PORTFOLIO · SELECTED WORK

Harjaap Khela

MECHANICAL PRODUCT DESIGN

Mechanical and Materials Engineering at Western University. Product design across consumer electronics style hardware, vehicle dynamics and mechanism design, from concept through tooling and validation to production release.

SOFTWARE

CATIA V6 / 3DEXPERIENCE · SolidWorks, CSWA certified · Onshape · Ansys, SimSolid

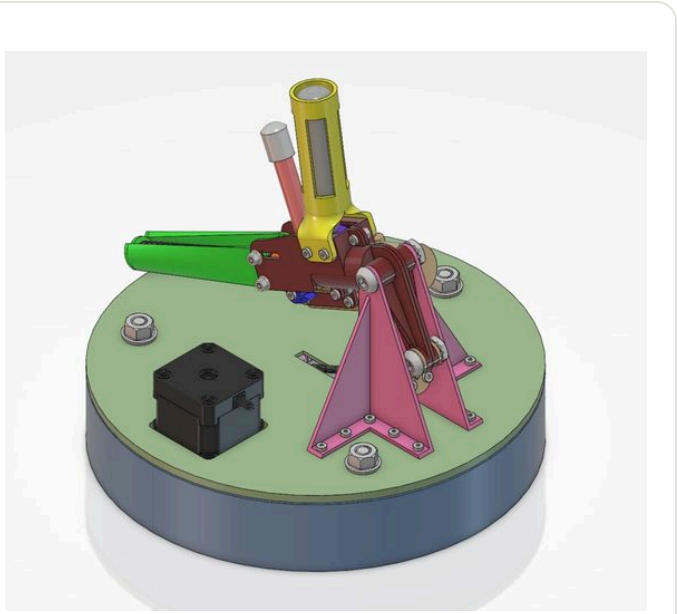
CONTACT

harjaapkhela@gmail.com · linkedin.com/in/harjaap-singh-khela

01 **Ford Motor Company, Design Concepts Engineering**
Product Design Engineer · 2025

02 **Western Formula Racing, Suspension and Steering**
Mechanical Design Engineer · 2023 to now

03 **Computer Vision Tracking Turret**
Personal project · 2026 to now







Profile

What I do and what I work in

I design parts and mechanisms that have to be made, assembled and validated, not just modelled. Most of my work sits between industrial design, electrical engineering and the supplier, where the job is to hold the requirement while the hardware changes around it.

CAPABILITIES

- Mechanical architecture and packaging
- Enclosure design inside ID-defined A-surfaces
- Design for injection moulding, MIM and CNC
- Tolerance analysis, worst case and RSS
- FEA driven mass reduction
- Test method and fixture design
- Production definition, GD&T, FAI and SPC

WORKED IN

- Consumer electronics style hardware
- Automotive and EV programmes
- Formula SAE vehicle dynamics
- Mechanism and gear train design
- Prototyping and 3D printing

EDUCATION

BESc Mechanical and Materials Engineering, Western University · expected May 2028

SOFTWARE

CATIA V6 / 3DEXPERIENCE · SolidWorks, CSWA certified · Onshape · Ansys and SimSolid · Enovia PLM

FORD MOTOR COMPANY · ADVANCED EV · CALIFORNIA, USA

Design Concepts Engineering

Product Design Engineer, Advanced EV

June to December 2025 · 6 months

Lead mechanical engineer on hardware built to validate a consumer electronics style product line. Developed the product using ID-defined A-surfaces, cross-collaborating with electrical engineering, suppliers and manufacturing. Parts were validated for power draw, shock and vibration, crash and thermal.

> The products are not public, so these slides cover the engineering work rather than the product. No product geometry, imagery, dimensions, tolerances, supplier names or quantities are shown.

Designed within ID-defined A-surfaces

Packaging, structure, assembly method, materials and CMF, manufacturing method, electrical integration and the validation plan.

Defined the envelope with electrical engineering

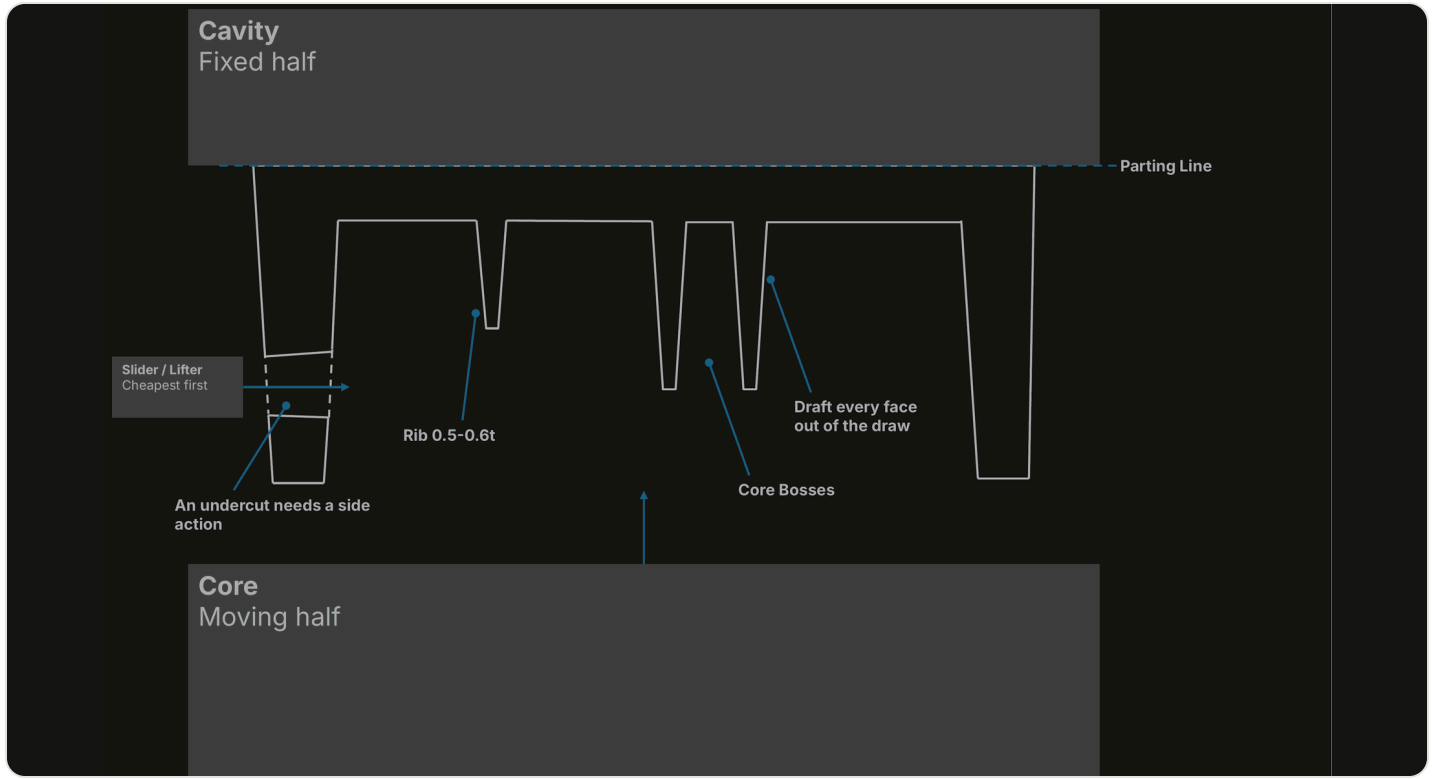
My MCOs, interfaces and packaging envelopes drove PCB layout, component mounting and connector architecture.

Owned production definition

GD&T drawings, tolerance analysis, datum strategy, FAI and SPC requirements and MSOP, then dispositioned supplier FAI findings.



SCOPE	TEAM	PROGRAMME
Concept to release	**Design Concepts**	**Universal EV**
enclosure, architecture, tooling, validation	new technology, closest thing to R&D at Ford	launching with the Ford Fathom in 2027



Moulded part and tool. Parting line, an undercut needing a side action, a rib, a cored boss and drafted faces.

Tooling lead time could not meet the first build dates, so one architecture was split into three build configurations with interfaces held common across all three.

CONFIG	PROCESS	PURPOSE
A	IM + MIM	Production intent, DVT and PVT
B	CNC machined	Representative hardware before tooling, EVT
C	CNC machined	Crash and impact articles

01

Injection moulding and CNC machining

Gate location written as a requirement on the mould

PC/ABS snaps were fracturing at assembly depending on how the tool filled. Flow direction and weld line position determine whether a snap deflects or fractures, so gate position stopped being a moulder preference.

KEY POINTS

- Specified where the gate feeds relative to the snap features and reviewed it against the tooling drawings.
- Parting line, side actions, ribs, cored bosses and draft reviewed on every face.
- Same parts redesigned for machining to get representative hardware before tooling.

PROCESSES

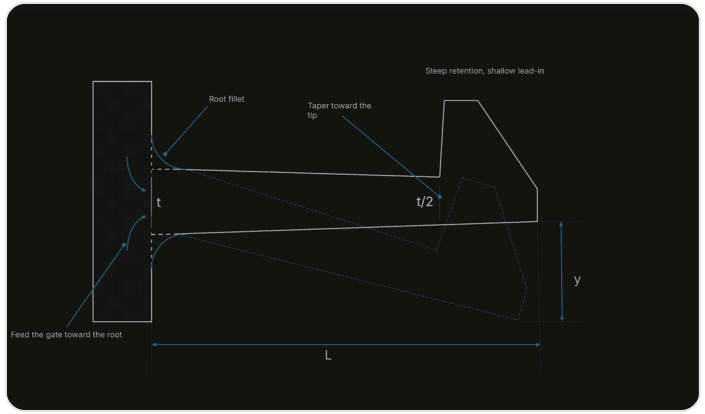
Injection moulding, MIM, CNC

MATERIAL

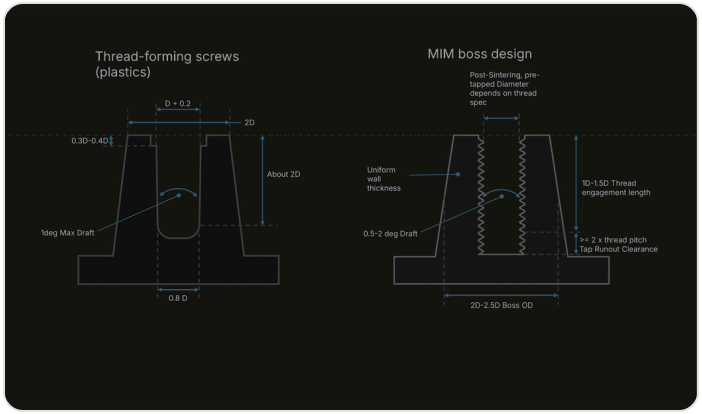
PC/ABS and sintered MIM

OUTCOME

Snap fracture at assembly resolved



Snap arm. Root fillet, taper toward the tip, steep retention face with a shallow lead-in.



Boss design. Thread forming into PC/ABS, and a pre-tapped sintered MIM boss.

Snap arm sizing, on invented numbers

PC/ABS, E = 2300 MPa. Arm L 10 × b 5 × t 1.5 mm, undercut y = 0.80 mm, lead-in 30°, μ = 0.3.

Strain at assembly	$\varepsilon = 1.5 \cdot t \cdot y / L^2$ **1.80 %, allowable 2 %**
Second moment	$I = b \cdot t^3 / 12$ **1.406 mm⁴**
Deflection force	$F = 3EIy / L^3$ **7.8 N**
Insertion force	$W = F(\mu + \tan\alpha) / (1 - \mu \cdot \tan\alpha)$ **8.2 N per snap**
Four snaps	4W **33 N to assemble**

Strain scales with t/L^2 and force with t^3/L^3, so halving the thickness cuts strain by two and force by eight. That makes the snap safe but loose. **Lengthening the arm is usually the better change.**

M2 screw into a moulded cover and a sintered boss

M2, stress area 2.07 mm², screw 700 MPa. MIM shear 312 MPa, PC/ABS shear 35 MPa. Head Ø4.0 on a Ø2.4 hole, PC/ABS 15 MPa bearing. Nut factor K = 0.20 dry, d = 2 mm.

Screw capacity	$A_t \cdot \sigma = 2.07 \times 700$ **1449 N**
Engagement, sintered	$L_e = 1449 / (312 \times 0.5\pi D)$ **0.74 D, spec 1.5 D**
Engagement, moulded	$L_e = 150 / (35 \times 0.5\pi D) \times 3$ **2.05 D**
Head bearing limit	$\pi/4\ (4.0^2 - 2.4^2) \times 15$ MPa **121 N**
Preload from torque	$F = T / (K \cdot d)$ at the handbook 0.25 N·m **625 N, five times the head limit**
Torque to suit the head	$T = K \cdot F \cdot d = 0.20 \times 100 \times 0.002$ **0.040 N·m for 100 N**

The limit is the plastic under the head, not the screw. Options are a flange head, a compression limiter, or a torque spec written from the bearing limit rather than the fastener table.

02

Sizing joints from the material that fails first

Snaps from strain at assembly, screws from the polymer under the head

Handbook torque would have crushed the polymer under the screw head. Thread engagement was calculated from shear area, separately for the sintered and the moulded boss, and the torque spec was written from the head bearing limit rather than the fastener table.

KEY POINTS

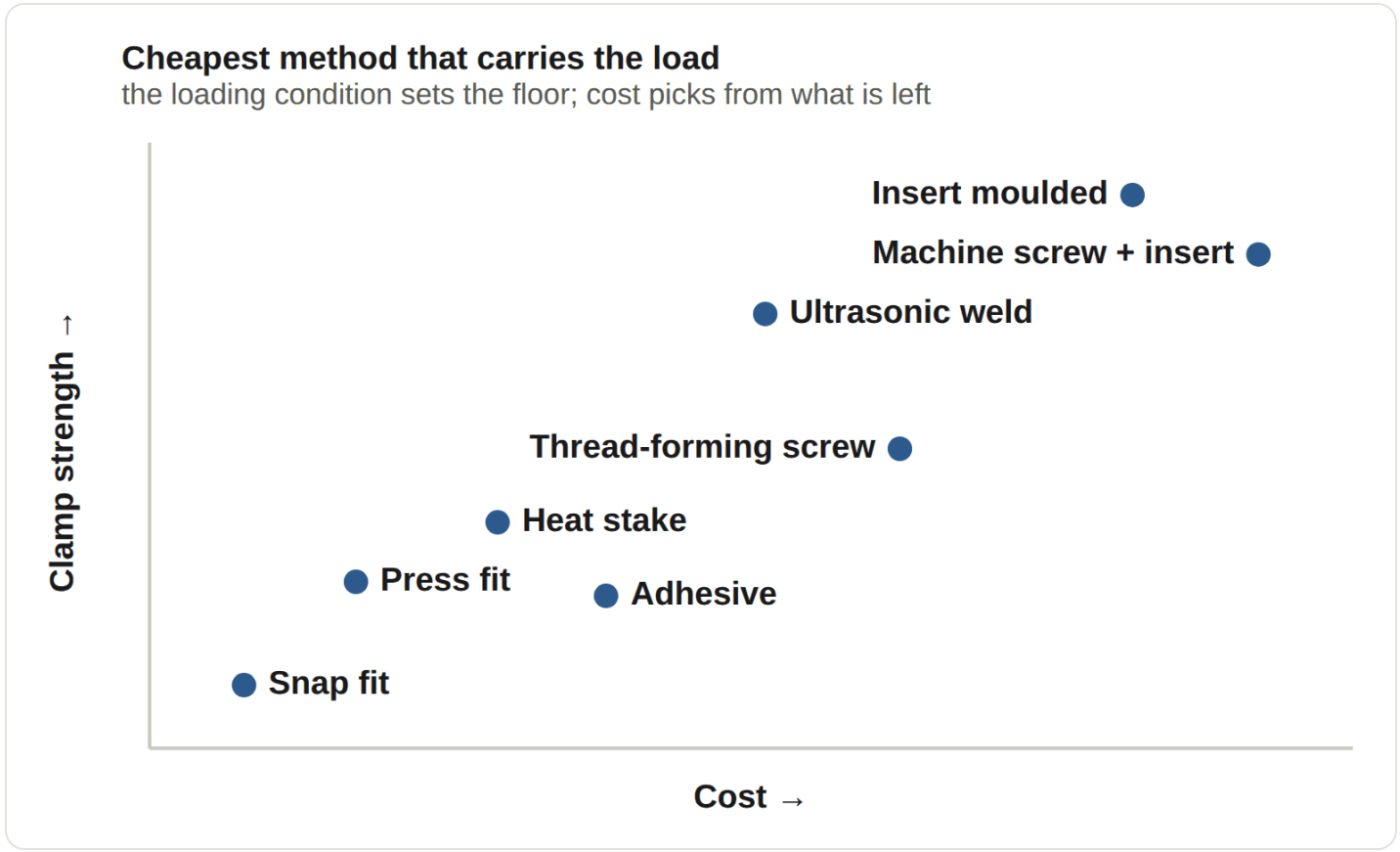
- Strain scales with t/L^2 and insertion force with t^3/L^3, so thinning a snap arm makes it safe and loose at the same time. Arm length is the better variable.
- The gate is fed toward the root so the weld line does not land on the hinge.
- For the same clamp load, a thread forming screw in PC/ABS needs roughly three times the engagement of a machine screw in MIM.

ALLOWABLE

2% strain in PC/ABS

GOVERNING LIMIT

Polymer bearing under the head



03

Choosing the joining method

The loading condition sets the floor, cost picks from what is left

Once a joint carries the load, the method is selected on cost. Screws were used on this joint because it goes into a MIM housing and the same joint locates and clamps a PCB.

KEY POINTS

- **Insert moulding** gives the highest pull out and torque out and the lowest serviceability. The inserts I worked on were retained by undercuts and locking geometry rather than threads.
- **Two shot moulding** builds the bond and interlock into the geometry, removing an assembly step and a tolerance loop.
- **Snaps and heat stakes** sit at the cheap end and carry the least, so they go where the joint only has to hold position.

CONSIDERED

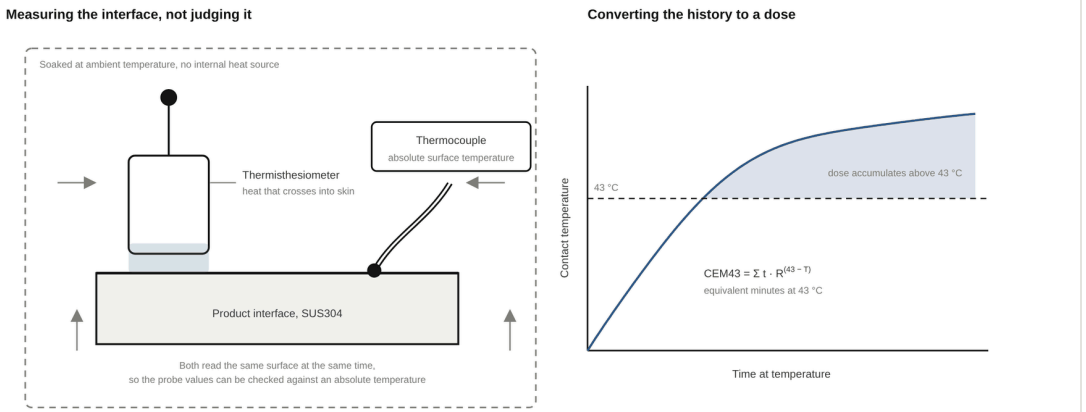
Snap, press, heat stake, adhesive, ultrasonic weld, screw, insert

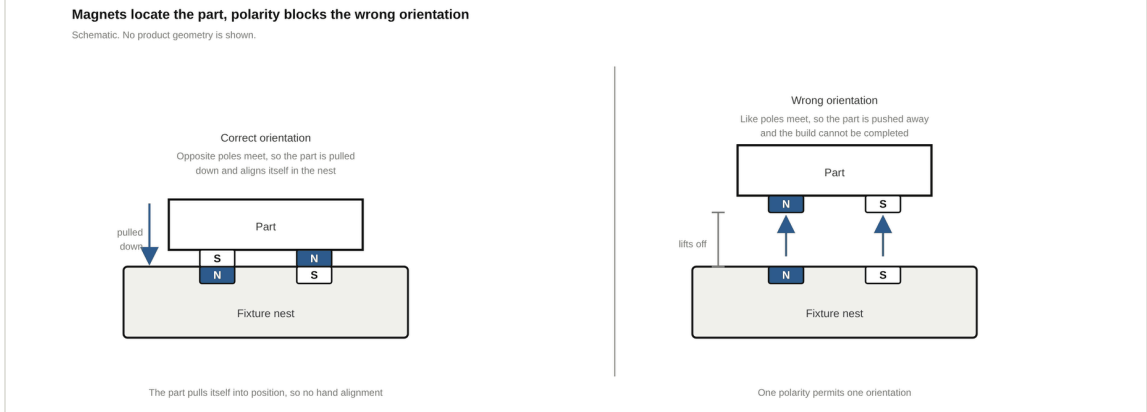
SELECTED

Screw into MIM, locating and clamping the PCB

Touch temperature and assembly fixtures

One solved by measurement, one by magnets and geometry





Touch temperature safety

Industrial Design, CMF and thermal safety all had a claim on the same surface, and "feels too hot" is not a requirement, so I measured it.

Interfaces were soaked at ambient temperature, with no internal heat source, and heat transfer measured with a thermisthesiometer, a skin analogue probe. A thermocouple read absolute surface temperature in parallel, so the probe values could be checked against it. The result was converted with the CEM43 thermal dose equation into equivalent minutes at 43 °C.

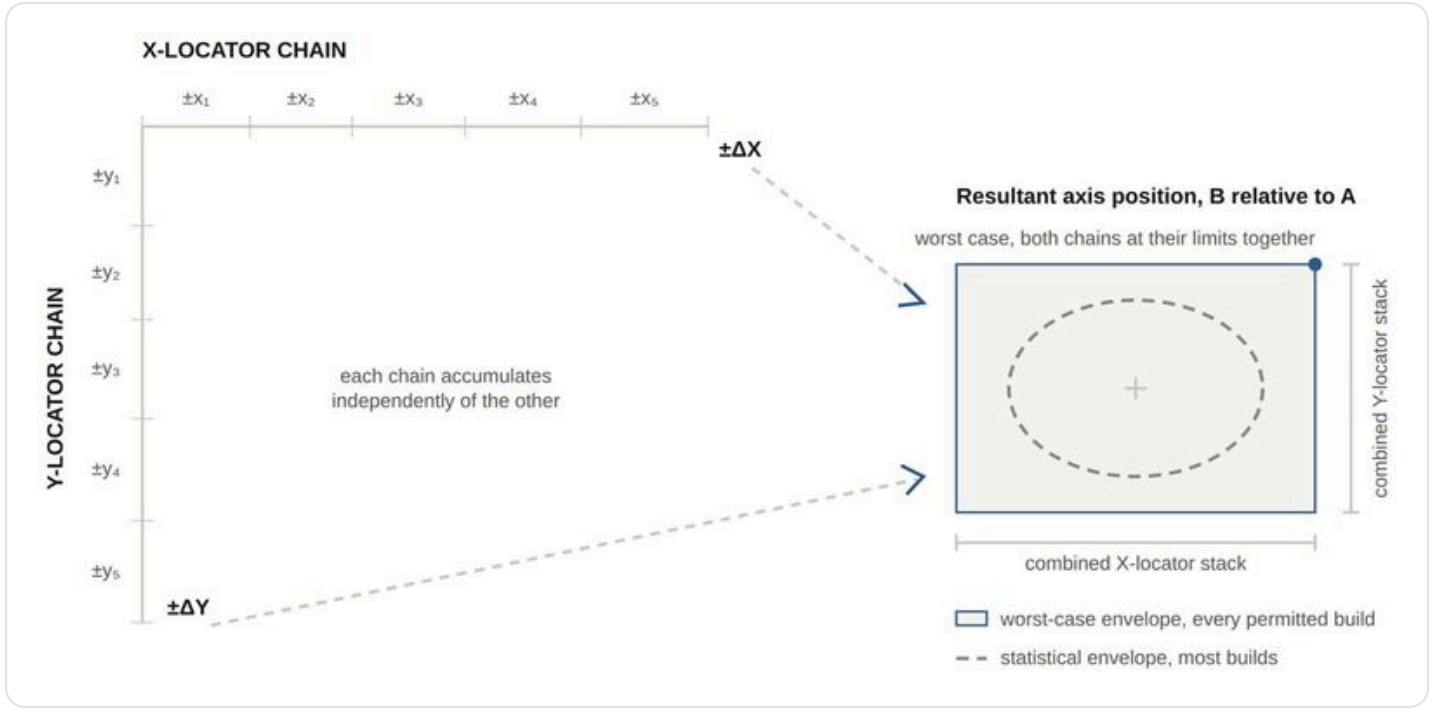
The measurement validated the SUS304 design. Two other candidates performed better thermally, but SUS304 met the requirement, so the interface stayed as ID and CMF specified it.

Assembly fixtures

A supplier called a no-build on a released component weeks before an EVT build, with no working alternative, so the fix had to come from the parts themselves.

I used magnets to locate and hold the assembly, so the parts pull themselves into position instead of being aligned by hand, and the polarity only permits the correct orientation. Part geometry carries the clamping.

Outcome. Unblocked a critical EVT build, enabled blind assembly where the operator cannot see the mating features, and was adopted as the production process and SOP. Developed on site at an overseas vendor.



Worst case covers the full rectangle, corners included. A statistical method treats those corners as unlikely.

05

Tolerance analysis

Worst case and RSS, fixed by datum strategy and part count

Two moving components were located independently, one off an X-locator and one off a Y-locator, so a user visible alignment depended on both chains at once and sat outside spec.

KEY POINTS

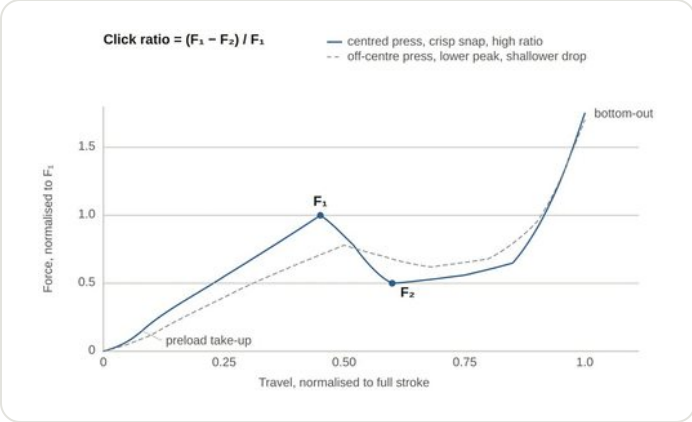
- Analysed worst case rather than RSS, because the interface had to hold on every permitted build.
- Re-datumed features onto common references, removed parts to take links out of each chain, and re-routed dimensions so tolerances no longer stacked through intermediate features.
- Industrial Design reviewed the revised design and accepted it.

METHOD

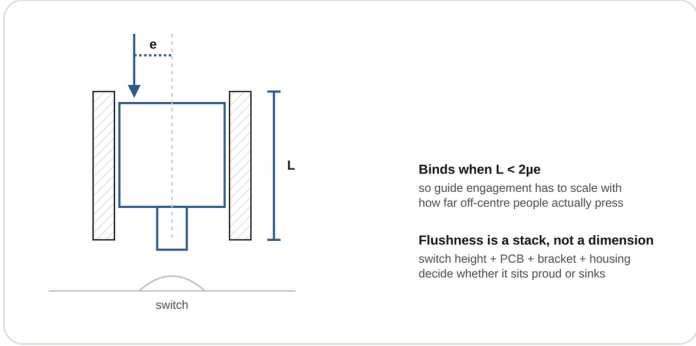
Worst case and RSS, 1D and 2D

RESULT

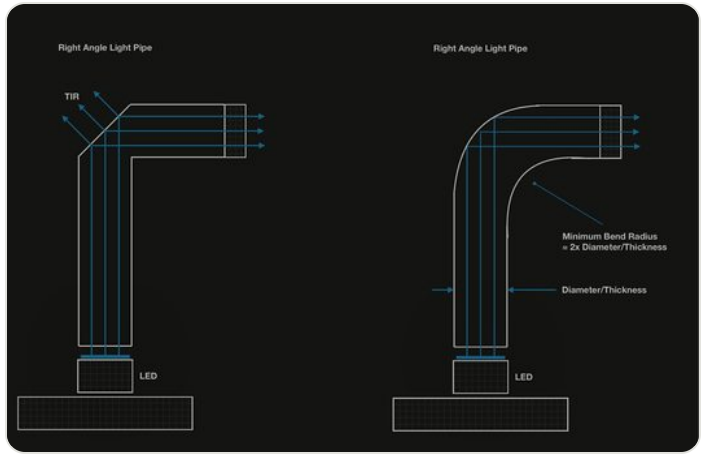
Alignment closed inside spec



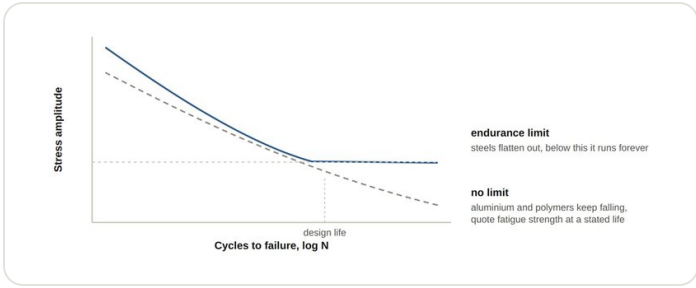
Click ratio. High reads as crisp, low as mushy.



Guide engagement has to scale with off centre press.



Light pipe in section.



Ferrous curves flatten to an endurance limit.

06

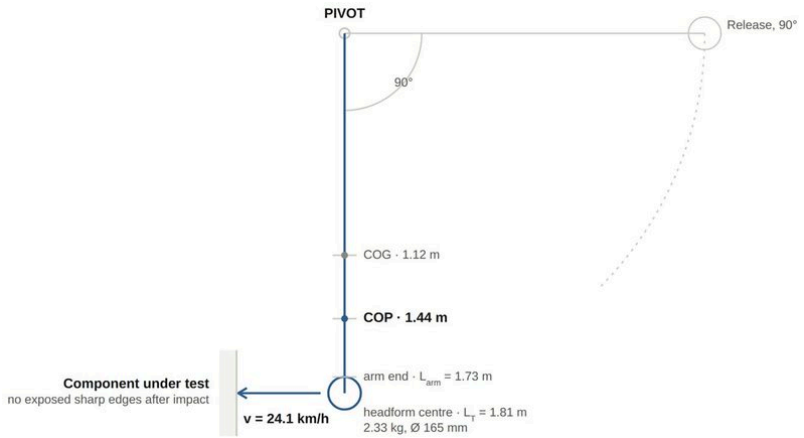
Click feel measurement

Turning tactile feel into numbers a drawing can specify

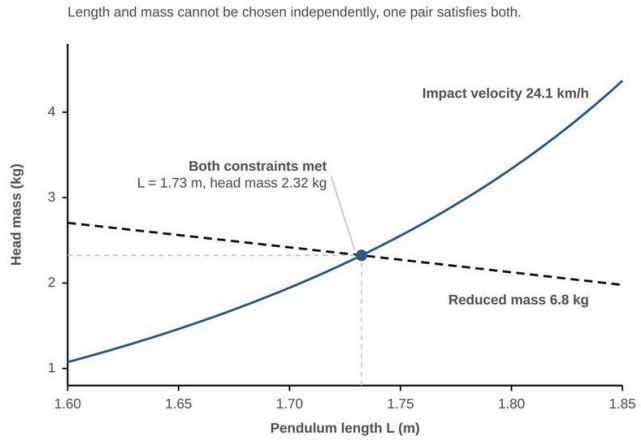
A tactile switch rises to a peak force F_1, snaps through, then drops to F_2 before bottoming out. The size of that drop relative to F_1 is the click ratio.

KEY POINTS

- **Preload.** The tolerance stack between press surface and switch sets how much force is already on the dome. Too much and F_1 arrives early with a shallow snap, too little and there is lost motion.
- **Press location.** Users press off centre, so guide scheme, surface stiffness, switch position and allowable tilt matter more than the switch itself.
- **Test fixtures.** Force on an Instron and torque on a Meca500 six axis arm, with fixtures I designed to locate the part rigidly and keep the load normal.
- **Outcome.** Raising preload removed the lost motion before the dome carries load, which was the source of the mushy feel.
- **Light pipes and fatigue.** Exit face brightness is set by the LED coupling gap, which makes it a tolerance problem. The plastic sees the full rated cycle count of the switch.



Apparatus to scale along the arm, measured from the pivot.



One arm length and headform mass satisfies both constraints.

07

Head impact pendulum

An in-house rig that screens designs before official testing

ECE R21 Annex IV fixes impact speed and reduced mass but not arm length or headform mass, and those two are coupled, so the apparatus had to be solved for rather than selected.

KEY POINTS

- Validation engineering confirmed the rig and the procedure against the official test.
- **A candidate failed in house and drove design changes.** We added a controlled failure point so the part gives way in a defined way rather than leaving exposed edges, and it passed on the pendulum after the change.
- Official ECE R21 testing has not been run.

STANDARD

ECE R21 Annex IV

SOLVED

Arm 1.73 m, headform 2.33 kg

Solving the pendulum for arm length and headform mass

Arm treated as a uniform rod, headform as a point mass at L_T. Released from horizontal through 90°.

Energy at release	$m \cdot g \cdot \ell_{cm} = \frac{1}{2} \cdot I \cdot \omega^2$	**$\omega = \sqrt{(2g / a)}$**
Centre of percussion	$a = I / (m \cdot \ell_{cm})$	**sets where the impact lands**
Impact speed	$v = L_T \cdot \omega$, so $a = 2g \cdot L_T^2 / v^2$	**$a = 0.438 \cdot L_T^2$ at 24.1 km/h**
Reduced mass	$m_r = m \cdot \ell_{cm} / a$	**must equal 6.8 kg**
Solved together	quadratic in m_h	**arm 1.73 m, headform 2.33 kg**

WESTERN FORMULA RACING · FSAE · ONTARIO, CANADA

Suspension and Steering

Mechanical Design Engineer, Suspension and Steering

September 2023 to present

Suspension and steering on Western's Formula SAE car, which runs a decoupled suspension. Work covers geometry, spring selection, FEA on the front damper cradle, and the steering system.



Geometry and spring selection

Pacejka tire models from the FSAE Tire Test Consortium, motion ratio and effective wheel rate, evaluated as a change in grip rather than an opinion.

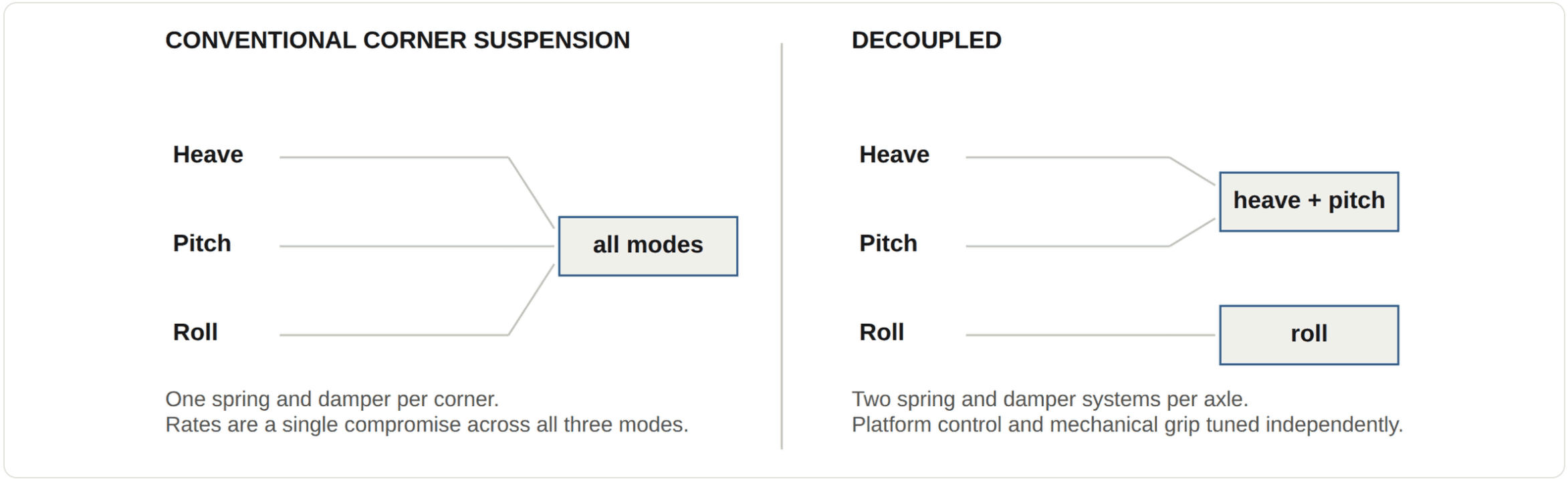
Front damper cradle

Iterative FEA against loads from on-vehicle data acquisition, with deflection rather than yield as the binding constraint.

Steering system

Clearance along the column path, bump steer through travel, and Ackermann placed against where the car spends its lap.

GRIP	CRADLE MASS	STEERING FREE PLAY
+6%	**−11.2%**	**5° to 2°**
maximum lateral grip, reduced lap times	same yield factor of safety and deflection limit	measured at the wheel



Which vehicle modes actuate which element.

01

Decoupled suspension architecture

Heave, pitch and roll tuned independently

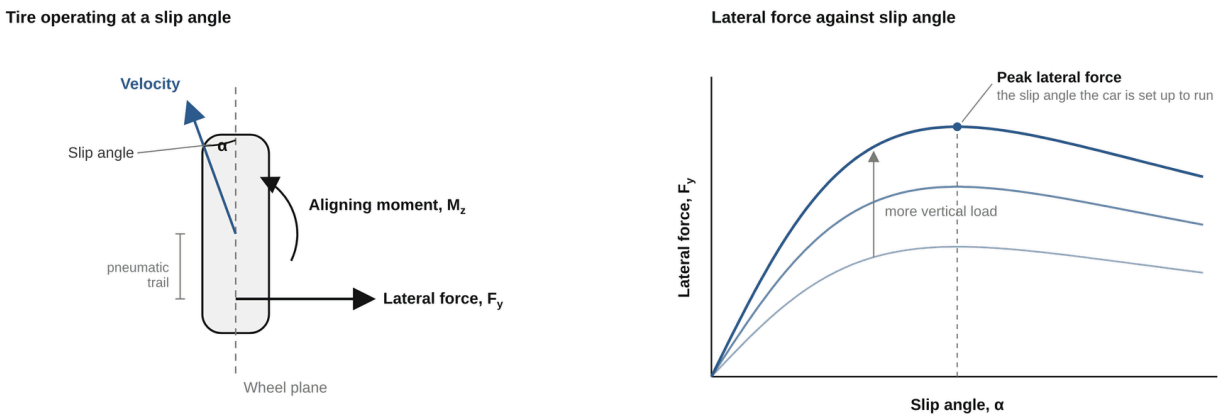
A conventional corner suspension actuates one spring in every mode, so its rate is a single compromise. Decoupling uses two spring and damper systems per axle, with heave and pitch on one element and roll on the other.

KEY POINTS

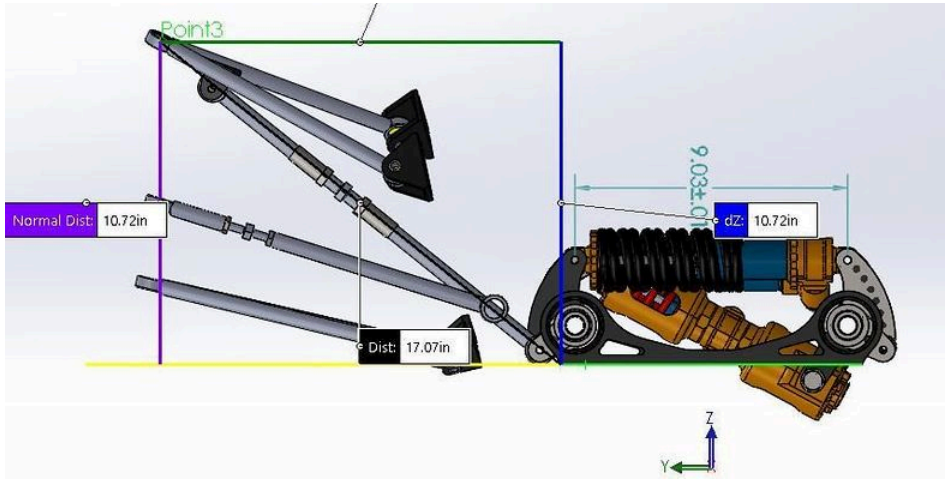
- A roll stiffness change no longer carries heave stiffness with it.
- Balance can be moved between axles without re-deciding ride.

ARCHITECTURE

Two spring and damper systems per axle



Slip angle and the lateral force it produces. The curve family shifts with vertical load.



Suspension kinematics model.

02

Geometry and spring selection

Evaluated against tire data instead of qualitative argument

The model is a Pacejka fit to the **FSAE Tire Test Consortium** data set. We bought into the consortium rather than running the tire testing ourselves.

KEY POINTS

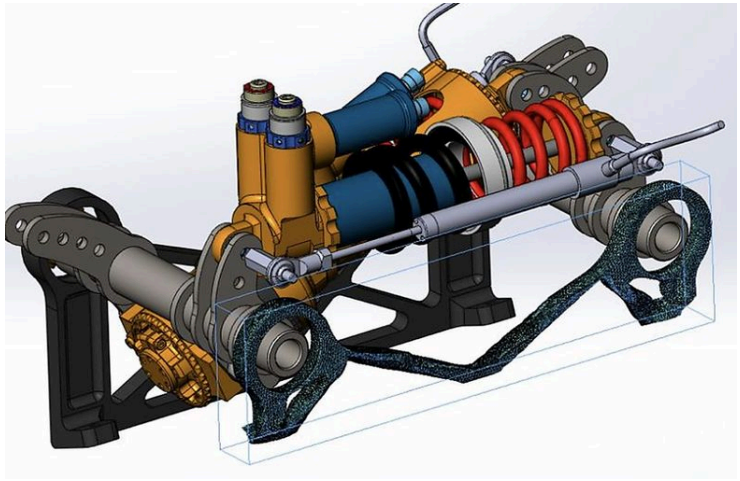
- Lateral force against slip angle and vertical load, so a geometry change can be evaluated as a change in grip.
- Motion ratio sets the effective wheel rate, so geometry and springs are selected together.

DATA

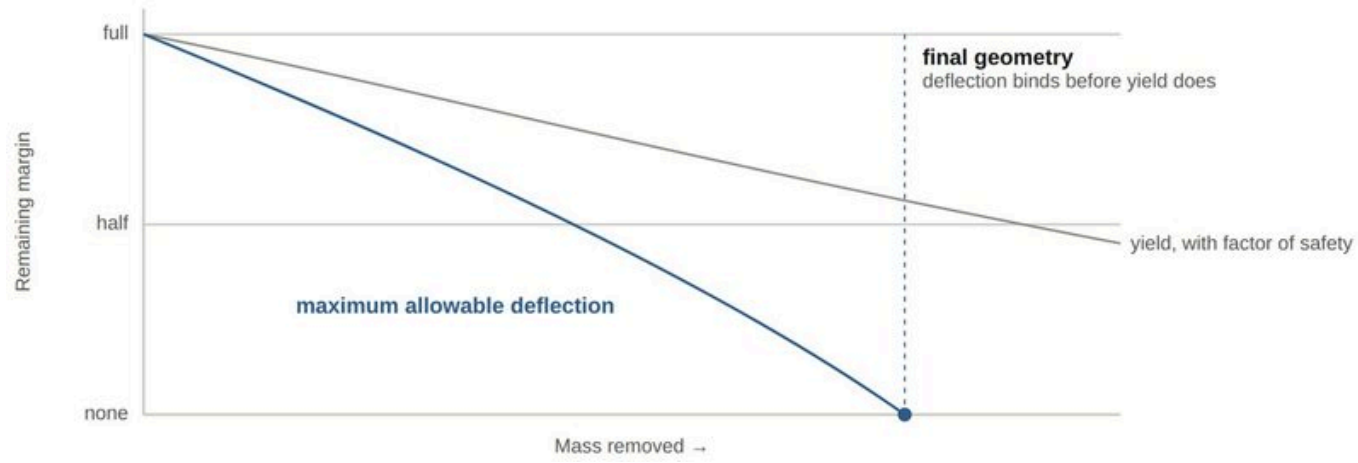
FSAE Tire Test Consortium

RESULT

Maximum lateral grip up 6%



Front damper cradle.



Deflection reaches its limit before yield. Schematic, not measured data.

03

Front damper cradle

Mass down 11.2% at the same yield factor of safety

The cradle carries real load and still had to lose mass, so the first thing to establish was which constraint actually binds. It was deflection, not yield.

KEY POINTS

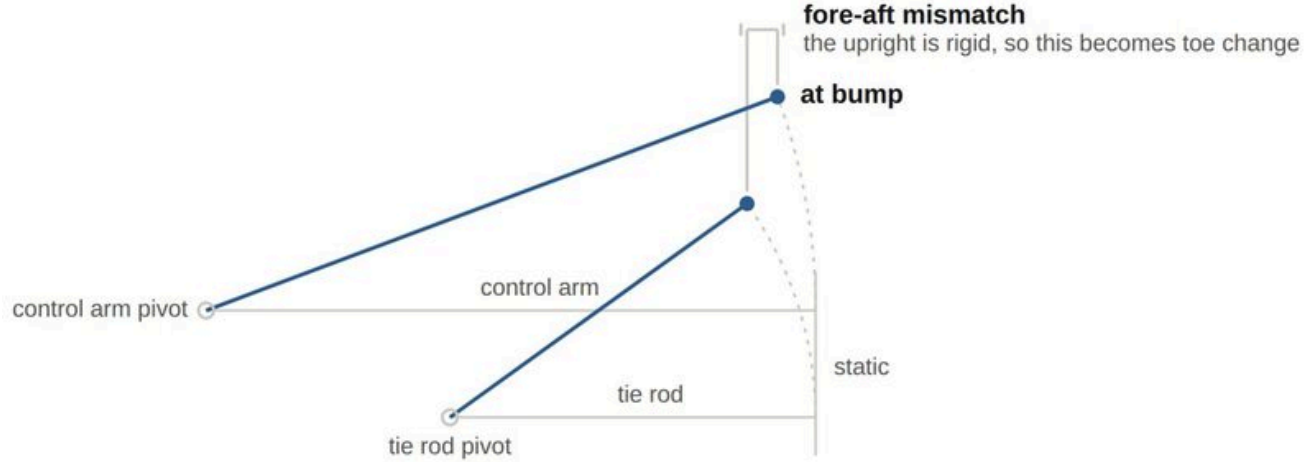
- Iterative FEA against loads from on-vehicle data acquisition rather than a single sizing pass.
- The cradle locates the damper, so compliance there costs wheel control.

TOOLS

Ansys, SimSolid

LOADS

On-vehicle data acquisition



Bump steer. Control arm and tie rod swing on different centres and lengths.



Steering and suspension assembly.

04

Steering geometry and effort

Free play at the wheel reduced from 5° to 2°

The free play was a stack, not one bad joint. Every connection along the column path carried its own clearance, and those compounded to 5° by the time they reached the wheel.

KEY POINTS

- Worked back along the path and removed the clearance connection by connection.
- **Ackermann is selected, not free.** At high slip angle the loaded outer tire wants less steer rather than more, so the geometry is placed against where the car spends its lap.

MEASURED AT

The wheel, not the rack

RESULT

5° to 2°

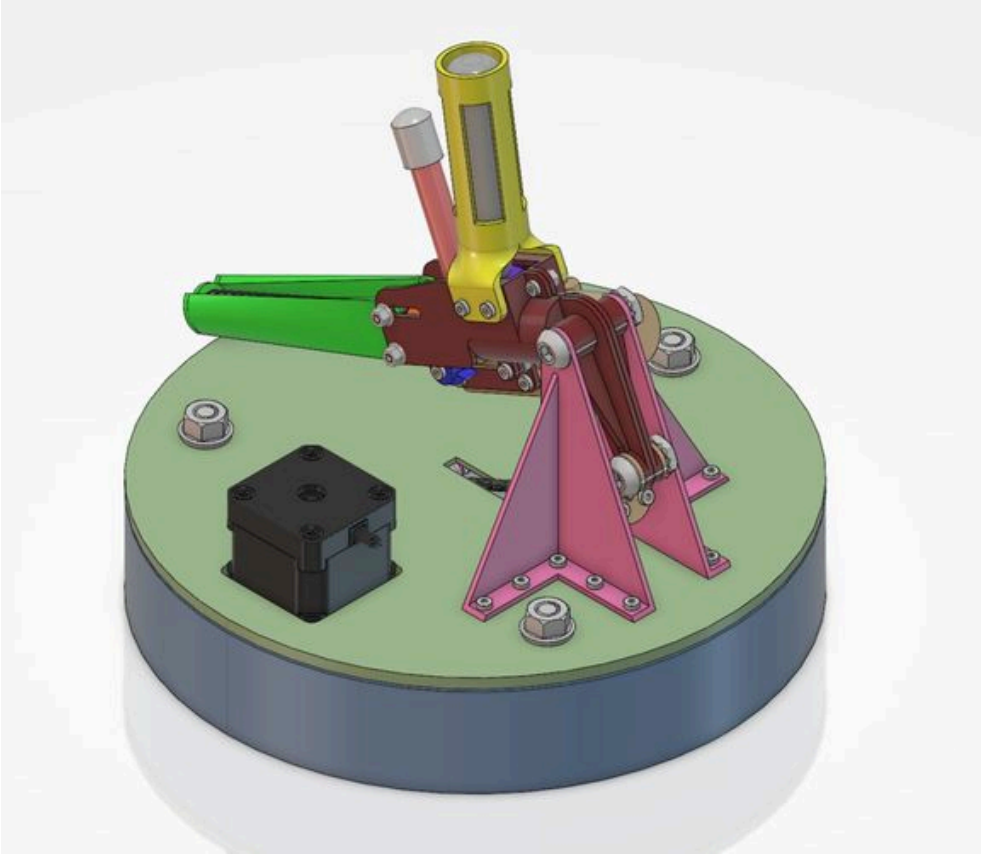
PERSONAL PROJECT · SOLE MECHANICAL DESIGNER

Computer Vision Tracking Turret

Sole mechanical designer

August 2026 to present

A two axis turret that tracks a target under vision guidance and fires a CO_2 launcher. Sole mechanical designer, covering the gear train, the pitch drive and the firing mechanism.



Yaw drive

Internal ring gear with a herringbone pinion on coprime tooth counts, giving continuous rotation with no end stops.

Pitch drive

Single start lead screw that self locks, preloaded by the payload itself, 60° of travel from +35.5° to −24.5°.

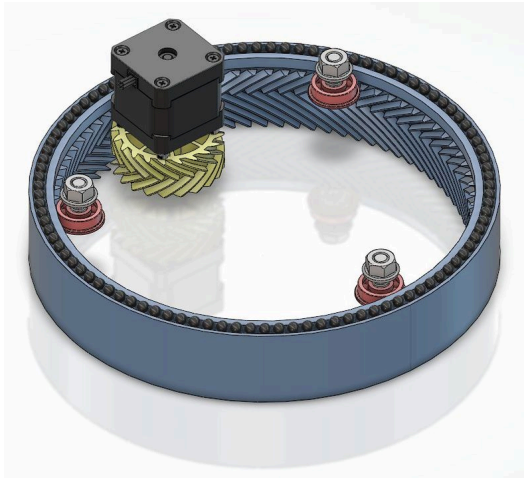
Firing mechanism

Barrel travel drives feed, valve trip and cocking from one linear stroke, with a drop-off cam setting rate of fire.

SCOPE	BUILT SO FAR	STILL OPEN
Whole mechanism	**Six prototypes**	**Backlash control**
yaw drive, pitch drive, firing mechanism	printed, assembled and run	split gear, cycloidal or harmonic



Ring teeth a single pinion tooth will contact. At 21 teeth it works around all 82.



Yaw stage. Internal ring gear, herringbone pinion and bearing plate.

01

Yaw gear train

Coprime tooth counts so contact does not repeat

The first layout paired a 22 tooth pinion with an 82 tooth ring. With both counts even, a pinion tooth only ever meets the same half of the ring, so form error repeats at a fixed period and wear concentrates there.

KEY POINTS

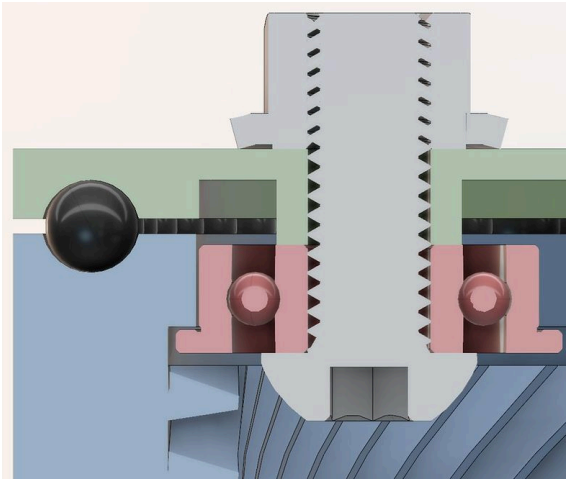
- A 21 tooth pinion resolves it, at a 4.8% change in ratio and half a module of motor mount offset.
- Internal ring gear gives continuous rotation in yaw with no end stops.

RATIO

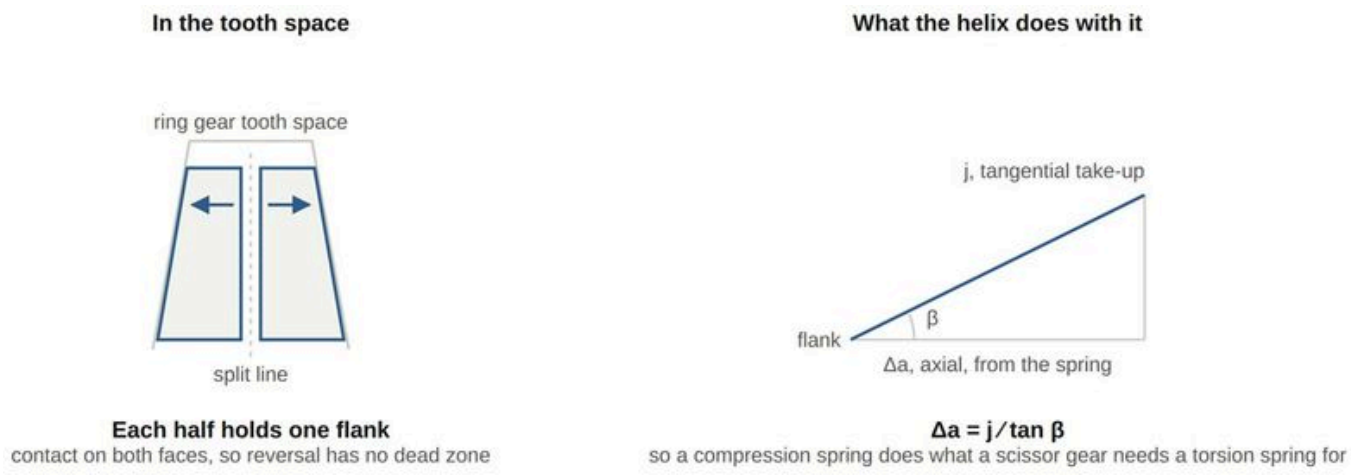
21 : 82, coprime

TEETH

Herringbone, opposed helices



Rotating plate in section. Ball groove, bearings and ring gear.



Split gear action in the tooth space.

02

Locating the plate and controlling backlash

A relationship between two features, not two numbers

Printed parts drift with process bias, so the two radial features were specified as a relationship. The race locates the plate and the bearings only retain it.

KEY POINTS

- The ball groove runs 0.1 mm of clearance and the bearings 0.2 mm, so the tighter feature picks up first. Both drift with the same process bias.
- Plate float is centre distance error. At a 20° pressure angle, 0.1 mm of float is 0.073 mm of backlash.
- **Backlash control is still an open trade.** The split gear is specified furthest because it is the option I can build and test soonest, against a cycloidal or harmonic reducer.

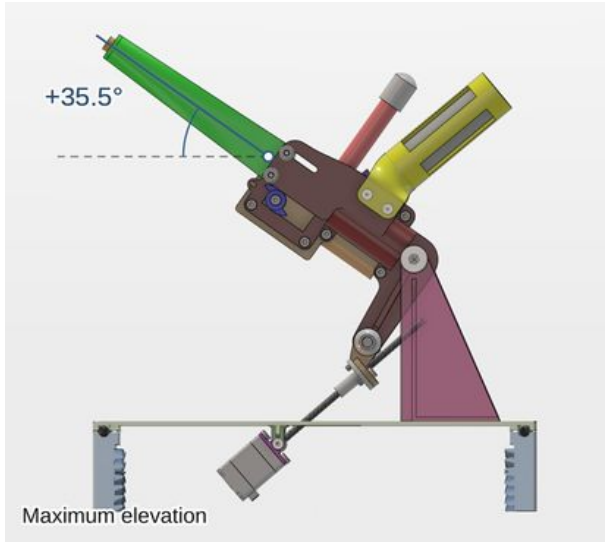
PRELOAD

Holds to the working load, about 2.4 N at the pinion

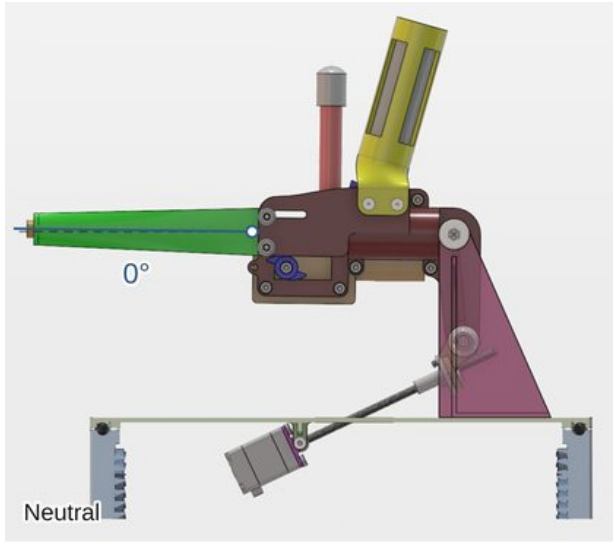
Lead screw pitch drive

The payload preloads its own drive, so no anti-backlash parts

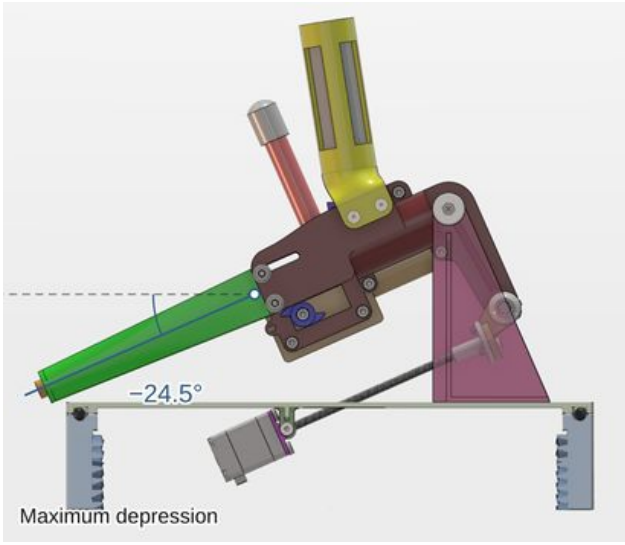
Pitch carries an unbalanced mass about a horizontal axis, so the load is gravity and never changes sign. The screw stays on the same nut flank and never crosses its backlash. A single start, fine lead screw self locks, so the axis holds elevation unpowered.



Maximum elevation. +35.5° above neutral



Neutral. Taken as zero



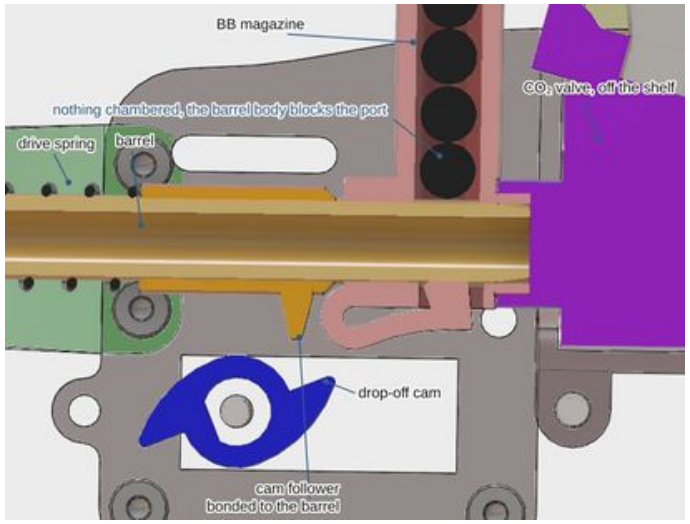
Maximum depression. −24.5° below neutral

60° of travel in total, measured on the barrel centreline with neutral taken as zero. The ends are set by the linkage geometry reaching its limit.

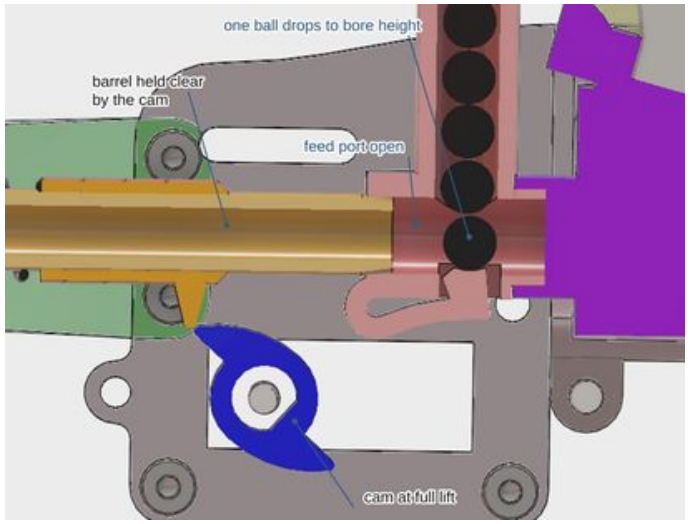
Firing sequence

One linear stroke instead of three mechanisms

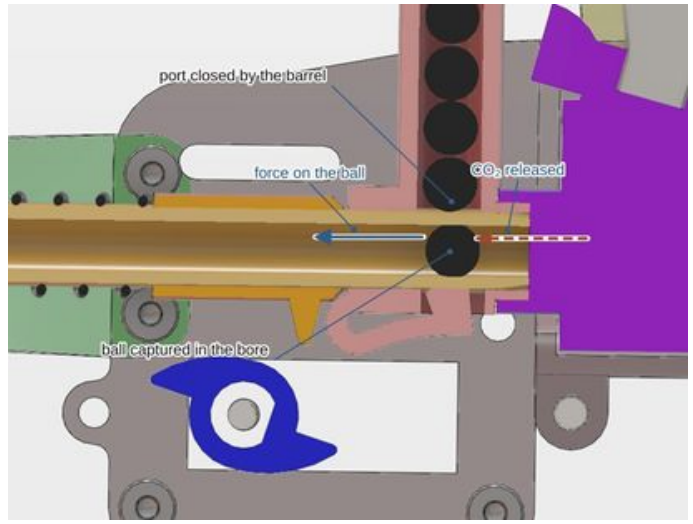
A normal layout needs a feed mechanism, a valve trip and a cocking stroke. Making the barrel the moving element combines all three. Barrel position opens the feed port and trips the valve, so the sequencing is geometric. A drop-off cam loads the spring over most of a revolution and releases it in milliseconds.



At rest. Barrel home against the valve, body blocking the magazine port.



At full cam lift. Port open, one ball dropped to bore height.



At discharge. Port closed, ball captured, CO_2 driving it down the barrel.

The motor only has to cock. Rate of fire is set by cam speed.

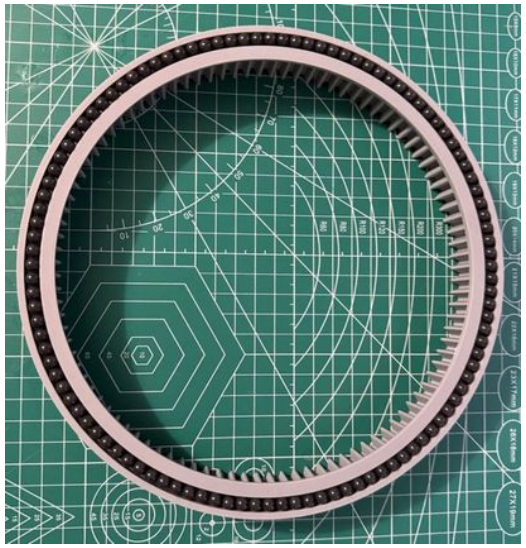
Prototype findings and revisions

Six iterations, each driven by a result from the last print

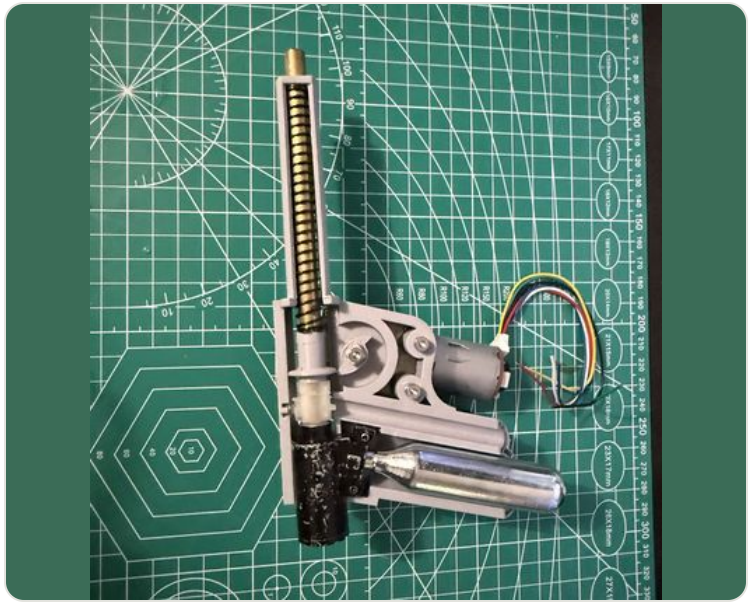
Friction. The first yaw bearing scraped, so it was changed to airsoft BBs running in a ground race. **Herringbone teeth** give smoother torque at low slew rate than a spur, and the opposed helices cancel the axial thrust that would lift the plate off its race.



Printed ring gear and pinion on the yaw plate.



Bearing race with the ground groove.



Firing mechanism split for print orientation.

Part count is high on purpose. Splitting the one piece firing mechanism lets each part be oriented for finish and hole accuracy, and a high part count keeps iteration cheap, since a change means reprinting one part instead of the whole assembly. Once the mechanism stops changing, the target is fewer parts, fewer fasteners and a simpler assembly order.