University of Southern Queensland
Faculty of Engineering and Surveying

Design and Retrofit a Compressed Gas Powered Engine to a Motor Scooter

Student Name: - Dan Walsh
Student Number: - Q97230194
Supervisor: - Steven Goh

Abstract

With an impending carbon tax and increased pressure to look for cleaner transport alternatives, different forms of compressed gas have been investigated for its use as a fuel/propellant. Already known for its high fuel economy the common scooter has been selected for conversion due to its significant popularity in developing nations.

Throughout the world the motorised scooter has seen enormous popularity in the congested streets of large cities due to its manoeuvrability and ability to be operated at a very minimal cost. Due to this large popularity they are on a whole a large contributor when it comes to carbon emissions.

The aim of the project is to:-

- Investigate the potential reduction in emissions from the scooter.
- Develop a series of tests for the subject scooter for use in future performance testing.
- Feasibility study to decide which setup was to be used.
- Convert a scooter motor to chosen gas (LPG).
- Design a mounting system for gas cylinders.
- Design a gas cylinder to fit the scooter frame.

The most important aspect of any research involving cleaner engine technologies is to ensure that we are in fact decreasing emissions. Studies into emission levels from government cars, running duel fuel, shows that they actually emit more carbon than straight LPG or compressed natural gas engines.

Hybrid Air / (LPG/CNG) motors, due to their losses between states, would also increase the amount of carbon emitted per kilometre travelled when compared to a straight Propane powered motor.

Significant advances in pneumatics have led to extremely efficient rotary motors which have been adapted for use on scooters. The amount of air required to generate enough power for every day commuting is still such that an enormous reservoir would be needed in comparison to an internal combustion engine. To generate enough air to fulfil these requirements on a reasonable commute would require an air compressor with an internal combustion engine.

A hybrid solution for power generation may not be viable as a retrofit solution, although it is viable to convert current models to operate on either liquified gas or compressed gases.

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Student Name: **Daniel Walsh**
Student Number: **Q97230194**

Signature

25/10/2011

Date

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I would finally like to thank my supervisor Steven Goh, for his assistance during the year with helping to open up research options.

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Chapter 1 – Project Introduction

1.1 Project Outline

This project envisages the design and implementation of a hybrid LPG / compressed air powered scooter. The intention is to explore the possibility of creating a scooter which can run solely on compressed air for shorter trips, while still having the capability of producing its own air supply for longer trips. In the event where the air supply is insufficient for the journey the scooter will still need to able to driven by the LPG Motor.

The project entailed the procurement of a suitable scooter, the conversion of the motor to LPG and the fitment of a suitable air compressor. Before the commencement of any adaptation a series of tests will be performed to test the characteristics of the scooter for use at a later date.

1.2 Introduction

Since the invention of the very first internal combustion engine sometime in the 17th century there have been a large number of modifications made for a variety of different reasons. In the early stages many of the modifications were made to make the engine more reliable. Issues such as the ignition pilot light being blown out were later solved by integrating a magneto which fired a spark or by increasing the cylinder pressure to allow for self-ignition of diesel fuel. As the technology evolved, the changes which were being made to the engines were done to increase the efficiency and cut down running costs.

The fuels that have been used since the engine was first invented have also come a long way. Gunpowder was used in a very primitive internal combustion engine as a fuel that was burnt to create the explosion to drive a piston inside of a cylinder. When the powder exploded, the gas exited past a non-return valve. Once the pressure was vented out of the combustion chamber a vacuum was formed which drew the piston downwards (Judge, 1965). Although the fuel has changed a lot since then, the idea of using a piston moving in a cylinder is still used widely today. This kind of motion is known as reciprocating motion.

In recent times, pressure from environmental lobby groups and the threat from governments to impose carbon taxes have led to the invention of a number of new power generation and power transmission devices that aim to cut down the emissions caused by burning hydrocarbon fuels. Devices such as constantly variable transmissions (CVT) aim to improve drivability and efficiency by allowing the motor to run in predefined rev ranges for different situations. For maximum acceleration the engine would run at its maximum torque producing velocity while the transmission is continuously changing its input to output ratio. To allow the vehicle to cruise at its peak efficiency, the engine management system would set the speed of the motor to as low as is practically possible while maintaining enough torque to keep the vehicles speed constant.

Greater restrictions have also lead researchers to create cleaner burning alternatives. Unleaded petrol was introduced in 1985 as a cleaner alternative to leaded petrol and as of 1 January 2002 all Australian states had phased out the use of leaded petrol (Australian Government, 2001). Since 1974 when ADR27 (Australian Design Rule) was introduced the allowable Carbon Monoxide emission per kilometre has been reduced from 24.2 grams for a passenger vehicle back to 2.3 grams under the current emission laws (ADR79/02). As better solutions become available, emissions laws will become more stringent to help create a more sustainable environment.

The reason for the ever tightening restrictions on emissions controls is because of the fact that whenever the emission laws are updated more motor vehicles are being put on the road as the world's population increases. Therefore even though every car by itself is doing less damage, the total combined damage is the same as before.

The focus of this project is to develop a hybrid system that has the ability to exceed current emission standards and also be able to run solely on compressed air pumped into the tank at the service station.

1.3 Project Objectives

LPG powered motor vehicles have been around for a few decades so it is an already established technology. However there isn't a readily available kit that someone can retro fit to their existing scooter. An air powered scooter is also a technology that has already been developed. Because of size restrictions, future components may need to be custom made to cut down on their size, therefore this prototype may need to be set-up as a bench mount to prove proof of concept

The objective of this project is to:-

- Investigate the potential reduction in emissions from the scooter.
- Develop a series of tests for the subject scooter for use in future performance testing
- Decide on which system is most suitable for use in Australia
- Design a system to mount all the components in accordance with the applicable standards
- If possible convert a scooter motor to run on the system which is most appropriate

Figure 1: Piaggio Zip 50 4T

1.4 Methodology

The process of developing a hybrid scooter requires a methodical approach to ensure that every element performs its task to the degree required.

- Recognition of need – Ever changing emission laws and an overall increasing respect for the environment in which mankind lives has ensured that this field of study will always be pursued. New technology will always be needed to lessen the carbon footprint of society.
- Conceptualisation – A number of different designs will be scrutinised to ensure that a system can be developed that is feasible with the technology currently available.
- Feasibility assessment - Different factors must be taken into account when considering which design to use. These include economic, ethical and environmental consideration.
    - From an economic point of view a feasibility study needs to be carried out to ensure that any cost incurred with retro fitting the system can be recuperated by the end user through savings in their fuel bills.
    - Ethically the design needs to meet all the required ADR's relevant to the moped class of light vehicle and any other Australian Standard relevant to the project.
    - Environmentally it is vital to ensure that the design as a whole reduces the impact that these motor vehicles have on the environment.
- Decision to proceed – A design will be decided upon which meets all of the design requirements.
- Preliminary design – Available components will be scrutinised to determine how best to implement the design. Elements such as gas conversion components, magnetic clutches, air compressors, air motors and storage devices will all need to be selected before the next stage.
- Detailed design – Once all the components are selected, the layout of the system needs to be designed. Belt tensions, pulley and shaft design for idlers, gas conversion specifics will all be finalised before the system can be assembled.
- Pretesting – A series of tests will need to be developed that will provide data such as acceleration, deceleration from braking and freewheeling deceleration which will all need to be documented for comparison to a future retro fitted design.
- Design implementation – The scooter used for testing will need to be stripped of its motor and any other non-critical components. The chosen scheme will then be implemented either on the scooter frame or as a bench mounted system.

1.5 Risk Assessment

The development of a bench mounted prototype as proposed by the research project entails a certain level of risk a number of different areas.

1 Construction / Fabrication

1.1 Welding – Risks such as burns, fire, weld flash and electrocution are all possible during this part of the construction procedure. Relevant PPE (Personal Protective Equipment) should be worn to ensure that injuries such as burns and weld flash do not occur. The workspace should be clear of any flammables that could catch fire from sparks. A suitably qualified person should also carry out the welding to ensure that the risk of electrocution is reduced. The workplace should also be well ventilated to ensure that the operator is not exposed to any potentially life threatening fumes.

1.2 Grinding – Risks such as burns, electrocution and eye injuries are common during the use of grinders. Friction from this activity causes the work piece to become hot which can result in burns from contact. Also the sparks created can cause flammable materials to catch fire creating another burning hazard. These sparks can also penetrate the eye, causing injuries ranging from the scratching of the eyeball through to blindness. PPE should be used at all times to prevent personal injury and the operator should also be extremely aware of his workspace so that sparks will not set fire to their surroundings.

2 Operation

2.1 Explosion – Flammable gas will be used to run the engine and therefore precautions must be taken to ensure that there aren't any gas leaks that could potentially catch fire and lead to an explosion of the gas bottles.

2.2 Moving Parts – When the system is running there will be a number of drive belts which could be a source of risk if they are not properly guarded. Also the wheel of the scooter will be spinning in a location where fingers or clothing could become caught in the spokes. Once again a guard will need to be put in place to prevent this.

2.3 Hot surfaces – During the compression of air and the combustion of gas, heat is generated which is transferred to different elements of the system. The engine itself and any pipe work associated with the compression of air will be hazardous areas. Buttoned up, long sleeve shirts and mechanics gloves should be used if contact with these surfaces is possible during the operation of the system.

2.4 Fumes – Combustion of any hydrocarbon in the presence of oxygen always creates carbon dioxide gas. There is always the possibility that incomplete combustion will occur and therefore carbon monoxide could also be present. Care should be taken to ensure that the system is operated in a well-ventilated environment to ensure the chance of asphyxiation is circumvented.

1.6 Resource Management

Design

For Bench mount

If the design stage of the project requires a frame that will be used for mounting the engine and rear wheel frame assembly, Autodesk Inventor 2012 3D modelling package would be used to create the design. To ensure that the frame is capable of withstanding loads generated by the drive assembly, certain elements of the frame will be scrutinised with the use of the Strand 7 FEA package.

For Scooter mount

If the design stage of the project requires the development of a mounting system on the existing scooter frame, Autodesk Inventor 2012 3D modelling package would be used to create the design. To ensure that the mounts are capable of withstanding loads as specified in the relevant Australian Standards, Strand 7 FEA package will be used.

Materials

The development of the proposed system will require a certain amount of materials and hardware. Consumables like welding wire, gas and grinding disks will be required to build either the bench mount frame or the scooter frame mounts which will be made primarily out of readily available square or rectangular hollow section and plate steel.

A scooter will be required to provide the engine and rear drive assembly. This engine will then be converted to LPG or CNG by way of certain gas conversion components such as gas bottles, vaporisers and mixers.

Electromagnetic clutches may also be used to change the flow of power through the system as will bearings for the shaft. These will both need to be sourced and perhaps modified to suit the design requirements.

Other incidentals such as nuts and bolts belts etc. will also be required.

Construction

During construction general workshop tools will be required as well as a steel drop saw, rotary drill and welder. A grinder may also be required for the preparation of the materials to be welded and also to clean up any weld spatter.

For any power transfer shafts a steel lathe may also be required.

1.7 Original Project Timeline

Decide which design to use and what components will be needed to allow time for procurement of hard to get components. IE air motors	30/4/11
First Presentation	12/5/11
Presentation due	19/5/11
Develop a series of test that can be used to compare the standard and new designs	13/5/11
Project appreciation	23/5/11
Procure a scooter and carry out the first series of tests (Loan or Purchased).	28/5/11
Remove existing motor and wheel assembly measure and model components for frame design	4/6/11
Design bench mount frame existing motor so it can be manufactured	11/6/11
Design transfer shaft for transferring the drive flow between gas, air and regenerative braking	25/6/11
Setup gas conversion	6/8/11
Second Presentation	9/11
Presentation due	16/9/11
Partial Draft dissertation Due	16/9/11
Dissertation Due	27/10/11

If time permits
Mount an air compressor and tank to bench mount setup

Chapter 2 – Literature Review

2.1 Brief History of the scooter

Figure 2: Hildebrand & Wolfmüller Scooter

The very first documented mass produced version of the scooter dates back to the late 1800's with Hildebrand & Wolfmüller's steam powered “motorcycle.” Their invention, which was patented on January, 20 1894 (Patent no. 78553), had a drive piston on either side of the rear wheel which worked like a locomotive. The piston was returned to its closed position via a large rubber band.

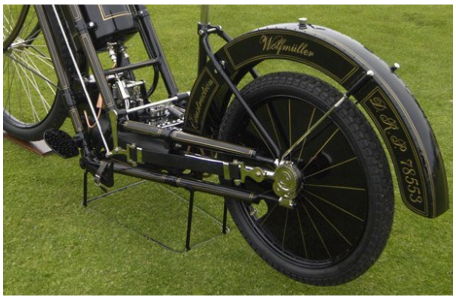


Figure 3: Piston Drive of Steam Scooter

This early scooter had a top speed of 48 km/h generated by its huge 1488cc 4 stroke engine. During its production, which ran through to 1919, several hundred scooters were sold (Hulsey, 2009).

After World War 2 when many European roads had been destroyed two Italian companies Piaggio and Lambretta set about making an affordable form of transportation which could easily manoeuvre around the now dangerous streets (The scooter report.com, n.d.).

Figure 4: Lambretta Model C

In recent years the sales of motorised scooters has continued to rise due to their high fuel economy and low initial cost. Although recently with the Global Financial Crisis, the number of sales have fallen quite substantially. These and other economic events have lead inventors to come up with an even better source of propulsion for the modern scooter.

Figure 5: Piaggio Paperino

2.2 Internal combustion engines

Today's modern internal combustion engines have been derived from the earliest models with a number of factors helping to speed along the refining process. During the world wars the need for planes that could fly higher lead to improvements such as turbochargers, which act as altitude compensating devices. Motor sport has also been responsible for many new concepts with a large number of them eventually being passed onto the everyday consumer.

There are three main types of internal combustion engine. The two stroke, four stroke and diesel engines all operate on the same principle. This being rotary motion created by harnessing explosions within the combustion chamber.

These explosions are accurately produced by igniting a mixture of air and fuel. Most of the fuels are some form of mixture of hydrocarbons. Hydrocarbons are a combination of Hydrogen and Carbon. Hydrogen having an atomic number of one can only attach to one other electron while Carbon can attach itself to four due to the fact that its atomic number is six and it has two electrons in the inner valence ring and the remaining four in the outer. In this way it is possible for many different combinations of hydrocarbons. Below is a methane molecule, CH_4.

```
  H
  |
H-C-H
  |
  H
```

The next hydrocarbon is ethane, C_2H_6. It can be seen below that by adding an extra Carbon atom and 2 hydrogen atoms that the length of the hydrocarbon is increasing.

```
  H H
  | |
H-C-C-H
  | |
  H H
```

If a pure hydrocarbon is burnt in the presence of pure oxygen the resulting product will be water and carbon dioxide (Judge, 1965). However because in an internal combustion engine air is mixed with the hydrocarbons instead of pure oxygen, there are other bi-products such as nitrous oxides created.

It is also essential that the correct air-fuel ratio is achieved. If too much fuel is sprayed into the combustion chamber there will be an excess of Hydrocarbons seen in the exhaust (these hydrocarbons are carcinogenic and can cause health issues (Brindle, 1999)). Also because there isn't enough oxygen for complete combustion there will be a lot more carbon monoxide molecules created rather than the more inert carbon dioxide.

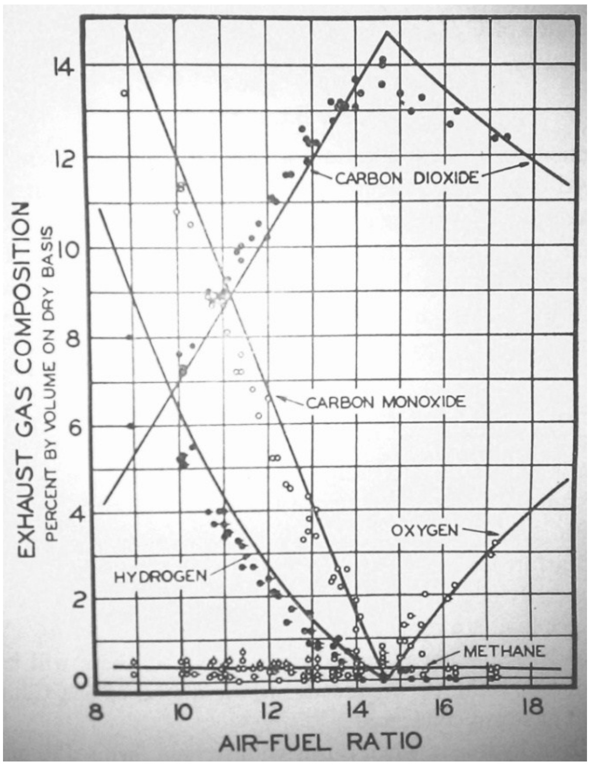


Figure 6: Percentages of gases in the exhaust gas (Judge, 1965)

A study done on motor vehicles in Australia in 1996 showed that by servicing all of the cars involved in the study, produced an average hydrocarbon emissions reduction of 21% in cars created to ADR37/00. They also had a 24% reduction in carbon monoxide emissions (NSW Environment protection authority, 1996).

This reduction would be been greatly attributed to the fact that the ignition timing may have been incorrectly set and because the air filter may have been blocked. If the air filter is blocked the motor will draw in more fuel. This is because of the vacuum created by drawing air into the motor faster than it can travel through the filter.

If there is too much oxygen on the other hand it means that the engine won't be producing the maximum amount of energy that it could possibly be creating. This is caused by insufficient fuel supply.

A four stroke motor works by moving its piston downwards while the intake port is open. This in turn draws in air from the intake manifold and due to the venturi effect created in the carburettor a small amount of fuel. The amount of fuel is governed by an adjustment screw in the carburettor.

The mixture is then compressed by the upward movement of the piston before being ignited just before the topmost position is reached. Once ignited the mixture “explodes” and sends the piston back down again. Upon reaching the bottom, the exhaust valve opens and the burnt mixture is forced out as the piston moves back up. Four stroke engines derive their name from these four different strokes of the piston.

A two stroke motor works by the air-fuel mixture being forced into the chamber when the piston is near the bottom of its stroke. At the same time this mixture forces out the burnt mixture from the last cycle. The air and fuel is compressed on the upward stroke of the motor. Just before the piston reaches top dead centre (TDC) the mixture is ignited. The piston is then forced back down by the ensuing “explosion” until just before the bottom the port is opened which allows the burnt mixture to be forced from the cylinder by the new air-fuel mixture.

A four stroke diesel engine works in much the same way as a petrol four stroke except that the fuel is not mixed before it enters the combustion chamber. The air is compressed during the compression stroke and just before it reaches TDC the diesel is injected as a fine mist into the chamber. Because of the heat generated by the compressing of the air, the diesel self-ignites. This means that there isn’t any need for a device such as a spark plug to create the initial ignition source. The power and exhaust strokes work the same as a petrol four stroke motor.

Diesel engines can also work on the two stroke principle with the intake and exhaust happening at the bottom of the power stroke.

2.3 LPG Powered motors

Liquefied Petroleum Gas (LPG) is a cleaner burning and cheaper alternative to petroleum and diesel and has already seen wide spread use in Australia and throughout the world. LPG is made from a mixture of propane, butane and other ingredients all of which make it denser than air, which makes it sink to the ground in the event of a leak (Go LPG!, 2001).

During combustion when sufficient oxygen is present, i.e. in a properly maintained engine, propane (C3H8) and butane (C4H10) reduces to Carbon Dioxide and Water. The power produced by propane is 50.34 MJ/kg while Butane produces 49.6 MJ/kg (Alternate Energy Systems, 2010)

Figure 7: An early LPG Scooter

Propane $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ + Heat

Butane $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ + Heat

In the event of the combustion being oxygen deprived carbon monoxide and carbon are also produced (Propane 101, n.d.).

Propane $2C_3H_8 + 7O_2 \rightarrow 2CO_2 + 2CO + 2C + 8H_2O$ + Heat

Butane $C_4H_{10} + 4O_2 \rightarrow CO_2 + CO + 2C + 5H_2O$ + Heat

The two main components required to convert a vehicle to LPG are a vaporiser and a mixer. Other components include gas storage cylinder, electrical switches, fuel shut off solenoids, copper pipe and flexible gas hose (Roads and traffic authority, 1998).

2.4 CNG Powered motors

Compressed natural gas (CNG) has seen limited use in Australia but its popularity around the world has seen it grow with over 12 Million vehicles powered by the gas. This can be seen in Table 1. CNG in Australia is currently being used mainly in Bus fleets in a few major centres such as Perth, Sydney and Brisbane. The gas is primarily methane and is lighter than air, so in the event of a leak the gas would rise up into the atmosphere and not cause a potential hazard.

During combustion methane mixes with oxygen to create Carbon Dioxide, water and heat. It produces 55.7MJ/kg of energy.

Methane $CH_4 + 2O_2 \rightarrow 1CO_2 + 2H_2O$ + Heat

In the case of incomplete combustion Carbon and Carbon Monoxide are also produced.

$6CH_4 + 9O_2 \rightarrow 2CO_2 + 2CO + 2C + 12H_2O$ + Heat

Because of the low density of Natural gas, the fuel occupies a larger area of the combustion chamber than petrol. This in turn removes an equivalent amount of oxygen which equates to a loss of power proportional to the amount of lost space (Combustion Engines Group of the institution of Mechanical Engineers, 1996).

The two main components required to convert a vehicle to CNG are a pressure regulator and a mixer. Other components include electrical switches, fuel shut off solenoids, copper pipe and flexible gas hose. A vaporiser isn't required as per the LPG system because the gas doesn't need to be converted from liquid to gas.

Due to the lack of infrastructure in Australia for CNG to be used in motor vehicles it could be a few years before this type of technology could be readily available. Although, with the Gladstone gas pipeline being run through the majority of southern Queensland there could be a potential shift in this direction.

	Country	NGVs @ Dec 2010	Total Vehicles*	NGVs as % of Total Vehicles
1	Pakistan	2740000	4481799	61.14%
2	Armenia	101352	315479	32.13%
3	Bolivia	140400	685653	20.48%
4	Bangladesh	193521	1155535	16.75%
5	Argentina	1901116	12399887	15.33%
6	Iran	1954925	15470000	12.64%
7	Colombia	340000	4912963	6.92%
8	Peru	103712	1580698	6.56%
9	Tajikistan	10600	268018	3.95%
10	Brazil	1664847	48899365	3.40%
11	Egypt	122271	4472945	2.73%
12	Ukraine	200000	7683955	2.60%
13	Myanmar (Burma)	22821	1024202	2.23%
14	Bulgaria	60270	2796890	2.15%
15	Kyrgyzstan	6000	318581	1.88%
16	Italy	730000	46256248	1.58%
17	India	1080000	81697000	1.32%
18	Venezuela	43000	4044012	1.06%
19	Trinidad and Tobago	4500	468255	0.96%
20	Moldova	5000	525751	0.95%
45	Australia	2750	15296542	0.02%
61	New Zealand	201	3226010	0.01%

Table 1: Number of Natural Gas Vehicles Worldwide By Country (NGV Global, 2011)

2.5 Air Powered Motors

Air Powered or Pneumatic motors use air to drive a number of vanes around the main shaft. The power is then transmitted out through the motor housing. In creating this circular motion large quantities of air are often used.

Engine Air in Melbourne have developed a unique rotary air motor called the "Di Pietro" motor which can generate a varying amount of power by varying the quantity of air and the amount of time it is allowed to flow into the expansion chamber. This design uses approximately 1 cubic meter of air per minute in a 2.49kW motor compared to 3.6 cubic metres per minute in a comparable model. At the same time the Di Pietro generates 26Nm of torque compared with 7.1Nm.

Although this motor has been through its testing phase and been deployed in a number of different vehicles it still isn't commercially available.

2.6 Regenerative Braking

Regenerative braking is a method of braking used in Hybrid vehicles to create stored energy by using the drive wheels to generate it. Under braking in a Petrol / Electric Hybrid, the wheels drive through a generator which creates electricity to recharge the batteries. The power used by the generator places a torque on the drive wheels causing them to slow down. In the event more braking force is required conventional brakes are still used.

In a compressed air system, drive would have to be transferred from the drive wheel back to an air compressor to create braking. Because of the large quantity of air required, the power to drive the compressor will also be quite large. This translates back through to the wheel as quite a significant amount of braking force and so therefore the compressor may have to be able to be setup in such a way that the braking force can be reduced.

2.7 Belt Transmission power losses

Modern scooter drive trains generally use a constant velocity transmission to achieve variable speed drive to the rear wheel. This is achieved by way of a belt driven between two movable disk plates. The closer the plates are together the further out the belt sits from the centre of rotation. The further away the plates are from each other the closer the belt is to the centre of rotation. As the drive diameter increases so too does the ratio between the drive and wheel pulley.

Because the drive plates need to be smooth to allow for differing belt speeds a grooved belt like a timing belt cannot be used and therefore a smooth V type belt is generally used. The percentage of power that can be transmitted through a belt drive varies from design to design. Some sources quote the efficiency as 95-98% (Bearing Service Pty Ltd, 2007), while others 90-99% with a median of 96% (Advanced Engineering Research Belt Technical Center, n.d.).

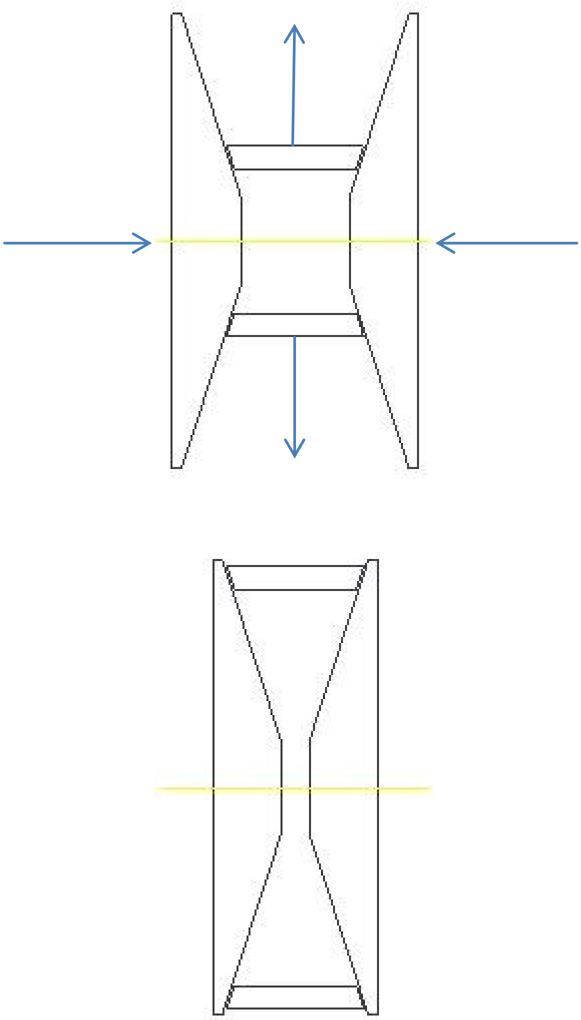


Figure 8: Constantly Variable Transmission Pulley

2.8 Adsorbed Natural Gas

Adsorbed natural gas is a method of storing natural gas in a way that greatly increases the storage capacity for a fixed volume of storage. Different adsorbents are available but generally activated carbons are used. These are commercially available from companies such as "Activated Carbon Technologies." The process by which it is made involves heating the material, such as coconut shells, wood or peach seeds, in an oxygen free environment to around 550 degrees Celsius. Once the carbon is created it is then processed to achieve the required particle size. The smaller the particles size the more surface area available for adsorption (Activated Carbon Technologies Pty Ltd, 2009).

Another process has also been trialled where by car tyres were used to create pellets of activated carbon. Even though they didn't have the same storage potential as the coal derived carbon used in the trial it is a viable use for old tyres (Sun, et al., 1996).

This activated carbon is placed inside of the gas cylinder so when the Natural gas is pumped in the gas adsorbs to the surface of the carbon. The process of filling the gas cylinders takes a number of hours due to the fact that the bottles have to be filled slowly so as to allow the gas to adsorb onto the surface of the carbon.

By using this method the cylinder can carry its normal volume at a much lower pressure due to the fact that the gas molecules are packed in a lot more tightly. Either that or the volume can be increased at the same pressure which it would normally be stored.

2.9 Emission requirements for Mopeds

At the time of writing there are no Australian Design Rules which cover emission requirements for L class vehicles.

Chapter 3 – Prospective Systems

3.1 Hybrid Systems

3.1.1 Liquefied Petroleum Gas / Petrol Hybrid

An LPG / petrol hybrid system maintains the current petroleum powered system while adding the cleaner LPG fuel as a secondary option.

The benefits of this system include:-

- Extended range due to having the same amount of petrol with the extra volume of LPG
- Possible reduction of average carbon emissions from standard petrol

The downside of this system include:-

- Different ignition timings are required for cleaner burning of both fuels
- Engine must be tuned either to one or the other fuel, or a compromise must be reached
- Potentially more emissions than straight petrol or LPG

A number of elements determine the amount of combustion that occurs in the combustion chamber. Because LPG is a mixture of propane and butane, it has a higher octane level than the highest octane petrol. At lower engine speeds LPG requires the spark to be initiated earlier than for petrol. Once the engine is running at a faster speed, it requires less advanced ignition than petrol. The graph below shows a generic ignition advance graph for LPG and petrol motors running at varying speeds.

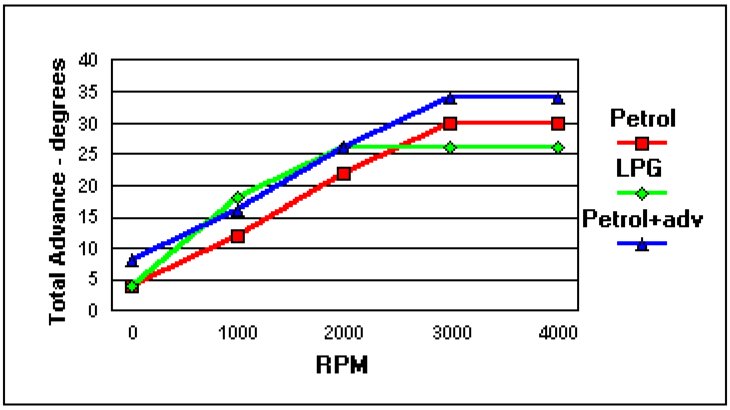


Figure 9: Ignition Timing Advance vs. RPM

It can be seen from the graph that if the ignition timing is advanced at idle (around 500 RPM) to accommodate the LPG, the timing would be too far advanced once the engine revs increase past 2500 RPM. Therefore the curve would also need to be altered so that at higher revs ignition occurs sooner (Dimovski, 1998).

3.1.2 Compressed Natural Gas / Petrol Hybrid

As with the LPG/Petrol Hybrid a CNG / petrol hybrid system maintains the current petroleum powered system while adding the cleaner CNG fuel as a secondary option.

The benefits of this system include:-

- Extended range
- Possible reduction of average carbon emissions from standard petrol
- In the event of a leak natural gas rises above air.

The disadvantages of this system include:-

- Different ignition timings are required for cleaner burning of both fuels
- Engine must be tuned either to one or the other fuel, or a compromise must be reached
- Fuel currently not available at service station
- Potentially more emissions than straight petrol or LPG

Compressed natural gas is delivered to a large number of households in some of the larger centres around Australia. This gas has the potential to be adsorbed into nano-porous material such as activated charcoal which allows it to be stored at a much lower pressure. With the right equipment it would be quite simple and convenient to be able to refuel at home.

3.1.3 Compressed Air / Petrol Hybrid

There are a number of different methods by which the system could be set up as a Compressed Air / Petrol hybrid system.

System 1

This system would leave the engine mounted as it currently is with an air motor mounted beside it. An electromagnetic clutch would be needed to change the drive from petrol to air. When the device is running on air, the petrol motor could be running a compressor to try to maintain air pressure.

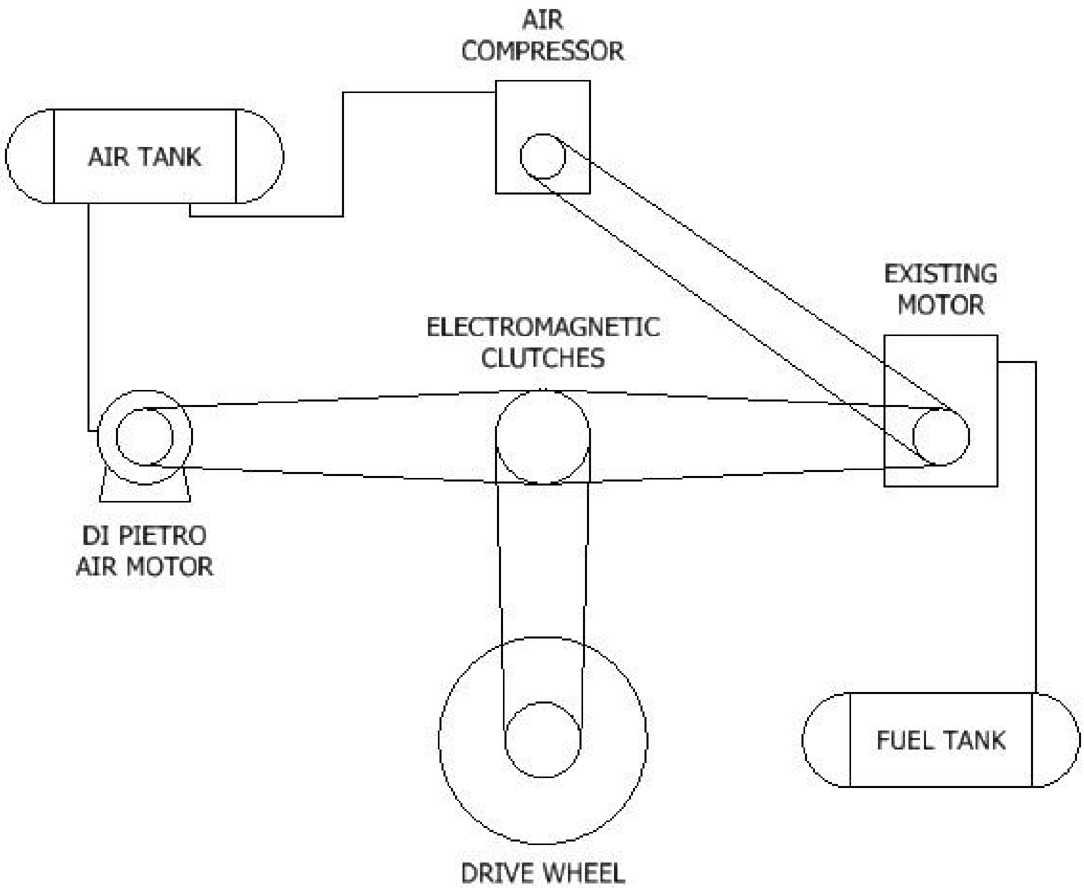


Figure 10: Compressed Air / Petrol Hybrid System 1

The benefits of system 1 include:-

- Absolutely no emissions during use of the air motor if the petrol motor is shut off.
- Possible reduction of overall carbon emissions when compared to a standard petrol setup.
- Potential to run on petrol if more power is required or air supply runs out.
- Air can be filled up from an external air compressor.

The disadvantages of system 1 include:-

- Due to trying to combine an internal combustion engine and a pneumatic motor, twice as much room was needed compared to the other dual fuel alternatives.
- Complex and expensive electromagnetic clutches are needed to change the drive between methods.
- The losses involved from driving an air compressor with a petrol engine to provide air for an air motor outweigh any gain. I.e. Approximately 5% loss in belt drive from motor to compressor, heat losses during compression, losses through the air motor and another 5% loss from air motor to the drive wheel.

System 2

This system would have the engine detached from the drive wheel and have an air motor mounted in its place. The petrol motor would be moved to another location where it could be permanently connected to an air compressor.

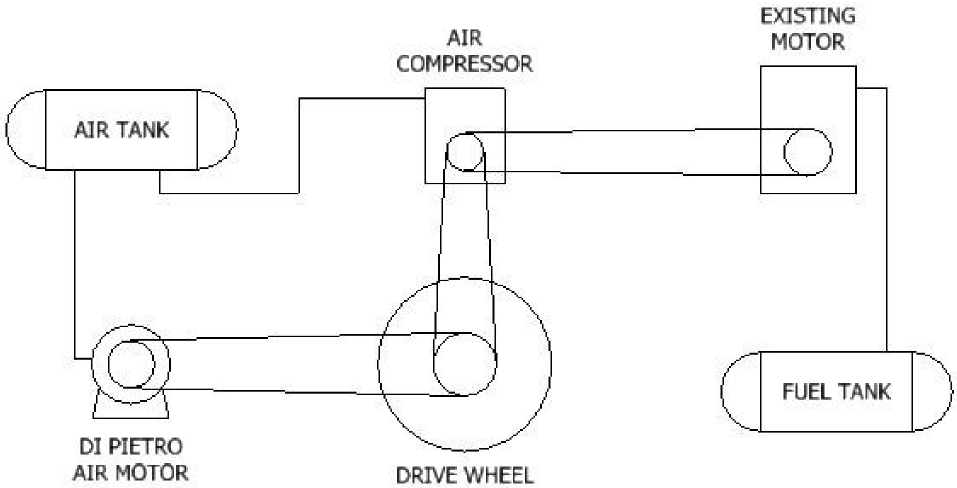


Figure 11: Compressed Air / Petrol Hybrid System 2

The benefits of system 2 include:-

- Absolutely no emissions during use of the air motor if the petrol motor is shut off.
- Possible reduction of overall carbon emissions when compared to a standard petrol setup.
- Air can be filled up from an external air compressor.

The disadvantages of system 2 include:-

- Due to trying to combine an internal combustion engine and a pneumatic motor, twice as much room was needed compared to the other dual fuel alternatives.
- Because of the large air consumption the size of the air compressor required would be quite large.
- Air compressor would run nearly constantly to maintain air pressure.
- The losses involved from driving an air compressor with a petrol engine to provide air for an air motor outweigh any gain. I.e. Approximately 5% loss in belt drive from motor to compressor, heat losses during compression, losses through the air motor and another 5% loss from air motor to the drive wheel.

Both of these systems could be setup with compressors connected to the wheels to allow for regenerative braking. If the compressor is large enough, the force required to pump the air would be such that the existing brake would see very minimal use.

3.2 Non-Hybrid Systems

3.2.1 Liquefied Petroleum Gas

A straight liquefied petroleum gas setup uses the currently installed petrol motor with a few adjustments and a number of different pieces of equipment to change the fuel which is burnt during combustion.

The benefits of this system include:-

- Potential for overall lower emissions than standard petrol.
- Simple setup.
- Cheaper running costs.
- Easier to tune than Petrol / LPG hybrid.

The disadvantages of this system include:-

- Lower range than Petrol and LPG/Petrol derivatives.
- Custom gas tanks required because of the small size required.

3.2.2 Compressed Natural Gas

A straight compressed natural gas setup uses the currently installed petrol motor with a few adjustments and a number of different pieces of equipment to change the fuel which is burnt during combustion.

The benefits of this system include:-

- Potential for overall lower emissions than standard petrol.
- Higher potential power output than LPG
- Simple setup
- Cheaper running costs
- Easier to tune than Petrol / CNG hybrid

The disadvantages of this system include:-

- Lower range than Petrol and CNG/Petrol derivatives.
- Custom gas tanks required because of their small size.
- Fuel currently isn’t available at the petrol station.

As per section 3.1.2 compressed natural gas has the potential for being used from the home in a home refuelling situation.

3.2.3 Compressed Air

A straight compressed air powered scooter requires the existing petrol motor to be removed and a pneumatic motor being put in its place. As a retro fit item this requires a fair amount of modification which on a brand new scooter would remove half of the original equipment. The range that is attainable out of even the best motor is still only a couple of kilometres per tank.

The benefits of this system include:-

- No emissions during operation.
- Quiet operation.
- Cheaper running costs.
- Can be fuelled up from home, work, etc.

The disadvantages of this system include:-

- Emissions are still created during the operation of compressing the air.
- Very low range not suitable for every day travel.
- Expensive carbon fibre tanks required to get extra range.
- Large modification compared to other systems

Chapter 4 – Scooter Selection

The target vehicle for this project is the moped class of motorised scooter. Due to its wide popularity as a civilian transport in large built up areas in Australia and other centres worldwide, there is a potential that a system which greatly reduces the emissions created during everyday commute will be met with wider acceptance. After a great deal of searching a Piaggio Zip was sourced from a private sale in Brisbane. The scooter had been involved in a collision with a motor car but the only damage was some broken cowlings and superficial scratches to the plastic guards.

Figure 12: Test scooter Piaggio Zip 50 4T

Powered by a four stroke 50 cubic centimetre motor with drive being achieved through a constant velocity transmission the scooter was able to achieve more than the maximum allowable speed of 50km that is allowed for this class of scooter. Braking comes by way of a disc brake on the front and drum brakes on the rear.

Chapter 5 – Testing

Prior to dismantling the scooter to see what is involved with retro fitting different fuel systems, testing was carried out to record the performance of different characteristics of the selected scooter. The initial concept for this project was to retro fit a pneumatic motor to create a compressed air/LPG hybrid. With this in mind the possibility of regenerative braking needed to be explored.

For this to be an acceptable means of providing deceleration to the scooter it would have to comply with the relevant Australian standards and Australian design rules with regard to deceleration.

ADR33/00 (Australian Government, 1995) – Brake Systems for Motorcycles and Mopeds 2007 section 3 describes the testing procedure for Moped class motorcycles. This procedure stipulates that the brake temperature must be between 55 and 100 degrees Celsius and the initial speed at the commencement of the test will be the lower of 40km/hr. or 0.9Vmax. Since the maximum speed of the vehicle is 60km/hr. (established after some initial testing) this would be the lower of 40 km/hr. or 54 km/hr. The brakes will be tested individually with a force no greater than 200N being applied to a hand brake and no greater than 350N being applied to the foot brake.

TEST	STOPPING DISTANCE (S)	MFDD
Single brake system, front wheel braking only	$S \leq 0.1\ V + 0.0111\ V^2$	$\geq 3.4\ m/s^2$
Single brake system, rear wheel braking only	$S \leq 0.1\ V + 0.0143\ V^2$	$\geq 2.7\ m/s^2$

Table 2: Braking Tests from ADR33/00

From the above table S=21.8m for the front wheel and 26.9m for the rear wheel.

From 5.3.1 MFDD (Mean Fully Developed Deceleration d_m) is calculated by:

$$d_m = \frac{V_b^2 - V_e^2}{25.92(S_e - S_b)} \quad m/s^2$$

Where:

V_b is 0.8 of V_1 (km/hr.)

V_1 is the speed at which the test is initiated (km/hr.)

V_e is 0.1 of V_1 (km/hr.)

S_b is the distance between when the test is started and when V_b is reached (m)

S_e is the distance between when the test is started and when V_e is reached (m)

During the testing a Brake-Testa MeHV inertial accelerometer was used. This device measures the deceleration as a percentage of gravity. From this information it calculates the average acceleration, the duration of the test, stopping distance and the initial speed of the test. The average acceleration is the value used in the measurement of the MFDD. Because the intention was to use the front brake for regenerative braking, the focus of the testing was on the single front brake tests.

Testing of the scooter took place at the Toowoomba show grounds on a day with very little wind activity. Even though there was no wind, tests were conducted in a number of different directions to determine how the brakes of the scooter performed. The scooter was accelerated up to the required speed and then decelerated as fast as possible without locking up the wheels.

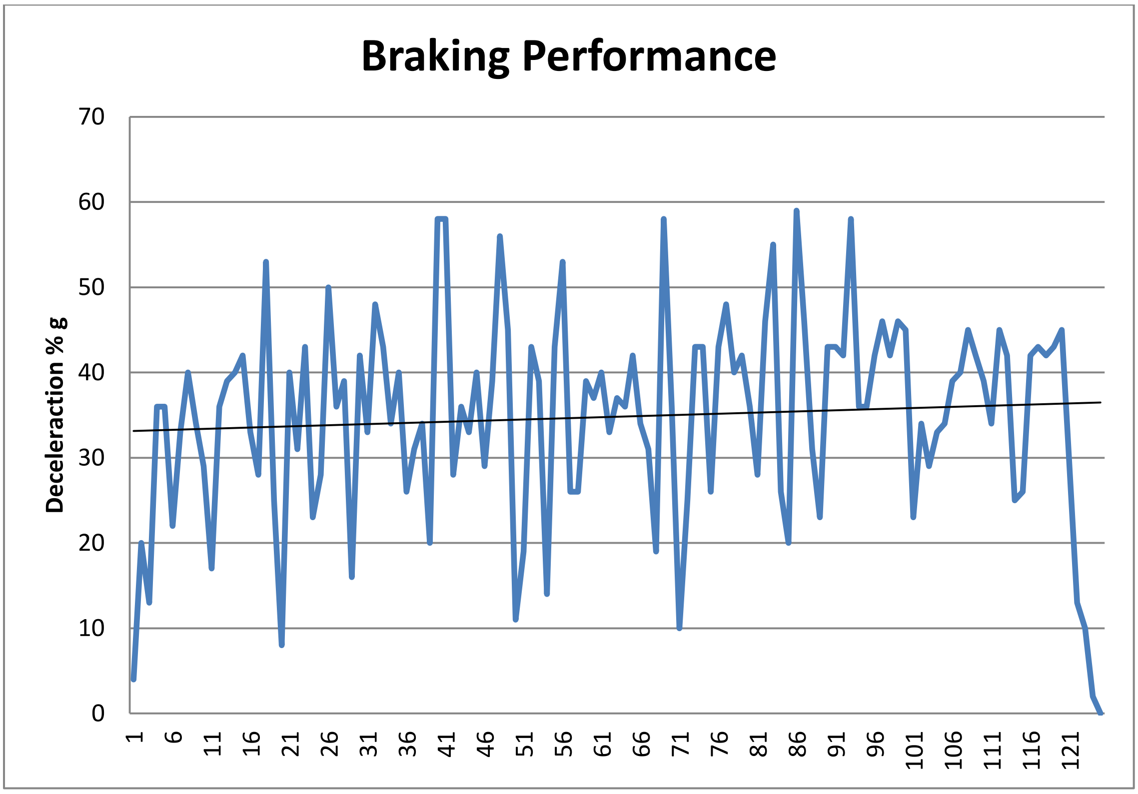


Figure 13: Front disc brake deceleration data

The data above shows a test run which passed the requirements of ADR33/00. The time scale across the bottom indicates the polling number from the machine. Each poll represents approximately 25 milliseconds. The stopping distance was 16.3m with an average deceleration of 3.4m/s^2. This information can be used to compare the deceleration of a regenerative braking system as described in section 2.5 with the existing braking system on the test scooter. If a regenerative braking system is to be used the deceleration will have to meet or exceed the existing braking system without being over braked. If the system is over-braked it will have a tendency of locking up without achieving maximum deceleration.

Chapter 6 – Preparation of Scooter for conversion

Before any decisions could be made on which system would be the most appropriate the scooter needed to be stripped to allow for a decision to be made where certain components could be mounted. The Piaggio Zip has a compartment below the seat which would usually be used like a glove box for storing a few items during transit or storing a helmet while the vehicle is parked.

Figure 14: Stripped down scooter chassis

This compartment proved to be the only place where a gas cylinder or pair of cylinders could be mounted. In the case of a LPG / compressed air hybrid, one cylinder could be used for LPG while the other used in conjunction with a carbon fibre tank for the storage of high pressure air.

During this phase of the project it was discovered that the transmission of the scooter has a complicated CVT drive belt system which has a variable width pulley at either end. One on the engine output shaft and the other on the drive wheel shaft. The drive belt is also inside an aluminium housing which acts as the rear support arm for the drive wheel. Because of this setup it is not possible to mount another set of electromagnetic clutches easily as mentioned in section 3.1.3 for the use of changing the drive from an air motor to the petrol motor.

For a pneumatic motor to be mounted in conjunction with the existing motor it would need to be mounted in front of it. This would cut down the available space used for the operator’s feet. Another problem with this would be the fact that the drive would have to come from the pneumatic motor via a drive belt to the drive shaft of the petrol engine to ensure that the rear pivot arm can still move without losing tension in the belt.

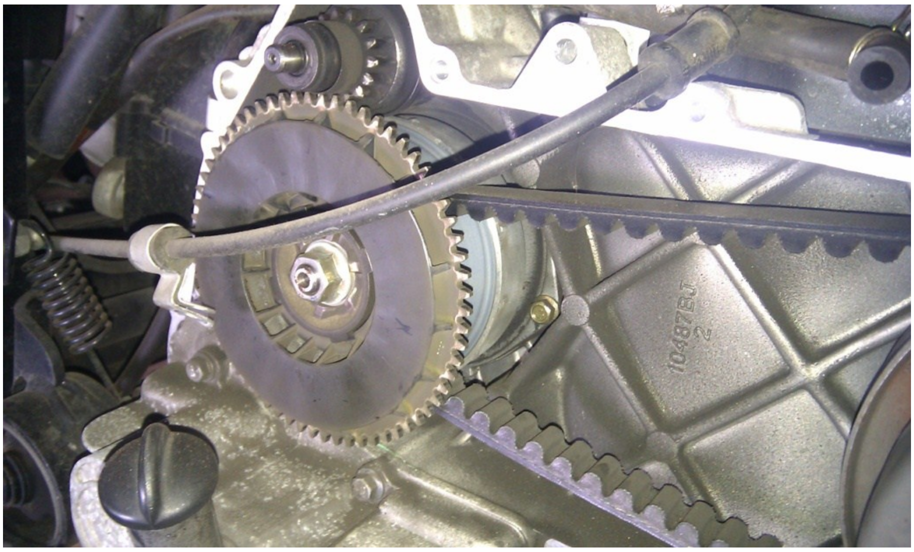


Figure 15: Engine output variable speed pulley with starter gear

Figure 16: Drive wheel variable speed pulley

Chapter 7 – Decision Process

There were a number of factors that were taken into account when deciding which system to use. As with all developments related to transportation, it is pertinent that the controlling of emissions is paramount when deciding which path to take. The efficiency of the system is also of high importance because if it is not an efficient system any gains from the upgrade would be negated by the inefficiencies. Therefore the energy used to create the components of the system would never be regained.

With an air / petrol hybrid system, there are a number of belt drives which all add to the loses in the system. Even if the current CV transmission has an efficiency of 95% it will still have only a fraction of the drive train loses of a hybrid system. For the dual drive system where either the air or petrol motors can be used, there would be a belt from the petrol motor to an air compressor (assume 95%). There are quite substantial loses in the compressing of the air (assume that 95% of the energy used in creating the compressive forces are transformed into stored energy). From there the compressed air is used to create drive (assume 95% efficiency for conversion of stored energy) which is transmitted through another belt at around 95% efficiency back to the original drive shaft and out through the existing transmission belt at around 95%.

Without going into any great detail or experimentation it can be seen that the efficiency of the compressed air / compressed gas hybrid as described earlier in system 1 could be around 77% using 95% efficiency for all transmission and power conversions. That equates to a potential power loss of 18% over the original setup without taking into account the loss in power from converting the petrol engine to LPG or CNG. Petrol has an energy content of 35MJ/l while a 50/50 Propane/Butane blend of LPG has an energy content of 27MJ/l. That equates to a further loss of nearly 23% giving a total potential loss of nearly 41%.

Because the scooter needed to be able to traverse a reasonable distance (up to 20km at a time for example) in a single journey, it was crucial that the fuel required for running the engine was readily available. The reason for this is that it would be very inconvenient for someone to have to travel 10 kilometres out of their way to find a service station that supplied the required fuel.

The convenience of the system refers to how much effort is required as a whole to operate the system. Everyone can operate a petrol pump and it is readily available therefore any system which has petrol as one of the fuels is given a higher score. Compressed natural gas is readily available in a large number of houses for use as a cooking fuel. If CNG is used with petrol as a dual fuel system the petrol can easily be purchased from the service station once or twice a month, while the gas can be filled every night with little effort. Due to its low range an air operated system has been given a lower score because of the inconvenience of having to stop every few kilometres to refuel.

As with any system the cost of the system will directly affect the rate of sale. Because a scooter can be purchase new for a couple of thousand dollars, it would be impractical to think that someone would want to purchase a retro fit item that costs half of the original purchase price.

The simplicity of the design affects a number of factors. A simple system will have fewer parts that will need to be installed and maintained. In the event that something goes wrong, troubleshooting a system with minimal parts is a lot easier than trying to find an error in a vast network of components.

The class of scooter which is being targeted by this report is greatly affected by the weight being carried. If the new system adds 20 kilograms to the dead weight of the machine that is a 20 percent increase. This increase therefore has to come off the total payload of the scooter either that or the performance is affected.

All the factors above have been weighted and the different systems have been assessed to see which one is most suitable for use as a retro fit system.

		System					
	Weight	Air/Petrol	LPG/Petrol	CNG/Petrol	LPG	CNG	Air
Emissions	10	3	5	6	7	8	10
Availability of fuel	9	10	10	6	10	4	10
Efficiency	9	1	5	6	7	8	3
Convenience	8	8	8	10	7	9	5
Cost	7	2	5	6	5	6	2
Simplicity of design	7	1	7	8	9	10	4
Weight	6	4	6	6	8	8	8
Distance	4	5	8	8	6	6	1
Totals		258	401	414	449	444	351

Table 3: Decision Matrix

From the decision matrix it can be seen that the system that meets the required criteria better than the rest is the straight LPG system. Because of the weighting applied to the availability of fuel, a straight CNG system has been severely penalised. When Australia has the infrastructure in place to allow for the use of CNG on a widespread scale, this form of fuel will be ahead of the other systems by quite a margin.

Chapter 8 – LPG Gas System

In a car based LPG system there are a number of modifications that need to be undertaken. Suitable gas cylinder mounts need to be designed and fabricated that will support a tank and ensure that it will not come free in the event of an accident. From the tank the gas flows through metal tubing to a vaporizer regulator.

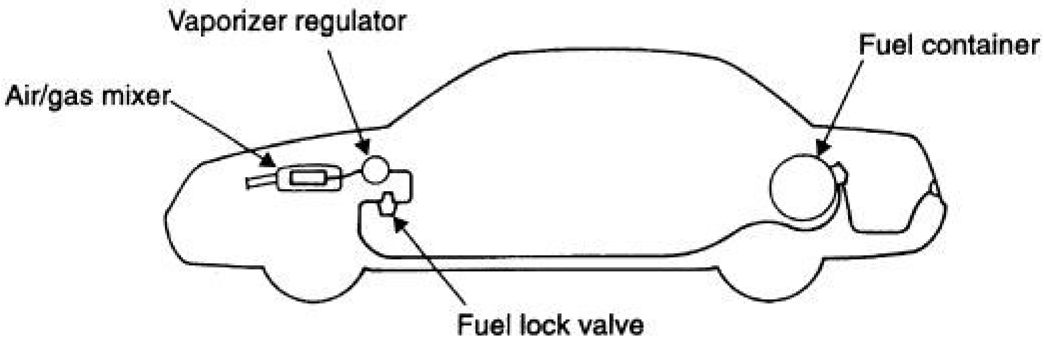


Figure 17: Typical Passenger Car LPG System

The vaporiser regulator reduces the pressure of the liquefied gas from around 1.034MPa to atmospheric pressure. With the heat from the engines coolant it changes the liquid gas to a vapour. From the vaporiser the gas travels through a rubber hose to the mixer.

The mixer sits on top of the carburettor and serves as a device for mixing the right quantities of air and gas. This is done by way of a venturi which allows the gas to be drawn into the mixer because of the low pressure created by the air being drawn past it. On a scooter engine the carburettor is very small in comparison to one used on a six cylinder car for example. This also leads to much smaller quantities of LPG being required to power the engine.

The scooter system still needs most of the components used on the car based setup. A suitable gas cylinder will need to be designed that will fit in the small space beneath the seat of the scooter. Because a custom cylinder is needed there will be a large amount of work required in the testing of the design to ensure that it meets the requirements of the relevant Australian standard (AS3509). To enable the scooter to have a reasonable mileage it has been designed with two cylinders mounted side by side. The reason for having two small ones instead of one larger one is because of the size of the area in the glove compartment. This was driving the diameter of the gas cylinders which have to be cylindrical.

A vaporiser that could be used on the scooter would require a heat source to aid in the conversion of the liquid gas to vapour. Since the scooter engine is air cooled it is not an option to route the engine coolant through the vaporiser to achieve this.

One solution to this problem would be to use the Exhaust from the scooter for adding heat to the fuel. The existing exhaust system could be cut and rerouted to travel through the vaporiser. To ensure that the exhaust gas would not corrode the aluminium housing of the unit, a stainless sleeve would need to be manufactured which could be inserted in the coolant intake port. This modification still allowed for the transmission of heat from the exhaust gas through the wall of the sleeve and into the aluminium housing. From here the heat could be passed by convection into the liquid gas aiding it to change into a vapour. From the vaporiser the gas would travel to the carburettor.

At the carburettor gas is drawn into the air flow by way of a mixer. The mixer as its name suggests mixes the gas with the air as it is drawn into the motor.

One problem encountered whilst trying to procure equipment for the project was to find a vaporiser small enough. The smallest vaporiser that could be acquired without sourcing from overseas had a maximum flow of 14 kg/hr. A 50cc scooter typically uses around one litre of fuel per 50km travelled. For a 50/50 Propane/Butane LPG mixture the energy content is approximately 27MJ/L (Alternate Energy Systems, 2010) compared to around 35MJ/L for petrol. This means that the best mileage that could be hope for with LPG is around 77% of that obtained using petrol. Therefore it can be assumed that the mileage will be approximately 39km/L. Travelling at 60km/hr (top speed) the scooter would be using 1.55 litres of LPG per hour or 0.775kg/hr. This is around 5.5% of the maximum capacity of the vaporiser that was procured.

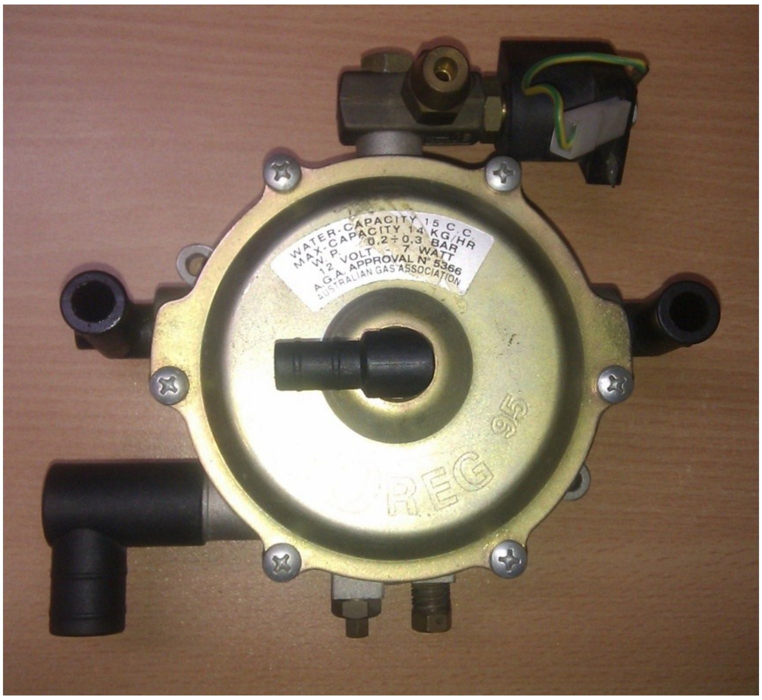


Figure 18: LPG Vaporiser procured for project

Figure 19: Pre Owned Garretson SD LPG Regulator acquired for project

This fact and the fact that this vaporizer would take up a lot of room on a vehicle the size of a scooter make it very impractical for the required application.

The usage rates mentioned above equates to 0.43 millilitres per second when the scooter is travelling at full speed. Because the consumption rate is so low there is a chance that the vaporizer may not be necessary. The boiling temperature of propane is -42 degrees Celsius and butane is 0 degrees Celsius. Assuming the mixture is 50/50, the boiling temperature of LPG would be somewhere around -21 degrees Celsius. At any temperature above the boiling point, the gas will begin to vaporize.

Inside of the gas cylinder this will occur until the area above the liquid reaches its saturation point and the vapour pressure has reached its limit for the current temperature. The rate at which this vaporization takes place depends on a number of factors one being the wetted area of the gas cylinder.

Because the wetted area in the gas cylinders is small this will adversely affected the vaporization rate of the liquid gas. The gas cylinder detailed in Appendices II has a volume of 1.4 litres. Therefore the total volume of two cylinders is 2.8 litres and because the gas cylinder will never be filled any more than 85%, to allow for thermal expansion, that leaves 400mL of vaporised gas available from the time the scooter starts. If the scooter accelerates up to full speed and maintains that speed, this 400mL of LPG will last around 15.5minutes. This is without taking into account that once the vapour starts being taken off the top of the liquid more vaporization will start to take place continuously.

As a scooter is usually used for short distance travel or travel in traffic, it would be very unusual for it to be used at its maximum speed for a period of 15 minutes without stopping for any period. This should mean that a regulator such as the one shown in Figure 19 could be used instead of a vaporizer.

For this to work it would be imperative that the outlet of the tank would have to be in the top so that it should be a vapour leaving in the pipe. Without constructing the gas cylinder described in chapter 9 it would be difficult to test this theory because as mentioned earlier in this chapter the rate of vaporization depends on the wetted surface of the storage device.

Chapter 9 - Gas Cylinder Design

The design of the gas cylinder is taken from AS3509:2009-LP Gas fuel vessels for automotive use.

9.1 General requirements for the thickness of the cylindrical section.

$$t = 2.5\left(\frac{D_i}{R_m}\right)^{1/2} \quad \text{….2.1 (AS/NZS 3059, 2009)}$$

$$t = \frac{2.55D_o}{2f\eta + 2.55} \quad \text{….2.2 (AS/NZS 3059, 2009)}$$

Where

t is the minimum calculated thickness.

D_i is the inside diameter of the cylinder.

D_o is the outside diameter of the cylinder.

R_m is the tensile strength of the material.

f is the lower of $\frac{R_e}{1.5}$ and $\frac{R_m}{C}$ where

R_m is the yield strength of the material.

C is a safety factor. (2.35 for carbon steel)

η is the efficiency of the welded joint. (0.9 or 1.0)

For the design an annealed steel with AISI number of 1015 was chosen. The tensile strength of this material is 386.1MPa with a yield strength of 284.4MPa. The outside diameter of the cylinder from the design is 76.2mm and an initial test thickness of 3mm was chosen giving an internal diameter of 70.2mm. To add an extra element of safety 0.9 was chosen as the weld efficiency (η).

$$t = 2.5\left(\frac{70.2}{386.1}\right)^{1/2} = 1.066mm \quad \text{….2.1 (AS/NZS 3059, 2009)}$$

f is the lower of $f = \frac{284.4}{1.5} = 189.6$ or $f = \frac{386.1}{2.35} = 164.3$

Therefore $t = \frac{2.55 * 76.2}{2 * 164.3 * 0.9 + 2.55} = 0.65mm$ ….2.2 (AS/NZS 3059, 2009)

Since the thickness of the wall shall be not less than the greater of 2.1 and 2.2 an average was taken between the initial try and the figure calculated at 2.1.

With a wall thickness of 2mm the new internal diameter is 72.2mm and

$t = 2.5\left(\frac{72.2}{386.1}\right)^{1/2} = 1.081mm$ ….2.1 (AS/NZS 3059, 2009)

$t = \frac{2.55 * 76.2}{2 * 164.3 * 0.9 + 2.55} = 0.65mm$ ….2.2 (AS/NZS 3059, 2009)

Because the cylinder will be mounted under the seat of the scooter a decision was made to say that it is the equivalent of being mounted outside of the vehicle and will have a wall thickness of 2.2mm in accordance with section 1.3 note 1. With a wall thickness of 2.2mm this will also allow for easier welding of the cylinder along its length and also the joints to the ends.

9.2 General requirements for the thickness of the end section.

For the cylindrical portion of the end it shall be the minimum thickness calculated in 2.1 in the previous section. Because of the shortage of space under the seat of the scooter, a torispherical end was chosen to try to maintain as much volume as possible in the ends.

From table 2.2 the greatest Ri/r value is 16 with a value of M=1.75. A value of 10mm was chosen for the minor radius (r) which gives a value 16 times larger for the major radius (Ri) of 160mm. Clause 2.1.3.3a however states that Ri shall not be greater than Do. If Ri equals Do then Ri/r would equal approximately 75/10=7.5 with an M value of 1.44.

From equation 2.5 the minimum thickness is given as

$$t = \frac{2.55 D_o M}{2 f\eta + 2.55} \quad \text{.....2.5 (AS/NZS 3059, 2009)}$$

Using the values from the previous section

$$t = \frac{2.55 * 76.2 * 1.44}{2 * 164.3 * 0.9 + 2.55} = 0.94mm$$

This still allows for a 2.2mm thick torispherical end to be used for extra safety as per 1.3 note 1 and for ease of manufacturing.

9.3 Construction

Construction of the gas cylinder will be carried out by a competent qualified welder. Welding procedures will also need to be prepared to specify the limits on all welding parameters.

9.4 Testing

Testing of the gas cylinder will be carried out in accordance with Section 5 of AS3509:2009. All new designs will need to be hydrostatically stretch and hoop stress tested. This would require setting up a dedicated test bench for the procedure which would require considerable costs not covered by the scope of this project.

Chapter 10 – Gas Fittings

The gas cylinder needs to be mounted in accordance with AS1425:2007 - LP Gas fuel systems for vehicle engines. This standard states that for a fixed fuel container mounting, the following components need to be fitted:

- Filler connection.
- Filler cap.
- Filler non-return valve system.
- Automatic fill limiter.
- Service valve.
- Excess-flow valve (except for a vapour withdrawal service outlet).
- Safety valve.
- Contents gauge.
- Automatic fuel shut-off device.

10.1 Filler connection

The filler connection needs to be made in accordance with Figure 20 and mounted below the seat where the old fuel filler used to reside.

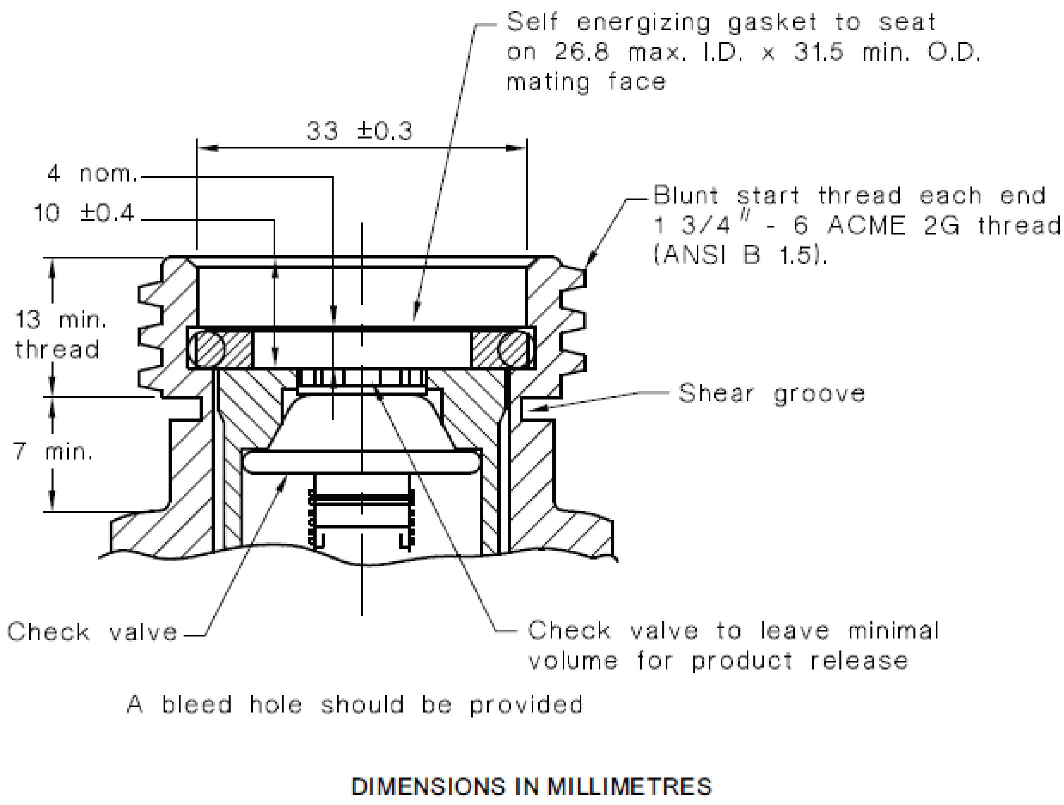


Figure 20: Filling Connection from AS1425

10.2 Gas Pipe

This filler connection will be connected to the gas cylinders by way of a rigid 10mm diameter copper pipe with a wall thickness no less than 1.02mm (AS1425, 2007, p. 33). At each cylinder there will be a spring loaded non-return valve to stop gas travelling back to the filler. Also in this supply line there will be a hydrostatic relief valve which is used to vent any build of gas in the line. The hydrostatic relief valve will be set at 3.1MPa and have its discharge vent pointing away from any possible source of ignition.

Gas will be supplied from the cylinders to the vaporiser through another 10mm copper pipe equivalent to that used in the filler pipe. Once the gas leaves the vaporiser it is at atmospheric pressure and can be transmitted through a low pressure class B flexible line in accordance with AS1869:1996 - Hose and hose assemblies for liquefied petroleum gases (LP Gas).

10.3 Filler Cap

AS1425:2007 states that the filler cap will be capable of either withstanding a pressure of 2.55MPa or be designed in such a way as to prevent the build-up of pressure.

10.4 Automatic Fill Limiter (AFL)

AS1425:2007 states that an automatic fill limiter shall be fitted to both gas cylinders to ensure that they are not over filled. They shall be installed in such a way that after installation the fill level cannot be modified and that the orientation of the cylinder for correct operation is clearly shown. The AFL must be capable of operating across any pressure between 70kPa and 1MPa.

10.5 Fuel Level / Contents Gauge

AS1425:2007 states that a fixed liquid level gauge will be fitted that has a sealed stem and is capable of retaining container pressure. It also needs to be of such design that no moving parts can be removed from the valve.

10.6 Excess-Flow Valve

AS1425:2007 states that an excess-flow valve will be fitted that ensures that the flow does not exceeds 215mL/s of liquid gas. If this flow is exceed the valve shall throttle the flow back to 3.3mL/s at no more than 350kPa. The valve shall be connected to the service valve on the engine side of the flow.

10.7 Automatic fuel shut off device

AS1425:2007 states that an automatic fuel shut off device will be fitted to the gas cylinder within one metre of the service valve. The valve must only allow supply of gas when the ignition is turned on and the engine is running. At start up, the valve may be able to supply gas for 3 seconds to allow priming of the system. A fuel filter must be fitted before the Automatic fuel shut off valve to prevent contaminants from blocking the shutoff operation.

10.8 Safety Valve

AS1425:2007 states that a safety valve or regulator will be installed to ensure that the full flow pressure shall be limited to 3.3MPa.

10.9 Service Valve

AS1425:2007 states that a service valve shall be provided in such a place as to allow the gas supply to be turned off for maintenance or emergency situations.

Chapter 11 – Gas Cylinder Mounting Design

The gas cylinder will be mounted so as to comply with the requirements of AS1425:2007. This standard states that the "force necessary to separate the container from the vehicle will be no less than 20g times the mass of the full container in any direction." The mass of the full gas cylinders is approximately 1.25kg therefore the applied force needs to be $1.25kg * 20g \approx 250N$. This force will be applied through the centroid of the cylinders and in every direction.

Our load cases therefore are:

- 20g Forward
- 20g Backwards
- 20g Sideways
- 20g Upwards
- 20g Downwards

Table 3.2 in the above code also states that containers from zero to one hundred litres shall have a band size of 30x3mm. The chassis of the test scooter is also made out of 3mm steel. Because of this it makes sense to make all of the mounting components out of 3mm plate as per the general arrangement below. Refer to Appendices II for the complete design set.

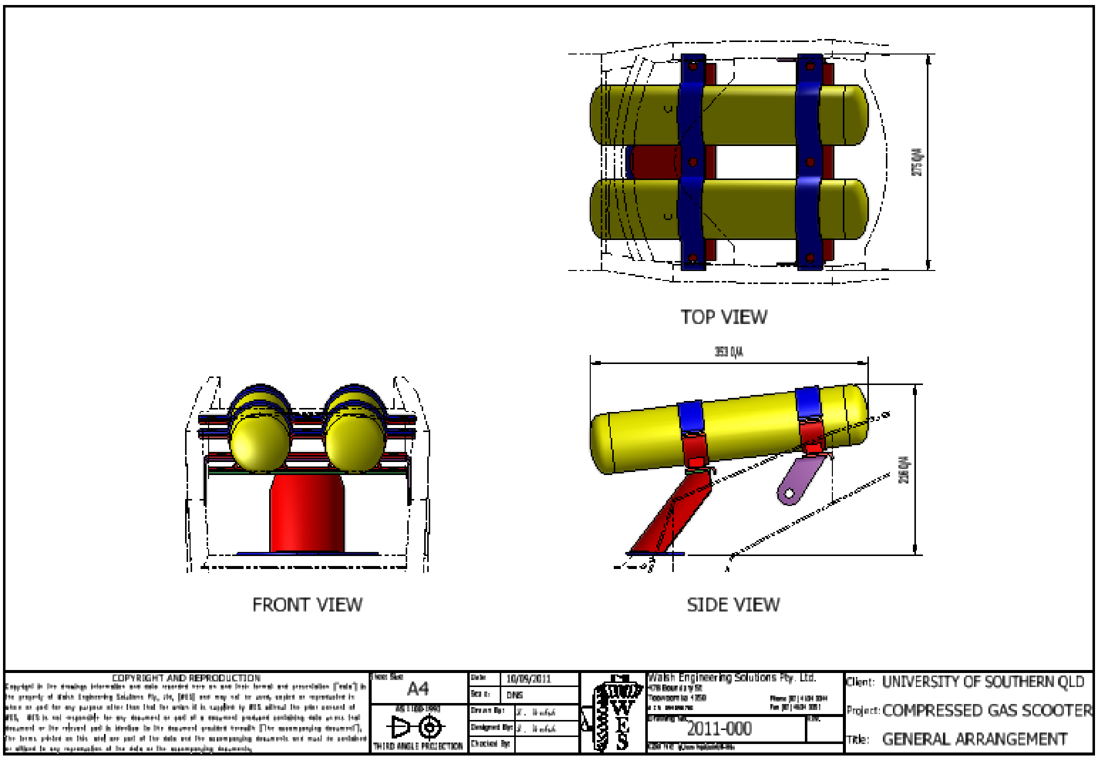


Figure 21: Gas Cylinder Mounting General Arrangement

The front mount of the system needed to be profiled around a service opening which allows access to the carburettor. Because this compartment will no longer be used as a sealed glove box this cover can be left open to allow ventilation for the gas cylinders.

A model was also built in the Strand7 FEA package for analysis of the applied load. Part of the chassis was also modelled so that the solid restraints could be placed a reasonable distance away from the location of the cylinder mounts.

Because the thickest part of the system was only 3mm thick, plates were used to model all of the geometry and given a suitable thickness. Point contact beam elements were then used to accurately simulate the contact between each of the individual mounting components. Beam elements were then run between the clamps for the application of the design load.

The 250N load was applied in the above specified directions at the centre of the cylinders. The allowable stress for this applied load would be the ultimate tensile strength as the gas cylinders need to remain attached to the vehicle in the event of an accident. This being said the yield strength was taken as being the allowable stress so that if an accident does occur the brackets would not need to be replaced. Using a standard 250 grade plate with a yield stress of 250MPa it can be seen from the results in Appendices III, that limits have been set well below yield just to see where the stress in the plates were.

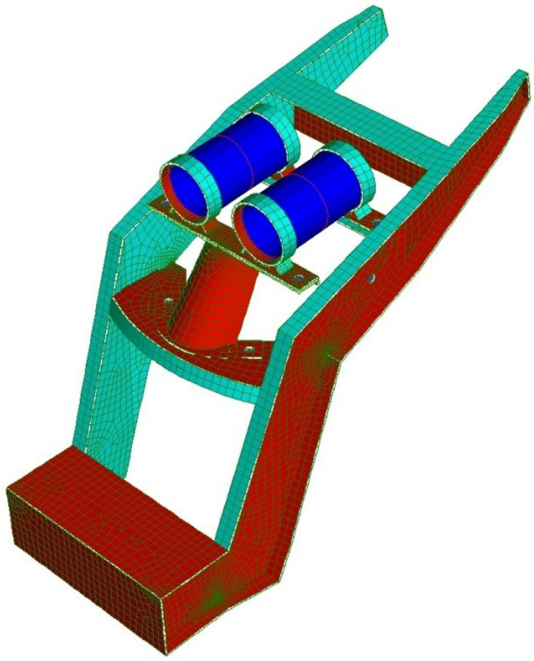


Figure 22: Complete FEA Model

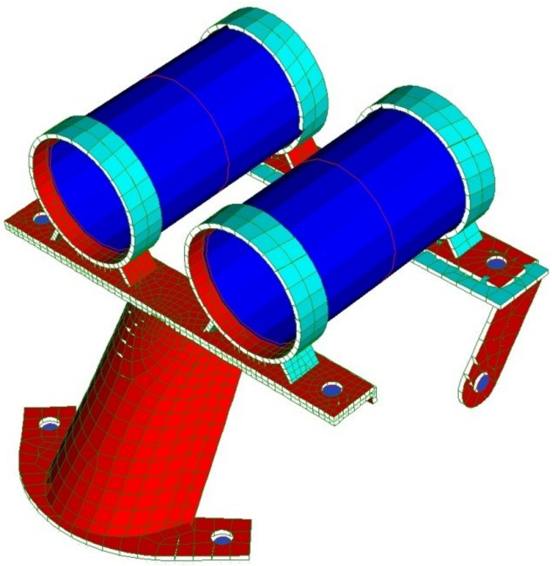


Figure 23: Gas Cylinder FEA Model

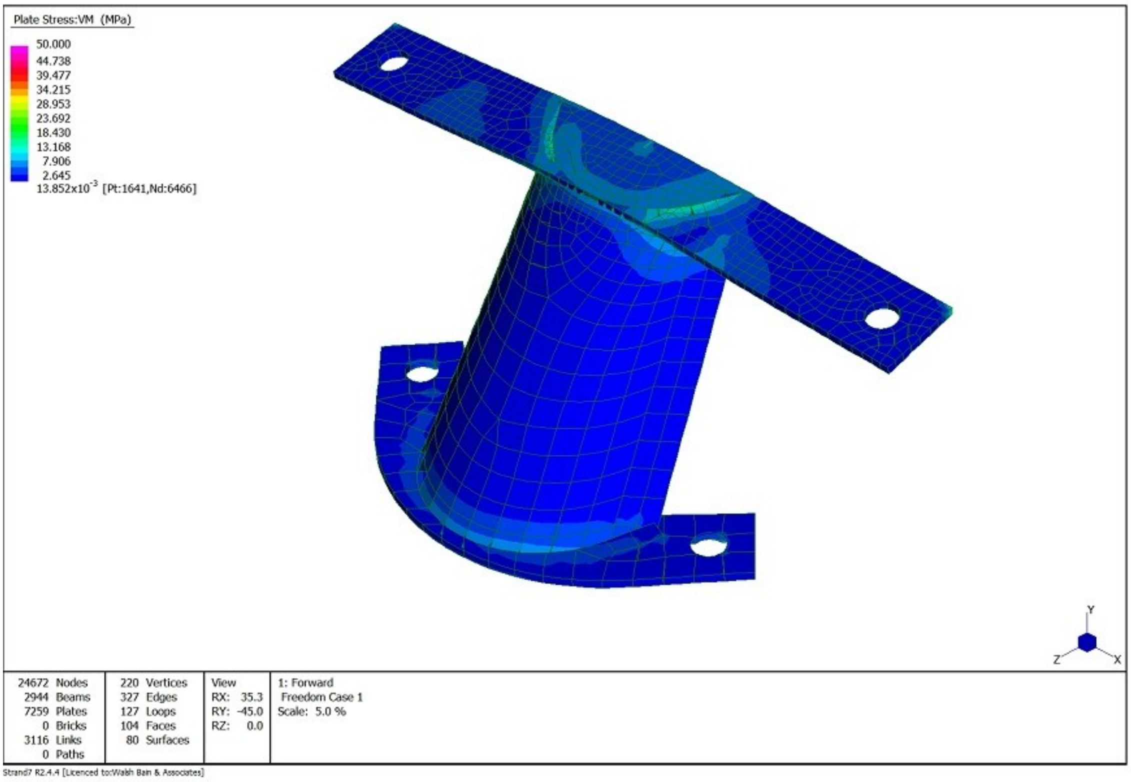


Figure 24: Lower Front Mount 20g Forward Von Mises

This design doesn't weigh a considerable amount so it will not affect the performance of the scooter by any noticeable amount so it will not need to be refined to make it lighter. Also by having the brackets manufactured from a heavier material there is less chance of it cracking.

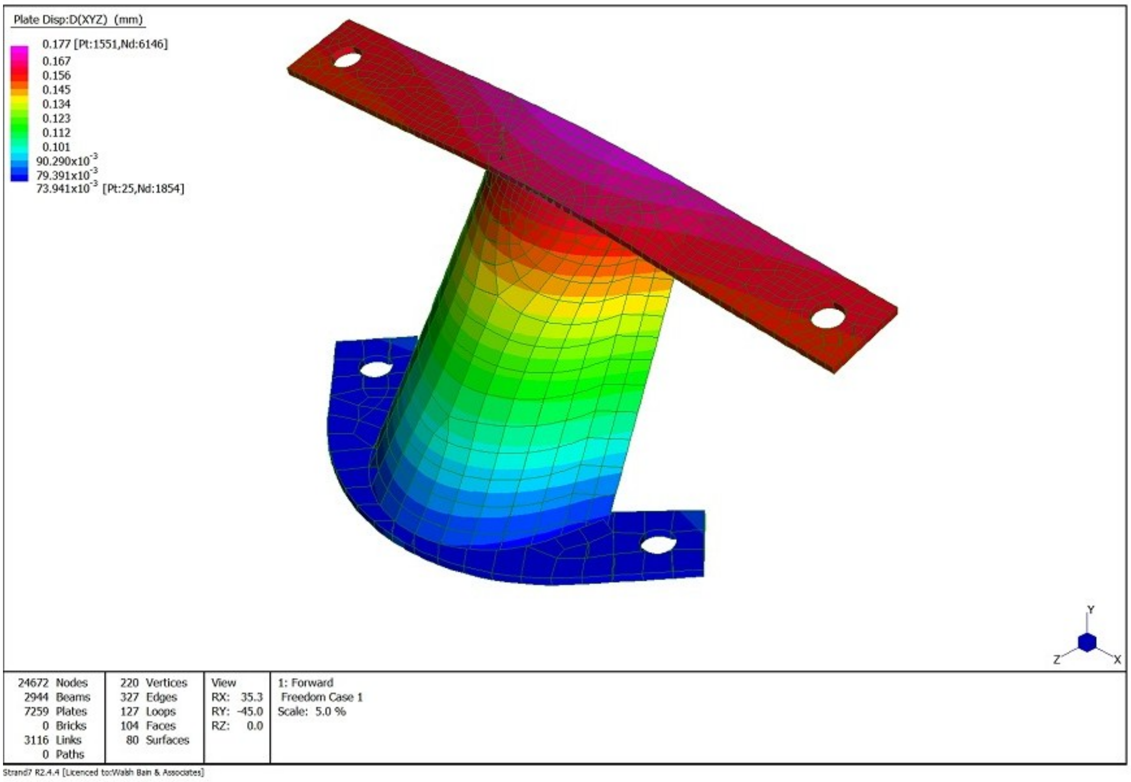


Figure 25: Lower Front Mount Displacement 20g forward

From the above figure it can be seen that the bracket is only moving 0.18mm under its 20g loading.

Chapter 12 - Parts Requisition

To provide a proof of concept for the design a number of essential parts were required. After consulting with a number of the local LPG gas fitters and researching suppliers online, it was decided that for a motor of this size a mixer would not be necessary and that a "Spud" could be used to supply the gas into the air stream. A "Spud" or "Spud In" is an insert that is drilled into the carburettor or intake manifold so that gas can be mixed before entering the motor. They can have a number of different designs, either a straight venturi type which runs perpendicular to the flow of air or as a diffuser. The diffuser type insert has a number of holes drilled through it perpendicular to the flow of the gas. This aids to mix the gas with the air more efficiently.

The next piece of equipment which was supplied by a local supplier was a vaporiser. After having ordered the part in early June, it finally arrived at the start of October. It was also too large for the application which the project intended. After further consultation with the supplier who was well aware of the time shortage, came to a conclusion that instead of a vaporiser a secondary regulator could be used. After some more time spent searching for one of these a second hand one was procured.

Chapter 13 - Construction

The brackets were made as to the design in Appendices II and mounted to the test scooter.

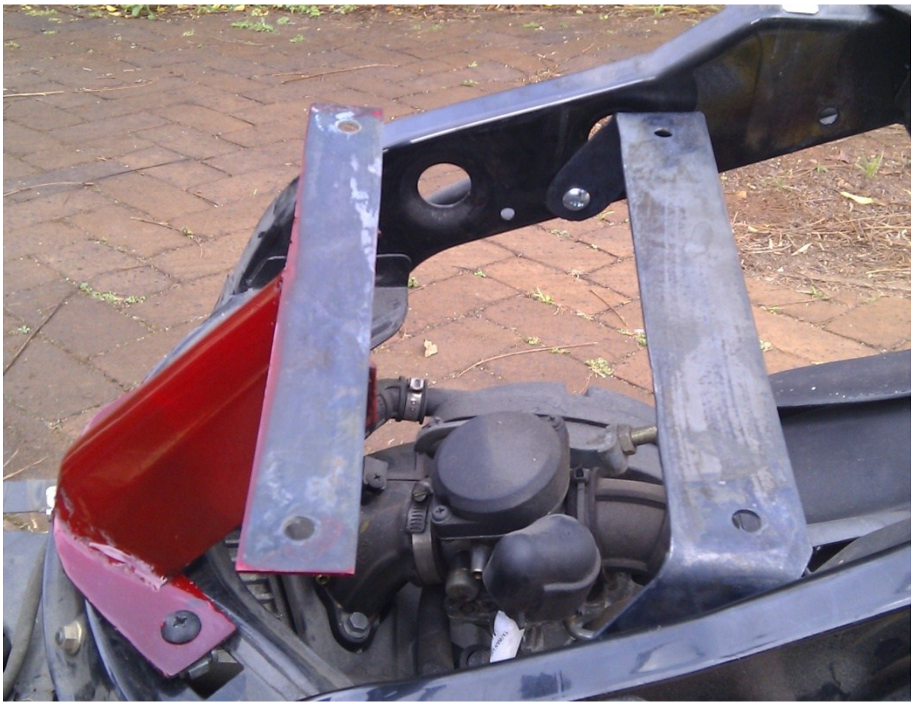


Figure 26: Lower Cylinder Mounting Brackets as installed showing the mounts in the correct location to support the gas cylinders accurately

As this was a prototype model all of the brackets were made by hand using only the hand tools and power tools available. This lead to a number of obstacles during the construction phase. The front lower bracket has an odd shaped spacer plate between the upper and lower attachment plates. Because the plate was cut by hand with a plasma cutter the accuracy achieved was far below what is achievable using a mechanical method such as laser or water cutting.

These inaccuracies added to the inaccuracies involved with not using a roller to form the required shape made it difficult to set the top and bottom plates at the correct orientation and position to each other. For a large scale manufacturing setup the spacer plate could be stamped out of a blank and then pressed to the required shape. A jig could be setup which would hold the three plates in the correct location ready for welding.

The cylinder clamps were also cut with a hand held plasma cutter and then formed by hand. This took an extremely long time to achieve an accurate shape and as such only one pair was made for proof of concept. Without automating the process the whole system would not be viable because of the high costs involved with making the brackets.

Due to the cost involved with setting up a hydrostatic test rig and making the torispherical ends it was not viable to construct the gas cylinders that are detailed in appendices II within the budget of the project. To manufacture the gas cylinders the torispherical ends would need to be stamped out of a sheet and then pressed using custom made dies into the correct shape. This is not a process which could be practically performed by hand. For proof of concept to ensure that the detailed gas cylinders would fit, two lengths of three inch pipe were cut and clamped in the cylinder mounts as shown below.

Figure 27: Front gas cylinder mount

Figure 28: Rear gas cylinder mount

Due to the straight cut ends of the pipe the cylinders didn't sit in as far as they should have towards the back of the scooter. If the torispherical ends as shown on the design drawings were actually fitted to the ends of the pipe, the cylinder would have sat all the way back in as per the design. This would allow the front of the cylinders to sit back just outside the front of the original plastic cowling.

Chapter 14 - Gas Conversion

Using the gas pressure regulator shown in Figure 19 an experiment was setup to test whether the system could in fact run on LPG without a vaporiser. To achieve this, a number of new parts were required to attach the gas to the scooter.

- A gas hose with pressure reducer was taken from a barbeque.
- A larger fitting was required to connect the hose to the Garretson regulator
- More gas hose was purchased along with some hose clamps
- A barbeque gas cylinder was used

Figure 29: Barbeque Pressure Reducer

The gas cylinder was connected to the barbeque pressure regulator. This served to provide a fitting which screwed straight in the bottle as well as acting as a non-return valve. This valve reduced the gas pressure from its storage pressure back down to 2.8kPa and ensures that the flow is kept below two kilograms an hour.

The hose which is crimped onto the reducer is then screwed onto the new adaptor valve that was screwed into the Garretson regulator.

This regulator's main purpose was to regulate the amount of gas sent to the motor. The higher the negative pressure on the motor side of the valve, the more gas it would let through. Another gas line was connected to the outlet of this valve which connected to the intake manifold between the carburettor and the motor. This was clamped in place using hose clamps.

Figure 30: Front side of connected regulator

Once everything was tight and in place, the battery was put back in place and the ignition turned on. After some initial winding without any sign of ignition, the gas line was removed and the fuel tank put back in place.

Once again the motor was wound over for a while before it finally started. After being left to run for around one minute, the motor was stopped and the fuel tank removed. The gas lines were then hooked back up and the ignition switch pressed again. This time the motor fired and began to run.

After around fifteen seconds the motor began to run rough and it was apparent that the motor had consumed all the petrol in the carburettor and was now running, if quite poorly, purely on LPG.

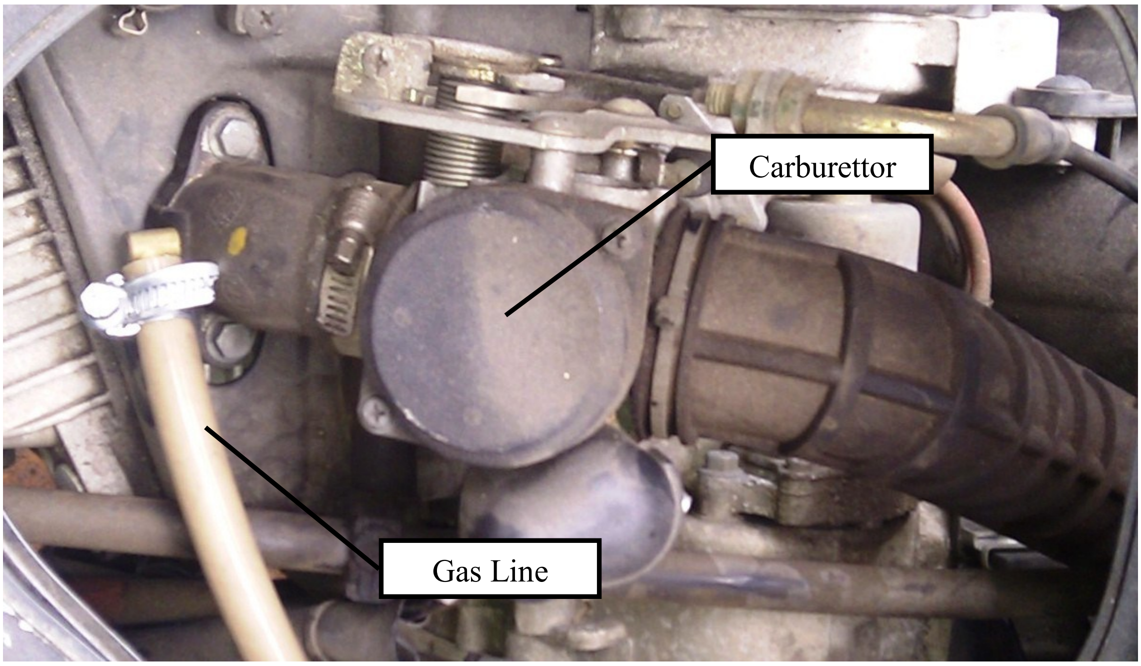


Figure 31: Gas supply line shown on left of carburettor

Chapter 15 - Tuning

With the motor on LPG it needed to be tuned so that it ran smoothly and efficiently. This was done by adjusting the two tuning screws on the regulator. After some investigation it was found that the adjustment screw on the valve body is for adjusting the sensitivity of the valve and the screw on the outlet line adjusts the flow through the line.

Figure 32: Main flow adjustment screw

Some initial adjustments were made to try to get the scooter to idle smoothly. During this time the adjustment screw on the regulator body was unintentionally wound too far in. This lead to the valve having to be fully dismantled to get the adjuster screw out of the inside of the valve.

This provided a great opportunity to see how the valve worked. The Garretson SD regulator is what is sometimes referred to as a demand regulator. Inside the regulator there is a valve which sits in the intake line that limits the flow through the valve. On the end of this valve is a lever which is attached to a diaphragm. There is also a spring attached to the limiting valve.

When a negative pressure acts on the outlet line, the diaphragm is drawn down opening the inlet valve. The spring acts to oppose the action of the diaphragm. A higher spring force means that it takes more effort to move the diaphragm. A lower spring force means that the valve is more sensitive to changes in pressure.

During the dismantling of the valve it was found that the initial setting of the regulator was such that the adjustment screw was binding on the diaphragm lever causing it to be fixed in one spot. Since the regulator is second hand it may have been wound too far in by the previous owner. If it was used on a stationary engine this probably wouldn't have affected the performance because the engine speed wouldn't have been changing too much.

Once the valve was put back together, the motor was tuned by adjusting the two adjustment screws until the motor would idle. This was done mainly by trial and error. It was also discovered during this time that the secondary larger outlet on the rear of the regulator had been damaged at some earlier date and could no longer be closed fully.

A length of hose was fitted to this outlet and a bung was placed in the line to seal it off. After this alteration was made the motor was able to be made to idle correctly. Next the speed was increased to check how it performed above idle. As soon as the throttle was moved the engine died down and almost stalled. This happened every time that the throttle was moved.

Because of the location of inlet which was used to attach the gas hose, it was decided that maybe the gas was being introduced into the air flow too close to the combustion chamber. This would then not allow enough time to mix the gas and air correctly. The gas line was then removed from this inlet and moved back to the inlet towards the rear of the carburettor where the petrol line used to be.

After adjusting the screws on the regulator for some time trying to get the scooter to start without any success, the top of the carburettor was removed to see what could be stopping the gas entering the system.

Inside the carburettor underneath the top lid was another type of diaphragm valve. This one worked by using the flow of air past the valve to lift a needle which then allowed petrol to flow into the carburettor. This needle was removed so that the gas was free to flow directly into the main valve body.

After reassembling the carburettor some adjustments were made to the regulator until the engine started. After running for several seconds the throttle was turned to increase the speed. This produced a much better result with the scooter revving up to a higher engine speed without dying back down first.

Just as quickly as the engine had started and appeared to perform, it suddenly lost power and stopped. Trying to start the scooter again with the same settings failed to work so once again the adjustment screws were altered to try to get the scooter to fire without any result. The gas line was then removed from the rear fuel line and put back to the port in the intake closest to the combustion chamber where it was connected originally.

This once again allowed the motor to be started quite easily. Because of this fact it was apparent that nothing had happened to the motor to cause the sudden loss of power. The gas line was once again moved to the fuel port on the rear of the carburettor. After some more trials with different regulator settings, another gas line was run from the second port on the back of the regulator to the front intake port.

This port was much larger than the initial port that had been used before and because the adjustment screw could not be closed fully because of the damage mentioned earlier, it caused the engine to keep flooding. By removing the line and placing it so that it was just in front of the inlet port on the intake manifold it supplied sufficient gas to allow the engine to start and idle roughly. As soon as this line was removed from the port, the engine would not continue to run solely on the smaller line at the rear of the carburettor, and stopped.

The next line of investigation was to make a diffuser for injecting the gas into the air stream. By using this method it would ensure that the gas would have a better chance of mixing with the air in the intake. To make this temporary diffuser, a small length of 6mm diameter copper pipe was used. One end was squashed closed so that very minimal gas could exit through the end.

Next 6 holes were drilled through the pipe at different angles and varying distances from the squashed end. The furthest hole was about 30mm from the end while the closest was about 15mm.

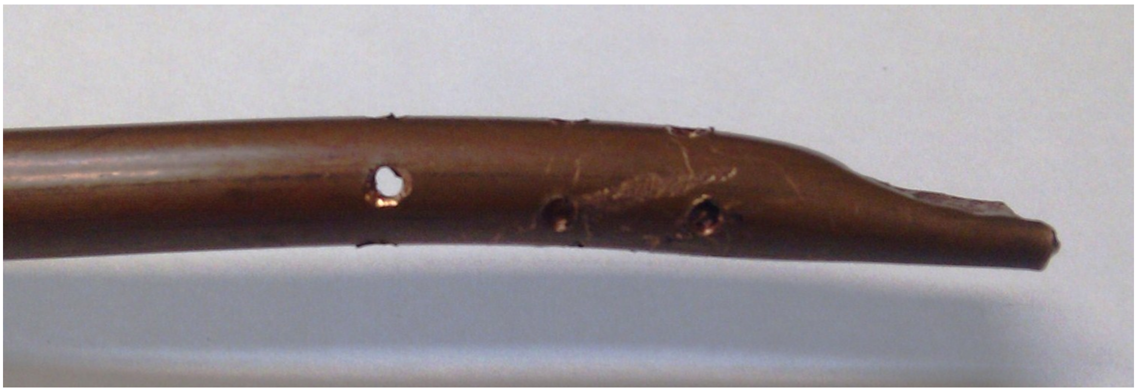


Figure 33: Gas Disffuser

All the holes were deburred and the pipe cleaned so that no foreign objects would be sucked into the motor. The air cleaner was removed from the scooter and the diffuser was inserted into the intake hose until it was about 50mm from the carburettor. Finally the gas supply line which was hooked to the carburettor was removed and attached to the diffuser.

Once again the scooter was started and the adjustment screws altered until a steady idle could be maintained. As before the motor died down as soon as the throttle was increased above idle. A decision was then made that it couldn't be the fact that the gas wasn't mixing with the air enough before entering the combustion chamber and that it must be something else. This lead to thinking of the possibility that there wasn't enough gas being delivered.

The diffuser was removed from the small gas supply line and a bung placed in the end. Next the bung was removed from the large supply line and the hose was placed directly into the intake hose. Again the engine was setup for idle and faded once the throttle was raised much more than idle. Another thing that was discovered, was that the engine seemed to stall when the gas supply tap was opened up too much, thus putting too much (too rich) gas into the air stream.

Another point which was discovered was that the speed of the engine could be altered by adjusting how much gas was being delivered. Once the engine started to fade from too much fuel, the throttle could then be opened up a little and more gas supplied. In this way the speed of the motor could in fact be made to run at a faster speed.

At the time of writing this report, the scooter was still unable to accelerate correctly without adjusting the regulator valve. With more time available and a larger budget, a dedicated air gas mixer could be sourced to see whether the acceleration problem could be solved.

Chapter 16 - Proof of concept

Once the scooter was tuned to be running as correctly as possible at idle, it was connected to a small 3.7kg gas cylinder. It was then slowly accelerated whilst adjusting the regulator until the scooter was running at the same engine speed as would be required to run the scooter at 60 kilometres per hour. The engine was then left to run for 20 minutes at the elevated speed. This was done to see whether there was any sign of the regulator freezing up or whether there appeared to be any drop in engine speed due a shortage of gas vapour.

The smaller size gas cylinder was used in this test because it was as close as could be sourced to the size of the two design gas cylinders as described in Appendices II. Comparing the wetted area of the barbecue bottle to the ones intended for the scooter it can be seen that the barbecue bottle is around 20% larger. The design cylinder at 85% full has a wetted area of 20032 square millimetres. This was determined by using the 3d modelling package which the design drawings were created in. The barbecue bottle on the other hand at 85% full has a wetted area diameter of 248mm giving it an area of 48305 square millimetres.

Another factor which would have influenced the gas consumption during the test was the fact that there was no load on the motor. Because of this the amount of fuel being used during the test would have been well below what would be used under normal operating conditions.

Figure 34: Initial setup using large gas cylinder

One way to circumvent this problem would be to put the scooter on a dynamometer once it is running well enough to be able to carry out this test with any sort of accuracy. This would ensure that the scooter is placed under enough load to get a true fuel usage. It would also be useful at this stage to have a pair or gas cylinders made to the design in Appendices II so that it would be a true test to see whether or not the rate of vaporization is sufficient to provide prolonged travel with the scooter without the need for a vaporiser.

During this phase of testing the full gas cylinders could be weighed and then reweighed after the 20 minute test. With these two weights average fuel consumption could be calculated and compared to the figures from Chapter 8 – LPG Gas System.

Chapter 17 - Conclusion

The original scope of this project involved developing a hybrid LPG / compressed air powered scooter. This system was rejected due to certain complexities which would make it very expensive to retrofit. The design also needed to be easily mounted without too much alteration to the scooter.

After completing the decision matrix in chapter 7, a decision was made to develop a straight LPG powered scooter. During the investigation, there were a number of different elements identified which were needed to complete the conversion.

These elements were the gas cylinders, the cylinder mounts, the gas regulator, the gas fittings/shut off valves, etc. and the gas lines. After fabricating the gas cylinder mounts detailed in Appendices II it was established that it would be very feasible to mount a pair of gas cylinders in the storage compartment of a Piaggio Zip 4T in accordance with AS1425.

The gas cylinders which are also detailed in appendices II are large enough to hold a combined volume of 2.4 litres of liquid gas when filled to 85 percent of their capacity. This would provide the operator of the vehicle with enough fuel to travel fairly conservatively around 95 kilometres at a cost of about $1.50 (as per the current price of Autogas). In comparison to the original scooter setup which would travel a little more than 50 kilometres for the same price it proves to be an excellent upgrade for its cost savings and its lower impact to the environment.

When compared to a small medium size 4 cylinder car which costs approximately $10 for every 100 kilometres it makes the LPG scooter a very cheap transport option, either for university students or in countries like India where there are already a large number of registered scooters.

From the initial test, which was run without load on the motor, it looks promising for these gas cylinders to be quite capable of supplying a constant flow of vaporised gas. If this proves to be accurate the cost involved with producing a conversion kit would be lowered quite considerably because the cost of a regulator is around half that of a vaporiser.

This saving may be negated however if the addition of a dedicated gas/air mixer or carburettor solves the acceleration problems. These units can cost anywhere up to $300 which in comparison to a $2000 scooter is quite significant.

A recommendation of this report would be for a mixer to be tested in conjunction with the current regulator to see whether reliable acceleration of the scooter could be achieved or if a different type of regulator is needed. If sustainable operation is achieved the scooter should be put on a dynamometer and run under load with the small barbecue bottle again to see whether it can last for at least 20 minutes without showing signs of running out of vapour.

This would need to be done prior to the gas cylinders being made as it would be beneficial to have the scooter running correctly before spending money setting up a test rig and making dies for pressing the torispherical ends.

If it proves plausible that the scooter can be successfully converted to liquefied petroleum gas there is a very high potential for a cross over to compressed natural gas once the infrastructure is in place to provide convenient supply to the public. The other possibility is for the operator to use a gas compressor to refuel an adsorbed natural gas cylinder in their garage at home making use of the gas pipe line running past their house.

Even if the cost of conversion exceeds half the cost of the original scooter, the benefits to the environment would easily make the extra price worthwhile, especially with a carbon tax likely to be incurred on all fossil fuel burning engines.

Appendices I

Definitions

ADSORPTION – “the adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact” (Merriam-Webster Dictionary, 2011)

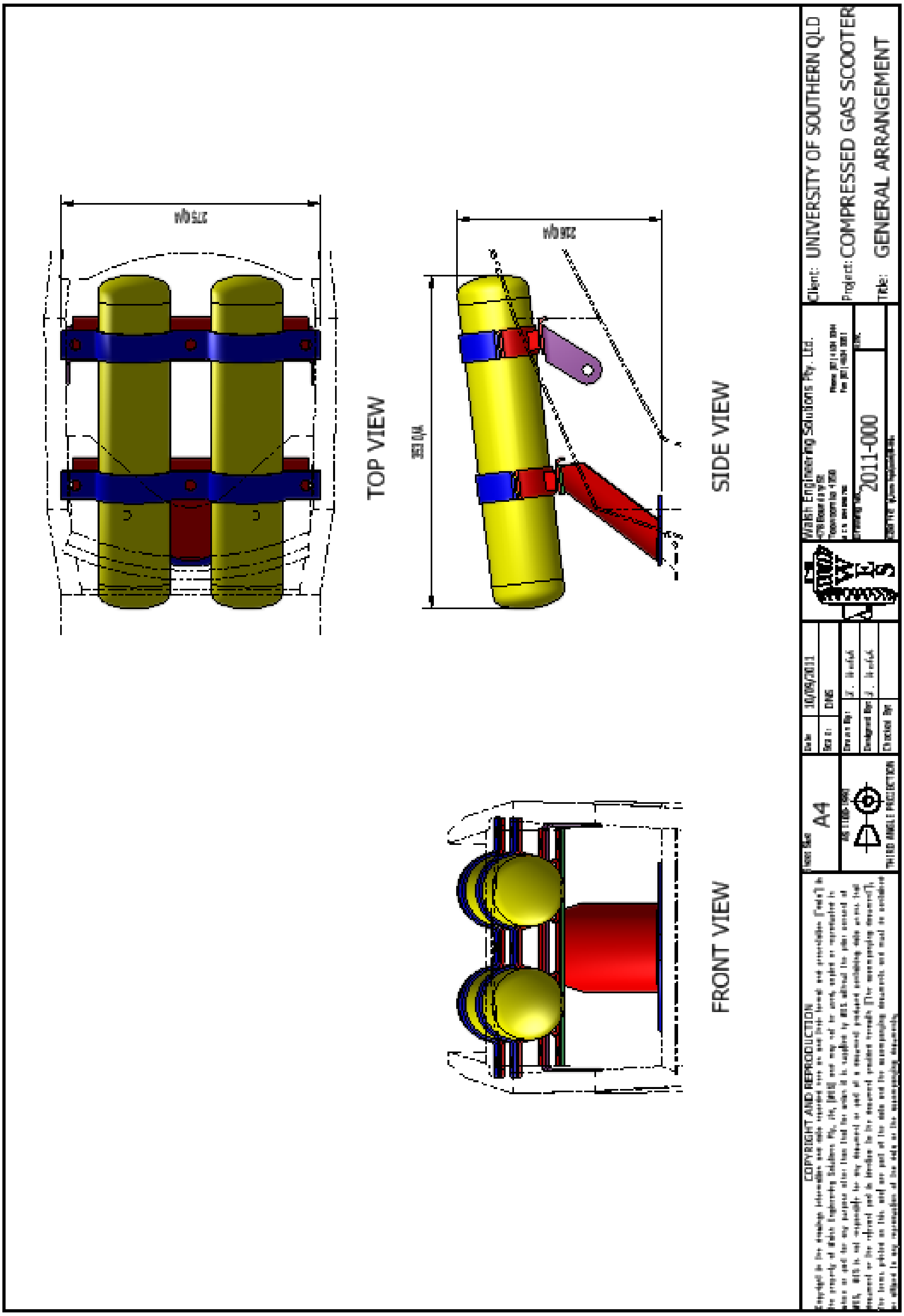
MOPED – “A 2-wheeled motor vehicle, not being a power-assisted pedal cycle, with an engine cylinder capacity not exceeding 50 ml and a ‘Maximum Motor Cycle Speed‘ not exceeding 50 km/h; or a 2-wheeled motor vehicle with a power source other than a piston engine and a ‘Maximum Motor Cycle Speed‘ not exceeding 50 km/h.” (Australian Government, n.d.)

OCTANE RATING – The measure of resistance a fuel has to ignition. The higher the rating the less chance of detonation and the greater chance of a clean burn. The lower the rating the easier it is to ignite.

Appendices II

Design Drawings

The Following pages are the design drawings for the individual components of the mounting system and gas Cylinder.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SIDE VIEW
FRONT VIEW
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Project: COMPRESSED GAS SCOOTER
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Walsh Engineering Solutions Pty. Ltd.
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10/09/2011
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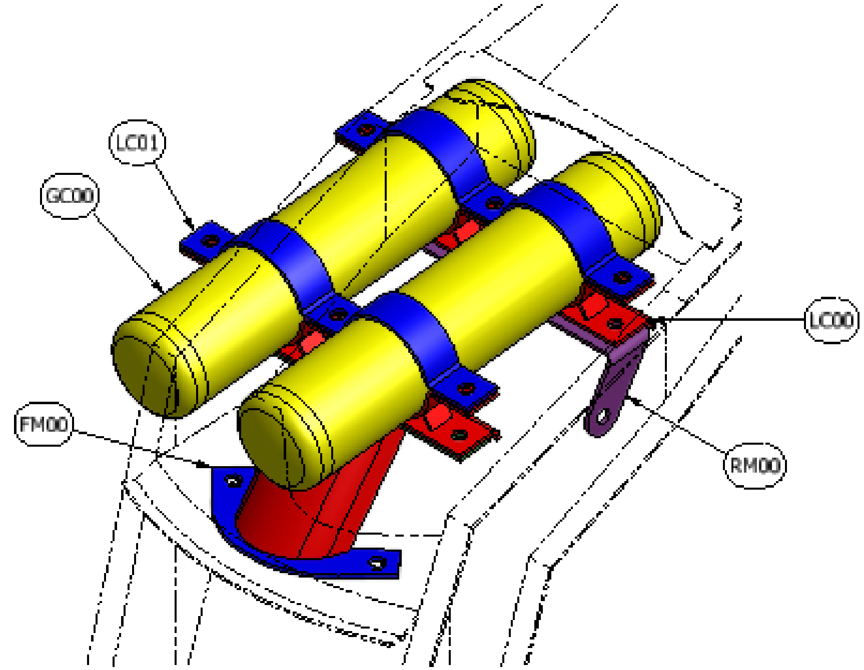

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FM00	FRONT MOUNT	1	010
LC00	LOWER CYLINDER BRACKET	2	020
LC01	UPPER CYLINDER BRACKET	2	021
RM00	REAR MOUNT	1	030
GC00	GAS CYLINDER	2	040

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	Designed By: J. Walsh		
	Checked By:		

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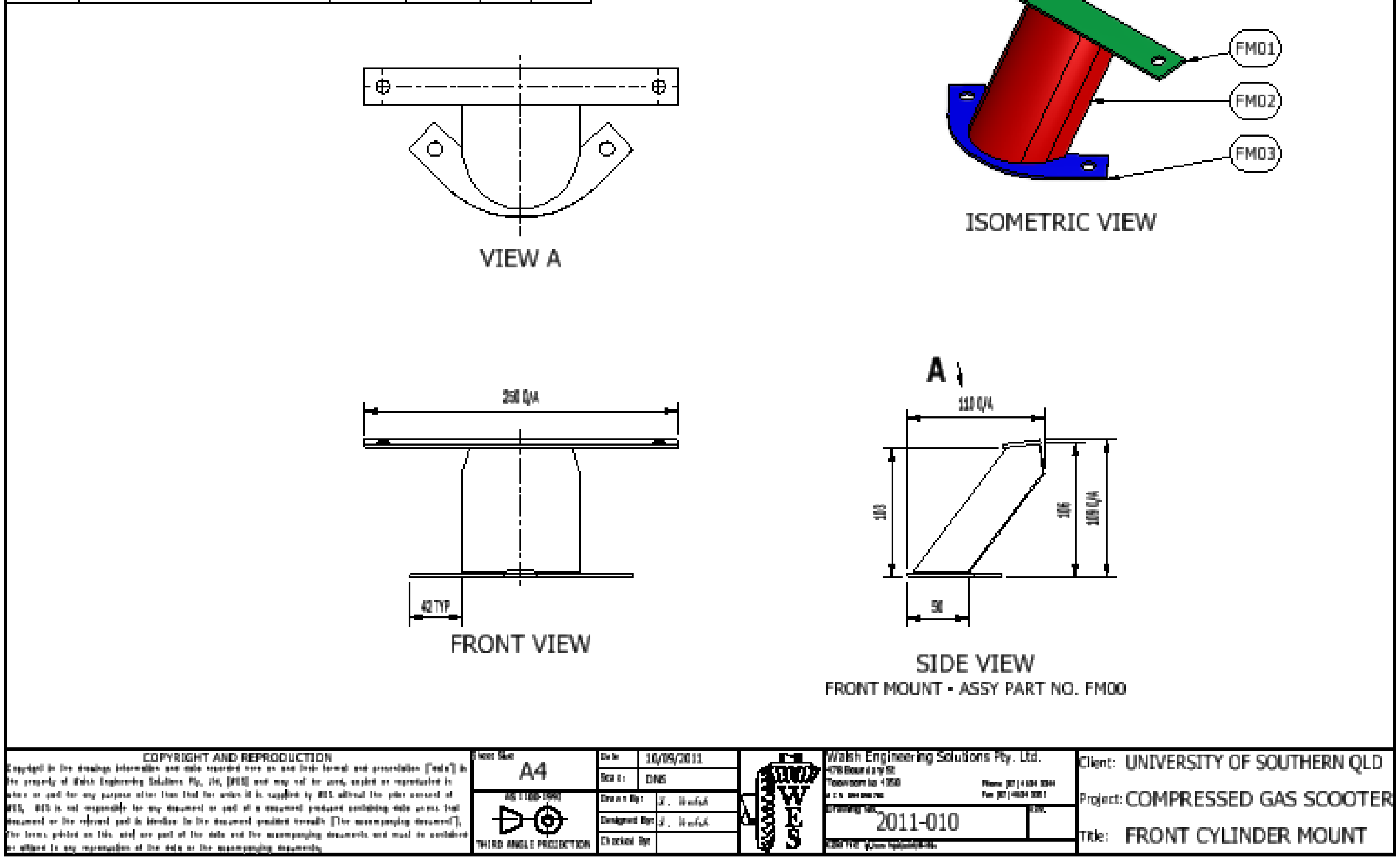

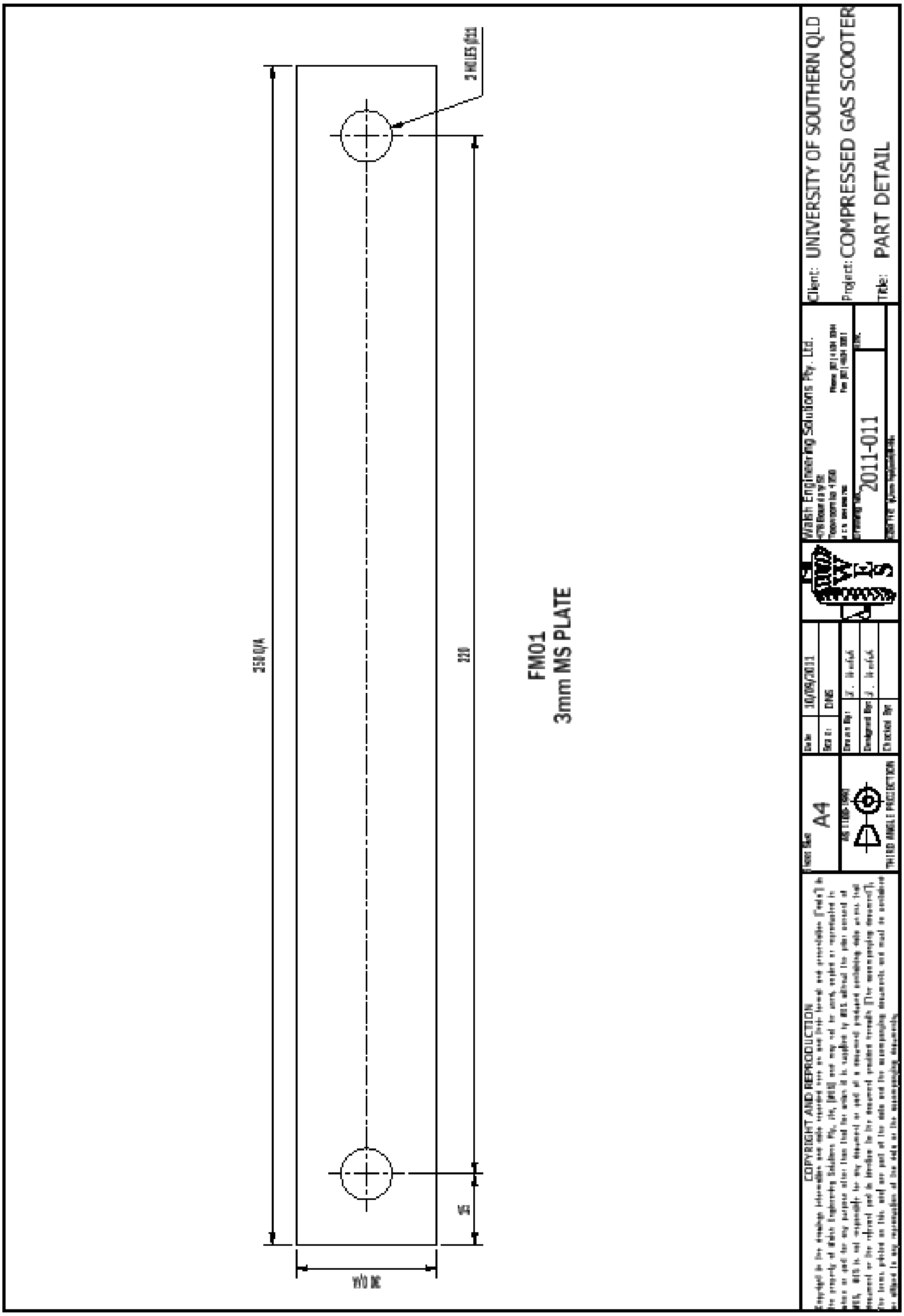
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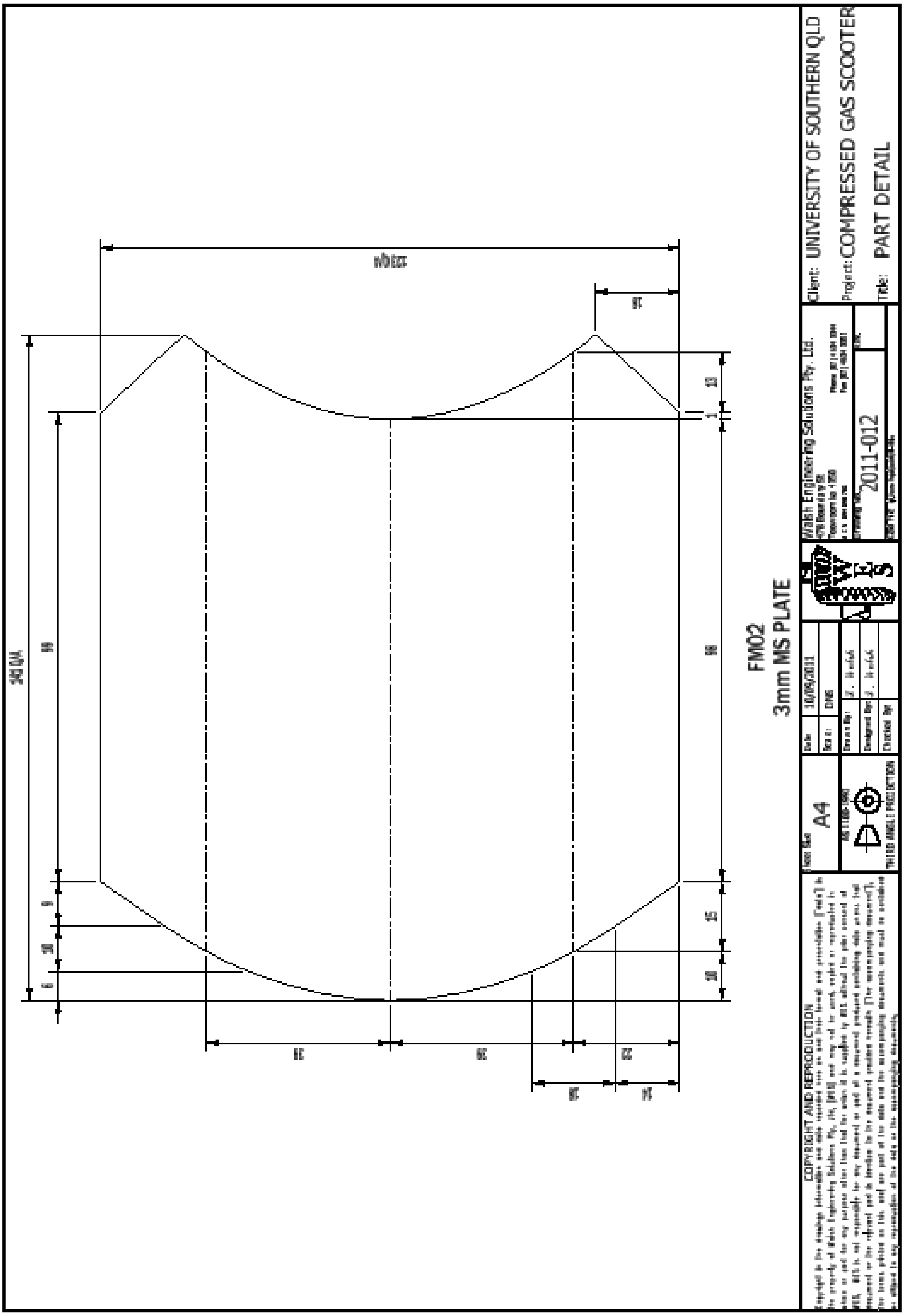
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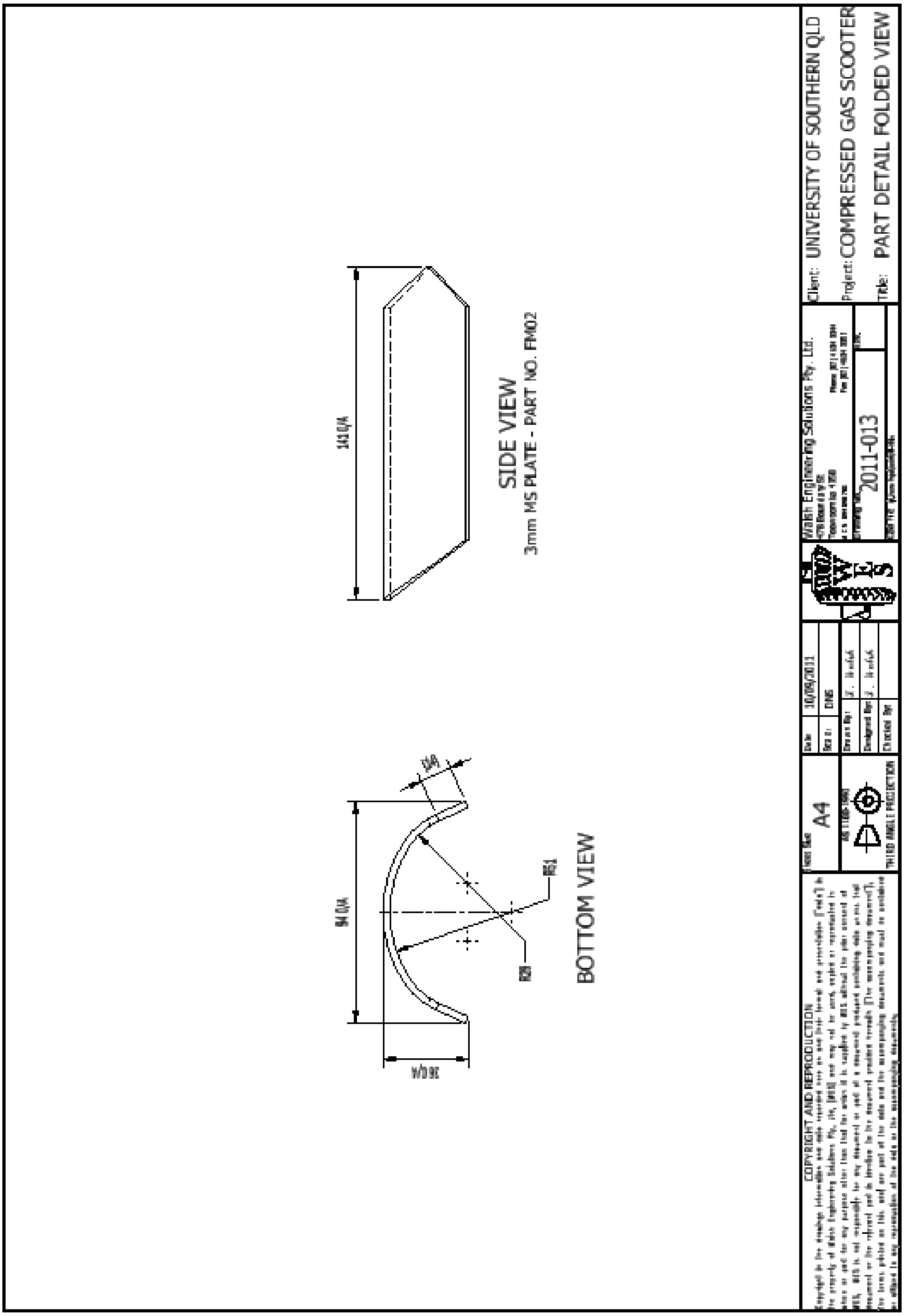
SIDE VIEW
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BOTTOM VIEW
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10/09/2011
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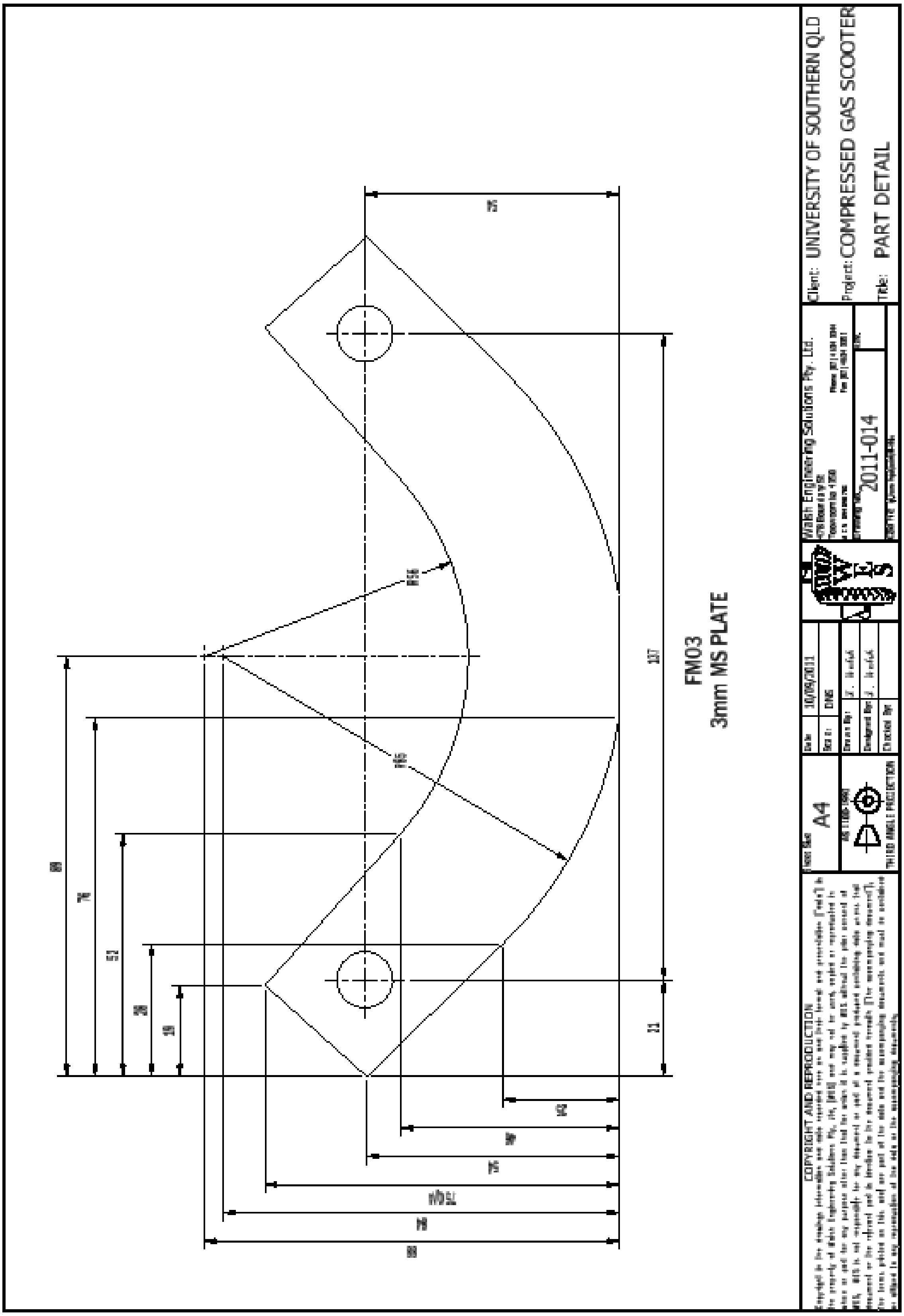
Title: PART DETAIL FOLDED VIEW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COPYRIGHT AND REPRODUCTION
FM03
3mm MS PLATE
137

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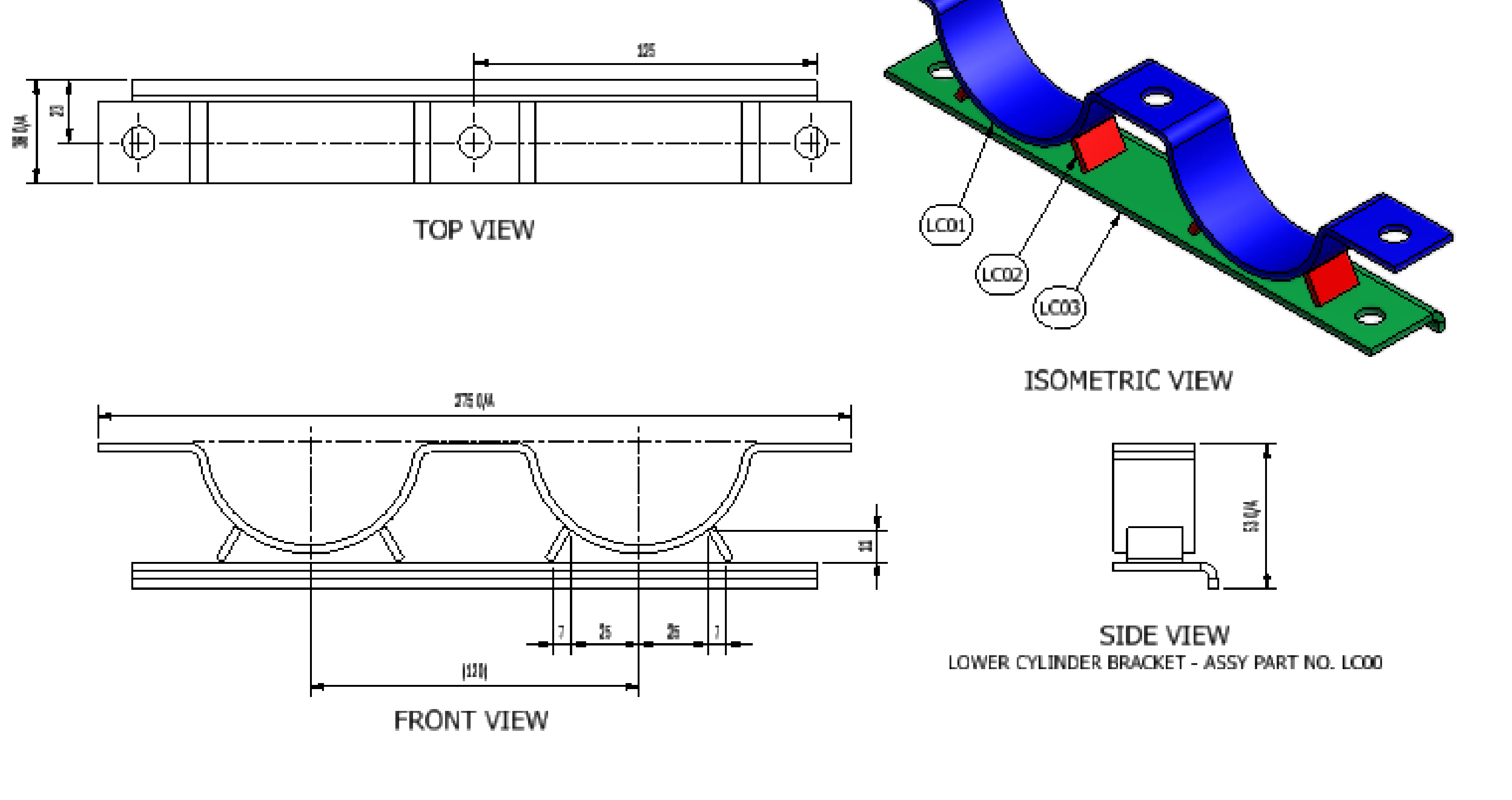

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THIRD ANGLE PROJECTION

Date: 10/09/2011

Scale: DNS

Walsh Engineering Solutions Pty. Ltd.

Drawing No.: 2011-020

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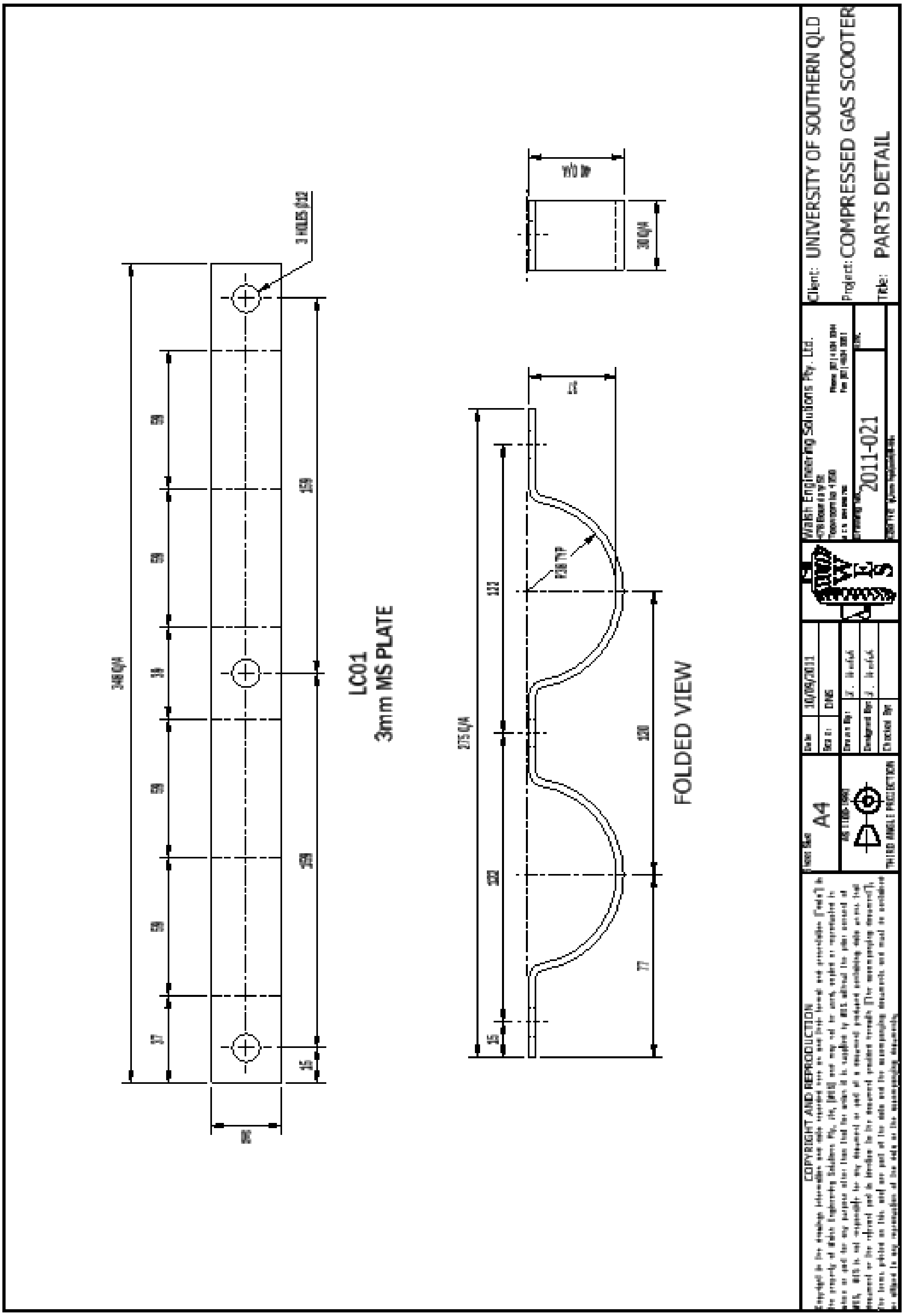
Project: COMPRESSED GAS SCOOTER

Title: LOWER CYLINDER CLAMP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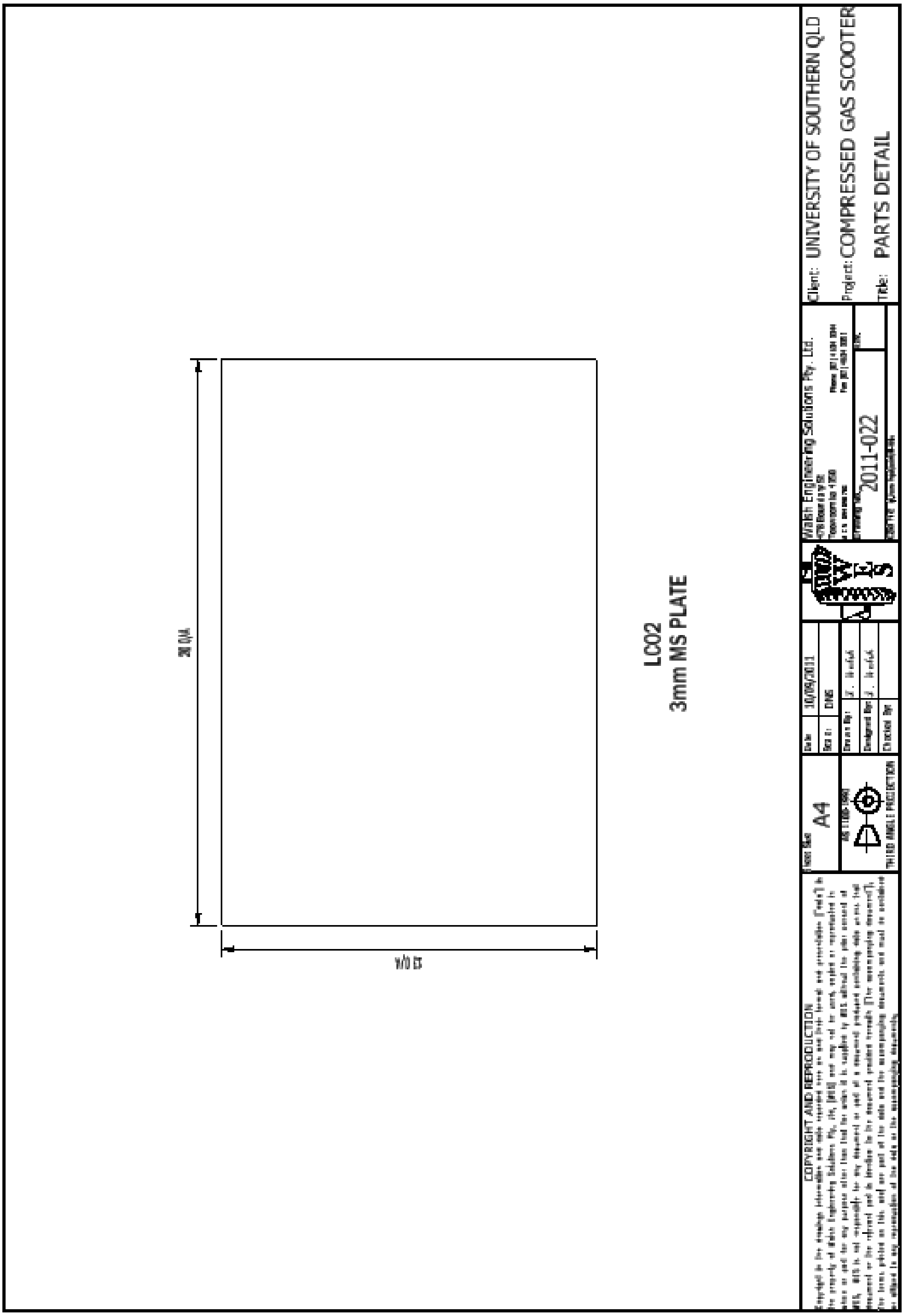
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Client: UNIVERSITY OF SOUTHERN QLD
Project: COMPRESSED GAS SCOOTER
Title: PARTS DETAIL
Walsh Engineering Solutions Pty. Ltd.
2011-022
A4
THIRD ANGLE PROJECTION
Date 10/09/2011
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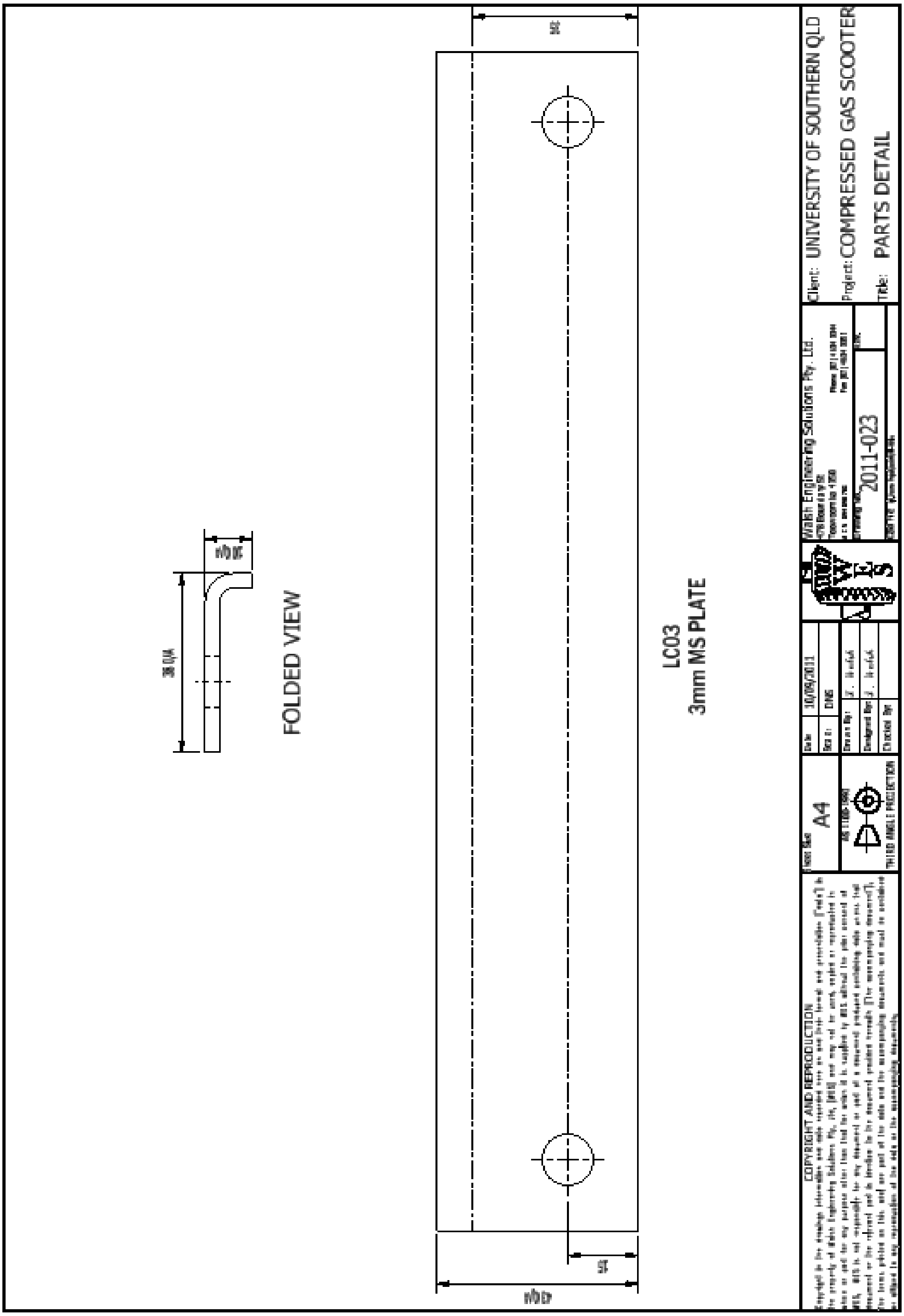
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Project: COMPRESSED GAS SCOOTER
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FOLDED VIEW
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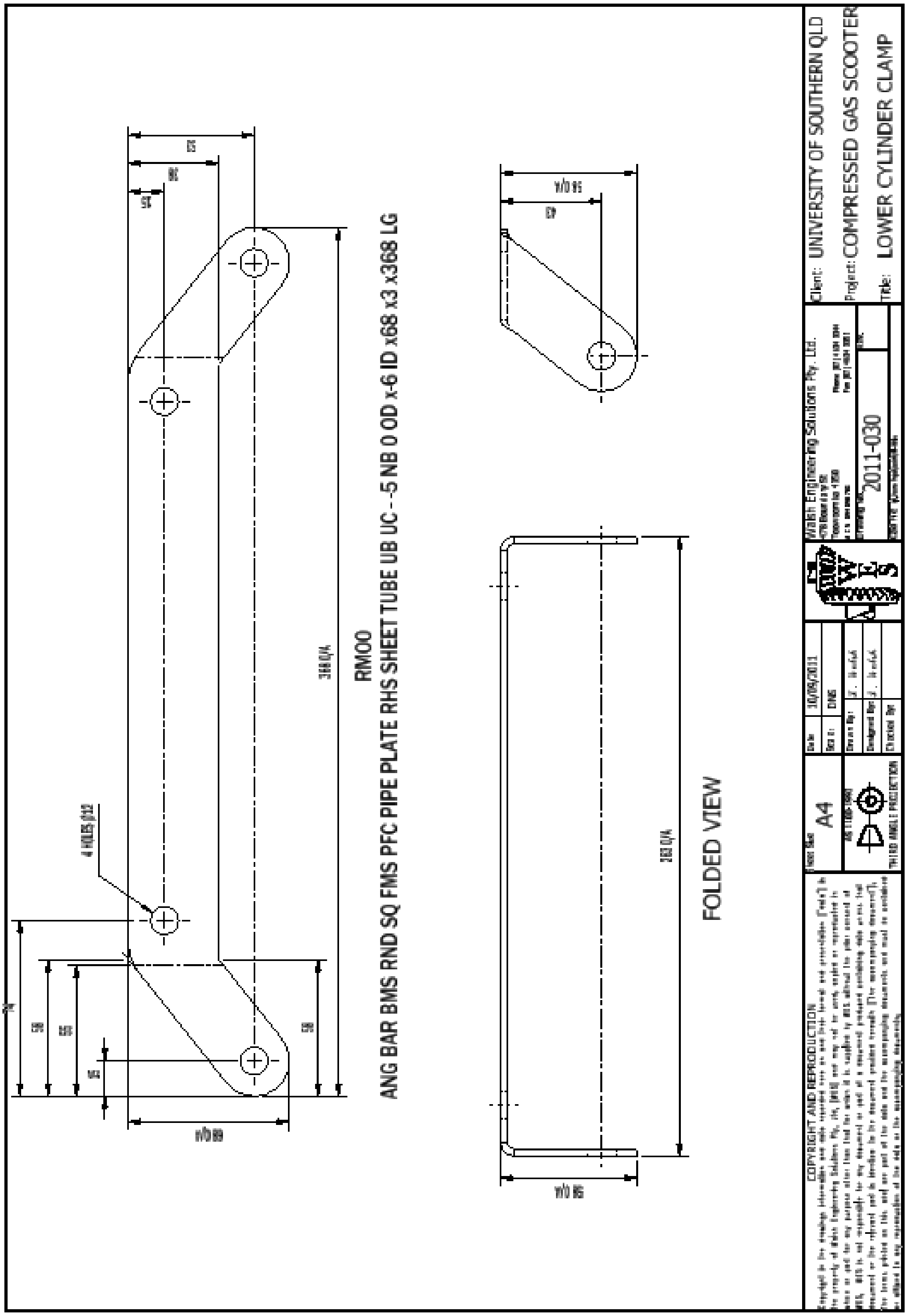
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Project: COMPRESSED GAS SCOOTER
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2011-030
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10/09/2011
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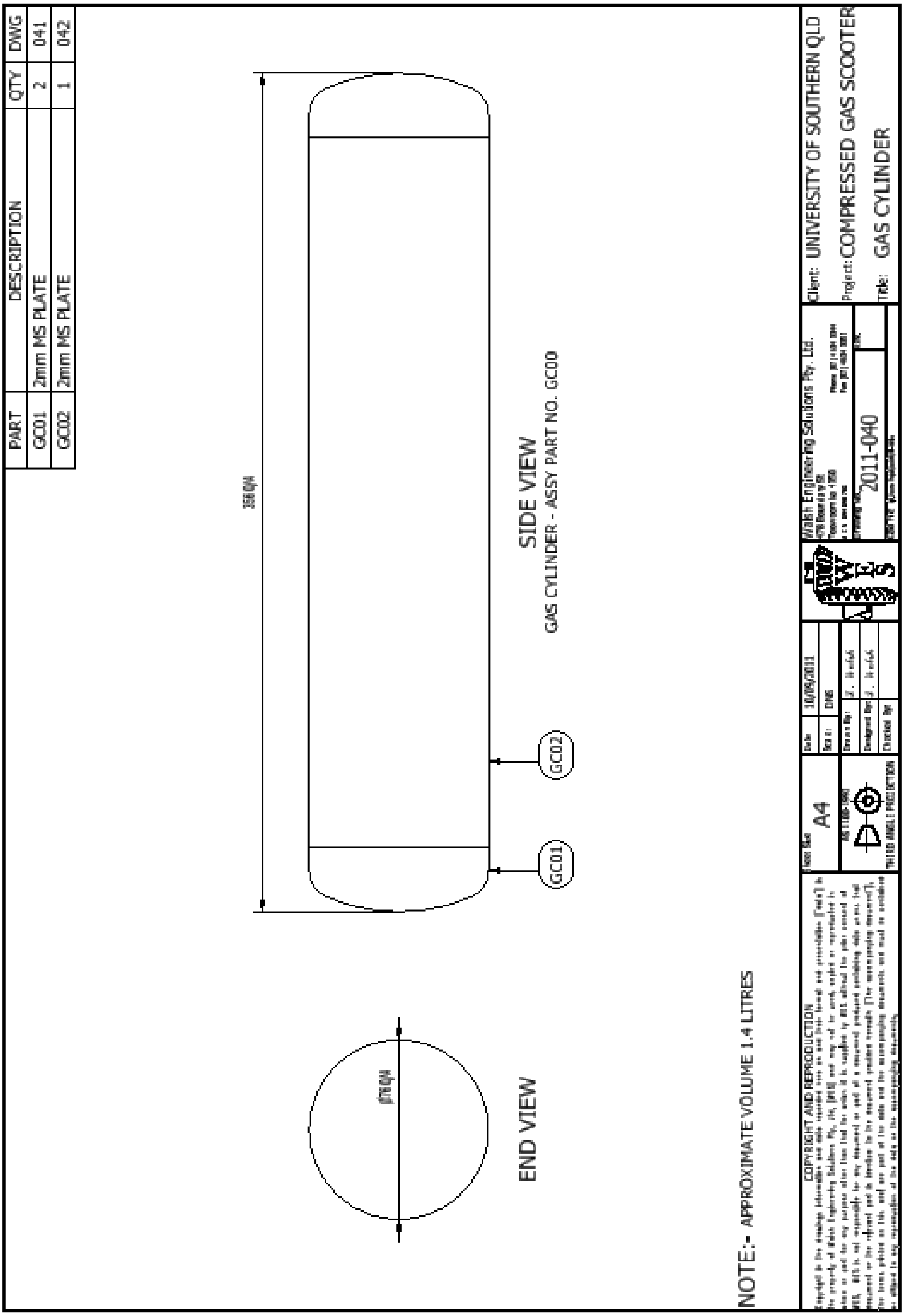
PART
DESCRIPTION
QTY
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041
GC02
2mm MS PLATE
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042
SIDE VIEW
GAS CYLINDER - ASSY PART NO. GC00
GC01
GC02
END VIEW
NOTE:- APPROXIMATE VOLUME 1.4 LITRES
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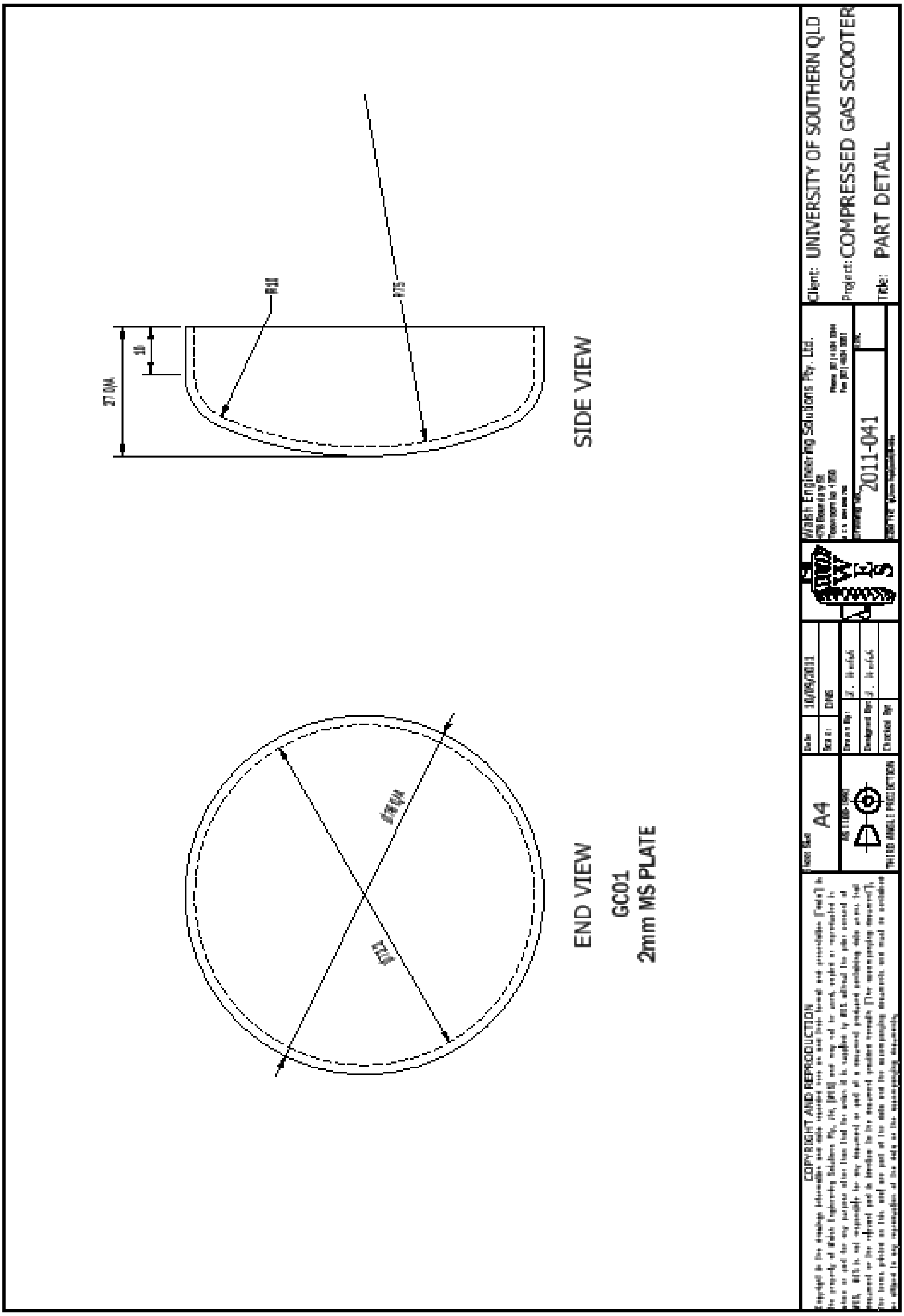
Project: COMPRESSED GAS SCOOTER
Title: GAS CYLINDER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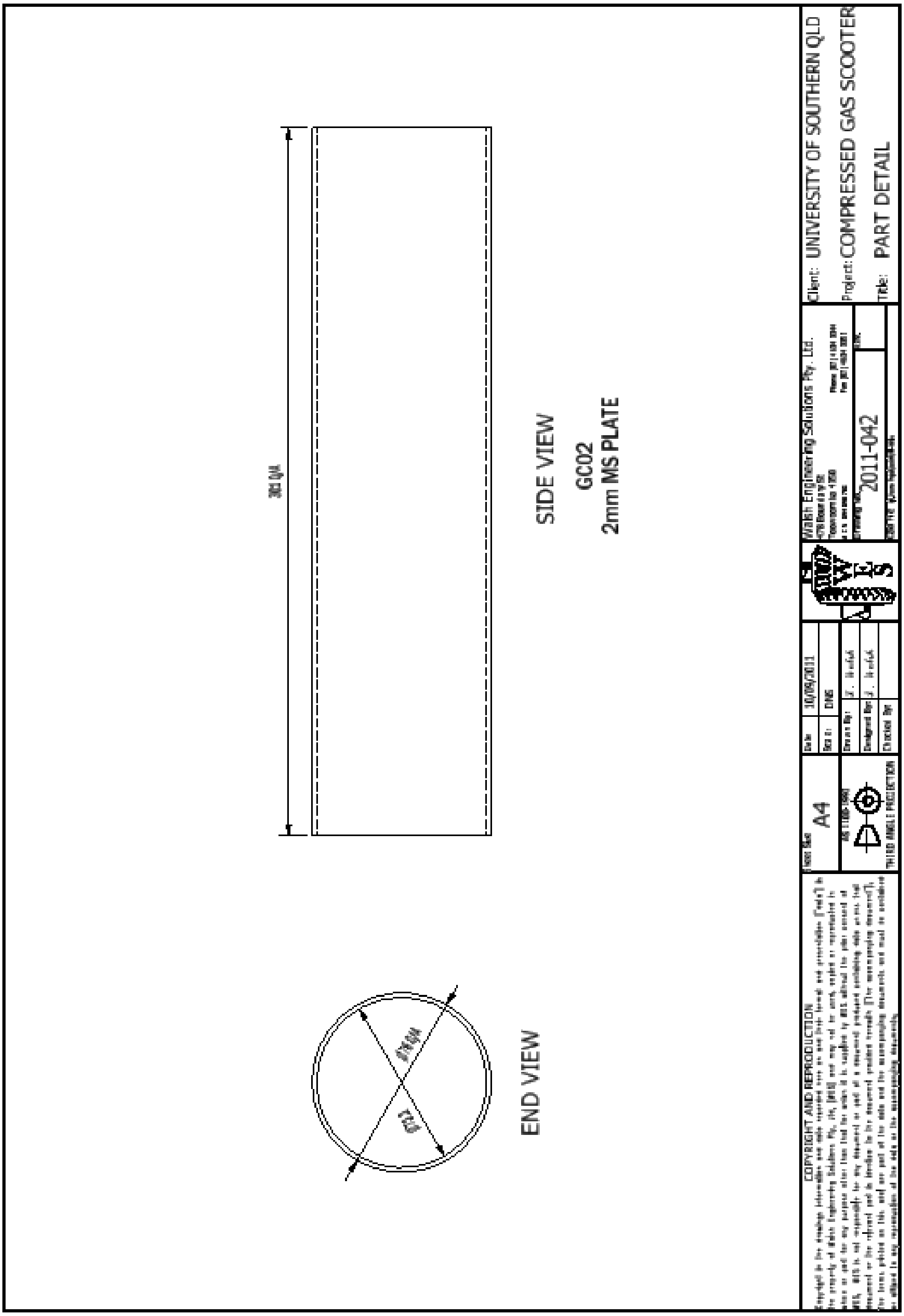
Client: UNIVERSITY OF SOUTHERN QLD
Project: COMPRESSED GAS SCOOTER
Title: PART DETAIL



END VIEW
SIDE VIEW
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10/09/2011
Walsh Engineering Solutions Pty. Ltd.
2011-042
Client: UNIVERSITY OF SOUTHERN QLD
Project: COMPRESSED GAS SCOOTER
Title: PART DETAIL

Appendices III

FEA Results

The Following pages are the results of the FEA analysis for the individual components of the mounting system.

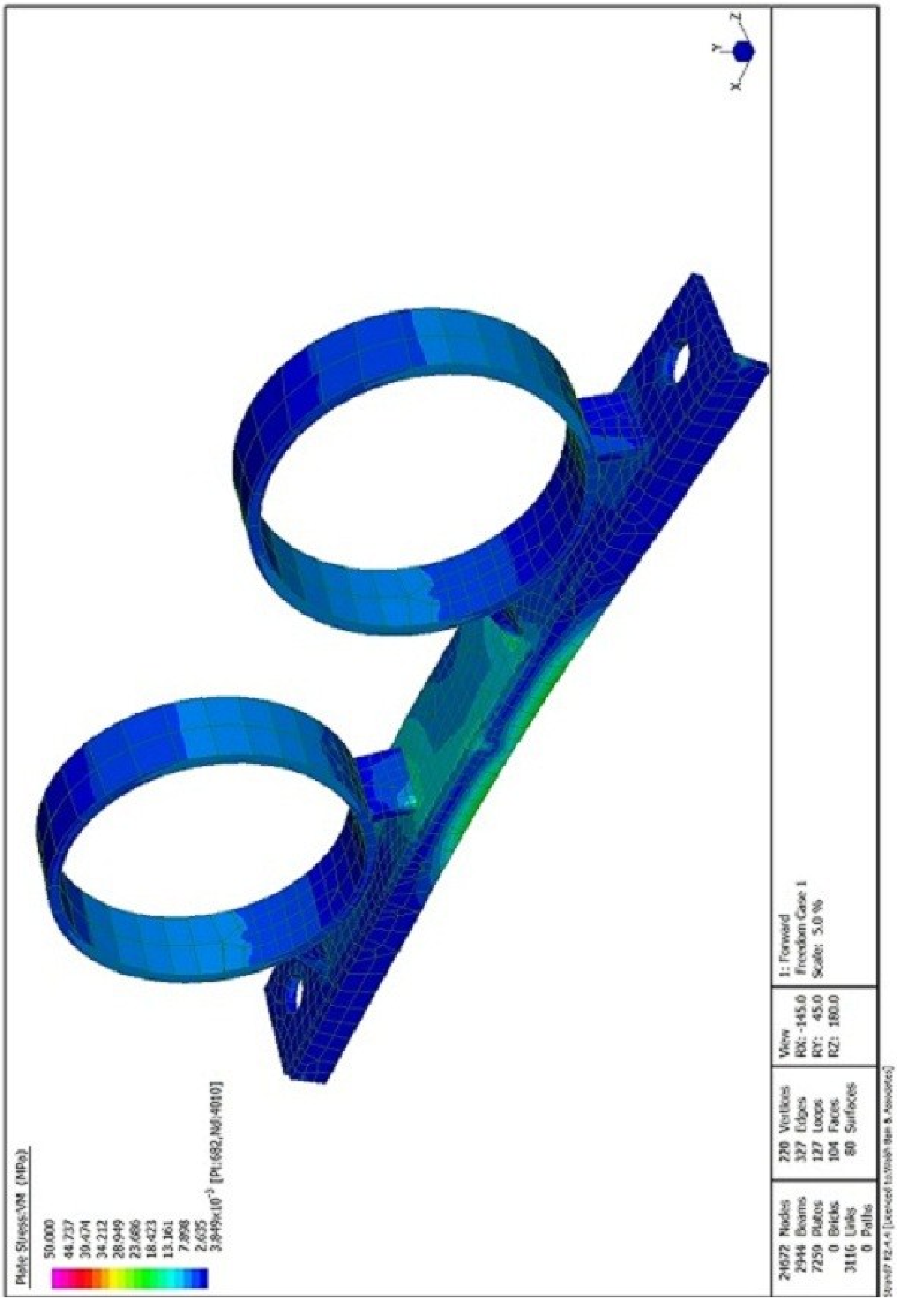

Figure 35: Front Bracket 20g Forward

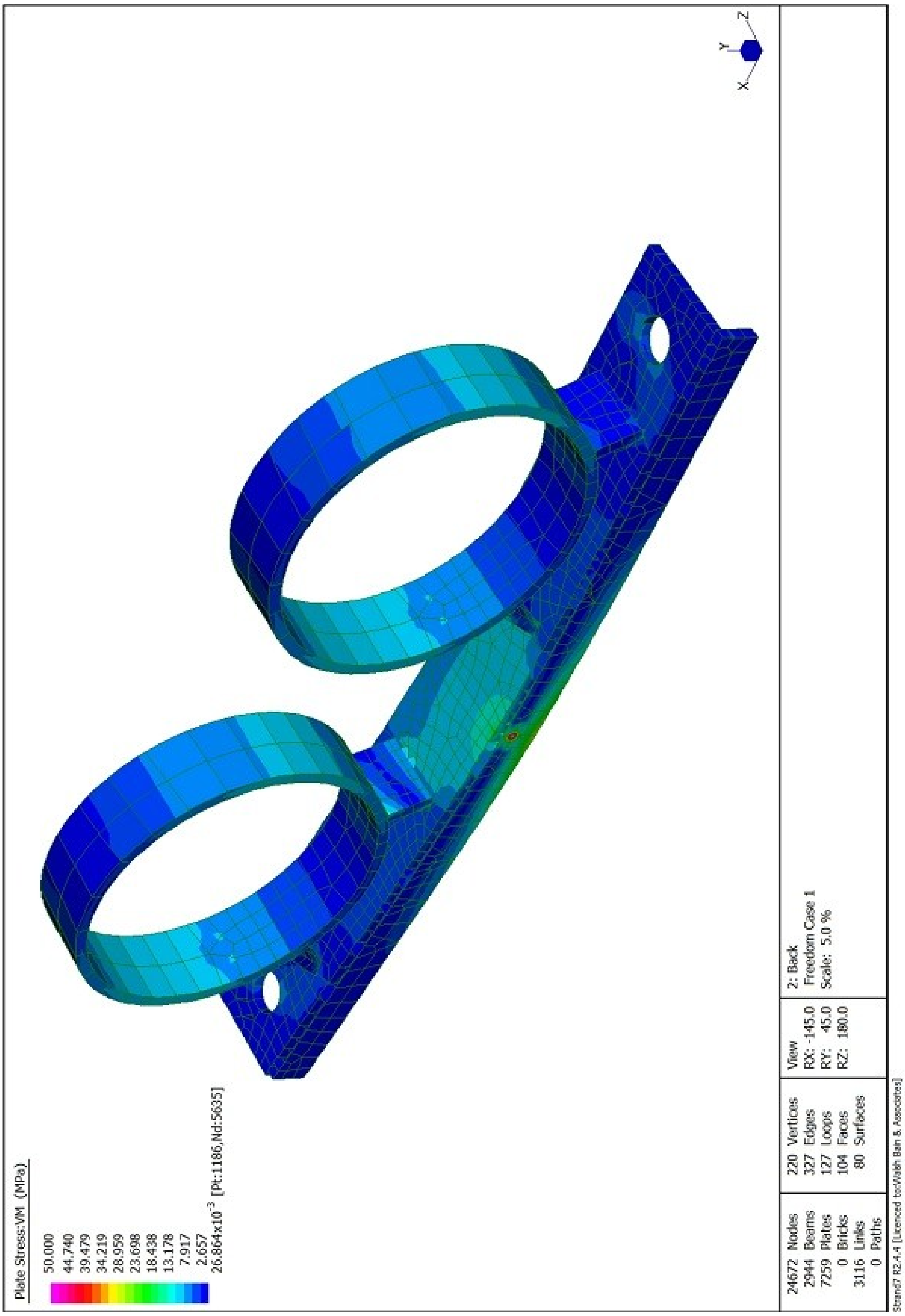

Figure 36: Front Bracket 20g Backwards

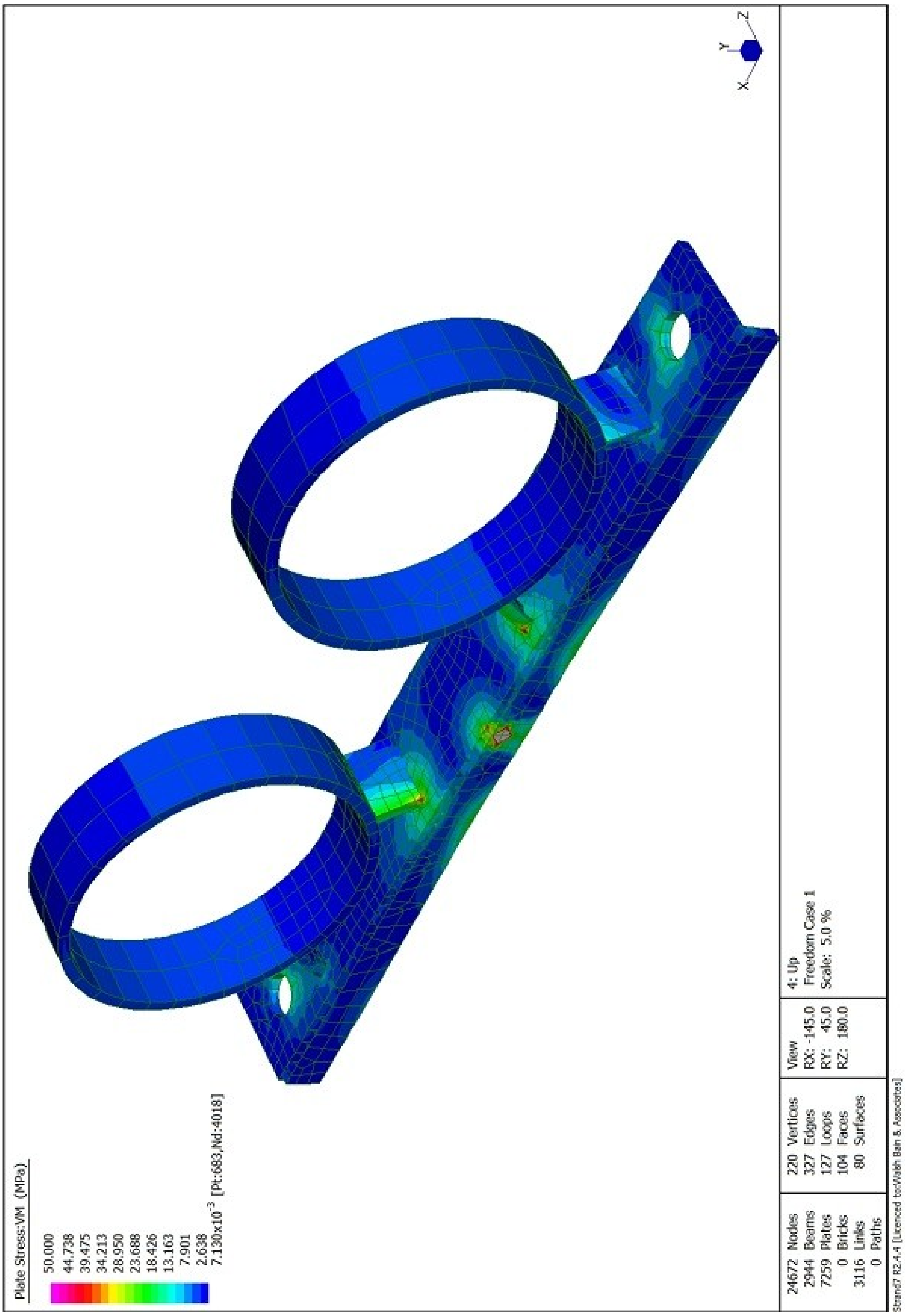

Figure 37: Front Bracket 20g Upwards

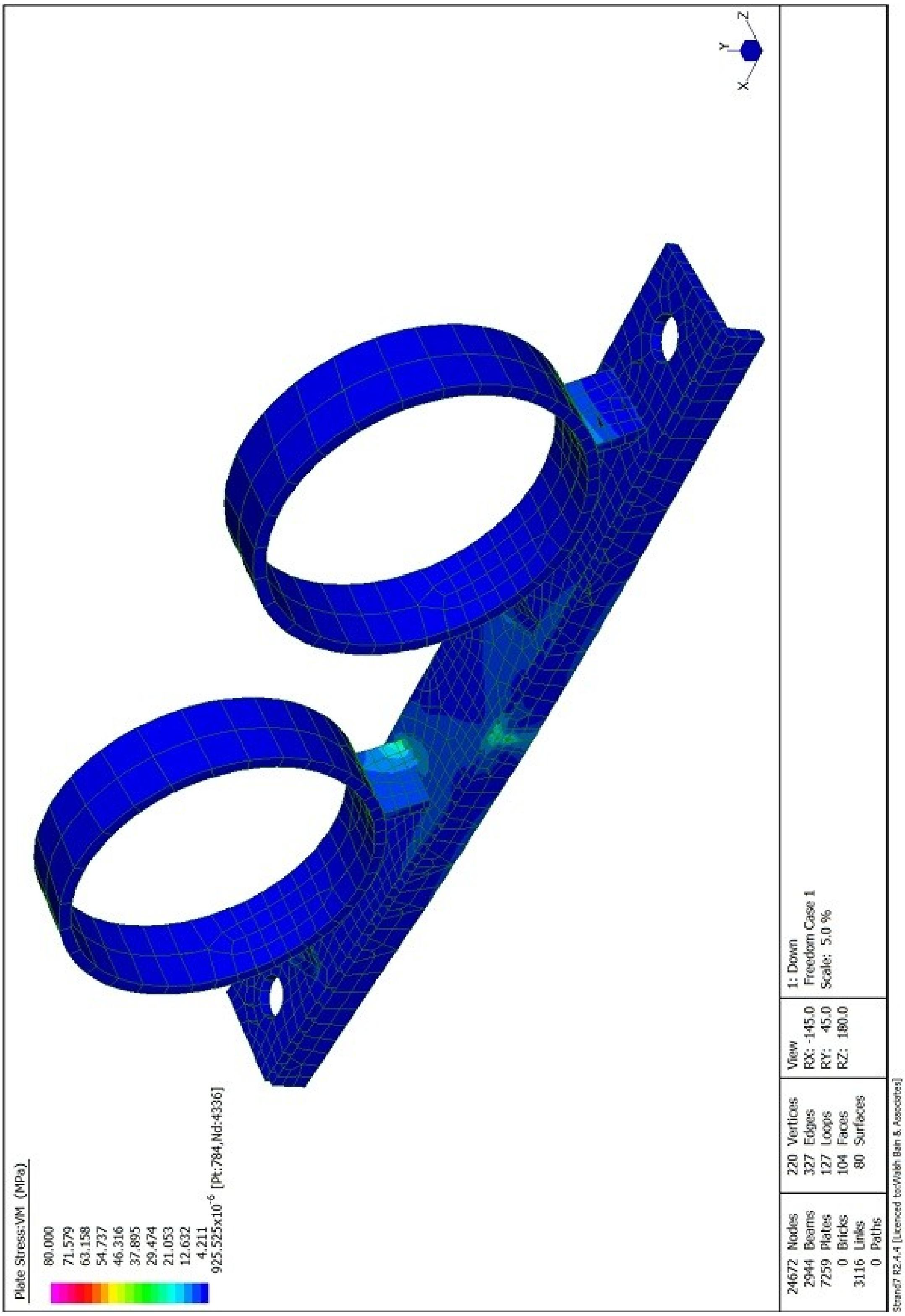

Figure 38: Front Bracket 20g Downwards

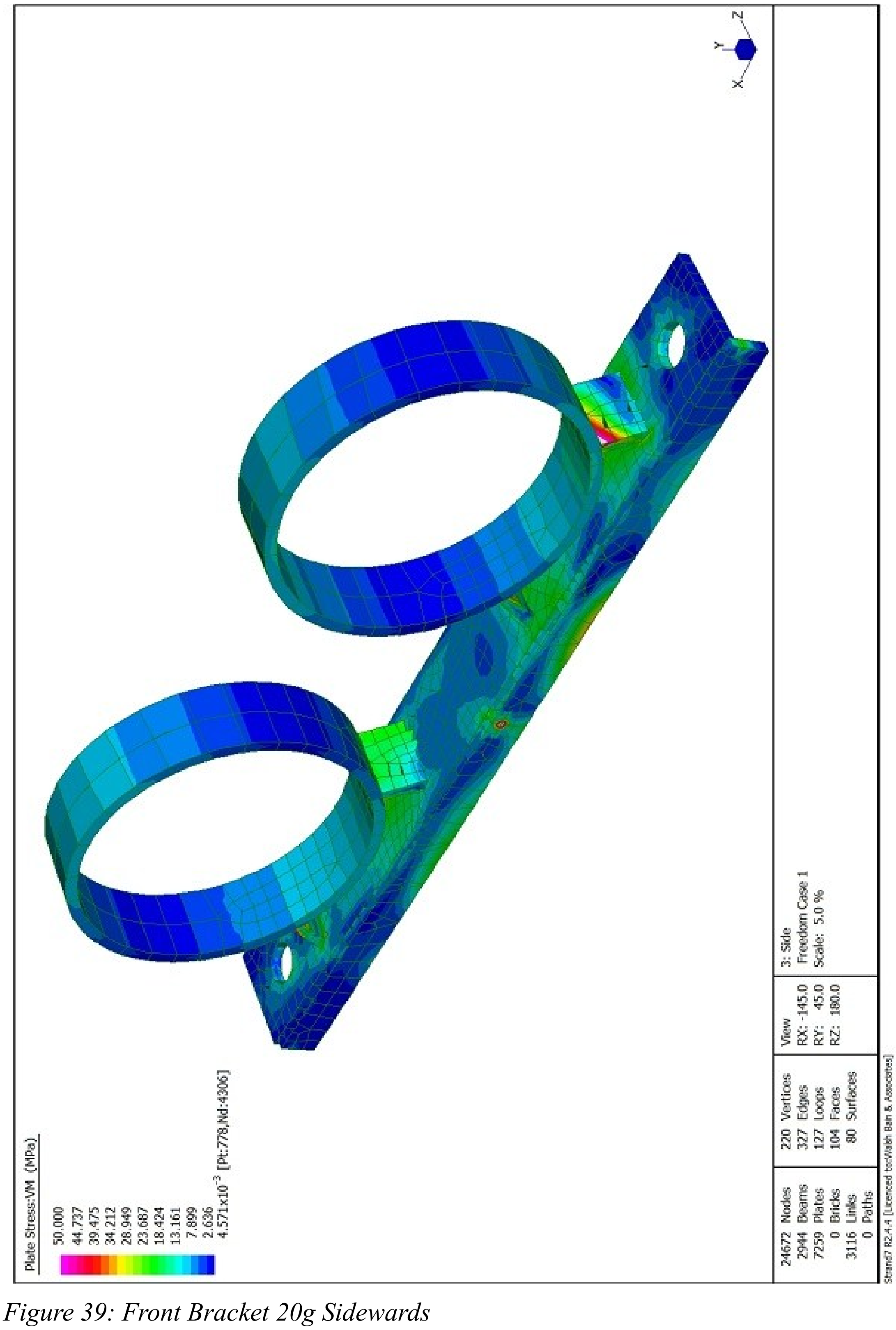

Figure 39: Front Bracket 20g Sidewards

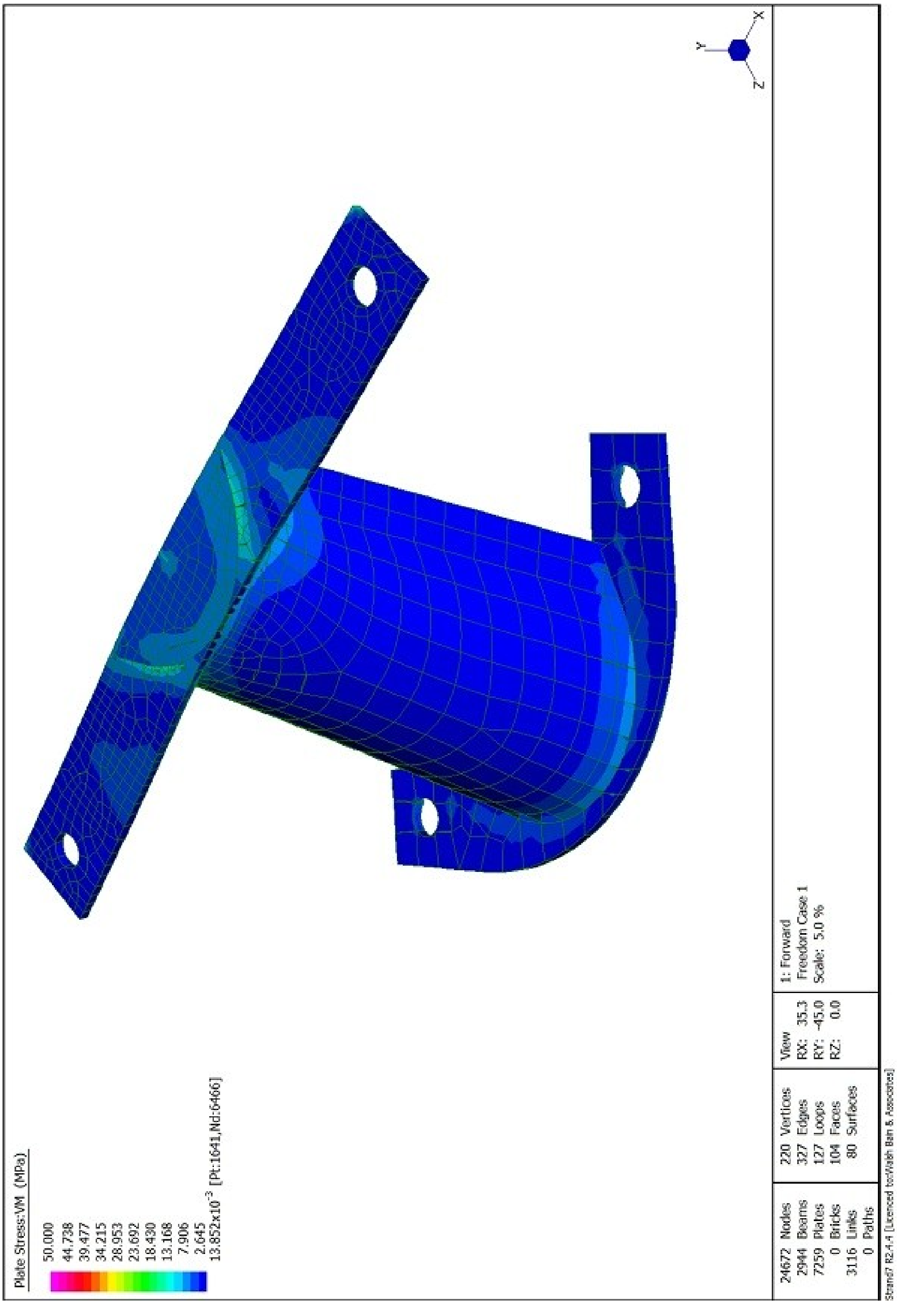

Figure 40: Front Lower Mount 20g Forward

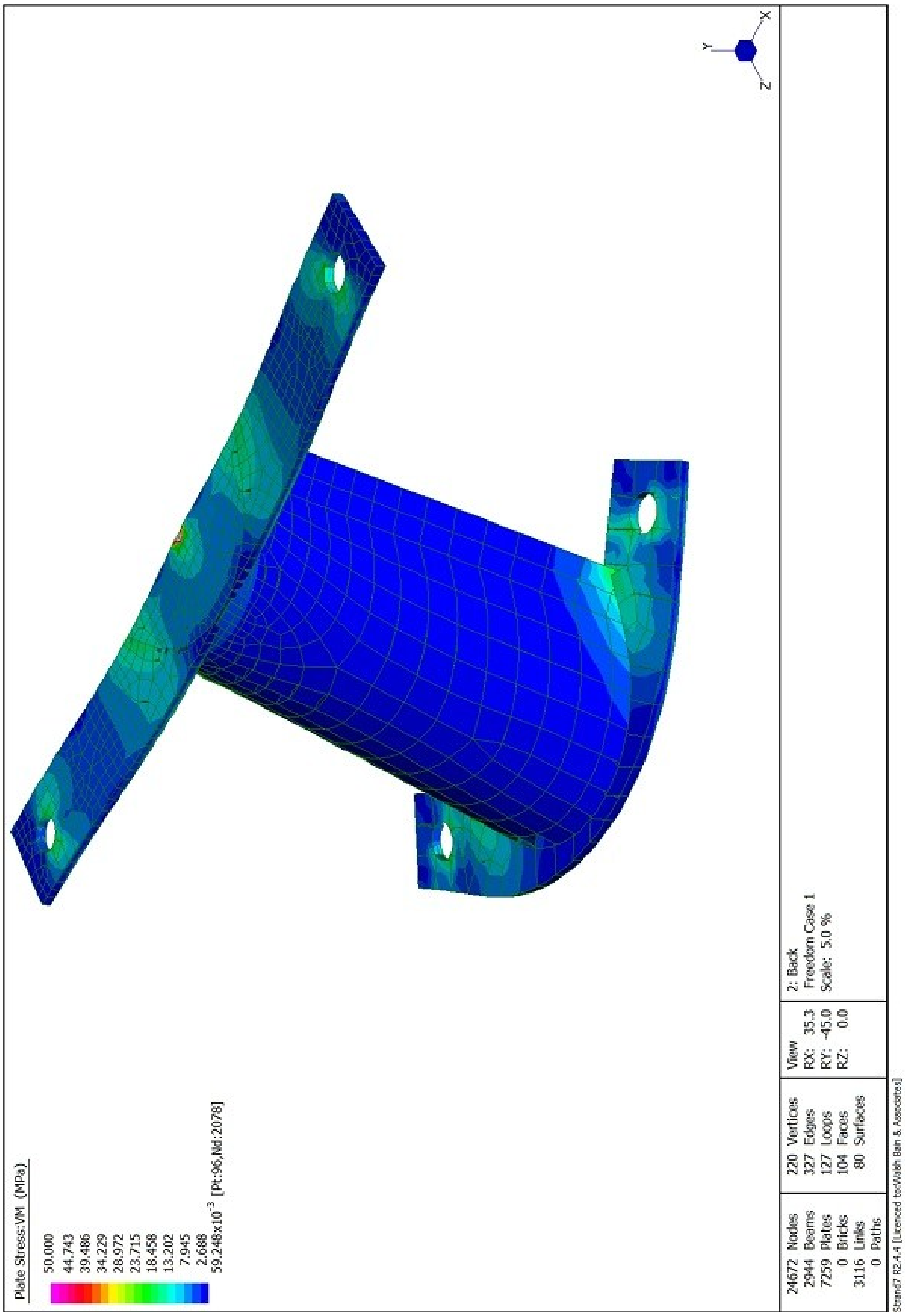

Figure 41: Front Lower Mount 20g Backwards

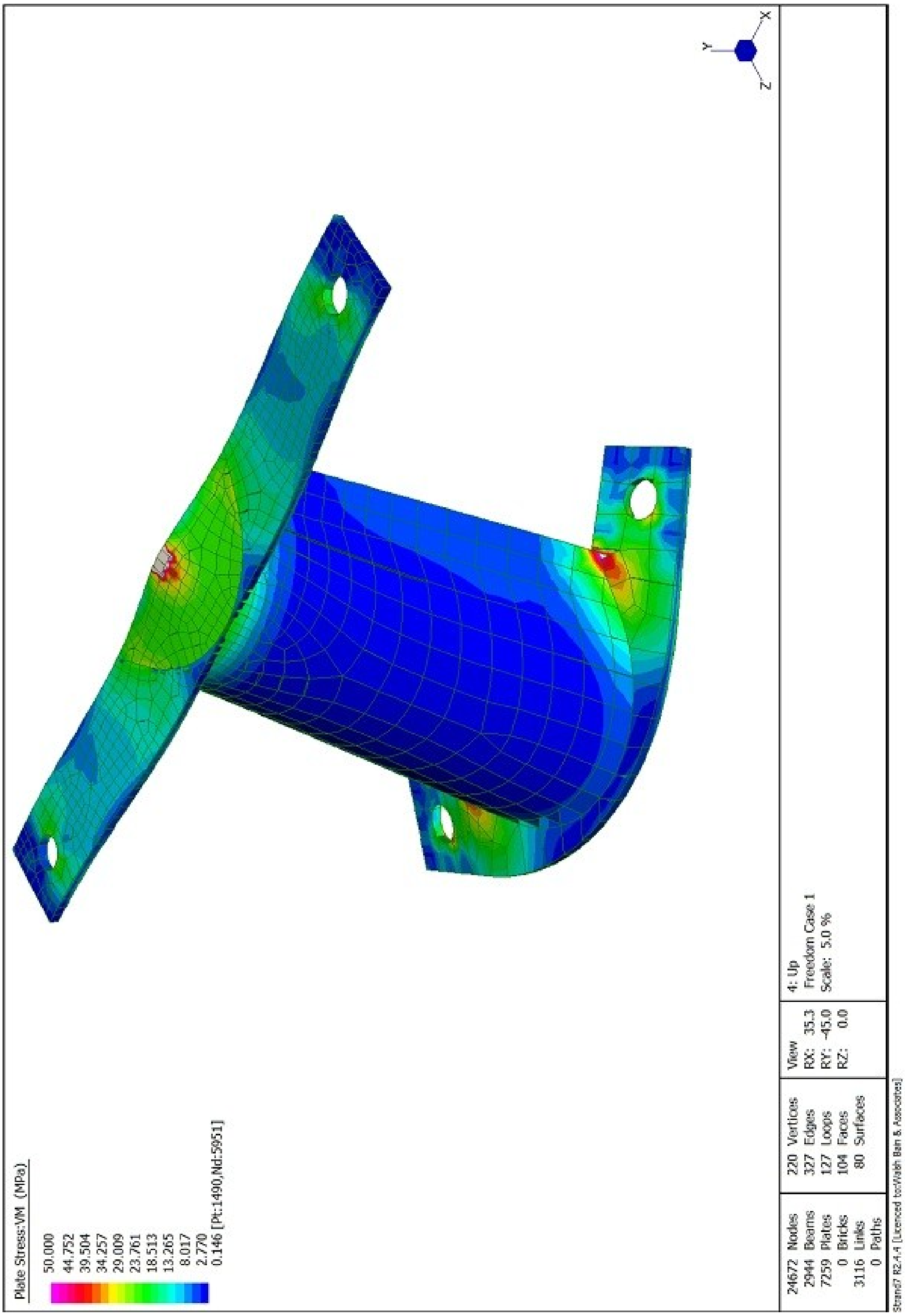

Figure 42: Front Lower Mount 20g Upwards

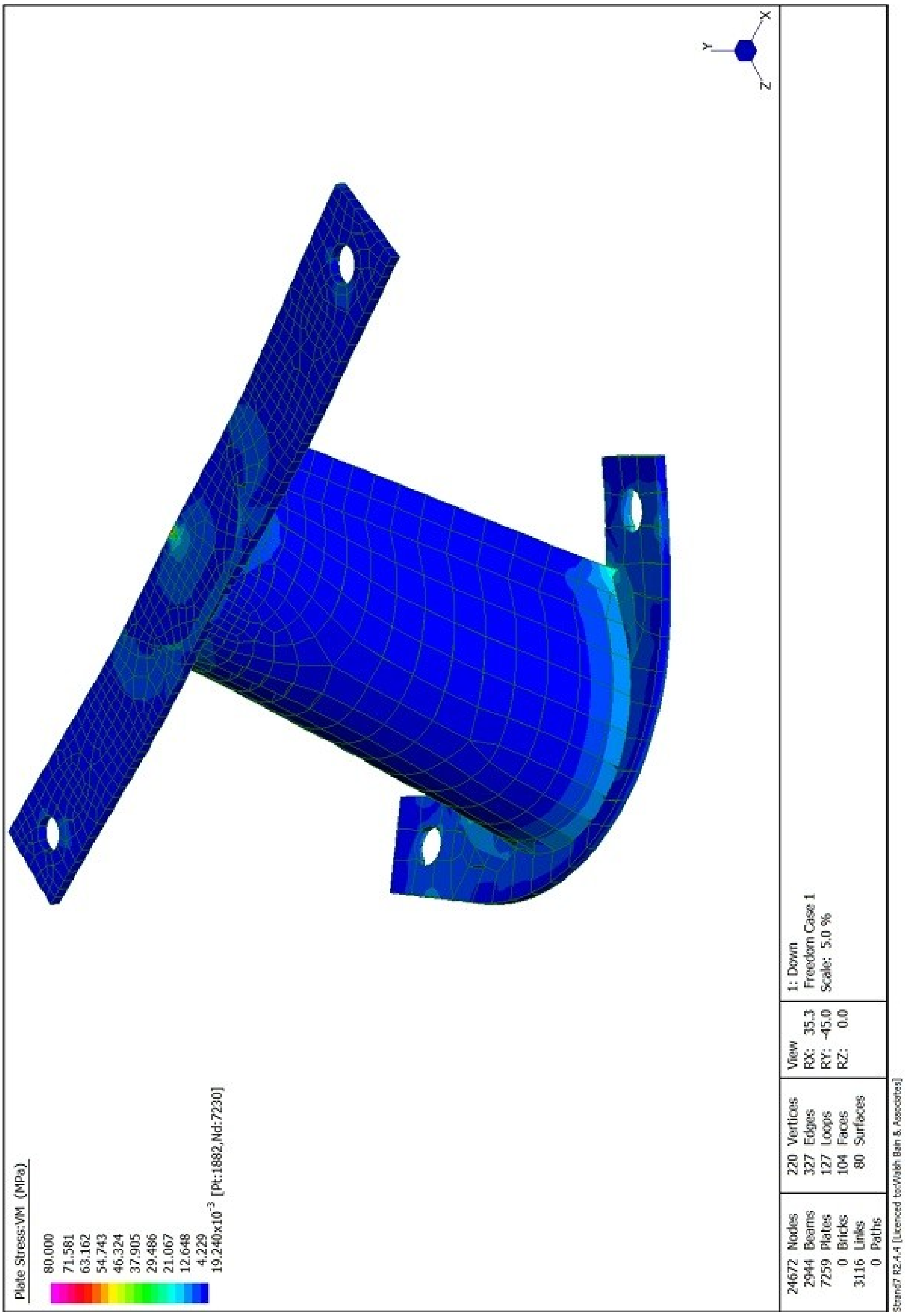

Figure 43: Front Lower Mount 20g Downwards

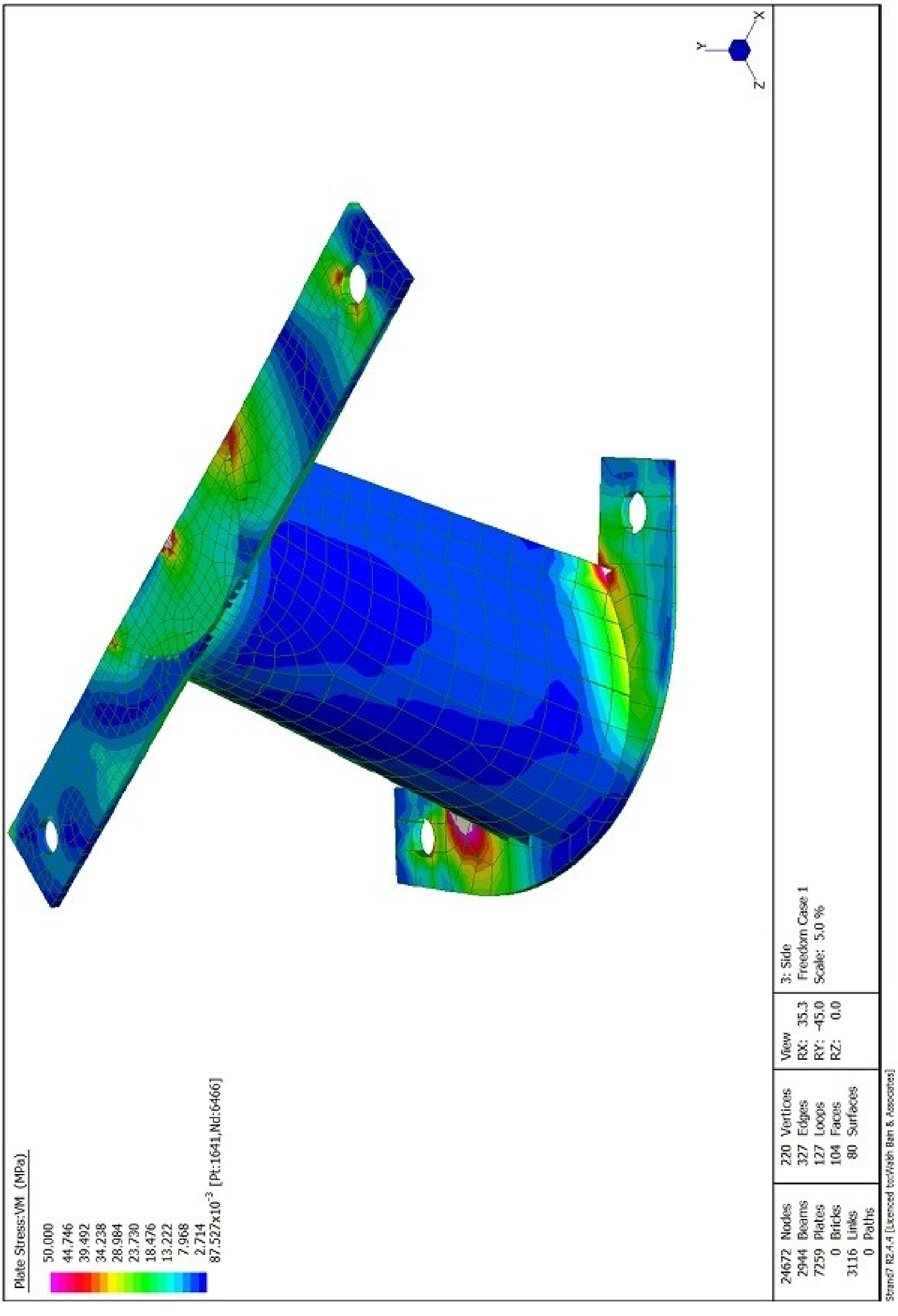

Figure 44: Front Lower Mount 20g Sidewards

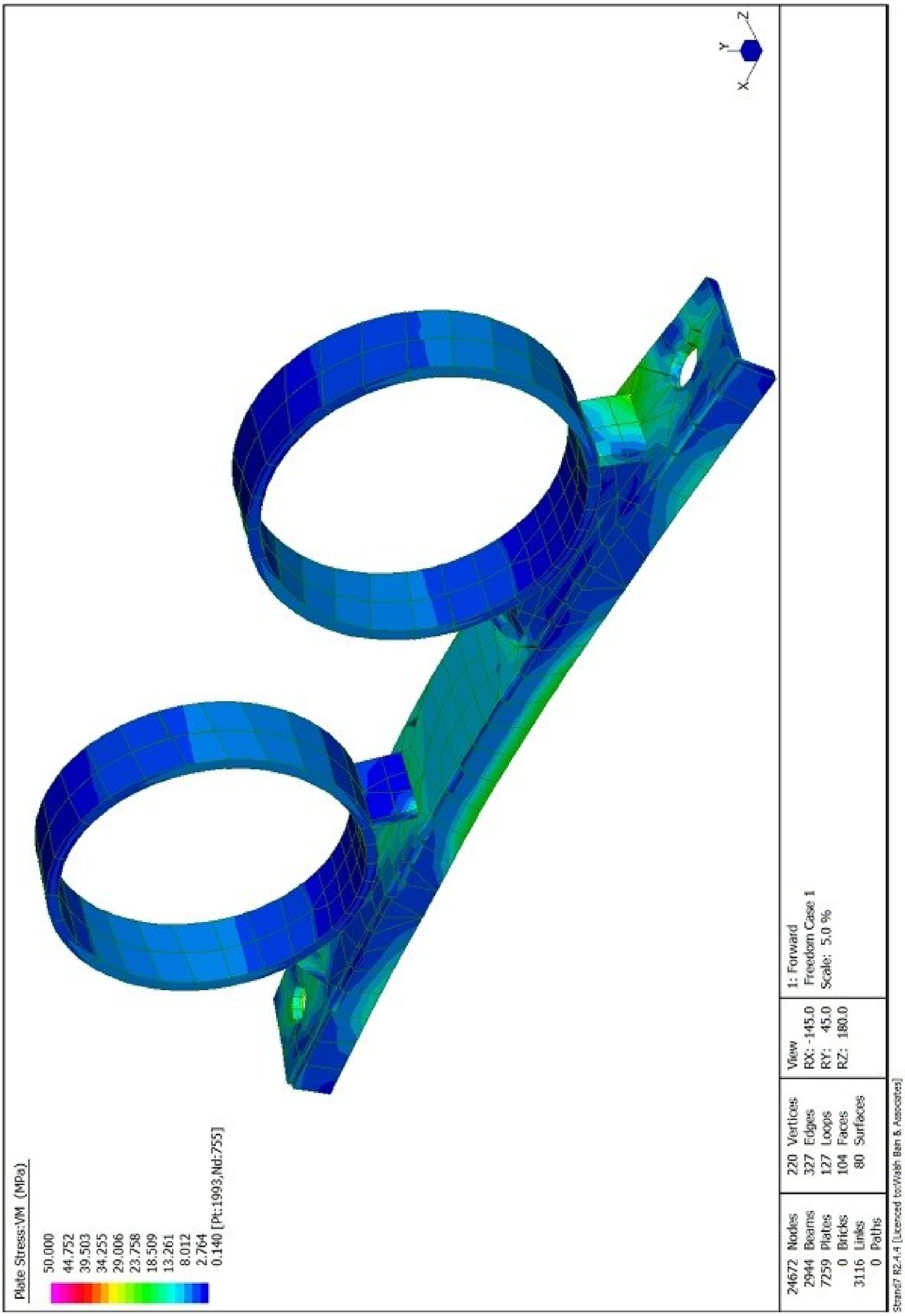

Figure 45: Rear Bracket 20g Forward

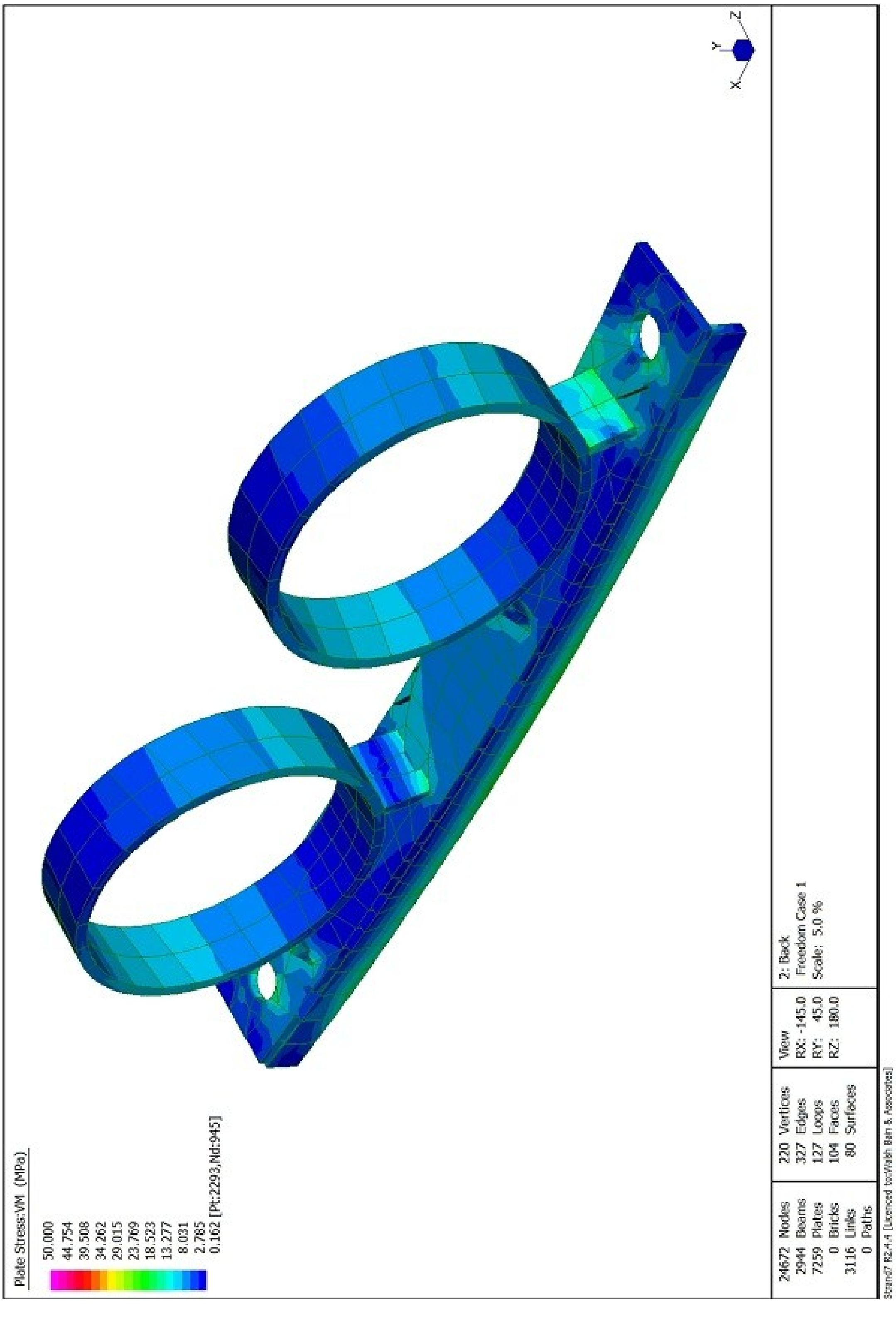

Figure 46: Rear Bracket 20g Backwards

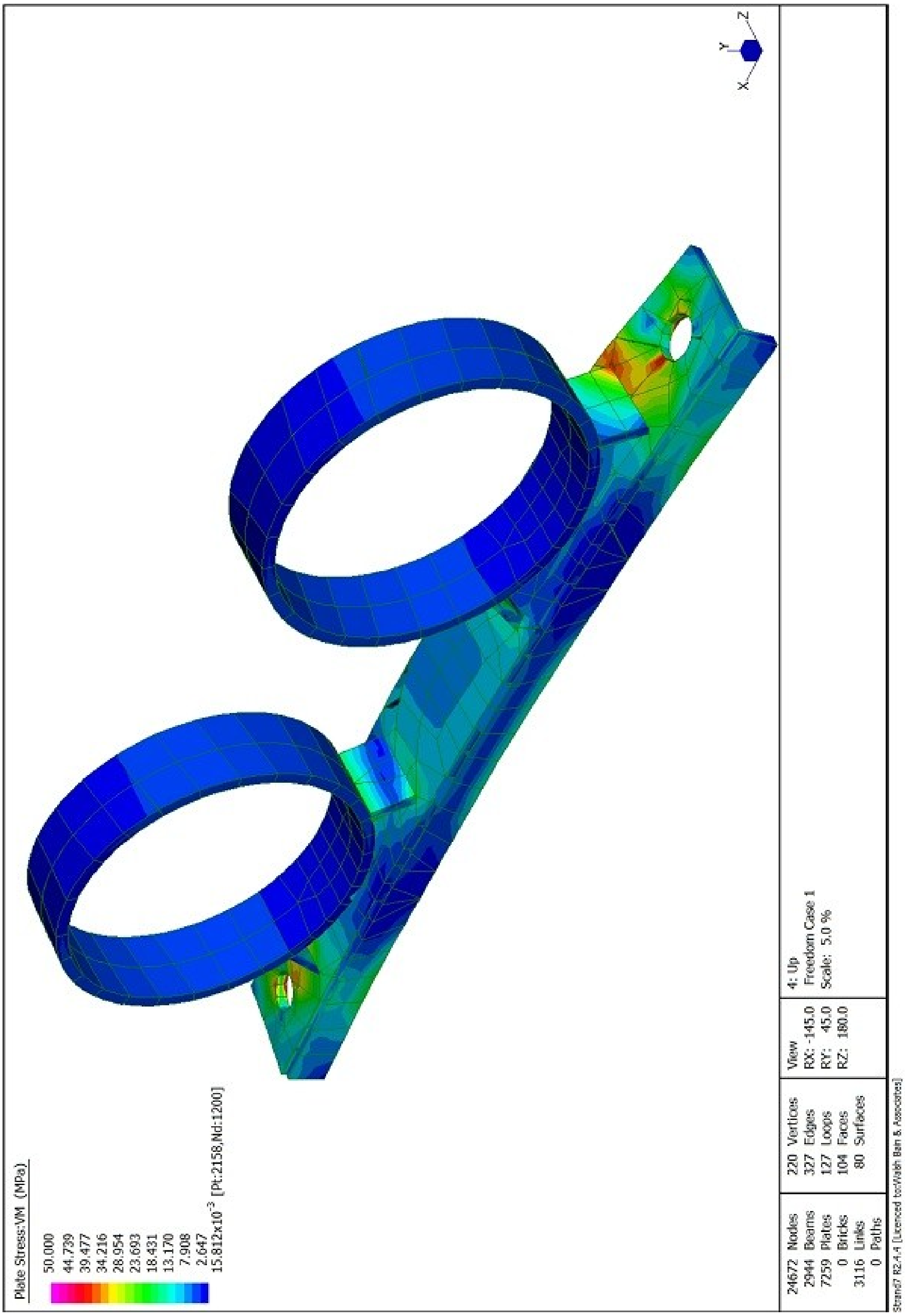

Figure 47: Rear Bracket 20g Upwards

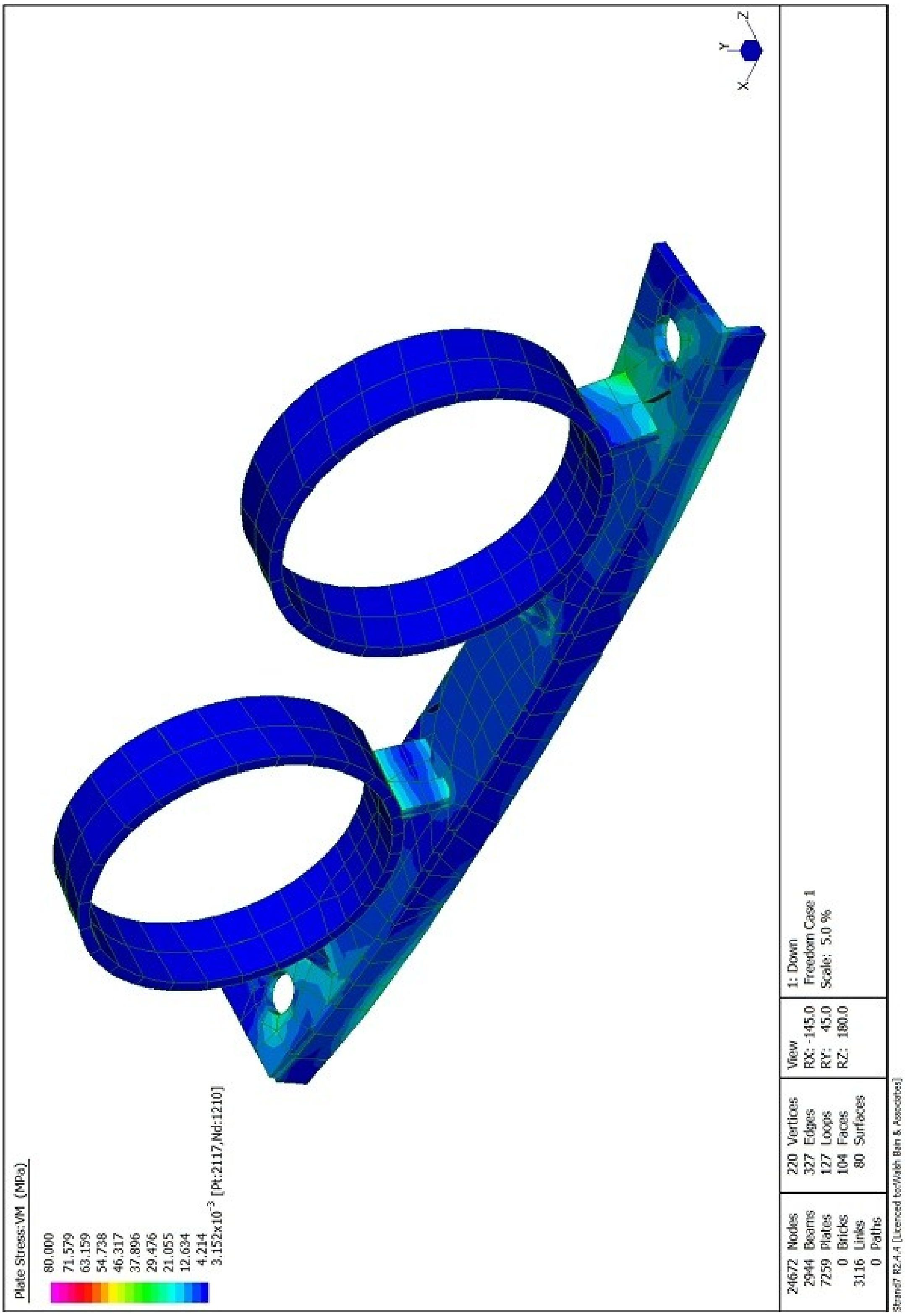

Figure 48: Rear Bracket 20g Downwards

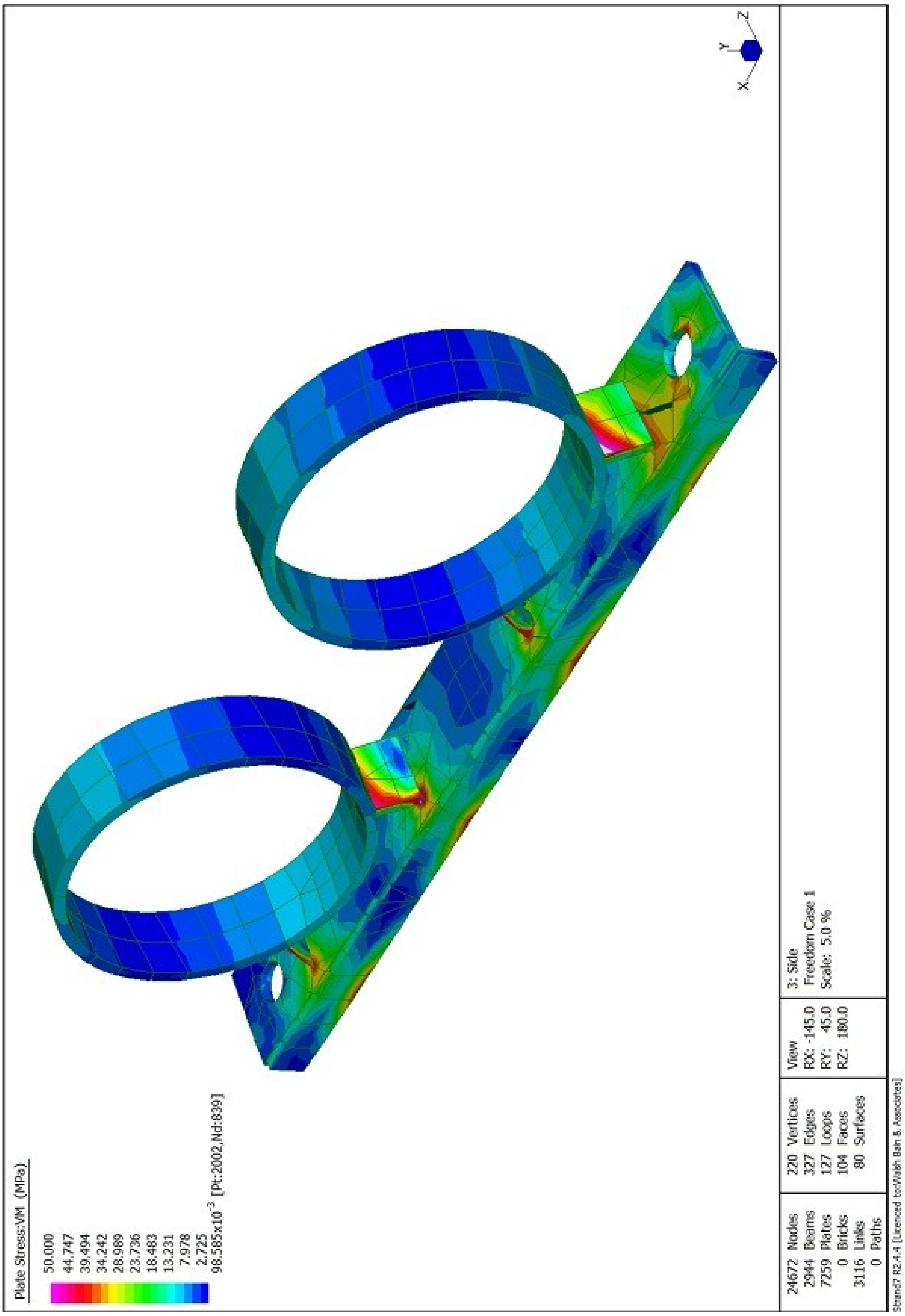

Figure 49: Rear Bracket 20g Sidewards

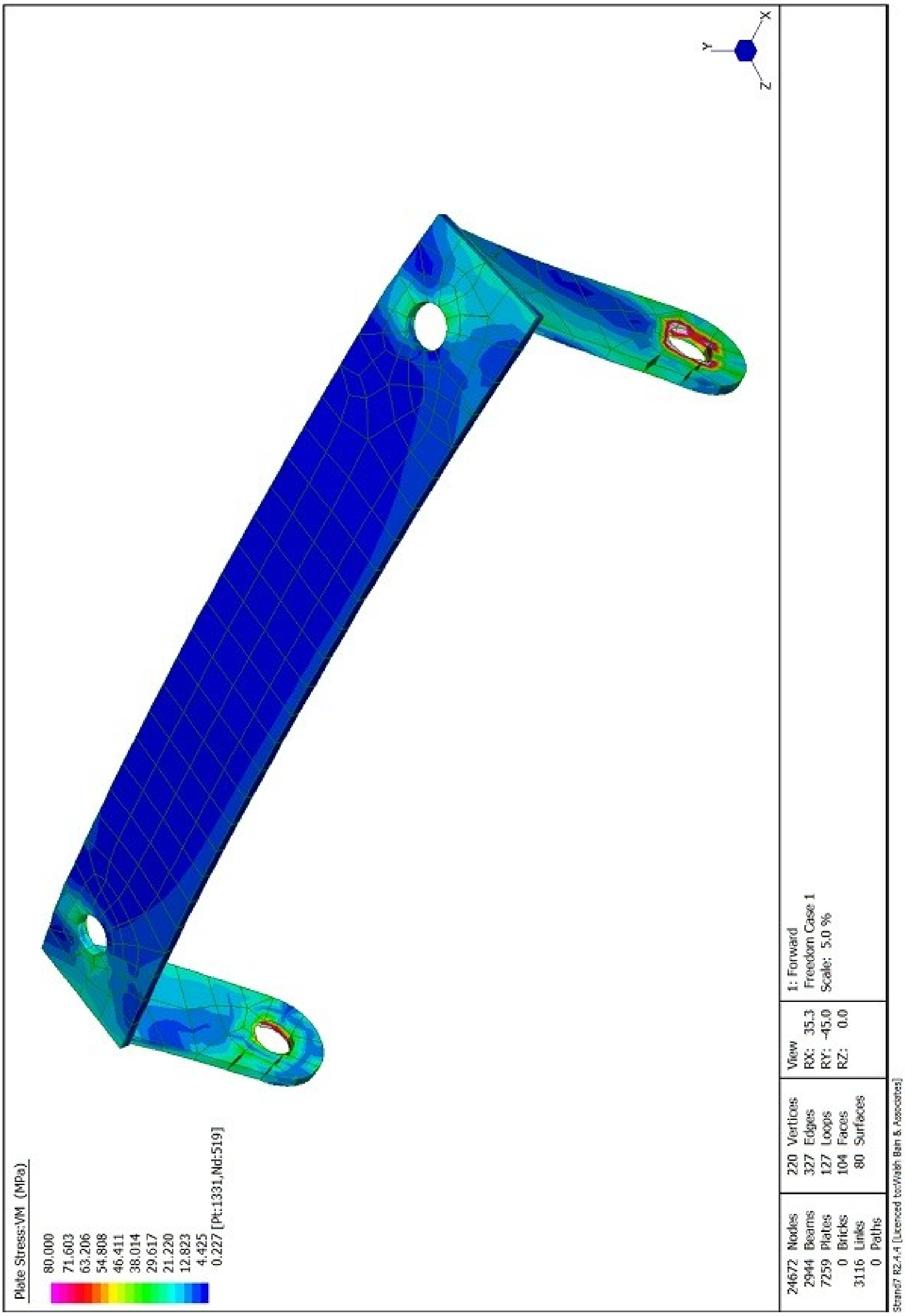

Figure 50: Rear Lower Mount 20g Forward

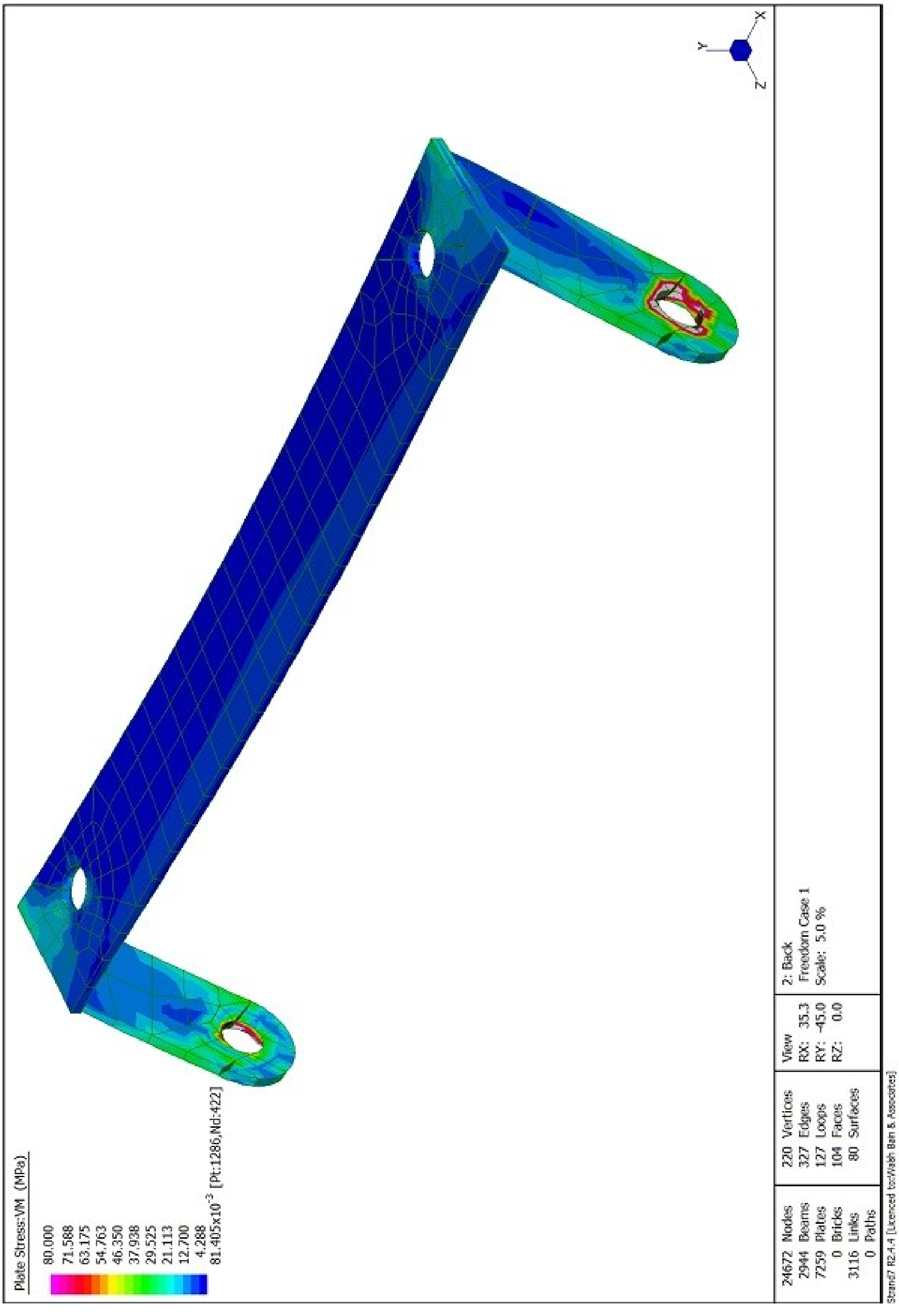

Figure 51: Rear Lower Mount 20g Backwards

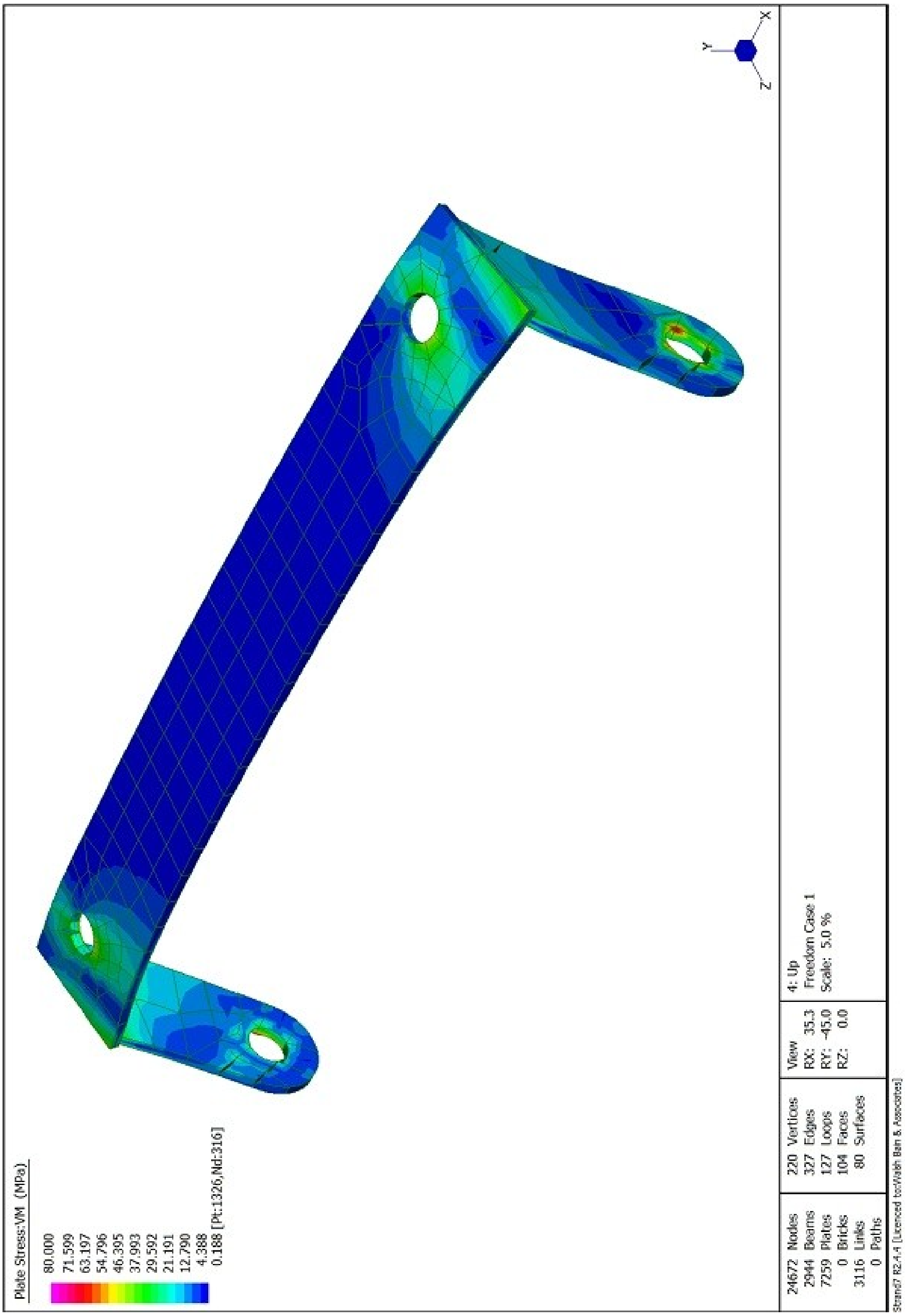

Figure 52: Rear Lower Mount 20g Upwards

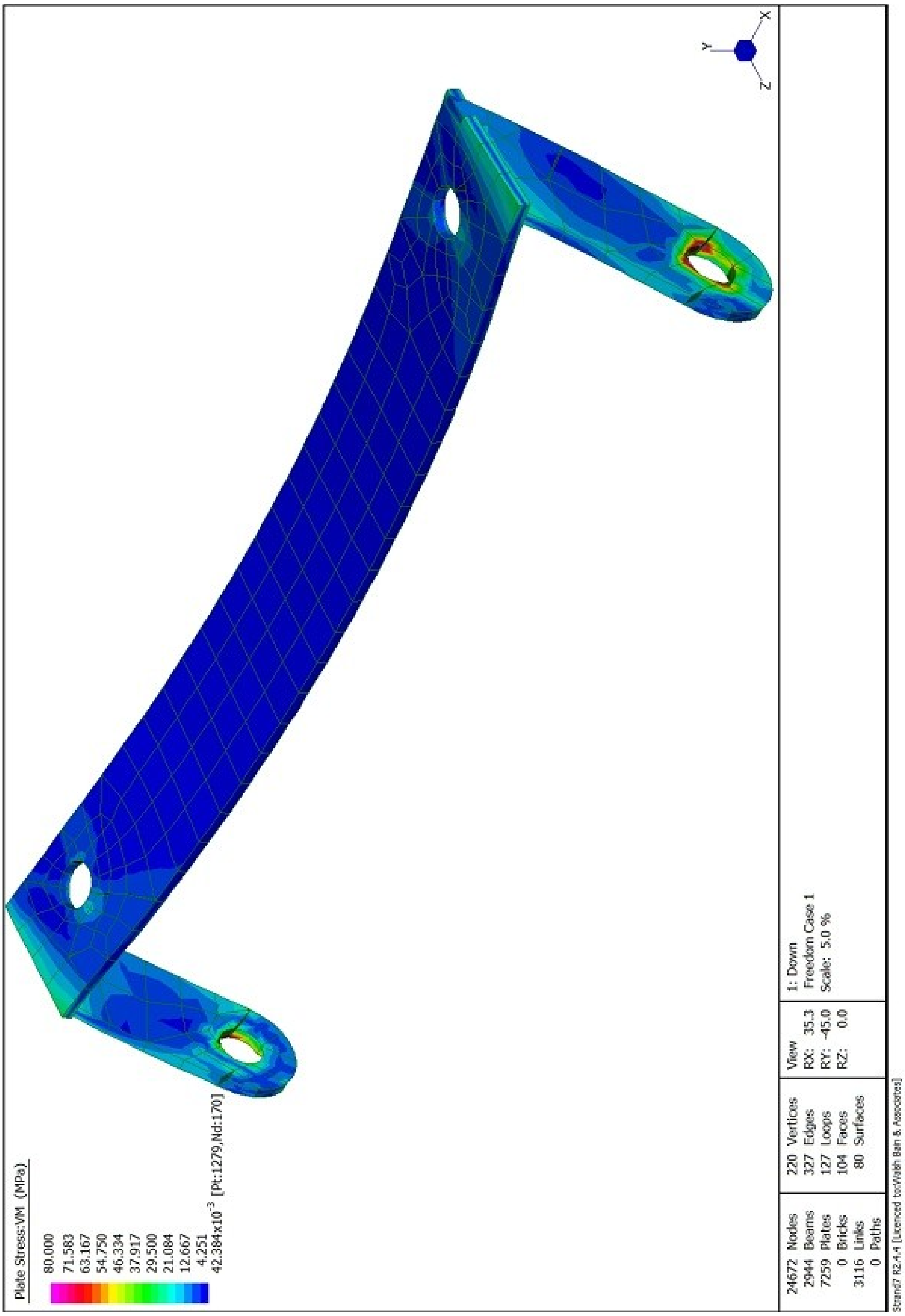

Figure 53: Rear Lower Mount 20g Downwards

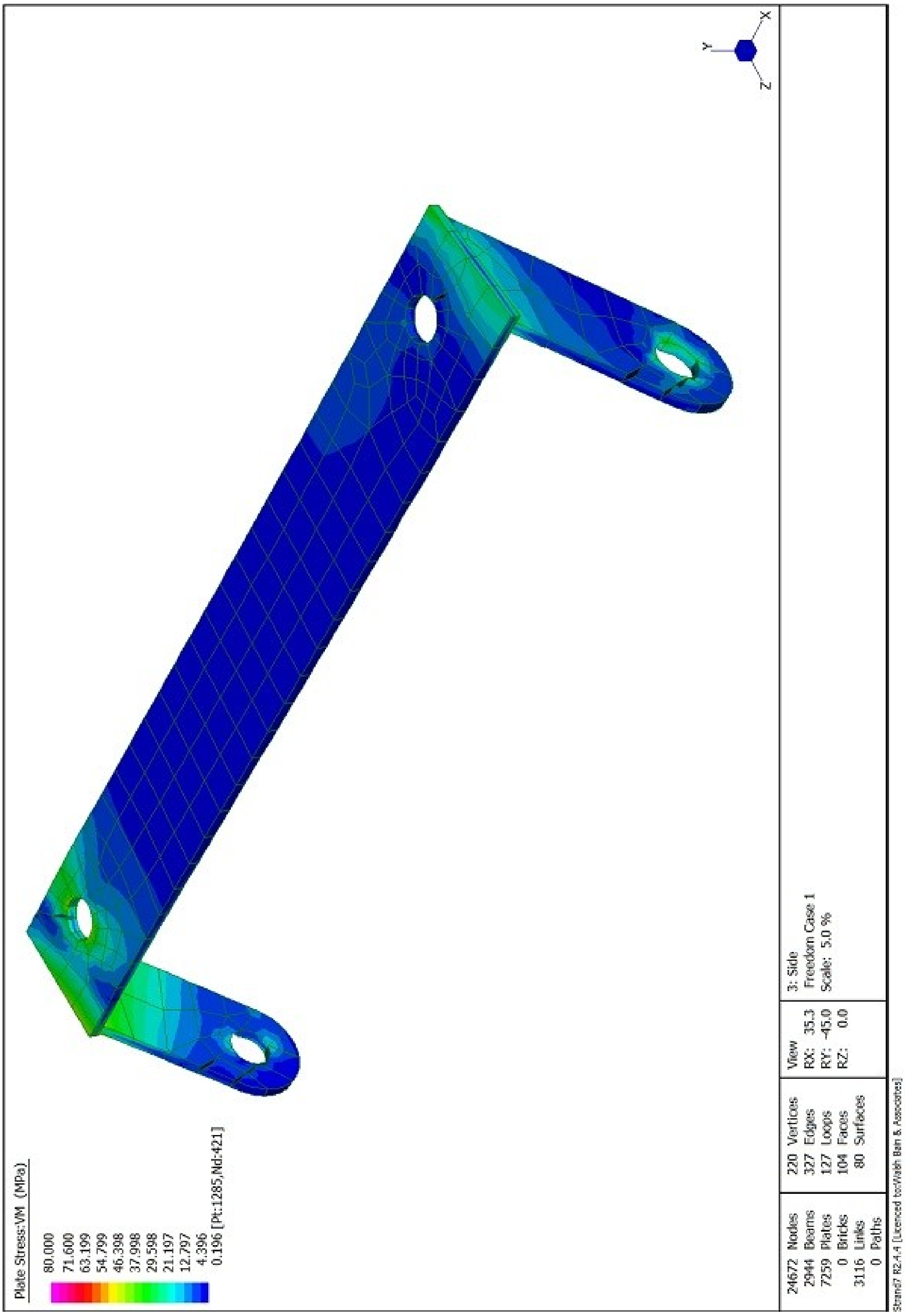

Figure 54: Rear Lower Mount 20g Sidewards

Appendices IV

Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/4112 Research Project

Name:- Daniel Walsh

Student No.:- Q97230194

Topic:- **Design and Retrofit a Compressed Gas Powered Scooter**

Supervisor:- Steven Goh

Project Aim:- **To research the feasibility of creating a compressed natural gas/air hybrid powered scooter and to compare the performance of the stock standard model to the new design.**

Programme:- Issue C, 20th May 2011

- Research and describe the recognition of need for the proposed design. 30/4/2011
- Do a feasibility study. 30/4/2011
- Decide which design to use and what components will be needed to allow time for procurement of hard to get components. IE air motors 30/4/2011
- First Presentation 12/5/2011
- Presentation due 19/5/2011
- Develop a series of test that can be used to compare the standard and new designs 13/5/2011
- Project appreciation 23/5/2011
- Procure a scooter and carry out the first series of tests (Loan or Purchased). 28/5/2011
- Remove existing motor and wheel assembly measure and model components for frame design 4/6/2011
- Design bench mount frame existing motor so it can be manufactured 11/6/2011
- Design transfer shaft for transferring the drive flow between gas, air and regenerative braking 25/6/2011
- Setup gas conversion 6/8/2011
- Second Presentation 1/9/2011
- Presentation Due …....
- Partial Draft dissertation Due 16/9/2011
- Dissertation Due 27/10/2011

If time permits

- Mount an air compressor and tank to bench mount setup
- Develop a regenerator which will use as much exhaust gas heat to preheat and expand the intake air for use in the air motor therefore increasing overall efficiency.
- Carry out the series of test on the modified scooter with a regenerator

Appendices V

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