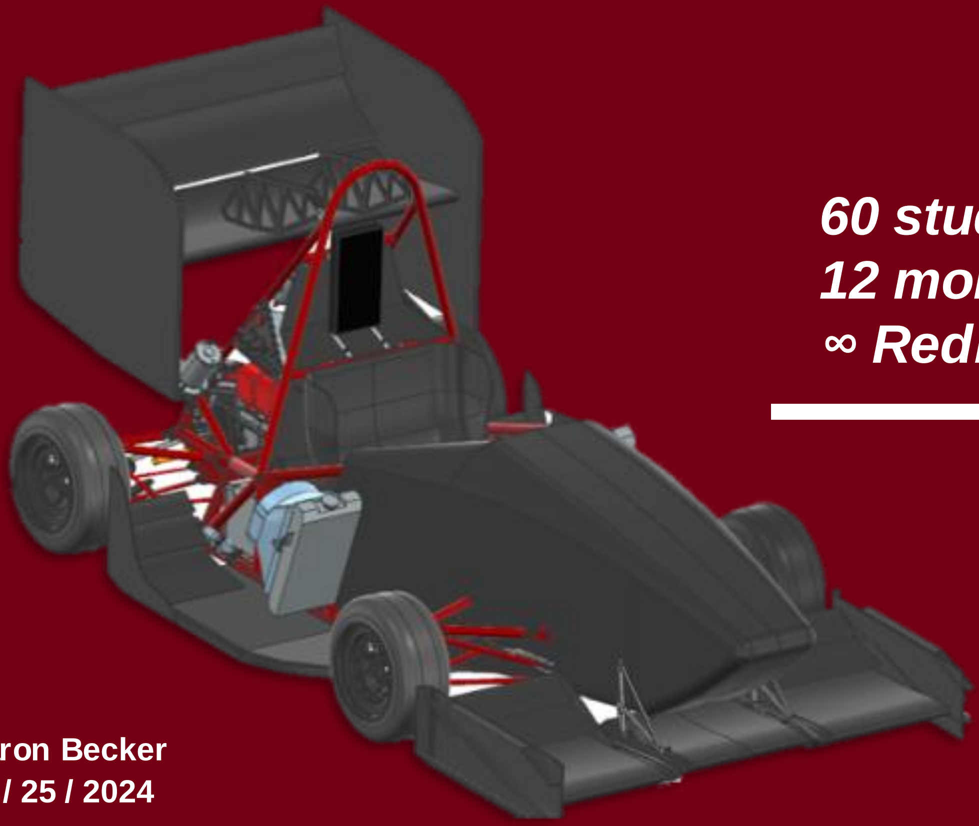
Massachusetts Institute of Technology

Formula SAE at MIT

MIT students building racecars!



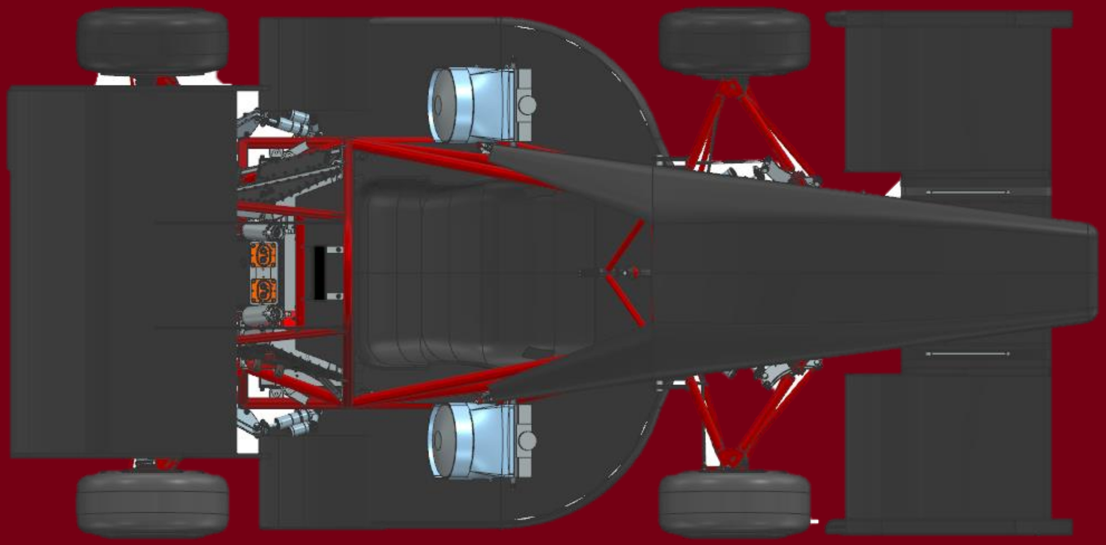
60 students
12 months
∞ Redbull

Aaron Becker
10 / 25 / 2024

What’s FSAE all about?

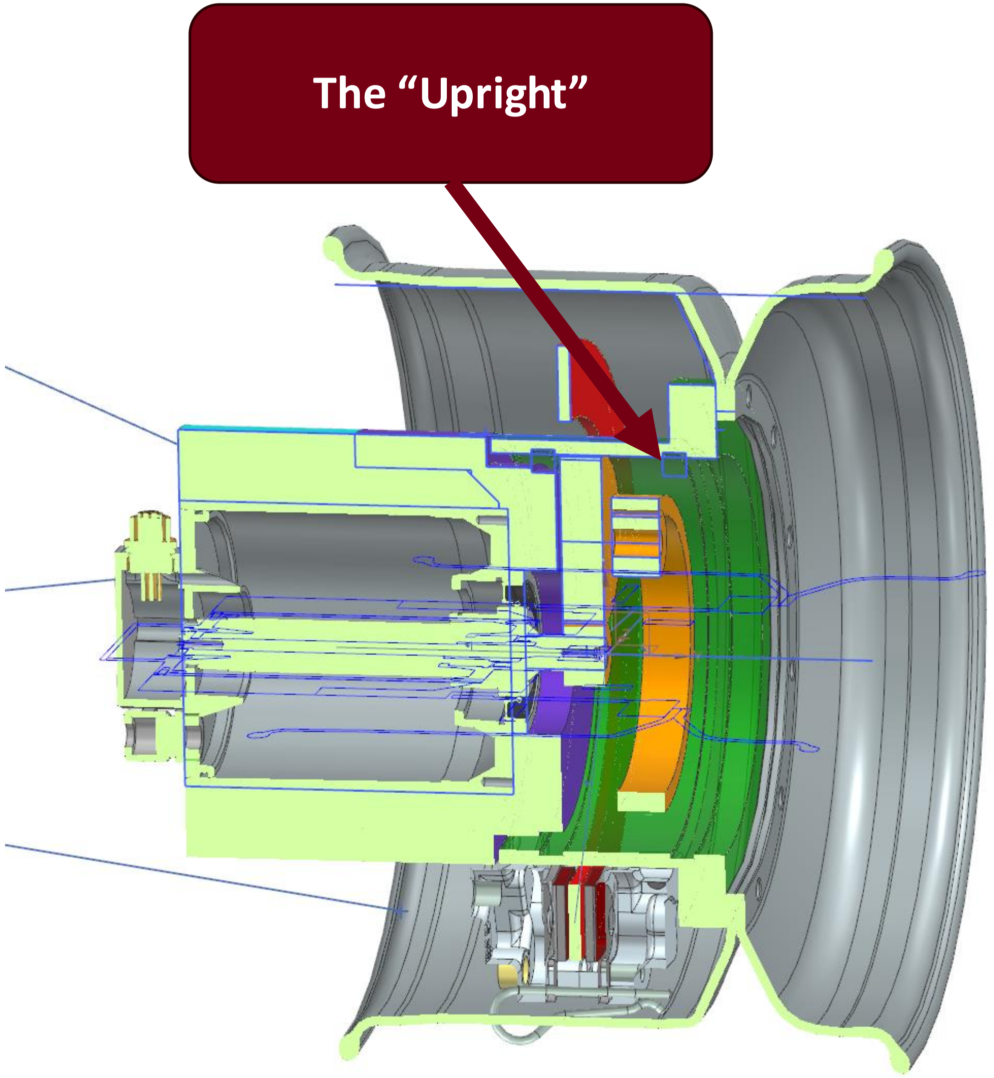
What’s FSAE all about?

- Build fast (electric) cars, and race them safely
- Learn to be great engineers by following a *design process*
- Have fun!



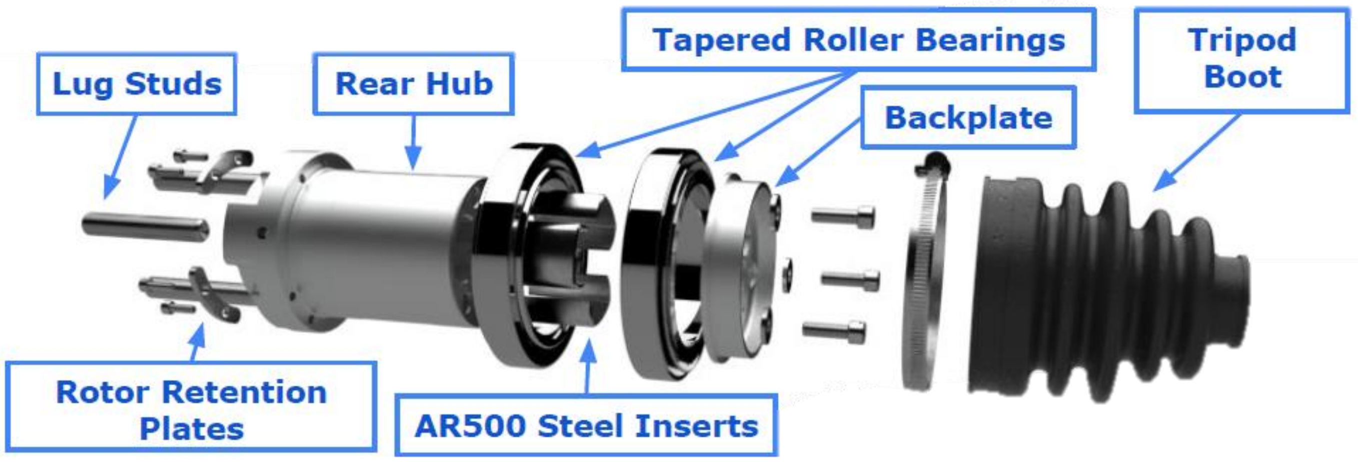
Let’s follow a part!

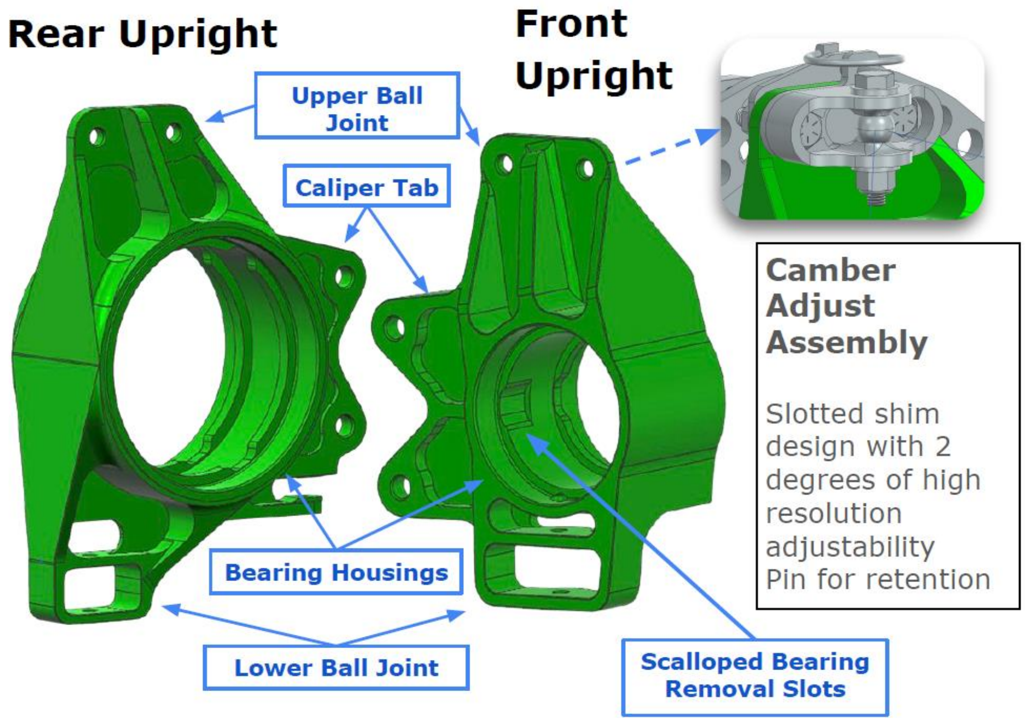
- Explain a year-long “design cycle”
- Talk about some of the fantastic resources at MIT that make it possible!



Let’s follow a part!

- Upright breakdown. How did we get here?
- There’s a lot of complexity – let’s go through it piece by piece





Design Process - Mirrors industry

DRDR
Design Requirements

CoDR
Concept Review

DR1/2/3
Design Review

MaDR
Manufacturing

Peer Review

Analysis

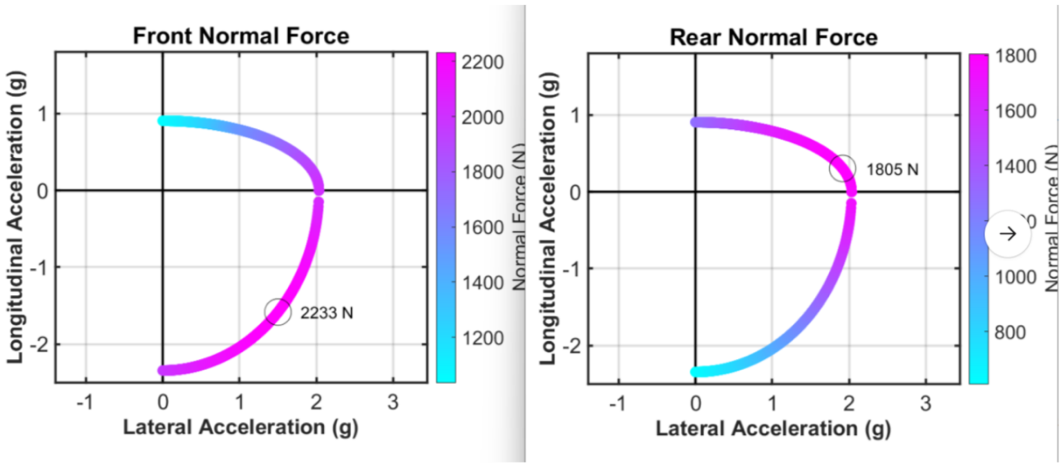
Testing

At all stages!

A lot of work!

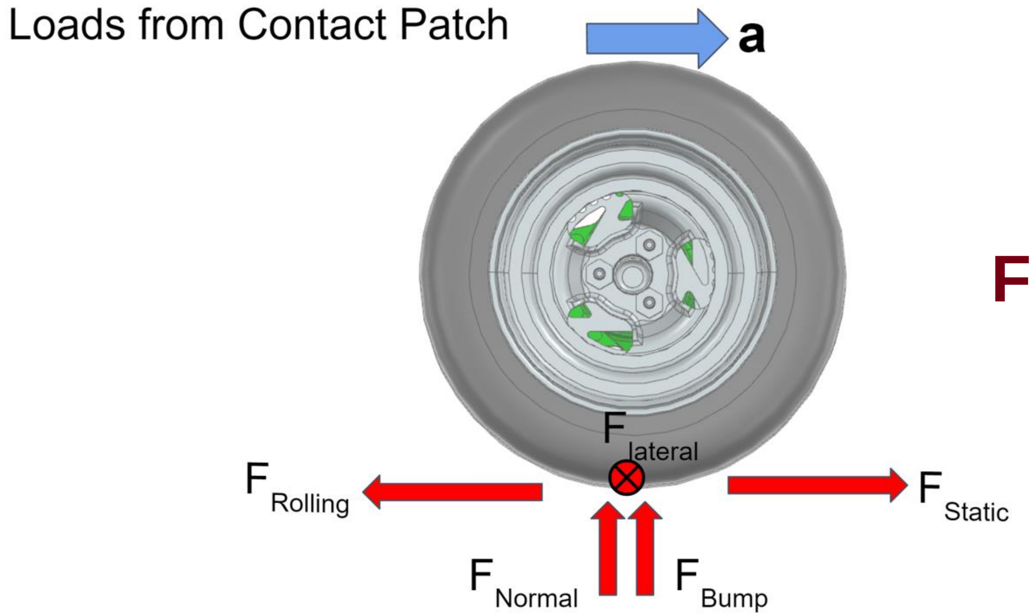
DRDR

- Design Requirements
- Quantify what you don’t know

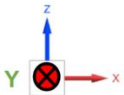


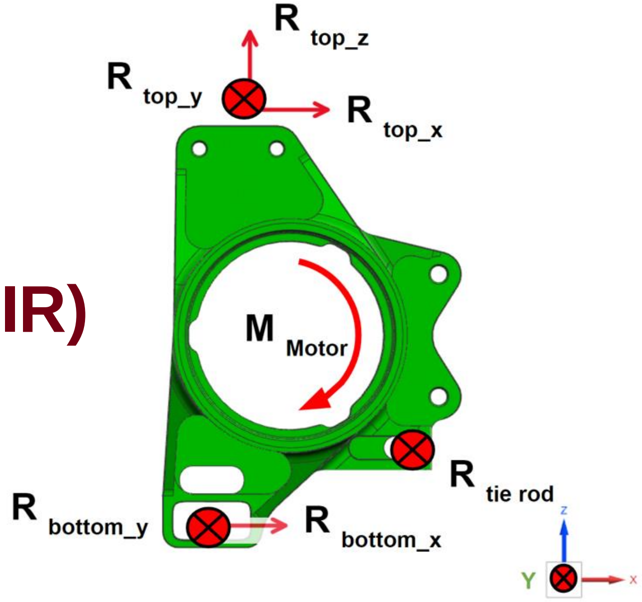
Initial Simulation

(F vs g’s)



FBDs (8.01 GIR)



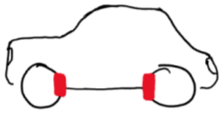
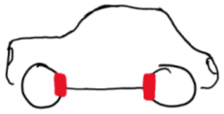
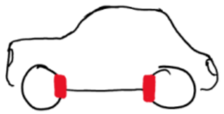
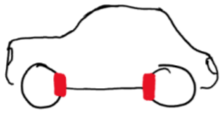


CoDR

- **Concept Review**
- **Evaluate risks and tradeoffs**

Risk Matrix For 3D Printing + Billet:

Risk	Likelihood (1-5)	Severity (1-5)	Risk Magnitude	Mitigation
Weaker/Directional Material used can break	2	5	10	Need to pay attention on orientation of print and sizing of part. (1.5-2 SF)
Post machining process messed up	2	5	10	Need to ensure that it is done properly out of house/insured?
Joint calculations are complex and get messed up/break	4	4	16	Need smart people to make sure that all calcs and FEA are done properly (scrutineered)
Bolt Tear Out of 3D printed material	3	4	12	Need to do calcs and testing validation on instron to ensure OK

Design Parameter	Concept 1	Concept 2	Concept 3	Concept 4
Camber Adjust	Slotted Shims	Slotted Shims	Slotted Shims	Slotted Shims
Brake Caliper Location	Inboard 	Inboard 	Inboard 	Inboard 
Manufacturability	3D Printed	Billet Machined	3d Printed w/ Billet portions	Tab and Slot
Camber Clevis Location	Top	Top	Top	Top

Get some real-life data!

MITMECHE

DR1/2/3

- Hand calculations
- First principles – 2.001. Quick order-of-magnitude estimate

Margins			
Margins	Failure Mode	Component	Feature
3.632072625	Tearout	Front Upright	Toe Tie Rod
8.264145249	Tension	Front Upright	Toe Tie Rod
6.645987924	Bearing	Front Upright	Toe Tie Rod
4.187221939	Tearout	Rear Upright	Toe Tie Rod
9.374443878	Tension	Rear Upright	Toe Tie Rod
7.562352001	Bearing	Rear Upright	Toe Tie Rod
2.22411535	Tearout	Rear Upright	UBJ
4.504587183	Tension	Rear Upright	UBJ
17.87287034	Bearing	Rear Upright	UBJ
1.660969869	Tearout	Rear Upright	Camber bracket upright attachment
3.543119289	Tension	Rear Upright	Camber bracket upright attachment
11.82977726	Bearing	Rear Upright	Camber bracket upright attachment

- Continue refining concept feasibility
- Get rough sizes of parts – "sizing"

Assuming SAE Grade 8

Office Online Frame

Inputs:				
Value Name:	Value:	Units	Value	Units
Tensile Strength:	1034	[Mpa]	1034000000	[Pa]
Shear Strength:	620.4	[Mpa]	620400000	[Pa]
Factor of Safety:	1.5	n/a		

General Car Forces									
	Rear					Front			
Force Name:	Value	Units	Value	Units		Value	Units	Value	Units
Max Lateral(+/-)	3.4	[kN]	3400	[N]		3.3	[kN]	3300	[N]
Max Longitudinal	2	[kN]	2000	[N]		2	[kN]	2000	[N]
??	-1.8	[kN]	-1800	[N]					
Max Normal	2.3	[kN]	2300	[N]		2.3	[kN]	2300	[N]
Max Bump	3	[kN]	3000	[N]		3	[kN]	3000	[N]

Input Forces				
Symbol	Value	Units	Descr.	Source
Fr_T_Brake	425	Nm	Front Brake Moment (M_y+)	Sam
Re_T_Brake	205	Nm	Rear Brake Moment (M_y+)	Sam
T_Tie_Rod	100	Nm	Tie Rod Moment (M_y+)	Suspension
T_UBJ	x	Nm	Upper Ball Joint Moment (M_y+)	Suspension
T_LBJ	x	Nm	Lower Ball Joint Moment (M_y+)	Suspension

7075-T6 Material Inputs						
Symbol	Value	Units	Converted Val.	Units2	Description	Source
T_Yield	58	ksi	399910000	Pa	Tension Yield	MMPDS
S_Yield	36	ksi	248220000	Pa	Shear Yield	MMPDS
Br_Yield (e	114	ksi	786030000	Pa	Bearing Yield	MMPDS
FoS	1.5	n/a	1.50	n/a	Factor of Safety	Powertrain

Derived Forces				
Symbol	Value	Units	Descr.	Source
FF_Caliper	1257.83	N	Force at the Front Brake Caliper	Derived
FR_Caliper	2578.55	N	Force at the Rear Brake Caliper	Derived
F_Tie_Rod	1238.44	N	Force at Tie Rod	Derived
F_UBJ	x	N	Force at Upper Ball Joint	Derived
F_LBJ	x	N	Force at Lower Ball Joint	Derived

Dimensions						
Symbol	Value	Units	Value	Units	Description	Source
Bolt_CR	3.13	in	0.0795	m	Caliper Bolt Circle Radius	CAD
Bolt_OD	0.3125	in	0.00794	m	Caliper Bolt Outer Diameter	CAD
C_Tab_t	0.2	in	0.00508	m	Caliper Tab Thickness	CAD
Tab_OD	0.625	in	0.0159	m	Caliper Tab Outer Diameter	CAD
TR_Dist	3.179	in	0.08075	m	Tie Rod Distance	CAD
TR_Bolt_O	0.1875	in	0.004763	m	Tie Rod Bolt Outer Diameter	CAD
TR_Tab_t	0.1	in	0.00254	m	Tie Rod Tab Thickness	CAD
TR_Tab_O	0.375	in	0.009525	m	Tie Rod Outer Diameter	CAD

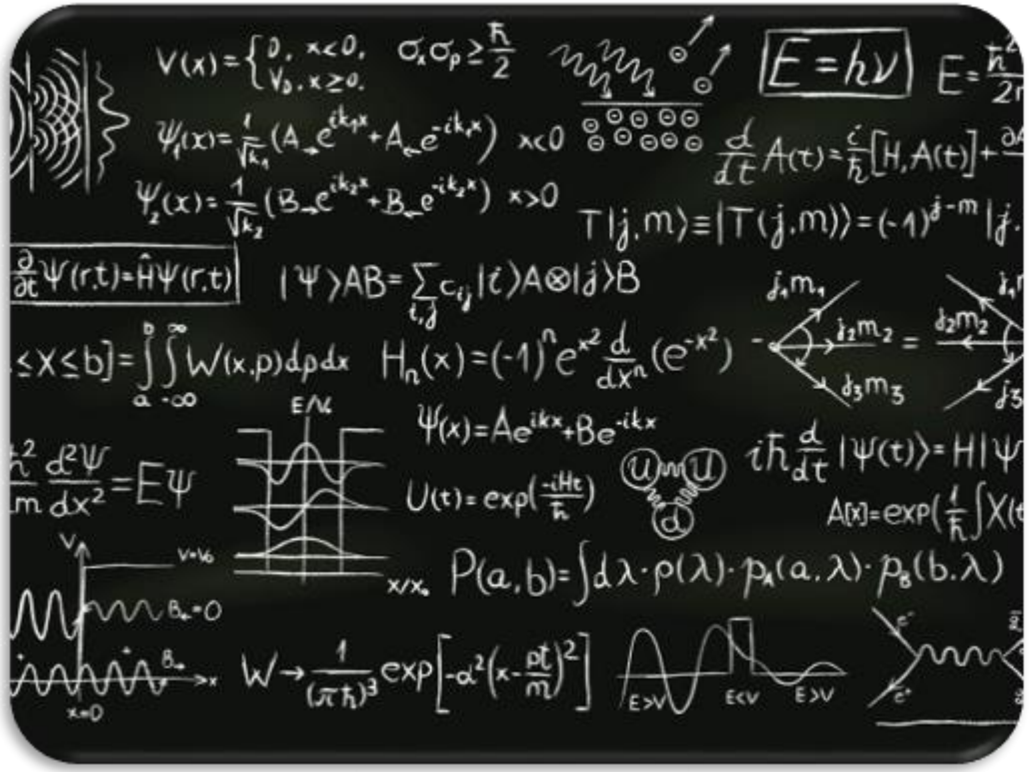
Table 3.7.9.0(b₂). Design Mechanical and Physical Properties of 7075 Aluminum Alloy Plate

Specification	AMS 4045													
Form	Plate													
Temper	T651													
Thickness, in.	0.250-0.499		0.500-1.000		1.001-2.000		2.001-2.500		2.501-3.000		3.001-3.500		3.501-4.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical Properties:														
F_{tu}, ksi: L	77	79	77	79	76	78	75	77	71	73	70	72	66	68
LT	78	80	78	80	77	79	76	78	72	74	71	73	67	69
ST	—	—	—	—	—	—	70	71	66	68	65	67	61	63
F_{ty}, ksi: L	69	71	70	72	69	71	66	68	63	65	60	62	56	58
LT	67	69	68	70	67	69	64	66	61	63	58	60	54	56
ST	—	—	—	—	—	—	59	61	56	58	54	55	50	52
F_{cy}, ksi: L	67	69	68	70	66	68	62	64	58	60	55	57	51	52
LT	71	73	72	74	71	73	68	70	65	67	61	64	57	59
ST	—	—	—	—	—	—	67	70	64	66	61	63	57	59
F_{su}, ksi: L & LT	43	44	44	45	44	45	44	45	42	43	42	43	39	41
F_{bru}, ksi: L & LT (e/D = 1.5)	117	120	117	120	116	119	114	117	108	111	107	110	101	104
L & LT (e/D = 2.0)	145	148	145	148	143	147	141	145	134	137	132	135	124	128
F_{bry}, ksi: L & LT (e/D = 1.5)	97	100	100	103	100	103	98	101	94	97	89	93	84	87
L & LT (e/D = 2.0)	114	118	117	120	117	120	113	117	109	112	104	108	98	103
e, percent (S-Basis): LT	9	—	7	—	6	—	5	—	5	—	5	—	3	—
E, 10^3 ksi	10.3													
E_c, 10^3 ksi	10.6													
G, 10^3 ksi	3.9													
μ	0.33													
Physical Properties: ω, lb/in.³	—													
C, K, and α	—													

FEM – Finite Element Modelling

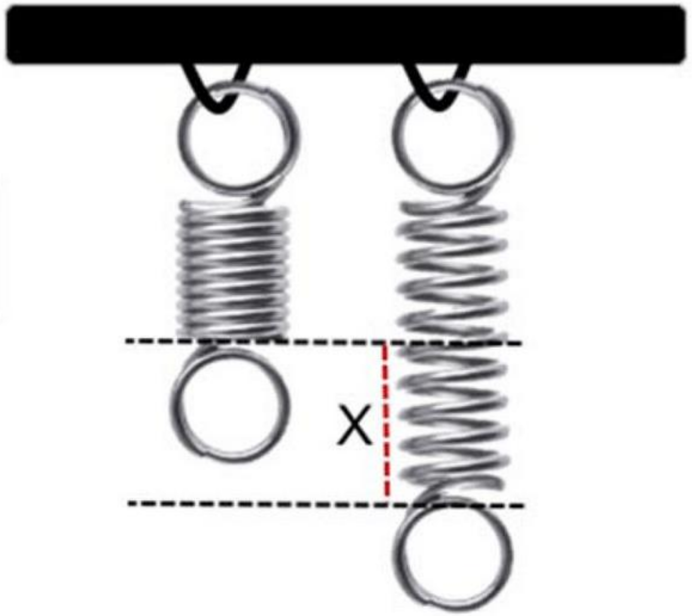
Reality is complicated… down to subatomic interactions

Everything is a spring! Simpler = better and less likely to go wrong



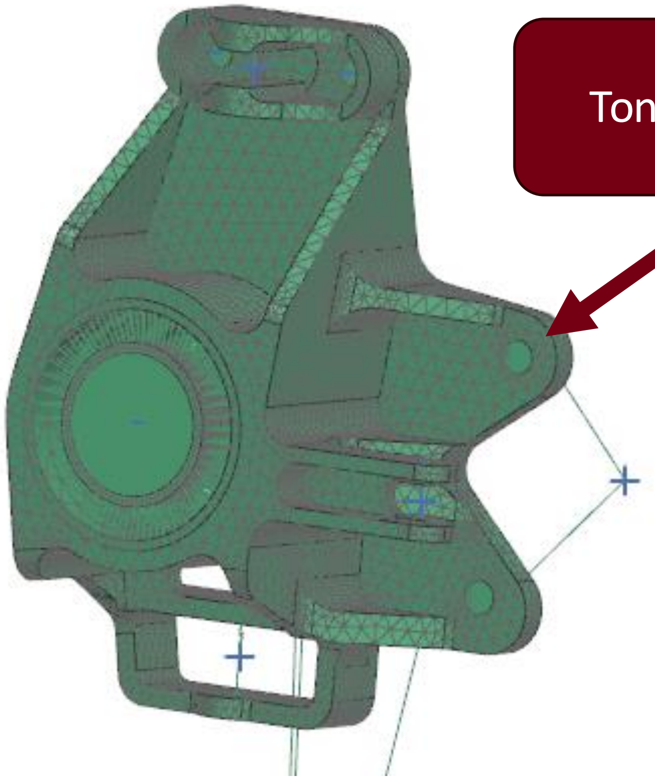
VS

$F=kX$

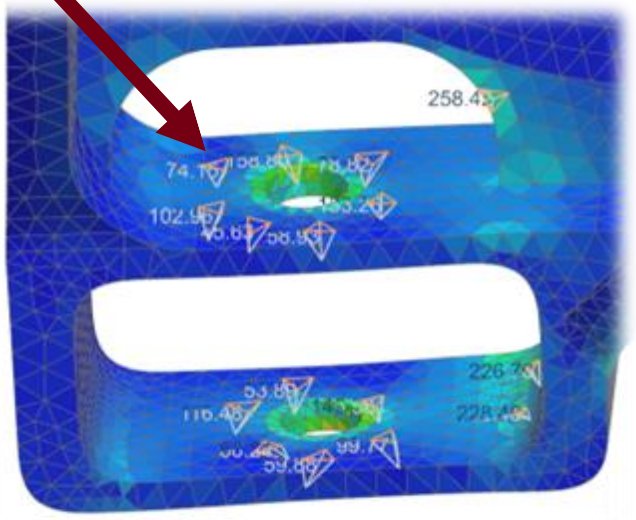


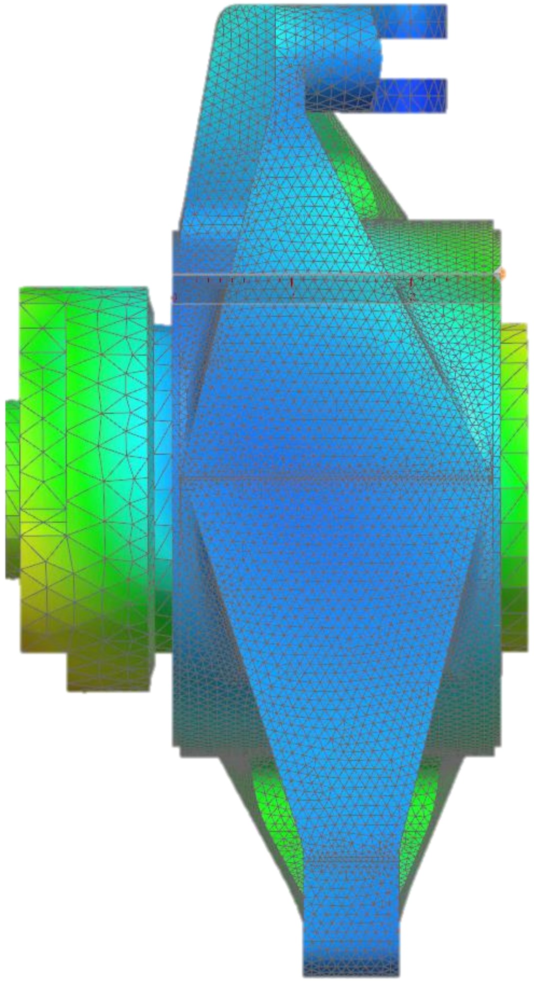
FEM – Finite Element Modelling

- What if we used *millions of springs?*
- Computers can do math – fast!
- “All models are wrong, some are useful” – George Box



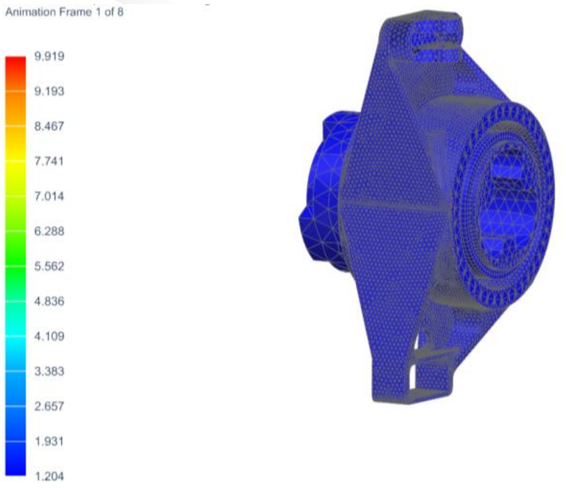
Tons of tiny springs



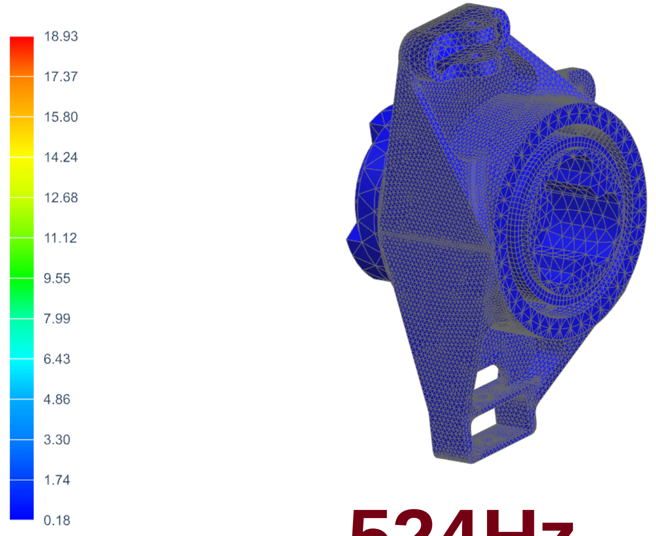


Simulated Displacement w/BCs

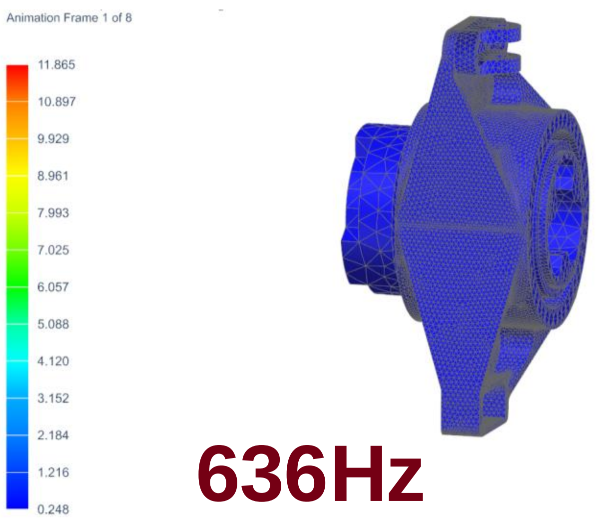
Simulation – Modal Analysis



250Hz



524Hz



636Hz

905Hz

Resonant failure **modes**

Treat upright like a tuning fork – what frequencies would it vibrate at?

First-order specific (mass-weighted) stiffness

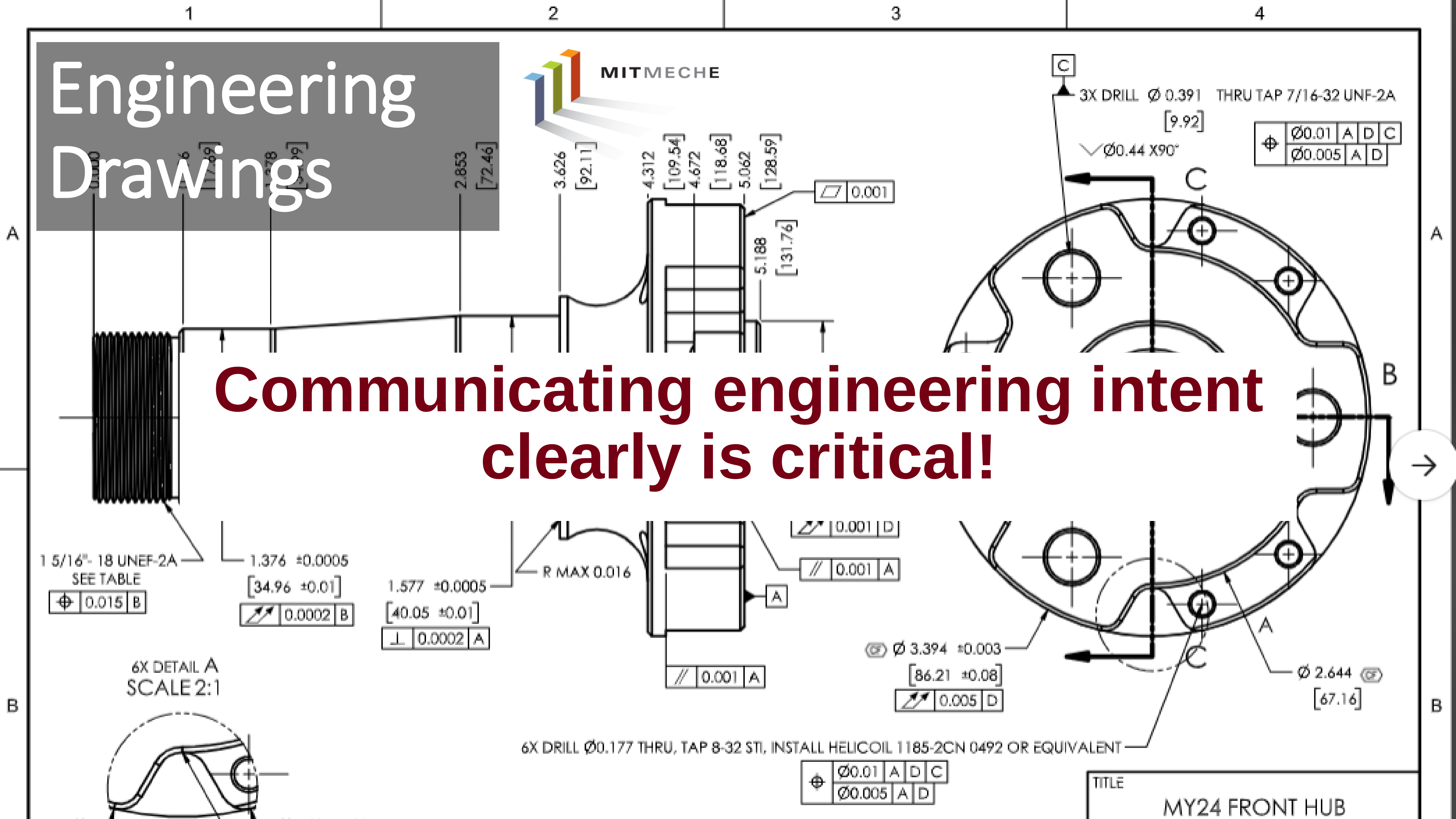
Fundamental Frequency

$$F_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Stiffness

Mass

Engineering Drawings

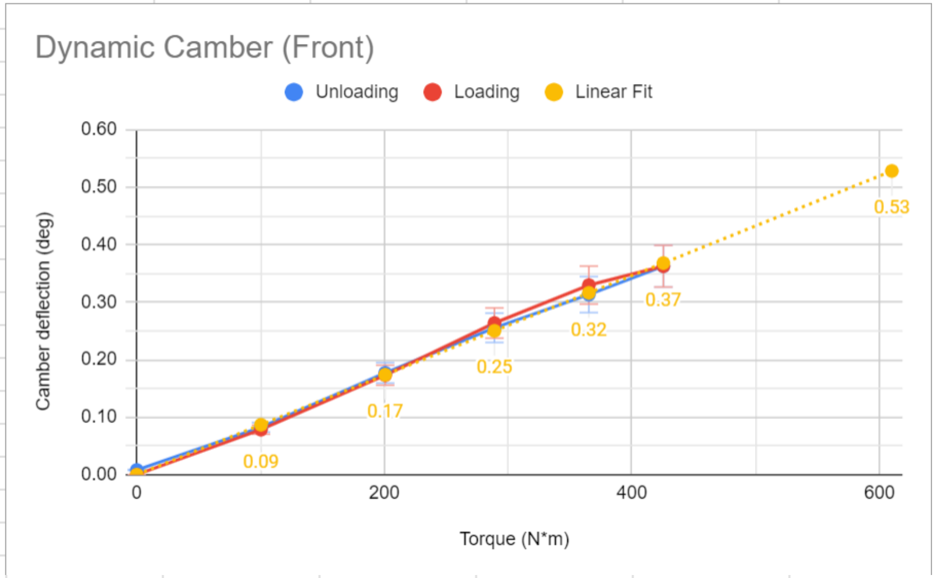


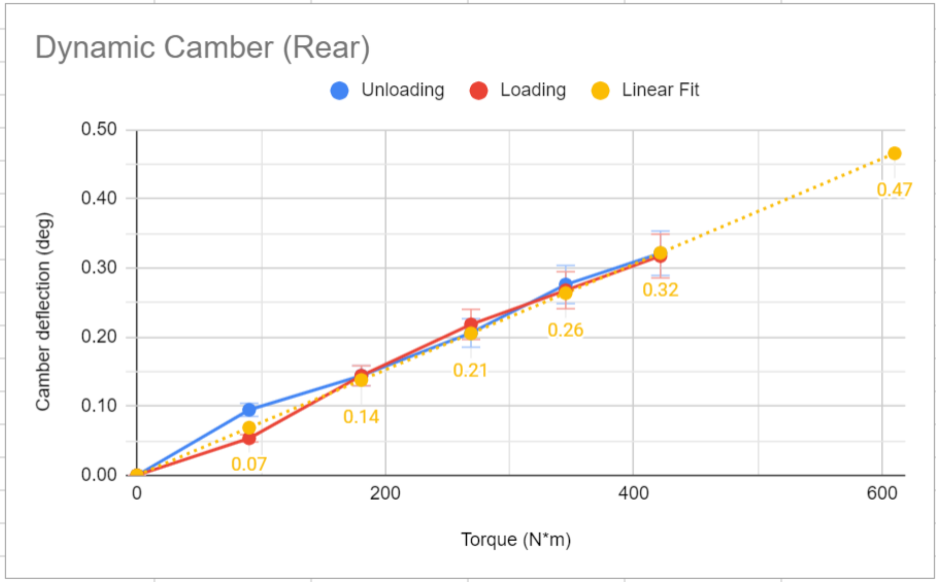
Communicating engineering intent clearly is critical!

Manufacturing

- Many parts made by students!
- In N51 – one of many makerspaces on campus!

Real World Validation





"Nature cannot be fooled"

- Richard Feynman (MIT B.Sc.)

Shakedown

Put the car through its paces!

Build capability slowly, take caution, and check all your safety systems first

(Testing procedure needed w/measurable variables – 2.671)

Shakedown… oops

Things will break! – "Integration Hell"

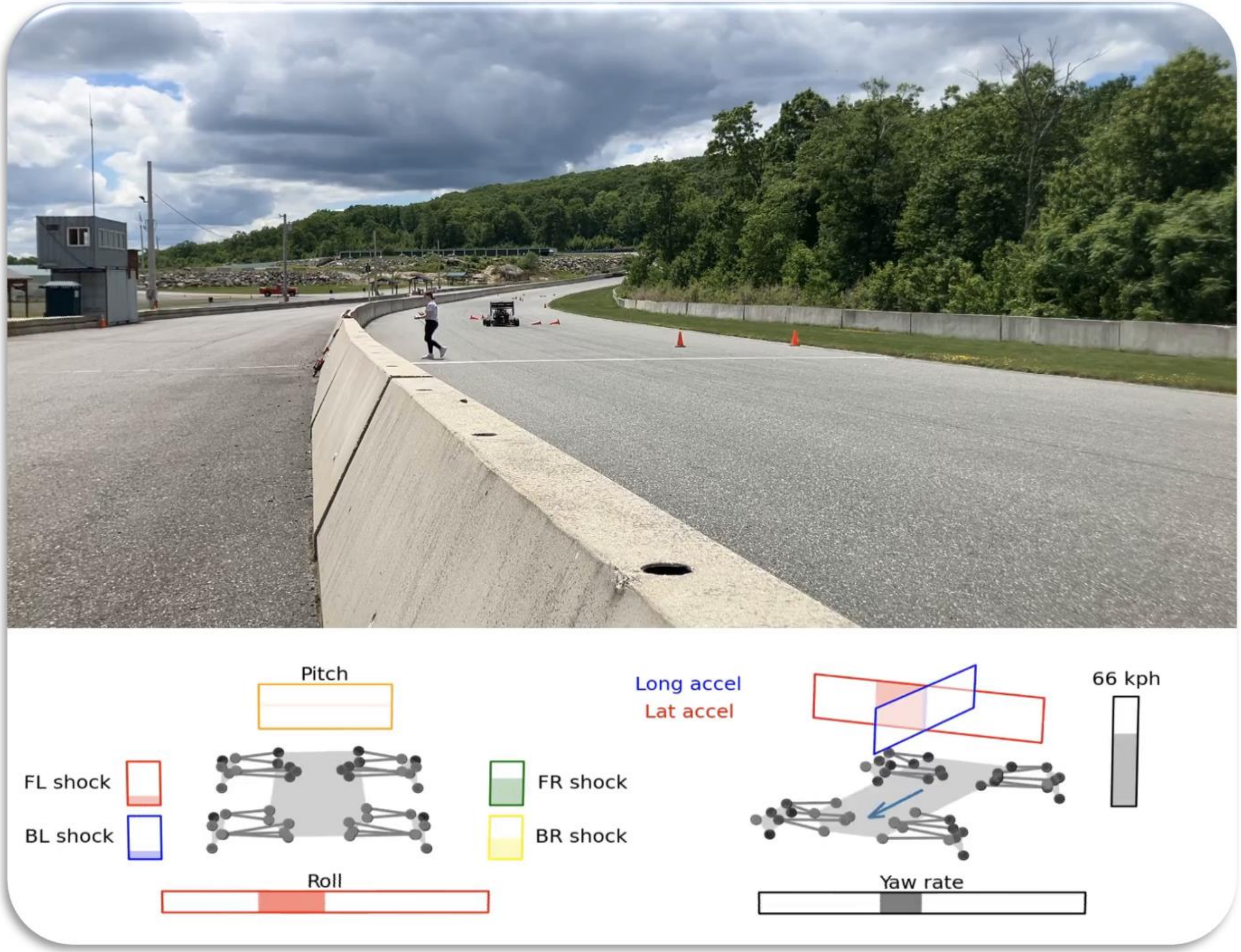
Fire extinguisher ☺

Collect & Use Data!

System as a whole needs to be tuned.

Full vehicle dynamics model

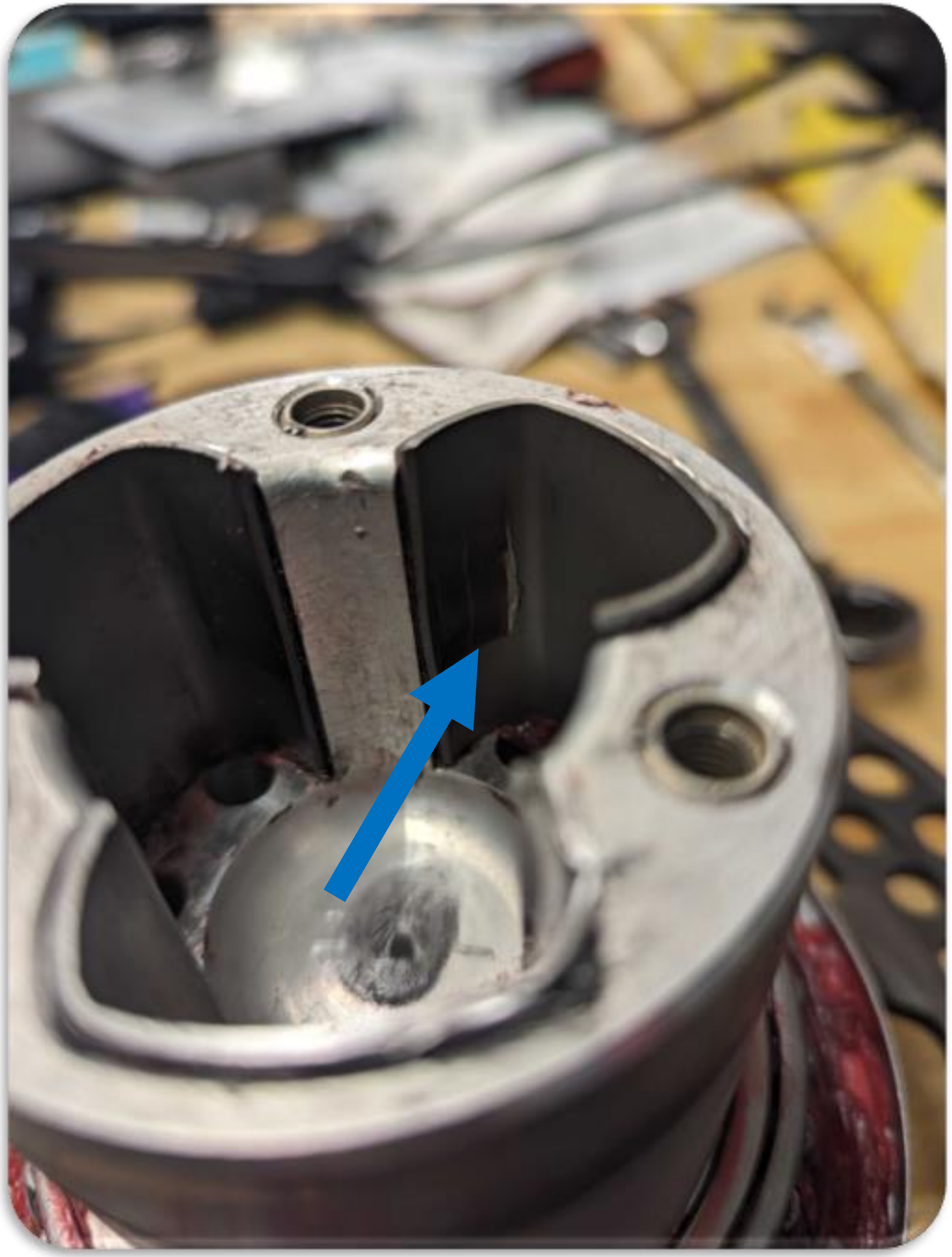
This is why teams win 🏆



Spot it?

No matter how much validation you do…

Stress exceeds allowable due to Hertzian contact stress, fatigue – 300km

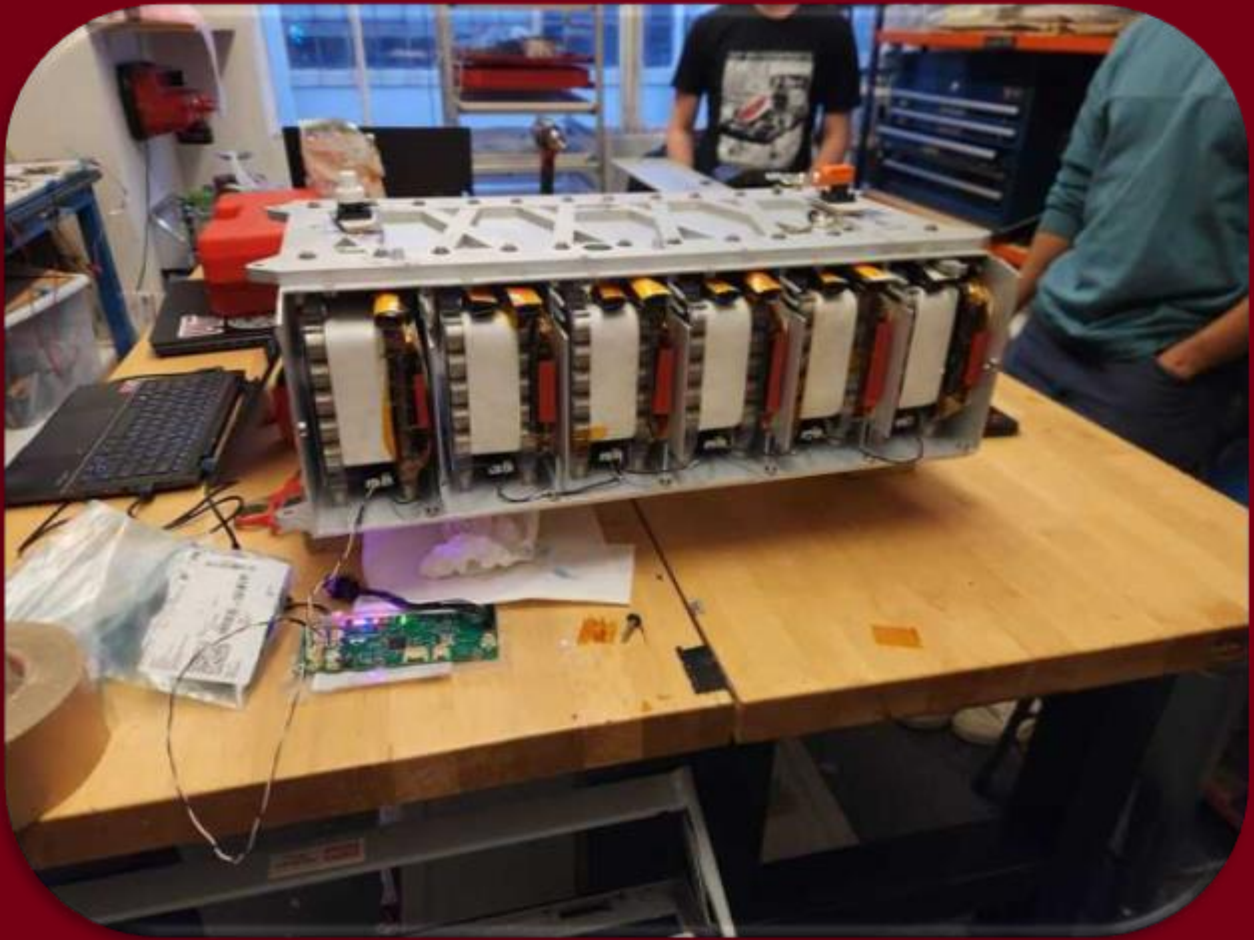


System Highlight - Frame

Welded fully in-house in ~35 days (over IAP)

System Highlight - Battery

Liquid-cooled, student designed and built



7.6kWh, 400V, 96s5p, P45B cells

System Highlight – Attenuator

Absorbs impact in event of a head-on collision. Similar to Falcon 9 landing legs

Thanks!!

Henry, Megan, Rakib, Faris, Abe, Sehar, Monica (C/O ‘25)

Patrick McAtamney (N51 Shop Manager)

Peggy Eysenbach (Shared cookie recipe!)

All Edgerton Center staff!!

MITMECHE

“The Senior Hug”

Thanks!!

All my teammates ☺

Post-Roman

(at 4am)

It's been an honor

Thanks!!

MITMECHE

palmer racing

MIT Edgerton Center

Accel

ALTIUM DESIGNER

gecko robotics

BATTLE MOTORS

MIT EECS

gm

SIEMENS

formlabs

MITMECHE

MIT AEROASTRO

HENRY FORD

THE CHAN FAMILY

NSE Nuclear Science and Engineering

BLUE ORIGIN

Bolt Depot fastener shopping made easy

GENE HAAS FOUNDATION

Red Bull

MITei MIT Energy Initiative

SBG SYSTEMS

MOZA RACING

CAMMUS

ALEX SOO

SKF

RALPH & LAURIE INGLESE