How to Pass the Brake Test in 2023 by Head Design Judge Neill Anderson

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What is the Brake Test and its objectives?

The brake test is one of the mandatory Scrutineering/Inspection requirements which must be passed before the car will be allowed on track. It's simple, defined by IN11 in the Rules and requires that all four wheels lock and stop the vehicle in a straight line.

The primary purpose of the brake test then, as implied, is to check all 4 wheels can be stopped under reasonable directional control at the command of the driver. The secondary purpose of the test is to identify any major structural issues early on such as seriously inadequate suspension and chassis structures, brake system compliances or other significant issues.

The Brake System Basics

Leaving aside the fact that an EV may have a degree of regen enabled at the brake pedal prior to engagement of the hydraulic brakes, then all FS brakes take the following form:

A twin circuit system comprising of a front brake circuit and a separate rear brake circuit for redundancy/safety/performance reasons.

Each independent circuit has a master cylinder connected hydraulically to brake calipers whose internal pistons force brake pads to squeeze a disc (connected to the wheel) between them.

Each master cylinder is connected to the brake pedal, operated by the driver's foot. In the hopeful absence of friction from poor system design or assembly, the brake force at the wheels is proportional to the hydraulic line pressure which in turn is proportional to the force applied at the pedal by the driver.

Unlike the adjacent control pedal (accelerator in case of confusion!) the brake pedal should be force sensitive and not position sensitive. Ideally the brake pedal travel should be near zero and the force required relatively high: the exact opposite of the throttle.

The Balance Bar for performance and safety

So, we have two master cylinders but only one pedal? The front and rear master cylinders are both attached to the brake pedal via a simple "beam" called the balance bar. Essentially each master cylinder's pushrod (or sometimes pullrod) is mounted to a pivot clevis at opposite ends of the beam and the brake pedal bears on the middle splitting the pedal force between the two cylinders.

It is near universal that the relative position of the pedal to the two cylinders is adjustable enabling a range of adjustment between perhaps 60% front/40% rear through 55%/45% to 50% front/50% rear.

In a near perfect system with master cylinder sizes, caliper sizes, pad size and materials properly matched, then the balance bar would be near mid position and adjusted rearwards slightly for the wet (less grip means less "unloading" of the rear tyres, hence proportionally more brake capability compared to dry).

The balance bar is also the vital safety aid: it must be set up correctly so that if one circuit fails the bar angle locks up as one-cylinder bottoms out to still apply load to the remaining operating circuit. This can also cause issues with consistent normal operation if not diligently set up correctly.

In my opinion, AP Racing are one of the very best brake system suppliers, and designers, out there. It's well worth reading carefully their online information documents, especially this one that details how to set up and adjust the balance bar itself.
https://apracing.com/drawings/Balance%20Bar%20Systems.pdf

Note the high importance of getting as close as possible with master cylinder sizes for a balanced system without relying on the balance bar to compensate for system design mismatches and the priority to set the balance bar **"square" to the pedal at maximum braking force.**

The Brake Pedal, the pedal box and master cylinder mountings

The hydraulic brake system is very simple and is a sealed fluid "lever" where the force from the driver's foot is mechanically leveraged into forces into the front and rear master cylinders (usual pedal leverage between 3 to 5:1) and in turn hydraulically magnified by differential piston sizes into substantial clamping forces at the calipers.

As it is a sealed leak free system then there cannot be any "lost" motion. Or can there??

Lost motion/free play, slop and compliance. And air!

As noted above the brake pedal wants to be solid, with force feedback rather than position to promote driver confidence. The pedal literally should hardly move!

The two most common reasons for a long or soft pedal are air in the system or poor mechanical design/assembly (free play or slop and compliance/bending). It is very rare that caliper flex or pad compressibility is the cause. It is just possible that the combined mechanical and hydraulic leverages are so large as to dictate very long travel and no effort: in such cases a review of calipers etc. is needed!

1. The sealed fluid system is only any good when full of fluid. Air is compressible, any air must be bled out. This requires a conscientious approach and is best done in the clean environs of the workshop
2. Any flexible hose is less rigid than a solid hard pipe. Where possible minimise the lengths of flexible hose to just connections to the calipers and if required at sliding/adjustable pedal boxes. Braided type hoses "Aeroquip/Goodridge/Earls" are way less expandable than car style rubber flexibles.
3. The geometry between pedal and master cylinder pushrod is important: we've seen many a "space saving" design with ultra-shallow operating angles that increase operating forces and often have falling rate type geometry. Ideally the pedal should be at 90 degrees to the cylinder pushrods at the loaded position. I strongly suspect this is perhaps the biggest single reason you are struggling to pass the brake test. Read the AP Racing information documents here to understand that the experts are especially paranoid about pedal/master cylinder operating angles, geometry and friction.

https://apracing.com/race-car/pedal-boxes/sliding-floor-mounted-reversed-pull-type

https://apracing.com/cdn/drawings/1035-CP5548-1cd%20-%20Sheet1.pdf

https://apracing.com/race-car/pedal-boxes/balance-bars/formula-3-upgrade-kit/cp5528-1?switch=1

https://apracing.com/race-car/pedal-boxes/balance-bars/trunnion-types/floor-mount-high-efficiency-types-cp5520-3-4?switch=0

https://www.essexparts.com/how-is-an-adjustable-pedal-box-designed

4. The master cylinder pushrods should not be mixed up: in motorsport master cylinders it is common for them to have been individually selected at assembly to minimise free travel before sealing off the feed port internally: often called "extra short cut off" cylinders. If you remove one to alter the length, ensure it goes back exactly as original. Similarly, the shape of the pushrod head where it fits the cylinder and circlip are often bespoke.
5. It is essential that in its free position the pedal allows both master cylinder pushrods to fully retract under their internal springs: only in this position does the internal feed port allow the fluid in the reservoir to fill up the cylinder. If this isn't happening then the system will be near impossible to bleed and the pedal travel will just get longer as pads wear!
6. You're going to stand hard on the brake pedal: you must think end to end where those loads start and finish. The pivot for the pedal must be rigid, the mounting for the master cylinders must be rigid and the driver seat back must also be rigid!
7. If you have a self-contained pedal box that is a work of art, rigid as a unit but mounted onto a thin floor where the whole thing can rotate when pressing the pedal, then that is useless. Visualise the load paths: pushing on the pedal will try to rotate the whole pedal box/floor assembly forwards and the considerable forces at the floor mounting must be reacted stiffly (as well as strongly). One way is to mount it to the side/longitudinal chassis tubes depending how widely spaced they are or alternatively consider a structural panel floor in the front quarter of your chassis. Off the shelf aluminium skinned honeycomb panels can be stiff enough (out of plane bending) to allow direct mounting of the pedal box, through suitable inserts. Again, this depends on finer details like the location of the pedal box relative to the perimeter, but at a guess a 15mm thick panel with 0.5mm skins might suffice.

The Fluid

Most suppliers of performance calipers and master cylinders do NOT recommend silicon brake fluid as it can suffer from trapped vapour, is more compressible, does not lubricate properly and is more viscous.

Use a good glycol-based fluid, a decent new DOT 5.1 type road fluid should be fine for most FS applications and has the advantage of being the most "long lived" compared to a bespoke "race fluid", e.g., AP Racing R2 (old 600 fluid).

Higher temperature fluids are available but be aware that all these fluids are hygroscopic, i.e., they absorb water. Most have the same "boiling" point once they are old… In an FS car it's highly unlikely that you will get enough heat soak into the fluid for this to be an issue.

Design Tips

1. Browse the AP Racing catalogue for lots of really practical design information: there's good advice on disc and pad materials and ongoing maintenance from a properly trusted source. Alcon also manufacture a variety of quality hardware, e.g., https://www.alcon.co.uk/products/motorsport/race/pedal-boxes/pba800/
2. Use a pedal ratio around 3.5:1 as a compromise between leverage and actuation angle efficiency.
3. Regardless of the theory there's a limited choice of master cylinder sizes. Common sizes are cheap sizes! Start with a common diameter that's in the middle of a range so it's easy to go up or down on either front or rear. It's usually cheaper to swap master cylinders than calipers!
4. Buy the best quality master cylinders with the shortest free play (cut off) you can afford. Keep them clean and sealed until you need to fit them. Don't take out the pushrod unless you have to.
5. The flanged style two bolt cylinders have quite brittle and weak flanges: they need to bolt to something that is actually flat or the flanges will crack and the cylinders will leak.
6. The flanged type (or the bulkhead mounting) type are the least efficient as the pistons are subjected to side forces once the pushrod is at any angle in any plane to the piston bore. It's not a lot but I'd suggest looking at the more efficient, and space saving type that have a spherical end or trunnion end mounting instead. This also allows you to put the balance bar at the pedal box end instead of in the (moving) pedal. Again, look carefully at the AP Racing information and drawings to get some ideas.
7. Pull type master cylinders are the most efficient but more expensive and the best are arguably those that mount on a spherical or trunnion at the end of the cylinder, e.g., https://apracing.com/race-car/master-cylinders/pull-type-trunnion-mounted
8. Remember the reservoir cap needs to "breathe" (to let air in as fluid is used) but not leak: manufacturers sell proper caps and bellows that do this well.
9. Brake fluid is highly flammable and horrible to work with, corrosive to paint and just nasty stuff. Be neat, don't spill it and don't ever shake the container! Screw caps back on tightly. Dispose of old fluid, bled from the system, in line with environmental guidelines: don't put it down the drain!

The strange case of the single rear disc

Most FS cars will have an outboard disc and caliper set up on each corner so giving 4-wheel brakes. Some will maybe have inboard discs at the rear whereby the disc and calliper are mounted next to the differential and so reducing the unsprung mass and potentially removing two flexible brake hoses (calipers are rigidly fixed to the chassis/differential mounting plates). All function in the same manner: if one wheel isn't locking then there is something amiss at that particular corner (I've even had new rubber flexible hoses with an internal fault that acted as a one-way valve!).

Some teams, in order to save weight and cost will elect to fit just one, central, inboard rear disc and caliper which is ideal with a "locked/spool" differential, i.e., no differential action is possible, both rear wheels always rotate at the same speed. Assuming the caliper, disc and pads are correctly sized (bigger) then this should work brilliantly.

However, if you're using a single disc arrangement at the rear and have a limited slip differential then you need to carefully think what happens when the two rear wheels have quite different loads/torque capacities. Some mechanical limited slip differentials have a different torque bias ratio on overrun (braking) than on forward torque application. Can you therefore guarantee to be able to lock both rear wheels (brake test requires all 4 to lock together to pass)? Given that the brake test is quite low speed, on a fairly good surface then I'd suggest it should be so.

But what about on track with lateral load transfer: will the differential characteristics give the driver a "funny feeling" that destroys their confidence I the area where they are most likely to crash, i.e., transition from braking to corner entry?

Years ago, some teams used the chain sprocket as the single disc: it can be made to work but remember the chain is greasy and you don't want oil or grease near a friction brake!

You don't need a track, or an engine to do a brake test!

I am sure you think I'm mad. How can you determine if all 4 wheels lock without running the car?

Quite easily. Albeit as organisers we won't accept it as "proof". But it will save you chasing your tail at the event for sure.

You will need the pedals and brake parts properly installed and some way to press and hold the brake pedal but you don't need an engine or a track. You're going to basically measure the torque resistance at each wheel for a range of brake pedal loads to determine that left to right are equal and front to back are roughly proportioned to your expected longitudinal load transfer values (e.g., 55% front). Whilst this test (on stands) is actually perhaps measuring "bite" rather than "rotating torque" it will weed out the obvious side to side and front to rear discrepancies. Remember the dynamic brake test at FS is very low speed so the on stands test won't be totally inaccurate. **Most importantly you can do it in the comfort of your workshop ahead of the event: this is the big plus point here.**

Before starting you can make a very rough approximation of the likely wheel torque values expected at say 0.25g, 0.5g, 0.75g and 1.0g braking. You should have this because without this basic data you won't have been able to design any part of your brake system! That same design information should also give you a rough estimate of pedal load for those decel values.

In reality, the pedal force on brand new discs and pads will be higher as you won't have full pad/disc contact. But it's a start and even if all you do is have someone sit in and press the pedal until you can no longer rotate the front wheels/tyres by hand that's better than knowing nothing! If you can roughly determine that left to right are equal and front to rear are similar then you're going to be ahead of those that don't! It's great for finding and eliminating fundamental faults.

1. Do all the balance bar set up and bleeding etc. as advised until you have no leaks, a firm pedal, no air and good operating geometry.
2. Get the car safely off the ground on stands.
3. You need some consistent method to press the brake pedal. A human can do this with surprising finesse or you can make some form of screwed actuator to press against the pedal. The human has the advantage of being able to know if the pedal loses pressure (goes away) and the drawback of maybe not pressing 100% consistently.
4. Depending on your wheel mounting arrangement you might need to make some form of adaptor for the studs or centrelock so you can apply a torque wrench to each individual

wheel/hub. This could be as simple as a beam from which you can hang weights. Again, if you want the roughest of checks leave the wheels on and just have the same person try to rotate each one forwards.

5. Apply force to the pedal and then try and rotate the wheels one at a time in the forwards direction. You're looking for the front left to be the same resistance/torque as the front right, the rear left to be the same resistance/torque as the rear right, the front left to be a bit more than the rear left etc.
6. If you have the numbers, you can do this for different pedal forces and record the individual wheel torques. The results should be fairly linear unless you have friction in the pedal box/master cylinders, poor geometry for the pedals or balance bar or other anomalies.
7. Again, if you have a torque wrench or calibrated beam/weight you can wind the balance bar 4 turns or so to the rear and measure again. There should be a difference and it's worth marking really clearly which way moves the brake bias forwards. It's quite amazing how when it rains people turn it the wrong way (**R**ain means **R**earwards).
8. It can be very illuminating, at higher force/torque levels to observe just what flexes: you'll likely see flexibility/compliance/slop in the whole pedal box area, the caliper/upright mounting and suspension wishbones/mountings and even chassis structure. To exaggerate this, you can rock the wheel forwards/backwards against the brakes. You'll probably also have a surprising amount of flex in the pedal box itself or its mountings. As a priority you need to fix all visible deflection issues.

Bleeding text, taken directly (with thanks and full acknowledgement) from Alcon website https://alconkits.com/technical-info/tech-tips/29-brake-bleeding-tips

1. Connect a bleed bottle and tube to each caliper bleed screw and fill the reservoir, leaving the reservoir cap off. Open the bleed screws of each caliper in turn to allow the system to gravity fill, until clean fluid can be seen in each bleed tube. Check that the fluid level in the reservoir does not fall below the outlet opening. Close all bleed screws.

2. Where dual master cylinders are used, bleed one front and one rear caliper together. For calipers with two bleed screws, bleed the outer side of the caliper first, followed by the inner side.

3. Never bleed the system by pumping the pedal until it is firm followed by opening the bleed screws. If there is air in the system, this procedure will aerate the fluid, making removal more difficult.

4. Air in the master cylinder primary and secondary chambers should escape to the reservoir via the feed line when the brake is off. If there are any restrictions in the feed line or reservoir connection that prevents air from escaping, air that remains in the feed line will be drawn back into the cylinder on the recuperation stroke. To minimise the restriction, dash 4 hose and fittings should be used for the feed line, particularly if the reservoir outlet is close to the cylinder inlet.

5. Open the outer bleed screw of a front and rear caliper and **slowly** depress the pedal to avoid fluid aeration, using the full master cylinder stroke. Close the bleed screws and let the pedal return fully to its original position to allow the master cylinder to recuperate fresh fluid from the reservoir. Do not allow the pedal to snap back, use a controlled rate of return. Rest for 5 seconds to allow the master cylinder to re-fill. Top up the reservoir as required. Repeat until no air is visible in the bleed tube. Depending on brake hose runs, a clear tube should be achieved within 3-5 strokes.

6. Repeat section 5 for the inner bleed screws of the front and rear caliper until no air is visible in the bleed tube.

7. Repeat sections 5 & 6 on the other side of the car.

8. Repeat sections 5, 6 & 7 if pedal travel is not satisfactory.

9. If the pedal is not firm after repeating the procedure, there must still be air in the system and an alternative procedure, backbleeding, is recommended. Using this method, a large volume of fluid and any air that is trapped in the system is returned to the reservoir via the master cylinder inlet port.

10. Fit thin pads, or preferably just pad backplates, to each caliper and slowly pump the pedal so that caliper pistons move forward to contact the pads. Working on one caliper at a time, squeeze the pistons back into the caliper, displacing fluid to the reservoir. The reservoir will fill with displaced fluid so it must be emptied to prevent it from overflowing. Repeat the procedure for each caliper and re-fit the original pads before pressurising the system with the brake pedal.

11. After bleeding, check the complete system for leaks before driving the car.

12. Do not over-tighten bleed screws: check the recommended torque setting.

13. The aim when bleeding is to achieve a firm pedal that holds its position under a sustained pedal load. Re-bleeding the brakes after some running can further improve the pedal.

14. IMPORTANT – When the system is fully bled, the threaded rod of the balance bar should be at right angles to the master cylinder push rods when the normal maximum pedal load is applied.

Additional notes from Neill:

- The bleed nipples ideally need to be the highest point in the fluid circuit: try not to have loops of pipe or hose that create a local high point that can trap air. Another advantage here for the floor mounted master cylinders (lower than the calipers).
- You can remove the calipers if needed and fit a piece of wood between the pads and bleed off the upright if somehow you have managed to fit the caliper upside down (or just were sent two of the same "hand")!
- If the master cylinders are not brand new, and in perfect condition, then manual bleeding with full strokes of the pedal/cylinder can move the internals seals into a worn/corroded/rough part of the bore and nick the seals. You'll never get anywhere then. I personally have never had any long-lived joy with fitting new seals after such an incident (no matter how good the master cylinder bore looked) and it's wise to simply buy new cylinders.
- A (low) pressure brake bleeder can be useful: normally a pressured fluid bottle is connected in place of the master cylinder cap and fluid can be "pushed" through the system without moving the brake pedal. It needs to be done slowly to avoid creating air bubbles but can sometimes remove air that manual bleeding will not. The proper kits are quite pricey.
- A cheaper solution is a large syringe attached to the bleed nipple to suck/pull fluid through. The advantage here is that the vacuum should pull air easier than fluid (good) but if the bleed nipple is a poor fit will often suck in air and make you think you're removed more air than you have. Still, it's cheap and therefore worth a go.
- It can sometimes help to lightly (but sharply) tap the caliper bodies with a copper hammer when bleeding to shock any air bubbles out. Obviously don't muller your expensive, shiny, alloy caliper with a lump hammer!

The pedal box/adjustable pedal box

Basic pedal box

You don't need anything fancy to make your own high quality pedal box. Remember the basics: stiffness, good geometry, no friction, sensible packaging. You don't need billet machined pedals, complex moulded parts. Remember also we provide a guideline minimum brake pedal load case of 2,000N. The force analysis is pretty much in one plane. It's quite possible to fold up a simple sheet metal design from thin sheet steel and you don't need much beyond a hacksaw, holesaw and welder to fabricate it.

The brake pedal should pivot on some form of proper bearing, not just a bolt in a hole. It should have no real play nor friction and be free throughout its arc of travel. This can be quite simple, see the IGUS range of flanged "top hat" bushes https://www.igus.eu/iglidur/sleeve-bearing-with-flange You don't need anything special to do a nice job, shoulder bolts make for off the shelf pivots: https://ie.rs-online.com/web/c/fasteners-fixings/screws-bolts/shoulder-bolts/

It seems sensible to me to mount it on the floor. It also seems sensible to me to look at placing the master cylinders behind the pedal rather than in front if space is an issue (it usually is because we want a short car). Yes, this does potentially raise the drivers' feet to sit above the master cylinders but on balance it's not a deal breaker.

As the pedal will be sort of vertical then placing the cylinders horizontally gives a good head start on not screwing up the pedal geometry: to both the driver's foot and to the master cylinders.

Please heed the advice and ensure the pedal is at 90 degrees to the master cylinders mid stroke/under pressure. Anything else is asking for problems. In particular this sort of style below has nice short packaging but at the expense of very poor geometry, as in nearly over-centre! It will also be awkward to bleed as the feed port is higher than the pressure outlet.

Using the end mounted master cylinders, especially with the trunnion mounts allows the balance bar to be on the pedal box not in the pedal: this makes fitting the bias adjuster cable a lot easier and makes the pedal design simpler.

The “other” pedals

The fundamentals of stiffness, lack of friction and good operating geometry apply equally well to the (possibly) two other pedals, namely the throttle and the clutch. If you’re going to have an adjustable (moveable) pedal box then it’s essential to have these other controls on the same assembly.

Arguably, a two pedal layout does give more space for packaging and a hand clutch would be quite simple and faithful to the original motorbike engine.

Good proper geometry for the clutch will make it simple for the driver to consistently find the “biting” point, something again I often see as a problem (lots of stalls) when watching the dynamic events.

More importantly perhaps, well considered throttle pedal and linkage geometry (from pedal to butterfly) will pay driveability dividends. The airflow through a butterfly throttle is very nonlinear: a few degrees of the butterfly from closed has a much larger influence than a few degrees near fully open. It’s quite common to see really simple lever arm type linkages with awful progression because of bad geometry. It’s also very simple and very little work to make a nice cam style quadrant for the end of the butterfly shaft so that the throttle cable has to travel proportionally more near fully closed than near fully open.


(courtesy https://shop.efi-motorsport.com)

It’s also worth having a longer throttle pedal travel than you think to ensure smooth control by the driver: it’s the opposite “feel” to the brake pedal scenario.

As an aside an electronic throttle control (drive by wire) should give driveability gains as the ergonomics can be “mapped” to suit, often with a “wet” map for greater progression.

Adjustable pedal box

By “adjustable” I’m describing a pedal box unit that can be moved fore and aft to accommodate the different driver sizes: although complicated it’s still easier than different seats steering wheel positions and massive seat belt re-arrangements.

A long time ago I suggested that a simple way to have an adjustable pedal box would be to use car seat slide rails with a cable operated latch mechanism and a gas strut that would push the pedal box towards the driver. In operation the driver would simply pull the cable and push the pedal assembly against the gas strut to the desired location and then release the cable and the unit would lock into place. Quick and easy.

Most car seats have seat belt anchorages on the seat: consequently, the slide rails under them are designed to accommodate bending loads. They generally have a good smooth action, indents/locking mechanisms every 15/20mm or so and an obvious lever to operate them. Under the seat they are used “flat” to keep them shallow but turn them 90 degrees and they will be much stiffer albeit more awkward to link/adjust.

Here's the sort, I’m sure you can find some production items for very little money in a breakers: https://www.demon-tweeks.com/eu/sparco-seat-runner-kit-s-s0049302/

Again, looks like AP Racing have done a professional version of this, see here https://apracing.com/race-car/pedal-boxes/sliding-floor-mounted-reversed-pull-type This is as good as you’re going to get, look carefully at the details.

A moving pedal box does mean some short flexible hoses to the master cylinders and also remote fluid reservoirs, again with flexible hoses. Nothing impossible and bear in mind that brake fluid is highly flammable. It does allow you to put the reservoirs somewhere accessible which might not be the case if they are integral to the master cylinders.

Golden Rules of Design

Risk versus Reward, Priorities and Resource Allocation

You don’t have enough time, money or skill to do everything that you think you want to do, properly.

So, you need to prioritise.

Firstly, you need to evaluate, even measure, your available resources such as time, space, money, equipment and skills.

Based on this you need to take a broad brush look at fundamental areas/sub systems that you can/should do in house versus those that you outsource. Part of this is the risk/reward type calculation to determine whether it is better to design, make and test something bespoke or look to buy a more common item and accept it with inevitable drawbacks. By way of example, the standard Impact Attenuator (IA), suitably mounted, guarantees a Pass at Scrutineering. If you do some additional work/calculations then instead of the default 8-point IA Grade penalty you can lose just one point! As per the Rules (T 3.18) the use of the standard IA is an automatic 8-point design penalty but you can reduce this to just 1 (one) point design penalty with some work! “*IA reports for the standard FSAE IA may be upgraded by up to two grades if they include additional analysis or testing – for example finite element simulation, or testing of material samples.”* So, for a new team it’s a no brainer to use the standard item: prioritisation of your scarce resources, risk exceeds reward.

To do this you need some basic understanding of the challenges posed in each area and look at how you might solve them. In the case of the pedal box, I would suggest it is a no brainer to buy the master cylinders as there is zero benefit (reward) in making your own but near 100% risk in so doing.

However, whilst there are commercially available pedal boxes most of the “affordable” ones are not really that good nor that suitable for the FS car, i.e., they come with substantial compromises, especially packaging and lacking adjustment. I humbly suggest that the pedal box is an excellent first design and make exercise as it is predominantly two dimensional and a great learning experience for the application of classical mechanics/forces/geometry.

Indeed, it’s a perfect part to make as part of a Concept class entry as it is small and cheap enough to carry from design through card/3D print prototype to full part/assembly. It’s near enough powertrain agnostic and, within reason, can be done without full knowledge of nearby chassis items.

Keep it Simple, Keep Load Paths Pure

Simple is usually best, simple is usually elegant and simple is usually cheap. Innovation is normally a gimmick, normally risky and always expensive.

Looking back at your resources, innovation usually implies that you literally had nothing else left to spend time and money on, i.e., everything else is "perfect". Believe me, this is rarely true! For example, making your own brake caliper is both very risky, rarely needed and arguably therefore isn't innovative.

We see lots of CAD, lots of FEA but very little proper consideration of the purity of load paths, very little genuine design elegance. Most of the FEA looks at detailed stresses and material allocation but for most things on an FS car you need to be looking more at the deflections under load. To avoid this flexibility/compliance/free play you need purity of load paths, not some wonder material…

Given the simple almost 2D nature of the pedals and pedal box assembly it's enlightening and educational to make a simple card model where you can literally see the load paths. You can also directly watch the geometry in action. You could go one step further and make second generation parts from wood, MDF or even plastic sheet. For most people this will help you visualise where to place material for better stiffness far easier than colours on the CAD screen.

As an aside, many years ago, quite sophisticated stress analysis was done with plastic models of components where mechanical deformation caused changes in the optical properties of the material. When polarised light passes through a displaced transparent model, interference patterns are formed. These patterns provided visible qualitative information about the stress distribution, locations of stress concentrations etc.

Finally, don't forget the Rules require a Brake Over-Travel Switch, see Rule T6.2

Good Luck, let's see plenty of locked wheels next year!