMars software.
Interfacing	Consistently receiving command from central controller, measure steering position and transmitting it to central controller.	Inter-connected STM32 microcontrollers can communicate internally and with motor.

1 Mechanical Strength

Materials

- PC with following software:
    - Ansys
    - Fusion 360
    - SolidWorks
    - Excel

Testing Procedure

<table>
<tr><th>Step</th><th>Testing Specification</th></tr>
<tr><td>1</td><td>Extract the latest model of the motor mount via shared files on Teams.</td></tr>
<tr><td>2</td><td>Start-up Fusion and open the target motor mount model on the design workspace</td></tr>
<tr><td>3</td><td>Navigate and switch from design to simulation workspace.</td></tr>
<tr><td></td><td>Simulation setup:
- Select the simulation material (Used materials: Mild steel & Aluminium in accordance to FSAE rules)
- Apply constraints to the motor mount by selecting the inner mounting holes on the base of the motor mount and constraint them to remain static in all available axes
- Apply a scaled-up vertical load of 10N (mass of the motor is 4N).
- Apply a lateral load of 1.25 times the maximum torque of the Cube Mars BLDC (available in Cube Mars AK80 – 9 data sheet)
- Generate automatic contacts via simulation settings dock.
- Ensure all bodies are rigid using the “DOF View” under the display in the simulation settings dock.
- Generate mesh and adjust the mesh to be SCALED PER PART.
- Adjust remaining mesh generation parameters accordingly.
- Set a safety factor of 1.5 or above.</td></tr>
<tr><td>4</td><td>Running the simulation
- Run (“Solve”) the simulation.
- Once the simulation ends, refer to the safety factor and review whether the structure is able to withstand the loads after the application of the safety factor.
- Check simulation progress via “Job Status” icon in the dock.
- For a deeper analysis, activate modes such as Stress, displacement or strain to clearly review the affected regions of the motor mount as a result of these load applications.</td></tr>
<tr><td></td><td>Simulation results:
- Given the simulation results, review the legend to observe the degree at which the loads cause the motor shaft to experience loads. (i.e.; Stress: Red for high-stress, Blue for low-stress)</td></tr>
<tr><td>5</td><td>Verifying and cross-checking all calculations and FEA results and hand calculations.
- Upon activating “Simulation Results”, visit the “INSPECT” tab in the dock and select point probes of choosing
- Create the point probe and apply them at the desirable regions to extract the relevant information with preferred units.</td></tr>
</table>

2 Lightweight

Must remain within the 300kg vehicular mass limit. Aim to keep the weight as low as possible without compromising mechanical integrity. The weight should not be excessively large, along with the system not be over-engineered design consisting of heavier components.

Materials

- SolidWorks files
- Manual calculations

Validation Procedure

Step	Testing Specification
1	Ensure that the calculations and computer simulations of the parts are not over-engineering.
2	Verify components after manufacturing to ensure that components match up with their designed weight with weight scale.

Results

By applying a factor of safety between 1.5 and 3 for various components, the parts are designed efficiently without being over-engineered. This approach avoids unnecessary and excessive material use in terms of thickness, width, to avoid unnecessary weight.

3 Ease of Manufacture

The ability to design the system with the goal of minimising the number of components in the assembly. The manufacturing process should be as efficient as possible to reduce unwanted complexities and cost.

Materials

- SolidWorks files
- Manufacturing procedure guidelines
- Manual calculations

Validation Procedure

Step	Testing Specification
1	Ensure that the calculations and computer simulations of the parts are not over-engineering.
2	Ensure that design of the components have ease of manufacturability as an intent (i.e. do not design parts which are hard to manufacture).
3	Ensure that the manufacturing process is a streamlined as possible.
4	Create manufacturing guidelines to ensure ease of manufacture and quality control.

Results

Using a factor of safety between 1.5-3 for various components, this results in the parts themselves to not be over-designed and have unnecessary and additional material components in terms of thickness, width, etc.

4 Modular

Ability to integrate the module in a variety of steering setups which would be present each UTSM car, over the years.

To alter the module to fit in future car variants, the angle of the wedge would need to change in accordance with the new angle of the steering shaft. This would bring the Motor mount to the correct orientation to fit with the new steering shaft.

Materials

- PC with SolidWorks
- SolidWorks file of wedge plate
- SolidWorks file of current Motorsports car

Validation Procedure

Step	Testing Specification
1	Open SolidWorks file of current Motorsports car.
2	Use Evaluate tool to find angle of steering shaft to the floor.
3	Open SolidWorks file of Wedge Plate.
4	Alter Angle of incline to match angle of steering shaft.

Results

In case of major design change, this may not work, and certain aspects of the motor mount design may have to be changed as well for it to be compatible with the new machine. Some of the factors that could be altered include:

- The height of the mount: Depending on the type of belt used to connect with the shaft, it can be brought lower down or higher up, if it is compliant with the FSAE template.
- The design of the side supports to enhance the stability of the motor.
- Inclusion of more or fewer bolts to secure the motor.
- Placing the motor on top of the mount or underneath.

5 Disengageable

To enable the system to be disengaged and thus allow manual driving, it was chosen to use a backdrivable motor which can be electrically disconnected. If the system significantly resists the force by the driver, it will impede the drivability of the vehicle.

Materials

- Datasheet for the motor
- Selection/design of connecting mechanism

Validation Procedure

Step	Testing Specification
1	Open the motor datasheet.
2	Find the backdrive torque.
3	Is the backdrive torque much lower than the expected steering torque?
4	Check if connecting mechanism is backdrivable.

Results

It is found in the datasheet that the rated backdrive torque is 0.51Nm, which is about 40 times lower than the maximum expected steering torque. The motor is connected to the steering column using a belt drive, which is backdrivable with negligible resistance.

6 Ergonomics

This is to ensure if the prevailing (to-be proposed) design of the Motor Mount assembly occupies space within the driver cockpit while obeying the constraints inflicted by the driver template, and with aims of passing driver template inspections.

Materials

- PC with SolidWorks
- SolidWorks assembly
- Driver template model

Validation Procedure

<table>
<tr><th>Step</th><th>Testing Specification</th></tr>
<tr><td>1</td><td>Locate the regions of the template that is to be affected (Refer to FSAE Rules Section T1.1 & T1.2).</td></tr>
<tr><td>2</td><td>Consult the dimensions of the template via 2024 FSAE rulebook.</td></tr>
<tr><td>3</td><td>Extract the latest model for the motor mount on the shared folder in week 10.
Model name: Motor_Mount v2_Mod.</td></tr>
<tr><td rowspan="2">4</td><td>Finding the X component (max length) via Fusion:</td></tr>
<tr><td>- Obtain the TOP or BOTTOM view of the motor mount.
- Activate the measuring tool.
- Measure the distance between each one of the mounting hole pairs on the mounting base of the mount.</td></tr>
<tr><td>5</td><td>Extract the latest model for the motor mount assembly on the shared folder in week 1
Model name: Assembly v4 for step 6.</td></tr>
<tr><td rowspan="2">6</td><td>Finding the Y component (max length) via Fusion:</td></tr>
<tr><td>- Obtain the FRONT or the BACK view of this assembly.
- Activate the measuring tool.
- Measure the distance between;
i. A vertice that belongs to the top face of the motor.
ii. A vertice that belongs to the bottom mounting face of the motor mount.
- To find the max vertical height of the module (assembly):
i. Activate the “Component 1 co-ordinate system” under the results tab of window that belongs to the measuring tool.</td></tr>
<tr><td rowspan="2">7</td><td>Evaluate whether the assembly obeys the constraints.</td></tr>
<tr><td>Compare the X and Y components of the assembly and review whether these dimensions satisfy the space available for the template to pass through in the cockpit.</td></tr>
</table>

Materials

- Software; Autodesk Fusion
- Test components; CAD Models via shared folders.
- Measuring tools; Fusion measuring tools.
- Instruments; Calculator (opt.)

7 Safety

To comply with the 2024 FSAE rules:

The rotating part of the Motor(s) must be contained in a structural casing. • Minimum thickness for aluminium alloy 6061-T6: 3.0 mm • Minimum thickness for steel: 2.0 mm

The motor casing may be the original motor casing, a team-built motor casing or the original casing with additional material added to achieve the minimum required thickness.

If lower grade aluminium alloy is used, then the material must be thicker to provide an equivalent strength.

Materials

- A rod
- Model of casing to identify any points of failure
- Micrometre

Validation Procedure

Step	**Testing Specification**
1	Ensure that steering components and its materials are designed to withstand track conditions.
2	Ensure all components are all are firmly attached to avoid any dislodgement during operation.
3	Use micrometre on most thin region and check thickness. Ensure it is within the acceptable thickness for the material used.
4	No sharp structures with could cause bodily injury should extend into the cockpit area in a manner that could hinder the driver’s control of the vehicle or create a safety hazard during a crash

8 Control

The motor must quickly and accurately respond to changes in the given position and/or velocity references.

Materials

- Laboratory power supply (24-48V, 3-24A)
- AK80-9 motor
- CAN+Serial cable
- R-LINK module
- USB cable
- Windows PC with CubeMars software

Validation Procedure

Step	Testing Specification
1	Connect the USB cable from the computer to the R-LINK module.
2	Connect the CAN+Serial cable from the R-LINK module to the CAN and Serial ports on the AK80-9 motor.
3	Connect the AK80-9 motor to the power supply.
4	Following the given instructions, setup the software to control the motor.
5	Check that the motor responds to commands. Use the internal and/or external sensors to measure position and speed.

Results

The motor can be controlled in speed mode and in position mode. In both modes, the motor responds promptly. The measured angle change in position mode corresponds with the expected angle change, given the reference.

9 Interfacing

The microcontrollers must be able to communicate with the central vehicle controller via CAN bus to receive commands and return feedback, and with the motor to control its position and velocity.

Materials

- STM32 NUCLEO-L476RG microcontroller development boards
- CAN transceivers
- Jumper wires
- Laboratory power supply (24-48V, 3-24A)
- AK80-9 motor
- CAN+Serial cable
- R-LINK module
- USB cables
- PC with STM32CubeIDE software

Validation Procedure

Step	Testing Specification
1	Connect the microcontrollers and CAN transceivers (refer to given documentation).
2	Connect both microcontrollers to a 5V power source, such as the PC, using the USB cable.
3	Test that the microcontrollers can send messages to each other. This can be done by pressing the blue button on either microcontroller and observing that the LED lights up on the other microcontroller. It can also be done by observing the received data in the debugger on the PC.
4	Connect the CAN cable from the AK80-9 CAN port to the CAN transceiver's CAN lines.
5	Connect the AK80-9 motor to the power supply.
6	Following the given instructions, use the software to send commands to the motor.
7	Check that the motor responds to commands. Use the internal and/or external sensors to measure position and speed.

Results

The microcontrollers communicate successfully with each other (Steps 1-3). Further testing of communication with the motor is required (Steps 4-7).