

The Designing and Testing of a Small Gas/liquid Rocket Engine AMEC 2006

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Overview

- (1) Examples of Rocket Engine Development today**
- (2) Theory**
- (3) The aims, the testing process and design choices**
- (1) The engine design**
- (2) The first test**
- (3) Results and conclusions**

Rocket Engine Costs

Some rocket engine costs are as follows:

Russian RD-180	US \$10m	455 tonne thrust	Now used on the Atlas V
Fastrac engine	US \$1m	27 tonnes thrust	Future X34 vehicle
SSME engine	US \$50 m	230 tonnes thrust	Space shuttle
RS-68 engine	US \$14 m	330 tonnes thrust	Delta IV

Rocket engine costs are a function of;

- The complexity of the engine;
- The operating pressure, efficiency and size of the engine;
- The testing and commissioning process.

Travel into space can be reduced by recovering and reusing the rocket stages.

Finally, very little work has been done on methane/LOX engines.

Kistler and Space X Engines

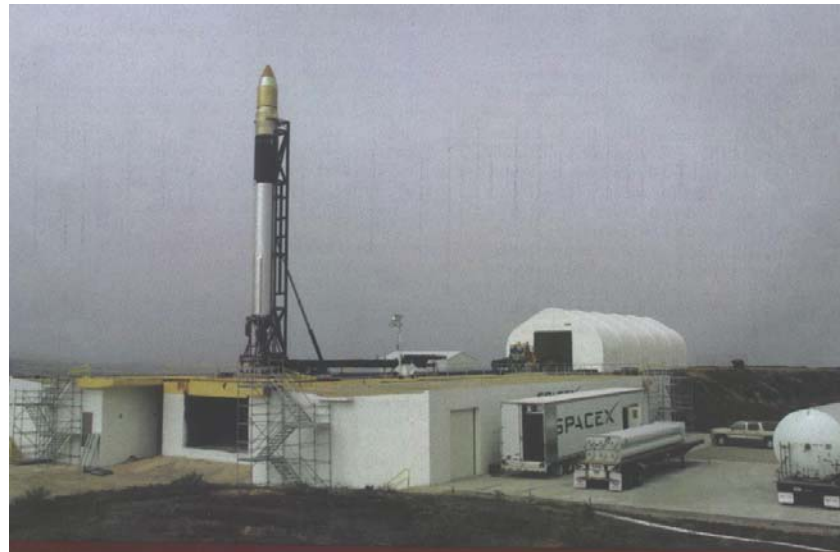
Kistler has adopted the engines from the Russian N1 moon rocket.

This engine feeds O₂ gas from a pre-burner and Kerosene liquid into the combustion chamber.

The Kistler rocket must be launched over land as the first stage is landed on land with parachutes and airbags

Space X use their own rocket engine design.

**They plan to land
The first stage in the
Sea with parachutes.**



EASY ASSEMBLY

Falcon 1 rises modestly out of Vandenberg Air Force Base's scrubby brown hills. "It takes some rockets two or three months to get stacked, assem-

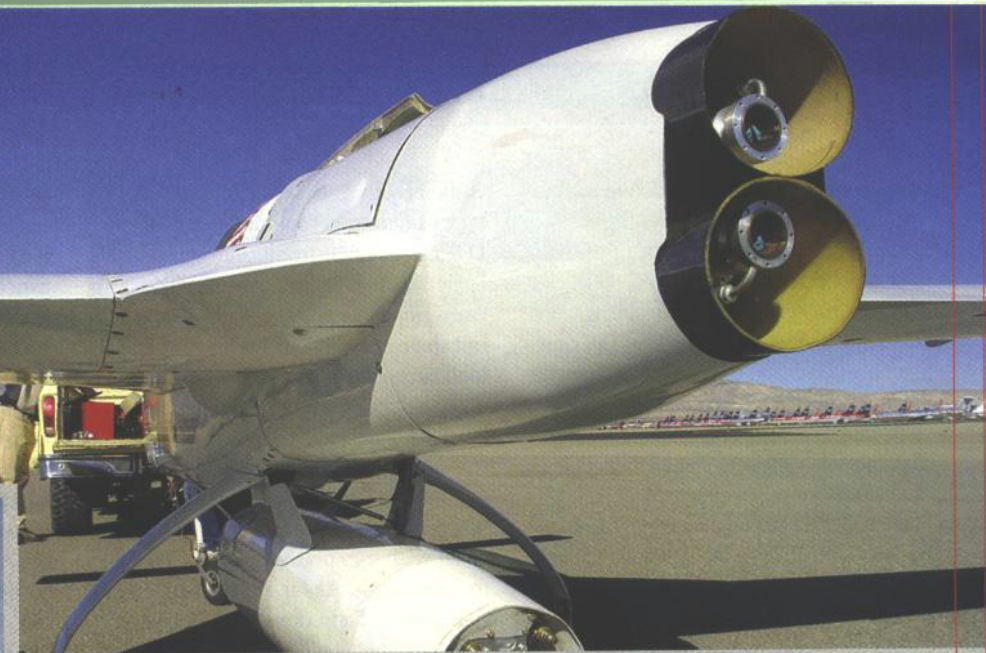
bled, and checked out on the pad," says Tim Buzza, who runs SpaceX's test and launch operations. "But when we stand our rocket up, it is essentially

ready to fly." SpaceX's second flight will depart from Vandenberg, possibly in December. The first will launch from the Marshall Islands in October



READY TO ROCK
Solid grain and cooling
are at the heart of the
engine from the 1960s and
the 1970s. The engine
is a masterpiece of
engineering and design.
The engine is a masterpiece
of engineering and design.
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of engineering and design.

Rocket Plane Racing



Rocket plane racing is being touted as the racing medium of the 21st Century.

If it 'takes off' as an industry, it will provide an economic driver to provide cheap high performing engines.

The engines shown use standard piston pumps to pump LOX and kerosene into the combustion chamber.

Theory

Basic Relations

$$\text{Exhaust Velocity } V_e = \sqrt{\frac{2\gamma RT}{\gamma-1} \left[1 - \left(\frac{P_e}{P_r} \right)^{(\gamma-1)/\gamma} \right]} \quad \text{m/s.}$$

$$\text{or: } \underline{V_e} \approx K \sqrt{T/M.}$$

M = molecular wt of products

γ = Specific heat ratio (C_p/C_v)

R = Universal Gas Constant.

T = Combustion temperature.

P_e = Exhaust Pressure.

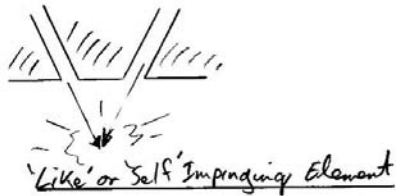
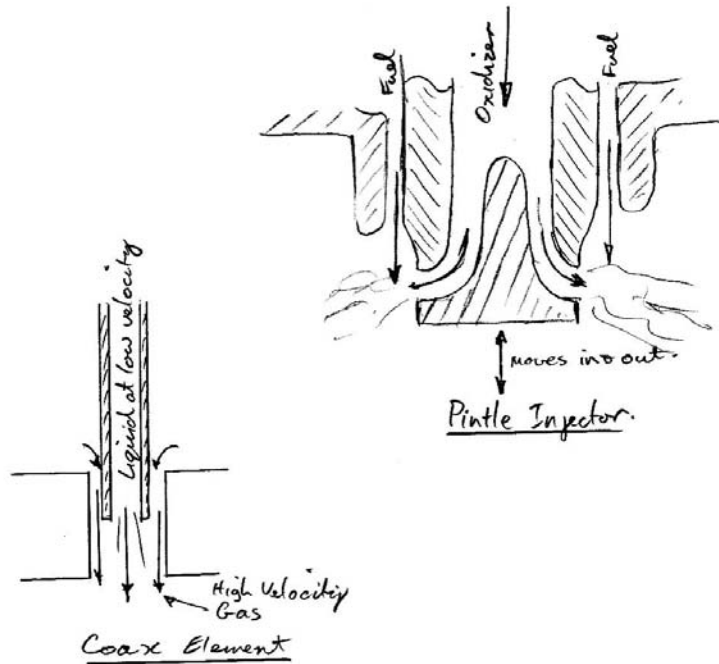
P_r = Combustion pressure.

$$\text{specific impulse } I_{sp} = \frac{F}{\dot{m}g} \quad \text{seconds}$$

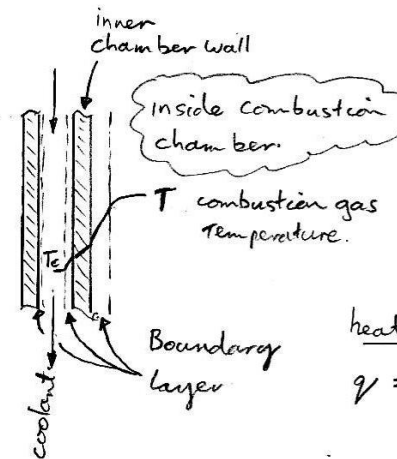
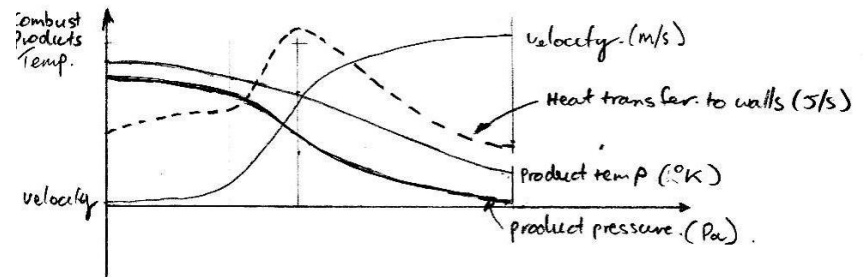
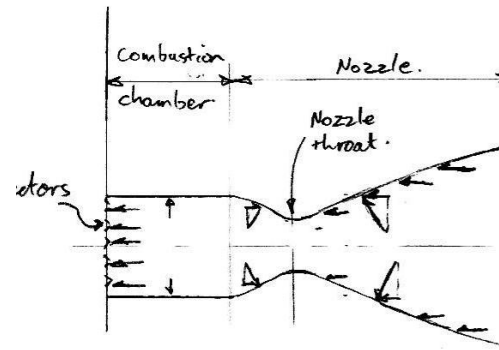
F = Thrust (N)
 $\dot{m}g$ = weight of propellant burnt per second.

Components

Injectors



Chambers & Nozzles



cooling

- Regenerative
- Film cooling
- Ablative cooling

heat transfer:

$$q = h(\Delta T), \quad q = \text{joules/sec}$$

h = transfer $\text{W/m}^2\text{K}$ coefficient

ΔT = Temperature change.

The Aim of The Small Gas/Liquid Rocket Engine

The aim of the engine is to be a learning tool intended to develop an understanding of the technical and practical issues in rocket engine design and testing.

A few Quotes: - To start us off in the right direction:

“... the development process could be essentially reduced if simple design were emphasized as a leading principle.... Essential elements have to be designed as simply as possible, even if this means a reduction in quantitative efficiency and a certain increase of bulkiness and/or weight.” -Quote from Theodore von Karman- Rocketdyne, 1959

“KISS” – Keep It Simple and Safe

“When I turn it on, One of three things will happen:-

- (1) It will go as intended;
- (2) Nothing will happen; or
- (3) It will blow up.” - Brett, the electrical commissioning engineer, about to switch on a 1 million dollar piece of electrical equipment

Design Choices

-Choosing an engine size.

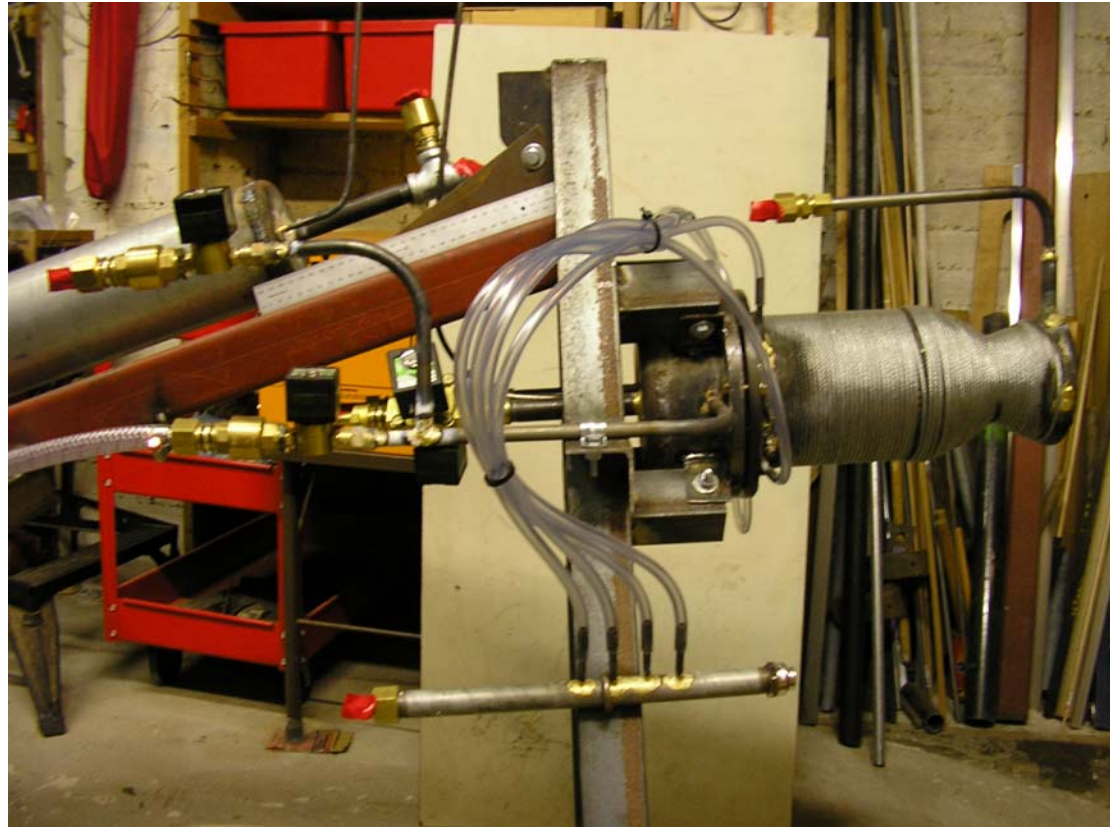
What engine size should we design? Clearly the engine size will influence the size of the test rig and propellant tanks.

-The engine needs to be large enough to gain useful experience and be a reliable benchmark for future scaling of the elements.

-The engine was made as large as possible

-A throat diameter, 60 mm & 120 mm chamber ID chosen as fitted in the author's lath.

-Maximum, operating pressure 10 bar (150 psi) enabled the purchase of cheap off the shelf valves.



Design Choices

-Propellants Choice.

Which propellants should we adopt?

We chose kerosene and oxygen gas mix due to simplicity and ease of supply.

Propellants to be fed using tank pressure.

No pumps.

-Materials Choice.

Which materials should we use for our engine?

We chose mild steel to keep the cost down. Mild steel is not a good choice for engines.

Other materials for combustion chambers.

-Austentic (300 series) Stainless Steel;

-Copper alloys - used in the shuttle

-Nickel

Design Choices

-Engine testing choice.

Where can we test the engine. What are the requirements for a test site? What test rig design do we adopt?

The engine test site attributes:

- Location within 30 minutes drive from home;**
- Location to be distant from habitation.**
to minimize noise impact and explosion damage.
- Water to quench noise and fires;**
- Low cost rent;**
- Electrical power available.**
- We adopted a horizontally fired engine test rig to minimize concrete mass and avoiding flame direction issues.**

**The test rig has '3.5 tonne' thrust
Engine capacity - the largest practical
Structure with foundations that could
be made by the team.**



The Test site

**Working on foundations
Trench in background**



**Engine in place. Fuel tank in
the background**

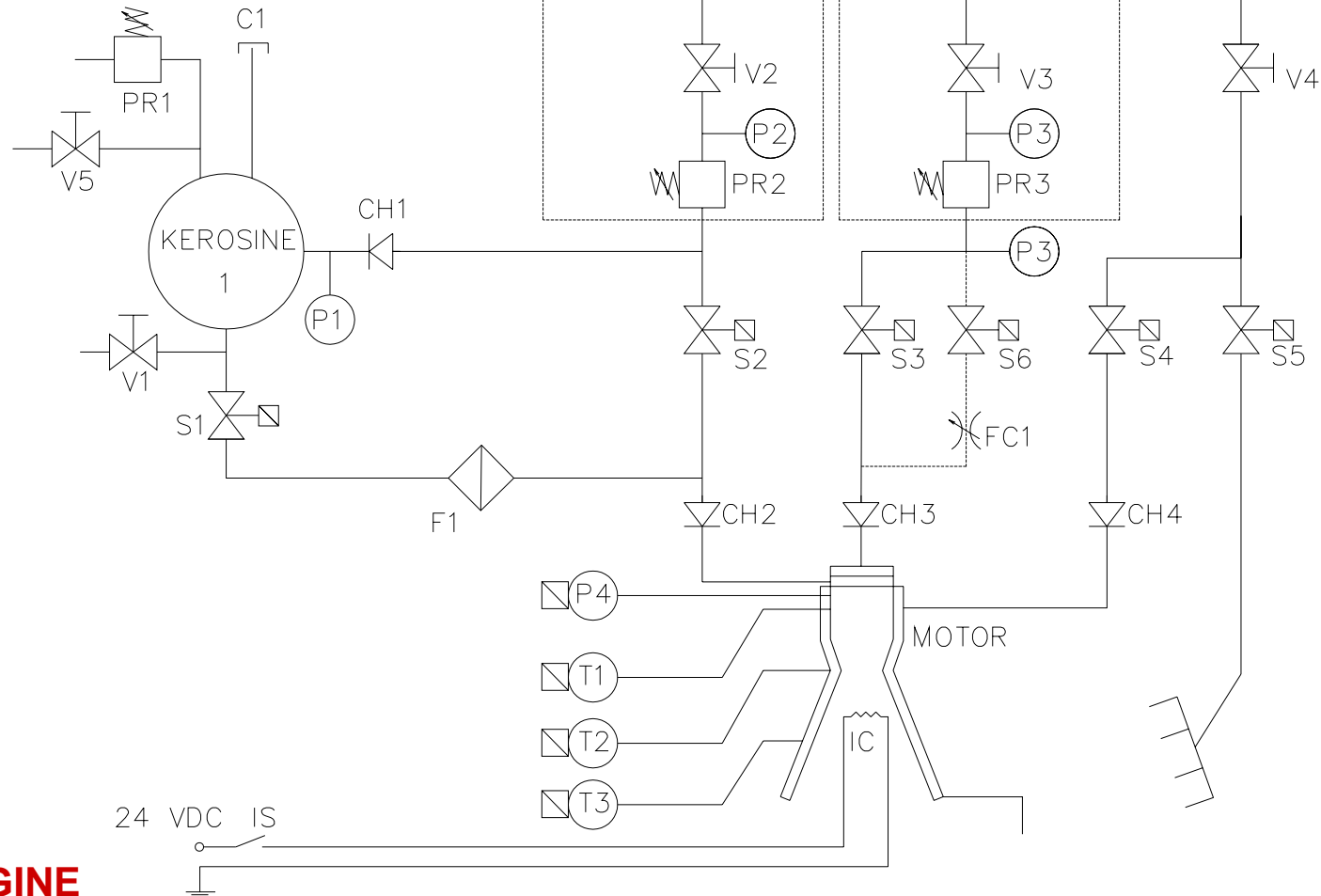
The Load Cell



Load Cell in place

The analogue pressure sensor could be calibrated from the pressure gauge and jack ID.

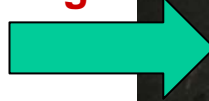




The analogue pressure sensor could be calibrated from the pressure gauge and jack ID.

Engine Design

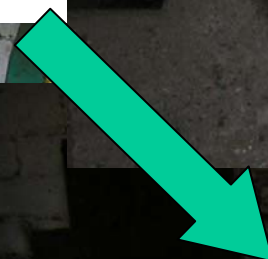
The combustion chamber, showing tubes.



The engine head
Showing kerosene
& nitrogen feed
Lines.



The O₂ gas and
kerosene injectors



Engine Design - Control

The engine was controlled from a laptop using 'Visual Basic' Software.

The Ignition lighter, O2 in-feed valves Kerosene in-feed valves and N2 purge valve was controlled sequentially.

In essence O2 is fed into the combustion chamber first before the kerosene fuel to prevent a 'hard start' or explosion.

The screenshot shows a Visual Basic application window titled "Form1" with a green background and a yellow title bar. The main panel is titled "O2 GAS - KEROSINE ENGINE CONTROL PANEL". It features several control buttons: "Idle", "ENGINE START", "ENGINE ESTOP", and "Reset". Below these are two large white rectangular areas labeled "PRESSURE kPa" and "THRUST KN". To the right of these are a series of status buttons: "NOGO IDLE", "NOGO START", "NOGO RUN", "GO STOP", and "NOGO ESTOP". A "VALVE PANEL" section on the right contains buttons for "GO COMMS CARD", "NOGO ENGINE LIGHTER", "NOGO O2 VALVE 1", "NOGO O2 VALVE 2", "NOGO KEROSINE VALVE", "GO NITROGEN VALVE", and "NOGO WATER VALVE". At the bottom, there is an "ENGINE SETTINGS INPUTS" section with four text boxes and corresponding labels: "Text1 ENDURANCE RUN TIME", "Text1 ENABLE O2.1 TIME AFTER START", "Text1 ENABLE O2.2 TIME AFTER START", "Text2 ENABLE KERO TIME AFTER START", and "Text3 N2 ENDURANCE RUN TIME AT STOP". On the far right, there are two data display sections: "LIST ENGINE PRESSURE DATA kPa" and "LIST ENGINE THRUST DATA kPa", each with a large white rectangular area for output.

TOSHIBA

This screenshot is identical to the one on the left, showing the same "O2 GAS - KEROSINE ENGINE CONTROL PANEL" interface. It includes the same control buttons, status indicators, valve panel, and engine settings inputs. The window title is "Form1" and the background is green. The layout and components are consistent with the first screenshot.

TOSHIBA

The First Test- Setting Up

The aim of this test was to trial the equipment in the areas of:

- Safe fuel loading and operating procedures;
- Safe start and shut down;
- Software control; and,
- Monitoring of the loads and pressures.

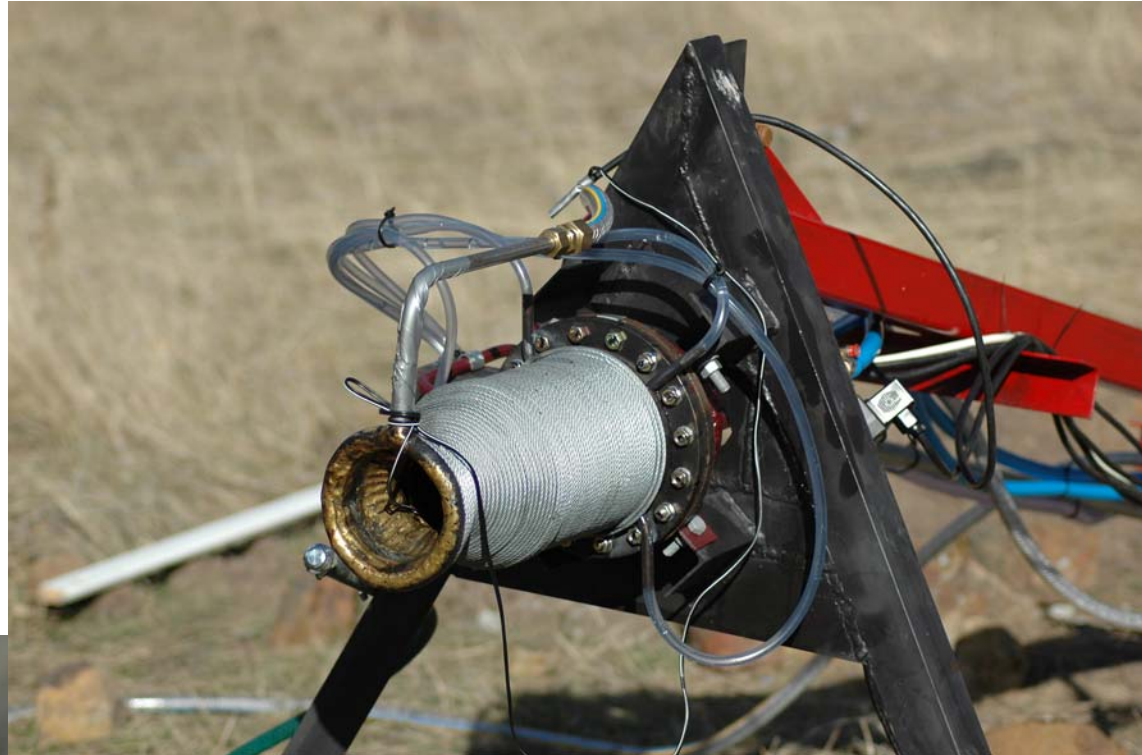
Engine performance was not relevant in this test.



Loading kerosene



Final Preparation



The First Test



**In the control trench
Ready to run**

**First run - Nothing happened!
Failed ignition system**

The First Test



A successful firing- at low pressure

Followed by a sloppy shut down

The First Test



A successful firing!

4 runs were completed.

**3 were 5 second in duration.
The final was a 15 in duration.**

The Results

-Safe fuel loading and operating procedures.

-Safe start, run and shut down;

-Software control;

-Monitoring of the loads and pressures.

Engine performance.

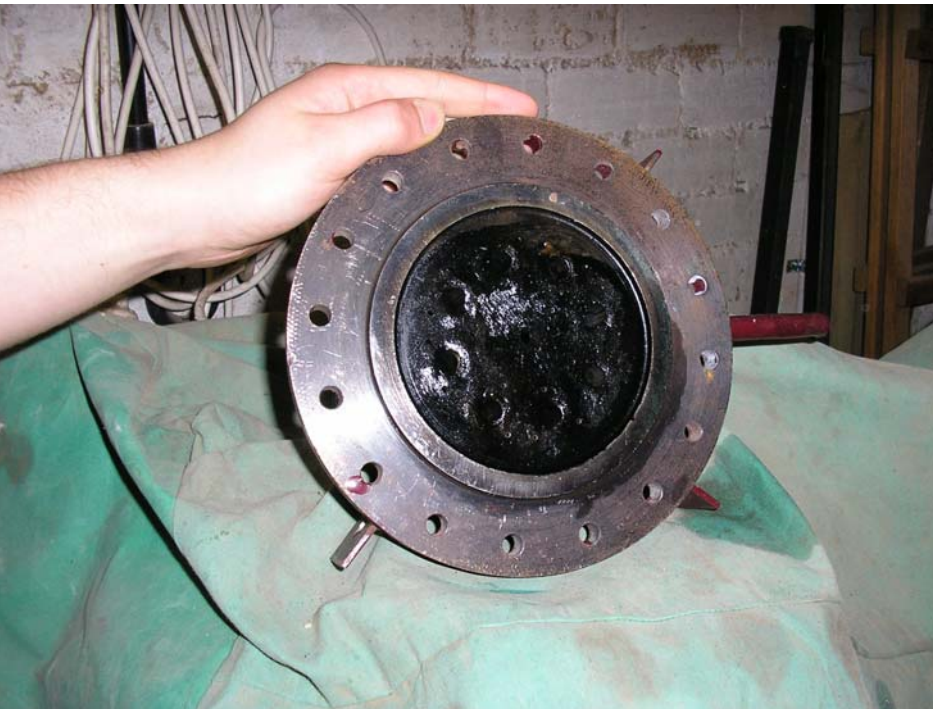
Difficult fuel loading and monitoring of the mass burned.

Safe. The runs provided confidence in system

Could not read input data. Output to field OK

Required to read gauges using camera.

**Probably achieved 0.25 kN thrust
Incorrect mixture ratio and poor injector
performance.**



Conclusions

The rocket engine and testing rig performed well. 3 out of 4 runs were achieved. The longest burn time being 15 seconds excluding the start up and shut down process.

A high confidence level in the system and procedures was achieved.

However improvements are required. These are:

- Replacing the software with standard industrial PLC system;
- Improving the fuel loading and monitoring of the fuel and oxygen burn rate;
- Providing sand bags around the test rig to absorb explosions;
- Improving the injector design;
- Monitoring the combustion chamber temperature;
- Improving the fuel/O₂ ratio; and finally,
- Measure the thrust, chamber pressures, chamber temperature and propellant burn rate to provide engine performance data.

The plan is to modify the present engine and complete a performance test before building a new engine employing liquid oxygen and kerosene.