UNIVERSITY OF CAPE TOWN

Industrial CFD Research Group

Department of Mechanical Engineering

RONDEBOSCH, CAPE TOWN, SOUTH AFRICA

Abstract

The following report aims to document the progress of a project run by the Industrial CFD Research Group at the University of Cape Town's Dept. of Mechanical Engineering. The aim of the work was to set a new world record for the altitude of a Class A water rocket. The current officially acknowledged world record is 623m. During this project an altitude of 830m was achieved.

Keywords: water rocket; world record; Class A

UNIVERSITY OF CAPE TOWN

Industrial CFD Research Group

Department of Mechanical Engineering

-Prof. A. G. Malan-

WATER ROCKET WORLD RECORD ATTEMPT

-Project Report-

by

Stuart Swan

B.Sc. Eng., UCT, 2013

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Cape Town, 11 September 2015

Affidavit of Oath

We, the undersigned, Stuart G Swan, Arnaud G Malan, Donovan M Changfoot and William Liw Tat Man do hereby declare under oath:

That all information contained within this report is true and accurate.

Contact details

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E-mail Address: swnstu001@myuct.ac.za

Stuart G Swan

Arnaud G Malan

Donovan M Changfoot

William Liw Tat Man

Signed and sworn/affirmed to be us at CAPE TOWN on this 21ST day of SEPTEMBER, the Deponents having acknowledged that they know and understand the contents of this Affidavit, which is disposed in accordance with the regulations governing the administration of an oath as more fully set out in Government Notice R 1258 of the 21st July 1972, as amended by Government Notice 1648 dated the 19th of August 1977 and Government Notice 903 dated the 10th July 1988.

Dedication

This project is dedicated to my Dad, Patrick Swan for his endless patience and for giving me the opportunity to do what I love. To Prof. Arnaud Malan for his belief in the project and input, without which the project would not have been possible. To my wife, Makeeda Swan, for her unending encouragement and support to persevere to the end.

Acknowledgements

I would like to thank the following people for their assistance on this project:

Professor Arnaud Malan who has supervised the project since 2013 and whose enthusiasm and belief has made the project possible.

Mr. Donovan Changfoot and Mr. William Liw who have been amazing partners in bringing this project to completion.

Mr. Albert Verburg of GRP Tubing (PTY) Ltd for his generosity in supplying numerous complimentary carbon fibre tubes over the years and for going out of his way to help the project succeed.

Mr. Pierre Smith, Mr. Horst Emrich, and Mr. Brandon Daniels for assisting with fabrication.

Mr. Jules Meyer for advising on the use of second-hand electronic parts from an old computer to drive the parachute release mechanism.

Mr. and Mrs. Mike and Marriette Greggor of Elandsberg Farms for granting us access to the farm from which the rocket was launched.

Mr. Andrew Parsons and Mr. John Soper of AMT Composites (PTY) Ltd for their advice of adhesives and composites.

Mr. Richard Bowen for his advice on rocket motor design.

Mr. Bernard Beyleveld of All Heat (PTY) Ltd for heat-curing the rocket.

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List of Acronyms

UCT	University of Cape Town
WRWRA	Single Stage Water Rocket World Record Rules for Class A

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Tel: +27 21 853 7089

Website: http://grptubing.com/ or contact

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Bernard Beyleveld

Owner of All Heat (PTY) Ltd

E-mail: allheat88@gmail.com

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For other queries contact one of the four team members:

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Figure 1 The Team. Pictured from left to right Donovan Changfoot, Stuart Swan, William Liw, and Prof. Arnaud Malan (rocket set-up for launch in the background).

Chapter 1.

Project outline: July 2013 to August 2015

The following report documents the progress of a project run by the University of Cape Town to set a new world record for the altitude of a Class A water rocket. The current world record is 623m (See web link http://wra2.org/WRA2_Standings.php).

1.1. Events of 2013

The project was initiated in July 2013 when Stuart Swan and Donovan Changfoot, supervised by Prof. Arnaud Malan, took on the challenge of setting a new world record as their final year project while studying Mechanical Engineering. Donovan focussed on building a numerical water rocket simulation model while Stuart focussed on designing and building the rocket. In November 2013 they launched their first full scale water rocket, Ascension I, to an altitude of approximately 600m, however the parachute failed to deploy on the first launch, resulting in severe damage to the rocket. Micro-cracking occurred in the carbon fibre tube resulting in slow leaks during pressurisation at the launch pad.

1.2. Events of 2014

With the possibility of a world record so close at hand the project was continued in January 2014 after both Donovan and Stuart had graduated. As such, all future work was done by all parties on a part-time basis (hence the drawn out development cycle). From January to May that year various ways of sealing the pressure vessel were tested in order to withstand the 10 minute launch pad wait at full pressure. Finally in May a simple and inexpensive sealing solution was found and a smaller test rocket was made and launched successfully at high pressure. William Liw, in his final year project of Mechanical Engineering, conducted repeated static tests to verify that the pressure vessel sealed and could be re-used as well as making improvements to the numerical simulation model. He also made a static test rig to measure the thrust that the rocket produced. This thrust measurement was then used to verify the numerical model. Based on the design that

William successfully tested, a full sized rocket, Ascension II, was made in November. Unfortunately, due to the high temperatures exposed to the rocket by the sun, the carbon fibre tube over heated on the launch pad during the 10 minute wait and the rocket could not be launched.

1.3. Events of 2015

In January 2015 the project commenced again with the construction of two pressure vessels, both of which disappointingly failed during hydrostatic testing. Looking for a way to get morale up and take more manageable steps, a smaller test rocket was made in May to test the payload systems which included the altimeter, camera and spring loaded parachute deployment mechanism. In July it was successfully launched twice within 90 minutes to an altitude of 192m and 283m respectively. This confirmed that all electronic systems were working correctly and that a world record was achievable. The tests were conducted at a remote farm with pre-arranged access.

With morale now higher a final attempt at building a full scale pressure vessel was conducted. On completion of the pressure vessel it was successfully hydrostatically tested. A carbon fibre payload frame with all the electronics and recovery system was then added to complete the rocket.

On 26 August 2015 the team headed out to a farm where previous launches had taken place. After arriving early morning to set up the launch pad, Ascension III was ready for its first launch at 9:37am. After a successful maiden flight the rocket was collected and flight data was downloaded, which showed an altitude of 835m. The second launch took place at 11:27am and reached an altitude of 825m setting a new record of 830m (awaiting official recognition).

A third launch was conducted at a higher pressure, but the parachute failed to deploy and the rocket landed in a wheat field and could not be found. This was a sad end to the project but, in a way, good for closure.

Chapter 2.

Rocket construction procedure

2.1. Pressure Vessel

The pressure vessel was, for the most part, the hardest thing to get right. Even though the design was finalised after testing in 2014 there were numerous flaws in the construction method which resulted in three consecutive pressure vessel failures.

The details of the design cannot be disclosed at this point because they are in the process of being reviewed for patenting (for more information contact Dr. Andrew Bailey, the UCT Intellectual Property Manager, at Andrew.Bailey@uct.ca.za or call +27 21 650 2425). However, the basic design consists of a standard thin walled carbon fibre filament wound tube with a PVC end cap and PVC nozzle held in place by an epoxy adhesive and a rubber liner to airtight the vessel. No metal was used to construct the pressure vessel as per WRWRA clause I. 3, III. 3 and IV. 4. The tube was not part of another high pressure enclosure as per WRWRA clause IV. 3.

The carbon fibre tube was manufactured by GRP Tubing (PTY) Ltd in Cape Town (For more information visit their website http://grptubing.com/ or contact Albert Verburg, owner of GRP Tubing (PTY) Ltd, at Albert@GRPtubing.com or call +27 21 853 7089). It was a standard tube not intended to be used in a high pressure vessel, as pressures of above circa 5 bar was found to result in significant leakage.

The end cap and nozzle were designed by the team specifically for the rocket and were machined on a standard lathe.

Figure 2 PVC water rocket nozzle and carbon fibre fins

The actual design, construction and assembly of the vessel was carried out by Stuart Swan, assisted by Donovan Changfoot (mail to chndon005@myuct.ac.za or call +27 82 385 5973) and William Liw (mail to William.LiwTatMan@alumni.uct.ac.za or call +27 71 994 4209), under the supervision of Prof. Arnaud Malan (mail to arnaud.malan@uct.ac.za or call +27 72 148 8987). To comply with the regulations in WRWRA clause I. 4 and IV. 2 the pressure vessel was entirely constructed from scratch, using no materials manufactured for model rocketry (no purchases were made from any model rocketry shops apart from the electronics and parachute disclosed in Chapter 3), by the team described above.

Once the pressure vessel had been constructed it was taken to All Heat (PTY) Ltd for heat-curing of the fibre epoxy laminate (for more information contact Bernard Beyleveld, owner of All Heat at allheat88@gmail.com or call +27 82 804 5409).

2.2. Payload

The payload was designed to be as light as possible while still having enough strength to withstand launch and recovery stresses. Strength calculations were done on the carbon fibre payload frame prior to construction. Once it was constructed static tests were carried out to simulate launch and recovery stresses. The only metal parts of the entire rocket assembly were the bolts that held the altimeter and the spring to release the parachute. All external parts of the rocket were non-metallic as per WRWRA clause I. 3. The entire payload was built from scratch including the nose cone and parachute deployment mechanism which used a spring loaded piston to eject the parachute and nose cone as per WRWRA clause I. 4. Pictured below is the partially assembled plastic payload frame made for the test rocket launched in July 2015.

Figure 3 Partially assembled payload frame for test rocket was made from plastic and carbon fibre. Based on this design a carbon fibre frame was made for Ascension III. Pictured is the Altus Metrum TeleMetrum altimeter.

Based on this design above, a more refined payload frame was designed to secure the Altus Metrum TeleMetrum altimeter (used to carry out WRWRA clause I. 5), HD Wing Camera (used to carry out WRWRA clause I. 7), three 3.7V LiPo batteries and the spring loaded parachute deployment device. A Fruity Chutes 24” Elliptical Parachute was used in order to slow the decent rate to 8m/s, which is below the 10m/s threshold as stipulated by WRWRA clause III. 2.

Figure 4 Payload of Ascension III just prior to launch

2.3. Fins

Fins were cut from carbon fibre sheet and not bought, as per WRWRA clause I. 4. Calculations were done in order to make the fins as small as possible.

2.4. Launcher

A launcher was designed as part of Stuart Swan's final year project in 2013. Design details cannot be disclosed as it is also in the patenting process (for more information contact Dr. Andrew Bailey, the UCT Intellectual Property Manager, at Anrdew.Bailey@uct.ca.za or call +27 21 650 2425). The launcher, pictured below, is made from three stainless steel components, which were machined on a lathe at the UCT workshop, mounted to an aluminium tripod. As per WRWRA clause V. 4 the rocket was launched from a stationary position and the launcher was fixed.

Figure 5 Launcher assembly

Figure 6 Rocket being loaded into launcher

Chapter 3.

Purchase list

3.1. Electronics

3.1.1. Altus Metrum TeleMetrum altimeter

Figure 7 Altus Metrum TeleMetrum altimeter.

For more information see:

http://altusmetrum.org/TeleMetrum/

3.1.2. HD Wing Camera

Figure 8 HD Wing Camera.

For more information see:
http://hobbyking.com/hobbyking/store/__17200__HD_Wing_Camera_1280x720p_30fps_5MP_CMOS.html

3.1.3. 120mAh 3.7V LiPo batteries

Figure 9 120mAh 3.7V LiPo battery.

For more information see:

http://www.e-fliterc.com/Products/Default.aspx?ProdID=EFLB1201S

3.2. Building Materials

3.2.1. Filament wound carbon fibre tube

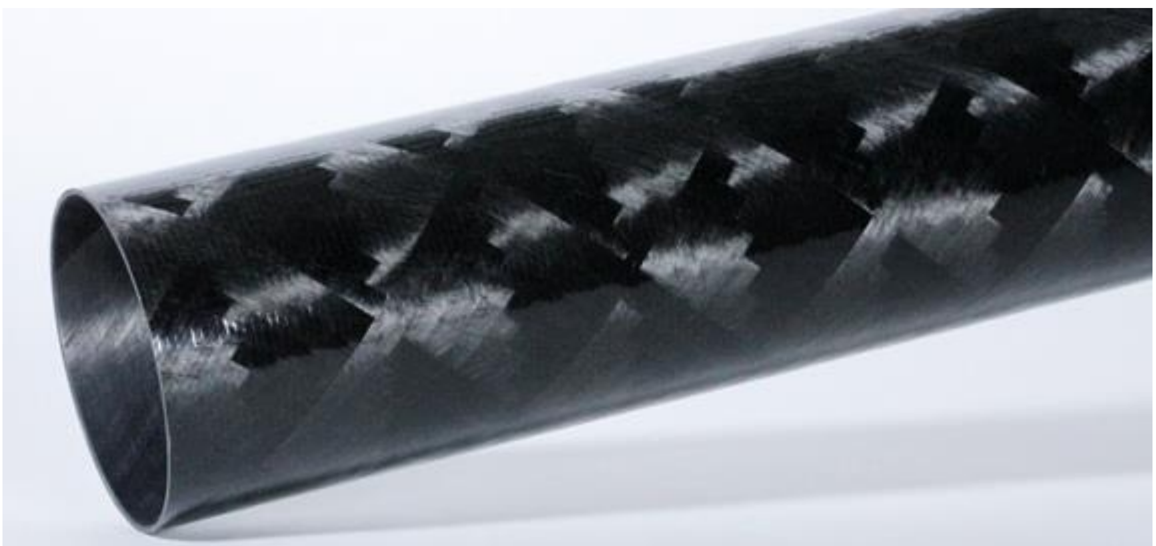

Figure 10 Filament wound carbon fibre tube made by GRP Tubing (PTY) Ltd

As mentioned above in Section 2.1 the tube was made by GRP Tubing (PTY) Ltd in Cape Town. Its intended purpose was not to form part of a high pressure vessel. In order to get the tube as smooth as possible and to reduce the mass, the tube was sanded. (For more information on the tube manufacture visit their website http://grptubing.com/ or contact Albert Verburg, CEO of GRP Tubing (PTY) Ltd, at Albert@GRPtubing.com or call +27 21 853 7089)

3.2.2. PVC round bar

The end cap and nozzle were turned on a lathe at the UCT workshop from PVC round bar.

3.2.3. Epoxy structural adhesive

Used to glue in the end cap and nozzle.

3.2.4. Epoxy resin

Used to make the carbon fibre laminates.

3.2.5. Carbon fibre fabric

Used together with the epoxy resin to make the fins as well as the payload frame and recovery mechanism.

3.2.6. Rubber

Applied to the inside of the pressure vessel to seal it.

3.3. Other

3.3.1. Fruity Chutes 24” Elliptical Parachute

As mentioned above, a Fruity Chutes 24” Elliptical Parachute was used in order to slow the decent rate to 8m/s, which is below the 10m/s threshold, as stipulated by WRWRA clause III. 2.

Figure 11 Fruity Chutes 24” Elliptical Parachute.

For more information see:

http://fruitychutes.com/buyachute/classic-elliptical-12-to-60-c-1/24-elliptical-parachute-23lb-20fps-p-14.html.

Chapter 4.

Static Testing

4.1. Pressure Vessel

Throughout the project all pressure vessels were hydrostatically tested prior to the launch. Ascension III was hydrostatically tested two days before the launch to 110% of the launch pressure. No leaks or any sign of defects were seen.

4.2. Recovery System

The spring loaded parachute deployment system was tested rigorously to ensure its reliability. Using the telemetry link the recovery system could be controlled manually, thus allowing the system to be tested without launching the rocket. (See video provided)

Static load testing was also done on the payload frame to verify that it would be able to withstand the force exerted on it when the parachute was deployed.

Chapter 5.

Rocket Characteristics

Length:	2.64m	
Mass:	1499g	Video footage provided
Volume:	6.25L	
Water fill volume:	1.25L	20% of 6.25L. Video footage provided

Chapter 6.

World Record Launch Details

6.1. Pre-launch logistics

As mentioned previously, the launch was conducted on a remote field viz. on the Elandsburg Farm which is situated outside Wellington, Western Cape, South Africa (see figure below). This location was chosen as:

- The farmer was known to the team and could therefore be approached for access.
- The farm is located on a strip for which air clearance may be sought from the local air traffic authority viz. Air Traffic Notification Service. This was done and a clearance height of 5,000 ft. above ground level (1,644 m) was obtained for 25 September 2015 from 5:30 a.m. to 4:30 p.m. (see certificate in Appendix B).
- The farm contains large open grass fields making safe launch and recovery easy.

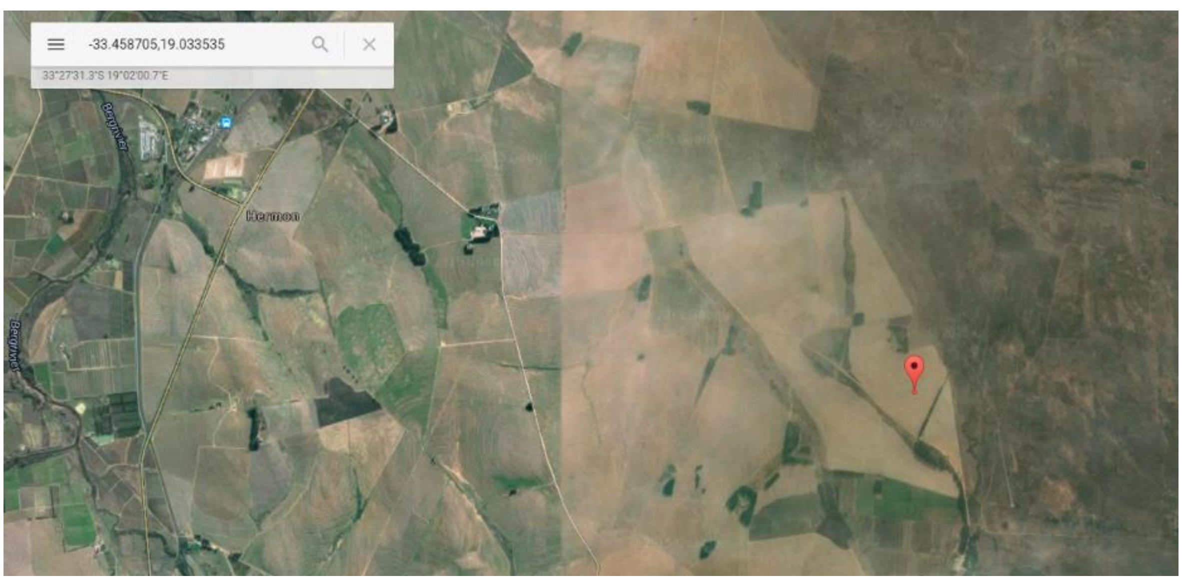

Figure 12 Location of launch site on Elandsberg Farms.

6.2. Launch procedure

6.2.1. Final weigh-in

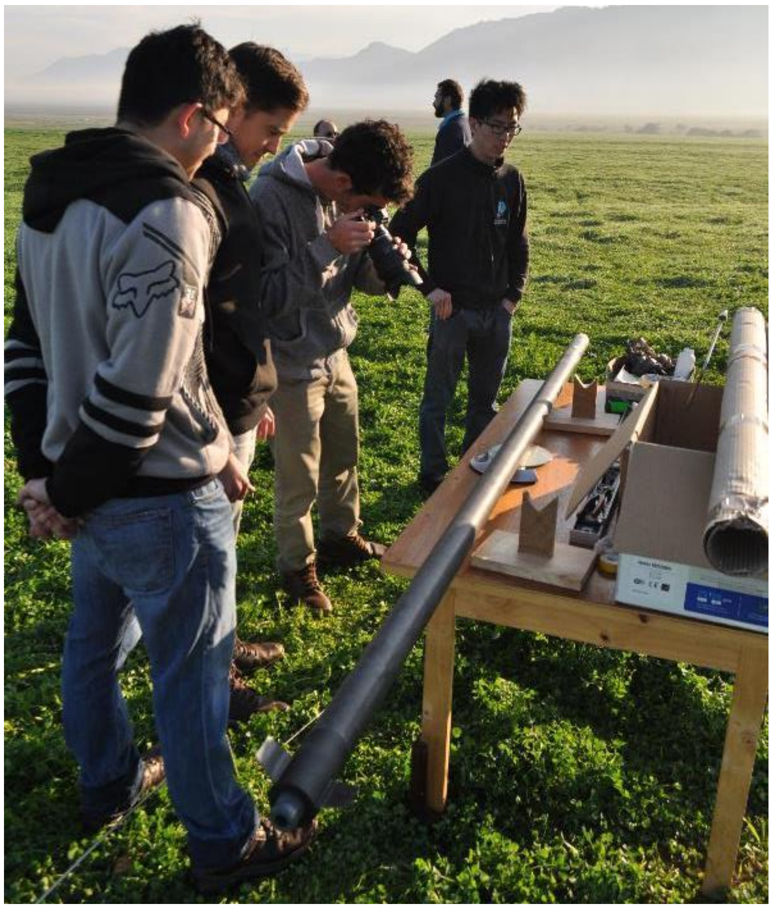

Figure 13 Filming the weigh-in before pouring water into the rocket

Before water was poured into the rocket a final weigh-in was conducted to make sure the rocket was under the 1500g limit as per WRWRA clause I. 1. The scale couldn't settle on a reading due to the light wind acting on the rocket. However the reading on the scale never went above 1499g. A video of the weigh-in is provided as proof.

6.2.2. Adding water

The rocket volume was 6.25L and, as per WRWRA clause V.2, a minimum fill volume of 1.25L (20% of 6.25L) was carefully poured into the rocket. Ordinary tap water was used as per WRWRA clause V. 1.

Figure 14 Filming the water being dispensed

Figure 15 Pouring rocket into rocket

6.2.3. Final launch preparation and rocket pressurisation

The rocket was loaded onto the launch platform. Once all the checks had been done to make sure that the rocket was safe to pressurise, the electronics were turned on and the on-board video camera started to record.

Once everyone was a safe distance away (30 metres) the rocket was pressurised using a SCUBA tank containing atmospheric air, as per WRWRA clause I.2 and II.1. The tank was certified (see Appendix A for tank certificate and filling station receipt) as per WRWRA clause II.2. All local laws regarding pressure vessels were adhered to. No certifications were required to handle the SCUBA tanks, satisfying WRWRA II.3. The SCUBA tank was located 30m away from the launch pad, which is more than the 15m stipulated in WRWRA clause II.5.

Once at full launch pressure the scuba cylinder supply was shut off and the rocket was left to stand for 10 minutes (see video footage for proof) before launching, as per WRWRA clause II. 4. The pressurisation is clearly audible on the attached on-board video footage (one can hear clearly the air entering the pressure vessel).

6.3. Actual launch details

6.3.1. Launch 1

On the 26th of August 2015 at 9:37am (see date stamp on altimeter file shown below) Ascension III was launched. The launch went perfectly and the parachute deployed. The rocket landed about 100m from the launch pad due to light wind. The rocket was collected and brought back to the launch pad where the flight data could be downloaded. An altitude of 835m was recorded by the TeleMetrum. One of the fins had to be re-glued to the rocket, as it came off during landing.

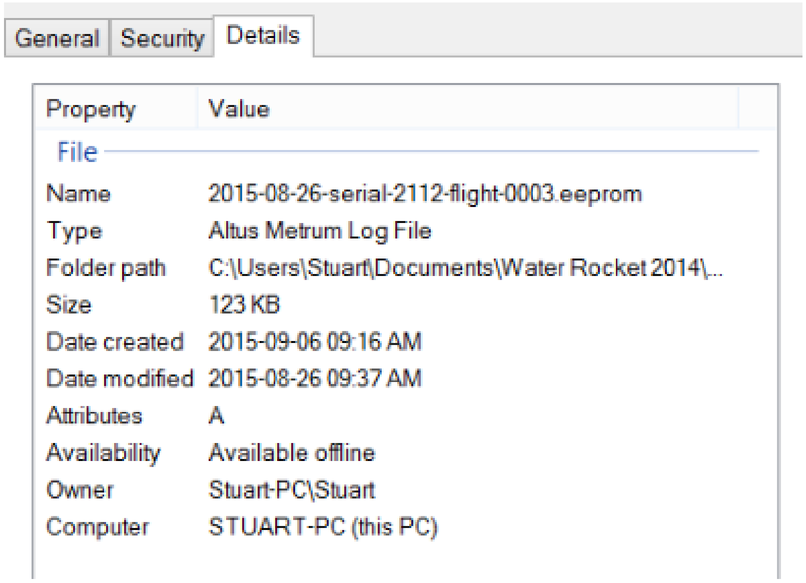

Figure 16 Date stamp, 2015-08-26 at 9:37am, on altimeter for launch 1. 'Date modified' shows the date and time that the rocket was launched.

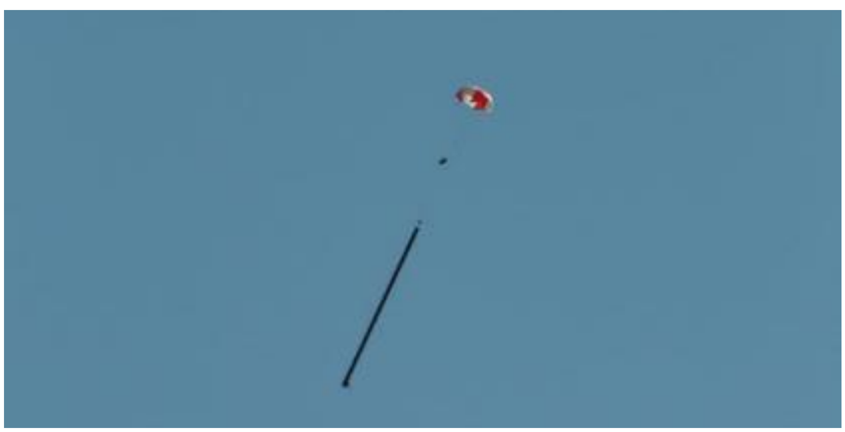

Figure 17 Successful parachute deployment on launch 1

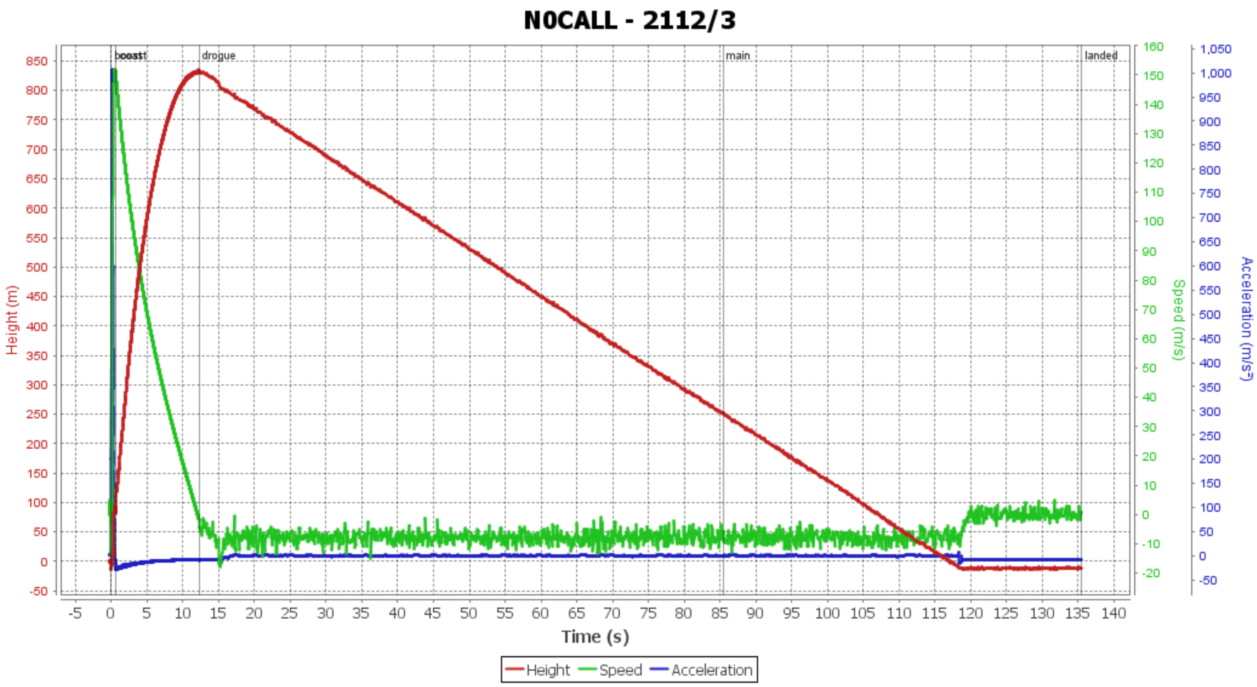

Figure 18 Graph of altimeter data from launch 1

Table 1 Table of altimeter data from launch 1. Note height of 835m.

Serial	2112		
Flight	3		
Maximum height	835 m	2739 ft	
Maximum speed	152 m/s	339 mph	Mach 0.4
Maximum boost acceleration	1006 m/s²	3301 ft/s²	103 G
Average boost acceleration	246 m/s²	807 ft/s²	25 G
Drogue descent rate	-8 m/s	-26 ft/s	
Main descent rate	-8 m/s	-26 ft/s	
Ascent time	0.7 s boost	0.0 s fast	11.6 s coast
Descent time	73.2 s drogue	32.6 s main	
Flight time	118.1 s		

6.3.2. Launch 2

The rocket was then prepped for the second launch. The second launch took place at 11:27am (see date stamp on altimeter file below). Again, the launch went perfectly and this time no fins were damaged during landing. Flight data from the altimeter for both flights are shown below. An altitude of 825m was achieved.

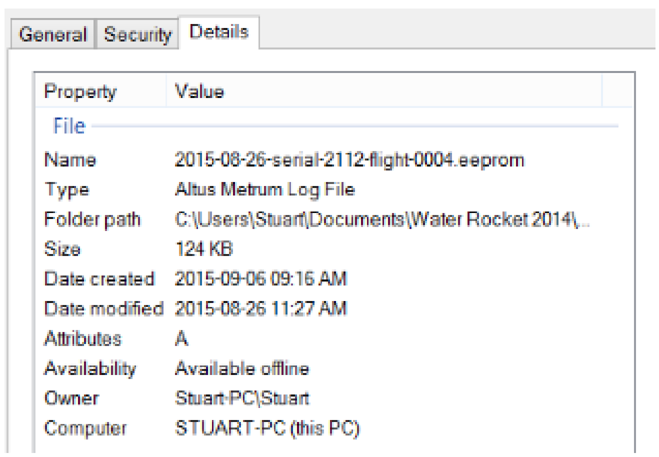

Figure 19 Date stamp, 2015-08-26 at 11:27am, on altimeter for launch 2. 'Date modified' shows the date and time that the rocket was launched.

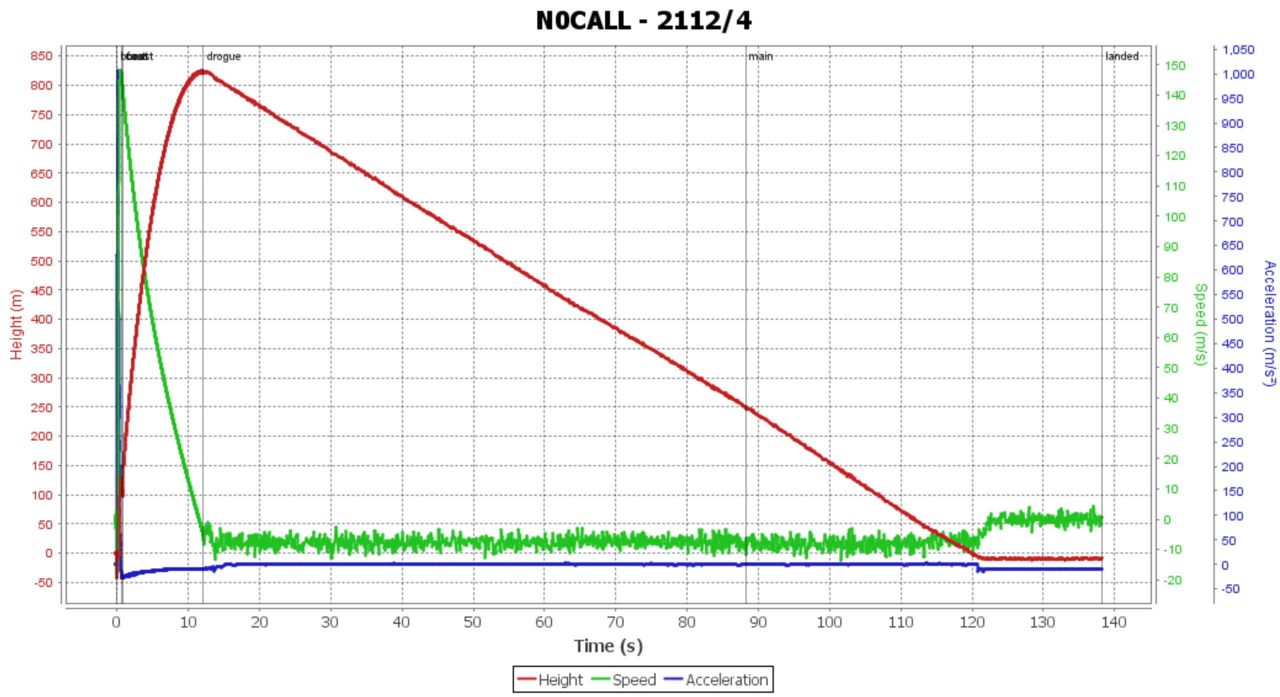

Figure 20 Graph of altimeter data from launch 2

Table 2 Table of altimeter data from launch 2. Note altitude of 825m.

Serial	2112		
Flight	4		
Maximum height	825 m	2706 ft	
Maximum speed	148 m/s	331 mph	Mach 0.4
Maximum boost acceleration	1006 m/s²	3301 ft/s²	103 G
Average boost acceleration	247 m/s²	811 ft/s²	25 G
Drogue descent rate	-8 m/s	-25 ft/s	
Main descent rate	-8 m/s	-26 ft/s	
Ascent time	0.7 s boost	0.1 s fast	11.3 s coast
Descent time	76.1 s drogue	32.6 s main	
Flight time	120.8 s		

Chapter 7.

A New World Record

Based on the average of the two flights a new world record of 830m has been set in accordance with WRWRA clause I.8 and I.9, which state that the altitude is the average of two flights, using the same rocket, launched within 2 hours.

Appendix A.

SCUBA tank certificate and receipt

ORCA INDUSTRIES

3 Bowwood Road Claremont7708
Phone 021 - 6719673 / 9
Fax 021 - 6719733
E- Mail duncan@orca-industries.co.za

ORCA INDUSTRIES

2015

Cert #…001………..

This is to certify that the cylinder described below has been inspected and tested in accordance with OHSA, SABS 019 - 1985 and SABS 50 - 1978

Owner of cylinder :..ORCA Industries……

Contact Name…Mark Elliott

Address 3 Bowwood road
Claremont
7708
Cape Town

Asset Number…" Mark"……

Date of Manufacture……11/1999……

Phone Number……021 671 9673……….

Serial Number……99/9713/192…… Date of Test…26/072015…… Cyl. Volume……12.2L……

Steel [X] Ali [ ] Working Pressure 232 BAR

Viz [X] Hydro [ ] Test Pressure 348 BAR

External Condition……Fine.……

Internal Condition……Good……

Condition of threads Cyl……Fine.……Pillar Valve…Fitted original valve……

HYDRO

Permanent Set…………… Initial Bulge YES [ ] NO [ ]

Maximum Expansion…………… Did bulge enlarge after hydro Yes [ ] No [ ]

Good for service Yes [X] No [ ]

Tested By ……Uri Steyn……

Signed By Examiner……………

ORCA INDUSTRIES NOT VALID WITHOUT WORKSHOP STAMP. admin@orca-industries.co.za Tel (021) 671 9673/9 Fax (021) 671 9733 CAPE TOWN

The issue of this certificate does not imply any warranty in respect of any cylinder as to its fitness for use once the cylinder has left the company's premises. The above cylinder is required to be periodically retested in accordance with the above mentioned codes and acts.

ORCA INDUSTRIES
25-08-2015 10:00:49
TT: IAL220 V:0412
M:1523028 U:0000D59A
MERCHANT COPY
N:0547 TSN:0634
H:1912 I:HI S:221
A:229026 B:0088
AID:A0000000041010
TVR:0000000000 TSI:E800
Savings
Default Unspecif
5284972215231610
Sale R780.00
TOTAL R780.00
Signature not required

ORCA INDUSTRIES
10-09-2015 10:40:00
TT: IAL220 V:0412
M:1523028 U:0000D59A
MERCHANT COPY
N:0618 TSN:0717
H:1927 I:TS S:221
A: B:0100
Default Unspecif
5284972215231610
Refund R400.00
TOTAL R400.00
CardHolder Signature
SWAN/SG.MR
Supervisor Signature

Orca D
3 Bowwoo
Claremont
7708

371-9673
1-9733
d@orca-industries.co.za

om

Name: S
Address: S

Tel (h):
Cell:
Deposit Amount:
Cash: R
C
customer to sign
Credit Card R

Sales Person Responsible: **Out**

No.	Item	Item No.	No of Days	Rate / Day	Total R	Returned
1	Filling End		2	50	100	✓
2	12L Steel	41	2	70	140	✓
3	12L Steel	Mark	2	70	140	✓
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Total Due R 380

I .... As Hirer, acknowledge that I am Trained and Certified in the use of the above rented equipment, and have checked that the aforementioned equipment is in good working order before leaving the premises.

Signature **Date** 25 08 2015

Weekend Hire is from Friday 2pm to Monday 12pm.
Week Day Hire equipment to be collected and returned by 12 noon the following day.

Appendix B.

Air Clearance

Collaborative Decision Making

working together more efficiently, effectively and transparently

ATNS

Find out More

#safeskies

Good Day,

ATNS does not have any objection to the Water Rocket Launch taking place from an Air Traffic Control perspective. ***All rules and regulations, as laid down in the CAR and CATS, Integrated Aeronautical Information Package and any other local, regional or national legislation are to be complied with. All requirements for this event to take place as laid down by SACAA are to be met.*** Please make sure you obtain all necessary permissions prior to the operation. Further to this, please comply with Air Traffic Control requirements as laid out below

CAMU RESPONSE TO APPLICATIONS FOR FLEXIBLE USE OF AIRSPACE

Reference Number:	**AG 24/08-2**
Company Name:	University of Cape Town
Contact Person:	Stuart Swan
Telephone Number:	0814122098
Email Address::	stuswan@gmail.com
Type of Operation:	Other
Specify if Other:	Water Rocket Launch
Dates of Requirement:	24 Aug 2015 - 30 Aug 2015
Duration of the Operations:	0530Z- 1630Z

1

Area/Location name:	Elandsberg Farms	
Area of operation:	332731S 0190200E	R060 CTV 37NM
Vertical limits of the area:	5000ft FT AGL	
Transponder type:	NONE	
Aircraft type:	Model rocket	
Aircraft registration:		
Additional Comments:	We are testing a model rocket. It is powered by compressed air and water. No flammables or explosives. A radius of airspace of 500m around the GPS point given is required and a height of 5000ft AGL.	

ATC/Airspace Requirements:

ATSU:	**FACT ACC / SACAA**
WE HAVE NO OBJECTIONS PROVIDED:	
THE FOLLOWING REQUIREMENTS TO BE MET:	**Contact Cape Town ATC 20 minutes prior to commencement of operation on Tel: 021-937 1116, to advise them of your intentions and coordinate your operation.**
SIGNED:	**G. CULLEN / Z. CIRA**
DATE:	**24 AUG 2015**

Kind Regards,

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