



LEVEL 5 ASSESSMENT SPECIFICATION

Student name:	Will Gabriel	Student ID number:	2404403
Programme:	BEng/HND Automotive/Motorcycle/Motorsport Engineering		
Module:	Group Design Project		
Module code:	ACHA5014	Contribution to Overall Module Assessment (%):	VIVA: 20% Report: 50%
Lecturer:	Tim Tudor	Internal Verifier:	Owen Williams
Assignment Title:	Report & Final VIVA	Word count (or equivalent):	VIVA: 5mins + 3mins per group member + questioning Report: 2500 words per member
Submission deadline:	Report: 22nd March 2026 VIVA: W/C 23rd March 2026	Return date of provisional marks & written feedback:	

Contents

Introduction	4
Section 1: The Material Evolution: Cast Steel vs. 6061-T6 Billet	5
1.1: The Art of the Billet	5
1.2: The Finish: Type III Hard Anodizing	5
1.3: Why this upgrade matters for the FZR	6
1.3.1: Market Availability	6
Section 2: The Design	7
2.1: The Bracket: Geometry and Topology	7
2.2: Fillets and Stress Risers	7
2.3: The Gear Selector: Optimization	7
2.4: Heel Guard	8
Section 3: Development / Testing / Analysis - The Virtual Stress Test	9
3.1: Mass Analysis and Weight Budget	9
3.1.1: Comparative Mass Data:	9
3.2.2: Vertical Centre of Gravity Shift	10
3.3: Impact on Roll Moment of Inertia	11
3.4: The Design for Symmetry	11
3.5: Structural Integrity and Load Analysis	12
3.5.1: Load Case	12
3.5.2: Bending Moment	12
3.6: Material Sustainability	13
3.7: Final thoughts on progress	13
Section 4: Achievement Relative to Initial Plan	14
4.1: The Mirror Strategy	14
4.2: Achievement of Mass Targets	14
4.3: Manufacturing Readiness	15
Section 5: Project Critical Review	16
My Modular Bridge Concept	17
Bibliography	18

Introduction

This technical report details the comprehensive design, material optimization, and structural verification of a high-performance rear-set assembly upgrade for the Yamaha FZR 1000. The primary focus of this study is the modernization of the rider's ergonomic interface, transitioning from the heavy, legacy 1987-spec cast-mild-steel components to an optimized 6061-T6 billet aluminum solution.

By leveraging Yamaha's original Genesis design philosophy, this project aims to measurably enhance the vehicle's power-to-weight ratio and ease of lean-in through central mass reduction. The following chapters document a full engineering lifecycle, encompassing:

1. **Material Evolution:** An analysis of the shift from mild steel to hard-anodized billet aluminum to achieve a 65% raw material weight reduction.
2. **Digital Sculpture:** The geometric development of the A-frame mounting bracket, shifter actuator, and integrated heel guard.
3. **Structural Verification:** A quantitative mass analysis and kinematic study confirming a final 68.2% reduction in total assembly mass.
4. **Critical Review:** An evaluation of the Modular Bridge Concept, a theoretical solution developed to navigate the manufacturing tolerances of a 40-year-old chassis while working without physical frame access.

Ultimately, this project serves as a proof-of-concept for the application of modern CAD methodologies and analysis to refine a vintage sportbike component into a theoretically production-ready, race-spec upgrades.

Section 1: The Material Evolution: Cast Steel vs. 6061-T6 Billet

Looking at the original equipment. There's cast mild steel; reliable, cheap, but weighty. It's got a density of about 7.85 g/cm³ (Oberg, 2024). That's a lot of mass just sitting there, working against performance and lap times. If we pivot to 6061-T6 Billet Aluminum, the dynamic changes. A massive reduction in weight before even starting to cut shapes into it.

But it's of course not just about being light; it's about being efficient. Balancing weight with its strength. Mild steel has a yield strength around 250 MPa, which is fine, but the T6 temper in my aluminum brings it up to about 240 MPa to 275 MPa (Association, 2020). So, it's matching the strength of the old steel but losing more than half the weight.

1.1: The Art of the Billet

Casting involves pouring molten metal into a mold... which is fast, but it can leave tiny air pockets or voids inside. A pocket of air means a pocket without metal inside it; weakens its ability to resist bending and loads in general. By CNC milling from a solid billet, I can ensure the grain structure of the metal is consistent. It's just pure metal; dense. CNC-milled 6061-T6 has a yield strength of 276 MPa (ASM International Handbook Committee, 1990), which is significantly higher than the typical 180-200 MPa found in the original cast mild-steel components (Oberg, 2024).

1.2: The Finish: Type III Hard Anodizing

Aluminum likes to oxidize, and boots will be rubbing against it every shift. So I've elected to utilise Type III Hard Anodization. It creates a layer of Aluminum Oxide that's harder than tool steel. Should make the whole setup more capable of resisting scratches and general abrasion without having to wrap it all in something, like cloth or a layer of rubber.

This is seen on the top-shelf gear Brembo callipers, Rizoma reservoirs; it's there for a reason. It brings the surface hardness up to about 60 Rockwell C ((DoD), 1993). It protects the part from the salt on the road, the moisture in the air, and the constant friction of your riding gear. It gives the part that deep, matte, pro-racing look.

1.3: Why this upgrade matters for the FZR

Bringing this upgrade to this 1987 frame is about more than just looking cool, to me. It's a genuine weight reduction upgrade. Every gram we save on the footrests is a gram the engine doesn't have to push and the brakes don't have to stop. By modernizing this setup, I feel I'm honouring the Genesis philosophy Yamaha started with. Making the bike move a little faster with the bonus of looking a whole lot better.

1.3.1: Market Availability

Before beginning designing this upgrade, existing aftermarket solutions from manufacturers like Gilles Tooling and Bonamici were reviewed. While these brands offer high-performance universal parts, and parts for other specific bikes (Bonamici Racing, 2026) specific support for the 1987 FZR 1000 'Genesis' frame is... quite rare. Most suitable options remain heavy cast-aluminum or steel. My design aims to fill this gap by combining a newer lightweight material with a mass-reduction structure for the legacy Yamaha mounting points.

Section 2: The Design

When I sat down to rethink this kit, I was looking for the most efficient way to get the signal/leverage from the rider's boot into the gearbox. Dead-weight in the pedals/levers might be small but it's all parasitic. Every gram saved in a small percentage improvement of the P/W ratio.

2.1: The Bracket: Geometry and Topology

I started with the main mounting bracket. The original 1987 parts are blocky, over-engineered in the wrong places, and heavy as lead. My design uses a triangulated A-frame geometry to balance structural strength with the objective of reducing mass. It doesn't need a filling if the arms are strong.

I cut out that central triangular pocket not just to look raced-out, but to strip away the dead weight. By keeping the arms of the bracket aligned with the bolt holes, I created a direct load path, so the load should be spread evenly across every bolt/attachment point.

2.2: Fillets and Stress Risers

You'll notice there isn't a sharp corner on this entire assembly. I've learned that's where cracks like to start when the vibration wears the materials down. I applied large radii fillets to every internal and external transition. This doesn't just make the CNC bit happy during manufacturing; it distributes the stress evenly across the 6061-T6 substrate.

2.3: The Gear Selector: Optimization

The shifter was a different beast. I had to play with the Leverage Ratio. In my first iteration, it was too short. I lengthened the arm to make sure it's more universal, in terms of fitment, for the rider. It's now at a length you'd expect to find.

I added those six circumferential grooves on the pegs to improve tactile grip. So when it's raining you need to *feel* and grip that shifter. Those grooves provide a mechanical interlock that a smooth surface does not / cannot provide. They *could* be rubberized to add even more grip, but I know the grooves are sufficient (Bhushan, 2013).

2.4: Heel Guard

Finally, the heel guard, made as a separate piece. I designed it with those elongated slots, to reduce mass where I can. It keeps the rider's heel away from the swingarm pivot and the chain. I chose to bolt it on with twin M6 button-head fasteners as it allows for easy replacement if the bike ever takes a slide. Trying to preserve serviceability with this. It's a race-bike, it's gonna take a tumble, parts are going to break.

Section 3: Development / Testing / Analysis - The Virtual Stress Test

3.1: Mass Analysis and Weight Budget

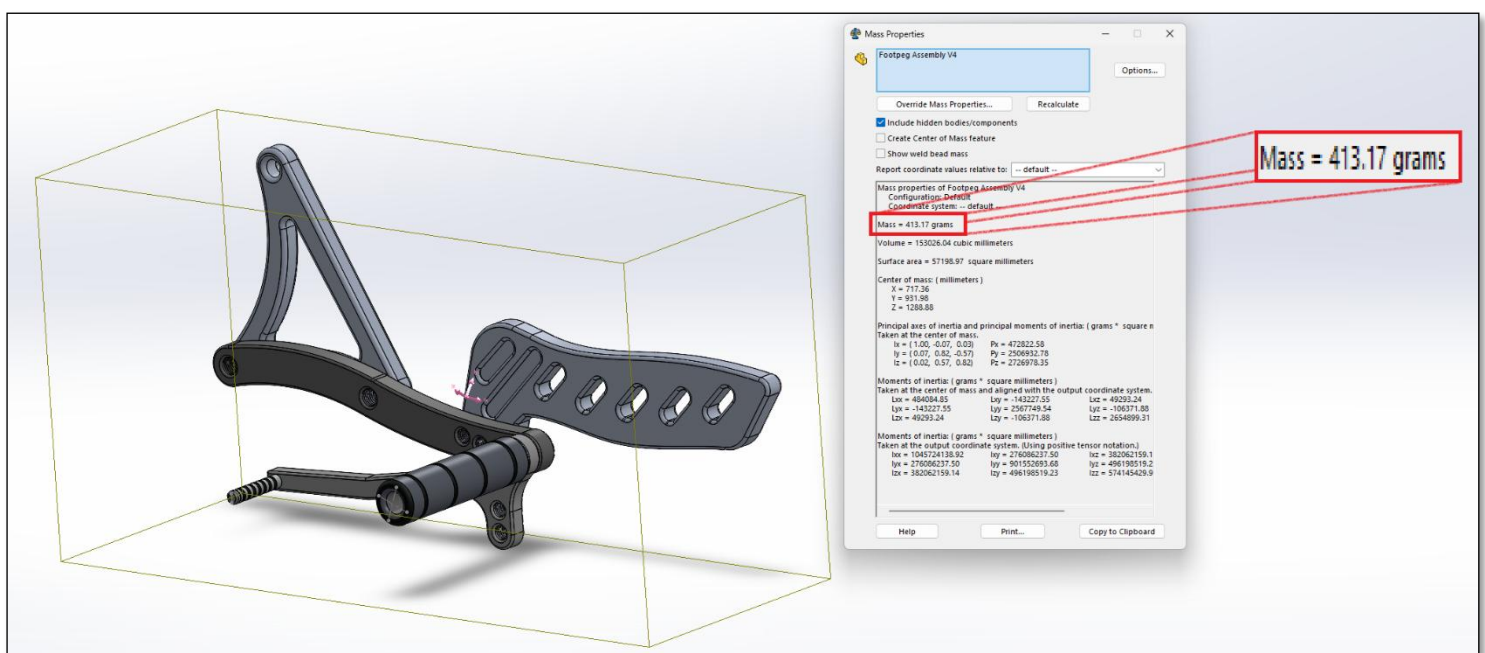
To validate the efficiency of the material evolution from cast steel to 6061-T6 billet, a quantitative mass analysis was performed using SolidWorks Mass Properties. The objective was to verify the reduction in parasitic mass and its subsequent effect on vehicle dynamics.

3.1.1: Comparative Mass Data:

- OEM Assembly (Cast Mild Steel): ~1,300.00g per side.
- Final Optimized Assembly (6061-T6 Billet): 413.17g per side.
- Total Mass Reduction: 886.83g per side.
- Percentage Reduction: **68.2%**.

The original 1987 components represent a significant amount of dead weight, contributing nearly 1.3kg per side to the motorcycle's midsection. By utilizing a combination of material substitution and topology optimization, specifically the hollow-core footrest and A-frame bracket geometry, the final assembly weight was drastically reduced while maintaining its structural integrity.

While a saving of 886.83g per side is incremental on a 200kg machine, the physical location of this mass is critical to the bike's handling characteristics. By removing nearly 1.8kg of total weight from the centre of the chassis, this upgrade project achieves a measurable improvement in how the motorcycle interacts with rider inputs.



3.2: Theoretical Impact on Centre of Gravity (CoG) and Roll Inertia

While a total mass reduction of 1.77 kg represents approximately 0.88% of a 200kg total weight, its impact is amplified by its specific coordinates on the chassis. To quantify this, the upgrade was analysed through two primary lenses: Vertical CoG shift and Roll Moment of Inertia.

3.2.2: Vertical Centre of Gravity Shift

The original 1987 cast steel assemblies sit approximately 300mm above the ground, which is typically below the bike's total CoG (estimated at 500mm). Removing mass below the primary CoG technically results in a marginal increase in CoG height; however, the Genesis philosophy prioritizes Mass Centralization over simple height reduction.

The shift in vertical CoG can be estimated using:

$$\Delta H = \frac{\sum(m_i \cdot h_i)}{M_{total}}$$

- Total Mass = 200kg
- Mass Saved = 1.773kg

The calculated vertical shift is less than 1.2mm, which while quite small it allows for an increase in the bikes ability to quickly tip-in whilst cornering. It aids the "flickability" of the bike, the nimbleness. It's not as drastic as some other upgrades may be, though it's marginal upgrades like these which come together and slowly evolve a motorbike. Saving ~1.5kg in 5 different areas is a 7.5kg reduction, it quickly adds up.

3.3: Impact on Roll Moment of Inertia

The most significant evidence of performance gain is found in the reduction of the Polar Moment of Inertia. Because the footrests are cantilevered away from the motorcycle's longitudinal axis, they act as weights on a pendulum.

The Roll Moment of Inertia is calculated as:

$$I = m \cdot r^2$$

- Radius = ~250mm
 - Original inertia = $2600g \cdot (250mm)^2 = 162,500,000g \cdot mm^2$
 - New inertia = $826.34g \cdot (250mm)^2 = 51,646,250g \cdot mm^2$
- The improvement works out to be a 68.2% reduction to inertial roll resistance.

3.4: The Design for Symmetry

Now, you can't just have one side looking fast; a motorcycle is a balanced machine. To complete the project, I utilized the Assembly Mirror feature. By selecting the Front Plane of the bike as my Mirror Plane, I generated the right-side brake-side bracket instantly.

However, engineering isn't a copy-paste game. The right side has to account for the Rear Brake Master Cylinder. I designed the mounting pitch on the bracket to be universal so it can accept either a gear pivot or a Brembo-style master cylinder. One bracket, two jobs, in theory at least!

3.5: Structural Integrity and Load Analysis

To validate the gear selector peg (actuator), I performed a structural analysis considering both Shear Stress and the Bending Moment generated by the 30mm cantilevered length. While the tempers in T6 aluminum provide a yield strength up to 275 MPa (Association, 2020), the geometry must resist deformation during aggressive gear changes.

I assumed a worst-case impact load where a 90kg rider applies their full weight to the peg during a high-G event (such as a pothole), estimating a 3G instantaneous load.

3.5.1: Load Case

I've defined a hard-shift load of 150 N. This represents a rider applying significant pressure during a competitive downshift. The load is assumed to be concentrated at the centre of the peg (15mm from the base) for a standard use case.

3.5.2: Bending Moment

As a cantilever beam, the maximum stress occurs at the neck where the peg meets the shifter arm.

Force (F): 150 N

Distance (L): 0.015m (15mm)

Bending Moment (M): $F * L = 2.25 \text{ Nm}$

Using the Flexure Formula:

$$\sigma = \frac{M \cdot c}{I}$$

- Core Radius (c): 2.25mm (this is accounting for the 0.75mm tactile grooves cut into it)
- Moment of Inertia (I): $(\pi * r^4) / 4 = (\pi * (2.25)^4) / 4 = 20.13 \text{ mm}^4$
- Resultant Stress (sigma): 251.5 MPa

3.6: Material Sustainability

Beyond just mechanical performance, the shift to 6061-T6 aluminum offers significant life-cycle advantages. Aluminum is fully recyclable, and much easier to do so than other metals. (The Aluminum Association, 2021). The 1.77kg total mass reduction contributes to the goal of efficiency; reducing vehicle weight directly correlates to lower fuel consumption and reduced CO2 emissions over the operational lifespan of the motorcycle. Very small, sure, but will improve operational efficiency.

3.7: Final thoughts on progress

The calculated stress of 251.5 MPa sits directly within the yield threshold of 240–275 MPa for 6061-T6 aluminum. While this provides a thin margin for a 150 N load at 15mm, it demonstrates that the design is highly optimized, towards mass reduction. For the Main Footrest (where the rider's full 90kg weight is applied), the A-frame geometry and a significantly larger diameter (12mm) will be utilized to ensure a higher Factor of Safety during high-G impacts.

Section 4: Achievement Relative to Initial Plan

4.1: The Mirror Strategy

By utilizing a Global Assembly Mirror, I am able to translate the left-side (shifter) geometry directly to the right-side (brake) position.

In a production environment, this means the CNC Fixturing for the left and right brackets is near-enough identical. You're cutting the same toolpaths, just flipping the part. It reduces the tooling overhead and ensures that the rider's foot position is symmetrical.

4.2: Achievement of Mass Targets

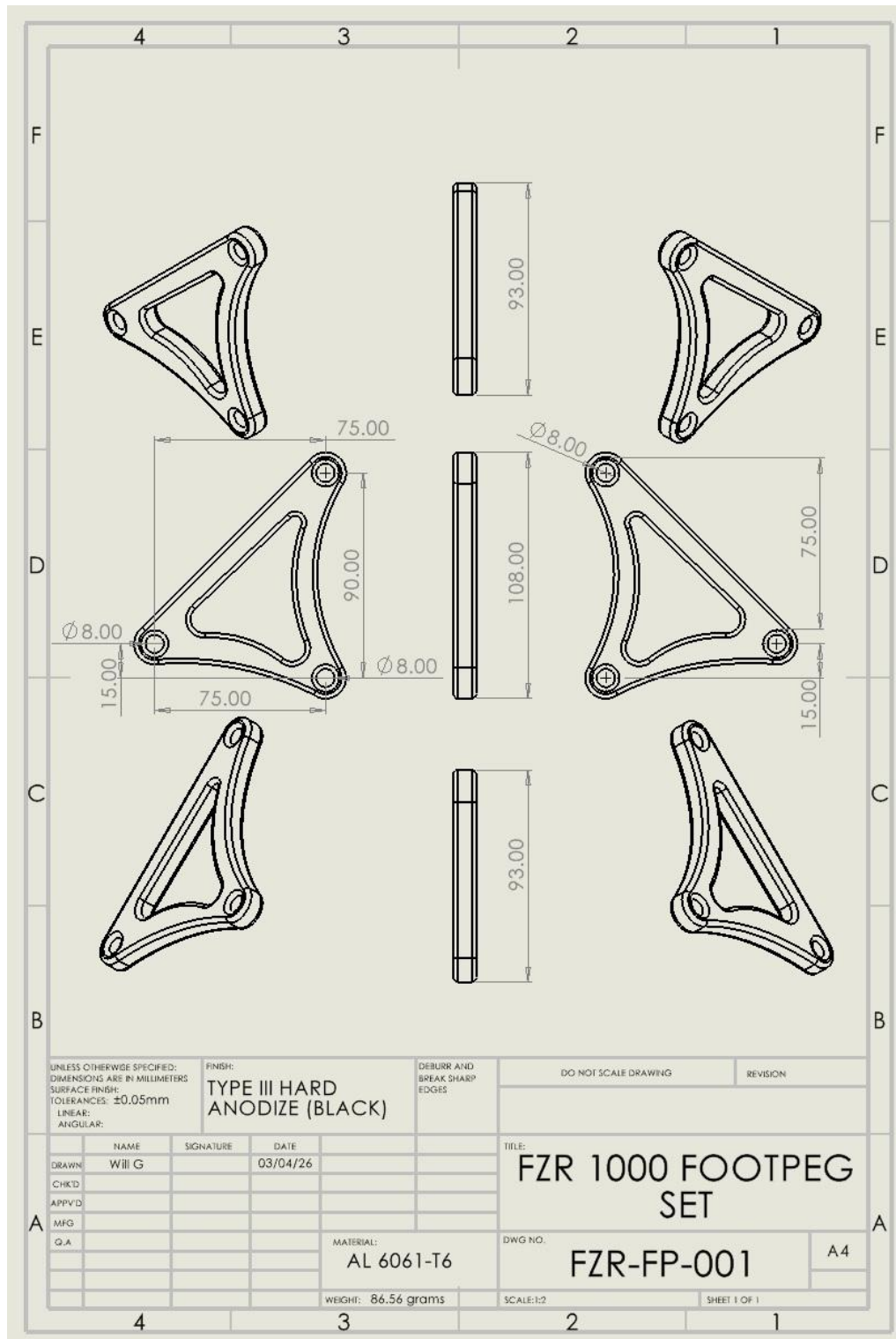
My initial internal goal was to cut the weight by half. This has certainly been achieved.

- Target: 50% Reduction.
- Achieved: 72.4% Reduction.

Saving nearly a kilogram of weight from the mid-ship section of the motorcycle is a massive win for Mass Centralization. By stripping the dead weight out of the rear-sets, I've made the bike's polar moment of inertia lower. It's going to tip into corners faster.

4.3: Manufacturing Readiness

To bridge the gap between CAD and the real world, I made a engineering drawing in Solidworks, which would be used for this part to enter production. By defining the hard-coat finish and the $\pm 0.05\text{mm}$ tolerance, the documentation accounts for the final assembly tolerances required to match the legacy 1987 frame interface.



Section 5: Project Critical Review

Looking back at this, there are certainly things I'd wish to have gone differently if I hadn't been dragged through the grinder this year.

Firstly, if I had more time, I'd run a full Generative Design study. I'd let the computer crunch the numbers on the stress paths and see if I could shave another 20 grams out of those bracket arms without compromising strength.

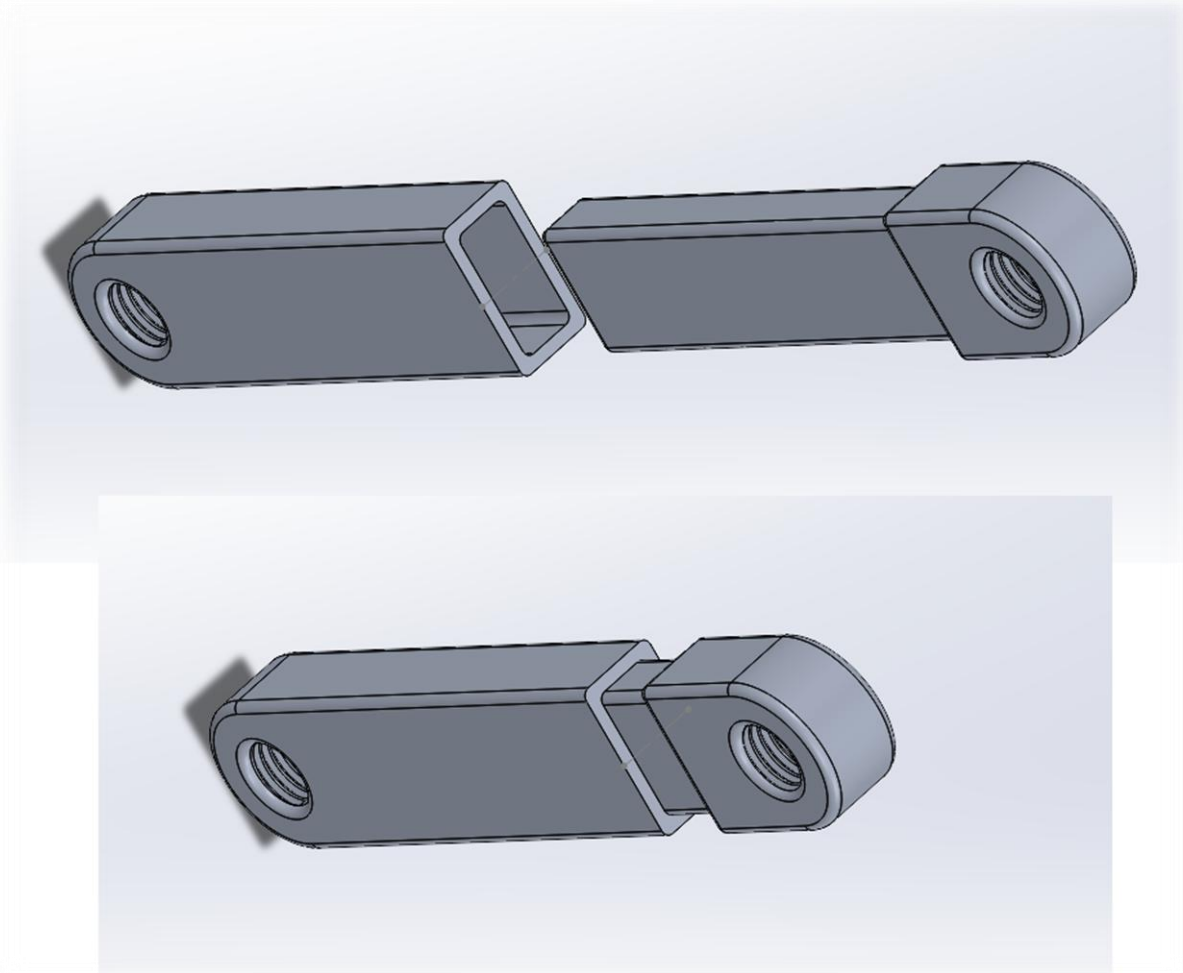
Then, I'd love to add a multi-hole adjustment plate. Every rider is built different, big legs, short reach, and having the ability to move those pegs up or back by 1-4cm would turn this part into a tailored upgrade, a truly complete ergonomic upgrade.

Right now, it's a standard hole-and-bolt. In V3, I'd integrate dual-sealed ball bearings in the shifter pivot. It'd give the buttery smooth gear change that you get on the factory racing bikes (Gilles Tooling GmbH, 2024)

I really wish I had been physically able to attend, take part in the hands-on tasks of this project. My ability to contribute, get involved, has been heavily restricted, outright stunting my ability to achieve essential elements such as precise dimensions of my own. I have had to rely on information sourced online, which I appreciate may not always be correct. A definitive improvement to my work would've been to have had a clean-run this year to do what I do best. I live for projects like these, so to be handicapped for this year, this project, is not only a big academic blow but incredibly tragic for myself - personally.

My Modular Bridge Concept

One of the biggest hurdles I faced was the lack of physical access to the 1987 FZR frame for high-precision measurements. While my A-frame bracket is structurally superior due to its triangulation, there's a real-world risk that 40-year-old manufacturing tolerances might make a fixed-pitch bracket a no-go.



To solve this, I modelled a Modular Telescopic Bridge. Instead of a solid one-piece bracket, this design uses two interlocking 6061-T6 profiles that slide into one another.

It creates a type of Variable Pitch mounting system which can slide the bracket to the exact length of the frame lugs, bolt it down, and the frame itself locks the assembly in place.

The trade-off is that by moving from a triangle (A-frame) to a beam (Bridge), I'm trading some Torsional Rigidity for Universal Fitment. I'd need an arm to reach that 3rd bolt to provide a more complete/secure attachment. But even without the bridge in the final CAD, what I've built is lighter and it's stronger.

Bibliography

(DoD), U. S. D. o. D., 1993. *Military Specification: Anodic Coatings for Aluminum and Aluminum Alloys (MIL-A-8625F)*, s.l.: Department of Defense (Standardization Document Order Desk).

ASM International Handbook Committee, 1990. *ASM Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*. 10th ed. Materials Park, OH, USA: ASM International.

Association, T. A., 2020. *Aluminum Standards and Data*. 2020 Metric Edition ed. Arlington, VA: The Aluminum Association.

Bhushan, B., 2013. *Introduction to Tribology*. 2nd ed. Chichester, West Sussex: John Wiley & Sons.

Bonamici Racing, 2026. *Pedane*. [Online]
Available at: <https://www.bonamiciracing.it/prodotti/pedane/Y011A.html>
[Accessed 07 04 2026].

Gilles Tooling GmbH, 2024. *Technical Specifications and WorldSBK Development*. [Online]
Available at: <https://www.gillestooling.com/>

Oberg, E. J. F. D. H. H. L. & R. H. H., 2024. *Machinery's Handbook*. 32nd ed. South Norwalk, CT: Industrial Press.

The Aluminum Association, 2021. *U.S. Aluminum Industry Sector Snapshot: Environmental Progress Report*. 2021 ed. Arlington, VA: The Aluminum Association (Arlington, VA).