Chassis for classic car body shell

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The Lightburn Zeta Sports car was manufactured by Lightburn Industries in South Australia during 1963. 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 part 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. This project aims to design a suitable vehicle chassis that could be fitted with modern readily available vehicular components and running gear, whilst remaining faithful to the external appearance of the existing body. This chassis will be designed in accordance with current Australian Design Rules and respective legislation regarding individually constructed vehicles. The main methodology for the design of the Lightburn Zeta Sports chassis is based on the principles outlined by M.Costin and D.Phipps.

I. Background to the thesis

The impetus for this thesis was that the author acquired a dilapidated Lightburn Zeta Sports body shell that had neither chassis nor mechanical running gear, Fig 1. In order to restore this vehicle into 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, less 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 emphasis for the chassis design is 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\textsuperscript{1} review of the 1963 Lightburn Zeta Sports stated that the car lacked style, innovation and was plain ugly. Despite this harsh criticism the Lightburn Zeta Sports vehicles are becoming popular as a collector’s item or as a display piece for motoring museums. But unfortunately, only 48 cars were built and only 21 surviving vehicles in various conditions, including the Authors, are known to exist\textsuperscript{2}. The aim of this thesis will be to produce a chassis design that will assist the Author in restoring his Lightburn Zeta Sports to a road going condition and as a consequence it will also contribute to the preservation of this interesting and unusual chapter in Australian motoring history.

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II. History behind the 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) 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 and 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 2 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. From Figure 2 it can be seen that Bedson favored the placement of the control pedals forward of the front suspension. This design feature reduced the overall length of the 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. As can be seen from Figure 3 the chassis for the Frisky cars were based on Bedson’s experience with the Formula 3. 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, Figure 4.

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. 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 Figure 4; fitting of a new front windscreen as well as small changes to the front and rear profiles; and the Excelsior 492cc 3 cylinder motor was replaced by the two cylinder Fichtel & Sachs 500cc engine built by FMR. Although all 48 Lightburn Zeta Sports were completed by 1961 they were not released for sale until 1963 when the Lightburn Company had

Figure 2 The Mackson chassis designed by Gordon Bedson for 500cc Formula 3 class racing

Figure 3 The prototype ladder frame chassis for the Frisky range of cars.

Figure 2. Gordon Bedson in the drivers seat of the Frisky Sprint at the 1958 British Motor Show.
completed construction of the Lightburn Zeta Runabout and Utility models. During this time the Lightburn Zeta Sports were trialed and raced in local South Australian hill climb championships and other events, Figure 5. Most notably was the use of four Lightburn Zeta vehicles during the world land speed record attempt by Sir Donald Campbell during 1964. 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 attributed poor reviews by popular motoring magazines, and the quirky nature of a fiberglass two-stroke car. 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. Lightburn Zeta Sports Chassis and Specifications

The 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, Figure 7. 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 as will be discussed. 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, Figure 8.

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 9. 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.

The rear suspension was of a trailing link 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, Figure 10. 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, Figure 11. At the time of writing, measurements of these components had only recently been obtained; therefore, a detailed analysis of the suspension geometry will be conducted in the future.

Table 1. Original Zeta Sports Specifications

<table>
<thead>
<tr>
<th>General</th>
<th>Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>German FMR 500 premixed two-stroke</td>
</tr>
<tr>
<td>Width</td>
<td>10’7” 3225.8 mm</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>1473.2 mm</td>
</tr>
<tr>
<td>Turning Circle</td>
<td>26° 7924.8 mm</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>8 cwt 406.4 kg</td>
</tr>
<tr>
<td>Max Speed</td>
<td>75 mph 120.7 kmh</td>
</tr>
<tr>
<td>Wheel Base</td>
<td>5’ 10 ¼” 1784.35 mm</td>
</tr>
<tr>
<td>Track Front</td>
<td>4’ ¾” 1238.25 mm</td>
</tr>
<tr>
<td>Track Rear</td>
<td>4’ ¾” 1238.25 mm</td>
</tr>
<tr>
<td>Suspension</td>
<td>Front Macpherson strut with lower wishbone</td>
</tr>
<tr>
<td>Brakes</td>
<td>Hydraulic 4 x 7” drum</td>
</tr>
<tr>
<td>Clutch</td>
<td>Multiplate dry clutch</td>
</tr>
<tr>
<td>Gear Box</td>
<td>Integral to engine. 4 speed constant mesh and reverse</td>
</tr>
<tr>
<td>Ratios</td>
<td>1st 4.23 : 1</td>
</tr>
<tr>
<td></td>
<td>2nd 6 : 1</td>
</tr>
<tr>
<td></td>
<td>3rd 10.4 : 1</td>
</tr>
<tr>
<td></td>
<td>4th 19.1 : 1</td>
</tr>
<tr>
<td>Performance</td>
<td>Top Speed 75 mph 120.7 kmh</td>
</tr>
<tr>
<td></td>
<td>Flying 1/4 mile 15s</td>
</tr>
<tr>
<td></td>
<td>Standing 1/4 mile 20.2s</td>
</tr>
<tr>
<td>Acceleration</td>
<td>0-30mph 4.5s</td>
</tr>
<tr>
<td></td>
<td>0-48.3 kmh 12.0s</td>
</tr>
<tr>
<td></td>
<td>0-80.5kmh 10.36m at 48.3 kmh</td>
</tr>
<tr>
<td></td>
<td>34’ at 30 mph 10.36m at 48.3 kmh</td>
</tr>
</tbody>
</table>

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 which will greatly assist in designing its chassis and the selection of other components.
IV. 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\textsuperscript{8}. 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\textsuperscript{9}.

A. 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 ladder frame due to its simplicity, versatility, durability and low development costs\textsuperscript{8}. 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 beaming stiffness due the use of closed section beams with a high second moment of area\textsuperscript{10}. 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\textsuperscript{8}. Torsional stiffness cannot be altered by changing the position of the cross-members and can only be improved by adding a cruciform structure. Figure 12 is a simple model representation of the torsional characteristics of a ladder frame chassis and how they can be improved by adding a cruciform brace. 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\textsuperscript{10}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{ladder_frame_chassis.png}
\caption{a) Shows the low torsional stiffness of a simple ladder frame model. b) Shows how little the torsional stiffness is improved by adding additional crossmembers. c) Shows by adding a cruciform brace the torsional stiffness can be improved.}
\end{figure}

Figure 10. A reproduction backbone chassis for the Lotus Elan manufactured by Spyder\textsuperscript{12}

2. Backbone Chassis

The backbone chassis consists of a large longitudinal structural beam positioned along the centre line of the vehicle, Figure 13. 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 take these forces, which normally results in a heavier body\textsuperscript{11}. 

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{backbone_chassis.png}
\caption{A reproduction backbone chassis for the Lotus Elan manufactured by Spyder.}
\end{figure}
3. **Space Frame Chassis**

The traditional space frame chassis, Figure 15, 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 dimensions. 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 aluminum space frames to greatly reduce the weight of the vehicle’s chassis. While they do not employ the use of tubing they use the same principles of triangulation to ensure that structural members are either in tension or compression, Figure 14.

![Figure 12. The space frame chassis for the 1960 Lotus 19](image1)

![Figure 11. The Audi A8 space frame chassis](image2)

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 monocoque vehicle is prohibitive for very small volume or one-off designs. 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 frame. The monocoque, while being cost effective 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. The University of Waikato, New Zealand, used aluminium clad honeycomb sandwich panel to construct the chassis for their battery powered electric vehicle. The honeycomb used was supplied by Ayres Composites Panels Pty Ltd, and can be provided in various widths and cladding thickness from 0.3mm – 1.0mm. 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 aluminum 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 report noted that the long term success of the chassis is dependent on the fatigue toughness of the aluminum clad honeycomb panels and the adhesive, and recommended that further analysis of
these properties be undertaken. The suspension components were attached to the honeycomb panel with special load dispersing inserts and braced with aluminum extrusions.

V. Proposed Development

The outcome of this thesis is to have a chassis design for a for the Lightburn Zeta Sports that when constructed and assembled as part of the Lightburn Zeta Sports restoration project will produce a vehicle that is able to be road registered in the ACT, maintains the outwards appearance of the original Lightburn Zeta Sports and is capable of a cruising speed of 100km/h with good handling characteristics. In order to design a suitable chassis for the Lightburn Zeta Sports it is important to consider: the desired performance and dynamics of the completed vehicle; current Australian, National and State, legislation regarding the construction and registration of individually constructed vehicles (ICV); the skill and expertise of the manufacturer; funds available to compete the project; availability of components and their integration; the engine and drive line; and the restrictions of keeping the outward appearance of the vehicle authentic.

The acquired Lightburn Zeta Sports body has been significantly modified by the previous owner. The fiberglass floor pan and inside skin that was moulded into the body has been removed and a large section from the front ‘bonnet area’ has been cut away. This provides a number of opportunities and issues in regards to the new chassis design. The open cavity where the floor pan once was will now accommodate a space frame or composite panel chassis. Once the chassis is completed the body can easily be slid over the top of the chassis and secured into place. The challenge of this is that the removed fiberglass floor pan and inside skins provided very good internal sealing of the occupant cavity from the road and acted as a firewall. With the fitment of a space frame chassis in particular additional cladding must be fixed to the frame in order to provide the same sealing and firewall characteristics. From the review of possible chassis types the two chassis that would be most suited to this project are the space frame chassis or the honeycomb chassis. Whilst the space frame chassis has been structurally proven over decades of use and testing, the honeycomb panel chassis would require further analysis of its fatigue toughness especially in regards to engine and suspension vibration. This is particularly important around the areas where the engine and suspension are mounted and at the glued and riveted joints of the panels. At this stage it is proposed that a comparative analysis between the space frame and honeycomb panel chassis be conducted to see which design is most suited to the replacement Lightburn Zeta Sports chassis.

B. Performance and dynamics

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 beamng, whilst also being light. A flexible chassis is a detriment to good handling and performance characteristics as it alters the suspension geometry while the vehicle is under load. It is proposed that a complete analysis of these loads and forces will be undertaken to ensure that the final design can be tested under correct loadings, using finite element analysis. As part of this thesis various suspension types will be evaluated in order to select the most appropriate type for the Lightburn Zeta Sports. The suspension system defines how effectively the tyres can be utilised to obtain traction with the road, and also determines driver comfort and control. 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 is proposed that the completed vehicle will have front and rear independent suspension primarily due to the nature of the drive train.

C. National and State Legislation

As the restoration of the Lightburn Zeta Sports is deemed as an ICV the whole vehicle must comply with Australian Design Rules (ADR) and the National Code of Practice (NCOP) to be able to be registered in the ACT. Currently the ACT is the only State or Territory to use both the ADR and NCOP for the certification of ICV. However, it is anticipated that other States and Territory’s will progressively adopt the ADR and NCOP therefore, if the completed Lightburn Zeta Sports complies with the ADR and NCOP it will be able to be registered without modification in any State or Territory in Australia. The ADR and NCOP that apply to the Lightburn Zeta Sports are in appendix A and B respectively. Specifically in regards to the chassis, NCOP 12 section LT1 specifies that the structure of the ICV car body/chassis shall be such that there are no abrupt changes in strength and stiffness of loaded sections. Abrupt changes in section must be avoided as they will produce stress concentrations and result in cracks and fatigue failure. Torsional rigidity should be at least 4000 Nm per degree over the wheelbase. It also specifies how the beaming and torsional tests must be conducted.
D. Skill and Expertise of the Manufacturer

The Lightburn Zeta Sports chassis is intended to be assembled and constructed by the Author in conjunction with the entire restoration project at some point in the future and is not considered being part of this thesis. Therefore, the design of the chassis has to take into account the skill level of the manufacturer and must be able to be assembled and produced using material and techniques that are available to the Author. Therefore the design must be relatively simple, and require a minimal amount of specialized tooling to manufacture.

E. Budget

The full Lightburn Zeta Sports restoration project will be funded by the Author and it has been estimated from previous experience that the project will cost approximately $7000. From this budget $2000 has been allocated to the design and construction of the chassis. It is expected that items will need to be purchased including, but not limited to: suspension components, steering mechanisms, controls and pedals, wheels and wheel hubs, in order to facilitate the design of the chassis. These items will be purchased from the remaining funds not allocated to the chassis project. To keep costs low the required components will be sourced from modern existing vehicles from local wrecking yards. Where used components are not suitable new components will be purchased or designed.

F. Engine and Drive Line

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 both lateral and transverse tended to have high side profiles and or long drive trains. This characteristic was undesired due to the short and narrow space available in the original body. However, as Lightburn had previously used motorcycle engines in the Runabout version of the Zeta a number of motorcycle engines were investigated for suitability. Motorcycle engines proved to be small and compact with short side profiles as well as 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 Honda CBR 600 engine was selected. The engine is a non fuel-injected water cooled four-cylinder four-stroke with a constant mesh six speed gearbox that produces 63.4 kW at 11000 rpm and 59 Nm at 8500 rpm. The unit has a wet weight of 62 kg and has four times the power of the original FMR engine. It was necessary to select the engine prior to commencing the design of the chassis so that weight distribution and mounting positions could be assessed. As the output from the engine will be 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 of the differential unit is currently being conducted to assess its suitability for this purpose.

As the CBR 600 engine does not have an inbuilt reverse gear a reversing mechanism is currently being developed parallel to this project. It is envisaged that the reversing module will be a separate unit that will be connected to the engine and differential by chain. The reverse mechanism will operate from a lever in the cockpit separate to the gear change lever. This mechanism will give the Lightburn Zeta Sports six gears in the forward direction as well as six gears in the reverse direction.

G. Vehicle Appearance

Throughout this project it will be important to make decisions and compromises regarding the chassis design in order to preserve the outward appearance of the Lightburn Zeta Sports. At the time of writing this report detailed measurements were obtained from a 1963 Lightburn Zeta Sports owned by Mr Fred Diwell that was located at the Australian Motorlife museum. These measurements will be used to ensure that the proposed chassis design will preserve the outward appearance of the Lightburn Zeta Sports. However, it is acknowledged that some alterations will be required to the body to accommodate cooling ducts for the water-cooled engine and to meet other ADR requirements.
VI. Design Process

Once the selection of chassis style, suspension geometry, and drive line have been finalised the chassis will be developed using CATIA and analysed in ANSYS. The procedure that will be closely followed when designing the chassis has been outlined by Costin and Phipps. The design of the chassis will be an iterative approach where the design will be progressively improved depending on the results from the structural analysis. The success of the design will be determined if the chassis meets or exceeds the beaming and torsional tests outlined in the NCOP for ICV, and if it satisfies the overall requirements of the restoration project. The chassis design project will be managed by the Author and the required client brief and project management documentation is at appendix C and D, respectively.

VII. Summary

From initial research it is possible to design a chassis for the Lightburn Zeta Sports that will meet ADR and NCOP that would allow the completed vehicle to be road registered within the ACT. The benefit of this thesis will be that it will preserve, to some extent, a part of Australian motoring history that would otherwise be lost, by enabling the restoration of a rare Lightburn Zeta Sports. Whilst it is acknowledged that the vehicle will not be mechanically original the overall characteristics of this vehicle will be maintained. General lists of components that need further consideration during the design are in appendix D.
References
1. Davis, T., Extra Lemon: More heroic failures of motoring. Transworld, Milsons Point, NSW, 2005
2. Lightburn Zeta Register of Australia, Mr Fred Diwell, 301 Putty Rd Windsor.

Appendices
A) Australian Design Rules Summary
B) National Code of Practice Summary
C) Client Brief
D) Project Planning Documentation
E) Components Requiring Consideration