Chassis for Classic Car Vehicle Shell

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The Lightburn Zeta Sports car was manufactured by Lightburn Industries in South Australia during 1961. This two seater sports car featured a rear mounted 500cc air-cooled two-stroke engine, a tubular steel chassis, and a one-piece fiberglass body. Of the 48 cars manufactured only 21 cars or parts thereof are known to exist, and many of these have found their way into National and International motor museums. A badly damaged body shell was obtained by the author and as a result of its rarity few, if any, repair parts are available. The aim of the project was to design a suitable replacement vehicle chassis, in accordance with Australian Design Rules (ADRs) and the National Code of Practice (NCOP), that could be fitted with modern readily available vehicular components and running gear, whilst maintaining the external appearance of the existing body. The importance of the proposed chassis design complying with ADRs and NCOP is to allow the Lightburn Zeta Sports, once restored, to be unconditionally registered in Australia. A study of the history, design and construction of the Lightburn Zeta Sports was conducted by investigating other surviving vehicles and from historical information in order to understand what design process had been undertaken by the Lightburn factory. Various chassis designs were explored for their suitability for the Lightburn Zeta Sports and it was decided that the replacement chassis would consist of an aluminium honeycomb sandwich panel monocoque front section coupled to a space frame rear section. Previous studies have shown that honeycomb monocoque chassis have been suitable for electric vehicles; however, they have not been used for conventional powered vehicles. The method used to develop the replacement chassis was to set the design space which the replacement chassis could occupy and select the various key components and running gear that would be used. The chassis was designed and modeled in CATIA around these components and design space and an iterative process was undertaken based on finite element analysis to ensure that the chassis was robust and functional. The novel use of aluminium honeycomb panel in conjunction with a conventional space frame proved successful in achieving a replacement Lightburn Zeta Sports chassis design that was light weight and rigid. From this project it has been determined that a replacement Lightburn Zeta Sports chassis can be constructed from aluminium honeycomb sandwich panel and a steel space frame that when constructed in the future will comply with ADRs and the NCOP.

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I. Introduction

The impetus for this project was that the author had acquired a dilapidated Lightburn Zeta Sports body shell that had neither chassis nor mechanical running gear, Fig 1. In order to recreate this vehicle using the existing body to a road worthy condition, a chassis, engine, driveline, and other running gear would have to be acquired or developed. Despite an exhaustive search over a 12 month period no mechanical parts, except for a set of hubcaps, could be obtained. Thus a decision was made to design a chassis for the body that would be based around an existing modern engine and other readily available vehicle components. The initial emphasis for the chassis design was that the chassis and assembled components should not significantly alter the outer appearance of the vehicle and would preserve the intrinsic characteristics of the vehicles original mechanical design.

Tony Davis\(^1\) review of the 1963 Lightburn Zeta Sports, Fig 2, stated that the car lacked style, innovation and was plain ugly. Despite this harsh criticism the Lightburn Zeta Sports cars are becoming popular as collector’s items or as display pieces for motoring museums. Unfortunately, only 48 cars were built and only 21 surviving vehicles in various conditions, including the Authors, are known to exist\(^2\). The aim of this project is to design a replacement chassis that complies with ADRs and the NCOP that, once constructed and fitted to the existing body shell, will enable the Lightburn Zeta Sports to be returned to a road worthy condition. This project will; examine the history and specifications of the Lightburn Zeta Sports to allow the replacement chassis to be designed with an understanding of what the original designers of the Lightburn Zeta Sports were trying to achieve; investigate the various types of chassis in order to select what replacement chassis design would be best suited to the replacement chassis; explore what static and dynamic loads the chassis will be subjected to during normal operation; identify the required mechanical components and associated running gear that will be necessary for the restoration of the Lightburn Zeta Sports; select raw materials and construction methods used to construct the replacement chassis; explore what ADRs and NCOP that the replacement chassis must comply with in order to be road registered. As a result of this study a replacement chassis will be designed and engineered in CATIA that when constructed at a later stage, not part of this project, will allow the Lightburn Zeta Sports to be restored to a roadworthy condition thus preserving part of Australia’s motoring heritage.
II. History of the Lightburn Zeta Sports

To be able to design and build a chassis that will allow the Lightburn Zeta Sports to be restored to a roadworthy condition, whilst preserving its original body shape and mechanical characteristic, a study of the design history of the Lightburn Zeta Sports was conducted. During the mid to late 1950s Harold Lightburn, the managing director of Lightburn Industries (a large Australian company famous for producing, cement mixers, automotive jacks, power tools, and white goods\(^4\)) had an idea to develop a range of small Australian built cars that would be affordable by most Australian families. The chosen designs would have to be able to be manufactured at his factory in South Australia and require minimal production setup costs including tooling. Lightburn enlisted the automotive design expertise of Gordon Bedson an experienced engineer with a background in structural and performance engineering in aircraft. Bedson after leaving the Vickers aircraft company designed and built a number of racing cars for the Formula 3 500cc class in England. Figure 3 shows the “Mackson” chassis that Bedson designed for the Eucuri Richmond team for the 1952 season. It had a tubular chassis with wishbone front suspension and a swing axle at the rear and was lower and sleeker than most cars of the time\(^3\). From Fig 4 it can be seen that Bedson favored the placement of the control pedals forward of the front suspension. This design feature reduced the wheel base of the vehicle which decreased the turning circle and allowed for an overall reduction in length of the completed vehicle. Bedson, after leaving the Formula 3 class, was employed by Henry Meadows as the Export Sales Manager for the Meadows company that produced engines and transmissions for the British car market as well as generators. Meadows quickly noticed Bedson’s small car designs and put into production the Frisky mini-car range of vehicles\(^5\). As can be seen from Fig 4, the chassis for the Frisky cars were based on Bedson’s experience with the Formula 3 through the use of steel tubing in a ladder frame construction. The Frisky range featured a rear mounted two-stroke engine with a fiberglass body mounted on a steel tube ladder frame chassis. Experience gained from attending the principal European motor shows led Bedson to favour the Italian school of styling thus he approached Giovani Michelotti of Turin, who had experience with body design for manufacturers such as; Lotus, Fiat, and Ferrari, to design the fiberglass body for the Frisky sprint, Fig 5.

Harold Lightburn purchased the design and manufacturing rights to the Frisky Sprint and when Bedson arrived at the Lightburn factory in South Australia he began redeveloping the Frisky Sprint to suit the Australian market\(^7\). The main differences between the Frisky Sprint and the Lightburn Zeta Sports was: the body was restyled to make it unique to Lightburn which included removal of the engine cowl behind the driver as can be seen in Fig 5; fitting of a new front windscreen as well as small changes to the front and rear profiles; and the Excelson 492cc 3 cylinder motor was replaced by the two cylinder Fichtel & Sachs 500cc engine built by FMR\(^7\). Although all 48 Lightburn Zeta Sports were completed by 1961 they were not released for sale until 1963 when the Lightburn Company had completed construction of the Lightburn Zeta Runabout and Utility models, Figs 6,7.
During this time the Lightburn Zeta Sports were trialed and raced in local South Australian hill climb championships and other events, Fig 8. Most notably was the use of four Lightburn Zeta vehicles during the world land speed record attempt by Sir Donald Campbell during 1964, Fig 9. The Zeta’s lightweight and fiberglass body was well suited to use on the salt flats for track survey work according to Andrew Mustard the project director for the land speed record attempt.

Despite Lightburn’s predicted demand for the Lightburn Zeta Sports, sales were very slow; this can be attributed to poor reviews by popular motoring magazines, and the quirky nature of a fiberglass two-stroke car being unfamiliar to the Australian public. The Lightburn Zeta Sports had no doors so drivers and passengers had to slide over the side of the body to get in and out. Weather protection was provided by a collapsible vinyl hood supported by a metal frame and with the hood in the upright position exiting the vehicle was near impossible.

III. The Original Lightburn Zeta Sports Chassis and Specifications

The original chassis for the Lightburn Zeta Sports was manufactured locally by Lightburn and was constructed from 2.25” mild steel pipe. It was of a ladder type construction that consisted of two bent parallel side rails with six cross members and an upright frame at the rear that supported the rear mounted engine and suspension, Fig 10. The chassis was attached to the one piece fiberglass body by eight bolts, two at the front four in the centre and two at the rear. Due to its ladder type construction the torsional rigidity of the chassis was poor. The steering box was of worm and peg type and as it was forward of the front wheels it was connected to them by a number of linkages that were attached to the chassis, Fig 11.
The engine was mounted rearward of the rear axle and the driveline of the Lightburn Zeta Sports was very compact as the two drive axles were directly coupled to the transverse gearbox of the FMR motor, Fig 12. The gear box was of a constant mesh type and had an integral reverse gear. The Engine had an extremely low profile that enabled the rear of the body to have a narrow taper.

![Figure 12. Underneath view of the motor showing the drive shafts directly connected to the gearbox.](image)

The rear suspension was of a swing axle style that used a long coil over shock absorber mounted to the wheel hub and chassis. The lateral position of the rear wheel hub was located by the fixed length drive axles, Fig 13. The front suspension consisted of a Macpherson strut that was anchored to the chassis by a channel bracket. A lower wishbone was mounted to the wheel hub by ball joint and to the chassis through rubber bushes, Fig 14.

From promotional literature and sales brochures the specifications in Table 1 were obtained for the Lightburn Zeta Sports. These specifications give a good understanding of the overall size and performance of the original car.

![Figure 13. The passenger side real wheel showing the swing axle, and coil over suspension.](image)

![Figure 14. The front driver's side suspension showing the Macpherson strut assembly and lower wishbone.](image)

<table>
<thead>
<tr>
<th>Table 1. Original Zeta Sports Specifications</th>
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<td><strong>General</strong></td>
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<td>Length</td>
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IV. ADR\textsuperscript{8} and NCOP\textsuperscript{9} Compliance

It is recommended by state and federal authorities that prior to commencing building or modifying a vehicle that consultation with vehicle registering authorities and approved engineering signatories be conducted. As it is intended that the restored Lightburn Zeta Sports will be registered in the Australian Capital Territory (ACT) guidance was sort from the ACT Road Transport Authority Vehicle Inspection Technical Unit and Mr Paul Nelson from Neltech Engineering Solutions in regards to possible issues with the proposed concept for the Lightburn Zeta Sports replacement chassis. As a result of this consultation it was advised that if the chassis and completed vehicle complies with the applicable ADRs and the NCOP, and is accompanied by an engineering certificate, by an approved signatory, when presented for registration there would be few if any issues in gaining unconditional vehicle registration in the ACT.

The NCOP for Light Vehicle Construction and Modification has been prepared in consultation with industry, user groups and government agencies with an interest in light vehicle construction and modification. The NCOP has been subsequently endorsed by all Australian State and Territory Authorities responsible for vehicle standards and the registration of vehicles for road use. The NCOP applies to both the modification of production vehicles and the construction of individually constructed vehicles (ICV). The aim of the NCOP is to provide a nationally acceptable set of technical specifications that ensure that the manufacture of individually constructed vehicles or the modification of production vehicles comply with the applicable requirements of the Australian Design Rules and the Australian Vehicle Standard Rules 1999 (AVSR). A review of the applicable NCOP and ADRs was conducted prior to commencing the design of the replacement Lightburn Zeta Sports chassis to ensure that any requirements would be implemented during the design phase. A summary of the applicable ADRs and NCOP are in appendix A and appendix B. There are two classification methods that the Lightburn Zeta Sports can be constructed under. The first is if the Lightburn Zeta Sports is classified as an Individually Constructed Vehicle, NCOP 10 Section LO, and the second is if the Lightburn Zeta Sports can be justified as a re-chassied body NCOP 6 section LH. If the Lightburn Zeta Sports is classified as an ICV it would mean that a number of significant modifications to the actual body shape would have to be conducted, such as but not limited to head light positions, windscreen supports and relocation of external safety lights. However, under the classification of NCOP6 section LH as a re-chassied vehicle many of these restrictions do not apply to the body.

A. Chassis and Body

Under NCOP 6 section LH5 the Lightburn Zeta Sports would be classified as an ‘extensive modification to production vehicles based on the construction of a vehicle from a newly constructed chassis and an un-modified or modified body from another vehicle model’. Under this condition the Lightburn Zeta Sports body will only have to comply with the standards applicable to a vehicle manufactured in 1963. This means that modification to the body shape or style of the Lightburn Zeta Sports will not be required in order for it to be registered. NCOP 6 LH5 specifies the vehicle structure must have adequate strength and stiffness to provide safe handling and that a vehicle with a newly constructed or specifically designed chassis will not need to undergo beaming and torsional testing to determine their relevant stiffness. It specifies that the manufacturer (Author) shall remain responsible for the design of the chassis and its inherent structural strength and thus safety and that a torsion rigidity of at least 400 Nm per degree is recommended.

B. Steering geometry and suspension

Under NCOP 6 LH5 steering and other suspension components can be sourced from various donor vehicles or manufactured to suit the require purpose provided that have adequate strength for the loads imposed and will not be at the risk of fatigue failure. All manufactured steering components that are welded must be subjected to X-ray and dye crack detection tests and must be accompanied by a metallurgical certificate. Where a wheel base is extended compared to the donor vehicle NCOP 6 LH5 recommends ensuring the Ackerman steering geometry is similar to the original design and throughout the range of suspension travel for the steering road wheels the maximum toe-in and toe-out shall not be greater than 20mm measured at the maximum tyre diameter. The completed vehicle must also successfully complete a lane-change maneuver test to verify the road holding ability and handling characteristics of the vehicle are safe. The lane-change maneuver test consists of driving a vehicle through a set track that simulates a lane-change maneuver. The vehicle is driven from its initial lane to another lane (parallel to the initial lane), then returning to the initial lane. The length of each track section remains constant whilst the track width is a function of the vehicle width and is specified in ISO Technical Report 3888-1:1999- Passenger cars - Test Track for a Severe Lane-Change Maneuver – Part1: Double lane change test. To pass this test a vehicle laden in accordance with NCOP 17 Section LT23, must safely change lanes at the vehicles maximum speed or 110 km/h (whichever is lower) with no unpredictable variations in the vehicles handling.

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C. Engine
In accordance with NCOP 3 Table LA1, the replacement engine size in cubic centimeters must be less than 3.0 x the weight of the vehicle in kg. This means that for the reconstructed Lightburn Zeta Sports that is estimated to weigh a minimum of 300 kg once completed will have a maximum naturally aspirated engine cubic capacity of 900cc.

D. Seats and Seat Belts
As the Lightburn Zeta Sports was not originally fitted with seat belts there is no legal requirement to install them in the finished vehicle due to the vehicle being classified as a re-chassied body. However, as a safety precaution it was decided to install lap-sash seatbelts in order to provide protection to the occupants in the case of an accident. In order to comply with ADR 3,4,5 and NCOP and in accordance with Vehicle Safety Bulletin 5A seat belt anchorages must have a steel backing plate of not less than 75mm x 50 mm x 3mm and be secured using a grade 8.8 M12 bolts.

E. Roll Hoop
Whilst one of the key design aspects for the Lightburn Zeta Sports chassis was that the design should not impact on the original appearance of the Lightburn Zeta Sports body, it was deemed necessary for safety by the author that the vehicle be fitted with a roll hoop to ensure protection to the driver and passenger in the event of a vehicle roll over. NCOP 7 Section LK8 specifies the spatial and engineering requirements for the roll hoop including the minimum diameter of steel tube of 45mm with 2.5mm wall thickness. The roll over hoop will also act as the upper mounting point for the passenger and driver’s lap-sash seat belt.

F. Ground Clearance
The ground clearance of a vehicle in accordance with ADR 43 specifies that a vehicle must have 100mm of ground clearance within 1 meter of an axle group and at least 1/13 of the wheel base at the midpoint between them. This results in the Lightburn Zeta Sports chassis being required to have a ground clearance at the midpoint of the vehicle of 138mm. This is greater than the 127mm ground clearance of the original vehicle however; it will not have a significant impact on the vehicles overall appearance.

V. Chassis Review
The purpose of an automotive chassis is to connect all key elements of the vehicle with a structure that is both rigid in bending and torsion and should absorb all loads fed into it without deflecting unduly. The chassis provides suitable mountings and areas for all components of the car including but not limited to: occupant seating and luggage, rear suspension and final drive, front suspension and steering, engine and transmission, fuel tank, steering column, pedals and other controls, radiator, battery, sensors and electronics, and spare wheel. One aspect of chassis design that has increasing importance is that of occupant safety in the event of a collision. As the chassis is the main structure by which forces are transmitted through the vehicle it should provide some means of absorbing energy from frontal, side and rollover impacts, either by controlled deformation or attenuation. The chassis should also provide protection to the occupants by ensuring that the spatial area of the seating positions is not significantly decreased thereby trapping/pinning the occupants.

G. Types of Chassis
In order to assess what type of chassis would be suitable for the Lightburn Zeta Sports an investigation into past and present chassis designs was conducted focusing on the advantages and disadvantages of each. The types of chassis that were investigated include: ladder frame, backbone, space frame, monocoque, and honeycomb panel.

1. Ladder Frame Chassis
Early car chassis designs were mainly of ladder frame construction, Fig 4, due to its simplicity, versatility, durability and low development costs. The ladder frame was very common for passenger vehicles until the 1960s and is still used for many four wheel drives and utility vehicles. The ladder frame consists of two longitudinal beams with multiple cross members joining the two beams. The ladder frame chassis is versatile as it allows virtually any body shape to be placed atop the chassis and has good beamling stiffness due the use of closed section beams with a high second moment of area. The high bending stiffness makes the ladder frame chassis well suited for carrying large weights; however, the ladder frame chassis has very poor torsional stiffness due to torsional stiffness depending on the cross section of the ladder rails. Torsional stiffness cannot be altered by changing the position of the cross-members and can only be improved by adding a cruciform structure. In modern conventional vehicles the body structure provides some improvement to the torsional stiffness; however, in convertibles and fibreglass bodied cars this improvement is negligible.
2. **Backbone Chassis**

The backbone chassis consists of a large longitudinal structural beam positioned along the centre line of the vehicle, Fig 15. The front and rear suspension is usually configured around a T or Y shaped cross member positioned at either end of the chassis. This chassis design caters for both front and rear mounted engines as the backbones cross section can be adapted to house the driveline. The torsional stiffness of this type of chassis is greater than that of the ladder frame, due to the large closed cross section of the main beam. The fabrication of this style of chassis is relatively simple and it can be made quite light. This form of chassis provides no side impact protection for occupants and as a result the body has to be designed to take these forces, which normally results in a heavier Body14.

3. **Space Frame Chassis**

The traditional space frame chassis, Fig 16, consists of a number of triangulated tubes that are only in tension or compression with no bending or twisting loads. Therefore, each load-bearing point must be supported in three dimensions15. The resulting structure is very light and has very good torsional stiffness compared to the ladder and backbone chassis. In order to maintain torsional and bending stiffness the space frame design requires high door sills; therefore, precluding the use of conventional doors, as was the case the Mercedes Benz 300SL. Construction of the space frame chassis is difficult to automate due to the complex geometry of the intersecting tubes and the requirement to manually weld each tube into position; therefore, it is seldom used in commercial production applications. However, high end vehicle manufacturers such as Audi have used aluminium space frames to greatly reduce the weight of the vehicle’s chassis. While they do not employ the use of tubing they use hydro-formed sections and apply the same principles of triangulation to ensure that structural members are either in tension or compression, Fig 17.

4. **Monocoque Chassis**

A monocoque or uni-body chassis is a chassis that is integral with the body. The monocoque chassis is the chassis of choice for all major high production car manufacturers due to the highly automated manufacturing process. The infrastructure and tooling set up costs to manufacture a commercial monocoque vehicle is prohibitive for very small volume or one-off designs16. Bending stiffness of a monocoque chassis is good due to the bending forces being resolved into tension or compression in the roof and lower structure; however, in convertible style vehicles the lower structure and side rails have to be significantly stronger due the lack of roof, as is the case with the MGB. The torsional stiffness of the monocoque chassis is far superior to that of the ladder frame and is comparable to that of a space frame17. The monocoque, while being cost effective in mass production applications it is also efficient at saving space due to the chassis being part of the body shell.

5. **Honeycomb Panel Chassis**

The use of composites in vehicle design is becoming increasingly apparent due to the increase in fuel economy that can be gained by reducing the overall weight of the vehicle. In 2005 the University of South Australia constructed a two-seater three-wheeled electric vehicle called TREV using an aluminium honeycomb panel chassis. The chassis comprised of a flat floor and a forward and rear bulk head. The side rails were formed by folding of the honeycomb panel after the top facing had been cut by routing, Fig 18. The folded section was then glued into position and reinforced with fibreglass tape. This provided a strong, rigid and lightweight monocoque chassis, Fig 19, that was easily manufactured by personnel with little metal working experience and minimal tooling.
The University of Waikato, New Zealand, used the same aluminium clad honeycomb sandwich panels to construct the chassis for their battery powered electric vehicle, Fig 20. The vehicle’s chassis was designed using an interlocking technique that uses finger and butt joints commonly used in carpentry to strengthen corner joints. This technique resulted in a 3D jigsaw type construction that was strong and stiff. All of the panels were accurately cut using water-jet cutting and were glued, using an aluminium specific epoxy adhesive, and rivets. The chassis performed well during testing and required only minimal fine tuning and weighed less than 70kg. It exhibited good beaming and torsional stiffness and since construction in 2007 it has completed in excess of 1800km without failure. The suspension components were attached to the honeycomb panel with special load dispersing inserts and braced with aluminium extrusions. The construction of this chassis compared to the TREV chassis is that very little manual cutting and shaping of the sandwich panel was undertaken, thus increasing the dimension accuracy of the completed chassis. By using minimal manual cutting the construction time of the chassis was reduced when compared with that of the TREV.

VI. Forces Acting on the Chassis

An investigation was conducted to determine what loading scenarios the Lightburn Zeta Sports chassis will be subjected to during normal operation. The dynamic and static loading, of the vehicle under normal driving conditions must be considered in order to design a chassis that is strong in both torsion and beaming, whilst also being light. A flexible chassis is a detriment to good handling and performance characteristics as it alters the suspension and steering geometry while the vehicle is under load.

H. Longitudinal Torsion

Torsional deformation in the chassis structure is caused as a result of applied loads acting on one or two opposed corners of the vehicle. These forces may be induced by irregularities in the road surface such as; bumps or potholes, the vehicle mounting a kerb or speed hump not squarely, or from lateral variations in the road surface. In high performance rear wheel drive vehicles with high powered front mounted engines the resulting engine torque during rapid acceleration can distort the chassis in this mode. The torsional deformation of a vehicular chassis, as depicted in Fig 21, can affect the suspension and steering geometry of the vehicle which may induce unpredictable and undesired handling characteristics.
I. Vertical Bending

Vertical bending of the vehicle structure, as depicted in Fig 22, is caused as a result of static and dynamic forces in the vertical direction. These forces are due to the vehicle carrying occupants and cargo and mechanical components such as engines, transmissions and ancillary equipment. Fig 22 is a simplistic representation of the first mode of bending as it does not consider the loads forward and rearward of the front and rear axles respectively. The magnitude of these forces can be increased depending on accelerations of the front or rear axles in the vertical direction.

J. Lateral Bending

Figure 23 represents lateral loading of the vehicular chassis that causes the chassis to distort in the lateral direction primarily acting through the centre of gravity. These loads can be induced due to the camber of the road surface, cornering maneuvers and lateral wind loadings. This loading causes transverse forces in suspension components and suspension mounting points.

K. Horizontal Lozenging

Deflection of the chassis in this form, Fig 24 is caused by a variation in traction on diagonally opposing wheels as a result of either surface conditions or from wheels striking an obstacle. This condition can be induced by the horizontal forces from a vehicle mounting a kerb or from the vehicle veering on to the soft unsealed shoulder of a road.

L. Design Loads

According to, Costin and Phipps\(^1\), and Riley\(^2\) the loads that a vehicular structure can be subjected to during normal operation are in Table 2. These design loads were used to calculate the stresses and forces acting on the Lightburn Zeta Sports chassis and associated components.

Table 2. Static and dynamic loads that are applicable to vehicle structures

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<thead>
<tr>
<th>Load Type</th>
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<th>Rear</th>
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<td>Static Load</td>
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<td>1g</td>
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<tr>
<td>Bump Load Symmetrical</td>
<td>3.5g – 4g</td>
<td>3.5g – 4g</td>
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<tr>
<td>Bump Load Diagonally opposed</td>
<td>3.5g – 4g</td>
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<tr>
<td>Braking Load</td>
<td>1g – 1.5g</td>
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<tr>
<td>Lateral Load</td>
<td>1.5g</td>
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VII. Measuring the Body Shell

In order to begin the design of the Lightburn Zeta Sports chassis and for the selection of components the existing body shell was measured and surveyed to define what space was available for the chassis and associated running gear. This was done by dividing the body shell into 8 transverse sections, Fig 25, and taking appropriate internal and external measurements. The resulting measurements formed the dimensional envelope that the chassis design could occupy. The original body shell was of a homogenous construction with all internal panels, firewalls, inner guards and floor pan being molded out of fiberglass. Unrestricted access was provided to an unmodified Lightburn Zeta Sports owned by Mr Fred Diwell at the Australian Motorlife Museum. This vehicle was also measured primarily focusing on the internal structure of the fiberglass body, seating positions, pedal location, steering wheel location, and the location of other primary controls. The measuring of this vehicle allowed for the comparison between the two vehicles to determine how significant the modifications to the acquired Lightburn Zeta Sports body were. It was noted that on the acquired body the fiberglass floor pan and all internal panels had been removed and a large section from the front ‘bonnet area’ has been cut away. The heavy internal modification that the body was subjected to prior to acquisition presented as both a challenge and opportunity. The opportunities that this presented was that the chassis design would not be restricted by any internal detail of inner guards, fire wall locations, seating positions or engine mountings. The internal design envelope was modeled in CATIA and was used to determine the space available for key components such as; occupants, engine, drive line, and suspension.

VIII. The Selection of Engine and Driveline

A. Engine

The replacement engine for the Lightburn Zeta Sports needed to be quite small and compact in order to be mounted in the rear of the vehicle. Most conventional car engines investigated, both lateral and transverse, tended to have high side profiles and or long drive trains that could not be accommodated in the Lightburn Zeta Sports body due to the short and low profile space. However, as Lightburn had previously used motorcycle engines in the Runabout version of the Zeta, a 324cc Villiers 3T two-stroke, a number of readily available motorcycle engines were investigated for suitability. Motorcycle engines proved to be small and compact with short side profiles and light weight. The integral gearbox on a motorcycle motor meant that the length of the drive train could be kept short and would not require further modification of the existing body. As a result of this investigation a 2001 Honda CBR 600 engine was selected from a local motorcycle wrecker. The selection of this engine was primarily based on the low side profile, engine capacity, and cost. The engine is a non-fuel-injected water cooled four-cylinder four-stroke with a constant mesh six speed gearbox with the following gear ratios: 1st 2.867:1, 2nd 2.929:1, 3rd 2.063:1, 4th 1.588:1, 5th 1.368:1, 6th 1.2:1, and 6th 1.087:1. The engine produces 63.4 kW at 11000 rpm and 59 Nm at 8500 rpm and has a wet weight of 62 kg.

It was necessary to purchase the engine, Fig 26, for $800 prior to commencing the design of the chassis so that weight distribution and mounting positions could be assessed. Figure 27 is a stylistic representation of the side profile of the engine that was used as part of the design envelope for the development of the chassis; however, the max width of the engine, not shown in the diagram, is 350mm.

Figure 25. Mock up of the Lightburn Zeta Sports using FSM 650 wheels showing the locations of lateral sections.

Figure 26. Engine that was selected from a local motorcycle wrecker.
B. Differential /Reverse Gear

As the output from the engine is via chain drive, a chain driven differential was obtained from a 1963 Lightburn Zeta Runabout. Due to the power increase of the CBR 600cc engine compared to Lightburn Zeta Runabout’s 324cc engine a stress analysis was conducted of the differential unit and it proved marginally capable of being able to take the torque produced by the Honda CBR 600 engine. As the Honda CBR 600 engine’s integral gearbox is not fitted with a reversing gear a separate reversing module was developed in parallel to this project. The reversing module developed, Fig 28, uses an internally splined input and output shaft that are connected by an externally splined lay shaft. The output shaft is fitted with a bevel gear that is permanently engaged to an idling bevel gear. The lay shaft which is mechanically actuated moves forward and rearward and is also fitted with a bevel gear. In the reversing position, Fig 29, the internal splines on the output shaft and the external splines on the input shaft disengage and the bevel gear on the lay shaft, Fig 30, engages the bevel gear on the idle shaft. The idle bevel gear then drives the bevel gear on the output shaft in the opposite direction to the input shaft. There is a spigot on the lay shaft that rotates inside a phosphor-bronze bush in the output shaft that is free to move in the lateral direction that provides support to the lay shaft when reverse is engaged. To engage forward gear, Fig 31, the lay shaft moves to the rear which disengages the lay shaft’s bevel gear from the idler bevel gear and engages the external splines on the output shaft. In both the forward and reverse position the internal splines on the input shaft are permanently engaged to the external splines on the lay shaft. The lay shaft is locked into either the forward or reverse position by a freely rotating cam block positively located on the lay shaft that engages locating lugs on the reversing modules housing. The longitudinal thrust generated by the bevel gears when the module is in the reverse position is prevented from disengaging the lay shaft by the use of the locking cam. The reversing modules housing is constructed out of 2024 aluminium and the input, output and lay shafts are 4140 steel in the hardened condition. The module is lubricated by 80W/90 GL-5 gear oil and is vented to the atmosphere. The input shaft is driven by chain to the output sprocket of the Honda CBR 600 engine and the output shaft is connected by chain to the differential.
The unit is activated by a lever in the cockpit by moving the lever forward the forward drive is selected and by moving the lever rearward the reverse drive is selected. The advantages of this unit is that it allows for easy adjustment of the final drive ratios by simply fitting various sized sprockets to either the input or output shafts. The unit is compact and can be easily mounted onto the chassis frame; however, the disadvantage of this unit is that the adjustment of chain tension has to be done both vertically and longitudinally.

Due to the cumbersome nature of the final drive going from the output of the engine to the reversing box and then to the differential an alternative commercial solution was investigated. Quaife Engineering manufactures of driveline and steering rack components have developed an integral differential, reversing gear and reduction unit that has been purpose built for motorcycle engine vehicles, Fig 32. The unit is capable of handling the torque and power of a Suzuki Hayabusa engine rated at 125kW. The advantages of this unit are that the output flanges are designed for readily available Ford Fiesta trans-axle components, the unit is light weight, and has been proven in a number of motorcycle engineied cars including the Radical. This option was chosen over the use of the 1963 Lightburn Zeta Runabout differential and custom built reversing unit for the following reasons: the Lightburn Zeta differential unit was only marginally capable of handling the torque of the Honda CBR 600 engine therefore, a stronger option was preferable; the custom made reversing module had not been manufactured and as a result was untested, the complexity of having two separate chains drives required additional adjustment mechanisms to ensure correct chain tension in both chains; custom made transaxle shaft couplings would have to be fabricated to suit the Lightburn Zeta Runabout differential. The only preventative factor in selecting the Quaife differential is the new purchase cost of $2550 however, significant reductions to this cost can be made if a used second-hand unit was purchased.

IX. The Selection of a Donor Vehicle/Components

Numerous attempts have been made to source original or replacement parts for the Lightburn Zeta Sports from both inside and outside of Australia. The motivation behind sourcing original or identical replacement parts was to maintain some original aspects and features of the vehicle. The micro car and scooter club of Australia have provided access to a number of members with information relating to the Lightburn Zeta Sports; however, no parts were able to be found or if parts were located their private owners were reluctant to part with them. This led to the decision to source parts and components from existing vehicles by other manufactures. It was preferable that the parts be sourced from either auto-dismantlers or from wrecked vehicles in order to ensure that the cost of these parts could be kept to a minimum.

The suspension system defines how effectively the tyres can be utilised to obtain traction with the road, and also determines driver comfort and control\(^1\). The selection of the suspension has a great impact on the handling and cornering stability of the vehicle as well as the shape and structure of the chassis due to spatial accommodation and locating fixtures. It was decided that the completed Lightburn Zeta Sports will have independent front suspension and due to the drive line comprising a motorcycle motor coupled to a chain driven differential, the rear will also have independent suspension. It was desired that when the Lightburn Zeta Sports restoration project is completed that there would be minimal changes to the outward appearance of the vehicle in order to preserve the vehicle’s historical significance and to allow it to be recognized as a Lightburn Zeta Sports. Therefore, the selection of donor parts or vehicles for the project focused on selecting components that would not require modification of the body structure. The diameter of the wheel arches and the desire to maintain a similar side profile resulted in the diameter of the donor rims to be no greater than 13”. Although 10” rims were fitted originally to the Lightburn Zeta Sports no current or modern vehicle uses them, except for the pre 1990’s Morris Mini, therefore the choice of rim sizes was restricted to 12” and 13” rims.

The restriction of rim size greatly impacted on the number and types of vehicles that could be used for donor parts due to the size limitation of wheel hubs and braking components. In conjunction with wheel rim diameter
the donor vehicles suspension system had to be compact in order to fit underneath the existing body whilst requiring minimal modification to incorporate it into the chassis design.

A field survey was conducted of local and interstate automotive dismantlers over several weeks with the aim of short listing vehicles or components that would be suitable for the Lightburn Zeta Sports project. Due to the constructed Lightburn Zeta Sports being mid-engined and rear wheel drive with independent rear and front suspension no single vehicle that was surveyed could provide all these features. The vehicles that were suitable based on rim sizes were all predominately front-engined front wheel drive vehicles and used Macpherson strut suspension on the front and various rear suspension arrangements.

The short list of vehicles identified as being suitable for wheels, suspension and drive line components are: Daihatsu (Charade, Mira); Suzuki (Swift); Mazda (Metro); Subaru (Fiori); Ford (Fiesta, Telstar) and Hyundai (Excel, Getz).

For the rear suspension and driveline for the Lightburn Zeta Sports the front suspension and driveline of the above vehicles would be suitable. However, in order to use any suspension or drive components from these vehicles, significant modification would have to be made in order to accommodate them in the Lightburn Zeta Sports design. The following issues were identified in adapting the front wheel drive suspension and driveline components to the rear wheel drive of the Lightburn Zeta Sports: The Macpherson strut suspension due to height restrictions of the rear section of the body will not fit, no handbrake mechanism is fitted to the hubs, and the hubs as they are used in the donor vehicle are steerable would be required to be fixed in position. To rectify this situation the Macpherson struts would be removed and only the wheel hub, knuckle assembly, brakes and transverse shafts would be retained. To these components upper and lower wishbones would be fabricated and fitted to the knuckle, with the upper wishbone fixing the knuckles steering rotation. Suspension and dampening would be provided by a coil-over shock absorber fitted to the upper wishbone and directly attached to the chassis. The two existing transverse shafts would be modified to suit the output flanges on the chain differential unit and to overcome the lack of handbrake an inboard brake disk would be fitted to each side of the chain driven differential unit.

For the front suspension and steering components of the Lightburn Zeta Sports a second set of front suspension, wheels, hubs and steering components, were required. However, due to the Lightburn Zeta Sports front axle weight being significantly less than the donor vehicles front axle weight and the restriction of height, due to the Lightburn Zeta Sports body, the Macpherson strut would have to be replaced by a shorter unit with a reduced spring rate.

Although these components were suitable and would work well, significant modification and fabrication of additional components was required in order to adapt the donor parts to the Lightburn Zeta Sports. The impetus behind the Lightburn Zeta Sports project was to use existing vehicle components with only minor modification and fabrication work being conducted. Therefore, continuing research into donor vehicle suitability led to the discovery of the FSM 650, Fig 33, otherwise known as the “Niki” or Fiat 650 as the donor vehicle. The FSM 650 was manufactured by Fabryka Samochodów Małolitrażowych (FSM) in Poland under License from Fiat Italy from 1973 to 2000 and imported to Australia. The main features of the FSM 650 that make it more suitable to the Lightburn Zeta Sports project over the selection of other components is that the vehicle is rear-engined rear wheel drive, has 12” rims compared to the 13” rims available on the other vehicles investigated and the dimensional similarity of the FSM 650 to the original specifications of the Lightburn Zeta Sports is relatively close as shown in Table 3. A list of parts that will be used from the FSM 650 for the Lightburn Zeta Sports project is in appendix C. The unregistered FSM 650 was purchased from Melbourne, using ebay, for $500 and was driven to Canberra under temporary registration.

![Image](image_url)
To obtain correct and accurate measurements of the suspension, drive line components, their spatial orientation and alignment to the chassis it was necessary to use a range of measuring techniques. The FSM 650 was raised above ground level on vehicle stands to allow easy access to the underside and the road wheels were removed as required. As it may be sometime before the components from the FSM 650 are required to be fitted to the new Lightburn Zeta Sports chassis it was decided that the all components will remain in situ and will not be removed from the vehicle for dimensional analysis. This course of action would allow the FSM 650 to be moved at any stage. However, this resulted in some measurements being difficult to obtain by conventional measurement techniques. To overcome this shortfall a datum line was established and up to three laser line generators were used, two were rotating head style and the third was a self leveling line generator. This technique proved very effective as it allowed key dimensions to be

<table>
<thead>
<tr>
<th></th>
<th>FSM 650</th>
<th>Zeta Sports</th>
<th>Measurement Difference - FSM vs Zeta Sports</th>
<th>% Measurement Difference compared to original Zeta specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>3109mm</td>
<td>3225.8 mm</td>
<td>-116.8 mm</td>
<td>3.6% ↓</td>
</tr>
<tr>
<td>Width</td>
<td>1377mm</td>
<td>1473.2 mm</td>
<td>-96.2 mm</td>
<td>6.5% ↓</td>
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<tr>
<td>Ground Clearance</td>
<td>180 mm</td>
<td>127 mm</td>
<td>+ 53 mm</td>
<td>41.7% ↑</td>
</tr>
<tr>
<td>Turning Circle</td>
<td>8600 mm</td>
<td>7924.8 mm</td>
<td>+ 675.2 mm</td>
<td>8.5% ↑</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>580kg</td>
<td>406.4 kg</td>
<td>+ 173.6 kg</td>
<td>42% ↑</td>
</tr>
<tr>
<td>Max Speed</td>
<td>125 kmh</td>
<td>120.7 kmh</td>
<td>+ 4.3 kmh</td>
<td>3.6% ↑</td>
</tr>
<tr>
<td>Wheel Base</td>
<td>1840 mm</td>
<td>1784.35 mm</td>
<td>+ 55.65 mm</td>
<td>3.1% ↑</td>
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<tr>
<td>Track Front</td>
<td>1141 mm</td>
<td>1238.25 mm</td>
<td>- 97.25 mm</td>
<td>7.9% ↓</td>
</tr>
<tr>
<td>Track Rear</td>
<td>1202 mm</td>
<td>1238.25 mm</td>
<td>-36.25</td>
<td>2.9% ↓</td>
</tr>
</tbody>
</table>

Table 3. Key dimensions of the FSM 650 and Lightburn Zeta Sports

X. Measuring the FSM 650

Figure 34. Two intersecting laser lines used to determine the angle of intersection of the trans axle and semi trailing link.

To obtain correct and accurate measurements of the suspension, drive line components, their spatial orientation and alignment to the chassis it was necessary to use a range of measuring techniques. The FSM 650 was raised above ground level on vehicle stands to allow easy access to the underside and the road wheels were removed as required. As it may be sometime before the components from the FSM 650 are required to be fitted to the new Lightburn Zeta Sports chassis it was decided that all components will remain in situ and will not be removed from the vehicle for dimensional analysis. This course of action would allow the FSM 650 to be moved at any stage. However, this resulted in some measurements being difficult to obtain by conventional measurement techniques. To overcome this shortfall a datum line was established and up to three laser line generators were used, two were rotating head style and the third was a self leveling line generator. This technique proved very effective as it allowed key dimensions to be

Figure 35. Laser line generators in position underneath the suspended vehicle.
measured accurately and relatively quickly when compared to the time it would have taken to remove, measure and refit the item. This was evident in measuring the rear semi trailing link axle axis and the geometrical relations of the front suspension components. The standard measuring devices used during this processes were tape measures, steel rules, vernier calipers, internal/external calipers, angle gauges, protractors and engineer’s square. Figs 34, 35, demonstrate how the laser line generators were used and the ease at which angles and points of intersection could be easily found without the removal of any components.

XI. Front Suspension

A. Existing

The front suspension assembly of the FSM 650 can be seen in Figs 36, 37. The front suspension consists of a transverse leaf spring that connects the bottom of the passenger and driver’s side steering knuckle and is connected to the underside of front cross member through rubber lined u-clamps that allow the leaf spring to flex and move under normal operation. The leaf spring is located laterally by a single locating bolt that passes through the centre of the leaf spring. The upper wishbone is connected to the top of the wheel knuckle and to the firewall. A rubber bump-stop is positioned above the leaf spring and is engaged when the wheel jounces upward, from normal ride position, 75mm. A non-adjustable telescopic damper is connected to the upper wishbone and to the inner body panel. Steering is provided by a rack and pinion that is connected to each front wheel knuckle’s steering arm by adjustable tie rods.

B. Modifications

Due to the increase in the front wheel track from the FSM 650 to the Lightburn Zeta Sports of 97.25mm the transverse leaf spring would not be able to be included in the proposed design as it was not possible to alter the dimensions of the leaf spring in anyway. As the transverse leaf spring acts as the lower control arm moving the support mounts to the sides would shorten the lower control arm radius and reduce the amount of suspension travel. This would also alter the suspension geometry and could induce unpredictable handling characteristics. The two possible options that were investigated to overcome this issue were to source a custom manufactured transverse leaf spring that would accommodate the increase in wheel track, or replacement of the transverse leaf spring by two separate lower wishbones. The transverse leaf spring can be custom made by Lovels Springs Pty Ltd for $280. Whilst this custom transverse leaf spring solution would work, the ability to raise or lower the mounting height of the front suspension would not be easily accommodated due to the proposed Lightburn Zeta Sports chassis design having a singular honeycomb panel for the forward floor pan. The investigation into using two separate lower wishbones as replacements for the transverse leaf spring determined that this option would be more suitable as the wishbones could be manufactured by the author, and greater flexibility in adjusting the mounting positions on the chassis during the design process could be achieved. By fitting of separate lower wishbones the standard non-adjustable damper would be removed and replaced with a coil-over shock absorber. This replacement uses the existing mounting positions of the existing damper, thus minimizing the need to fabricate or modify
the front suspension components any further. The proposed design for the lower wishbone, Fig 38, utilises the original mounting positions on the front wheel upright as the original transverse leaf spring. It is cross braced and manufactured from 4130 Chrome Moly steel tube of 19.05mm diameter and a 2.41mm wall thickness. 12mm grade 8.8 bolts are used to secure the lower wishbone to the wheel upright and to the chassis mounting plate, Fig 39, and Nothalane bushes are used to isolate the vehicle chassis from road noise and road vibrations. The lower wishbone was designed to pivot around the same geometric centre as the original transverse leaf spring and analysed in CATIA. The design was subjected to a 1g braking load in the lateral direction which induced a moment of 132.5 Nm about the lower wheel upright mounting bolt and was also subjected to a 1.5g lateral load.

C. Kinematics

Once the replacement lower wishbone had been designed and analysed a kinematic analysis was conducted of the front suspension geometry. The model used for this analysis is in Fig 40. From the measurements obtained from the FSM 650 the kingpin inclination, scrub radius, and castor angle were found to be 5.5 degrees, 58.56mm and 6 degrees respectively, as shown in Figs 41,42. The model was then manipulated to simulate the change in suspension geometry due to a change of +/- 75mm of road wheel movement in the vertical direction; the results are displayed in Table 4.

1. Camber Change

Camber is the inclination of the wheel plane from a plane perpendicular to the road surface. The maximum camber change is -2.131 degrees on full jounce and -4.491 degrees on full rebound. This camber change alters the tyres contact patch with the road and will vary the caster thrust of the tyre and thus the chassis as the suspension moves up and down.

2. Toe-in (Bump Steer)

The toe in change during jounce and rebound will affect the handling of the car mainly during a corner either as a result of body roll or due to irregularities in the road surface. If the toe-in is positive during jounce and rebound the vehicle will tend to turn at a greater rate than the drivers input thus leading to unpredictable steering characteristics. From the kinematic analysis the maximum toe-in is -2.300mm at full bounce and -2.342 at full rebound this indicates that the wheels will not tend to toe-in during normal operation thus leading to fairly good driver feel.

Figure 40. Front passenger side suspension assembly showing replacement of the transverse leaf spring by the lower wishbone.

Figure 41. Passenger side view of front steering suspension components, less steering knuckle, hub and road wheel

Figure 42. Wheel position at normal ride height showing king pin inclination and scrub radius
XII. Rear Suspension

A. Existing
The rear suspension of the FSM 650 is an independent semi trailing link as shown in Fig 35, 43. The vertical location of the rear roll centre in the FSM 650 is 179.73mm above the ground datum and acts on the centre line of the differential. The rear suspension is controlled by an independent spring and damper combination that acts forward of the axle line. Full jounce and rebound of the rear suspension is 85mm and 60mm respectively. The left and right trans axles are equal length and are connected to the wheel hubs by constant velocity joints and to the transverse differential by universal joints. The rear suspension was measured using the same method used to measure the front suspension. Once all measurements were taken the rear suspension components were modeled in CATIA.

B. Modifications
Due to the slight increase of 36.25 mm in rear wheel track of the Lightburn Zeta Sports compared to the FSM 650 very little changes will be made to the rear suspension in order to adapt it to the design and layout of the Lightburn Zeta Sports chassis. Except for adjusting the mounting positions laterally to increase the wheel track by 36.25mm the only other modification that was made to the rear suspension was the removal of the two separate coil and damper units and replacing them with two coil over shock absorbers. This modification only requires minimal modification to the trailing link arms by the inclusion of a reinforcing and mounting plate in the position of the old coil.

Table 4. Kinematic analysis of the front suspension geometry under 75mm jounce and rebound.

<table>
<thead>
<tr>
<th>Wheel Travel mm</th>
<th>Camber Change Deg</th>
<th>Toe-in mm</th>
<th>Wheel Travel mm</th>
<th>Camber Change Deg</th>
<th>Toe-in mm</th>
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</thead>
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<td>75</td>
<td>-2.131</td>
<td>-2.300</td>
<td>-75</td>
<td>-4.491</td>
<td>-2.342</td>
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</tr>
<tr>
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<td>-0.003</td>
<td>-0.050</td>
<td>0</td>
<td>-0.003</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Figure 43. Semi trailing link rear suspension and geometric location of the rear roll centre
spring. This modification gave greater flexibility in positioning the chassis mounting point for the coil over shock absorber than would have been possible if the original coil spring and separate damper were retained in the chassis design.

XIII. Design

From the previous investigation into chassis’s used in vehicle design it was decided that the Lightburn Zeta Sports replacement chassis would be manufactured from aluminium honeycomb sandwich panels and steel tubing. Due to extensive internal modifications made to the Lightburn Zeta Sports body by previous owners the honeycomb panel would be used to provide an enclosed monocoque forward section that would require no further internal structures to seal the internal occupant seating area. Mounted to the honeycomb monocoque would be the front suspension, steering components, seating and vehicle controls. This honeycomb monocoque would then be coupled to a rear tubular steel space frame to which the engine, driveline and rear suspension would be mounted. Whilst both these methods of chassis construction have been used in previous vehicles they have rarely been coupled together in a singular vehicle chassis.

C. Selection of Materials

1. Aluminium Sandwich Panel

The aluminium sandwich panel used in the design, Fig 44, is manufactured by Ayres composites in Western Australia. The panels were originally designed for the lightweight construction of internal walls and fixtures in ships. However, due to their light weight and high strength the panels are being increasing used in light weight electric vehicle design. The panels are constructed out of 5052 aluminium honeycomb with an internal wall thickness of 0.1mm and external hexagonal cell radius of 7.5mm to which a top and bottom cladding of 5052 aluminium sheet is bonded using a proprietary adhesive.

The sandwich panels can be produced with a core thickness ranging from 6mm to 150mm with the aluminium cladding ranging in thickness from 0.3mm to 1mm. In order to use this honeycomb product in the design of the Lightburn Zeta Sports chassis it was important to understand how the panels would perform under loading. The main modes of failure of honeycomb panels are shown Fig 45, In honeycomb panels it can be assumed that facings take all the bending stresses (one panel in tension whilst the other is in compression) and the core carries the shear load. The equations governing the performance of the sandwich panels based on cladding of equal thickness are:

\[ b = \text{width of panel [m]} \]
\[ E_f = \text{cladding modulus} \]
\[ E_c = \text{core modulus} \]
\[ h = \text{centroid distance [m]} \]
\[ M = \text{bending moment [Nm]} \]
\[ \sigma = \text{cladding stress [Pa]} \]
\[ \sigma_{cr} = \text{critical cladding stress [Pa]} \]
\[ \tau_c = \text{core shear stress [Pa]} \]
\[ S = \text{cell size} \]
\[ t_c = \text{core thickness [m]} \]
\[ t_f = \text{cladding thickness [m]} \]

Figure 45. Failure modes in honeycomb sandwich panel.

Figure 44. Aluminium honeycomb panel construction.
\[ h = t_f + \frac{1}{2} t_c \]  

\[ \sigma = \frac{M}{t_f h b} \]  

\[ \sigma_{cr} = \frac{2Ef}{\lambda} \left[ \frac{t_f}{S} \right]^2 \]  

\[ \sigma_{cr} = 0.82E_f \left[ \frac{E_c t_f}{E_f t_c} \right]^2 \]  

From Eq (1,2)\(^2\) the bending stress in the top and bottom facings can be determined when there is a bending moment applied to the panel or alternatively this was used to determine the maximum bending moment that the panels could support. In the 50mm panel this equated to 15.8kN/m and 9.4kN/m in the 30mm panel. Eq. (3,4) are used to determine if the sandwich panel will fail as a result of face dimpling or face wrinkling.

For the design of the Lightburn Zeta Sports chassis the two sizes of honeycomb panels that were selected are 1mm top and bottom cladding with a 48mm core and 1mm top and bottom cladding with a 28mm core. The overall weight and dimensions of these panels are 1200mm x 2400mm x 50mm (8.7kg/m\(^3\)) and 1200mm x 2400mm x 30mm (7.4kg/m\(^3\)).

In CATIA the panels were modeled as a singular part that consisted of a honeycomb core and a top and bottom facing, Fig 46. This model neglected the honeycomb glue interface as Ayres composites stated that during testing the aluminium core fails prior to the failure of their proprietary adhesive.

A singular test panel was analysed in CATIA using the FEA package in compression, tension and torsion to compare the results with the published mechanical data. The comparison yielded results within 1% of the published data\(^2\) therefore, it was assumed that the model would be adequate to use to design the honeycomb panel structure. The downside of such a complex model was that the analysis of the honeycomb structure took several days to compute and often resulted in the computer crashing prior to completing the analysis.

There are numerous methods employed in industry for the joining of honeycomb structures these include the use of extrusions, scoring and folding, using edge inserts, butt joints with angle reinforcing, and splicing as can be seen in, Fig 47 For all these joints a two-part epoxy adhesive is used to bond the cladding panels to either an extrusion or reinforcing angle. The method of joining to be used on the honeycomb structure of the Lightburn Zeta Sports project is simple butt joints using glued and riveted aluminium angle on the inside and outside of the joint for support. The glue that will be used is Techniglue – HP R15. This glue is a two-part toughened epoxy adhesive specifically designed for the
bonding of aluminium structures and will cure at room temperature. The failure stress, after full cure, of the adhesive is 26MPa with a shore D hardness of 77. The aluminium angle will be glued then secured in position with 3.2mm pop rivets an example of which can be seen in Fig 48. This method of jointing provides a stiff joint that distributes the forces in adjoining surfaces over a large area thus reducing localised stress concentrations. Cutting of the honeycomb panels can be performed on CNC routers or water jet cutters which provide accurate dimensional stability. For this project the panels will be cut to shape using a hand held router and guiding templates. This method whilst not as accurate as CNC cutting is very inexpensive and can facilitate a change in design due to unforeseen issues as the panels are test fitted together.

2. **Steel tube**

4130 Chrome Moly tube was selected as the structure for the rear spaceframe due to its high tensile strength and good weldability. The three sizes used for the spaceframe are 63.5mm diameter by 2.5mm wall thickness round tube, 34.9mm diameter by 2.1mm wall thickness round tube, and 25.4mm by 50.8mm by 2.1mm wall thickness rectangle section. The mechanical properties of the tube used are: tensile strength 620.5 MPa, yield strength 482.6 MPa, Poisson's ratio of 0.290, and hardness 91 Rockwell B. The basis behind selecting this material other than its mechanical qualities was that it has been used extensively by the UNSW@ADFA FSAE team and has performed well. The steel tubes will be cut to length and ground to fit each intersecting joint.

D. **Actual Design**

The overall design concept for the Lightburn Zeta Sports was to design a chassis that would allow for the restoration of the Lightburn Zeta Sports body to a roadworthy condition. With this in mind the design had to be able to be manufactured using common workshop tooling and be able to be constructed by a person with some workshop experience. The chassis has been designed to be assembled as a rolling unit so that it can be tested and evaluated prior to fitting the restored body to the chassis. The chassis design allows the body to be fitted to the chassis by lowering the body to the chassis and securing it into position with mounting bolts.

1. **Honeycomb Monocoque**

The design emphasis for the sandwich panel monocoque was that it must fit underneath the existing body, seat two adult sized occupants, allow relative easy ingress and exit out of the vehicle, withstand the forces and loads from the front suspension, and be able to be easily fitted with the necessary vehicle controls. As the Lightburn Zeta Sports had no doors this provided the opportunity to create a structure that would have a permanent shape and that would not have to account for the weakening of the structure due to an opening and closing door. The sandwich panel monocoque structure, Fig 49, consists of 10 individual honeycomb panels that have been designed to interlock with adjoining panels. The interlocking nature of the panels reduces the need for jigs and other alignment procedures prior to gluing and securing them in position. The single piece floor plan is designed as the main load bearing structure for the front chassis and is made from 50mm honeycomb panel that has good beaming and torsional characteristics. The upper panel is the only panel where a bend has been incorporated into the structure. The bend was required to follow the contour of the body and allowed for a single piece of material to be used without creating additional joints and the panel. The three panels on each side are made of 30mm sandwich panel, and the front and rear panels are constructed from 50mm sandwich panel. The rear panel has been designed to be mounted to the rear roll hoop of the rear space frame section and serves as cross bracing for the rear roll hoop. The floor panel is mounted to four longitudinal supports located on the rear space frame through which the seats and seat belts will be mounted. The four supports also increase the bending stiffness of the front monocoque section.

![Figure 49. a) sandwich panel monocoque with top panel b) sandwich panel monocoque with top panel removed showing interlocking nature of the panels](image-url)
Due to the narrow nature of the Lightburn Zeta Sports it was not possible to fit a centre box section down the centre line of the structure nor was it possible to fit side sills to the passenger or driver side positions. If these sections had been able to have been fitted the beaming performance of the monocoque structure would have been greatly improved. Forces are transmitted from the suspension to the chassis from static and dynamic impacts. Therefore, the suspension attachment points must be capable of preventing catastrophic failure, particularly at high speeds. Increased loading is placed on the suspension mounting points when hard braking and cornering occur simultaneously. Initially it was decided that the front suspension would be mounted to the sandwich panel by an externally mounted lateral cross frame, Fig 50. The frame was designed to be fitted underneath the front floor pan and two uprights on either side of the frame would be used to mount the coil over shock absorber. The purpose of this frame was to ensure that no undue side forces would be applied to the forward lateral panels by the suspension. However, the additional size of the frame reduced the width of the floor pan thus encroaching on the leg room of the passenger and driver. It was decided to remove the cross member and mount the suspension components to the sandwich panel directly, Fig 51, using load displacing bushes. The point at which the upper mounting point of the coil over suspension attaches to the sandwich panels on either side of the vehicle is reinforced by an internal cross member that is also attached to the underside of the top panel. This stiffens the front of the chassis by creating direct load paths between the two shock absorber mounts and thus minimising chassis flex as the forces are being transferred through the strut brace, not through the chassis. Mounting of bolts and fasteners to the sandwich panel is done through a two-piece force distributing aluminium bush, Fig 52. that is glued and clamped into position. These bushes ensure that forces acting normally to the plane of the panel are distributed over a wider area thus reducing the shear stress in the panel and also distributing forces parallel to the panel equally to the top and bottom claddings. The bush also acts as a crush tube by preventing the collapse of the honeycomb core when a bolt is torqued. The bush is made from 5058 aluminium and has been designed in various sizes to accommodate different size fasteners.

The panel structure was analysed in CATIA under the loading conditions outlined in Table 2. For the static load condition of 1g the rear panel was held clamped and the load was applied to the top suspension mounts on each side of the structure at an angle of 15 degrees to account for the angle of the coil over shock absorber. This was repeated with the load increased to 3.5g to simulate the bump loading condition on both front wheels. To simulate the diagonal bump load this condition was repeated except the opposite sides suspension mounting positions was also clamped. To simulate the braking load only the rear panel was held clamped and a 1g force was applied to the wheel uprights lower mounting flange at an offset distance to simulate the moment produced at the wheel under braking. The lateral load condition was simulated by clamping the side of the structure and applying 1.5g load at the opposite wheel upright’s lower mounting position at an offset distance to simulate the moment created due to the wheel. The resulting maximum stresses in each panel was located and Eq. (3,4) were applied to determine if any failure in the sandwich panels would occur.
2. Rear Space frame

The design emphasis for the rear space frame, Fig 53, was that it is required to fit underneath the original body whilst accommodating the engine, drive train, fuel tank, battery, ancillary equipment, and rear suspension. Once the rear wheel centre was located the semi trailing link mounting positions could be determined as well as the mounting position of the quaife differential and coil over shock absorber. With the drive for the differential located the engine could be positioned. The engine had to be far enough rearward to allow for maximum space between the exhaust manifold and the rear sandwich panel and far enough forward so as to not interfere with the suspension and differential. Once these key items were located the tubular space frame was constructed around these components. In order to provide rollover protection to the occupants a roll hoop was considered essential in the design. The resulting rear space frame consists of 25 members. The roll hoop is the main frame member to which other members are attached as can be seen in Figs 54, 55. The rear roll hoop is constructed from 63.5 mm steel tube to comply with NCOP, and all other members are constructed from 34.9mm steel tube. The four lower bars located on the front of the rear space frame are designed to be mounted to the underneath side of the sandwich panel structure to provide additional beaming strength for the sandwich pan structure and provide a suitable mounting anchor points for the seats and seatbelts. The bars are constructed from rectangular section 25.4mm by 50.8mm by 2.1mm wall thickness, crush tubes will be used to prevent the section collapsing when a bolt is tightened through them. The construction of the rear space frame will be more time consuming and require a higher level of skill than that of the sandwich panel structure as a result of each member being required to be cut to length and then be individually shaped to fit the corresponding end joints. The rear space was analysed in CATIA under the loading conditions in Table 1 using a similar procedure that was used in the analysis of the sandwich panel structure, with the exception that the roll hoop was held clamped instead of the rear sandwich panel. From this analysis a number of members were adjusted, removed or added to the frame to ensure that the frame was structurally sound and to minimize stress concentrations. The engine and differential installation in the space frame were designed not to be used as stressed components. The space frame has been designed to allow for the easy mounting of other components as required.

Figure 53. Rear space frame with engine, differential, and suspension

Figure 54. Side view of the rear space frame

Figure 55. Isometric view of the rear space frame
3. **Overall assembly**

The front and rear sections of the chassis were combined and reanalysed in CATIA to see if there were any inconsistencies or anomalies in the structural analyses and or design. The assembled design, Fig 56, was subjected to the design loads in Table 2 and proved sound and as a result in no failures in the sandwich panel structure or the rear space frame. In the combined model the overall torsional rigidity was assessed and was calculated to be 4521.3Nm per degree.

![Side view of the assembled chassis](image)

By modeling the geometry and mechanical properties of the aluminium honeycomb panels and the steel space frame in CATIA the centre of gravity of the bare chassis could be calculated. The mass of the 10 honeycomb panels used in the construction of the cockpit of the chassis totaled 34.84 kg and once combined with the 8.1 kg of reinforcing aluminium angle the combined mass was 42.94 kg. From the CATIA model the centre of gravity (COG), in the x direction, for the cockpit was located using the inertial calculation tool and as a result the COG is located 322.12mm rearward of the front axle centerline. The same method was applied to the rear space frame. The mass of the rear space frame including the roll hoop is 40.18 kg and using CATIA the COG was calculated and is located 396.40mm forward of the rear axle centerline. However, in both these calculations the mass of the adhesive for the honeycomb panels and corresponding mass of welds in the space frame were neglected. The combined mass of the honeycomb panel cockpit and rear space frame is 83.12 kg and the corresponding COG is located 838.6mm rearward of the front axle centerline.

The COG of the bare combined chassis structure is located 53.58mm forward of the geometric centerline between the front and rear axles. This gives a corresponding mass distribution of 53/47 forward to rear. This resulted in a combined front axle reaction with the ground of 44.07 kg and a combined rear axle reaction with the ground of 38.99 kg. Figure 57 is a graphical representation of the resulting forces and reactions in the combined bare chassis including the COG, the main reaction forces at the front and rear axles is 432.96 N and 382.47 N respectively. This corresponds to 216.48 N reaction at the front left and right wheels and a 191.24 N reaction at the left and right rear wheels.
The preceding procedure was repeated with the inclusion of the key mass contributions from the driver, passenger, engine and differential components. For the driver and passenger the mass of 85 kg was applied at the location of the corresponding seating positions. This procedure was conducted in order to estimate the reaction forces that would be experienced at the front and rear axles and the vehicles approximate COG. The following were not taken into consideration the distributed load from the body shell (30 kg) or the mass of 20 liters of fuel or battery nor wheels and suspension.

This increase in mass results in the movement of the COG by 140.79mm to the rear compared to the unladen chassis making the position of the new COG 968.46mm to the rear of the front axle centreline as shown in Fig 59. The effect of the mass change takes the total mass of the chassis and components to 328.82 kg which corresponds to mass reactions at the front and rear axles is 150.35 kg and 178.47 kg. This gives a corresponding mass distribution of 46/54 forward to rear. Thus the reactions at the front left and right wheels are 737.48 N and 875.39 N at the rear left and right wheels.
XIV. Budget

From initial planning $2000 was allocated for the materials for use in the construction of the Lightburn Zeta Sports chassis. Table 5 shows that the estimated cost of the Lightburn Zeta Sports chassis will be $2144.63. This is forecasted to change dependent on the date of purchase of the materials. Not factored into the cost of the project are labor costs as it is intended that all work will be carried out by the author. No additional tooling will be required to be purchased to construct the chassis.

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XV. Conclusion

The impetus for the design of a replacement chassis for the Lightburn Zeta Sports was to preserve a part of Australian motoring history by being able to restore the vehicle to a roadworthy condition. Whilst the completed vehicle will no longer be original in mechanical components or underlying structure the overall appearance of the vehicle has been preserved, less some features that have been added to improve safety. Therefore, this project has demonstrated that it is possible to build a replacement chassis for the Lightburn Zeta Sports using existing components from a donor vehicle that will comply with ADR and the NCOP and is structurally sound.

XVI. Recommendations

A. FEA

In order to reduce the time used on performing FEA on the honeycomb structure it is recommended that the approach outlined by Bitzer be adopted. The honeycomb properties that are normally measured are the compressive strength, modulus in the thickness direction and the shear strengths and moduli in the length thickness planes and width thickness planes the properties in other directions are rarely measured including the Poisson’s ratio of the honeycomb. Blitzer recommends using the published compressive properties in the thickness direction and the published shear properties in the width and length direction. 1% of the compressive thickness properties for the compressive properties in the length and width direction and 1% of the shear properties in the length and width directions for the length and width plane and assume a Poisson’s ratio of 0.1. This method could then be evaluated against actual test data on the sandwich panels.

B. Sandwich Honeycomb Structures for FSAE

Due to the ease at which the sandwich panel monocoque can be constructed it is recommended that the feasibility of using this form of construction be investigated for application to the UNSW@ADFA FSAE vehicle. The advantages of having the panels cut to size using CNC equipments including the drilling of any necessary mounting holes means that the FSAE vehicle’s chassis construction time can be cut dramatically. It is recommended that initially this investigation should focus on keeping the space frame rear section up to the roll hoop and using the aluminium clad honeycomb section for the forward section of the vehicle, with later investigations looking at using a chassis wholly constructed from sandwich panel.

C. Joints

It is recommended that different joint methods be experimentally tested to determine what joint configuration is the strongest and lightest.

D. Reversing Box

Currently there is no commercially available simple or cost effective reversing mechanism, for reversing a motorcycle powered vehicle. Motorcycle engineed vehicles are popular amongst hobbyists and off-road
enthusiasts and it is recommended that further development of the reversing unit be undertaken. If the cost of production of the unit can be kept under $1000 it would occupy a unique place in the market as its’ nearest competitor is well over double that cost.

E. Construction

It is recommended that the Lightburn Zeta Sports replacement chassis be constructed by the author to validate the structural analysis of the design and to commence the restoration project of the Lightburn Zeta Sports.

References

2. Lightburn Zeta Register of Australia, Mr Fred Diwell, 301 Putty Rd Windsor.

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Final Thesis Report 2008, UNSW@ADFA

Appendices

A) Australian Design Rules Summary
B) National Code of Practice Summary
C) Items to be used from the FSM 650
D) Project Planning Documentation