# Aim93: Designing the fastest bicycle in the world

## with a little help from Autodesk Generative Design

Mike Burrows, Burrows Engineering
Glen Thompson & Barney Townsend, London South Bank University

London South Bank University
EST 1892

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AUTODESK UNIVERSITY

ALIAS | INVENTOR | POWERMILL | CFD MOTION | FUSION | GENERATIVE DESIGN | NETFABB

# Part 1: Design strategy

Mike Burrows

# Richard Ballantine’s legacy

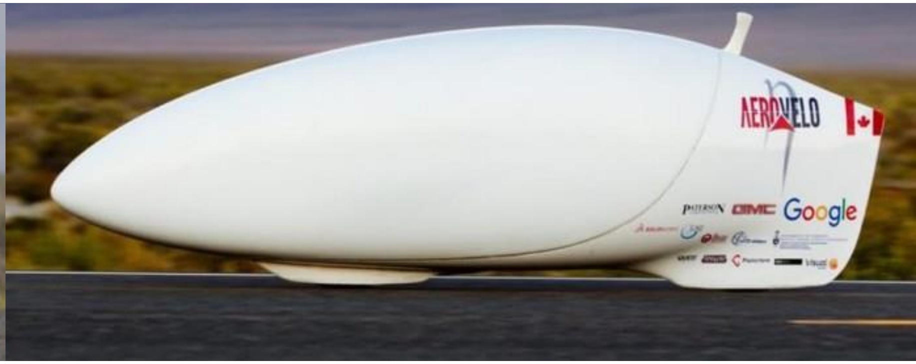


https://www.theguardian.com/lifeandstyle/2013/jun/07/richard-grant

Plug

Moulds


# Mat Weaver’s legacy





# The concept

As all the best products should, it started with a lash-up

# Short cranks

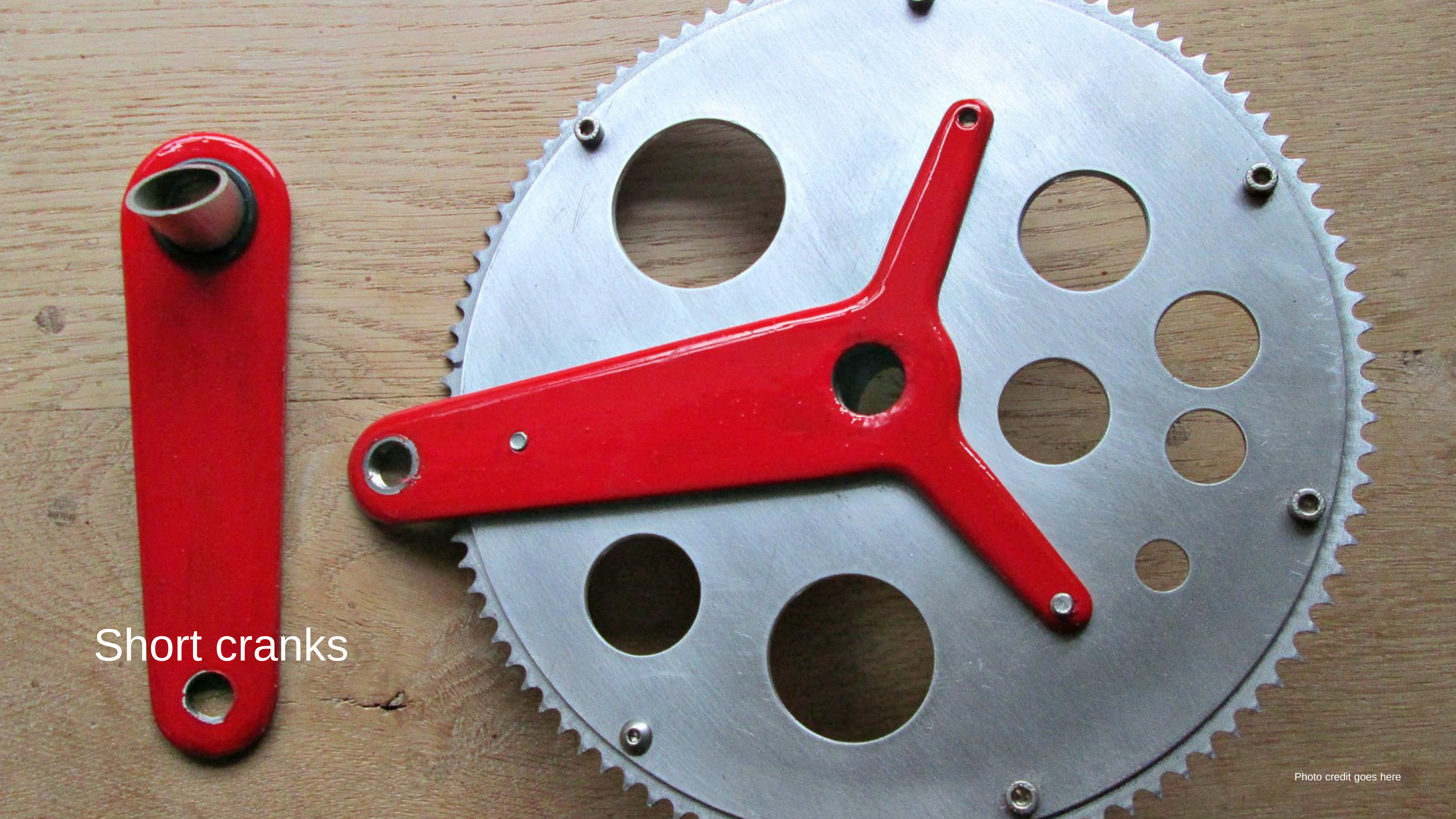
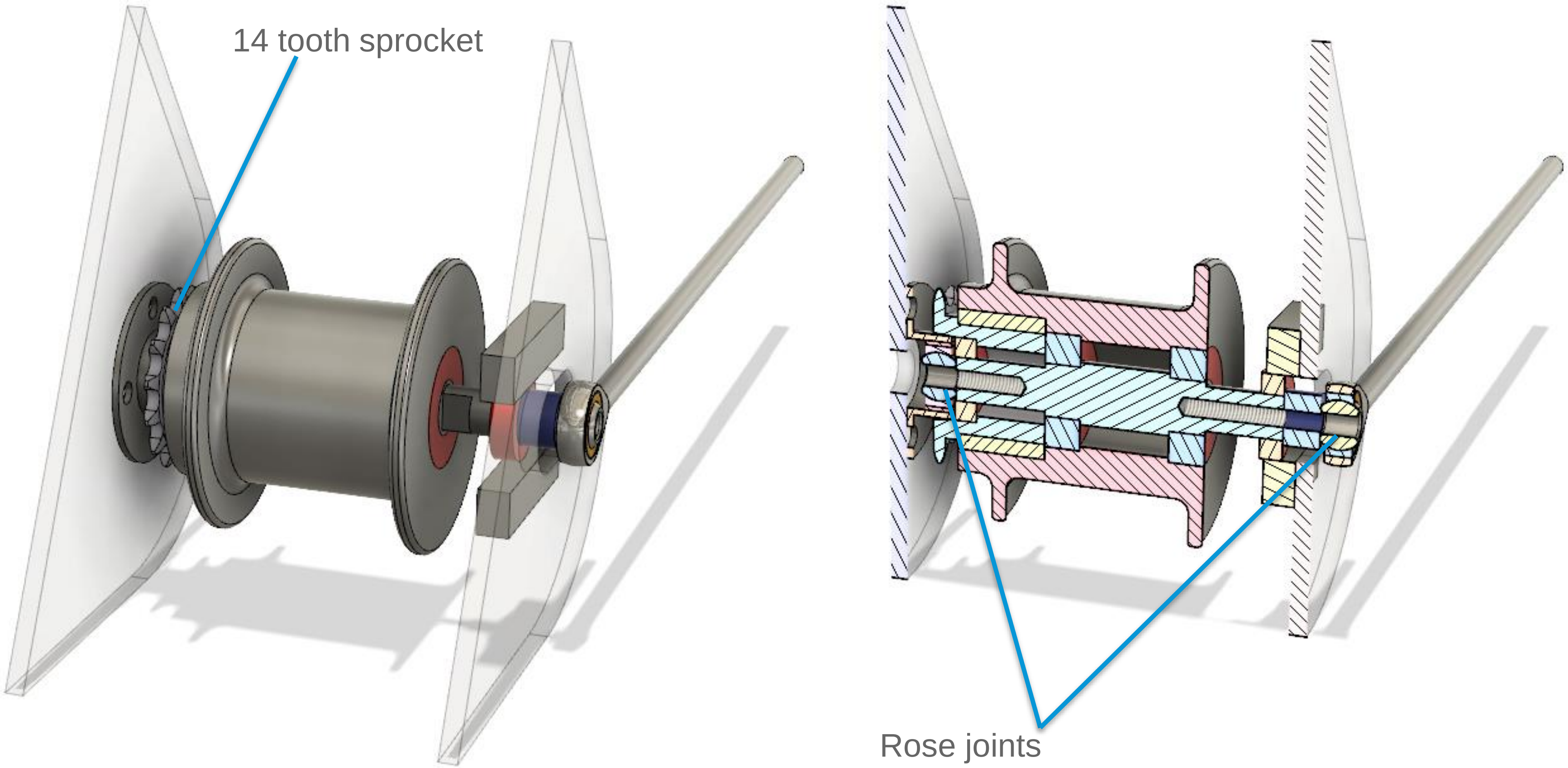


Photo credit goes here


Steering system

# Steering system

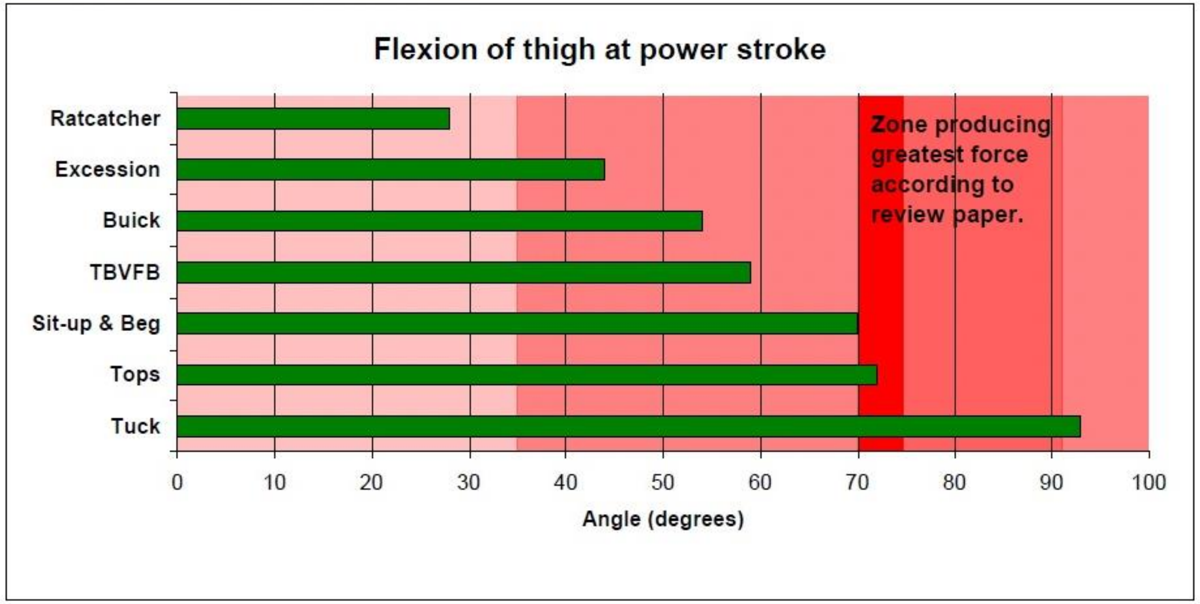


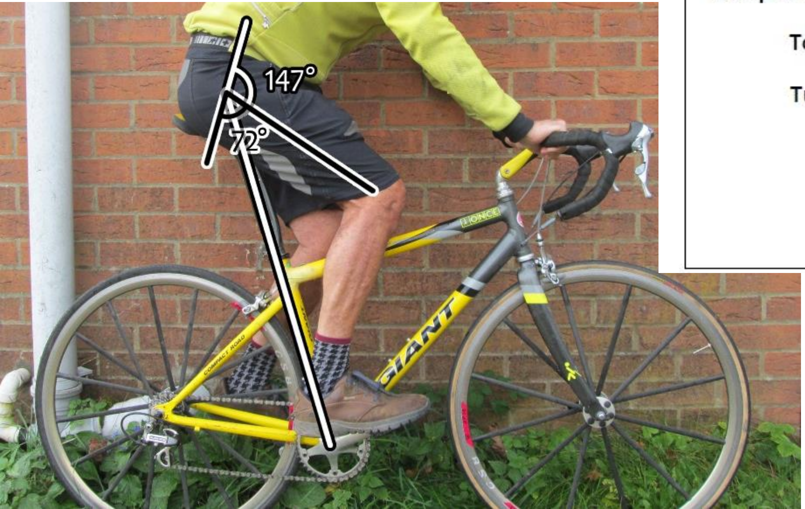


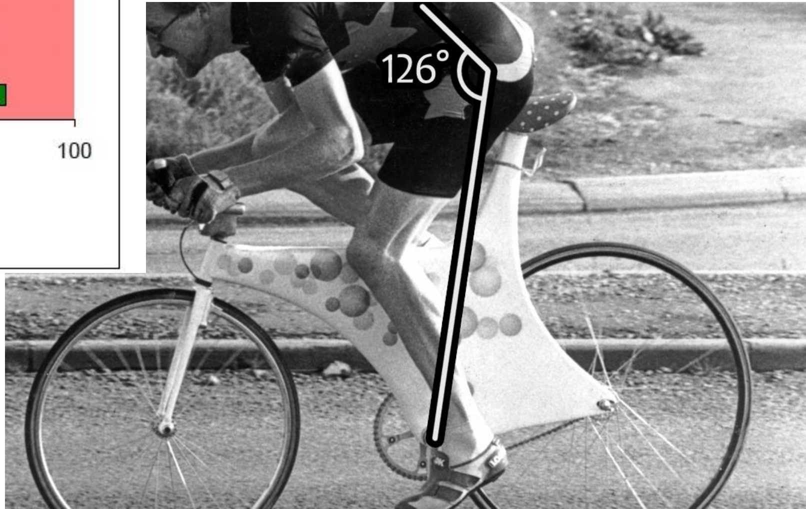

# Power

| | Tuck | Tops | Sit-up & Beg | TBVFB | Buick | Excession | Ratcatcher |
|---|---|---|---|---|---|---|---|
| Angle between lower back & hip to bottom bracket line | 126 | 147 | 149 | 160 | 165 | 175 | 191 |
| Flexion of thigh at power stroke | 93 | 72 | 70 | 59 | 54 | 44 | 28 |

(Flexion = 180°- Angle lbhbb + 39° for 140mm cranks)



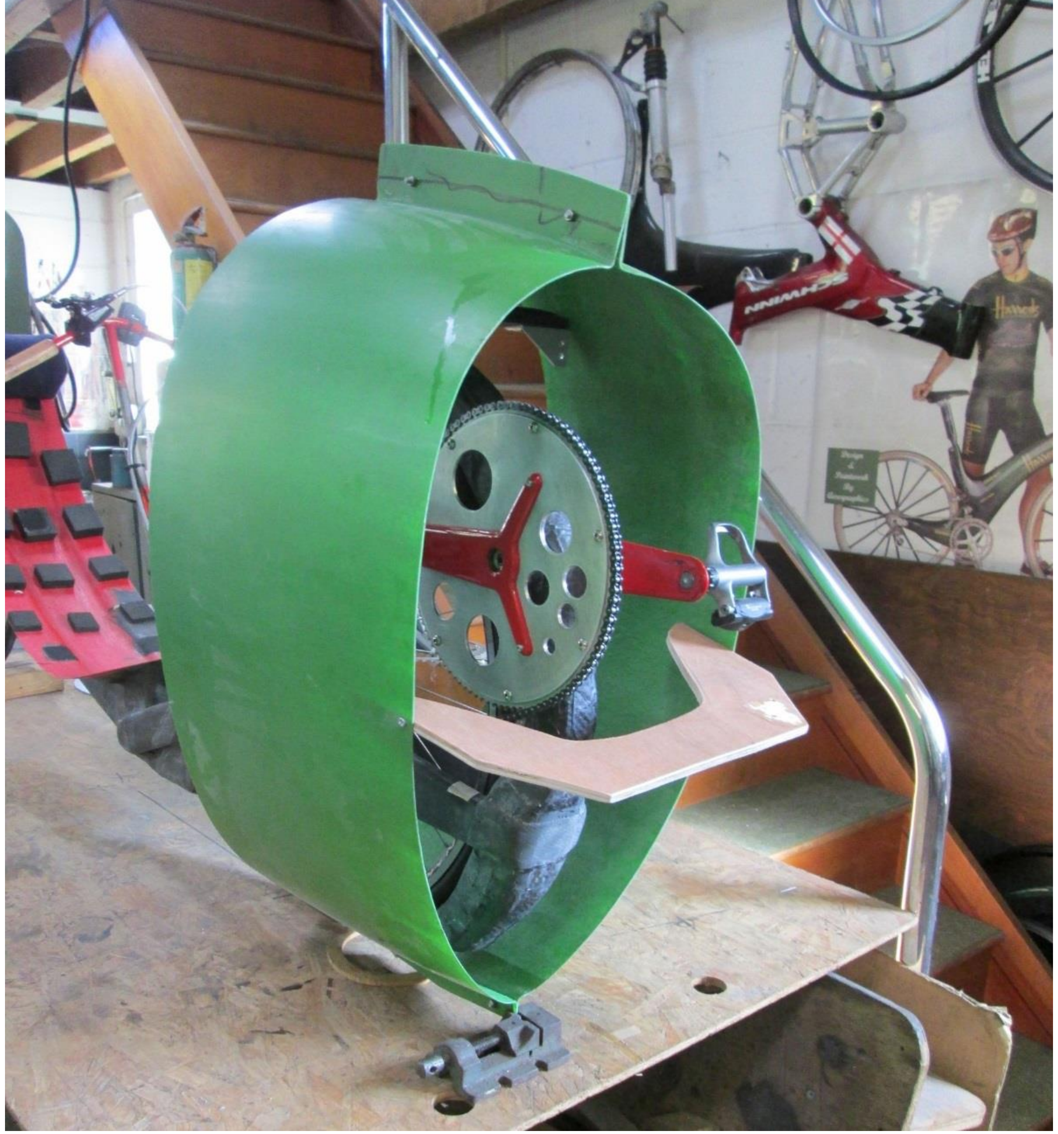




Ready for track testing…


CATEYE VELO 9
360 degree vision…!

# 150 tooth chain ring

Large enough to serve a round of Best on…



# Testing internal space

In particular – the footbox

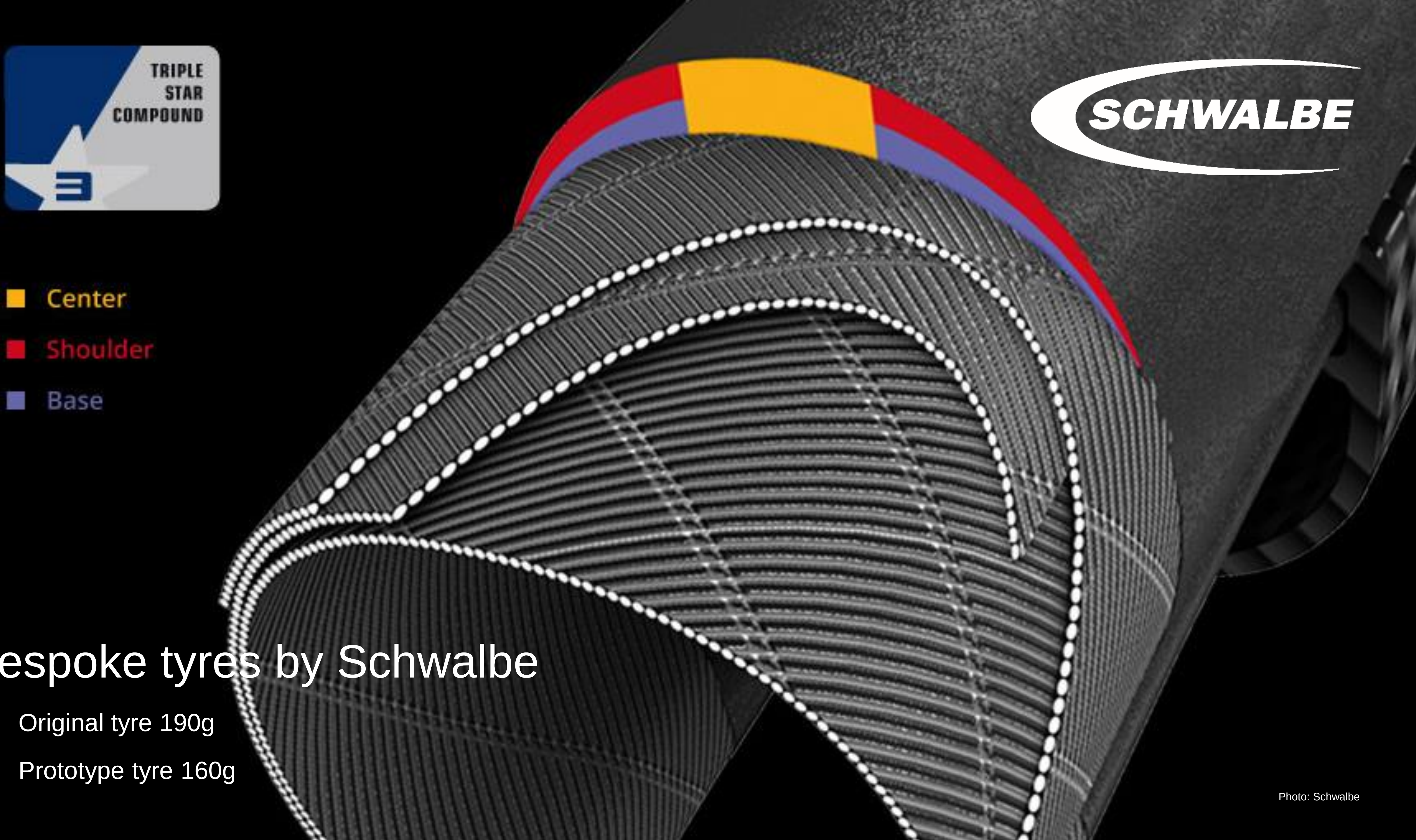
# Single sided landing gear

Enables

reduction in front

wheel hole size


Rear casting, mounting brakes and hubs from Hope




# Bespoke tyres by Schwalbe

- Original tyre 190g
- Prototype tyre 160g

Photo: Schwalbe

# Part 2: Aerodynamics & shell

Glen Thompson

# Aerodynamic drag on a Human Powered Vehicle

Parasitic drag

Interference drag = very low

Form drag (induced drag) = very low

Viscous drag (skin friction) = mainly high

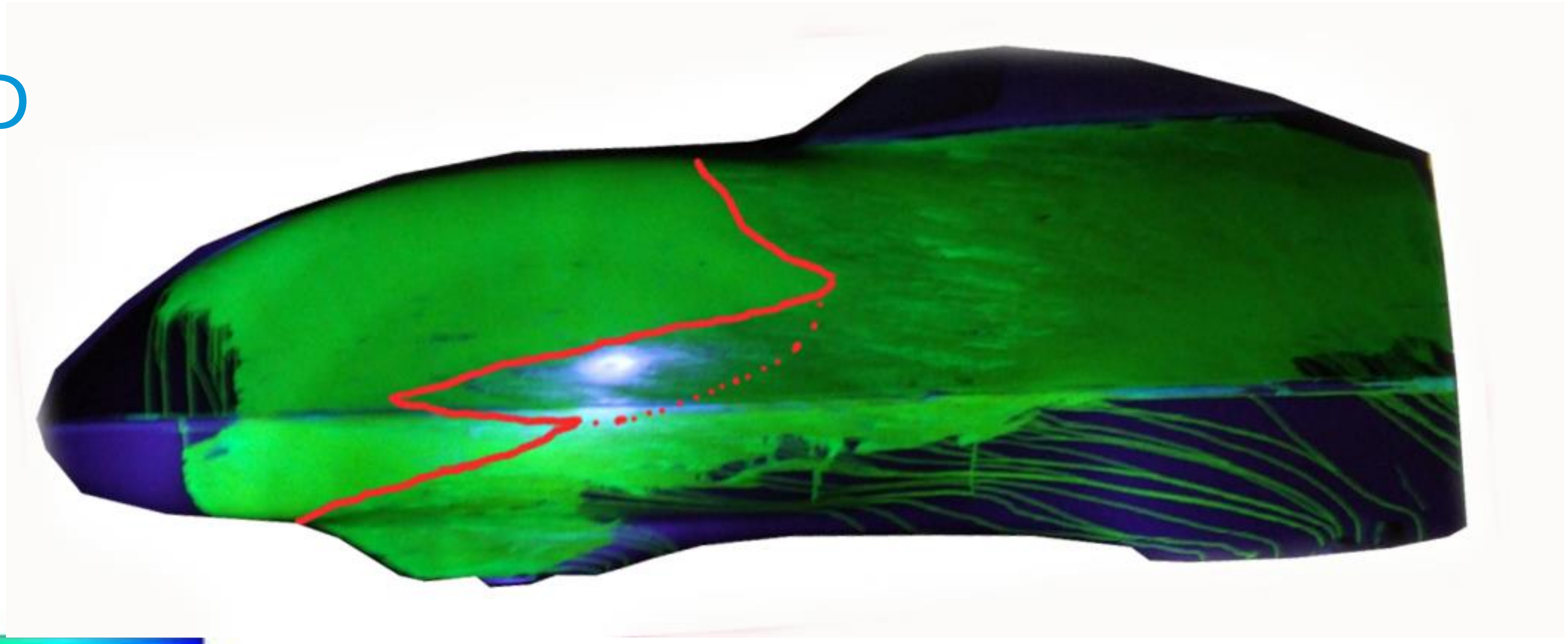
Air density plays a significant role in skin Viscous drag (skin friction)

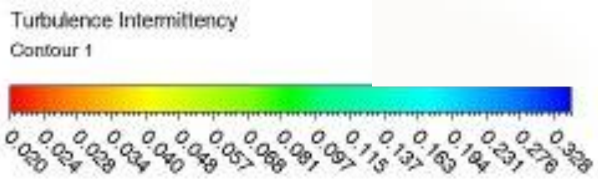
Battle Mountain 5 mile

Altitude 1400m @ 21c Density = 1.067 (kg/m^3)  13% thinner air then sea level.

Downhill road the slope gives 220 watts max at the finish it levels and reduces 82 watts.

# Calibrating CFD





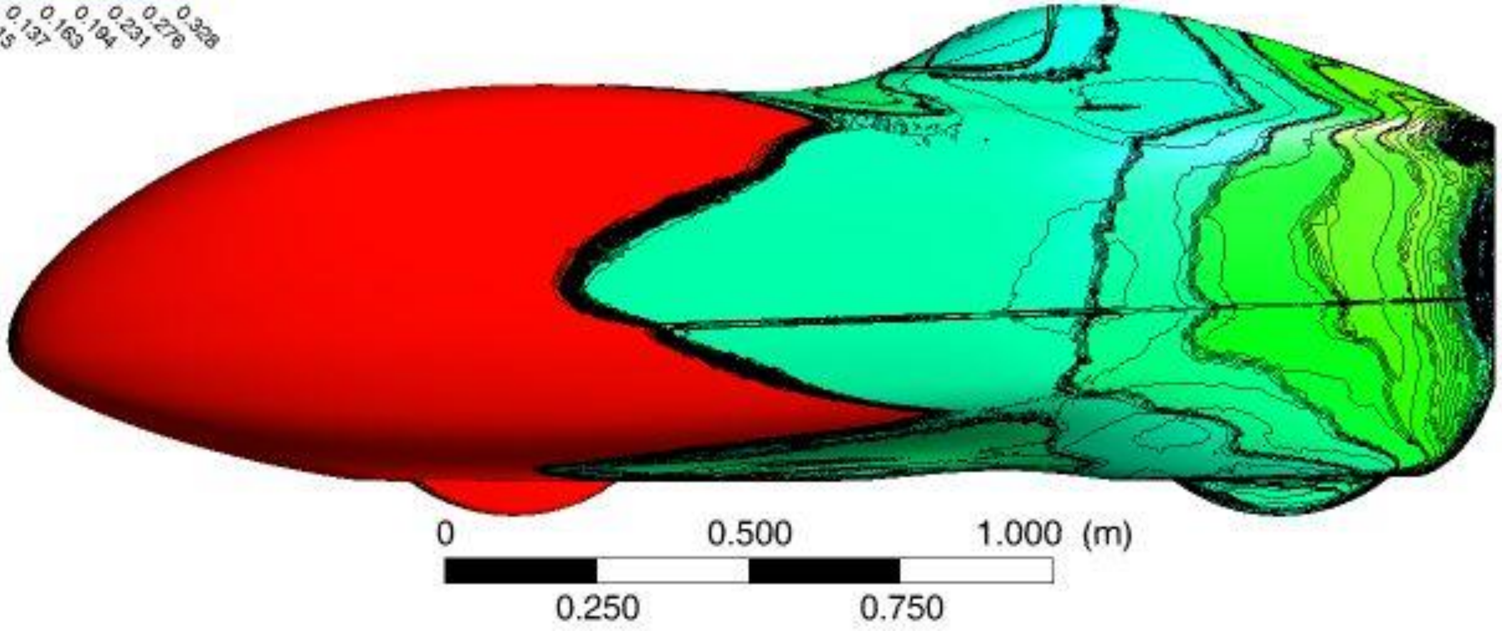
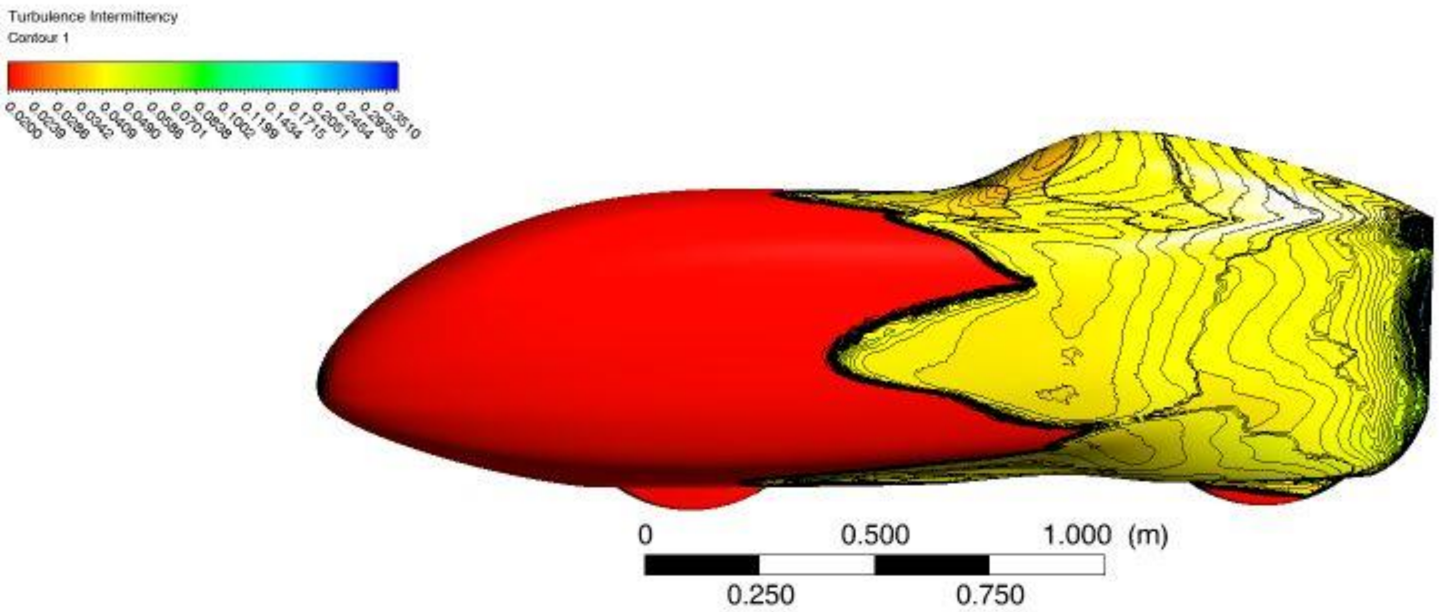
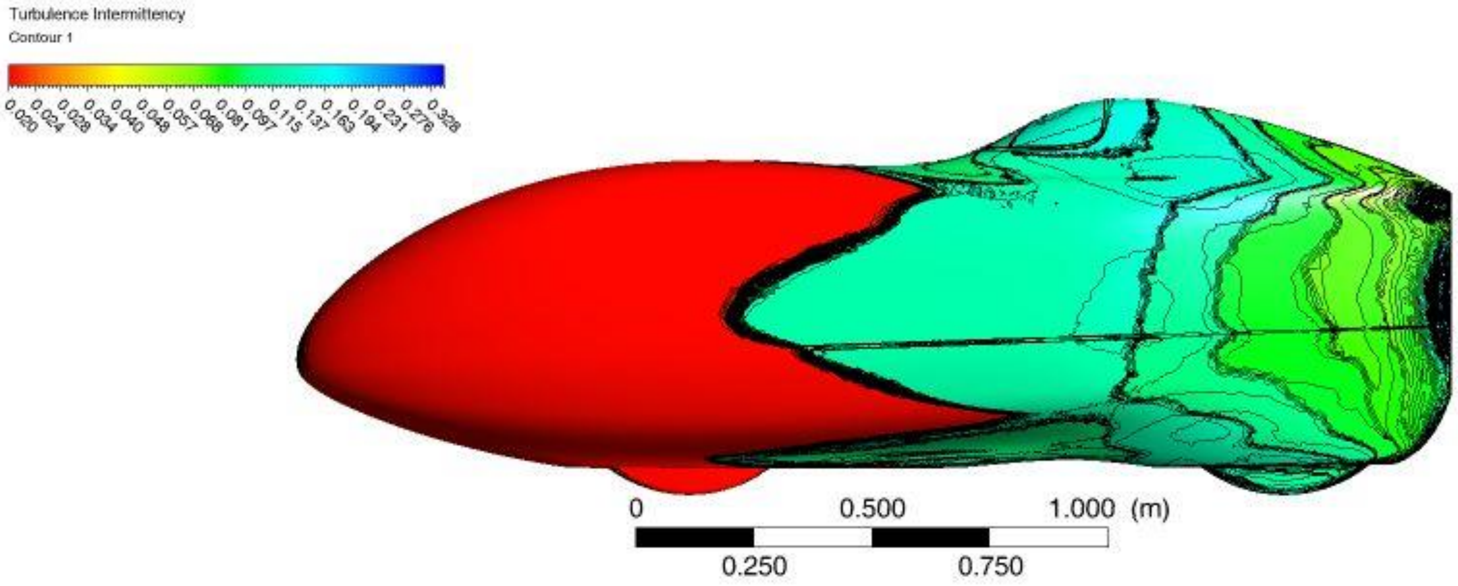




Photo credit: Delft University




8.95 N smooth walls
328 watts
No transition zone

| Resistance | CFD 36 m/s | BM 36 m/s | BM 41 m/s |
|---|---|---|---|
| ROLLING (w) | 178.0 | 178.0 | 199.0 |
| SLOPE (w) | -82.0 | -82.0 | -93.0 |
| DISK DRAG (w) | 37.0 | 37.0 | 48.0 |
| MECHNICAL (w) | 25.0 | 25.0 | 35.0 |
| AIR (w) | 430.9 | 363.6 | 508.6 |
| AIR (N) | 11.75 | 9.92 | 13.87 |
| TOTAL (w) | 588.8 | 521.6 | 697.7 |




11.75 N rough walls
430 watts
With transition zone

**Cfd settings**

**Mesh**
Size = 3mm
Curvtature normal angle 1.5 degrees
**Inflation layers**
Y plus = 1  first layer height = 0.01126mm
Number of layers = 50  Growth rate = x 1.12

| Nodes | Elements |
|---|---|
| 4,776,778.00 | 11,758,998.00 |

**Steady state**
**Turbulence Model = Shear Stress Transport**
**Transitional Turbulence = Gamma Theta Model**
**Langtry Menter**
Density  = 1.185 [kg/m^3]
Normal Speed  = 36.66 m/s
Fractional Intensity = 0.5%

Sand grain roughness height (s.g.r.h.)

Geometric roughness height (g.r.h.)

**Polished metal**

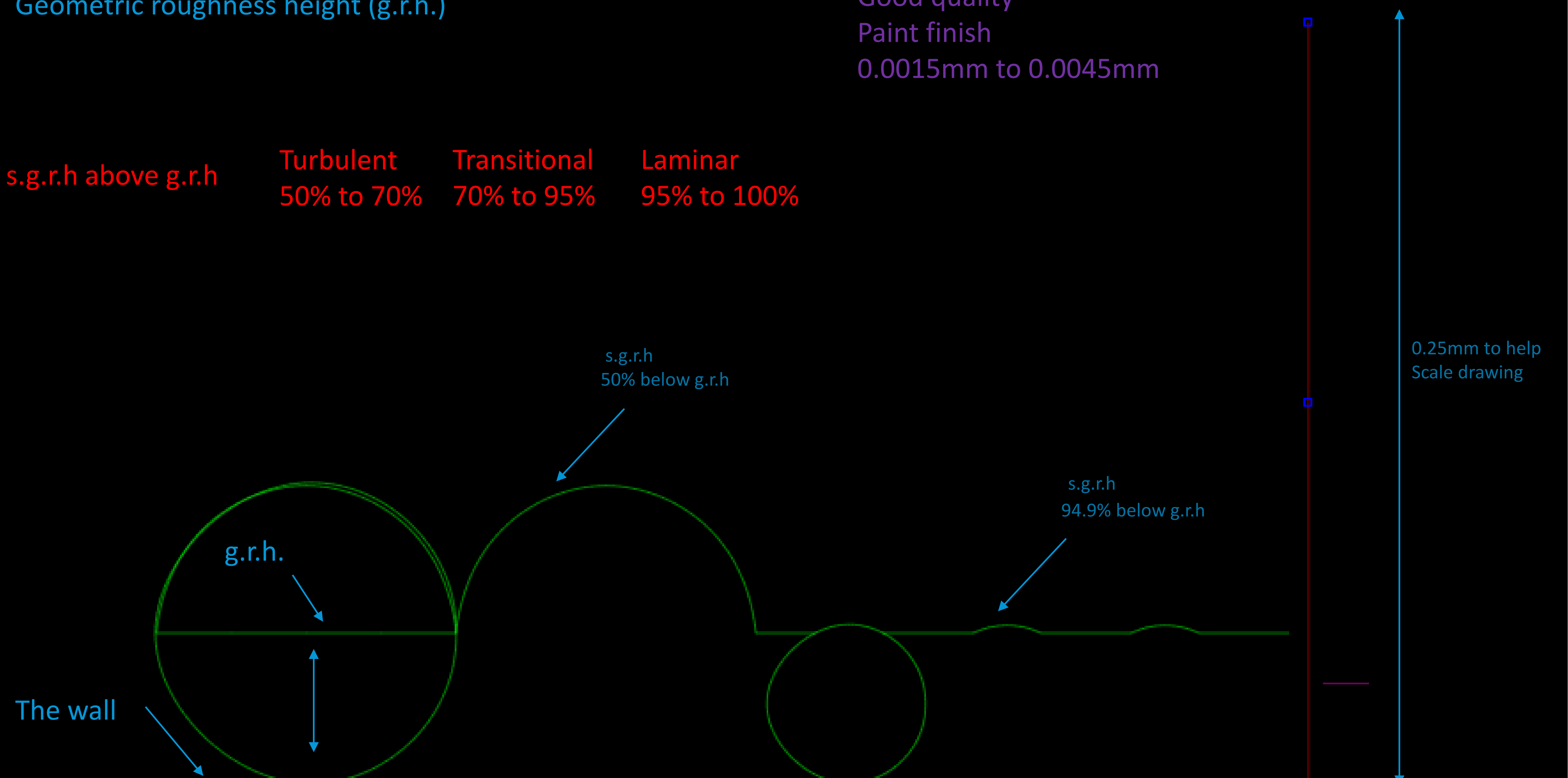
**Wet dry p600 grit**

Good quality

Paint finish

0.0015mm to 0.0045mm

| s.g.r.h above g.r.h | Turbulent | Transitional | Laminar |
|---|---|---|---|
| | 50% to 70% | 70% to 95% | 95% to 100% |

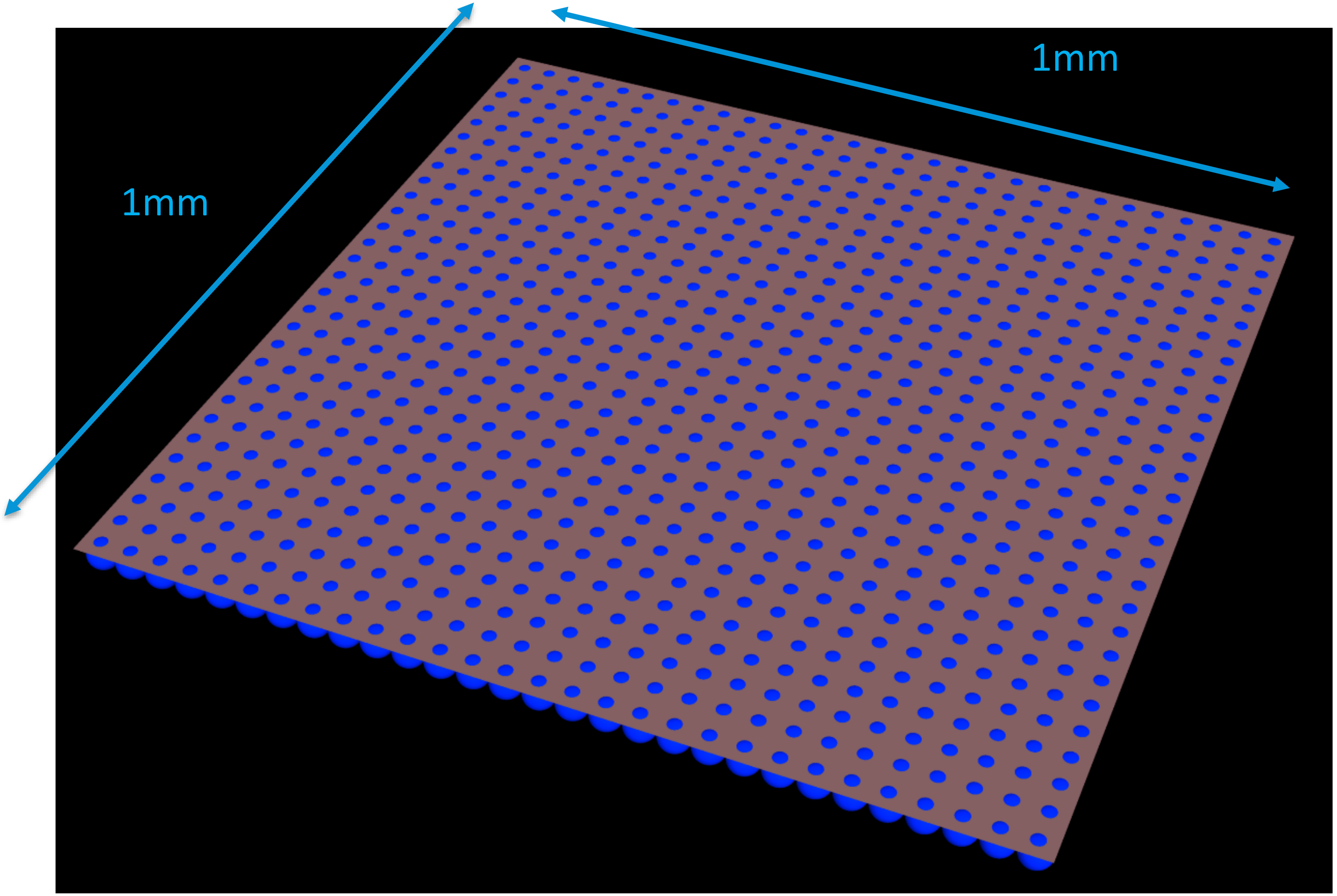


# Surface roughness

## Sand grain roughness height

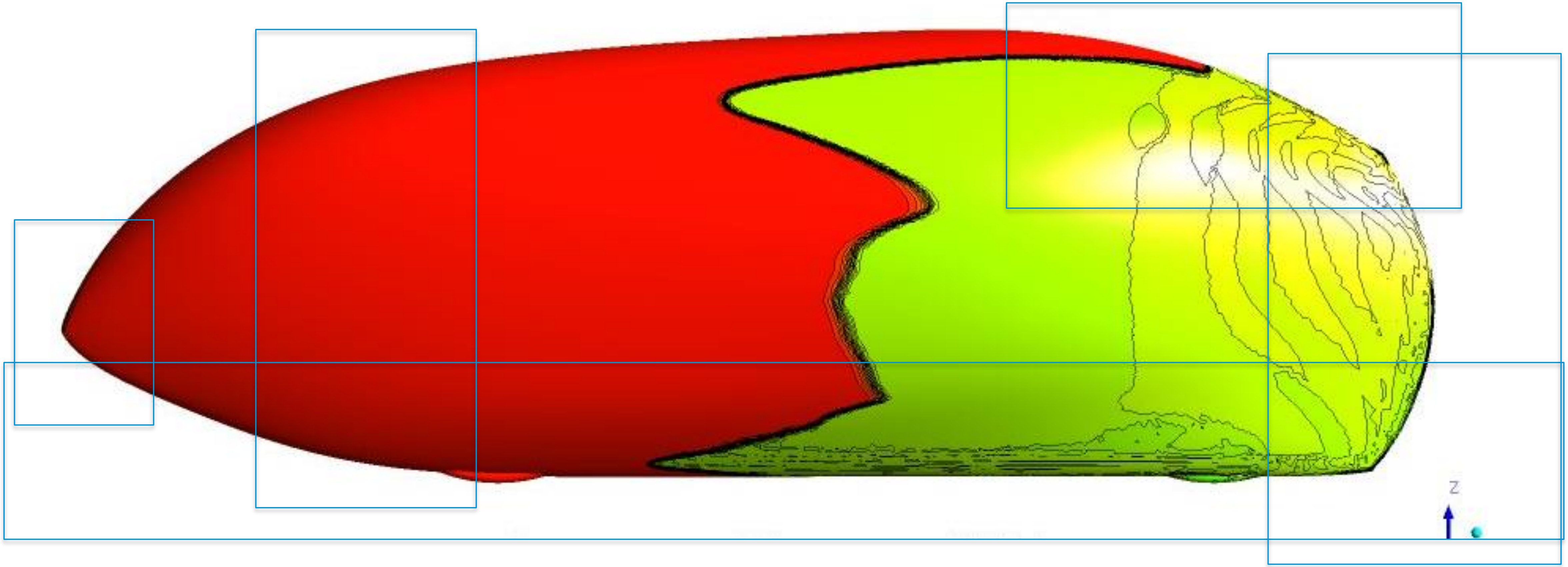
Aim93 wetted area = 4.394 m^2
Fa = 0.29 m^2

Number hemispheres
in 1mm squared = 841
This equals 3 trillion
hemispheres over the
Wetted area

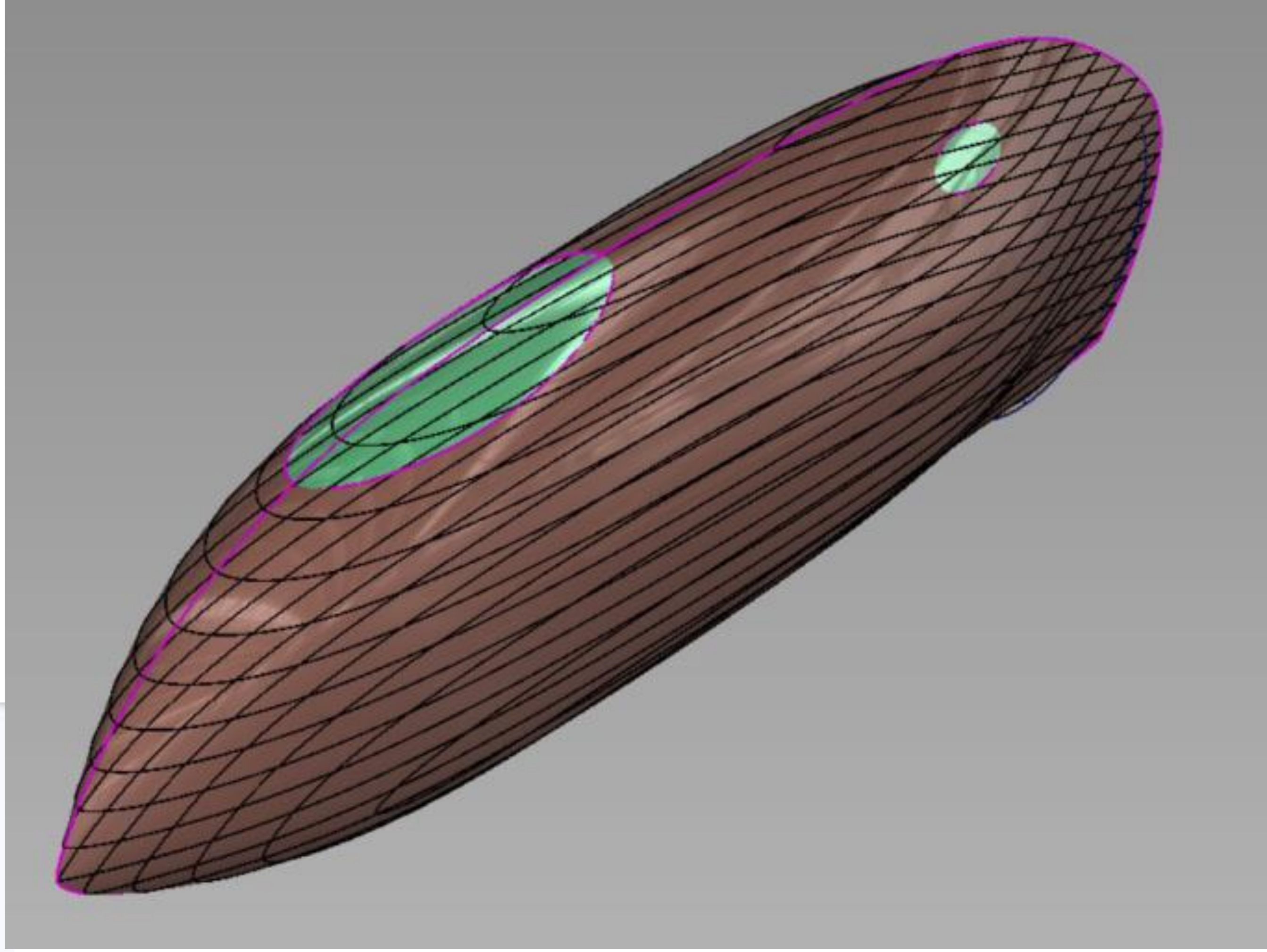


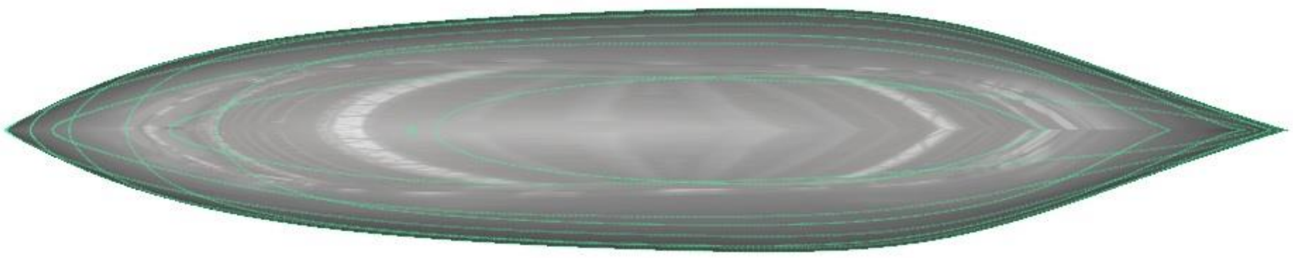
# Drag zones

optimizing the critical zones



# Frontal profile area





Velox 2 frontal
area= 0.35 msq

New design frontal
area= 0.29 msq

Varna frontal
area= 0.246 msq

# Velocity 37 m/s

Hydraulically Smooth

7.394 N or 270 watts

33% lower drag

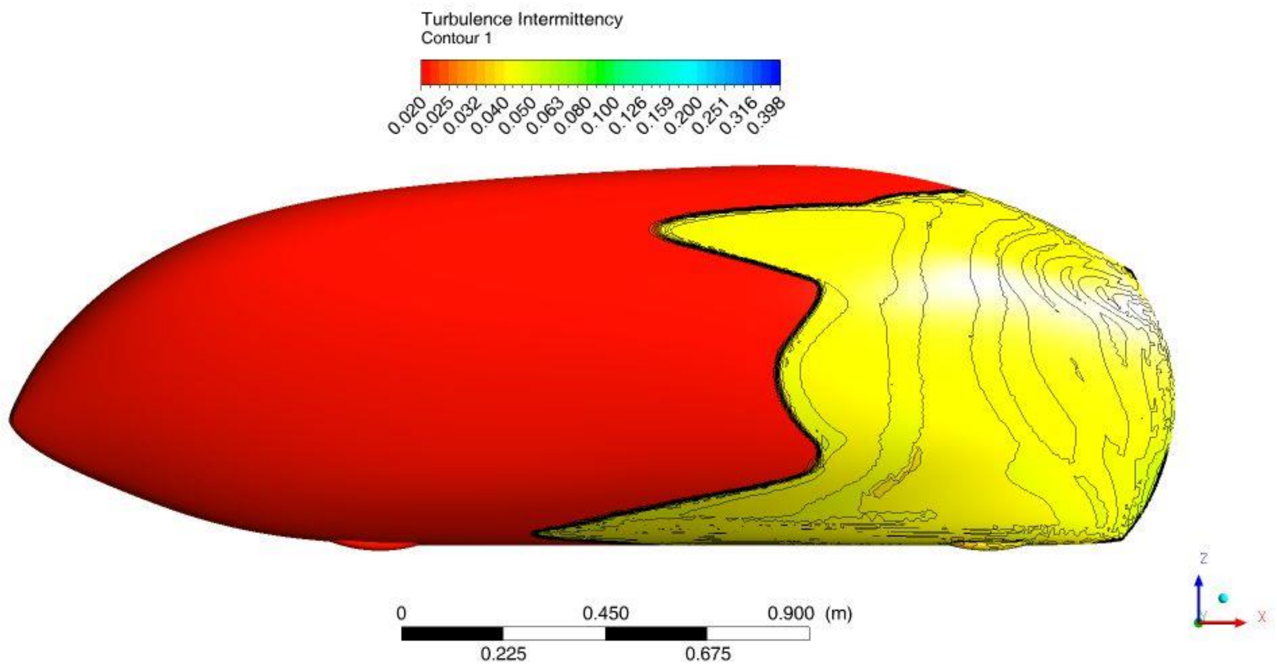
Hydraulically Smooth surface condition has not detected any transition zone because no surface roughness applied.

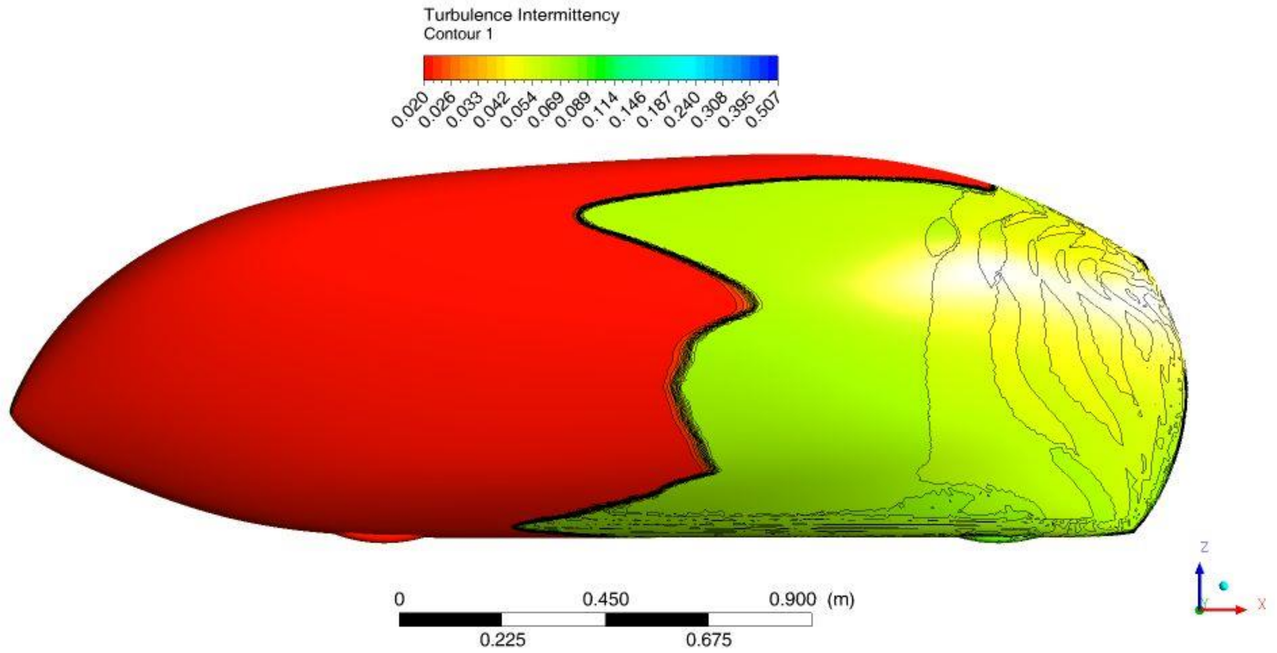
Polished metal surface

Wet & dry p600 grit

Using sand grain roughness height

9.837 N or 360 watts



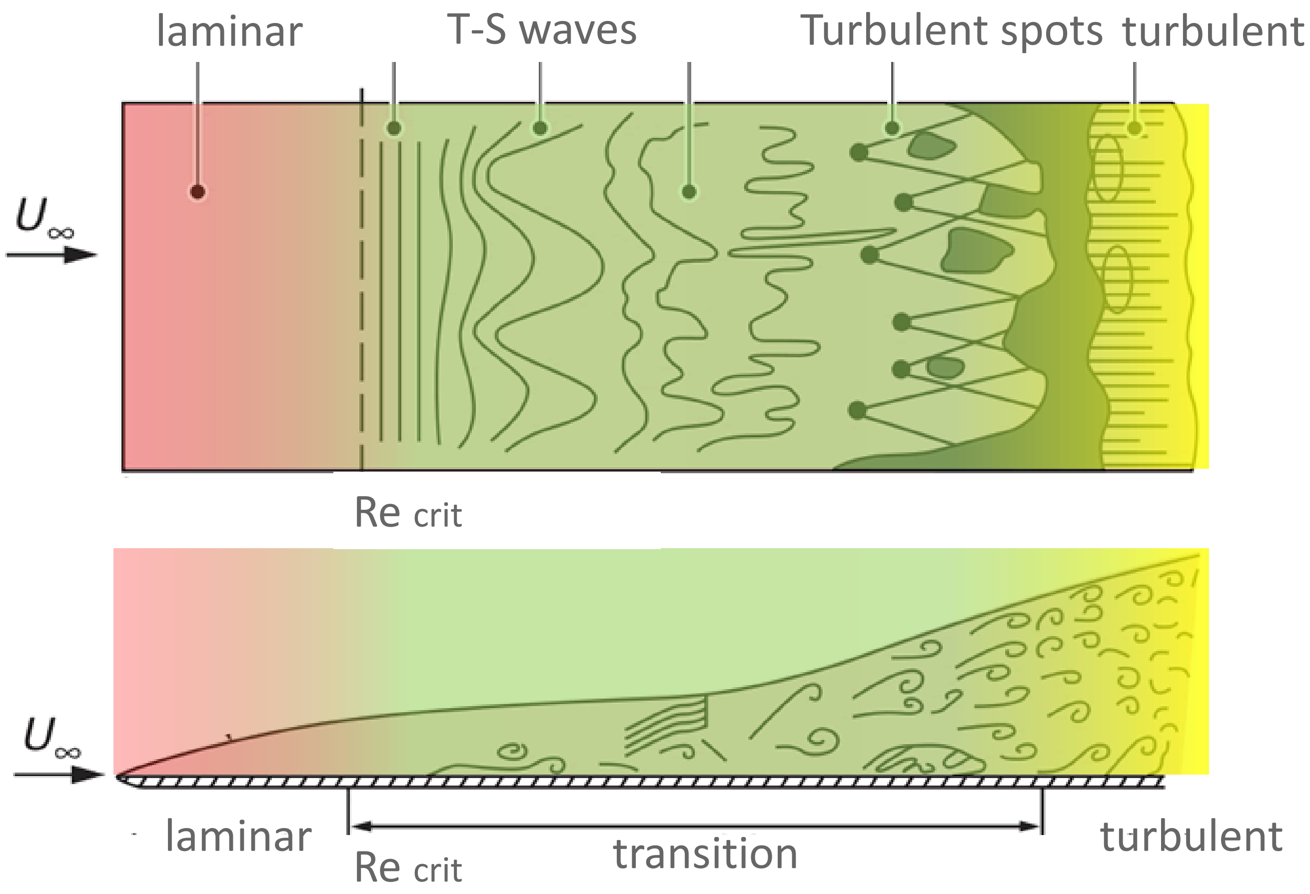



# Transition zone

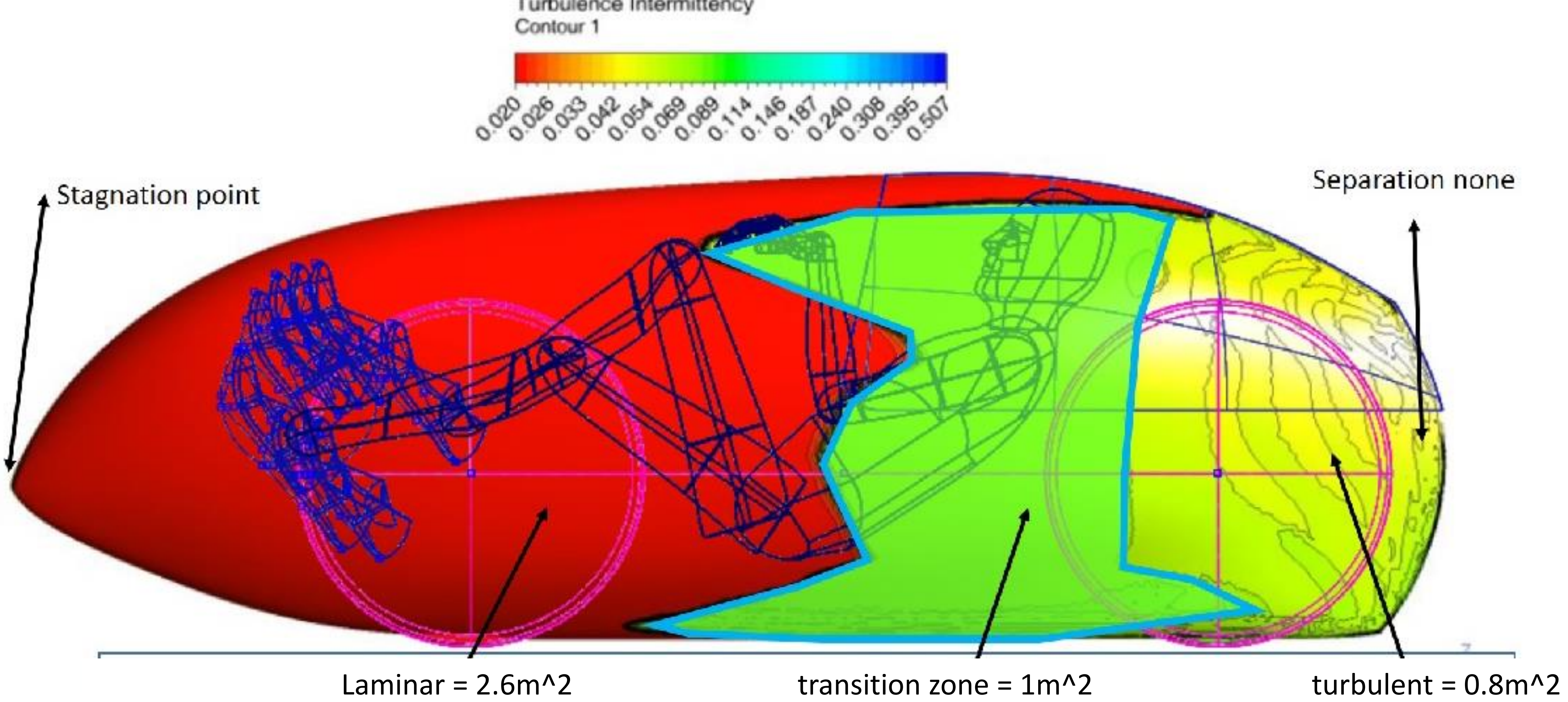
Tollmien – Schlichting wave T - S wave

Question : what is the breakdown of drag forces in the three zones laminar, transitional, and turbulent.

Could the transitional zone be the highest drag force area?



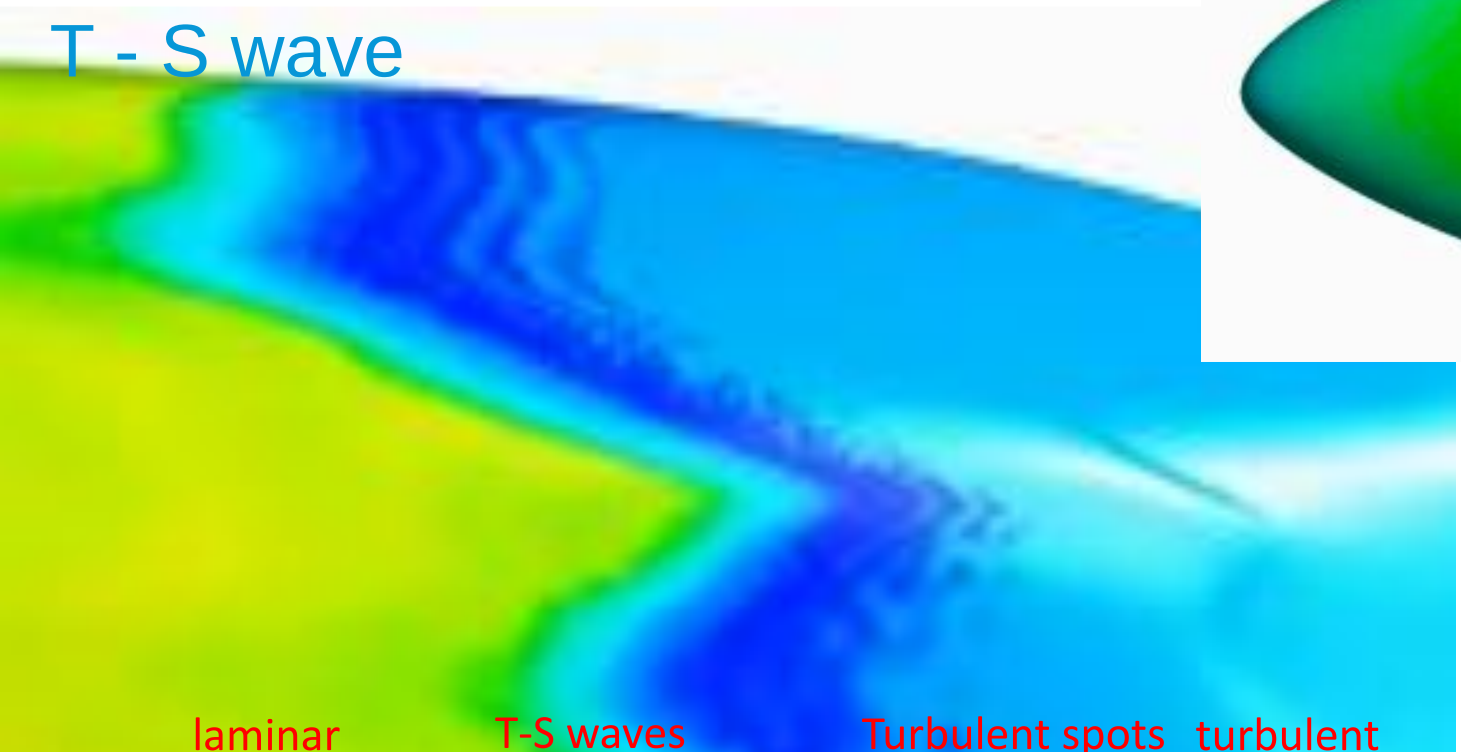

http://hmf.enseeiht.fr/travaux/bei/beiep/content/g08/transition-laminaire-turbulent

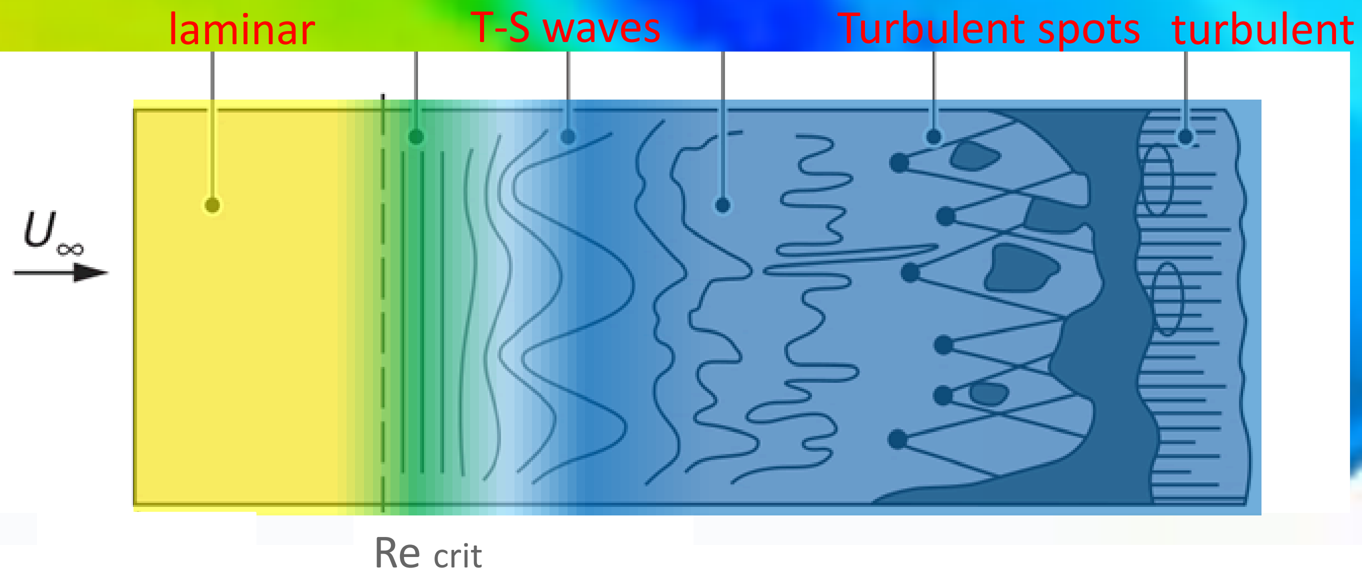


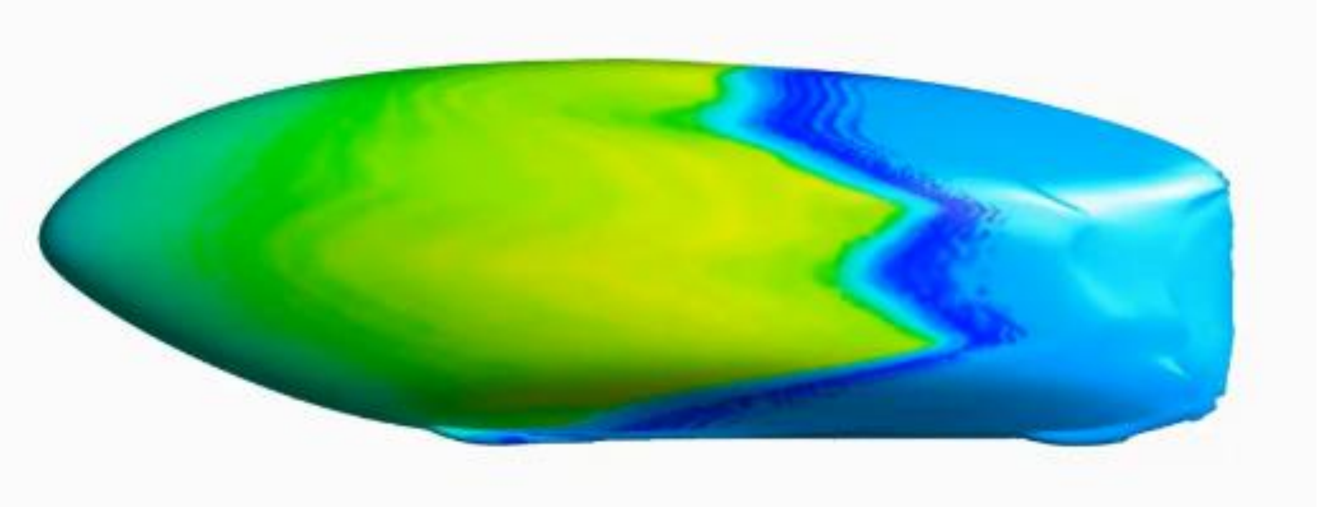

wetted area = 4.394 m^2

# Transition zone

## T - S wave

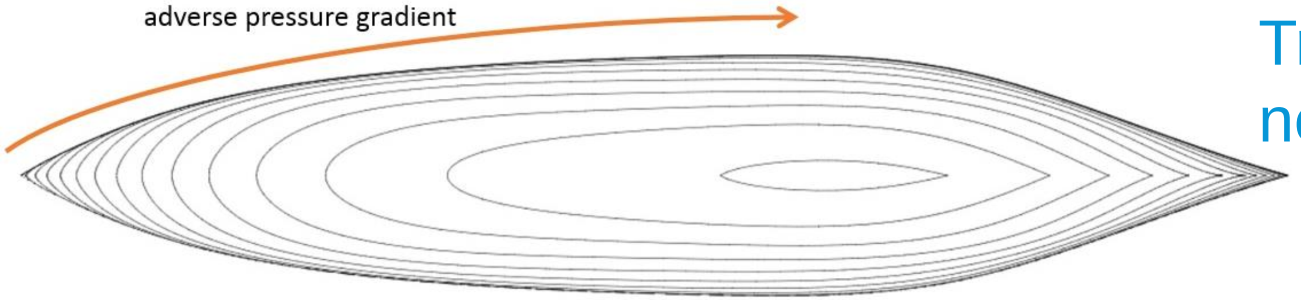


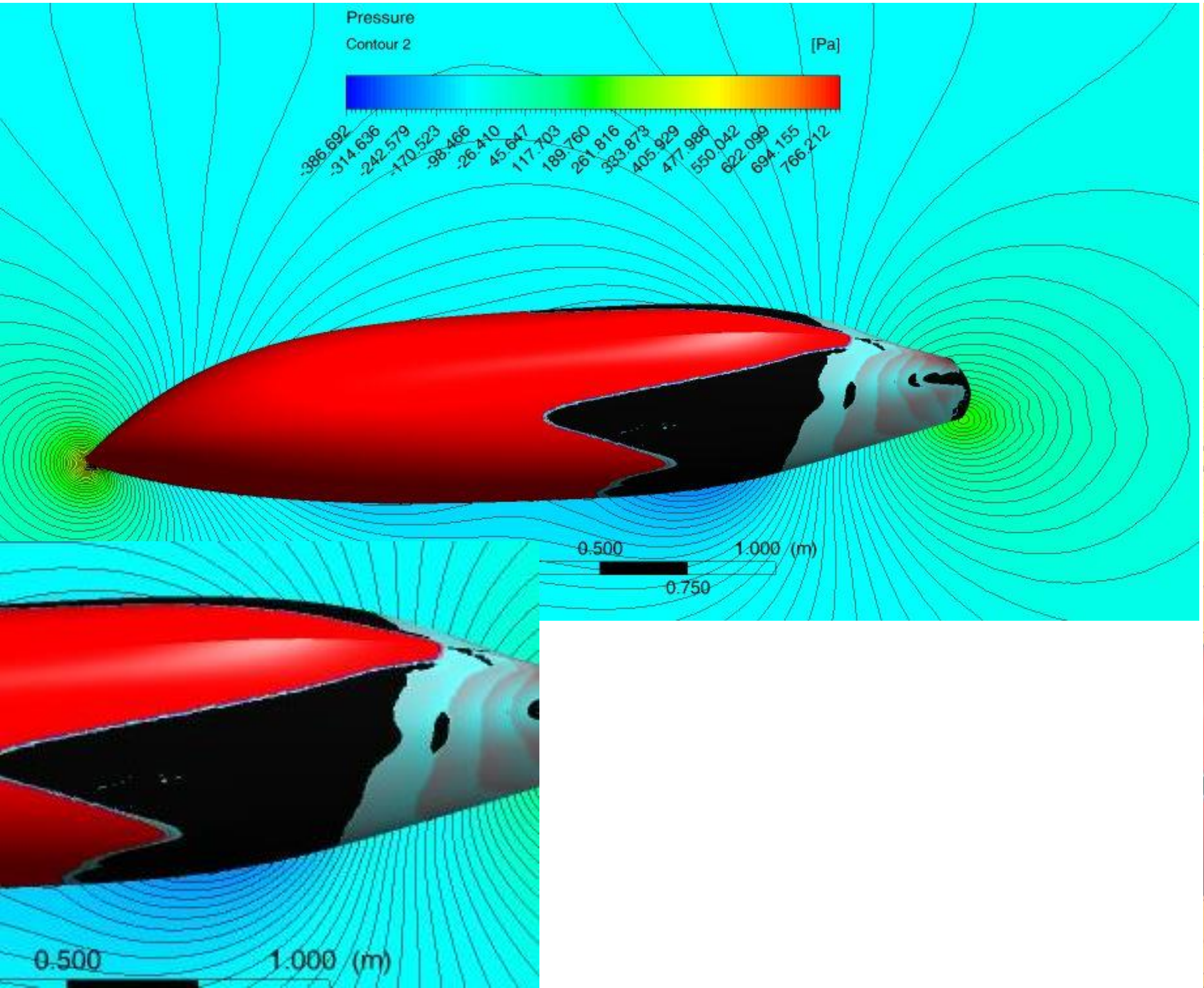


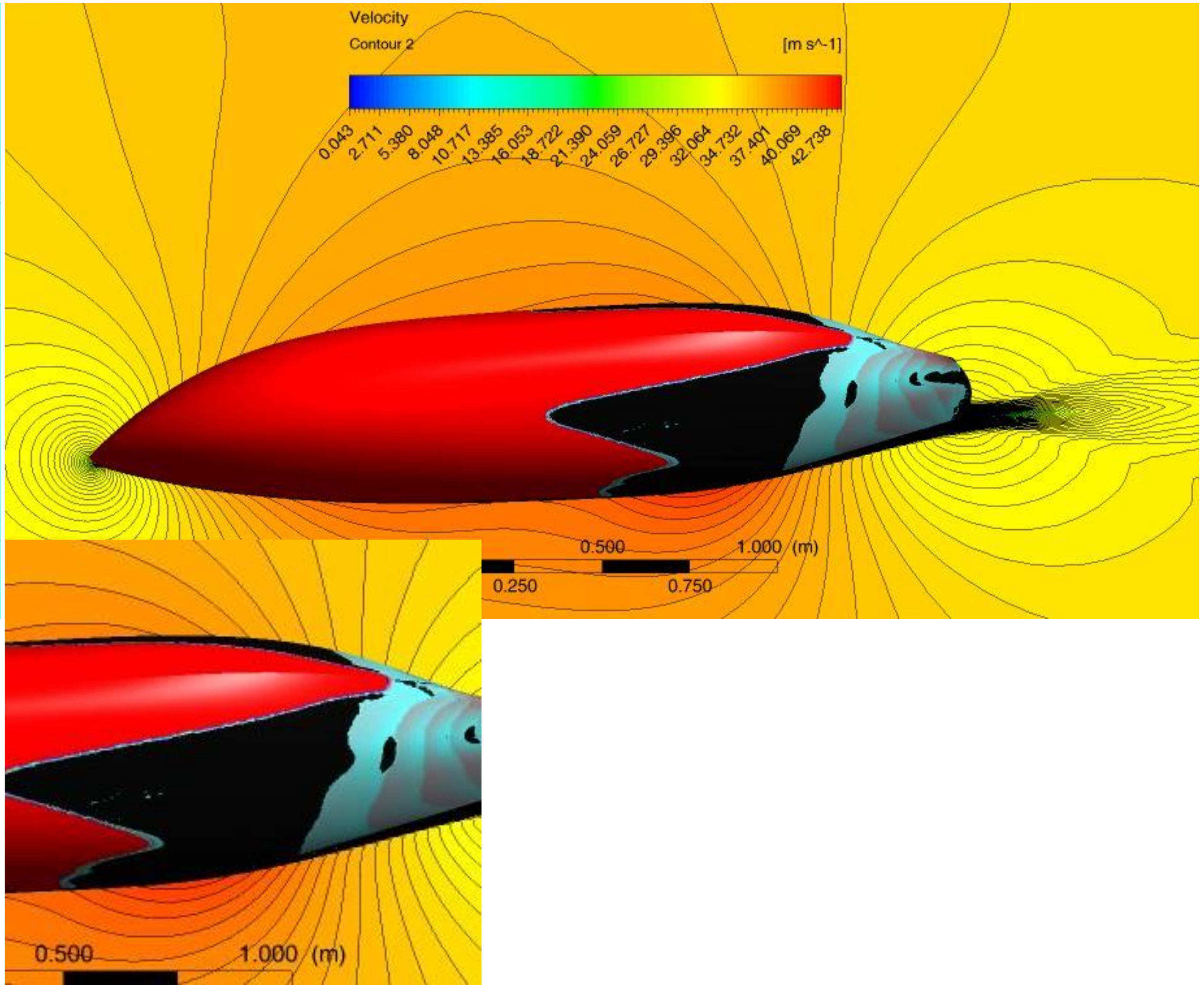



Vortex core regions plots

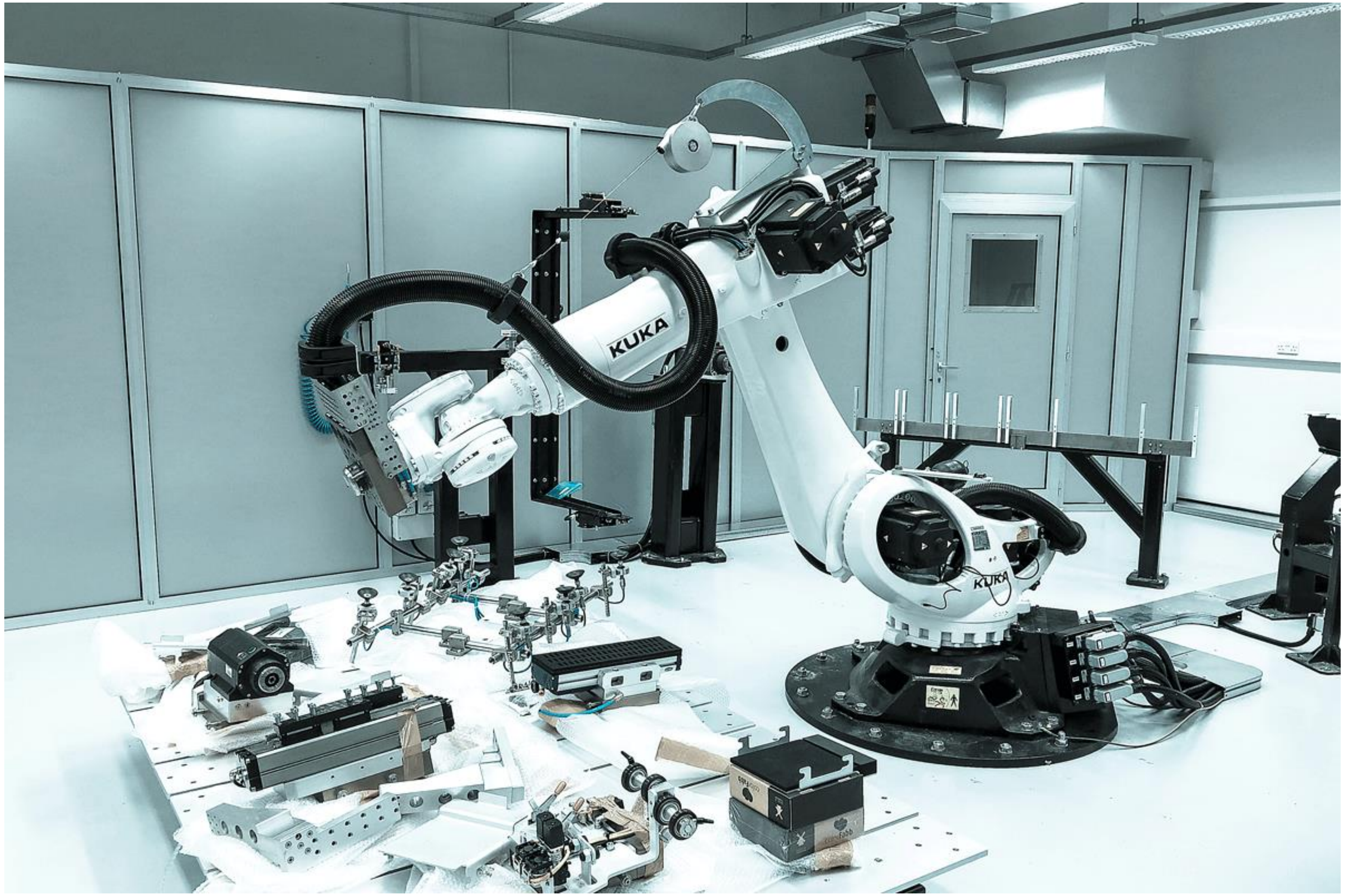
# Transition zone
# negative pressures and high velocities



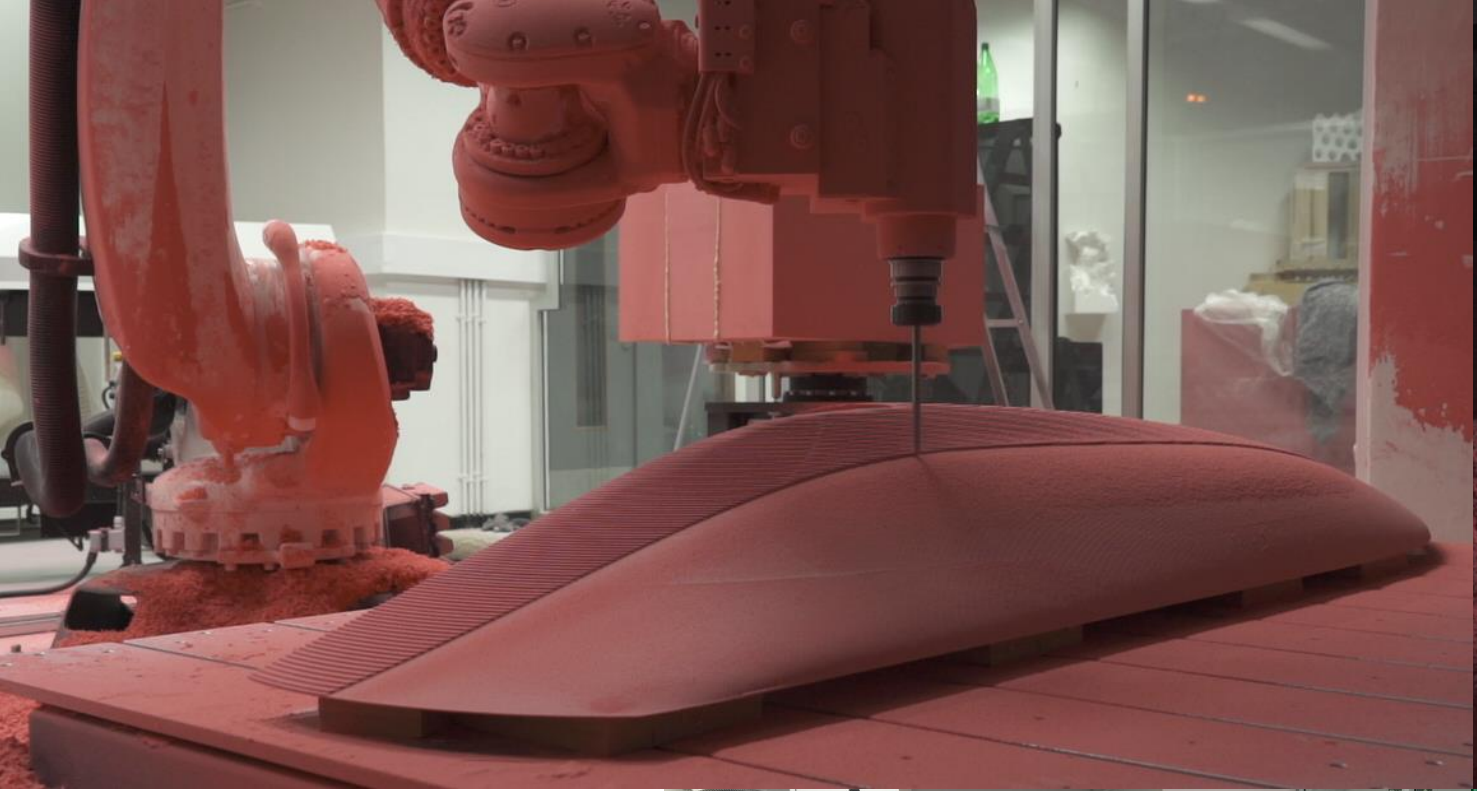



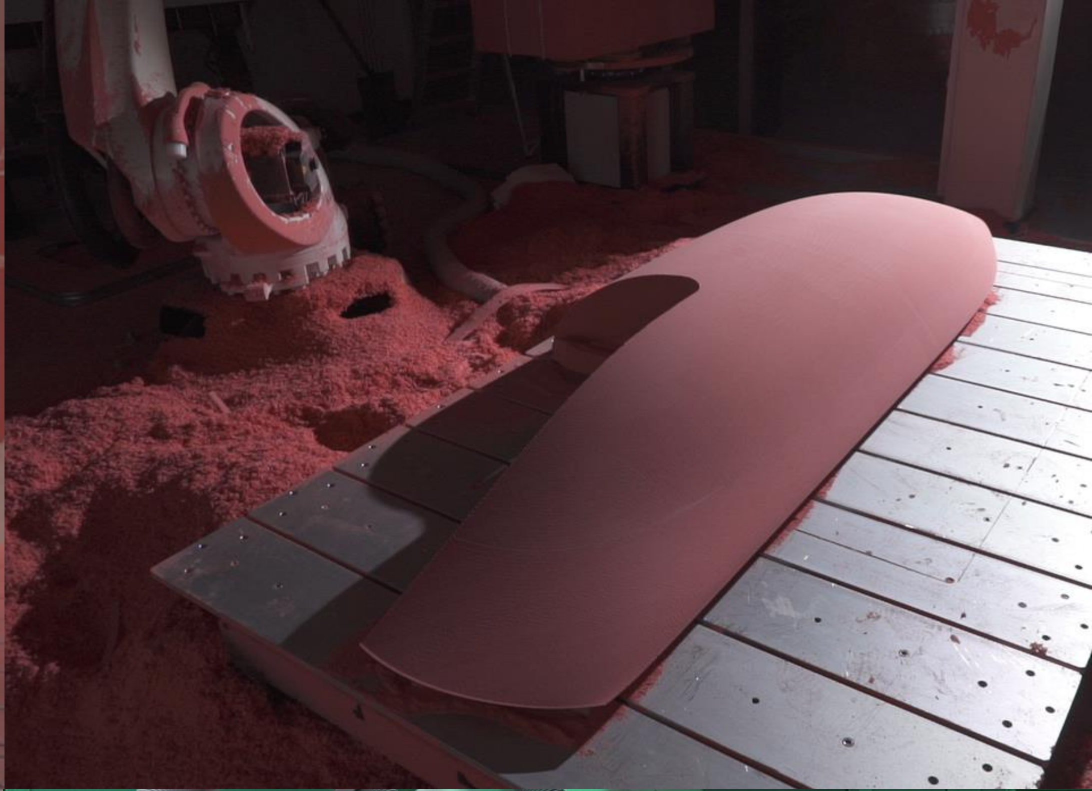



DAR | LAB
DIGITAL ARCHITECTURE ROBOTICS




https://vimeo.com/214323637

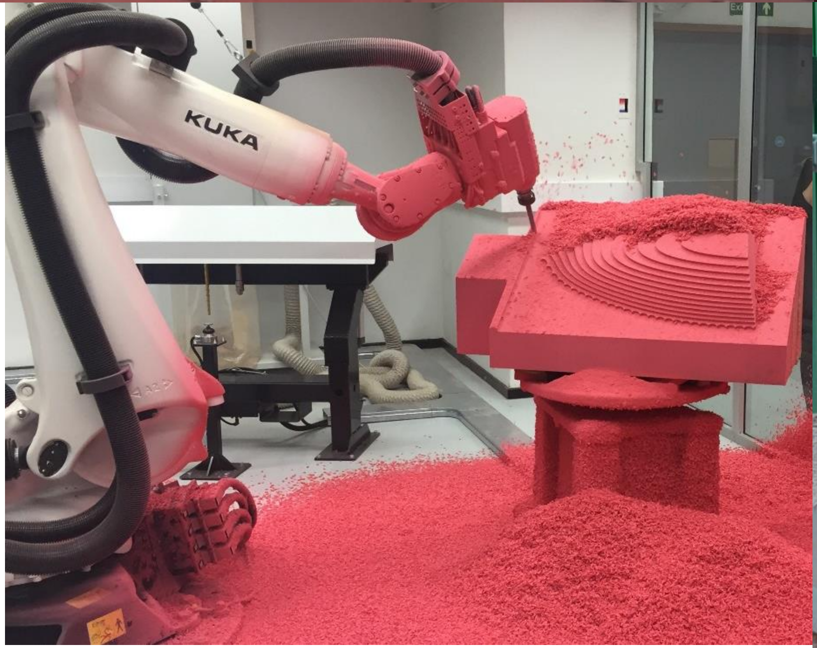




# CNC

PowerMill
software

**Federico Rossi**
Digital Architectural
Robotics lab

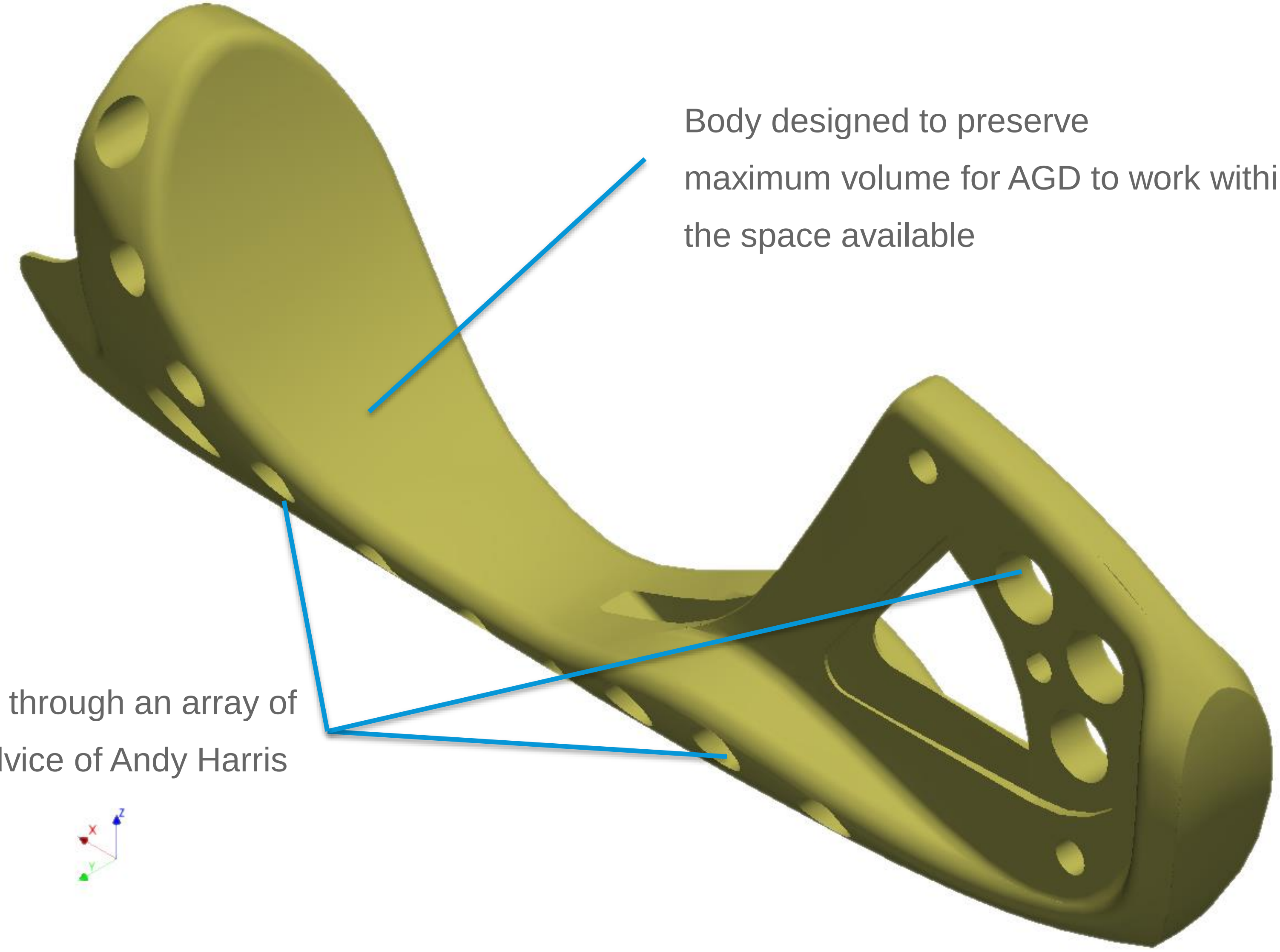



# CNC machining

# Part 3: Generative Design

Barney Townsend

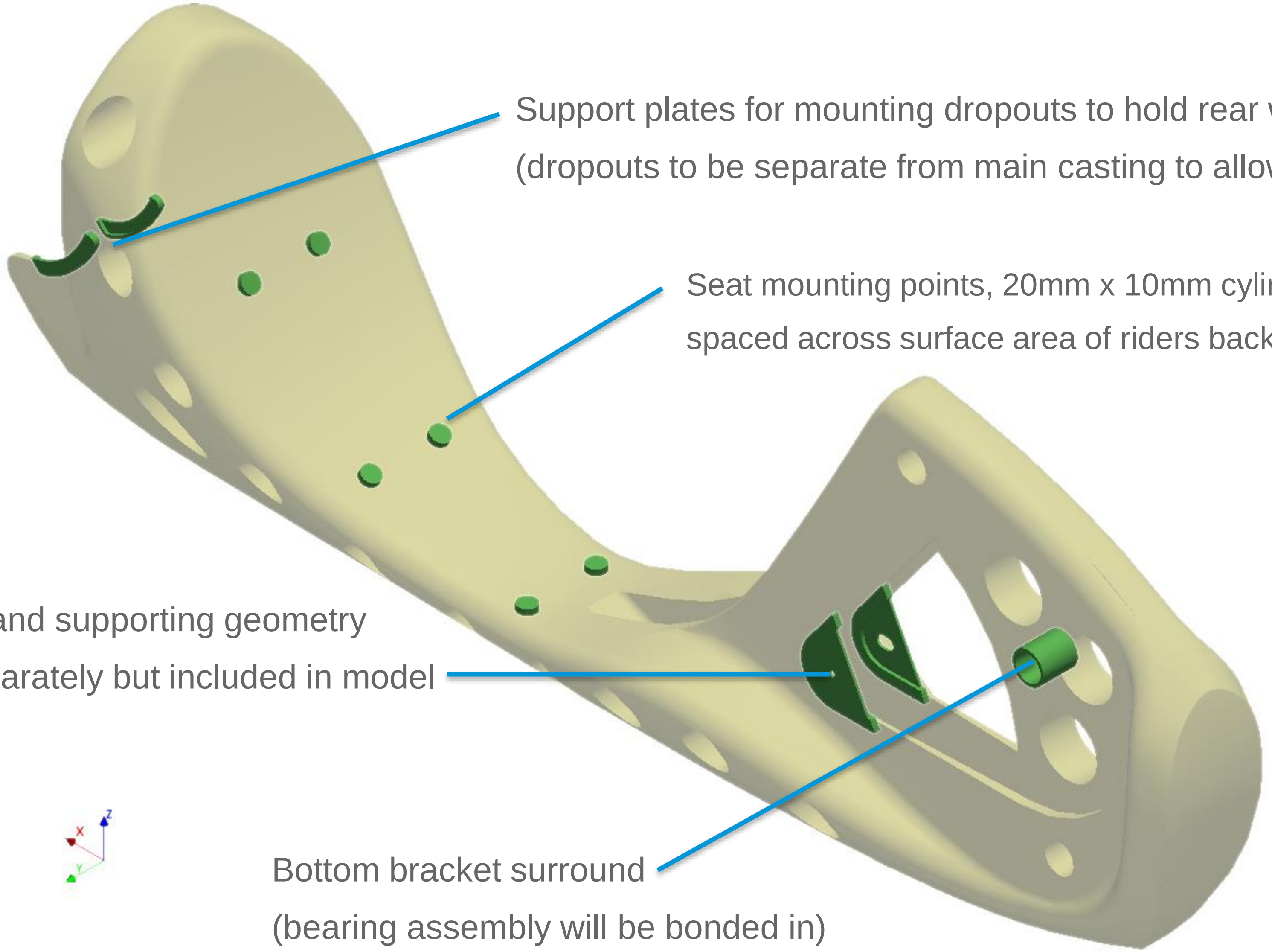

# Defining the design space: starting shape



Body designed to preserve maximum volume for AGD to work within the space available

Extra surfaces created through an array of transverse holes on advice of Andy Harris (Autodesk)


# Defining the design space: preserve geometry



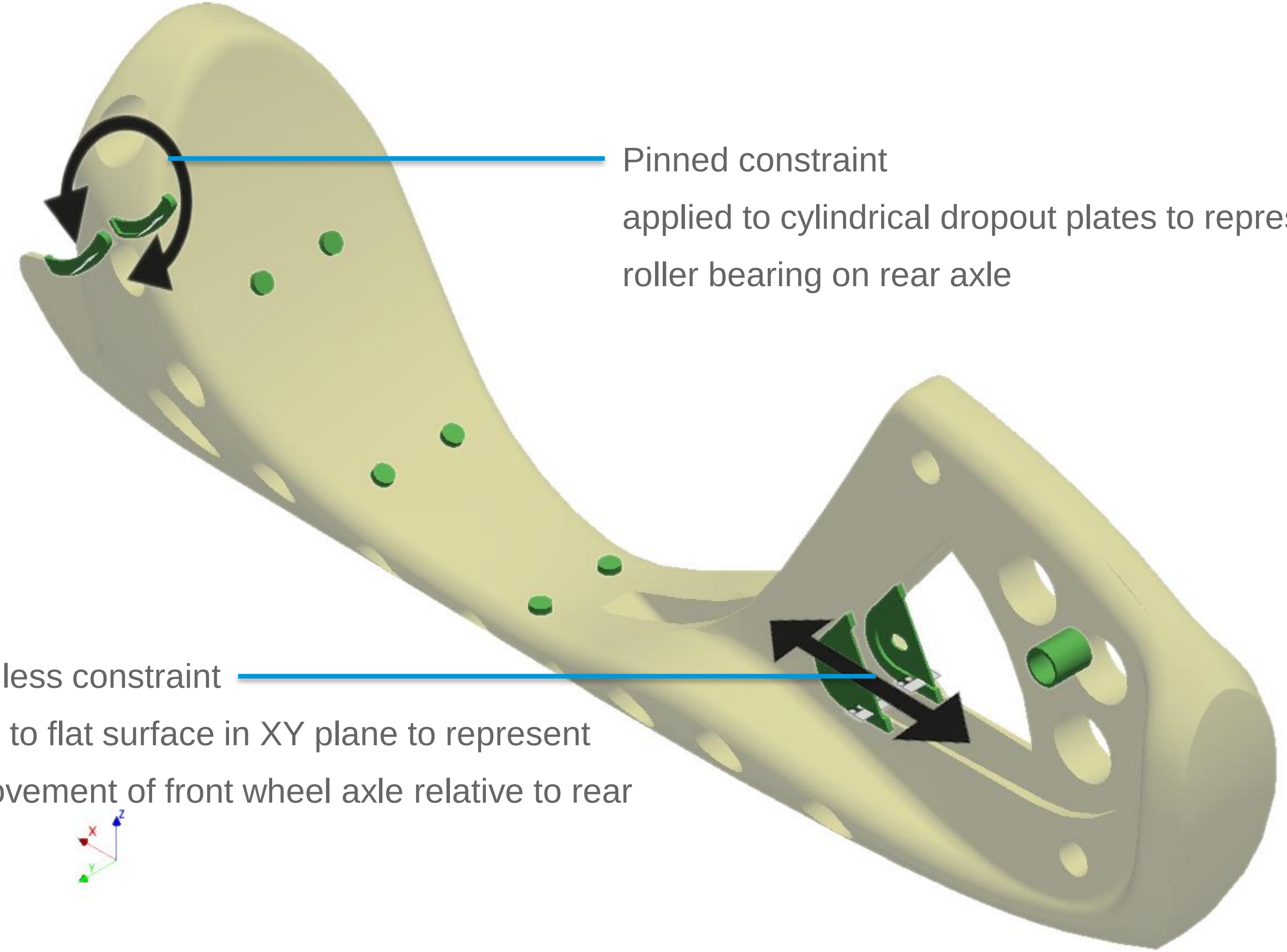
Support plates for mounting dropouts to hold rear wheel
(dropouts to be separate from main casting to allow replacement)

Seat mounting points, 20mm x 10mm cylinders
spaced across surface area of riders back for even load distribution

Front axle mounting plates and supporting geometry
(plates will be produced separately but included in model
to allow application of BCs)

Bottom bracket surround
(bearing assembly will be bonded in)


# Defining the design space: constraints



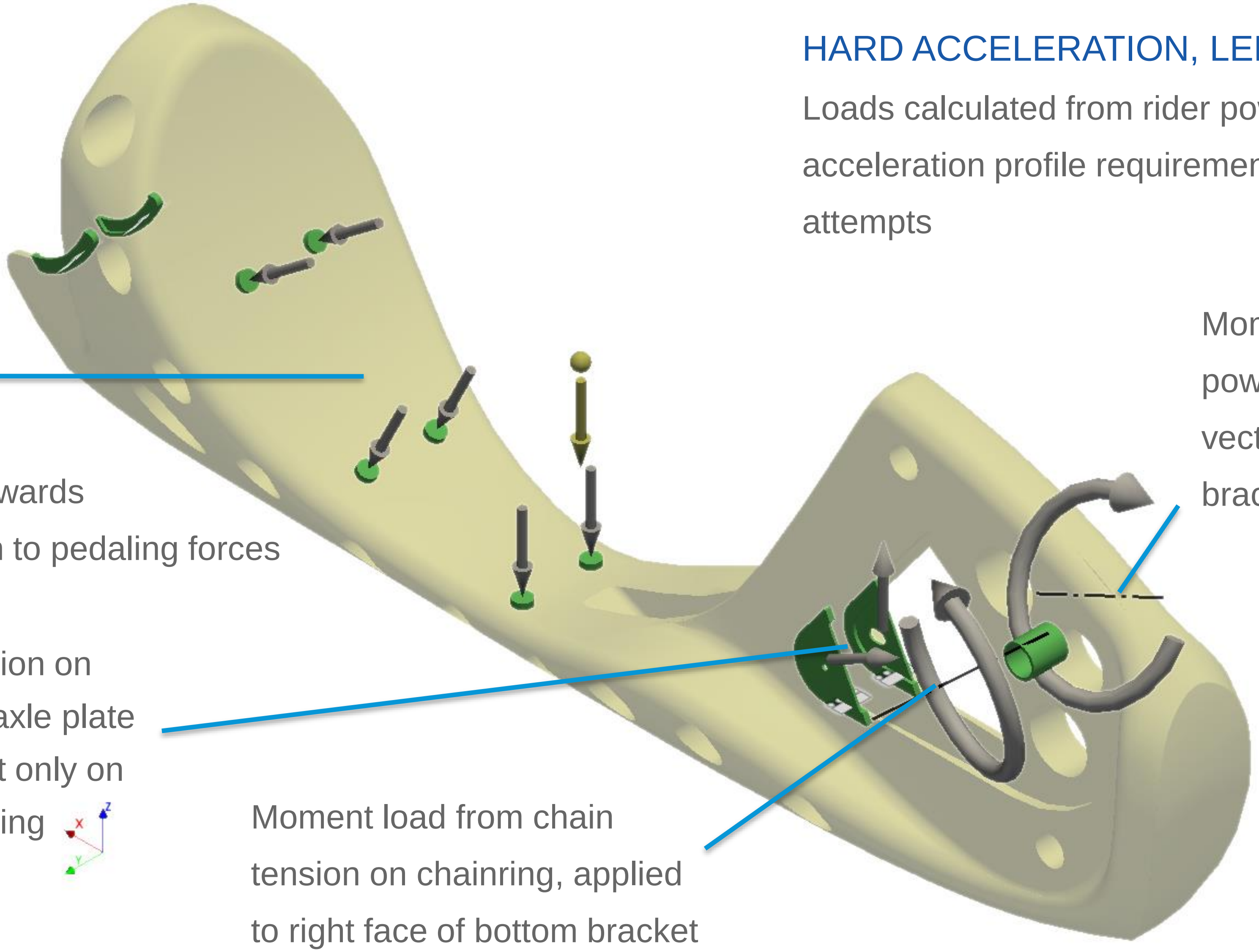
Pinned constraint

applied to cylindrical dropout plates to represent roller bearing on rear axle

Frictionless constraint

applied to flat surface in XY plane to represent free movement of front wheel axle relative to rear


# Defining the design space: load case 1a



## HARD ACCELERATION, LEFT PEDAL

Loads calculated from rider power capability and acceleration profile requirements for record attempts

Rider weight of 800N distributed across seat mounting points, biased towards shoulder points as reaction to pedaling forces

Force load from chain tension on small sprocket, applied to axle plate bodies. Vertical component only on left hand plate due to steering bearing

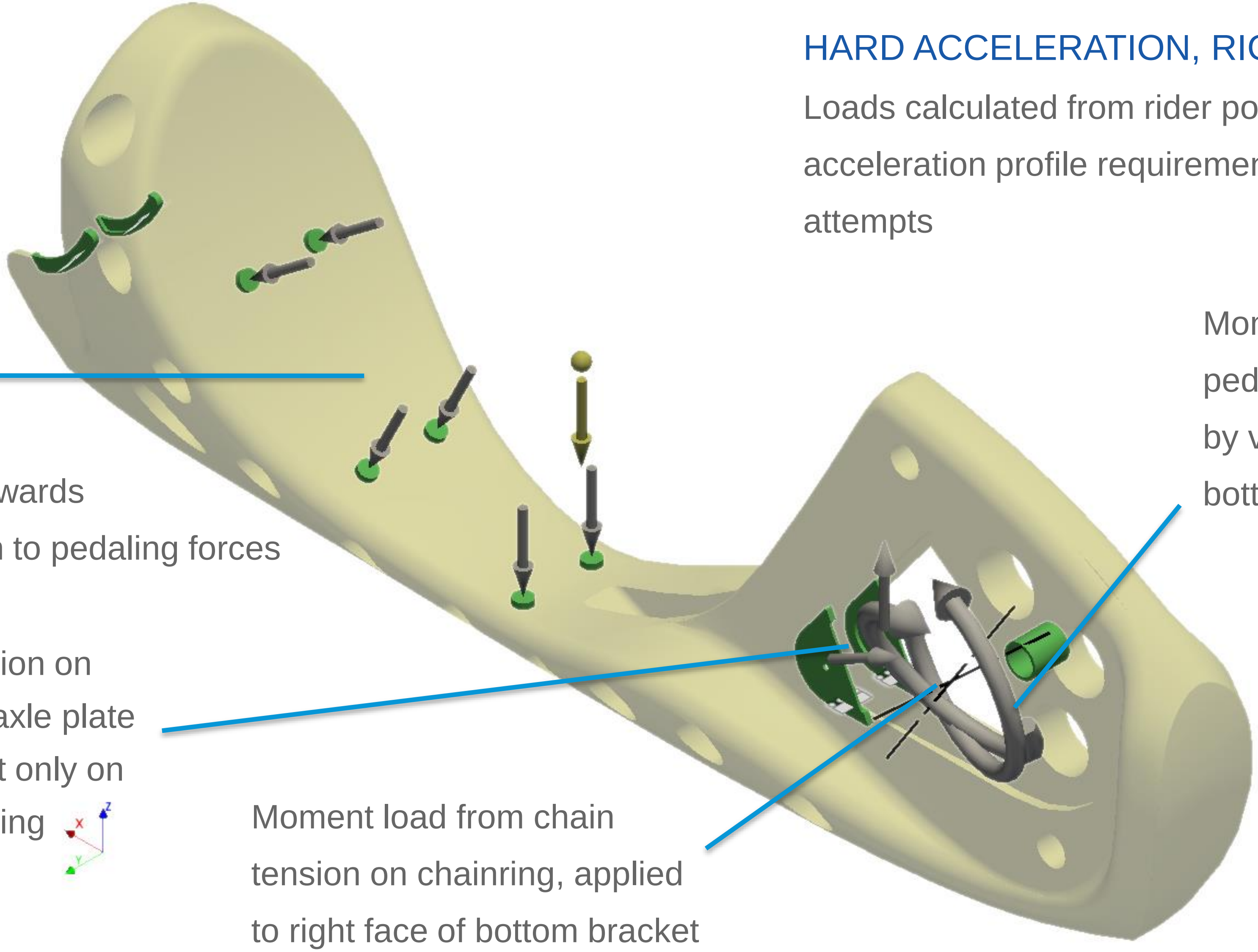
Moment load from chain tension on chainring, applied to right face of bottom bracket

Moment load from left pedal power stroke, applied by vectors to left face of bottom bracket


# Defining the design space: load case 1b

## HARD ACCELERATION, RIGHT PEDAL

Loads calculated from rider power capability and acceleration profile requirements for record attempts



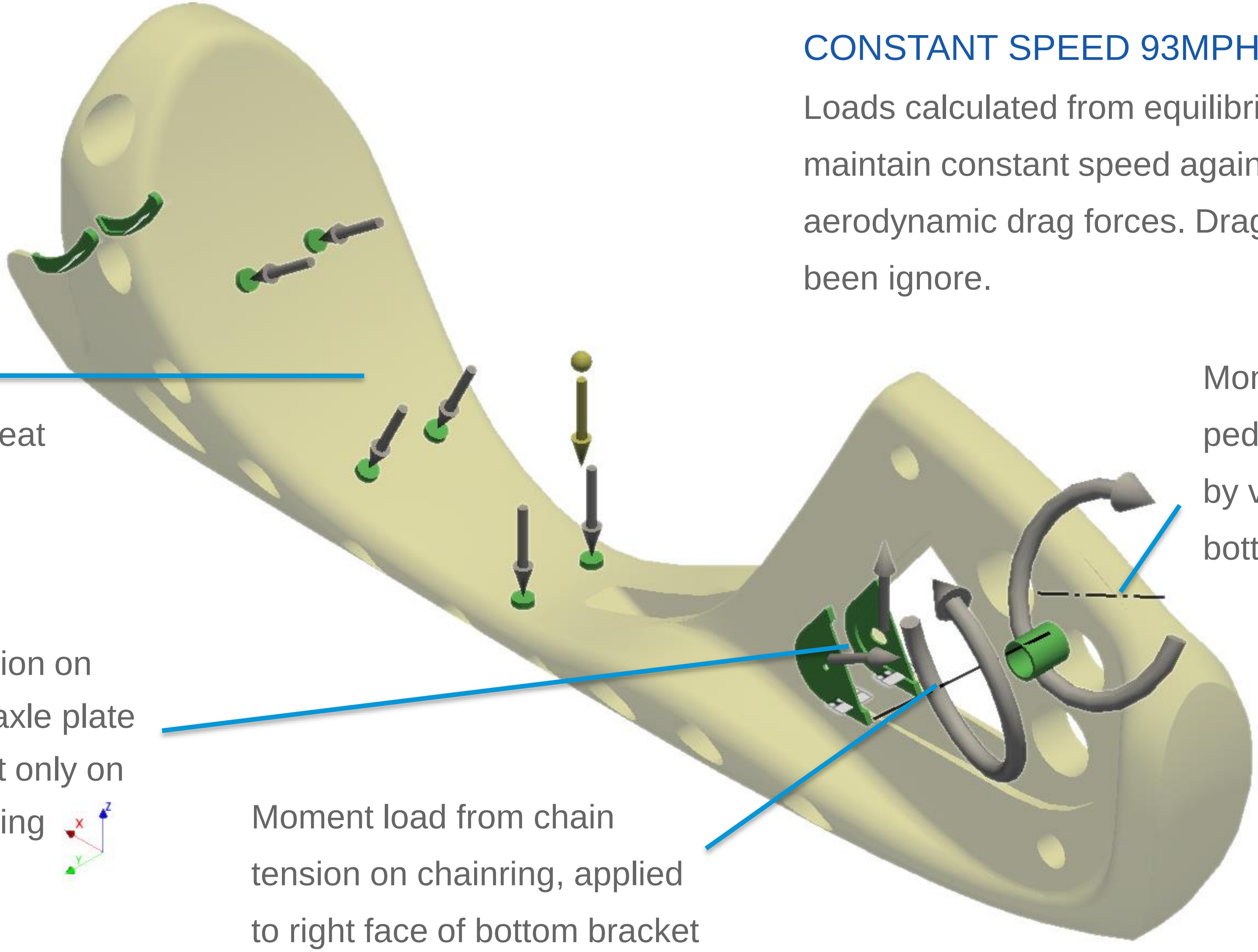
Rider weight of 800N distributed across seat mounting points, biased towards shoulder points as reaction to pedaling forces

Moment load from right pedal power stroke, applied by vectors to right face of bottom bracket

Force load from chain tension on small sprocket, applied to axle plate bodies. Vertical component only on left hand plate due to steering bearing

Moment load from chain tension on chainring, applied to right face of bottom bracket


# Defining the design space: load case 2a



## CONSTANT SPEED 93MPH, LEFT PEDAL

Loads calculated from equilibrium requirements to maintain constant speed against mechanical and aerodynamic drag forces. Drag load on shell has been ignore.

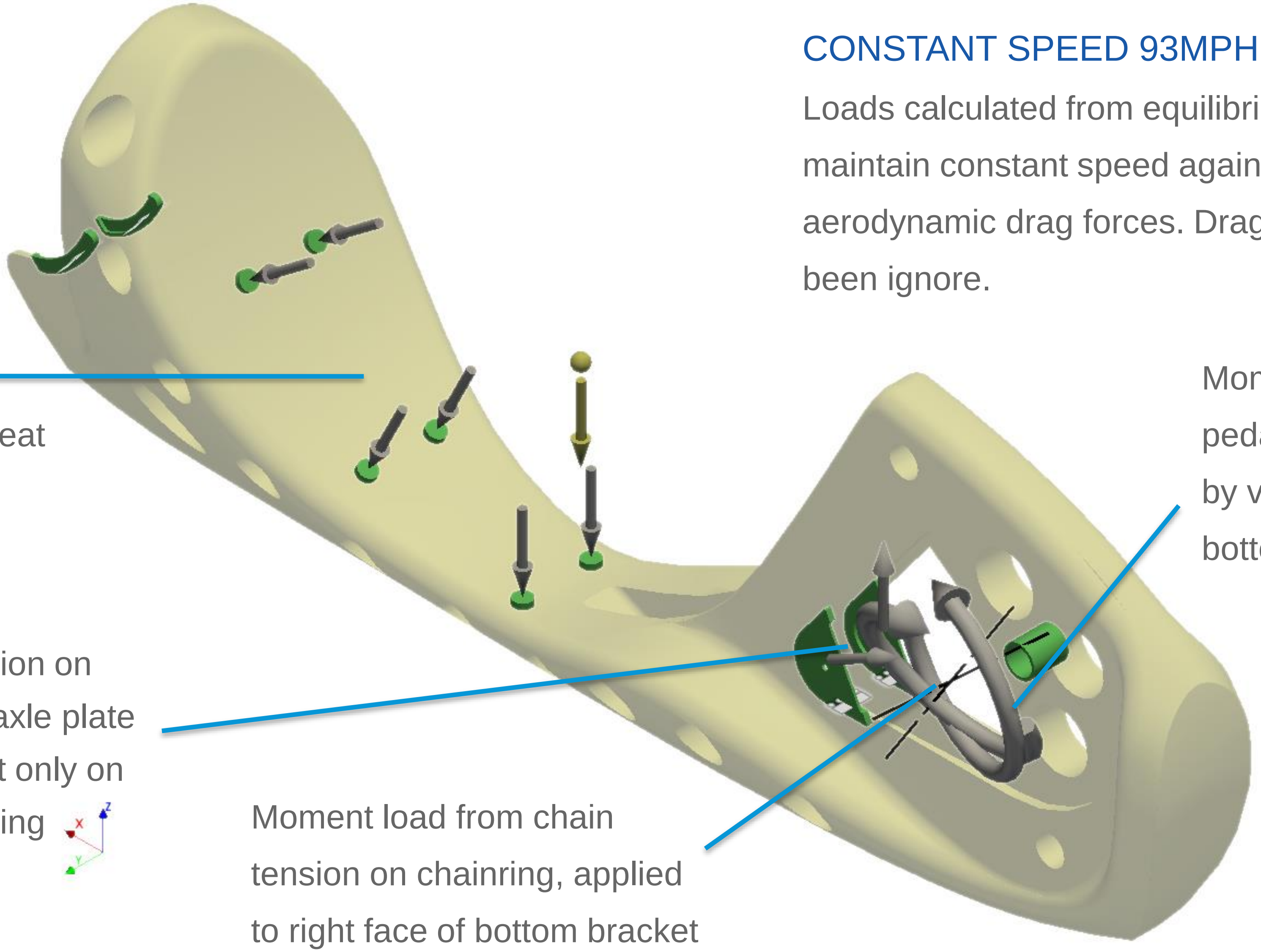
Rider weight of 800N distributed evenly across seat mounting points

Moment load from right pedal power stroke, applied by vectors to right face of bottom bracket

Force load from chain tension on small sprocket, applied to axle plate bodies. Vertical component only on left hand plate due to steering bearing

Moment load from chain tension on chainring, applied to right face of bottom bracket


# Defining the design space: load case 2b



## CONSTANT SPEED 93MPH, RIGHT PEDAL

Loads calculated from equilibrium requirements to maintain constant speed against mechanical and aerodynamic drag forces. Drag load on shell has been ignore.

Rider weight of 800N distributed evenly across seat mounting points

Moment load from right pedal power stroke, applied by vectors to right face of bottom bracket

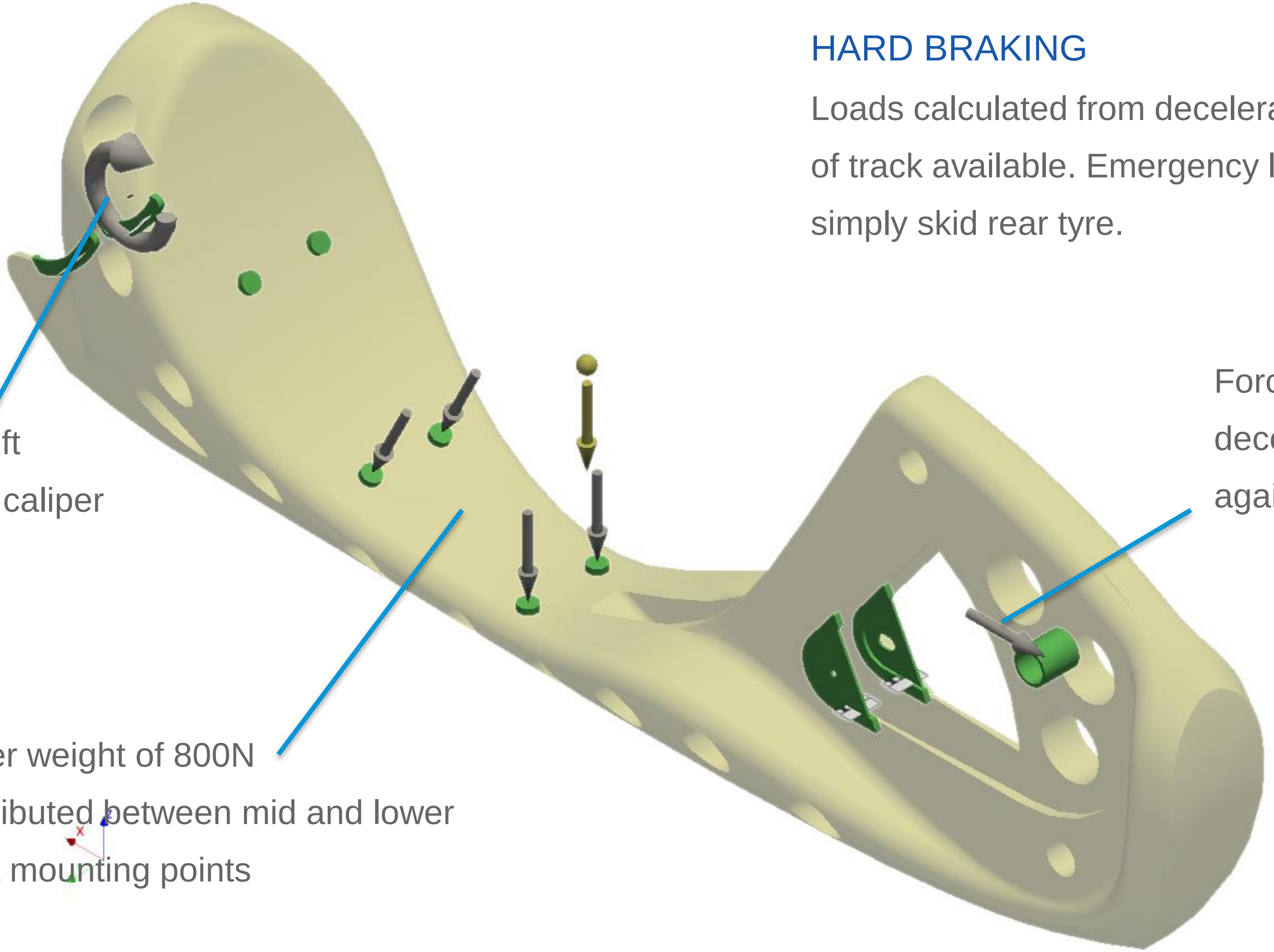
Force load from chain tension on small sprocket, applied to axle plate bodies. Vertical component only on left hand plate due to steering bearing

Moment load from chain tension on chainring, applied to right face of bottom bracket


# Defining the design space: load case 3

## HARD BRAKING

Loads calculated from deceleration requirements of track available. Emergency lock braking will simply skid rear tyre.

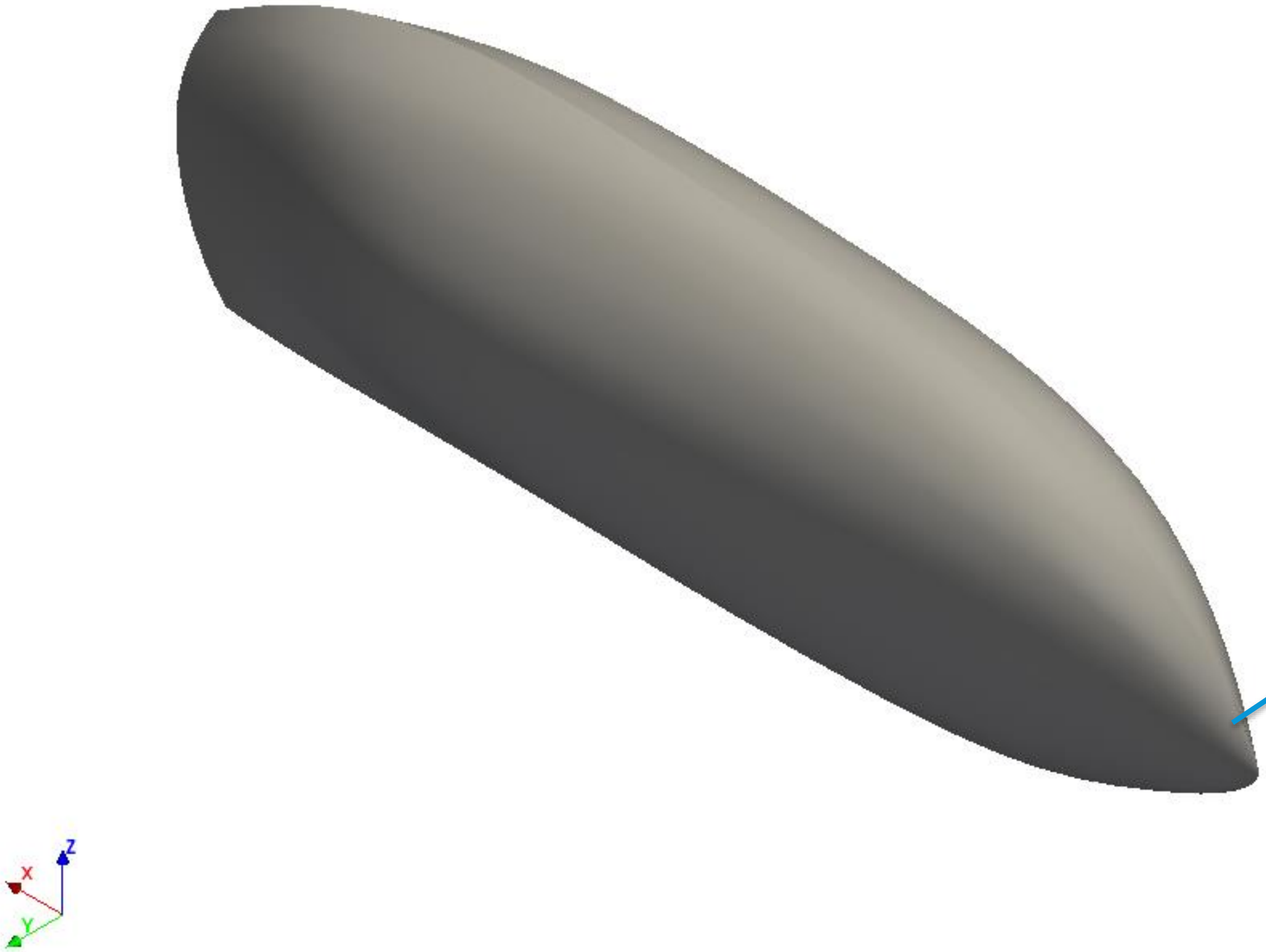


Moment load imposed on left hand rear dropout by brake caliper

Force load from deceleration of rider mass against both pedals

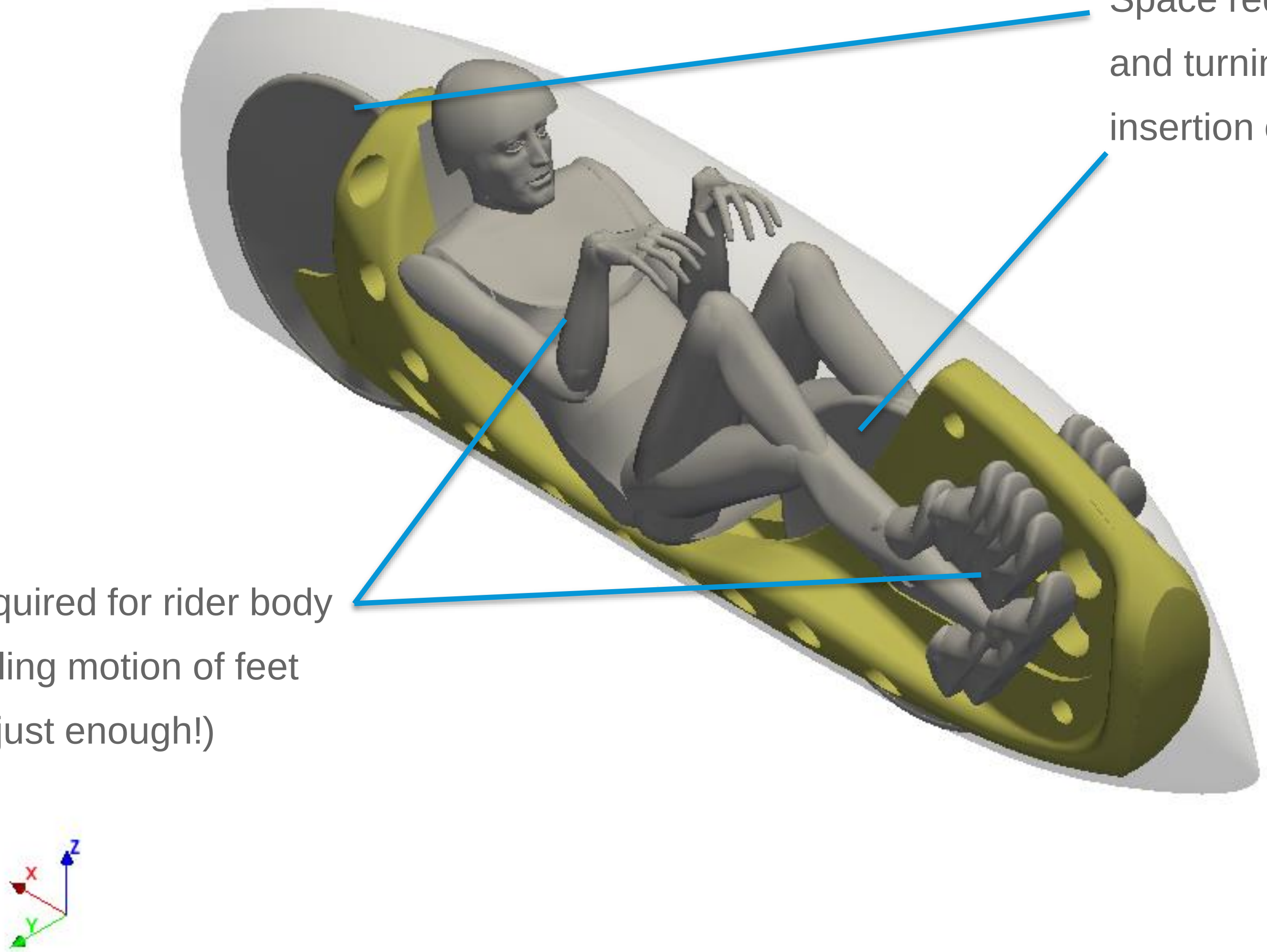
Rider weight of 800N distributed between mid and lower seat mounting points


# Defining the design space: obstacle geometry




Outer limits defined by external shell


# Defining the design space: obstacle geometry

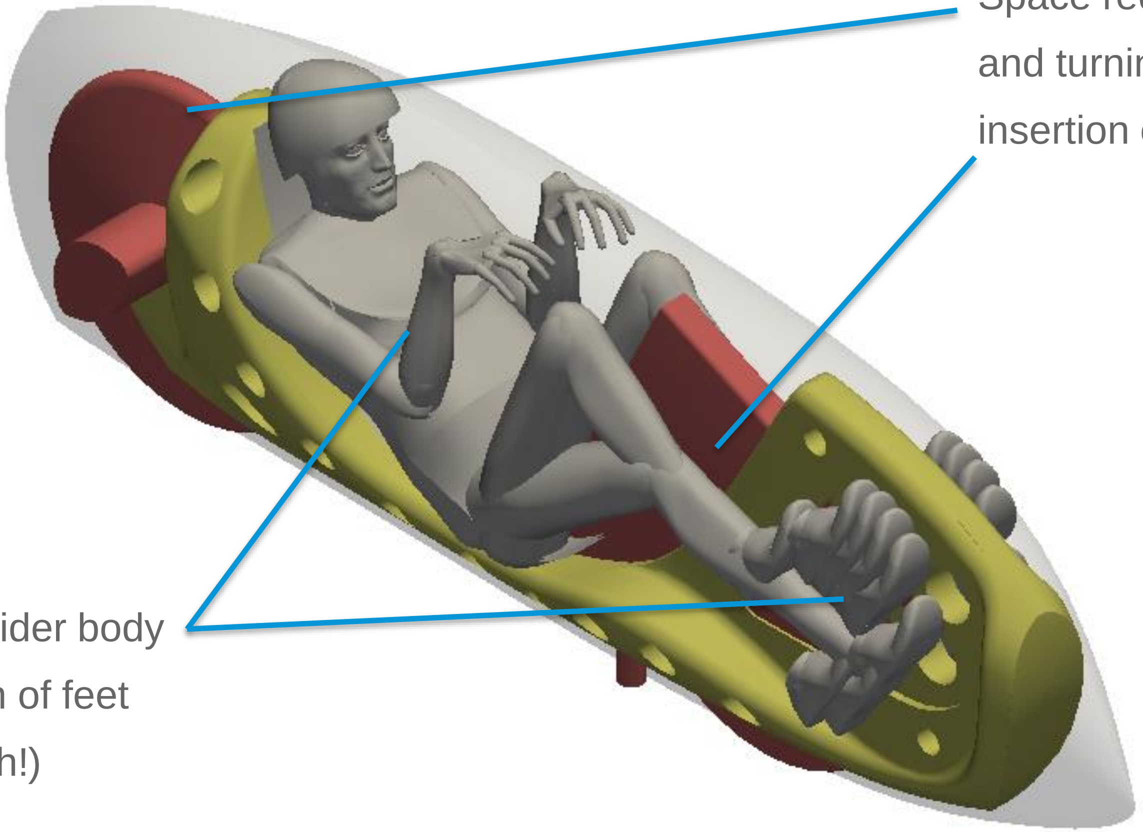



Space required for wheels
and turning radius of front wheel. Also,
insertion of front wheel into structure

Space required for rider body
and pedaling motion of feet
(but only just enough!)


# Defining the design space: obstacle geometry

Space required for wheels
and turning radius of front wheel. Also,
insertion of front wheel into structure



Space required for rider body
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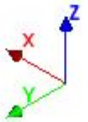


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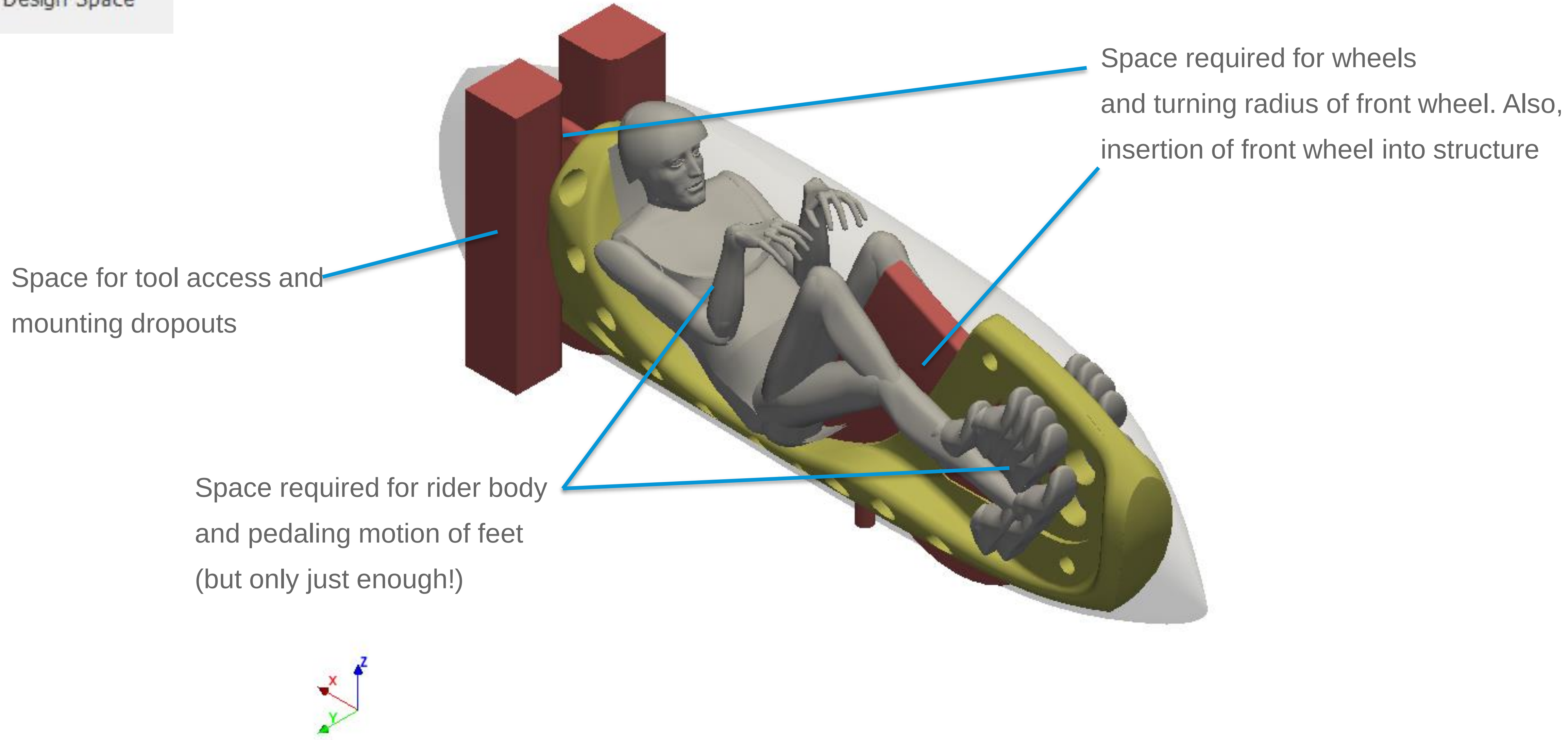
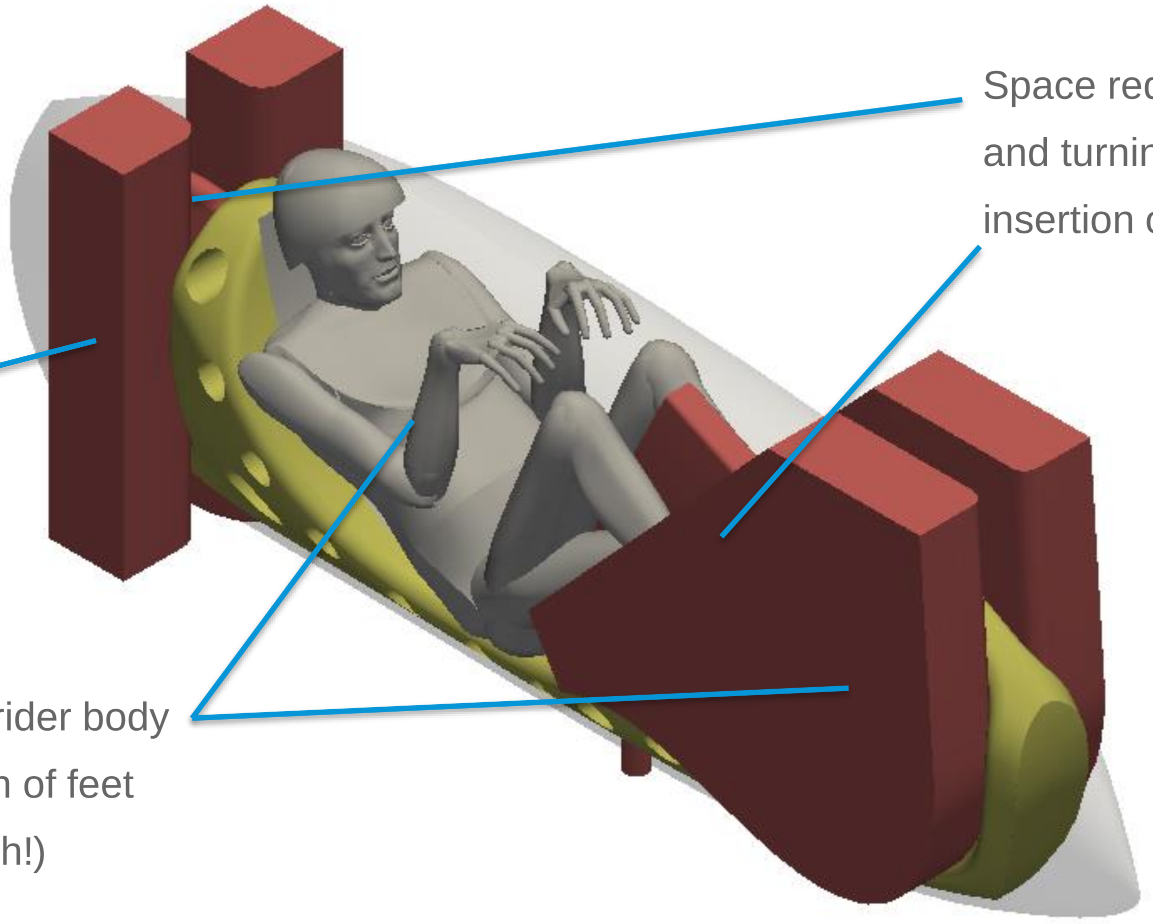



# Defining the design space: obstacle geometry

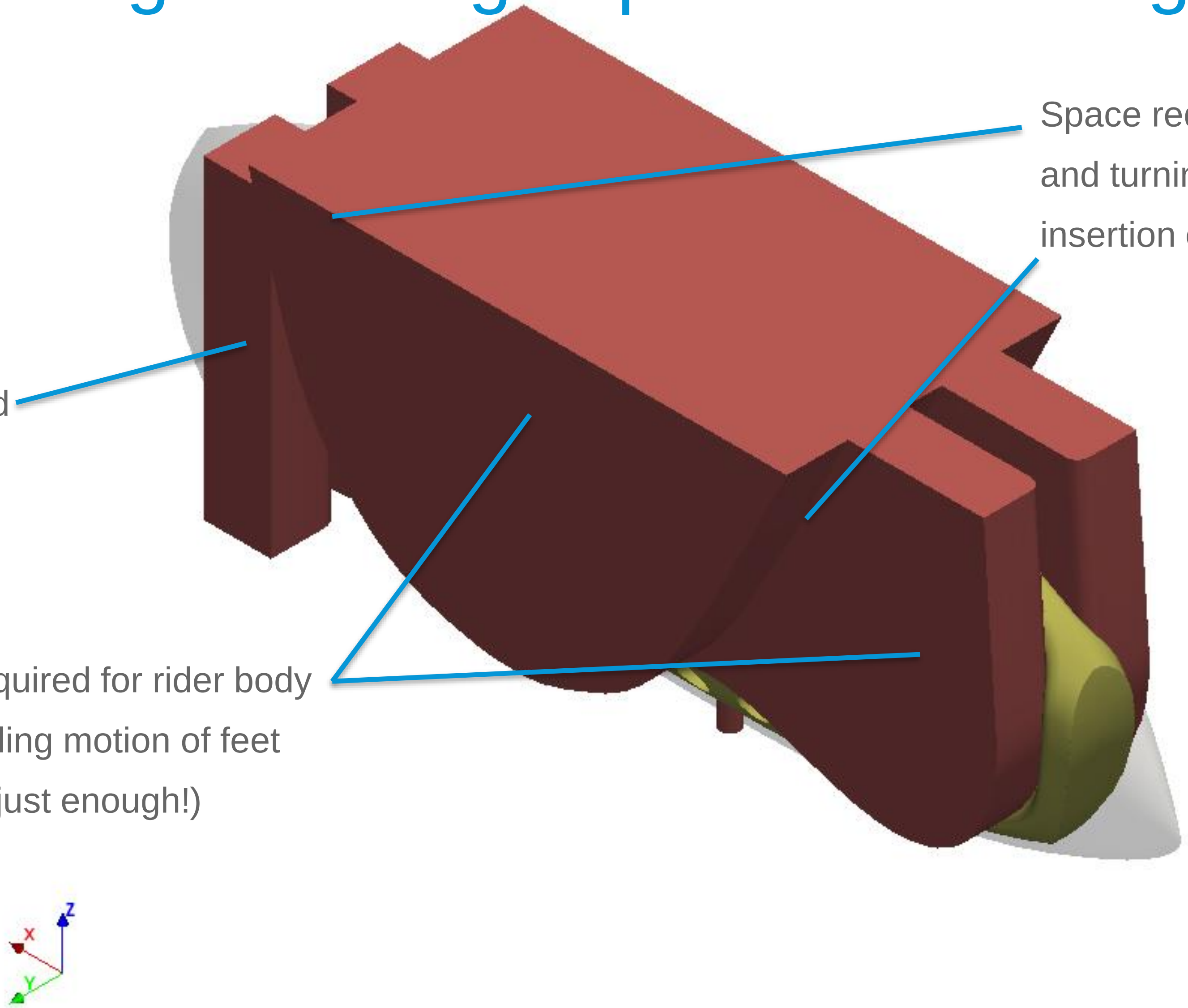


Space required for wheels and turning radius of front wheel. Also, insertion of front wheel into structure

Space for too access and mounting dropouts

Space required for rider body and pedaling motion of feet (but only just enough!)


# Defining the design space: obstacle geometry



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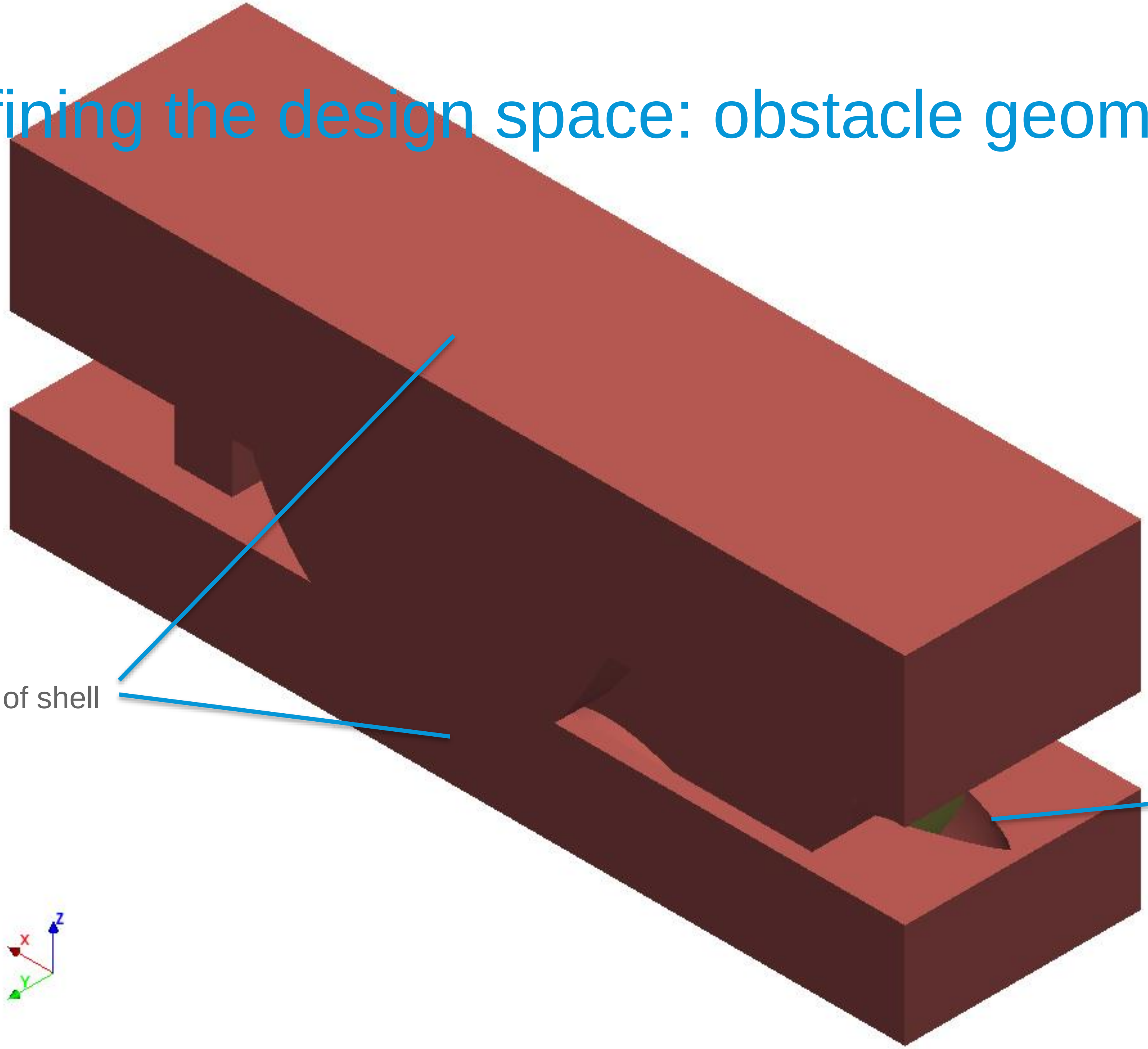
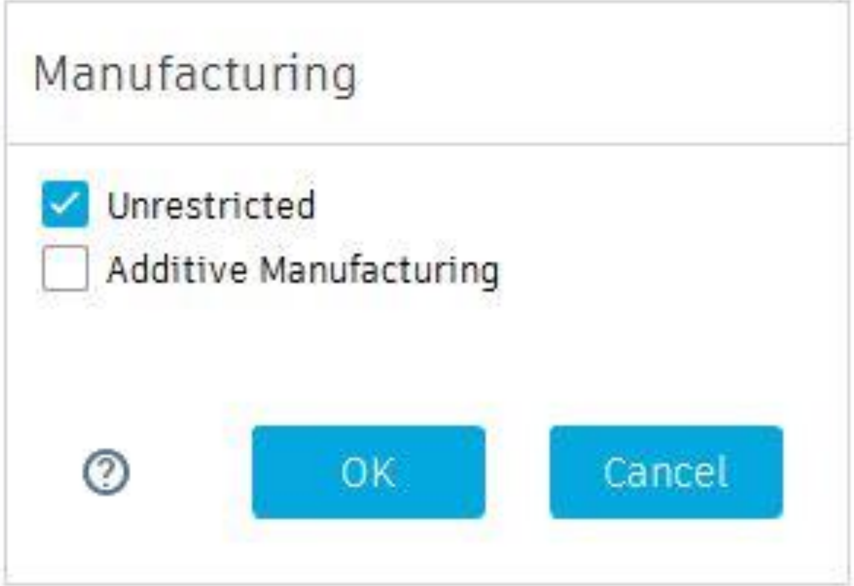
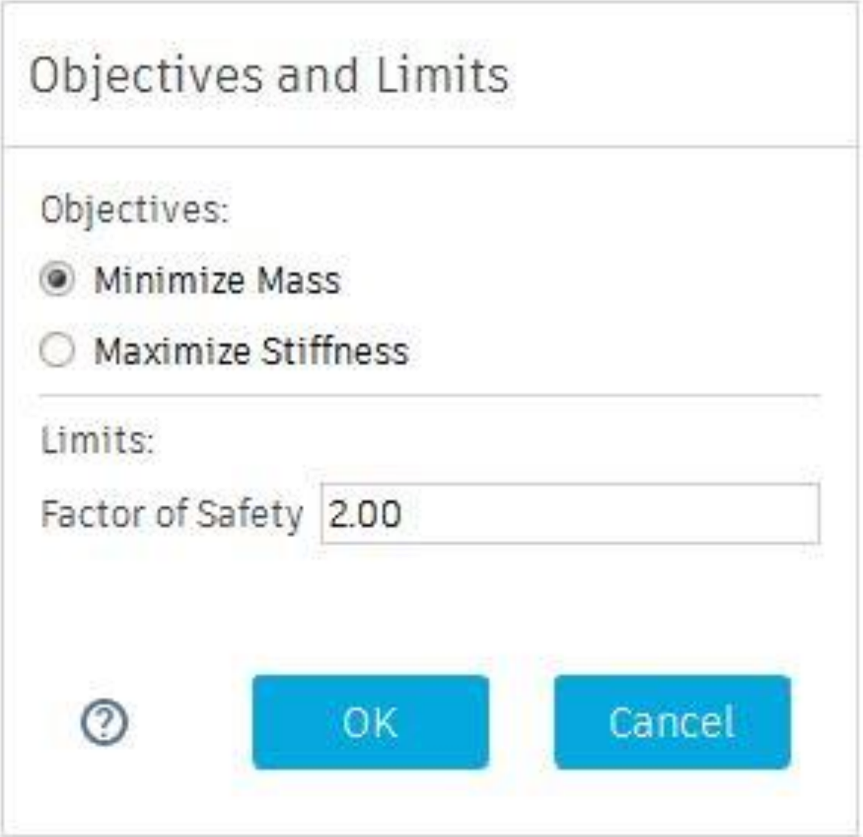


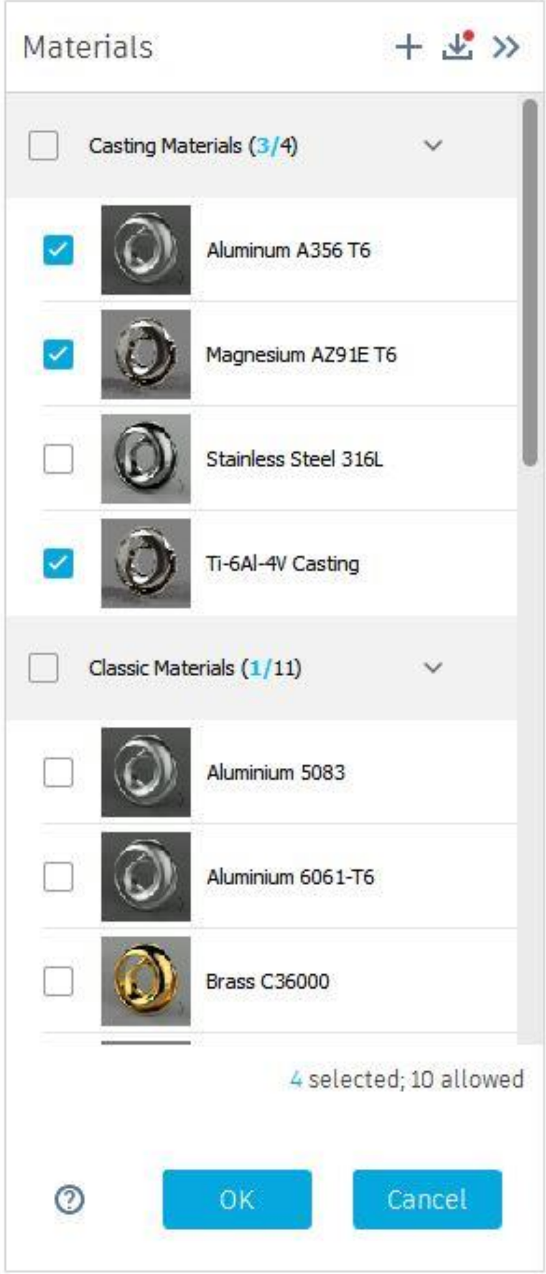

Upper and lower limits of shell geometry

Outer limits defined by external shell

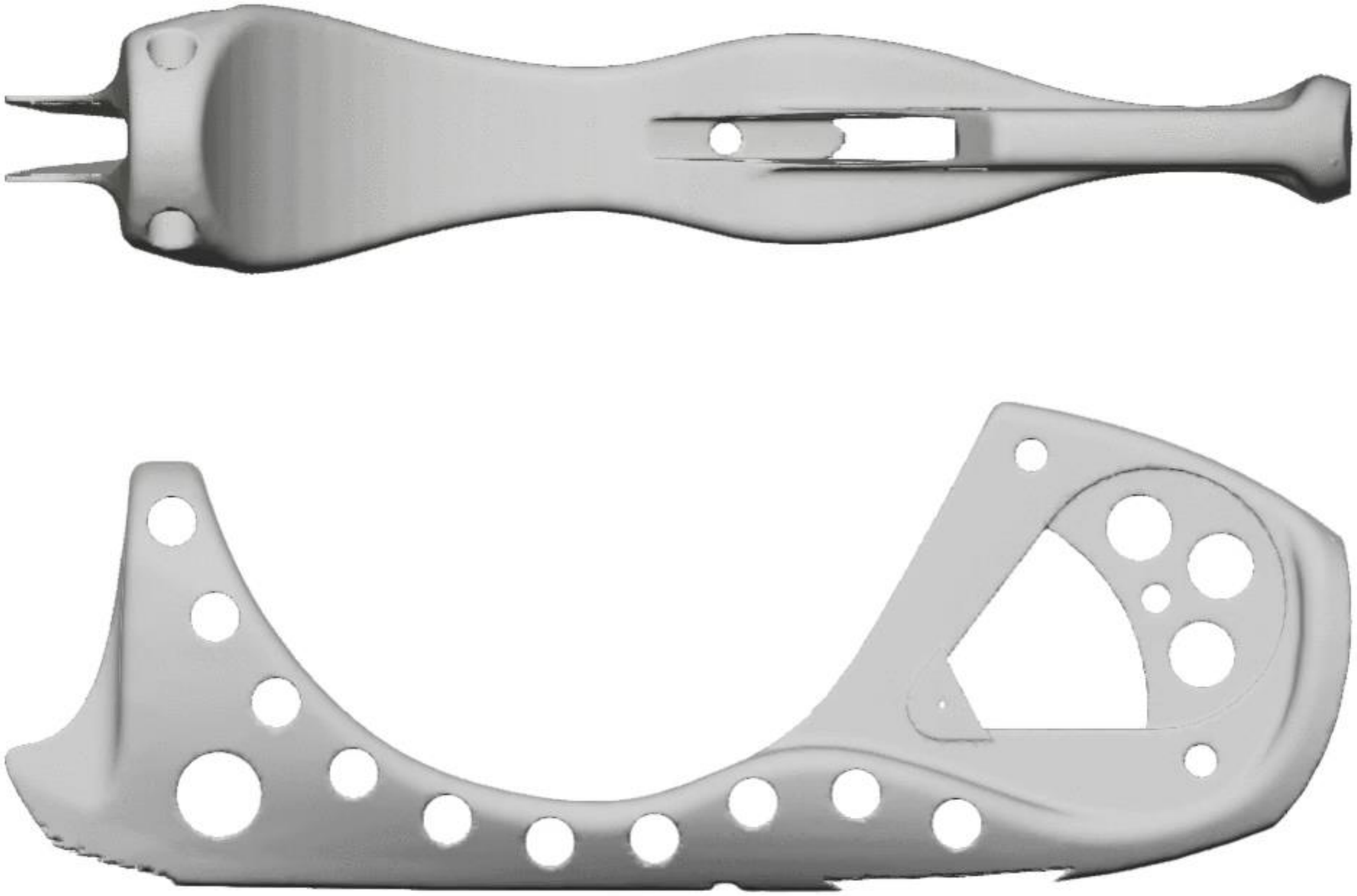
# Defining the design space: objectives, manufacturing, & materials

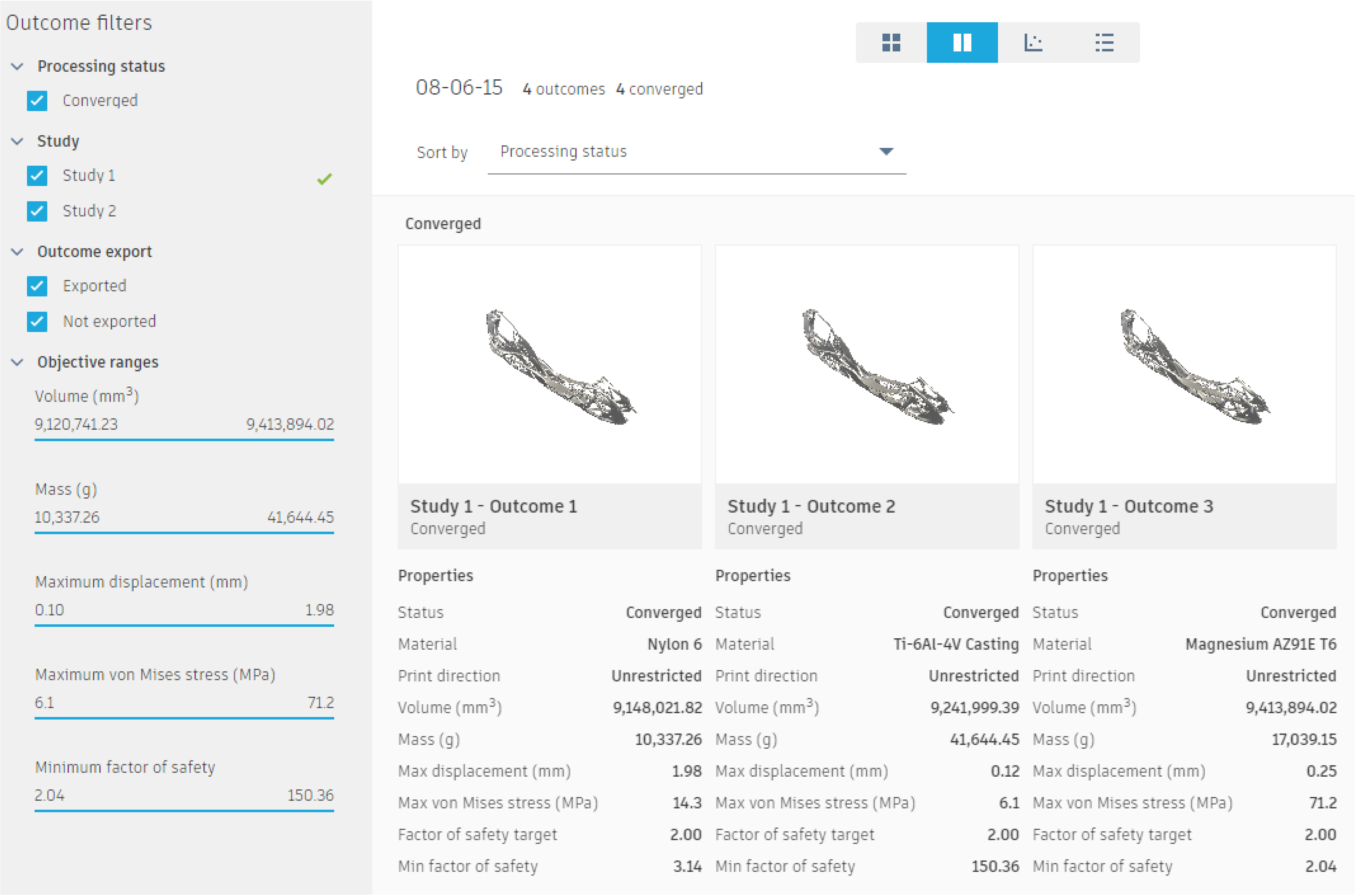



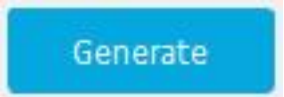



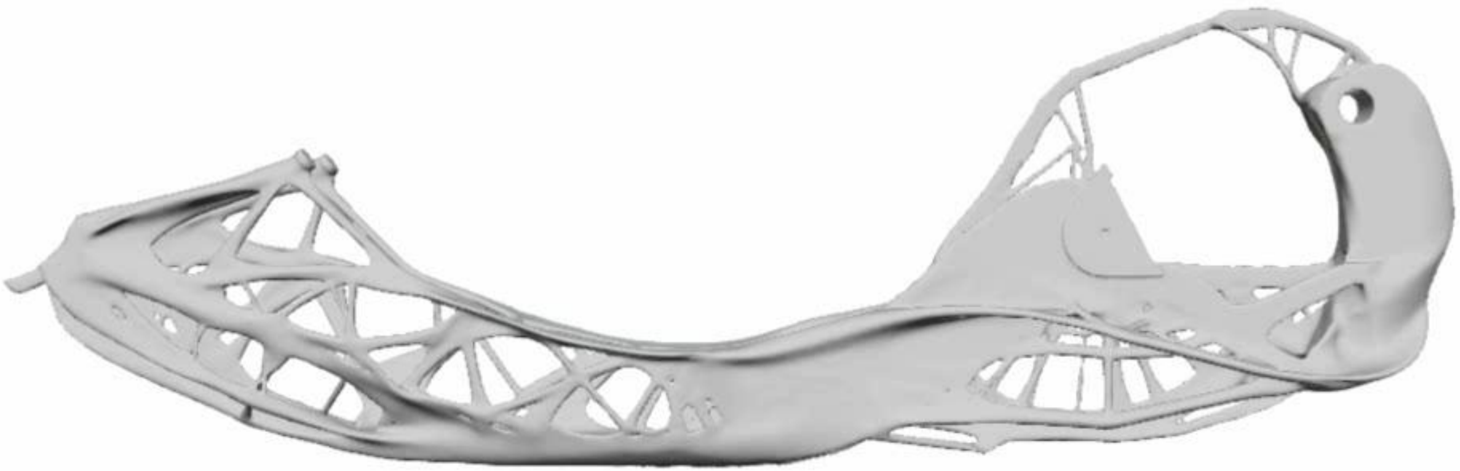
Generate



43 iterations later….


Outcome filters
Processing status
Converged
Study
Study 1
Study 2
Outcome export
Exported
Not exported
Objective ranges
Volume (mm3)
9,120,741.23
9,413,894.02
Mass (g)
10,337.26
41,644.45
Maximum displacement (mm)
0.10
1.98
Maximum von Mises stress (MPa)
6.1
71.2
Minimum factor of safety
2.04
150.36
08-06-15
4 outcomes
4 converged
Sort by
Processing status
Converged
Study 1 - Outcome 1
Converged
Study 1 - Outcome 2
Converged
Study 1 - Outcome 3
Converged
Properties
Status Converged
Material Nylon 6
Print direction Unrestricted
Volume (mm3) 9,148,021.82
Mass (g) 10,337.26
Max displacement (mm) 1.98
Max von Mises stress (MPa) 14.3
Factor of safety target 2.00
Min factor of safety 3.14
Properties
Status Converged
Material Ti-6Al-4V Casting
Print direction Unrestricted
Volume (mm3) 9,241,999.39
Mass (g) 41,644.45
Max displacement (mm) 0.12
Max von Mises stress (MPa) 6.1
Factor of safety target 2.00
Min factor of safety 150.36
Properties
Status Converged
Material Magnesium AZ91E T6
Print direction Unrestricted
Volume (mm3) 9,413,894.02
Mass (g) 17,039.15
Max displacement (mm) 0.25
Max von Mises stress (MPa) 71.2
Factor of safety target 2.00
Min factor of safety 2.04



Latest version outcome in Magnesium

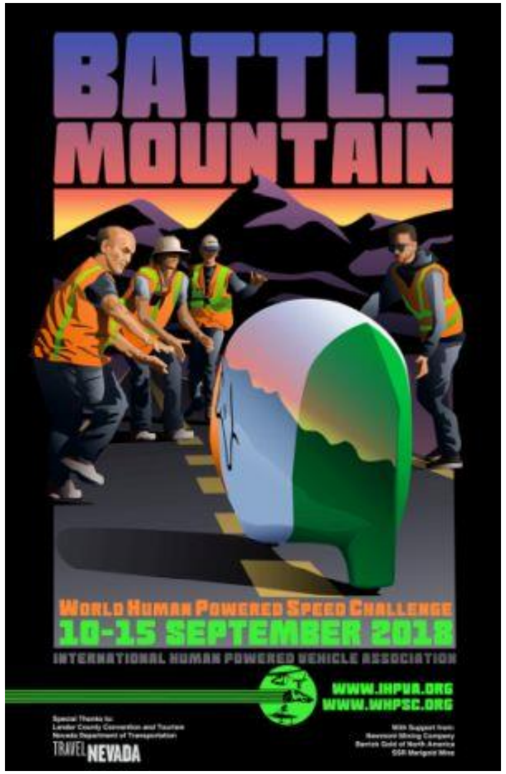
# AGD Vs. Mike Burrows!

# AGD Vs. Mike Burrows!

# AGD Vs. Mike Burrows!

# Part 4: What next?

# Track testing and record attempts




Hour Record

Standing start, maximum distance in 1 hour

Current British Hour record: 46.96 mph; Current World Hour record: 57.43 mph

World Human Powered Speed Record

5 mile track in Battle Mountain Nevada. Timed over final 200m. Current record: 89.59 mph

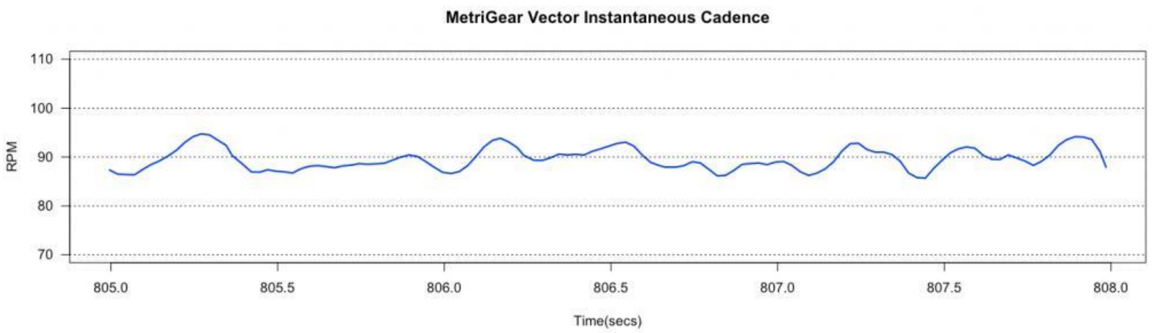
# The hour records

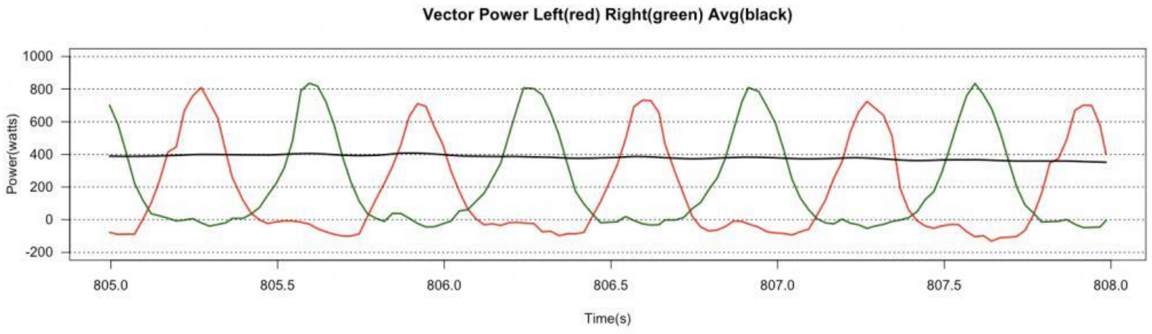
| Dynamic pressure 34mph = 15.2m/s | Cda | position | air watts | other watts | total watts | |
|---|---|---|---|---|---|---|
| 2142.2 | 0.185 | Sir Bradley Wiggins modern uci | 396.3 | 40.0 | 436.3 | 34 mph |
| Dynamic pressure 58.16mph = 26 m/s | Cda | position | air watts | other watts | total watts | |
| 10721.4 | 0.0135 | 75yrs Mike Burrows Aim93 1hr | 144.7 | 85.0 | 229.7 | 58.16 mph |

Thanks to Will Thomas and the staff at
Rockingham Motor Speedway
for track testing and the 1hr attempts

# Further analysis

- Further weight reduction by optimizing models in both AGD and Netfabb
- Consideration of buckling AGD outcomes
- Validation of calculated load conditions from load sensors on vehicle in use
- Optimisation of cranks, chainring, and dropouts for CNC machining in titanium




https://www.sigmasports.com
http://djconnel.blogspot.com/2013/08/applying-pedal-smoothness-algorithm-to.html

# Get involved!

BLUE HIPPO MEDIA


Feature length documentary + shot film series being produced by Blue Hippo Media (pip@bluehippomedia.com)
Thanks to Paul Burrows for the livery and power calculations

# Laid Back Bikes in Schools

Project pack for schools to run HPV design project using recycled bikes and bamboo. Prototyped over 5 days at LSBU. Objective to encourage STEM uptake, based on F1 in schools model

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