E-Bike Frame

ME3 DMT Seminar

Group 1A:

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Seminar Structure

Key Terminology

1. *Final Product Overview*

2. *Overall Design Requirem ents*

3. *Inter-group Project Division*

4. *Project Approach*

5. *Design & Evaluation*

6. *Budgeting & Manufacturing*

7. *Testing*

8. *Future Considerations*

Top-tube
Saddle
Headtube
Seat-post
Crown
Seat-tube
Fork
Seat-stays
Down-tube
Dropouts
Chain-stays
Rear-axle

1.
Final Product Overview

- *Key design features*
- *General specs*

Key Design Features & Specs

Frame

- *Columbus Omnicrom steel tubing*
  top-tube, inner seat-tube, seat-stays, chain-stays
- *Mild steel custom tubing*
  head-tube, down-tube, seat-tube
- *Brazed joints*
- *Designed for riders 5′8″ – 6′8″*
- *Weight: 5.8kg*
- *Comfort riding geometry*
- *Suited for urban terrain conditions*

Key Design Features & Specs

Dropouts

- *12mm OD, 142mm length THRU axle compatibility*

- *Flat mount disc brake callipers compatibility*

- *Total 1.8cm chain tensioning adjustability*

3 Component Design:

- *Custom laser-cut stainless steel black plates*
  - *brazed to main frame*

- *Custom CNC aluminium inserts*
  - *socket head screws – quick adjustment*

Key Design Features & Specs

Brakes

- *Shimano flat mount disc brake calipers*
- *160mm diameter center-lock rotors*

Wheels

- *700cc (622mm) OD, 25mm width, aluminium alloy rims*
- *142mm wide integrated freehub for sprockets*
- *12mm THRU axle*

Key Design
Features & Specs

Seats / Seat tube

- *27.2 mm internal diameter seat tube to be compatible with industry standard seat tubes*

Bottom Bracket

- *68 mm long 40 mm diameter bottom bracket*
    - *Compatible with motor team's torque sensor*

2.
Design Requirements

- *Initial inter-group PDS*
- *Revised inter-group PDS*

Revised Inter-group PDS

UK Laws & Regulations

- *Aged **14** or over with e-bikes meeting requirements*
- *EPACs: "electrically assisted pedal cycles"*
  - *license not required for usage, no need for registration, tax or insurance*

Available from: https://www.gov.uk/electric-bike-rules [1]

UK Laws & Regulations

What Counts as EPACs?

- *Pedals to propel*
- *Pedal must be in motion for motor assistance*
- *Show either power battery's voltage or maximum speed*

- *Motor max output =* ***250 W***
- *not able to propel when speed* ***> 15.5 mph***
- *Can have more than 2 wheels (e.g. tricycle)*

Available from: https://www.gov.uk/electric-bike-rules [1]

3. Intergroup Project Division

- *Sub-group allocations*
- *Integration with the frame*

Frame Sub-assembly

Integration with other subgroups

Steering
Sub-assembly

- Handlebar
- Front fork
- Headset assembly
- Front disc brakes

Frame & Steering
Shared roles

- Rear and front wheels
- Disc brake selection

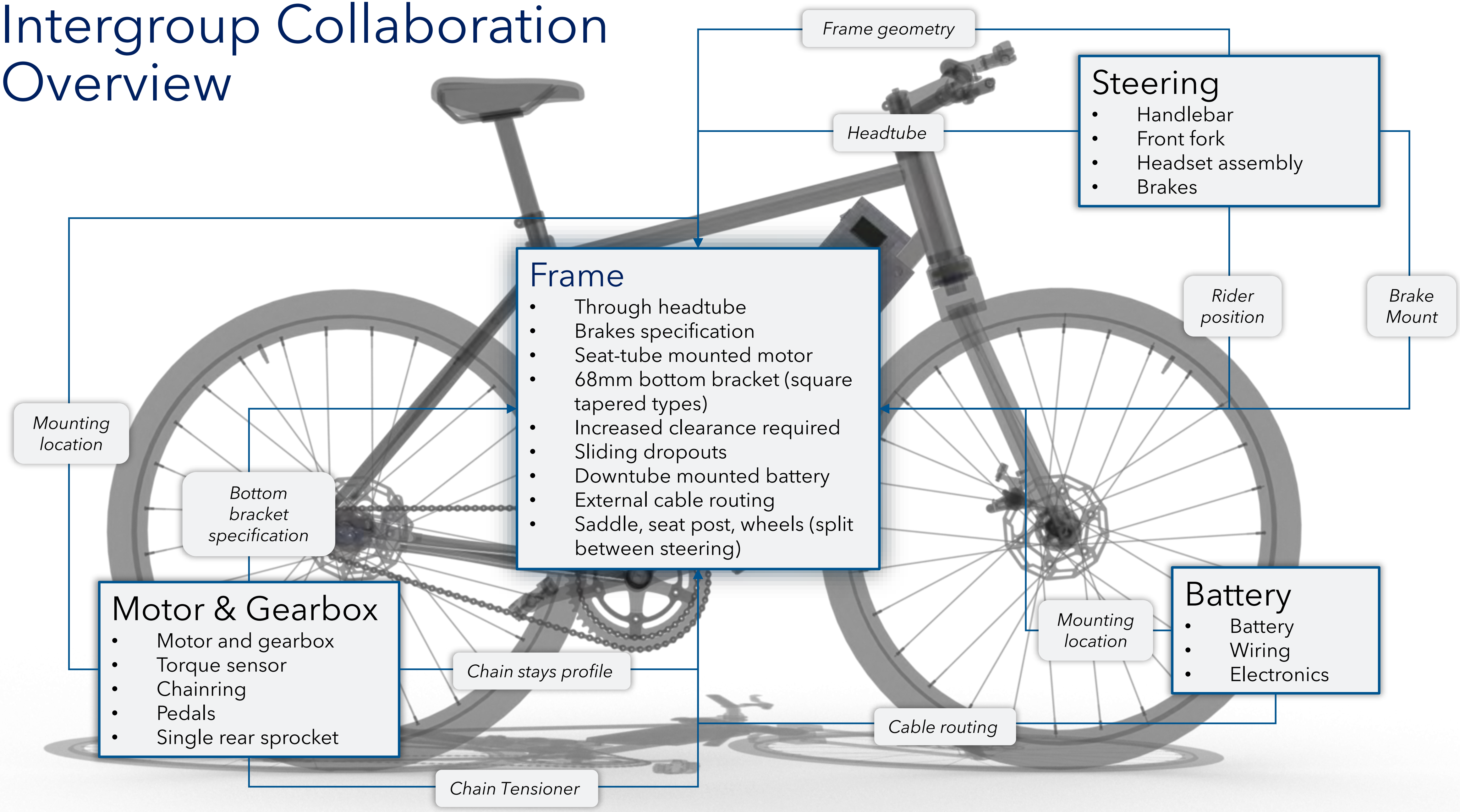
Motor and Gearbox
Sub-assembly

- Motor
- Gearbox
- Torque sensor
- Chainring & rear sprocket
- Pedals and crankset

Battery
Sub-assembly

- Battery
- Wiring
- Electronics

Intergroup Collaboration Overview



Complete E-Bike

**final render*

Frame Isolation

Frame Isolation

***Static** loading scenario*

Frame PDS

Element	Criteria	Verification	Date Modified
User Experience			
Needs	To accommodate for a comfortable ride position. Battery module must be integrated into frame.	Market Research on what is preferred and required.	05/11/2020
Market	Type of bike and specific features must fit city cycling requirements.	Research and compare to current urban, hybrid and road bikes.	05/11/2020
Physical Properties			
Size	54cm frame designed for a rider of height (169-176cm). Reach of approx. 380mm and handlebar height of approx. 830mm.	Research average human dimensions and corresponding frame measurements.	05/11/2020
Weight	Overall weight range: 15-30kg Frame weight range: 8-14kg	Calculate material weight using overall dimensions before manufacturing. Confirm weight by weighing manufactured frame.	05/11/2020
Wheels	700cc (622mm) Quick release mechanism.	Will be purchasing wheels. Detailed stress analysis will be performed to verify frame compatibility.	05/11/2020
Material	Must be able to withstand impact stress tests according to British standards. Must meet frame weight range. Corrosive and weather resistant.	Material Selection through CES Material Package.	05/11/2020
Cables and Wiring	Must accommodate for connections to motor and battery. Internal wiring reviewed; not employed on first iteration.	Review with drivetrain, battery, and motor team.	16/02/2021
Shape	Avoid having sharp edges and corners.	FEA analysis and design review.	05/11/2020
Saddle and seat-post	Frame must accommodate for standard 27.2mm seat post.		05/11/2020
Fenders and mudguard.	Mudguard attachments for front were responsibility of steering group. Rear mudguard does not need explicit attachment as it can clamp to the seat post.		16/02/2021
Performance			
Fatigue	Must be able to withstand cyclic forces to simulate riding conditions on the road and pedalling forces.	Testing according to (BS EN 15194:2017) sits outside of the budget of the group and specialized rigs for these tests are costly to produce and obtain. Tests also call for deformation of the frame which serves to weaken the bike; dummy component test methods will be employed. (to avoid damaging the original frame). FEA to be used to predict most vulnerable components. Verification by visual inspection of visible cracks or fractures in the assembly. There should also be no separation of parts at the joints.	26/02/2021
Impact Resistance	Must be able to withstand direct impact forces (horizontal and vertical) in cases of unnatural conditions and collisions.	Visual inspections of deflection and cracking performed under loading. FEA to be used to predict most vulnerable components.	26/02/2021
Bending, deformation and stress.	Frame must be able to support an 80kg rider under static stresses.	Measurement of stresses required to cause complete failure of critical components taken with Instron machine. FEA modelling and stress analysis used to predict most vulnerable components under largest stress.	26/02/2021
Operating Environment	-5°C - 40°C for wide range of cities	Select materials based on these operation temperatures.	26/02/2021
Safety factor	Frame must exhibit a safety factor of 3 under normal riding loads.	FEA modelling.	26/02/2021
Life Span			
Product Life	5 years	To be considered during material selection and calculation	05/11/2020
Service Life	10 years		05/11/2020
Production			
Quantity	10 million.	To cater for the ever-growing need for urban transportation	05/11/20

Frame PDS

Important points

Size	54cm frame designed for a rider of height (169-176cm).	Research average human dimensions and corresponding frame measurements.
	Reach of approx. 380mm and handlebar height of approx. 830mm.	
Weight	Overall weight range: 15-30kg	Calculate material weight using overall dimensions before manufacturing.
	Frame weight range: 8-14kg	Confirm weight by weighing manufactured frame.

Bending, deformation and stress.	Frame must be able to support an 80kg rider under static stresses.	Measurement of stresses required to cause complete failure of critical components taken with Instron machine. FEA modelling and stress analysis used to predict most vulnerable components under largest stress.

4. Planned Approach

- *Project roles*
- *Planned timeline*
- *Gantt chart*
- *Collaboration and workflow*

Project Roles

Rohit
-Project Manager
-Design
-CAD
-Manufacturer communications

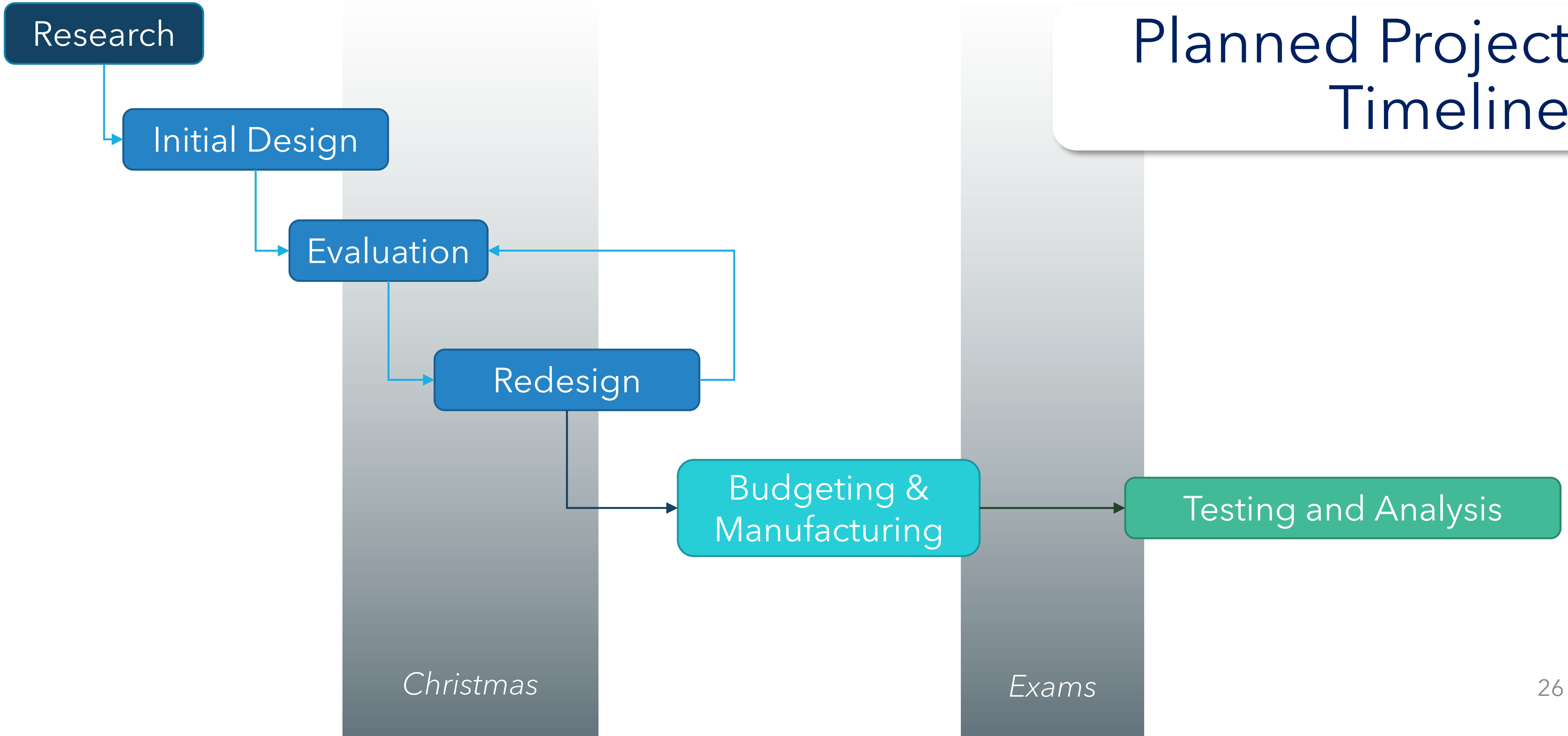
Theo
-Minutes
-Document organisation
-Finite element analysis
-Test liaison

Rohhil
-Reporting
-Material selection
-Test development
-Document quality control
-Intergroup communications

Mingquan
-Budgeting and finance
-Procurement
-Literature Research
-Testing Iterations

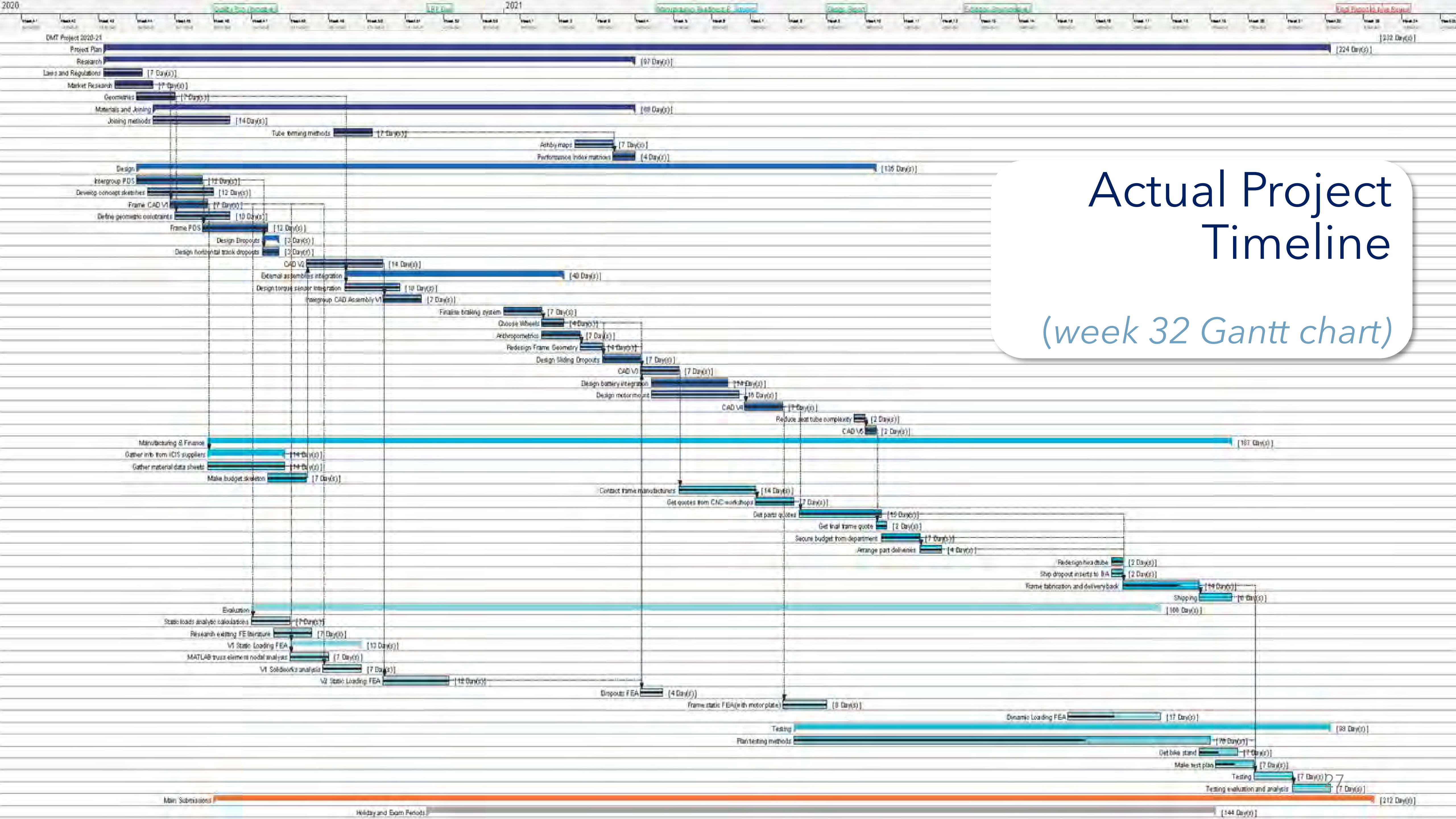
Zhongtian
-Evaluation
-Stress Analysis
-Formatting

Planned Project Timeline



Actual Project Timeline

(week 32 Gantt chart)



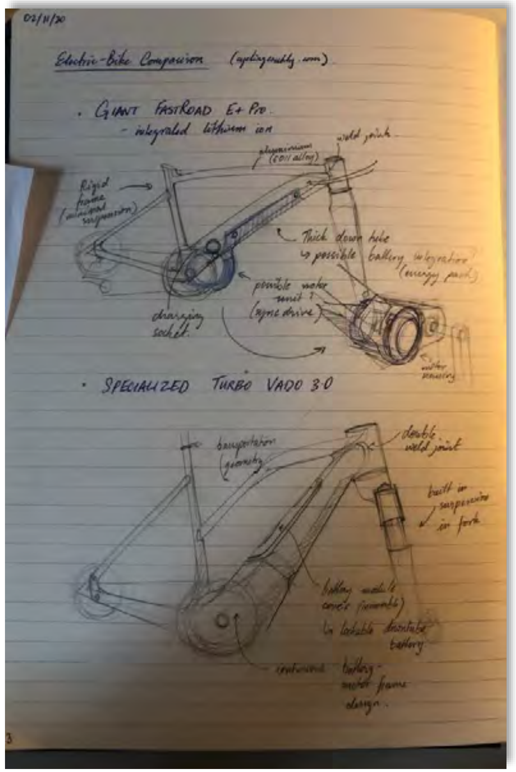
5.
Design & Evaluation Phase

- *Conceptual design*
- *Design challenges*
- *Finite element analysis and iterative design*

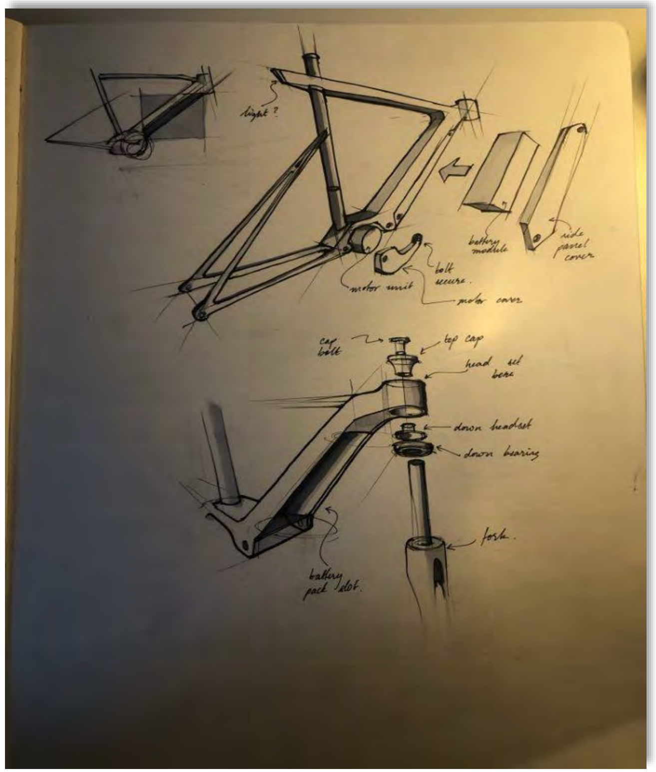
Research:

Model Name	Weight (kg)	Max Assistance Speed (mph)	Battery (Wh)	Assistance Motor Power (W)	Max Range (km)	RRP (£)
Giant FastRoad E+ Pro 2	19.0	15.5	500	250	60	2749
Specialized Turbo Vado 3.0	23.0	15.5	460	250	80	2400
VOLT Infinity 1	24.2	15.5	418	250	112	2400
Ampler Curt	15.0	15.5	336	250	70	2599
Specialized S-Works Turbo Creo SL	12.3	15.5	320	240		10999
Cannondale Topstone Neo Lefty 3 2021	17.4	15.5	500	250	128	5000
Wilier Cento1Hy Ultegra Di2	12.1	15.5	250	250		4299
Cairn Cycles E-Adventure	14.6	15.5	250	250	144	2989
Focus Paralane2 9.8	13.2	15.5	250	250	50	6499
Bianchi Impulso e-Road	12.9	15.5	500	250		4600
BMC Alpenchallenge AMP Road	14.9	15.5	418	250		6299
Brompton Electric	16.6	15.5	300	250	72	2595
Gocycle GX folding Electric Bike	17.8	15.5	300	250	65	2898
Tern Vektron D8 electric folding bike	22.1	15.5	400	250	144	3000
Ribble Hybrid AL e	14.6	15	250	250	96.5	1999
Carrera Crosscity Electric Bike	18.0	15.5	313	250	50	999
Elops 900 E Step Over Classic Electric Bike	24.0	15.5	418	250	70	999
Carrera Crossroad Electric Bike	19.5	15.5	310	250	64.3	999
Gtech Sports Hybrid Electric Bike	16.0	15.5	200	250	48	995
Max	24.2	15.5	500.0	250.0	144.0	#####
Min	12.1	15.0	200.0	240.0	48.0	995.0
Average	17.2	15.5	352.3	249.5	83.6	#####
Median	16.6	15.5	320.0	250.0	70.0	#####

Inspiration:



Concept Sketching:



Market Research & Conceptual Design

Design Iterations

V1.0

Features:

- *Integrated battery*
- *Integrated motor housing*

Problems:

- *Large stress concentrations*
- *Hard to manufacture*

Design Iterations

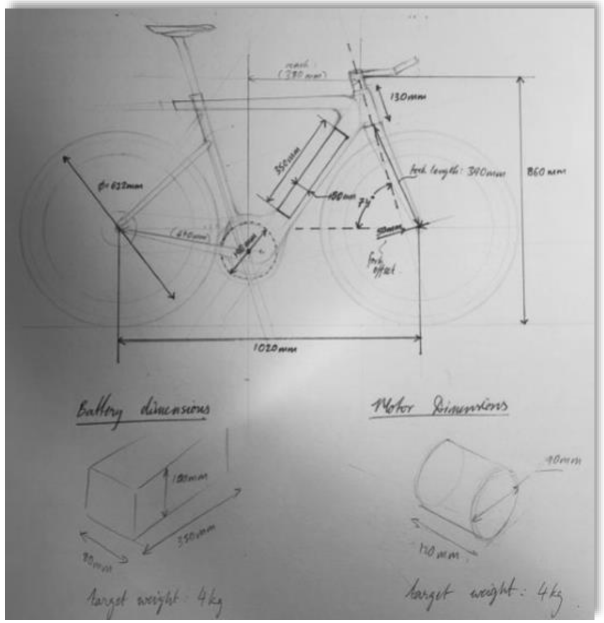
V1.2

Features:

- *Box section downtube*
- *Aluminium alloy construction*
- *Standard bottom bracket*

Problems:

- *Top tube intersection unnecessary*



V1 critical layout dimensions

Design Iterations

V2.0

Features:

- *Main tubes are stocked parts*
- *27.2mm seatpost*

Problems:

- *Chainstays expensive to manufacture*
- *No bridge support between stays*

Design Iterations

Features:

- *All tubes (including stays) are stocked parts*
- *Bridges between stays to support lateral pedalling loads*

Problems:

- *Seatstay will buckle under nominal loads*
- *Motor mounting solution lacking*
- *Track dropouts:*
  - *No support for disc brakes*
- *Aluminium: hard to work with*

Design Iterations

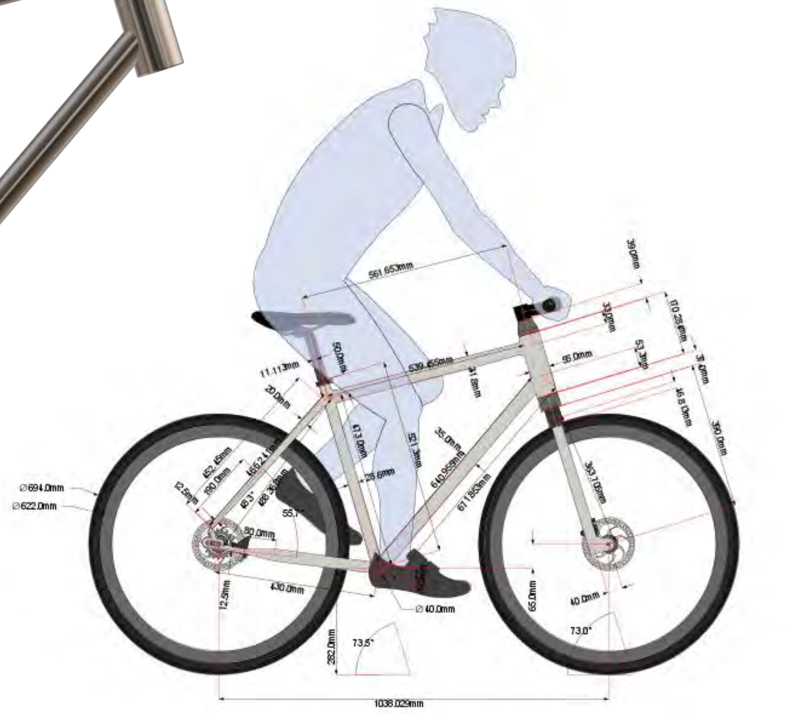
V3.0

Features:

- *Custom geometry*
- *Sliding dropouts*
- *Disc brakes*
- *Plated mounting tabs*
- *Omnicrom steel Columbus tubing*

Problems:

- *Mounting tabs are hard to weld*
- *Bolted joining is not preferred*

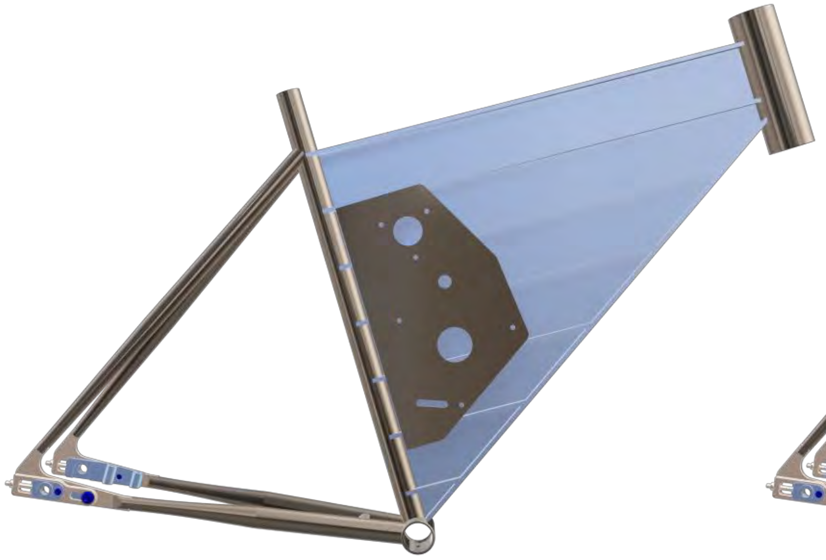


V2 critical layout dimensions (BikeCAD)

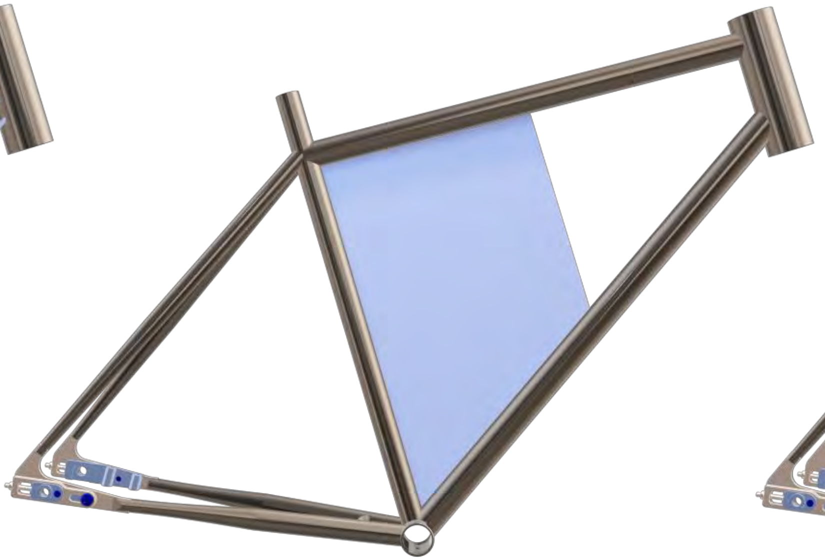
Design Iterations

V4: *Rethinking motor plate mounting*

a. *Aluminium support frame*



b. *Mid frame plate*



c. *Square tubes*

Initial Stress Evaluation based on script

Method:

- *Assumed the components to be 2D truss elements*
- *Derived stiffness matrix*

Freedom	{F}		1X	1Y	2X	2Y	3X	3Y	4X	4Y	5X	5Y	{δ}
1X			A_1+A_2	A_1+A_2			A_1	A_1	A_2	A_2			u1
1Y			A_1+A_2	A_1+A_2			A_1	A_1	A_2	A_2			v1
2X					A_3	A_3			A_3	A_3			u2
2Y					A_3	A_3			A_3	A_3			v2
3X	0	=	A_1	A_1			$A_1+A_4+A_5$	$A_1+A_4+A_5$	A_4	A_4	A_5	A_5	u3
3Y	0		A_1	A_1			$A_1+A_4+A_5$	$A_1+A_4+A_5$	A_4	A_4	A_5	A_5	v3
4X	0		A_2	A_2	A_3	A_3	A_4	A_4	$A_2+A_3+A_4+A_6$	$A_2+A_3+A_4+A_6$	A_6	A_6	u4
4Y	0		A_2	A_2	A_3	A_3	A_4	A_4	$A_2+A_3+A_4+A_6$	$A_2+A_3+A_4+A_6$	A_6	A_6	v4
5X	0						A_5	A_5	A_6	A_6	A_5+A_6	A_5+A_6	u5
5Y	-VL						A_5	A_5	A_6	A_6	A_5+A_6	A_5+A_6	v5

{F} Force vector — [K] Stiffness matrix — {δ} Displacement vector

[2]

[2] 2020 ME3 FEA Notes

Initial Stress Evaluation
(based on script)

- *The FEAA method is implemented by the code in MATLAB*

- *Several advantages throughout the conceptual design stage*

K

8x8 double

	1	2	3	4	5	6	7	8
1	2.5337e+07	4.6732e+06	-1.9096e+07	2.7144e+06	-6.2408e+06	-7.3876e+06	0	0
2	4.6732e+06	9.1310e+06	2.7144e+06	-3.8583e+05	-7.3876e+06	-8.7451e+06	0	0
3	-1.9096e+07	2.7144e+06	3.1467e+07	1.5853e+06	-2.3696e+06	7.4430e+06	-1.0001e+07	-1.1743e+07
4	2.7144e+06	-3.8583e+05	1.5853e+06	3.7552e+07	7.4430e+06	-2.3378e+07	-1.1743e+07	-1.3788e+07
5	-6.2408e+06	-7.3876e+06	-2.3696e+06	7.4430e+06	2.8993e+07	5.1930e+06	-2.0382e+07	-5.2484e+06
6	-7.3876e+06	-8.7451e+06	7.4430e+06	-2.3378e+07	5.1930e+06	3.3475e+07	-5.2484e+06	-1.3515e+06
7	0	0	-1.0001e+07	-1.1743e+07	-2.0382e+07	-5.2484e+06	3.0383e+07	1.6991e+07
8	0	0	-1.1743e+07	-1.3788e+07	-5.2484e+06	-1.3515e+06	1.6991e+07	1.5139e+07
9								

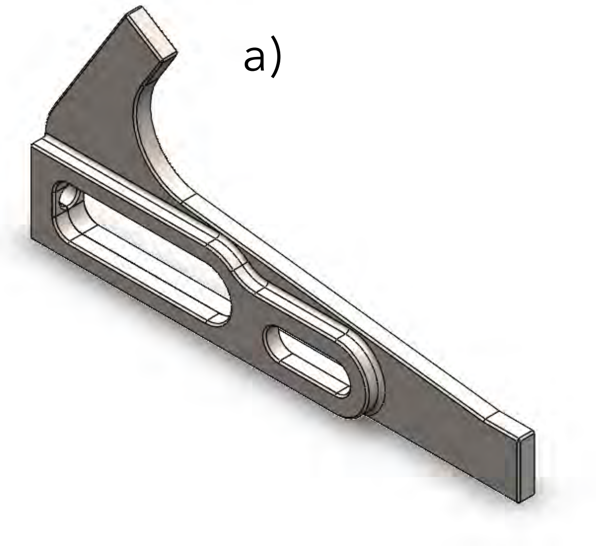
```
%the order is corresponding to chainstays, seattube, seatstays, downtub
A = [43.79 * 10^-6, 57.9 * 10^-6, 31.9 * 10^-6, 92.8 * 10^-6, 69.67 * 1
d = [-8.09*2*pi/360, 107.66*2*pi/360, 49.81*2*pi/360, 49.58*2*pi/360, 1
L = [0.47202, 0.47223, 0.44702, 0.81921, 0.67318];
E = [210 * 10^9, 210 * 10^9, 210 * 10^9, 210 * 10^9, 210 * 10^9]
```

```
Stress =

   1.0e+07 *

    1.2690   -1.0051   -1.7288    0.7231   -0.2787
```

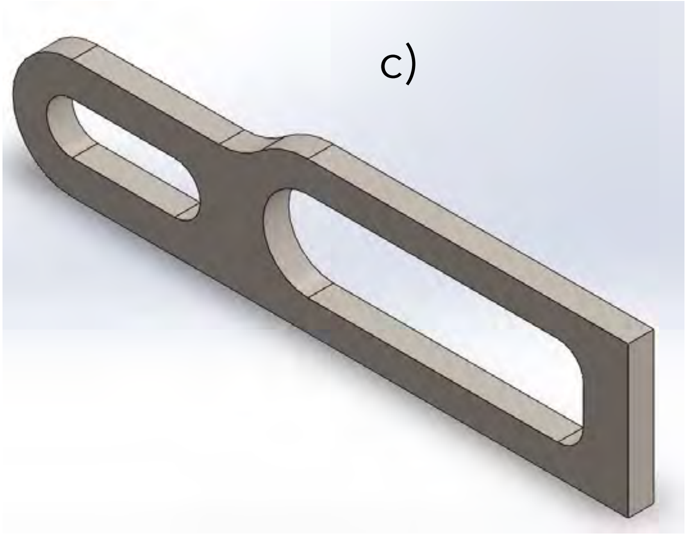
Dropouts

- Analysed separately to the frame, found to have a minimum safety factor of 4.3 (above the PDS value of 3; screenshot b)
- Initially designed to be produced entirely by CNC
- Redesign for manufacturability – made into laser-cut components which were produced individually then joined to give the required shape. (Screenshots c & d)
- Final component shown in Screenshot (a).
- Dropout redesign lowered total cost by ~ 3 times.

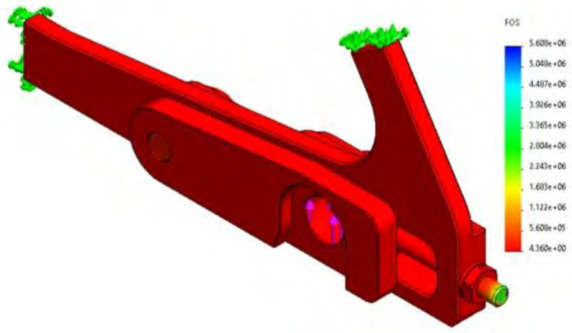
a)



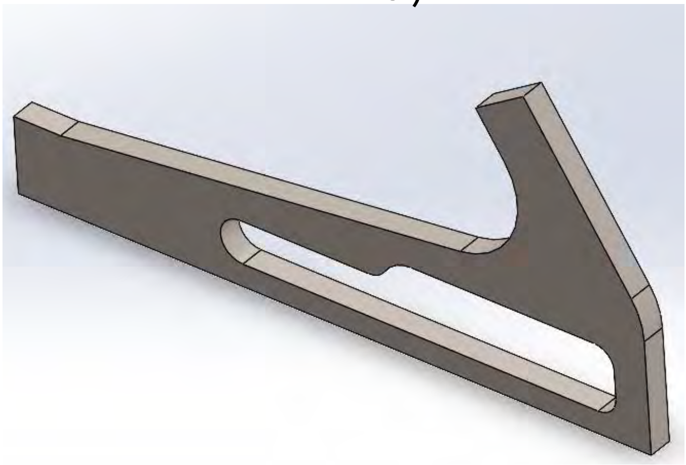
c)



b)

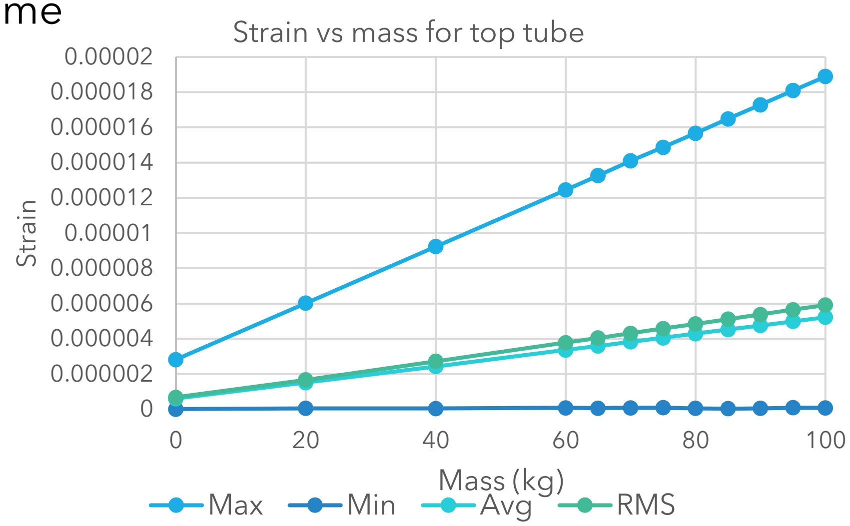


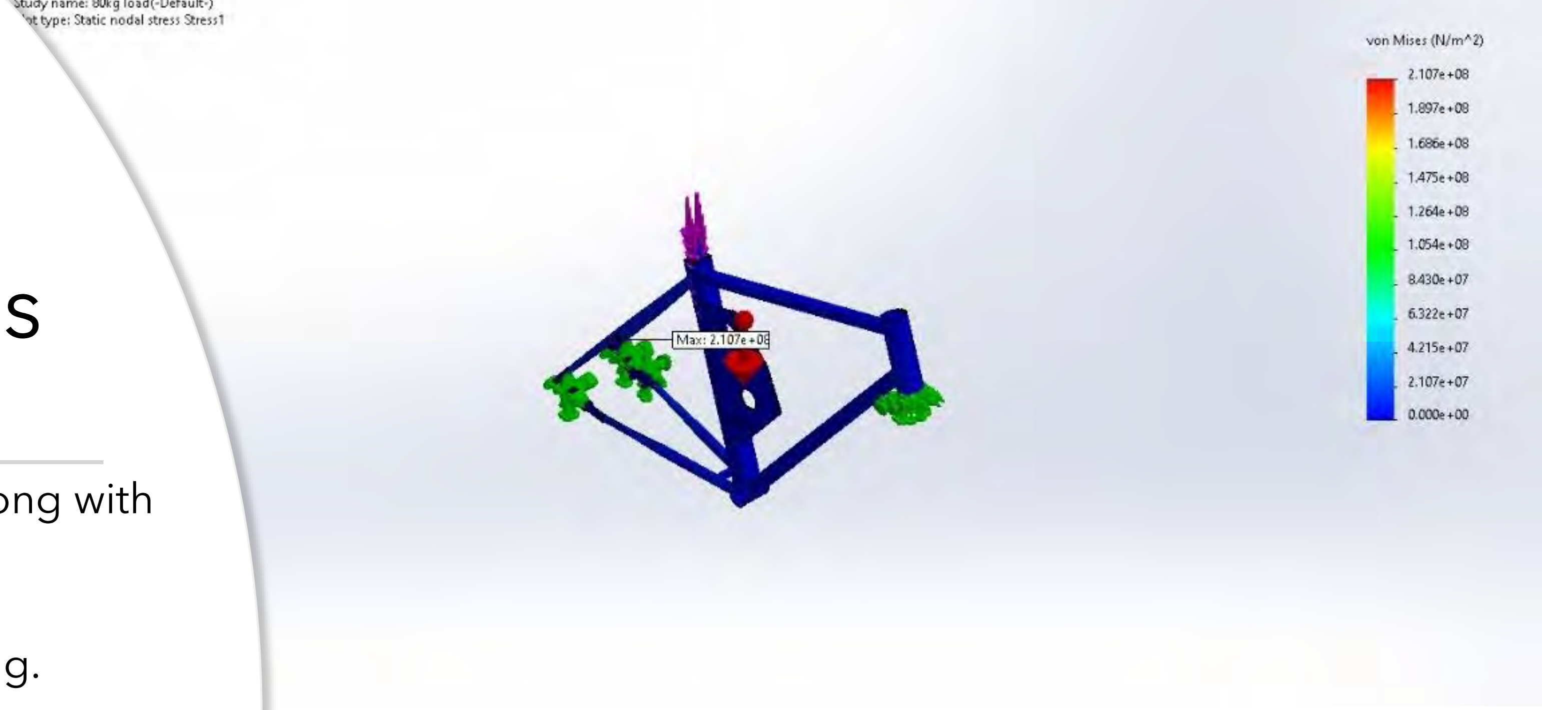
d)

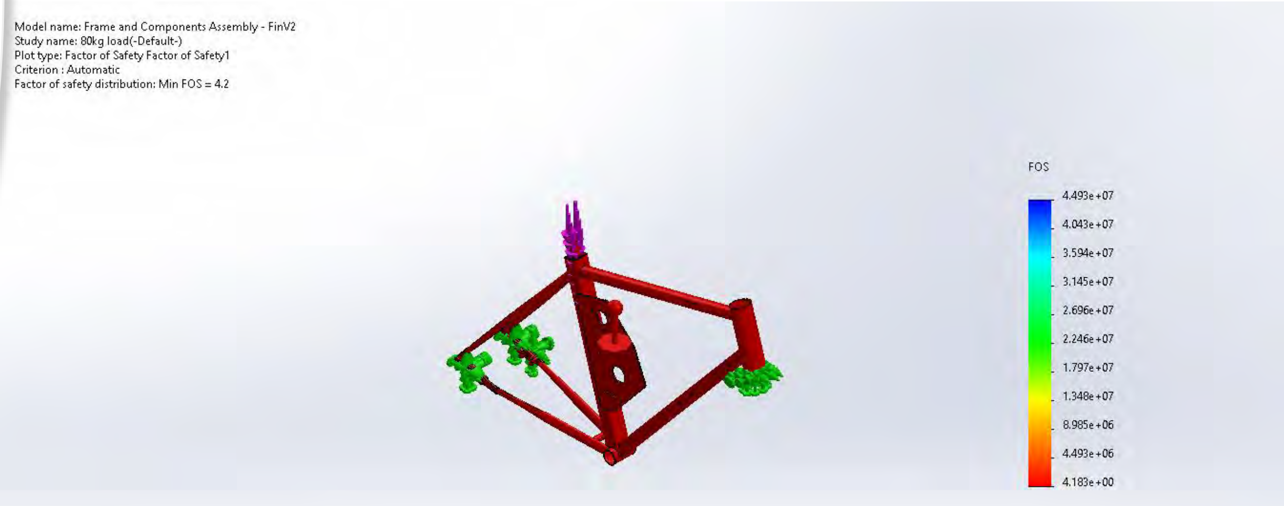


Finite Element Analysis

- SF predicted to be high in this load case, so strong with the rider on the bike.
- Max stress predicted at dropout joint, stress concentration due to weld path and cut in tubing.
- Linear trends expected in all data sets with mass (one graph for example)
- Low strains imply little deformation expected in the frame

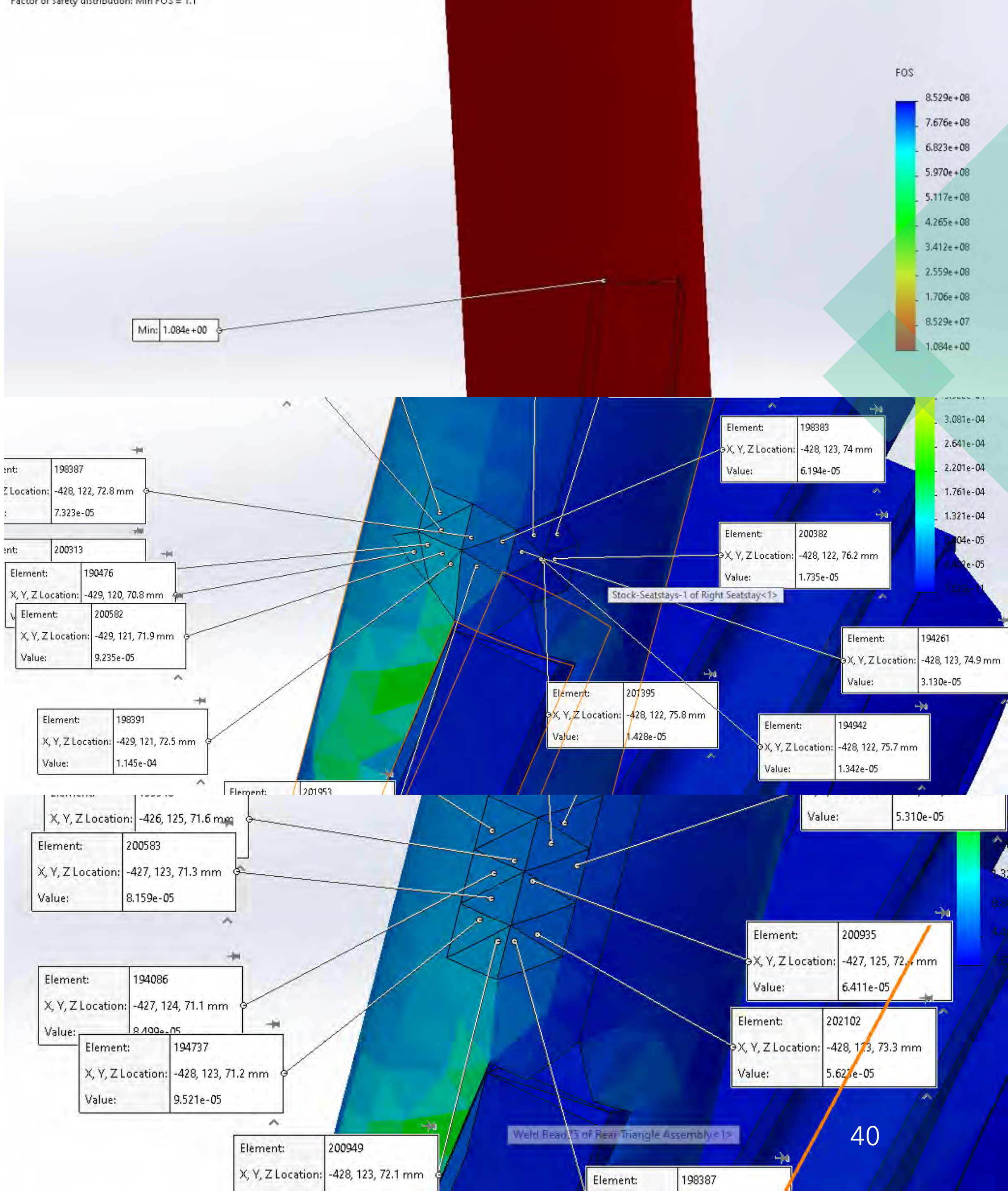






FEA: Stress concentration sites

- Screenshots show left seatstay above dropout with cut and increased areas of strain.
- Both this and a site on the chainstay were considered as they had higher stresses (therefore higher strain values).
- The top screenshot shows the low safety factor (due to a stress concentration) at the cut in the seatstay.



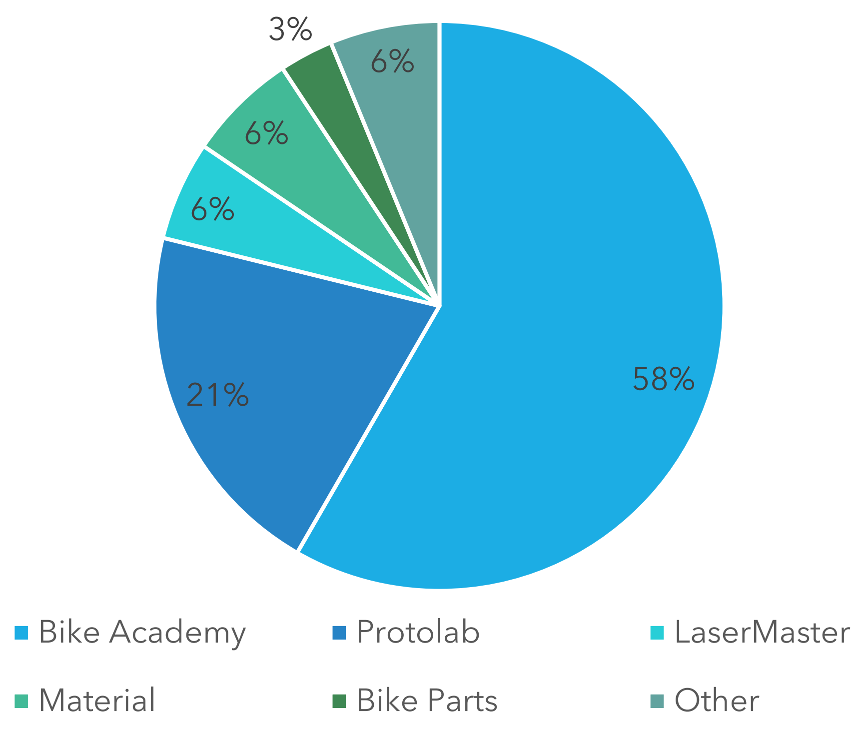
6. Budgeting and Manufacturing

- *Manufacturers*
- *Financing*

Budgeting

- *Over £1000 quickly, extra funding application needed*
- *Mainly spent on tubing and self-designed parts (axle, insert, dropouts)*
- *Final approved budget was £2834.89 including testing costs and shipping*

Expenditure Distribution



Detailed Budgeting

profile	x 2 mm, 1 m length	Mild steel E220	N/A	SKU 12120	desired length	Metals4U.co.uk	4.81	£	5.77	https://imperiallondon-my.sharepoint.com/								
Seat Tube; box profile	Machined from 40 x 40 x 2 mm, 1 m length	Mild steel E220	N/A	SKU 13663	Extrusion; milling to desired length	Metals4U.co.uk	8.54	£	10.25	https://imperiallondon-my.sharepoint.com/:i:/g/personal/tmh918_ic_ac_uk/EXvXMzZv6VVFgkfRhEwUWKUBIKQetjsB19wLglRkuVUpsA?e=6kBrvN								
Purchased Tubing Cost								**£**	**266.68**		**Tridan:**			**Incl VAT:**		**MRT Castings**	**Incl VAT:**	
Left and Right Dropouts		Stainless Steel	N/A		CNC						£	1,370.00	£685 x2 - left and right dropout	£	1,644.00	£500 left & right dropouts	600.00	https://im
Left and Right dropouts back plates	Machined from 5 mm steel plate	304 2B stainless steel	N/A		Laser Cut	LaserMaster	15.48	£	18.58	https://imperiallondon-my.sharepoint.com/								
Left and Right dropouts outlines	Machined from 4 mm steel plate	304 2B stainless steel	N/A		Laser Cut	LaserMaster	9.52	£	11.42	https://imperiallondon-my.sharepoint.com/								
Dropouts joining and boring cost			N/A		N/A	LaserMaster	150	£	180.00	https://imperiallondon-my.sharepoint.com/								
Left dropout Insert (flat mount brake mount)		6082-T651	N/A		CNC	Protolabs	178.41	£	214.09	https://imperiallondon-my.sharepoint.com/	£	490.00		£	588.00			
Right dropout Insert		6082-T651	N/A		CNC	Protolabs	133.92	£	160.70	https://imperiallondon-my.sharepoint.com/	£	465.00		£	558.00			
(unthreaded)		6082-T651	N/A		CNC	Protolabs	107.39	£	128.87	https://imperiallondon-my.sharepoint.com/	£	220.00		£	264.00			
Right nut		6082-T651	N/A		CNC	Protolabs	108.75	£	130.50	https://imperiallondon-my.sharepoint.com/	£	225.00		£	270.00			
Manufacturing Cost								**£**	**844.16**		£	2,770.00		£	3,324.00	Threading done by STW - said that threading will be included in asse		
Fasteners Cost								**£**	**50.00**									
Painting		**Powder Coating**	**cycles**			**The Bicycle Academy**		**£**	**80.00**	**Liquid painting given as another option, £120; powder coating chosen to save costs and as intricate graphics not needed.**								
Sending parts Cost								Delivery to Bicycle Academy for tubing, dropouts from lasermaster. Else delivered to ICL.										
						LaserMaster - dropouts	8.95	£	10.74	7 day turnaround								
						Protolabs - axle and dropout inserts	£7.61	£	9.13	by 4:30pm receive by 9/mar - 6 days								
						Wiggle - saddle, seatpost, clamp		£	-	Standard tracked delivery free - by 25/2	Delivered							
						Metals4U - tubing	£6	£	7.20	4 days								
						Merlin cycles - wheels		£	-	DPD 1-2 days	Delivered							
						steelexpress.co.uk - headtube	25	30										
						Bicycle Academy - frame delivery		£	15.00	Estimated								
Shipment Costs								**£**	**72.07**									
						Daily fee - 10 KN INSTRON machine, Mechanical Engineering dept £30		£	30.00	Estimated based on mech eng machinery daily costs								
						GTA Pay - 6 hrs total testing @ £16.38 / hr		£	98.28									
Testing								**£**	**128.28**									
Software								**£**	**30.20**									
Total Cost								**£**	**2,834.89**									

Outsourcing Frame Manufacturing

Company	Service	Contacted? New cell for each communication / response.
Doré Metal Services	Aluminium tubing / stock	Emailed asking about data sheets, metal types, sizes, joining.
Parkside Steel	Steel tubing / stock	Emailed asking about data sheets, metal types, sizes, joining.
RS	Al & steel tubing as a backu	Emailed asking about data sheets, metal types, sizes, joining.
Finetech Eng LTD	Manufacture	Asked about stock purchase, welding/brazing
Tenon Eng LTD	Manufacture / assembly	Asked about stock purchase, welding/brazing
Frazer Nash Manufacturin	Manufacture / assembly	Asked about stock purchase, welding/brazing
Bonlea Eng LTD	Fabrication	Asked about stock purchase, welding/brazing
Penta Precision Eng LTD	Precision machining	Asked about stock purchase, welding/brazing
MultiGrind Services	Grinding	Asked about stock purchase, welding/brazing
CTC Precision Eng	Precision machining	Asked about stock purchase, welding/brazing
Valuframe	Material	Asked about stock price in a specific range
Aluminium Warehouse	Material	Asked about stock price in a specific range
Aalco	Material	Asked about stock price in a specific range
Rourke	Bike shop	Asked about seatposts specifically
B And A	CNC / material	Contacted RE CNC Dropouts

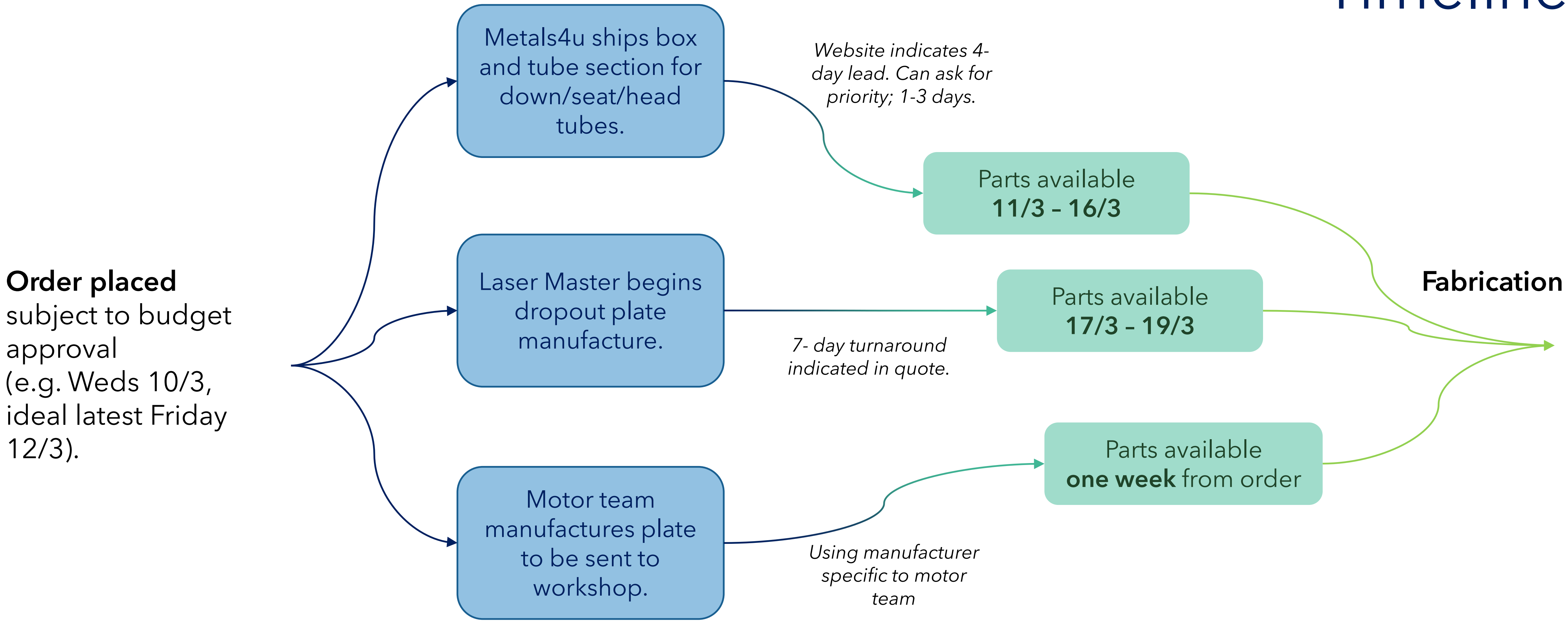
Sub-contractor Name	Town	Phone No.	Contact	Contractor Type	Post Code	Column1
Finetech Engineering Ltd	Hatfield	01707 258855	Andrew Carruthers	Milling, turning, grinding, tapping, spark erosion, plating, etc.	AL9 5JT	http://finetechengineering.co.uk/
Tenon Engineering Ltd	Dorking	01306 867 416	Terry Healy	Milling, turning, grinding, assembly, etc.	RH4 1EJ	www.tenon-eng.com
Frazer Nash Manufacturing	Petersfield	01730 230 340	Paul Mprtlock	Milling, turning, grinding, assembly, etc.	GU32 3FG	https://frazernash.com/
Leedsheath	Guildford	01483 503248	Tony Skidmore	Laser Cutting and Fab		
Cirrus Laser	Burgess Hill	01444 870386	Andy White	Laser Cutting		
Galtec	Wokingham	0118 977 2556	Gary Longhurst	Precision Machinging		
Duckworth & Kent	Reading	0118 942 6232	Stuart Gleeson	Wire Erosion	RG31 6HB	
Hinkell	Leatherhead	07752 591 359	Andy Hine	General Machining		
Aqua Cut	Northfleet	01474 532 878	Toby Lewis	Waterjet Cutting		
SJP Engineering	Bilston	01902 401781	Stephen Price	Specimen manufacture		
A & M EDM	Smethwick	0121 558 8352	Richard Madeley	Wire Erosion	B66 2JE	
Test House	Cambridge	01223 894252	David Elin	Charpy Samples		
Proto Labs	Telford	01952 683047		CNC Machining & 3DP		
Engineering Solutions	Newbury	01635 582582	Alan Dale	Design & Machining	RG14 5SH	
Penta Pattern & Model	Nuneaton	01455-890571		CNC - Punch & Dies		
Control Waterjet Cutting Limited	Staveley	01246-284000	Craig Herring	Waterjet Cutting	S43 3PF	
Erodatools	Sheffield	01226 763725	Caroline Healey	EDM CNC Wire & Spark Erosion	S36 6HF	
Penta Precision Engineering Ltd	Portsmouth	02392-668334		CNC Milling / Turning		
MultiGrind Services	Rickmansworth WD3 1PQ	01923-721011		CNC Mill / Turn / Grinding	WD3 1PQ	
CTC Precision Engineering	Radstock	01761-437639		CNC Mill / CNC Turn +	BA3 3RD	
Malden Plating Works	Mitcham	020 8640 1272		Plating	CR4 4NB	

- *Over 40 workshop & contractors contacted*
  - *most do not have the ability or time to weld/braze the bike frame*
- *Bicycle Academy chosen as manufacturer*
  - *professional industry-grade bike frame fabricator*

How we cut down the budget?

- *Reduced testing to only static loading*
- *Avoid painting as strain gauges need to be put onto the frame*
- *Dropout: CNC to laser-cut, less complex shape*

Manufacturing Timeline



Manufacturing Timeline

Fabrication

Fabrication
(2-4 working days est.?)
Start 22/3; end 24-26/3.

Dispatch, shipping (1wk)

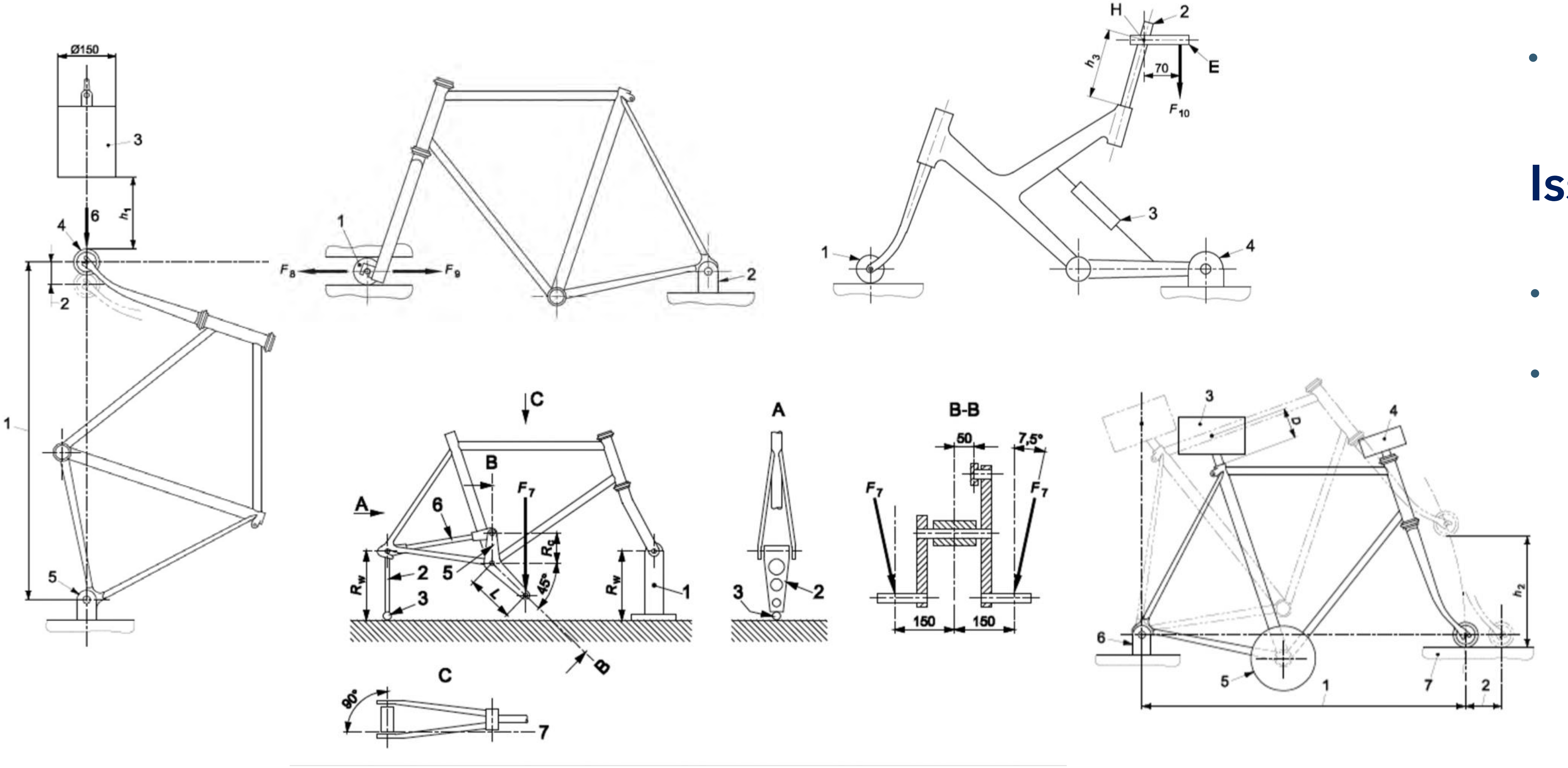
Frame & test subassemblies at Imperial College
(31/3 – 2/4).

7.
Testing

- *Test set-up*
- *Results*

Test Development

Iteration 1 – British Standards



Testing For:

- *Fatigue (Horizontal and Vertical Forces)*
- *Impact*

Issues

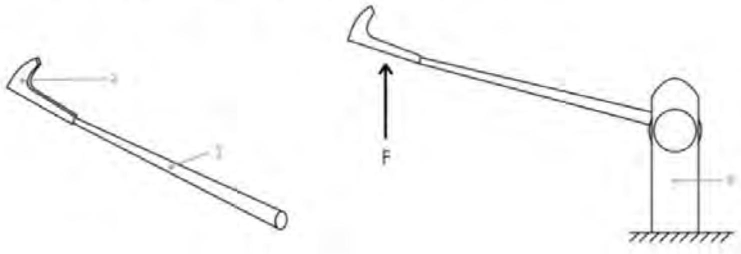
- *Long duration*
- *Resource Heavy*

Drawings from British Standard BS EN 15194:2017, BSI (2017) [3]
Available from : https://bsol-bsigroup-com.iclibezp1.cc.ic.ac.uk/BibliographicInfoData/000000000030384746

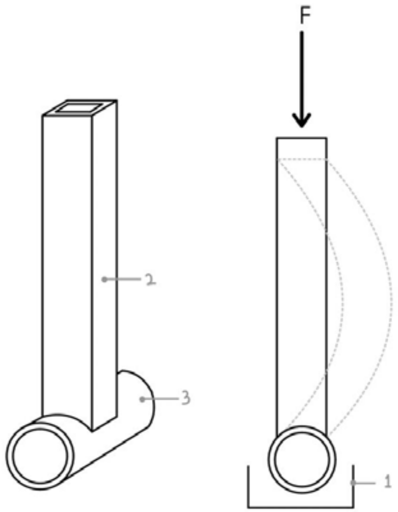
Test Development

Iteration 2 – Self Developed

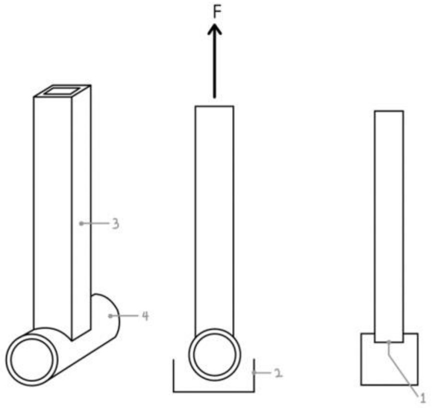
Test 1: Chain stay and Dropout Fatigue



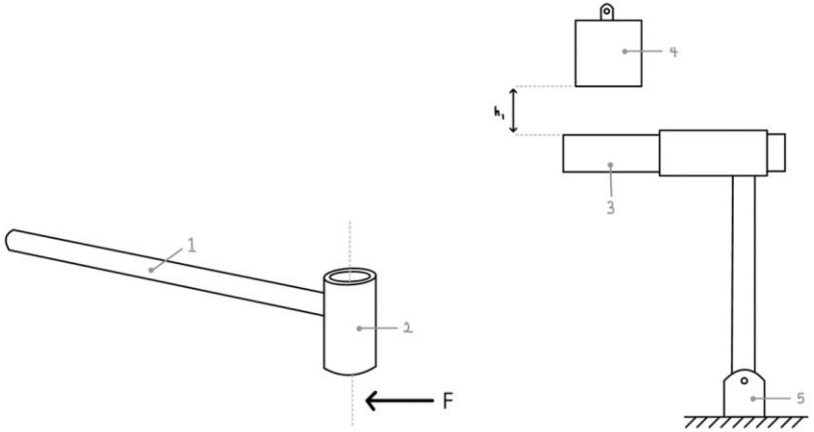
Test 2: Box Section Seat Tube Buckling



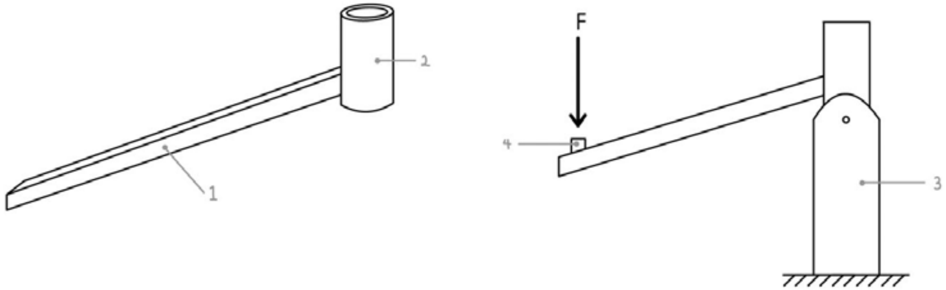
Test 3: Bottom Bracket Brazed Joint Fatigue



Test 4: Top Tube Impact Fracture



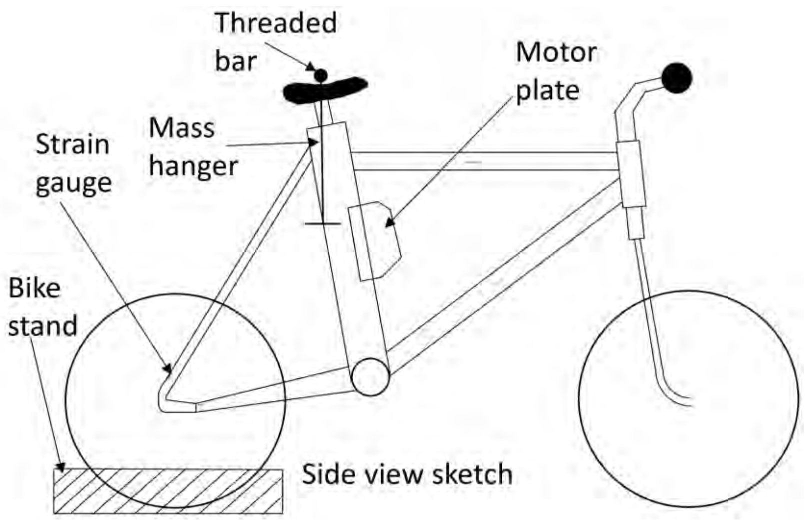
Test 5: Down Tube Brazed Joint Pedalling Fatigue



Issues

- *Long duration*
- *Unavailability of test rigs*

Test specification



- *Masses were applied in 20 kg increments from 0 kg to 60 kg then in 5 kg increments from 60 kg to 100 kg*
- *Design weight is 80 kg so this is exceeded to test the strength of the frame*

Test specification

Component	Strain gauge number	Limiting strain value (100 kg)	
		Max	RMS
Axially oriented, inner seatstay (0°)	1	9.645×10^{-5}	7.381×10^{-5}
Hoop oriented, inner seatstay (90°)	2	1.145×10^{-4}	7.155×10^{-5}
Axially oriented, inner chainstay (0°)	3	6.356×10^{-5}	6.088×10^{-5}
Hoop oriented, inner chainstay (90°)	4	6.324×10^{-5}	5.741×10^{-5}
Axially oriented, top tube	5	3.331×10^{-6}	2.772×10^{-6}
Axially oriented, downtube	6	1.086×10^{-5}	1.076×10^{-5}

- *Sites chosen for strain gauges*
  - *dropout join at chainstay and seatstay (identified as stress concentration area by FEA) and down tube, top tube for reference and comparison at relatively un-stressed areas*

- *6 strain gauges used; one broke during soldering (chainstay hoop orientation)*

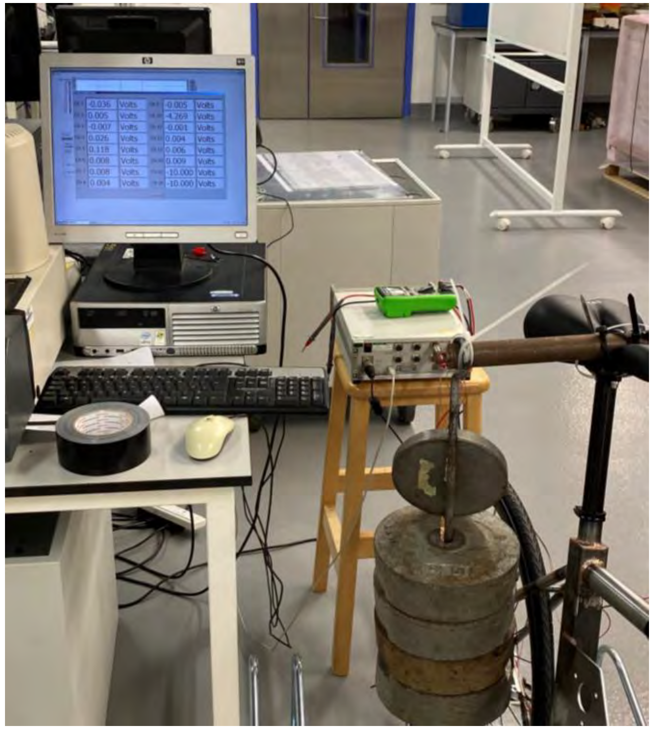
- *Strain is measured to avoid excessive deformation and compare with FEA predictions*

- *Advisory limiting values provided to avoid deformation*

Test setup

Yellow dots show strain gauge sites.

- Set up in a bike stand for support with masses suspended from hangers via a bar attached to the saddle.
- Strain gauges connected to Madaq 16 and data recorded at each load.
- Voltage data shown by Madaq, so strains could not be compared during test



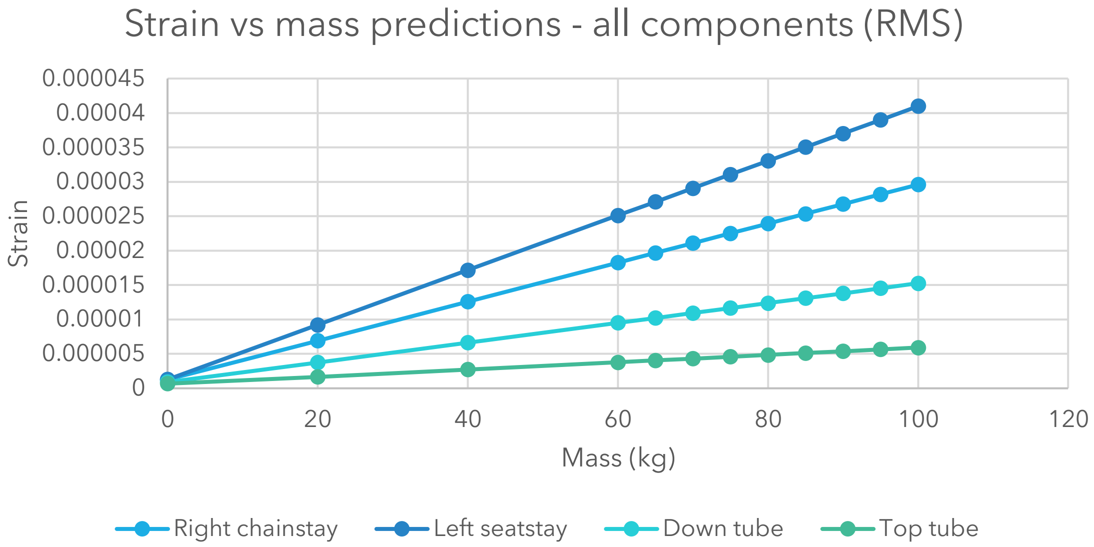
Test setup

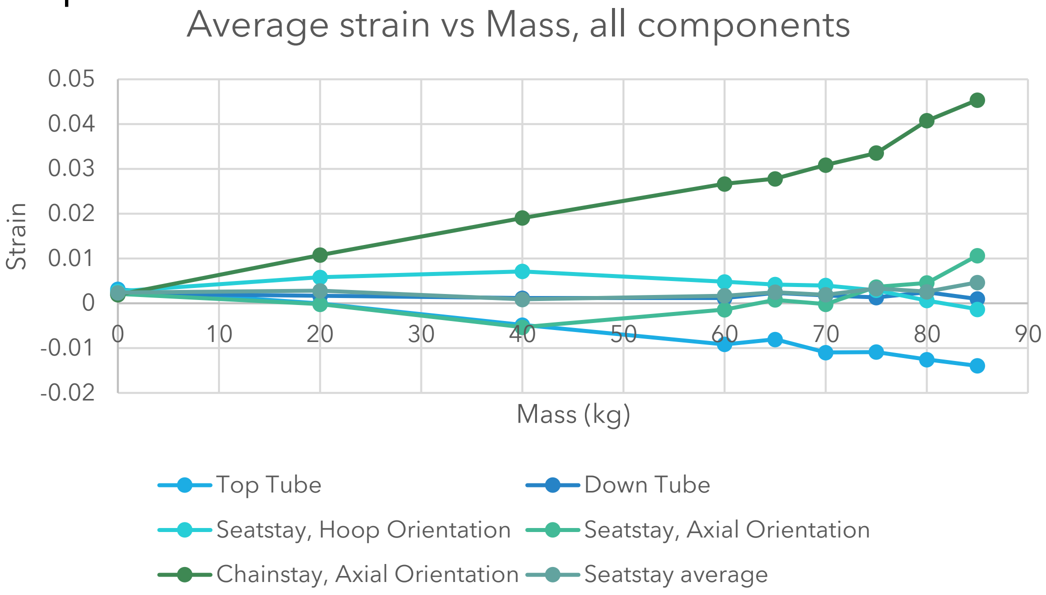
- Not painted to avoid interference with strain gauge adhesion.
- Progressed up to 85 kg until the stand began to deform – the bike did not, and experienced no damage or wear.

- At 40 kg, the bar supplied from the stores bent significantly so a new one was sourced.

Results

- Linear trends broadly observed across data, as expected, although magnitudes differ to FEA.
- Likely due to strain gauges being applied by less experienced GTA.
- Validates FEA as trends are as predicted.





- Relative sizes of strain values in each component could be improved by higher-resolution FEA.
- Strains also seem very high in test data; did not correspond to the low level of deformation in the frame.
- Measurements in V rather than mV, noise in software.

Results – Raw Strain Data

1	Mass (kg)	Channel	Component	Voltage 1	Voltage 2	Voltage 3	Voltage 4	Avg Voltage	Conversion to strain
2	0	1	Top tube	0.017	-0.001			0.008	strain = 4 * Voltage / Bridge Volta
3	0	2	Downtube	0.011	0			0.0055	
4	0	3	Seatstay hoop	0.007	0.007			0.007	
5	0	4	Seatstay axial	0.008	0.003			0.0055	
6	0	5	Chainstay axial	0	0.01			0.005	
7	20	1	Top tube	-0.002	0.003	-0.004	0.003	0	
8	20	2	Downtube	0.005	0.006	0	0.006	0.00425	
9	20	3	Seatstay hoop	0.016	0.014	0.017	0.014	0.01525	
10	20	4	Seatstay axial	-0.004	0.002	-0.002	0.002	-0.0005	
11	20	5	Chainstay axial	0.027	0.027	0.032	0.027	0.02825	
12	40	1	Top tube	-0.015	-0.01	-0.012		-0.012333333	
13	40	2	Downtube	0.003	0.003	0.003		0.003	
14	40	3	Seatstay hoop	0.017	0.022	0.017		0.018666667	
15	40	4	Seatstay axial	-0.016	-0.013	-0.013		-0.014	
16	40	5	Chainstay axial	0.05	0.052	0.048		0.05	
17	60	1	Top tube	-0.023	-0.024	-0.023		-0.023333333	
18	60	2	Downtube	0.007	0	0.002		0.003	
19	60	3	Seatstay hoop	0.015	0.013	0.01		0.012666667	
20	60	4	Seatstay axial	-0.008	-0.004	0.001		-0.003666667	
21	60	5	Chainstay axial	0.069	0.07	0.071		0.07	
22	65	1	Top tube	-0.014	-0.027			-0.0205	
23	65	2	Downtube	0.012	0			0.006	
24	65	3	Seatstay hoop	0.012	0.01			0.011	
25	65	4	Seatstay axial	0.004	0			0.002	
26	65	5	Chainstay axial	0.072	0.074			0.073	
27	70	1	Top tube	-0.025	-0.031			-0.028	
28	70	2	Downtube	0.007	0.002			0.0045	
29	70	3	Seatstay hoop	0.011	0.01			0.0105	
30	70	4	Seatstay axial	-0.001	0			-0.0005	
31	70	5	Chainstay axial	0.081	0.081			0.081	
32	75	1	Top tube	-0.029	-0.025	-0.029		-0.027666667	
33	75	2	Downtube	0.003	0.005	0.002		0.003333333	
34	75	3	Seatstay hoop	0.007	0.009	0.007		0.007666667	
35	75	4	Seatstay axial	0.007	0.01	0.012		0.009666667	
36	75	5	Chainstay axial	0.089	0.088	0.087		0.088	
37	80	1	Top tube	-0.033	-0.033	-0.03		-0.032	
38	80	2	Downtube	0.001	0.006	0.012		0.006333333	
39	80	3	Seatstay hoop	0.004	0.002	-0.001		0.001666667	
40	80	4	Seatstay axial	0.009	0.013	0.014		0.012	
41	80	5	Chainstay axial	0.108	0.109	0.104		0.107	
42	85	1	Top tube	-0.036	-0.035			-0.0355	
43	85	2	Downtube	0.005	0			0.0025	
44	85	3	Seatstay hoop	-0.007	0			-0.0035	
45	85	4	Seatstay axial	0.026	0.03			0.028	
46	85	5	Chainstay axial	0.118	0.12			0.119	

1	Mass (kg)	Channel	Componer	Strain 1	Strain 2	Strain 3	Strain 4	Avg Strain - tra
2	0	1	Top tube	0.006667	-0.00039			0.003137
3	0	2	Downtube	0.004314	0			0.002157
4	0	3	Seatstay hc	0.002667	0.002667			0.002667
5	0	4	Seatstay ax	0.003048	0.001143			0.002095
6	0	5	Chainstay a	0	0.00381			0.001905
7	20	1	Top tube	-0.00078	0.001176	-0.00157	0.001176	0
8	20	2	Downtube	0.001961	0.002353	0	0.002353	0.001667
9	20	3	Seatstay hc	0.006095	0.005333	0.006476	0.005333	0.00581
10	20	4	Seatstay ax	-0.00152	0.000762	-0.00076	0.000762	-0.00019
11	20	5	Chainstay a	0.010286	0.010286	0.01219	0.010286	0.010762
12	40	1	Top tube	-0.00588	-0.00392	-0.00471		-0.00484
13	40	2	Downtube	0.001176	0.001176	0.001176		0.001176
14	40	3	Seatstay hc	0.006476	0.008381	0.006476		0.007111
15	40	4	Seatstay ax	-0.0061	-0.00495	-0.00495		-0.00533
16	40	5	Chainstay a	0.019048	0.01981	0.018286		0.019048
17	60	1	Top tube	-0.00902	-0.00941	-0.00902		-0.00915
18	60	2	Downtube	0.002745	0	0.000784		0.001176
19	60	3	Seatstay hc	0.005714	0.004952	0.00381		0.004825
20	60	4	Seatstay ax	-0.00305	-0.00152	0.000381		-0.0014
21	60	5	Chainstay a	0.026286	0.026667	0.027048		0.026667
22	65	1	Top tube	-0.00549	-0.01059			-0.00804
23	65	2	Downtube	0.004706	0			0.002353
24	65	3	Seatstay hc	0.004571	0.00381			0.00419
25	65	4	Seatstay ax	0.001524	0			0.000762
26	65	5	Chainstay a	0.027429	0.02819			0.02781
27	70	1	Top tube	-0.0098	-0.01216			-0.01098
28	70	2	Downtube	0.002745	0.000784			0.001765
29	70	3	Seatstay hc	0.00419	0.00381			0.004
30	70	4	Seatstay ax	-0.00038	0			-0.00019
31	70	5	Chainstay a	0.030857	0.030857			0.030857
32	75	1	Top tube	-0.01137	-0.0098	-0.01137		-0.01085
33	75	2	Downtube	0.001176	0.001961	0.000784		0.001307
34	75	3	Seatstay hc	0.002667	0.003429	0.002667		0.002921
35	75	4	Seatstay ax	0.002667	0.00381	0.004571		0.003683
36	75	5	Chainstay a	0.033905	0.033524	0.033143		0.033524
37	80	1	Top tube	-0.01294	-0.01294	-0.01176		-0.01255
38	80	2	Downtube	0.000392	0.002353	0.004706		0.002484
39	80	3	Seatstay hc	0.001524	0.000762	-0.00038		0.000635
40	80	4	Seatstay ax	0.003429	0.004952	0.005333		0.004571
41	80	5	Chainstay a	0.041143	0.041524	0.039619		0.040762
42	85	1	Top tube	-0.01412	-0.01373			-0.01392
43	85	2	Downtube	0.001961	0			0.00098
44	85	3	Seatstay hc	-0.00267	0			-0.00133
45	85	4	Seatstay ax	0.009905	0.011429			0.010667
46	85	5	Chainstay a	0.044952	0.045714			0.045333

Voltage readings converted into strain values using a similar method to fairground lab;

$$Strain = \frac{4 \times voltage\ reading\ at\ gauge}{Bridge\ voltage \times gauge\ factor}$$

. Equation from National Instruments Application Note on strain gauges, 1998. [4]

Results – Transfer Strain to Stress

(Based on avg. strain)									
Component \ Mass	0	20	40	60	65	70	75	80	85
Top tube	658.8235294	0	-1015.69	-1921.57	-1688.24	-2305.88	-2278.43	-2635.29	-2923.53
Downtube	452.9411765	350	247.0588	247.0588	494.1176	370.5882	274.5098	521.5686	205.8824
Seatstay hoop	560	1220	1493.333	1013.333	880	840	613.3333	133.3333	-280
Seatstay axial	440	-40	-1120	-293.333	160	-40	773.3333	960	2240
Chainstay axial	400	2260	4000	5600	5840	6480	7040	8560	9520

- The stresses would have caused the frame to fail if they occurred in testing

Results – Confidence Interval for the data

Small size of data but with large fluctuations so the average value might not be very accurate

The 95% Confidence interval method is used to indicate the range that the true value of measurement mostly likely falls in, useful to estimate the magnitude of stresses

Mass/Component	Top tube	Downtube	seatstay hoop	seatstay axial	chainstay axial
0	(-8341.6 , 9596.5)	(-5049.7 , 5912.5)	(533.3 , 533.3)	(-2001.2 , 2839.3)	(-4459.5 , 5221.4)
20	(-444,17 , 444.17)	(-25.13 , 691.80)	(980.1 , 1343.8)	(-401.80 , 325.61)	(1849.3 , 2455.5)
40	(-1457.6 , -477.0)	(235.29 , 235.29)	(875.9 , 1968.6)	(-1394.5 , 738.8)	(3431.0 , 4188.1)
60	(-1942.6 , -1717.6)	(-467.19 , 937.78)	(-488.8 , 1441.4)	(-1132.8 , 574.1)	(5144.1 , 5522.6)
65	(-8085.5 , 4869.8)	(-5508.8 , 6450.0)	(-130.0 , 1806.2)	(-1783.8 , 2088.6)	(-4593.8 , 6530.0)
70	(-5185.8 , 793.6)	(-2138.5 , 2844.4)	(316.0 , 1284.0)	(-522.14 , 445.9)	(6174.4 , 6174.4)
75	(-2619.9 , -1720.0)	(-36.18 , 559.05)	(365.58 , 802.67)	(260.2 , 1212.8)	(6515.5 , 6894.0)
80	(-2847.3 , -2172.3)	(-576.3 , 1569.8)	(-349.33 , 603.29)	(413.5 , 1415.0)	(7651.6 , 8653.1)
85	(-3282.6 , -2286.0)	(-2295.3, 2687.5)	(-3655.0, 3121.7)	(197.2, 4069.5)	(8099, 10035)

8.
Future Considerations

- *Improvements*
- *What could have been better?*

Future design progression

Short term:

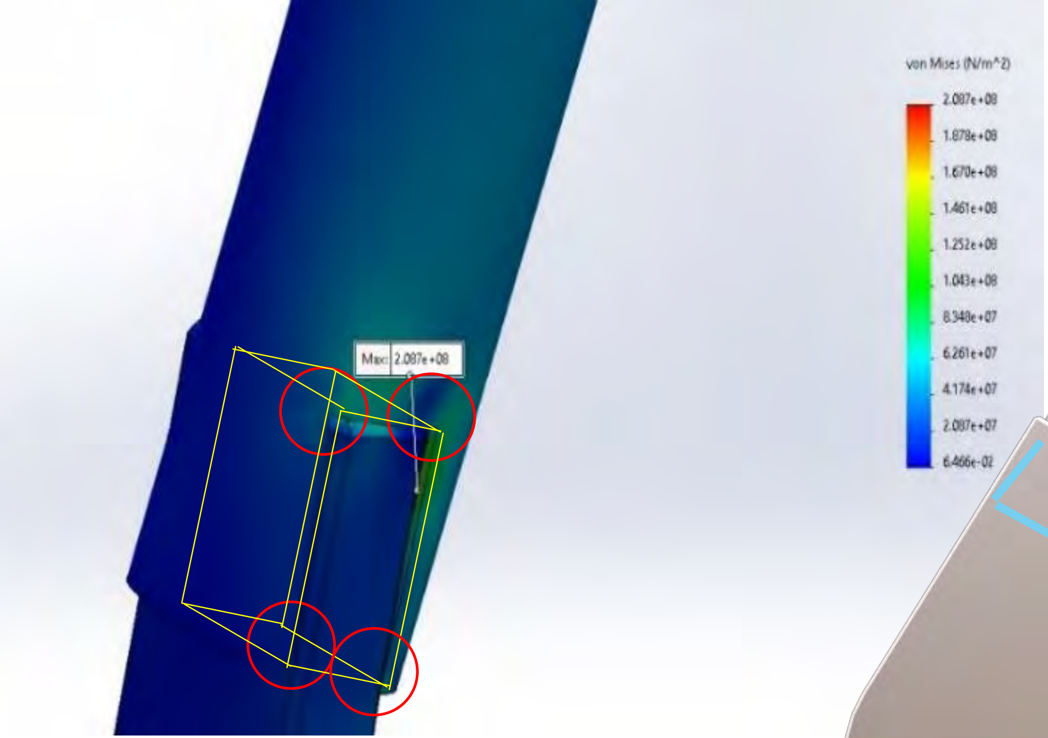
- *Painting*
- *Change dropouts (next slide)*

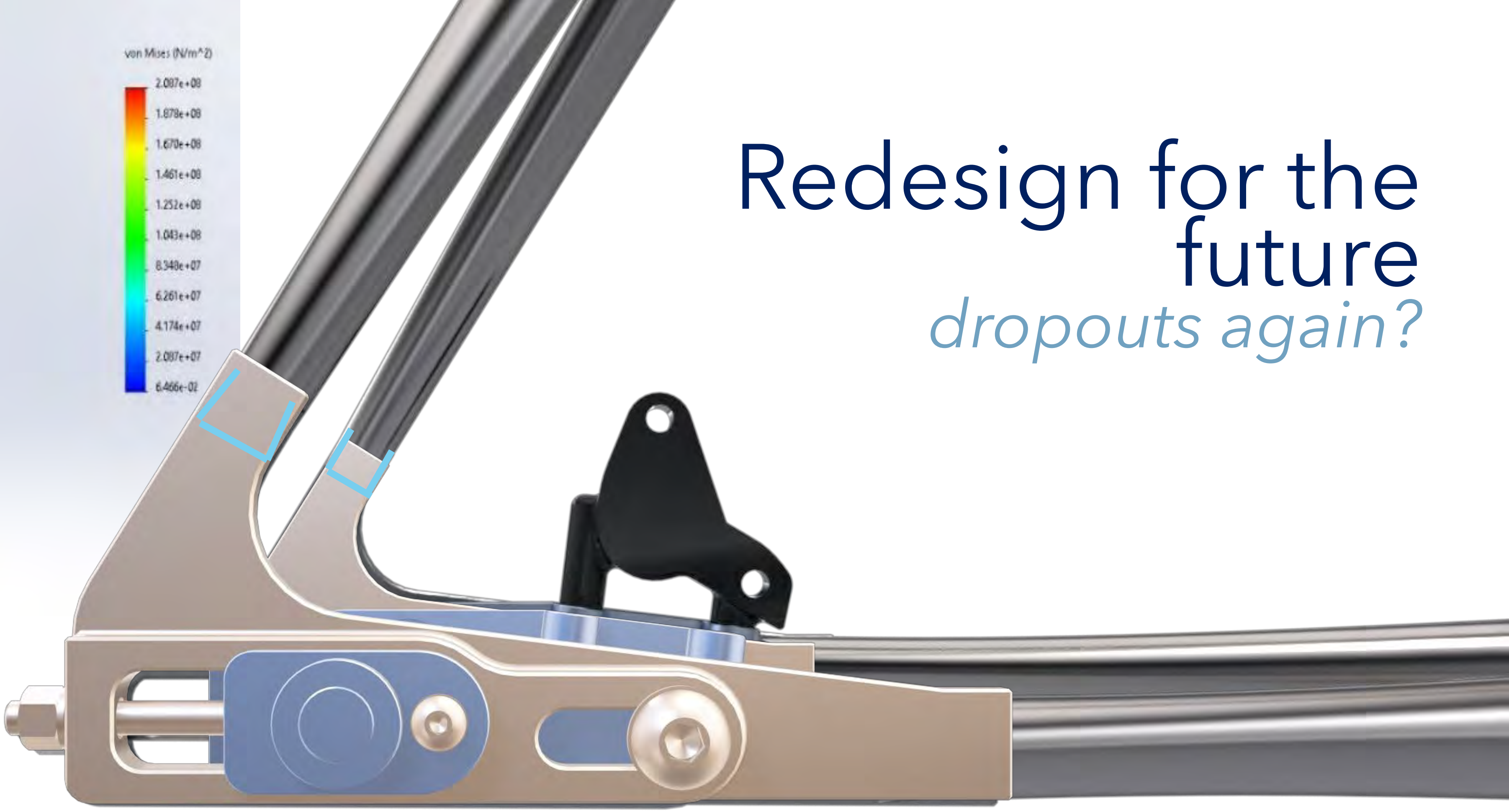
Long term:

- *Lighter with more budget*
- *Additional integration with other groups*
- *Re-dimensioning parts for greater strength during manufacturing*
- *More specialised materials (eg carbon fibre)*

Redesign for the future

dropouts again?





▲ Pre-test analysis

- *Von-misses stress*
  ***safety factor* ≈ 1.1**

Dropouts - Stays Interface Problems

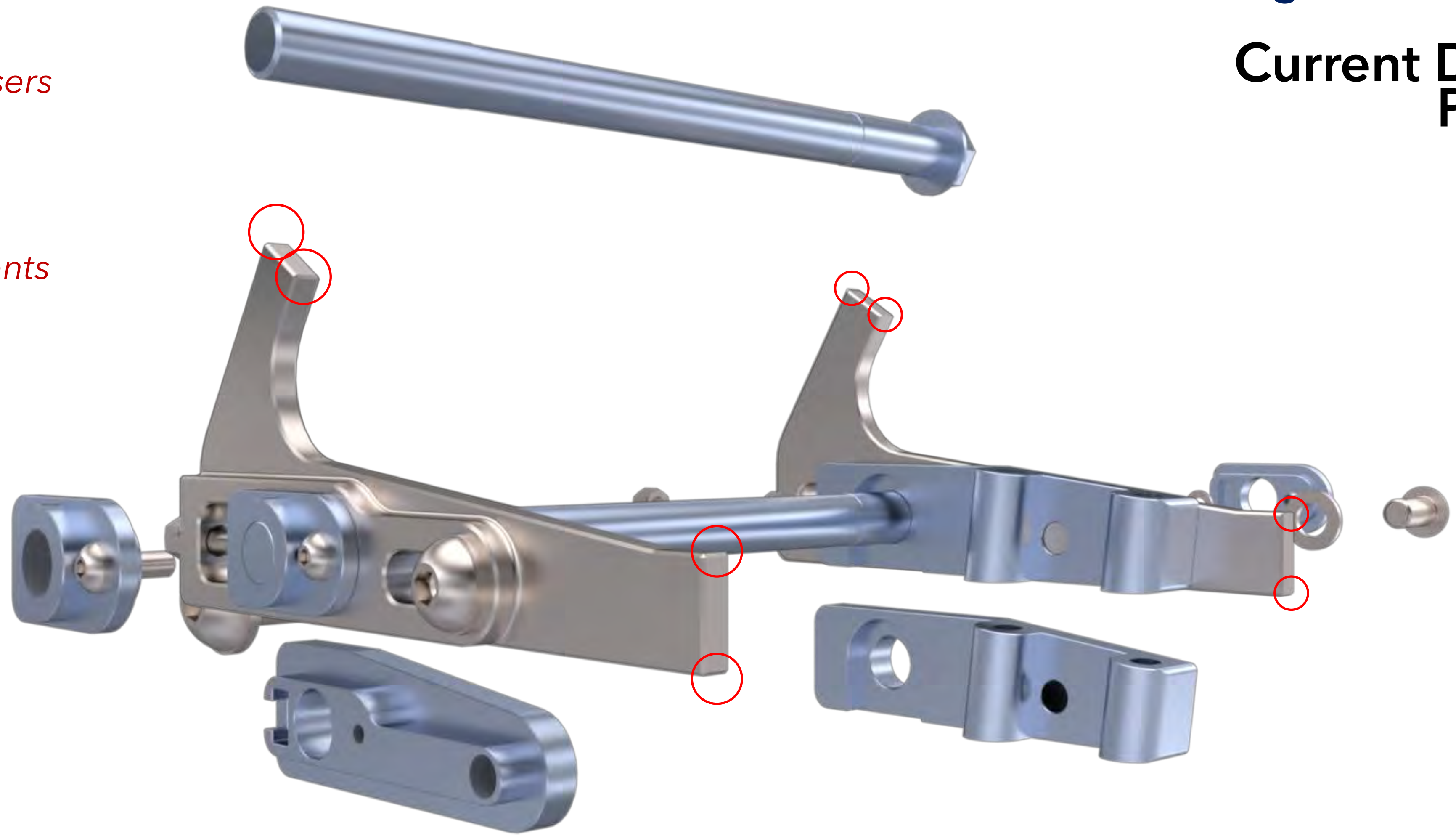
- *Too many stress raisers*
- *Complex cuts required*
- *Low weld joint strength*

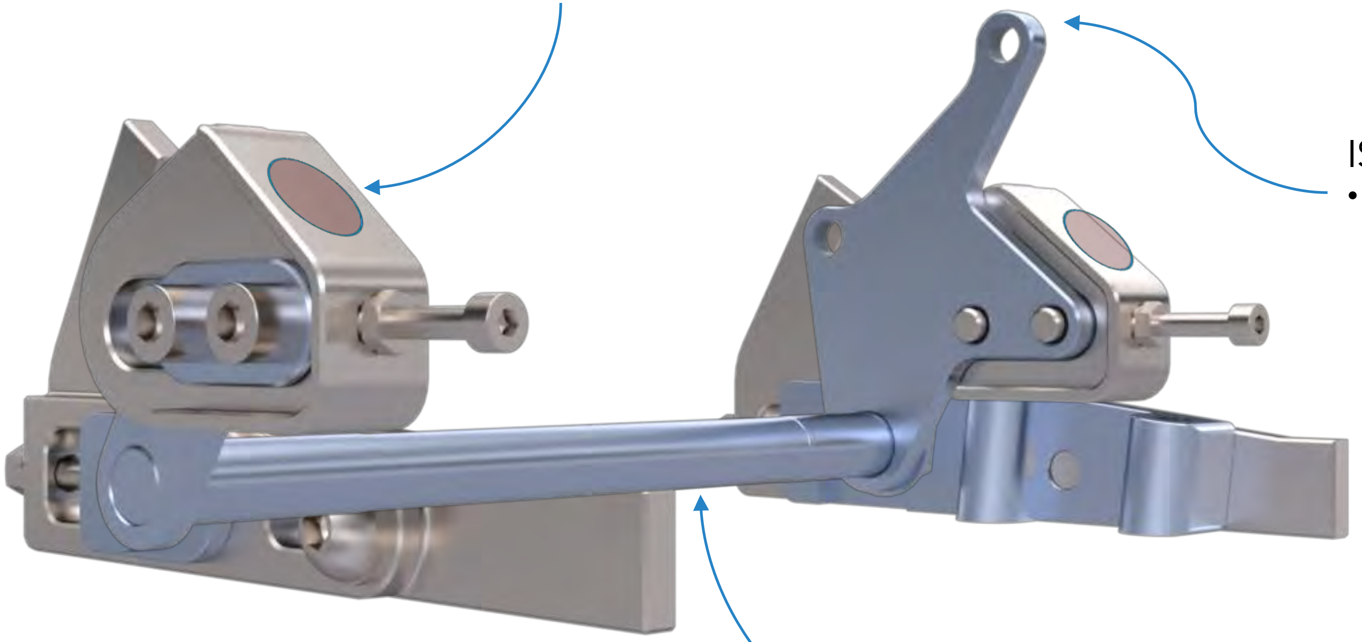
Redesign for the future

Current Dropouts Problems

Problems:

- *Stress raisers*
- *Complex assembly*
- *Unique components*





Flat attachment surfaces

- *Increased weldability*
- *Stronger joint*

ISO brake mount

- *Lower CNC machining costs*

Identical thru axle

- *Less manufacturing required*
- *Inter-changable design with current frame*

Redesigned Dropouts

References

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Thank you for watching!

Any questions?