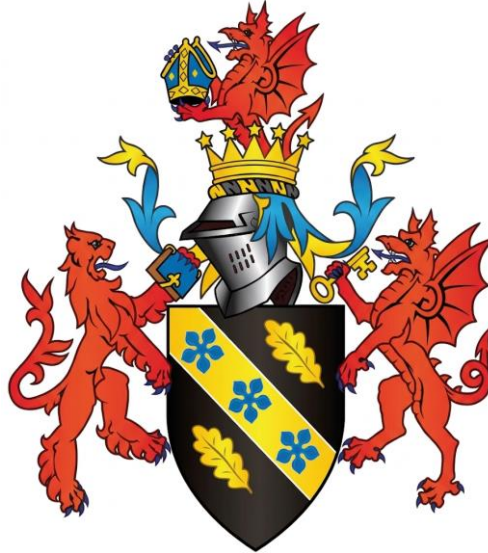




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Abstract

The Body in White (BIW) construction of a 2019 Morgan Plus 4 (registration VX69 XJC) that was developed for motorsport use in the UWTSD workshop is evaluated critically in this study. Structural stiffness, noise vibration and harshness (NVH), materials, production, joining procedures, safety, comfort, and regulations are the eight main categories covered by the assessment. The CX-Generation aluminium bonded-and-riveted chassis serves as the foundation for the Morgan Plus 4. Changes made at UWTSD consist of: installation of a complete multi-tube steel roll cage and an upgrade to the suspension geometry to meet Morgan Plus 6 specifications (retaining the chassis, upright pick-up points, and larger A-arms) Yokohama A052 semi-slick tires; the airbag system is removed; the standard seat is replaced with a Tillett carbon composite racing bucket and Sparco steering wheel; mirrors and the passenger seat are removed; a rear anti-roll bar, a Lifeline mechanical fire extinguisher and a kill switch on the front right side of the body are added. The original road-legal homologation requirements and pertinent Motorsport UK General Regulations are used to assess these modifications.

Introduction

The Body in White (BIW) is the structural shell of a vehicle prior to the installation of mechanical and trim components. It is the primary load-bearing architecture responsible for torsional and bending stiffness, crash energy management, and the mounting of all major systems (Sharanbasappa et al., 2016). Transitioning a vehicle from road use to motorsport competition requires significant modifications to the BIW and associated systems, with consequent implications for structural integrity, safety, and regulatory compliance.

The vehicle under assessment is a 2019 Morgan Plus 4, registered VX69 XJC, powered by a BMW B48 2.0-litre four-cylinder turbocharged engine producing 255 bhp. Morgan Motor Company has employed an aluminium bonded-and-riveted chassis architecture since the Aero 8 in 2001 (European Aluminium Association, 2013). The CX-Generation platform, introduced across the Plus 4 and Plus 6 range in 2019, refines this with a fully bonded aluminium monocoque that eliminates the traditional ash wood frame, reducing kerb weight to approximately 1,025 kg. UWTSD has subsequently modified this vehicle for motorsport purposes, as documented in photographs taken in the UWTSD workshop and shown throughout this report.



Figure 1: Front view of the UWTSD Morgan Plus 4 (VX69 XJC) in yellow race livery. Competition Yokohama A052 tyres are visible in the foreground awaiting fitment.

Structural Stiffness

Bending and torsional rigidity are important aspects of BIW design. Handling, ride quality, and component fatigue life are all negatively impacted by undesired deformations caused by insufficient stiffness under dynamic loading (Sharanbasappa et al., 2016). The 32 aluminium alloy panels that make up the Morgan CX-Generation chassis are riveted and adhesively bonded together. This technique prevents the stress concentrations that occur in spot-welded assemblies by distributing stresses over wide bonded interfaces (European Aluminium Association, 2013). With a Young's modulus of roughly 70 GPa and a density of roughly 2.7 g/cm³, aluminium alloy used in this way provides high specific stiffness in comparison to steel, which has 200 GPa and 7.8 g/cm³ (Busarac et al., 2022). The flexibility to use larger section sizes at a reduced mass penalty makes up for aluminum's lower absolute modulus.

As an open-top roadster, the Morgan Plus 4 is inherently less torsionally stiff than a closed-body car. Torsional stiffness values for open-top sports cars typically fall in the range of 3,000–8,000 Nm/deg, compared to 15,000–30,000 Nm/deg for closed-body passenger cars (Yang et al., 2011). This deficit is significant from a vehicle dynamics perspective: low torsional stiffness permits relative deflection between the front and rear suspension subframes, degrading camber control and steering response. The multi-tube steel roll cage fitted at UWTSD introduces an alternative load path across the occupant cell, substantially increasing global torsional stiffness. From an engineering standpoint, this is the primary structural benefit of the cage modification for an open-top vehicle, partially compensating for the absence of a roof structure.

However, this improvement in global stiffness is accompanied by increased local stress concentrations at the cage mounting interfaces with the aluminium BIW. Without formal finite element analysis (FEA) validation, the stress margins at these locations remain unquantified. The suspension geometry change from Plus 4 to Plus 6 specification involved fitting longer A-arms whilst retaining the original chassis pick-up points and uprights. Increasing the A-arm length from the standard 350 mm to the Plus 6 specification of approximately 390 mm (an increase of approximately 11%) increases the moment arm acting on the chassis mounting bracket during cornering. For a lateral

force of 5 kN at the wheel contact patch, this increases the bending moment at the inner chassis mounting by approximately 200 Nm, a loading condition for which the original bracket was not designed. This deviation from original design intent may accelerate fatigue damage at the mounting interfaces under repeated high-load cornering (Sharanbasappa et al., 2016). It is recommended that UWTSD commission a stress analysis of the suspension pick-up nodes under Plus 6 loading conditions before sustained competition use.



Figure 2: Rear view of the full multi-tube steel roll cage installed in the UWTSD Morgan. The main hoop, diagonal cross-braces, and side members are visible. The Tillett racing seat, Sparco steering wheel, and exposed aluminium CX-Generation chassis floor can also be seen within the cockpit.

Noise, Vibration and Harshness (NVH)

The regulation of vibration transmission from excitation sources, such as the engine, road surface, tires, and exhaust, through structural transfer pathways to the occupant interfaces of the seat, steering wheel, and floor, controls NVH performance in road cars (Nikhade, n.d.). In order to prevent resonance and lower perceived quality, modal analysis of BIW structures makes sure that natural frequencies do not overlap with prominent excitation frequencies (Yang et al., 2011). The Morgan CX-Generation bonded aluminium chassis has built-in dampening benefits: the continuous bond line removes the micro-slip at spot-weld spots that causes squeak-and-rattle noise, and structural adhesives dissipate vibrational energy through viscoelastic behaviour (Sika, 2023).

The NVH management of the original design is seriously jeopardised by the motorsport modifications. A key vibration absorption mechanism at the occupant interface is eliminated by replacing the regular foam-padded seat with a stiff Tillett carbon bucket seat. The vehicle's Yokohama A052 semi-slick tire produces more stress inputs into the chassis through the suspension since it has a stiffer carcass than a regular road tire. Hafizi et al. (2017) showed that extra structures affixed to a BIW drastically alter its modal frequencies; the steel roll cage is notably more massive than the examples examined (windcreens) and will have a noticeable impact on the body's overall modal behaviour. For motorsport use these NVH penalties are irrelevant structural rigidity and driver feedback take precedence. Additionally, the increase in structural stiffness due to the roll cage raises the natural frequency of the system, potentially shifting vibration to higher frequency ranges where damping is reduced and driver perception is increased.

Materials

Aluminium alloy sheet and extrusion are the only materials used to build the Morgan CX-Generation chassis (European Aluminium Association, 2013). The main structural components are the flat aluminium floor panels, which are easily seen beneath the car in Figure 5. The 5xxx series (Al-Mg) for panels and the 6xxx series (Al-Mg-Si) for extrusions are two aluminium alloys that are frequently used in structural automotive applications because they provide an excellent balance of formability, strength, and corrosion resistance (Busarac et al., 2022). In particular, extrusions use 6082-T6, which has a yield strength of about 260 MPa, whereas Morgan's chassis panels are known to use 5182-O aluminium sheet, which offers a yield strength of about 130 MPa and good formability. This substantial difference indicates that extruded members, rather than flat sheet panels, are primarily responsible for carrying structural loads. Lightweight materials such as aluminium can yield mass reductions of up to 40% versus steel equivalents, contributing directly to the Morgan Plus 4's kerb weight of approximately 1,025 kg (Jenny, 2023)

The body panels are aluminum, formed to the characteristic Morgan retro shape. The interior panels visible in the cockpit photographs (Figures 3 and 5) appear to be carbon fiber composite — most notably the prominent carbon fibre centre tunnel and cockpit side panels. Carbon fibre reinforced polymer (CFRP) offers the highest specific stiffness of automotive body materials, and its use in interior trim and structural panels in niche sports cars is well established (Wazeer et al., 2022). This is a material not present in standard road car trim and represents either an original Morgan option or a UWTSD modification for weight reduction.

The roll cage is fabricated from steel tubing, as required by Motorsport UK General Regulations (Motorsport UK, 2024). Motorsport UK mandates CDS (cold-drawn seamless) steel tube to BS EN 10305-1, with a minimum yield strength of 350 MPa for roll cage applications. This introduces a three-material structure: aluminium BIW, CFRP interior panels, and steel cage. Zheng et al. (2023) confirm that multi-material body construction can achieve significant weight reductions over mono-material equiva-

lents, but that the dissimilar material interfaces require careful design and manufacturing management. Critically, whilst aluminium offers superior specific stiffness, its lower absolute elastic modulus necessitates increased section thickness to achieve equivalent structural stiffness to steel — a fundamental trade-off that Morgan's chassis designers have addressed using closed-section extruded members (Lightweighting World, 2017).



Figure 3: Cockpit interior showing the Sparco suede racing steering wheel (no airbag), Tillett carbon composite racing bucket seat (driver side only — passenger seat removed), roll cage side member, carbon fibre cockpit side panel, and the bare aluminium CX-Generation chassis floor. The Lifeline fire extinguisher pull cable is visible at lower left, and the Motorsport UK kill switch sticker is on the right side panel

Manufacturing

Morgan Motor Company is one of the world's few remaining low-volume specialist manufacturers, producing approximately 800–1,000 vehicles per year. The CX-Generation aluminum chassis is assembled using structural adhesive bonding and self-piercing riveting (SPR). According to the European Aluminum Association (2013), the predecessor Aero 8 chassis employed 32 aluminum alloy panels bonded with Gurit Essex structural epoxy adhesive and riveted with self-piercing rivets a process confirmed to carry through to current CX-Generation models. This approach was

chosen to minimize capital tooling investment for low production volumes, in stark contrast to the robotically stamped and resistance spot welded BIW construction of high-volume manufacturers, which requires tooling investments of £100–400 million per model programme (Roland Berger, 2017).

Morgan's manufacturing process requires significant manual skill for panel preparation, adhesive application, and rivet placement. The adhesive bond is the primary structural element; correct surface preparation (degreasing and chemical pre-treatment of aluminium surfaces to promote adhesion) is essential for achieving the design bond strength. Modi and Vadhavkar (2019) note that adhesive bonding introduces sensitivity to surface preparation quality and curing conditions that is not present in resistance spot welding — a manufacturing limitation that is particularly relevant in a low-volume hand-built environment. This represents a key quality risk for long-term structural durability of the BIW that a high-volume manufacturer would control through automated surface pre-treatment.

At UWTSD, roll cage fabrication and fitting are carried out in accordance with standard motorsport procedures: steel CDS (cold-drawn seamless) or ERW tube is cut and bent to shape before being TIG welded. Instead of being a straightforward roll bar, the cage seen in Figures 2 and 8 has a full multi-tube structure with a main hoop, front hoop, rear stays and several diagonal braces. This is consistent with a full cage that complies with Motorsport UK regulations. Important manufacturing factors include the design of the cage mounting feet, which transfer loads into the aluminium BIW, and the quality of the weld. According to Modi and Vadhavkar's (2019) Technology Roadmap, process management is necessary when combining steel and aluminium in multi-material constructions in order to avoid intermetallic compound production and galvanic corrosion. However, the reliance on adhesive bonding introduces sensitivity to manufacturing conditions such as surface preparation and curing quality, which may influence long-term durability and fatigue performance.

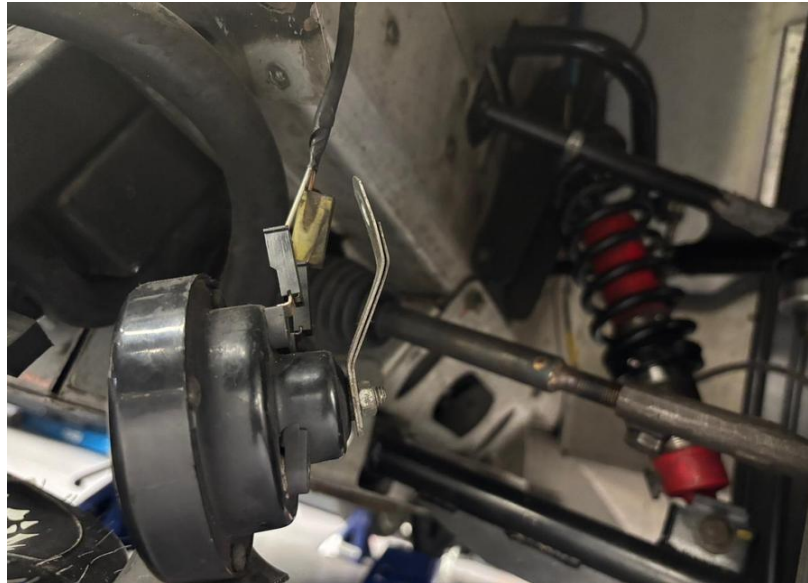


Figure 4: Close-up of the Plus 6 specification front suspension showing the longer A-arm and red coilover damper/spring unit. The lightened aluminium suspension cradle/chassis bracket with oval lightening holes is visible in the background, along with the anti-roll bar drop link.

Joining Techniques

Self-piercing riveting (SPR) and structural adhesive bonding are the two main connecting methods used in the Morgan CX-Generation chassis. Structural adhesives offer an ongoing bond line that evenly distributes stress, enhancing corrosion resistance and fatigue performance in contrast to discrete fastener joints (Sika, 2023). Because SPR eliminates the heat input of fusion welding, which would deteriorate the temper and mechanical properties of age-hardened aluminium alloys, it is especially well suited for aluminium constructions (European Aluminium Association, 2015). The flat panel construction with visible rivet heads typical with SPR assembly can be seen on the chassis floor in the workshop photos (Figures 3 and 6). SPR and clinching provide carrying capacities similar to resistance spot welding for aluminium body constructions, according to Kašák and Spišák (2013).

Papa et al. (2024) highlight that joining dissimilar lightweight materials is a central challenge in modern body construction. For the UWTSD Morgan, the steel roll cage must be connected to the aluminium BIW. Fusion welding of steel to aluminium

produces brittle intermetallic compounds and is generally avoided. The standard motorsport solution involves steel mounting plates bonded and bolted to the aluminium chassis, with the cage then welded to these plates consistent with what can be inferred from the cage mounting details visible in the photographs. Without isolating materials at the joint, electrochemical corrosion between steel and aluminium (a galvanic couple with approximately 0.6 V potential difference) represents a long-term durability risk (Naito and Suzuki, n.d.). The aluminium–steel interface presents a significant durability concern due to galvanic corrosion and differences in elastic modulus. Under cyclic loading, these factors may promote fatigue crack initiation at the joint interface, particularly if adequate isolation or protective measures are not implemented.



Figure 5: Underside view of the Morgan CX-Generation aluminium chassis on axle stands. The flat bonded-and-riveted aluminium panels are clearly visible, along with the suspension lower arm, coilover spring (red), and chassis bracket with lightening holes.

Safety

For type approval, the original 2019 Morgan Plus 4 has to adhere to European road safety rules. In addition to active safety requirements like airbag systems and anti-lock brakes, road-legal passenger automobiles must adhere to passive safety standards encompassing frontal impact (UN Regulation 94), side impact (UN Regulation 95), and whiplash protection (Wissenbaum, 2015). The safety profile has changed significantly because of the UWTSD adjustments. Supplemental restraint protection, which is essential in frontal crashes, is eliminated when the airbag system is removed. The Sparco racing wheel (seen in Figure 3) is now supported by the steering column without an SRS module. Regulation 61 of The Road Vehicles (Construction and Use) Regulations 1986 is violated when mirrors are removed. When combined, these modifications make the car unfit for use on public roads.

However, an alternative safety paradigm is offered by the motorsport adaptations. Rapid fire suppression is possible with the Lifeline 2020 mechanical fire extinguisher, which is installed in the passenger footwell and has a pull lever that can be accessed from outside the car (Figure 7). Immediate electrical isolation is made possible by the kill switch, which is located on the front right side of the cockpit (Figure 8). Both things are required for competition use under the Motorsport UK General Regulations (Motorsport UK, 2024). For an open-top vehicle where rollover would otherwise be disastrous, the full multi-tube roll cage offers primary occupant protection in the event of an overturn. According to Fedotova et al. (2020), BIW structure optimisation for passive safety is essential to the creation of contemporary race cars, and the roll cage serves this purpose for the converted Morgan.

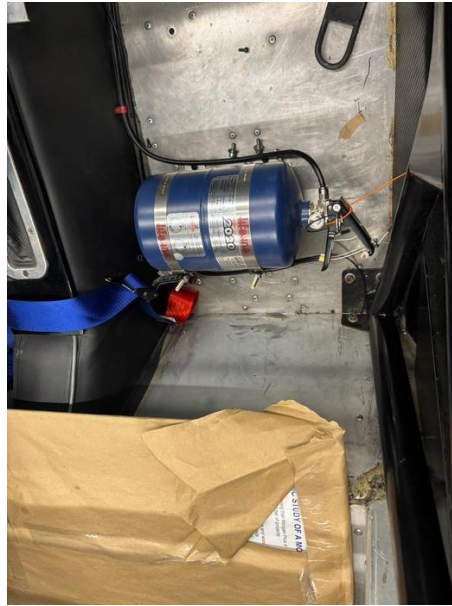


Figure 6: Lifeline 2020 mechanical fire extinguisher mounted in the former passenger footwell area. The blue multi-point racing harness is also visible. The bare aluminium floor panel confirms the passenger seat has been removed. The extinguisher actuation cable leads to the external pull handle on the body.



Figure 7: Kill switch (red push-button, top) and ignition/start button (blue, bottom) mounted on a bracket on the right-hand cockpit sill, with the Motorsport UK electrical hazard triangle sticker adjacent. Wiring runs along the exposed aluminium inner chassis panel. The Lifeline extinguisher bottle is partially visible at lower right.

Comfort

Road vehicle comfort includes ergonomic seat design, acoustic performance, ride quality, and thermal comfort. As the mounting substrate for seats, trim, and HVAC systems, as well as its function in vibration isolation, the BIW makes a contribution (Nikhade, n.d.). Comfort features are methodically removed in favour of motorsport performance in the UWTSD upgrades. The passenger seat has been entirely removed, eliminating the second occupant position and significantly reducing mass. A fixed-back Tillett racing bucket has taken the place of the driver's seat, which increases lateral support under heavy cornering loads but causes the occupant to experience significantly more vibration. Ergonomic refinement is diminished by the lack of mirrors and the installation of the Sparco racing steering wheel (which lacks the original airbag boss cushioning). The Yokohama A052 semi-slick tyre, while road legal, has a stiffer carcass construction than the original road tyre, increasing vibration inputs at the chassis.

Although they provide some material sophistication, the carbon fibre interior panels and tunnel seen in the photos don't help with acoustic dampening. These modifications are totally in line with motorsport principles, which prioritise weight reduction and driver feedback over road comfort. The Tillett bucket with multi-point harness shown in Figure 6 seems to comply with the minimum criteria required by Motorsport UK regulations for seat and harness installation (Motorsport UK, 2024).

Regulations

In accordance with UN/ECE standards and EU directives, the original Morgan Plus 4 was homologated for road use under the UK and EU type approval framework. UN Regulations 12 (steering mechanism), 21 (interior fittings), and 94 are important prerequisites. (frontal collision), as well as UN Regulation 95 (lateral collision). In the UK, mirrors, illumination, and general roadworthiness were all re-

quired under The Road Vehicles (Construction and Use) Regulations 1986 (Wissenbaum, 2015; ACEA, 2023). Type approval compliance is an extensive engineering task because European vehicles are subject to more than 150 EU rules and 30 directives, as the ACEA (2023) Automotive Regulatory Guide attests.

The removal of the airbag system, the removal of mirrors, the replacement of the standard steering wheel, and the removal of the passenger seat collectively withdraw compliance with UN Regulations 94, 21, and 12 as well as Regulation 61 of The Road Vehicles (Construction and Use) Regulations 1986, all of which have compromised road legality. As a result, the car is not permitted on public roads and should only be used for competition. The removal of the airbag system should have complied with the UK End-of-Life Vehicles Regulations (DEFRA, 2010), which mandate that licensed treatment facilities remove hazardous compounds, including airbag propellants.

Motorsport UK General Regulations is the applicable framework for competition use. In order to comply with Motorsport UK Section K electrical standards, the kill switch is located on the front right side of the cockpit and is prominently marked with the required Motorsport UK electrical hazard symbol (see Figure 7). Motorsport UK's fire suppression regulations are met by the Lifeline fire extinguisher with an exterior pull handle (Figures 6 and 7). The Yokohama A052 tires have a major regulatory advantage over complete slick compounds because they are road-legal semi-slick compounds, which means the car may theoretically compete in events where road-legal tires are required (Motorsport UK, 2024).



Figure 8: External fire extinguisher pull handle (red T-bar, centre) and external kill switch (red push-button, below it) mounted on the top of the scuttle/body between the windscreen and bonnet. The Motorsport UK fire(E) symbol sticker and electrical hazard triangle sticker are also visible, as required by Motorsport UK General Regulations.

Critical Discussion and Conclusions

The UWTSD Morgan Plus 4 is a well-thought-out motorsport adaptation of a speciality road car with an aluminium chassis. The additions of occupant protection (roll cage), fire suppression (Lifeline system), electrical isolation (kill switch), and bulk reduction through the elimination of unnecessary road equipment are all improvements that adhere to accepted motorsport preparation guidelines. Yokohama A052 road-legal semi-slick tires maintain alternatives for competition classes that require road tires.

The interface between the bonded aluminium BIW and the steel roll cage is the main structural issue. The road vehicle's mass distribution and load pathways were taken into consideration when designing the CX-Generation chassis. The steel cage produces different material joins that are susceptible to thermal fatigue and galvanic corrosion, greatly increases local stiffness, and modifies global torsional behaviour (Naito and Suzuki, n.d.; Sika, 2023). The longer Plus 6 A-arms increase strains at

certain mounting locations over their initial design loads by further altering load introduction at the chassis nodes. The structural margins at these places remain unquantified in the absence of a formal finite element analysis reappraisal, such as the one outlined by Fedotova et al. (2020) for BIW optimisation.

The vehicle has been appropriately converted to a competition-only form from a regulatory perspective. The photos seem to show that important Motorsport UK standards, such as multi-point harness installation, fire extinguisher type and accessibility, and kill switch positioning, have been met. Before the car enters competition, it is still necessary to legally verify all cage dimensions, material grades, and weld quality to Motorsport UK General Regulations Section K. A key limitation of this analysis is the absence of quantitative validation, such as finite element analysis or experimental testing. As a result, while qualitative improvements in stiffness and safety can be inferred, the exact structural performance and long-term durability remain uncertain.

To sum up, the UWTSD Morgan Plus 4 illustrates the basic trade-offs involved in racing conversion: improvements in bulk reduction, roll-over protection, and fire safety come at the expense of road legality, NVH performance, and occupant comfort. Although the CX-Generation Morgan's bonded aluminium BIW is a sophisticated, lightweight structure that is ideal for a niche sports car, its interaction with the additional steel cage structures necessitates careful engineering attention to ensure long-term structural integrity in the demanding environment of motorsport competition.

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