Quarter-Car Test Rig

Group 10E

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Introduction

Quarter car test rigs see extensive use in the automotive and motorsport industry to assess noise, vibration, and harshness (NVH), handling characteristics and suspension durability. Testing of race car suspension focus's almost solely on assessing handling performance. These rigs are used to characterise the response of a single isolated wheel and suspension system and form an integral part in validating suspension models and design.

Aims

The rig was developed as part of Imperial Formula Racing (IFR), the student-led Formula Student team at Imperial College London. The rig will be developed in subsequent iterations to integrate hardware-in-the-loop testing through procurement of a programmable linear actuator. This can be used as a low-cost supplement to track-testing, providing repeatable results.

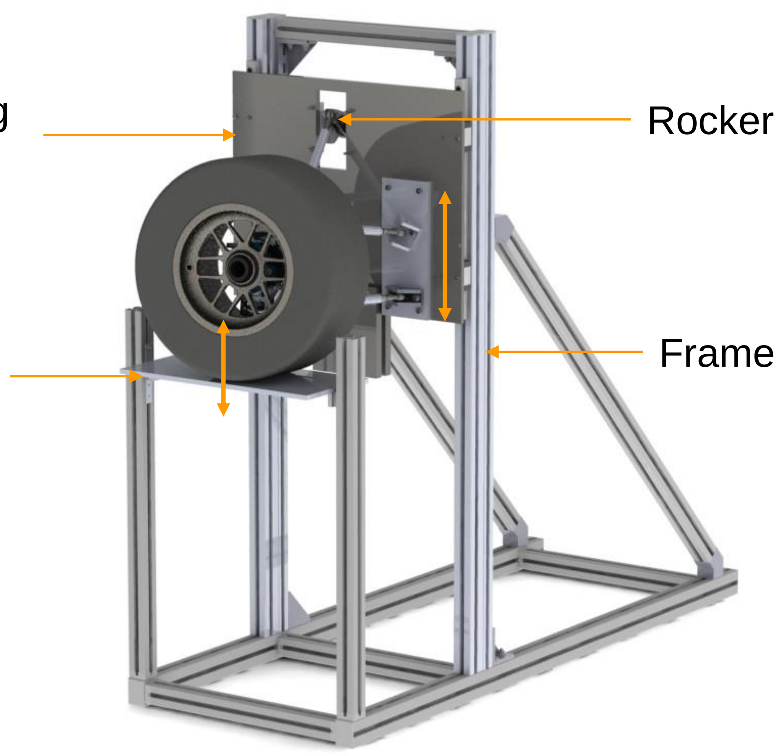

Figure 1: *Complete quarter car test rig assembly.*

Objectives

The final rig design was completed to meet the following criteria:

- Adaptability: The rig should accommodate a range of double wishbone suspension configurations as well as different actuators. It should be easy to (dis)assemble quickly for storage.
- Response Measurement: A data acquisition system is included in scope to enable the sprung and unsprung mass responses to be recorded.
- Structural Integrity: The rig must withstand the forces and moments exerted by an actuator simulating a typical road profile.

Design

Frame

The frame uses modular strut and joint connections to maximise adjustability. This was intended for future alteration and to reduce space usage in the pit garage by flat-packing while not in use.

One downside of this approach was the balance between frame adjustability and flexibility. The joint connections may have introduced additional, difficult to quantify, compliance into the structure. This is undesirable as frame flexibility contributes to additional friction and experimental errors.

Figure 2: *Quarter-car rig complete assembly*

Suspension Mounting Plate

The mounting plate simulates ¼ of the cars sprung mass, interfaces with a range of different suspension types and geometries and accommodates adjustable sprung masses.

Figure 3: *Mounting plate subassembly exploded view*

Rocker

The rocker was designed specifically for the rig, transferring force from the outboard suspension to the coil-over-damper unit. The rocker enables the user to select a motion ratio of 0.7~1.4, whilst ensuring inspection and replacement of bearings is simple.

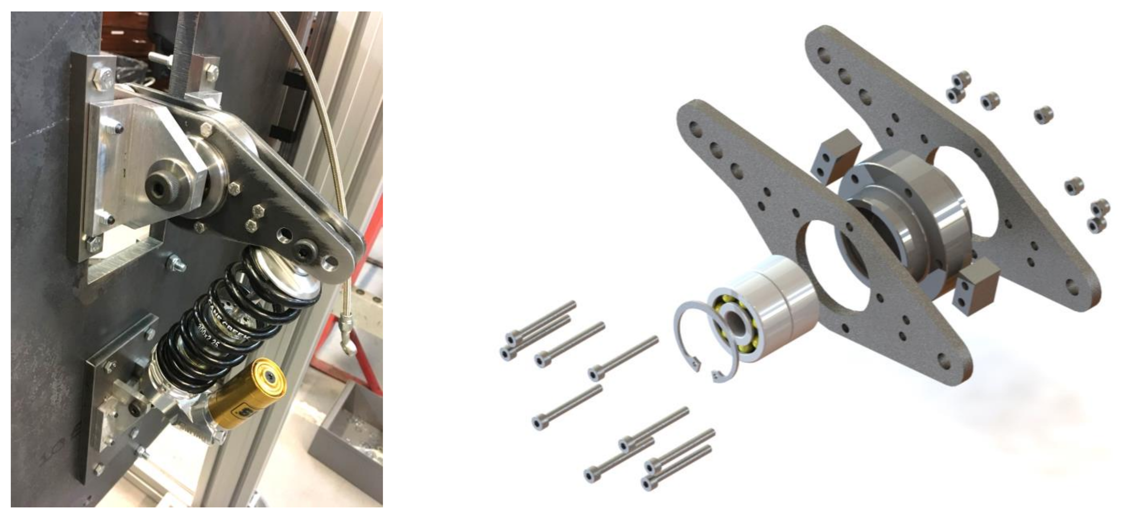

Figure 4: *Render and photo of the rocker subassembly*

Wheel Guide Subassembly

This platform supports the unsprung mass and accommodates a range of actuation systems to be used to drive the wheel. Motion is restrained vertically by linear bearings.

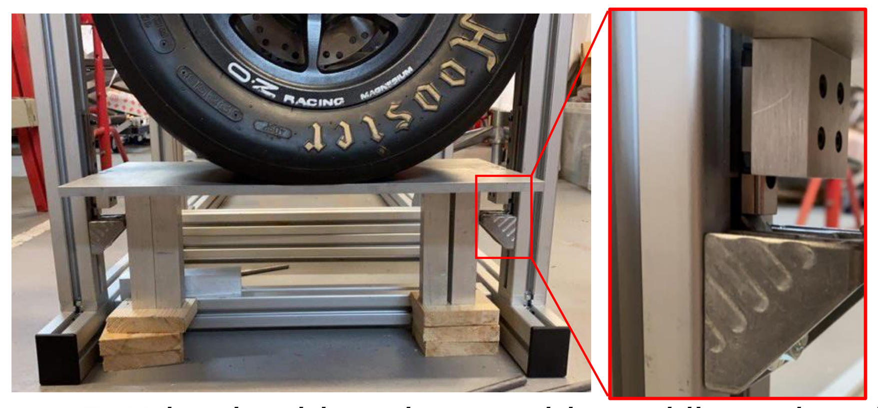

Figure 5: *Wheel guide subassembly and linear bearing*

A combination of manufacturing error and compliance in the frame caused excessive friction in the bearings under drop test conditions, which were not initially designed for, prompting a redesign. The redesign incorporates larger bearings and cross members, leadings to a 75-times increase in stiffness.

Figure 6: *Wheel Guide Redesign*

Results

Tests were kindly conducted by Jaime-Parra-Raad under the supervision of Dr Cegla; testing occurred in two rounds prior and post attachment of the mounting plate.

The first round consisted of bearing quality control tests detailed in Table 1, and the second was the wheel drop test. The quality control test objectives were to:

1) Maximise bearing life.
2) Minimise friction due to the bearings.

Table 1: *Bearing quality control test results.*

Test	Criteria	Outcome
Rail Parallelism	$P < 46\,\mu m$	$P = 40\,\mu m$
Height offset between bearings, opposite rails	$s_1 < 0.31\,mm$	*Incomplete due to inadequate testing equipment*
Height offset between bearings, same rail	$s_2 < 20\,\mu m$	$s_2 = 80\,mm$

Key outcomes from testing included that minimal load applications affected DTI readings suggesting stiffness in the rig needed to be increased to mitigate deflections. These results were implemented through design changes during the second iteration.

Wheel Drop Test

A 50 mm vertical wheel drop test was performed to record the natural response of the sprung and unsprung masses, which was compared to a simulated drop test adapted from a quarter-car model developed by Owen Heaney [1]. The position of the masses was extracted from video footage using a MATLAB program modified from Sean Jackson's FYP [2].

The result of the sprung mass displacement response is shown in Figure 7 with the observed response in blue and the simulated response in orange.

Whilst both responses exhibit underdamped behaviour, the observed response has a lower frequency of oscillation and a faster rate of decay. This is indicative of excess damping in the assembly which is believed to originate from a manufacture flaw causing the wheel pan to be oversized, increasing friction.

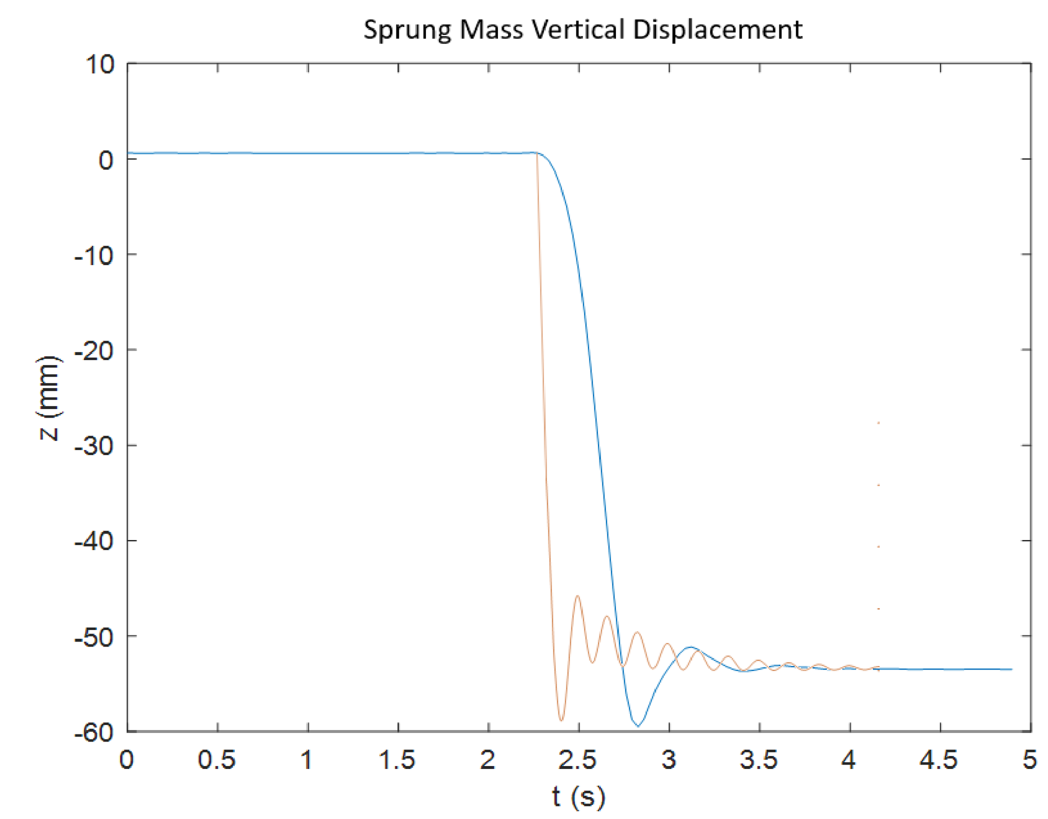

Figure 7: *Sprung mass displacement response against time. Observed response in blue. Simulated response in orange.*

Conclusions

Testing concluded that the assembly stiffness was less than designed and insufficient to meet all tolerances for bearing mounting. Although this is likely to compromise bearing life, the rig was still able to operate safely. Stiffness-enhancing modifications to the wheel guide subassembly are recommended to reduce variation in tolerance readings.

Mechanical compliance was estimated to be 3 mm. This is expected to be further reduced by including a T-slot base in future iterations to anchor the rig.

These changes should be made as part of further development before an actuator is added to the final assembly.

Acknowledgements

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References

[1]: Heaney, O. Modelling and Simulation of a Formula Student Suspension System. London; 2019.
[2]: Jackson, S. Amplification of vibrations and extraction of vibration characteristics from video footage. London; 2021.