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

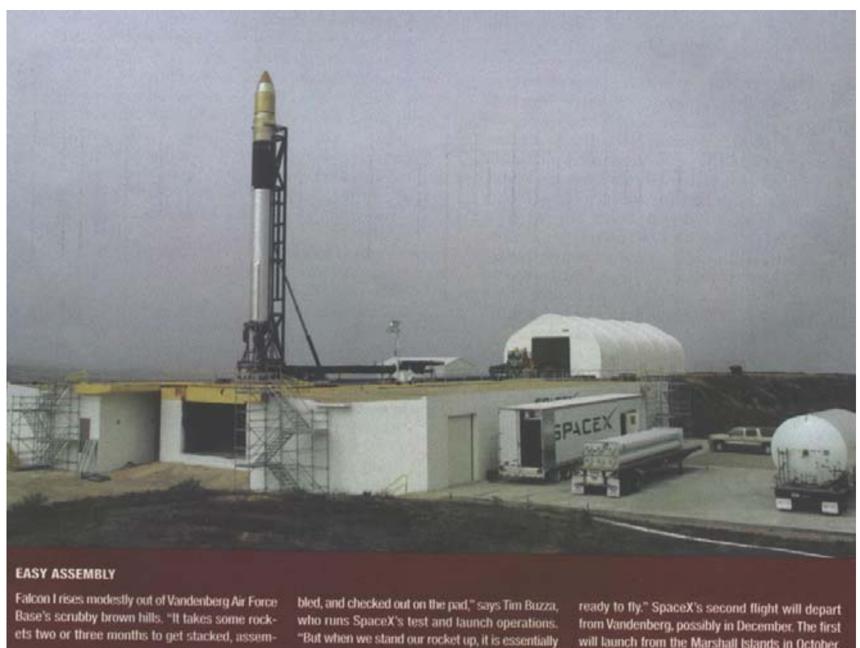
Kistler has adopted the engines from the Russian N1 moon rocket.

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

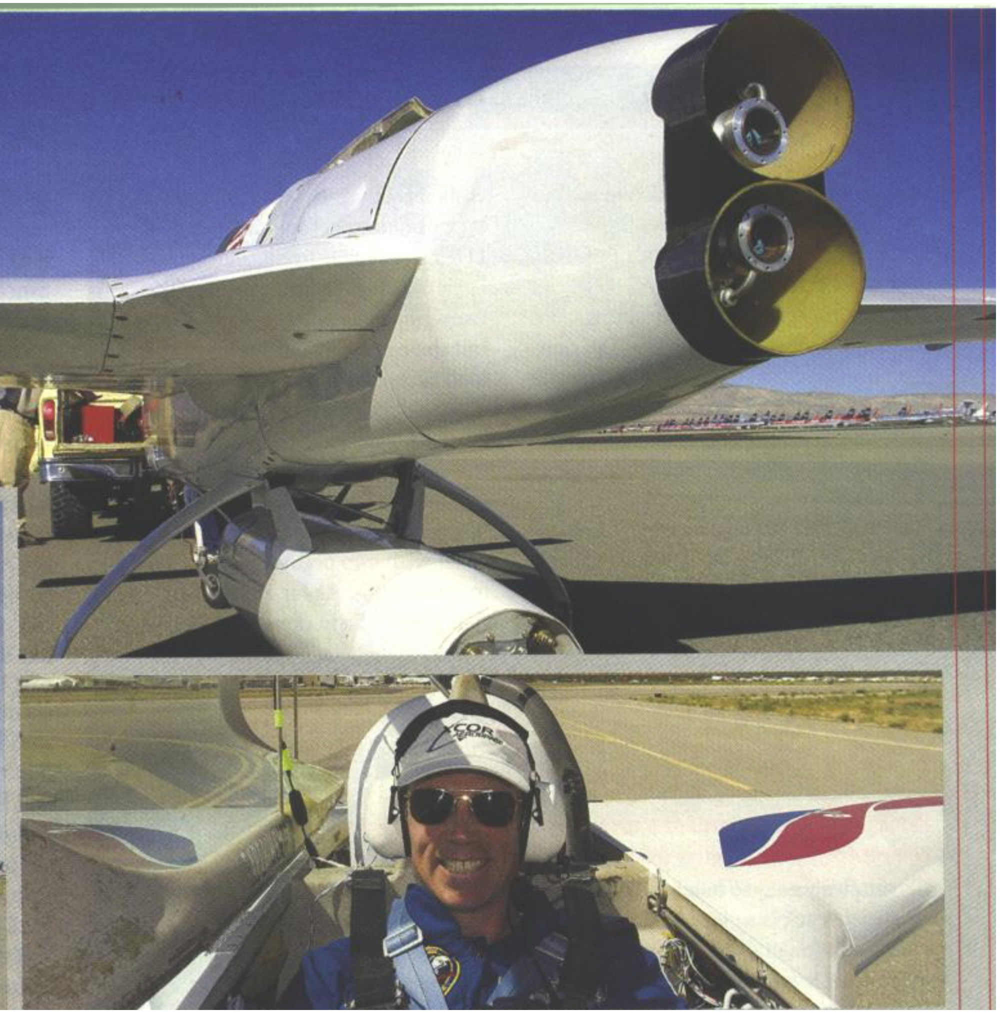
The Kistler rocket must be launched over land as the first stage is landed on land with parachutes and airbags

Space X use their own rocket engine design.

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



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

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

γ = Specific heat ratio (C_p/C_v)

or: $V_e \simeq K\sqrt{T/M}$.

R = Universal Gas Constant.

M = molecular wt of products.

T = Combustion temperature.

P_e = Exhaust Pressure.

P_T = Combustion pressure.

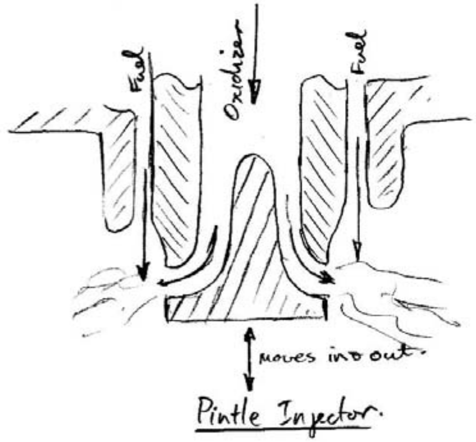
Specific impulse I_{sp} $= \frac{F}{\dot{m}g}$ seconds

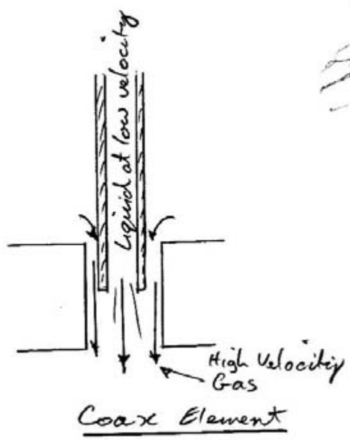
F = thrust (N)

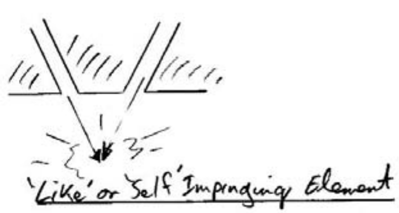
$\dot{m}g$ = weight of propellant burnt per second.

Components

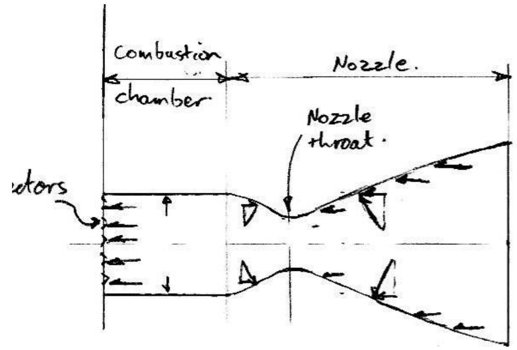
Injectors

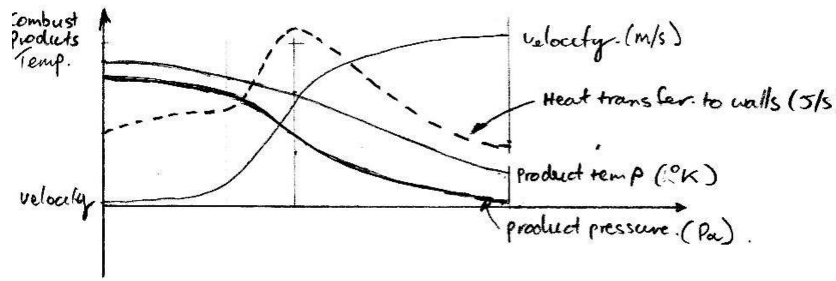


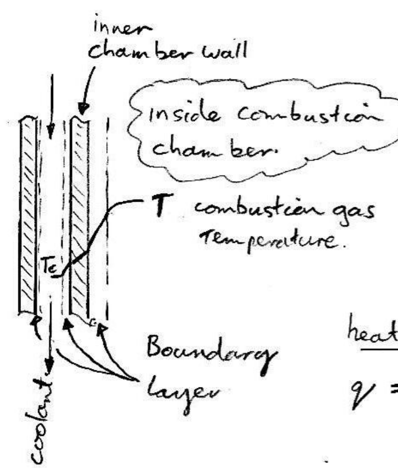




Chambers & Nozzles







Cooling

- Regenerative
- Film cooling
- Ablative cooling

heat transfer:

$q = h(\Delta T)$, q = joules/sec

h = transfer coeficient W/m^2K

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.

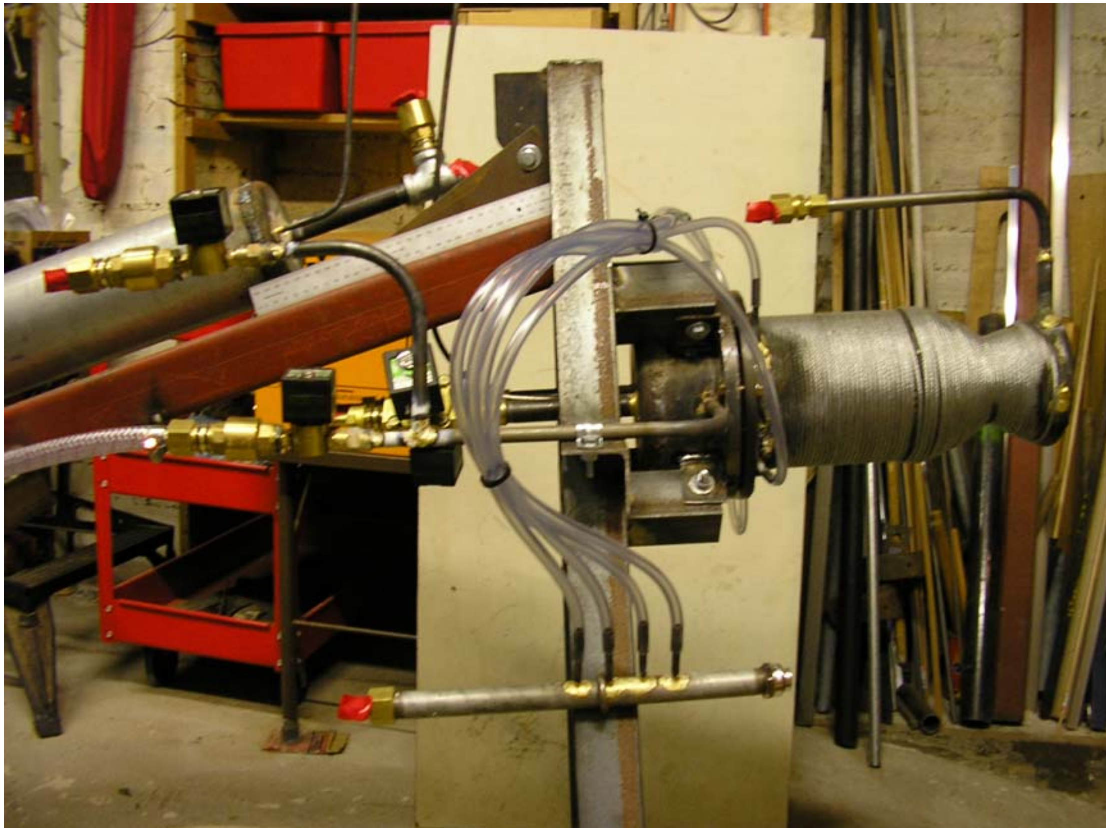
What engine size should we design? Clearly the engine size will influence the size of the test rig and propellant tanks.

-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

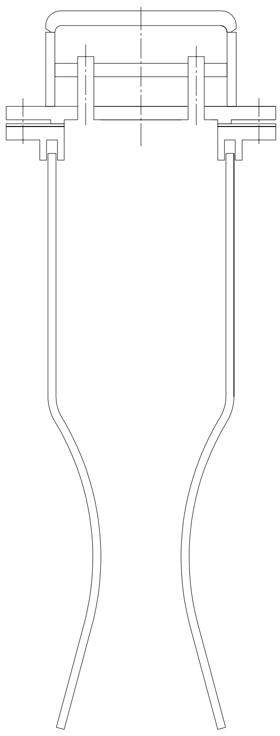
Engine in place. Fuel tank in the background

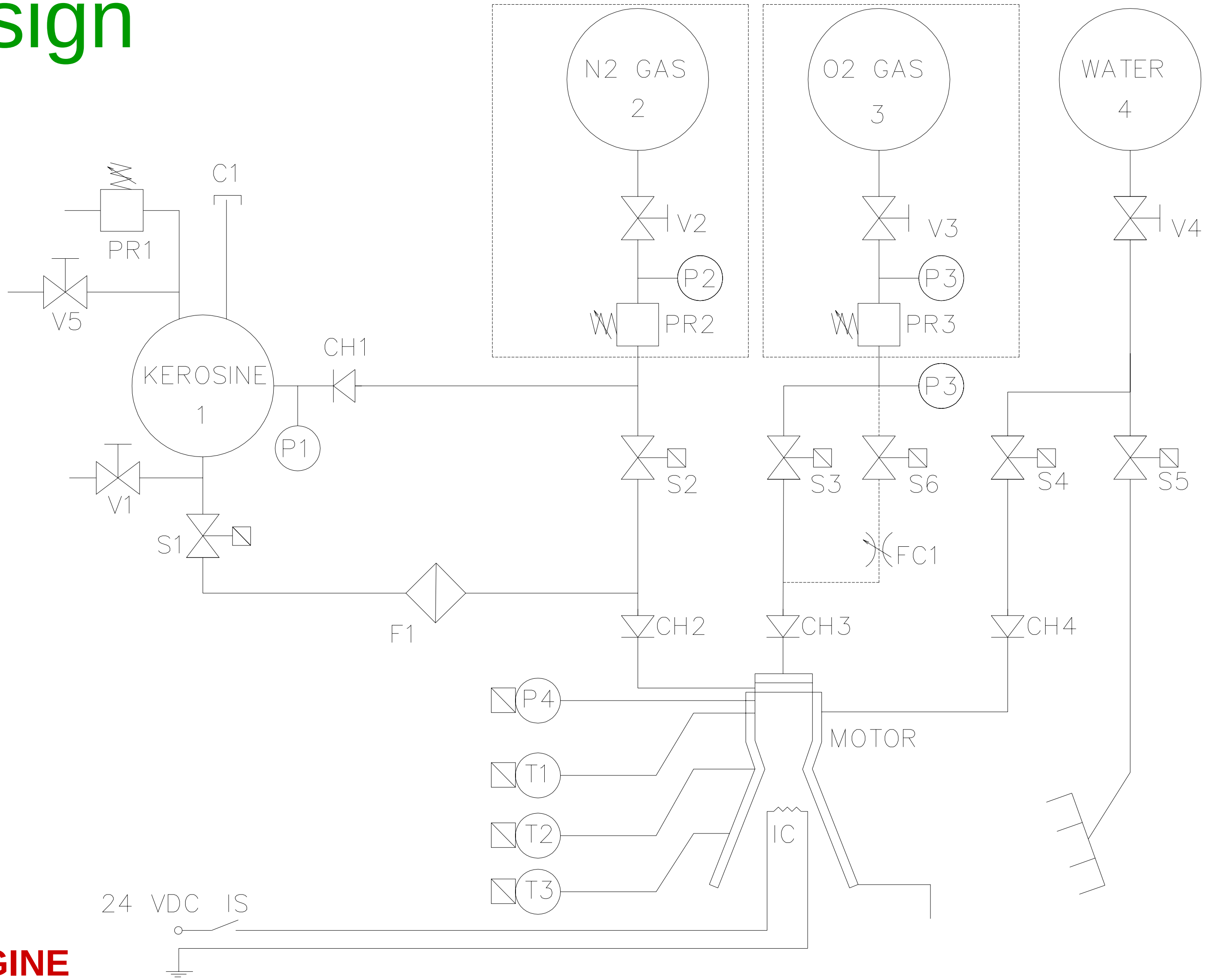
The Load Cell

Load Cell in place

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

Engine Design





SCHEMATIC OF ENGINE

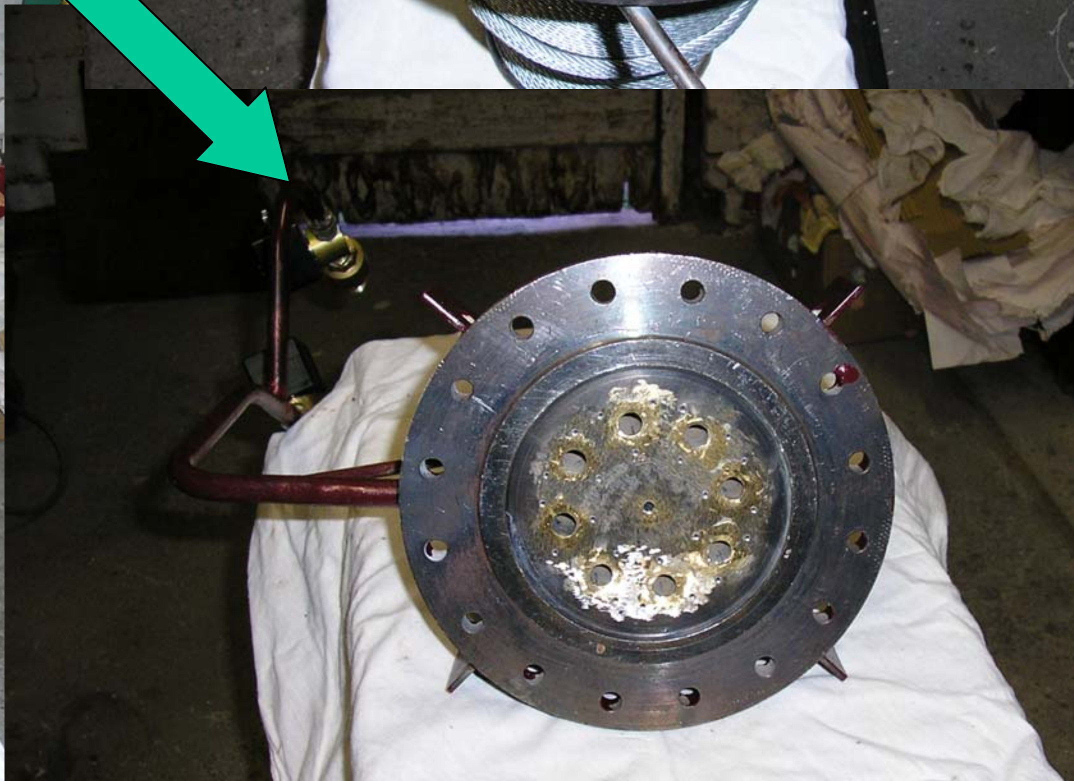
The analogue pressure sensor could be calibrated from the pressure gauge and jack ID.

Engine Design

The combustion chamber, showing tubes.

The engine head Showing kerosene & nitrogen feed Lines.

The O2 gas and kerosene injectors

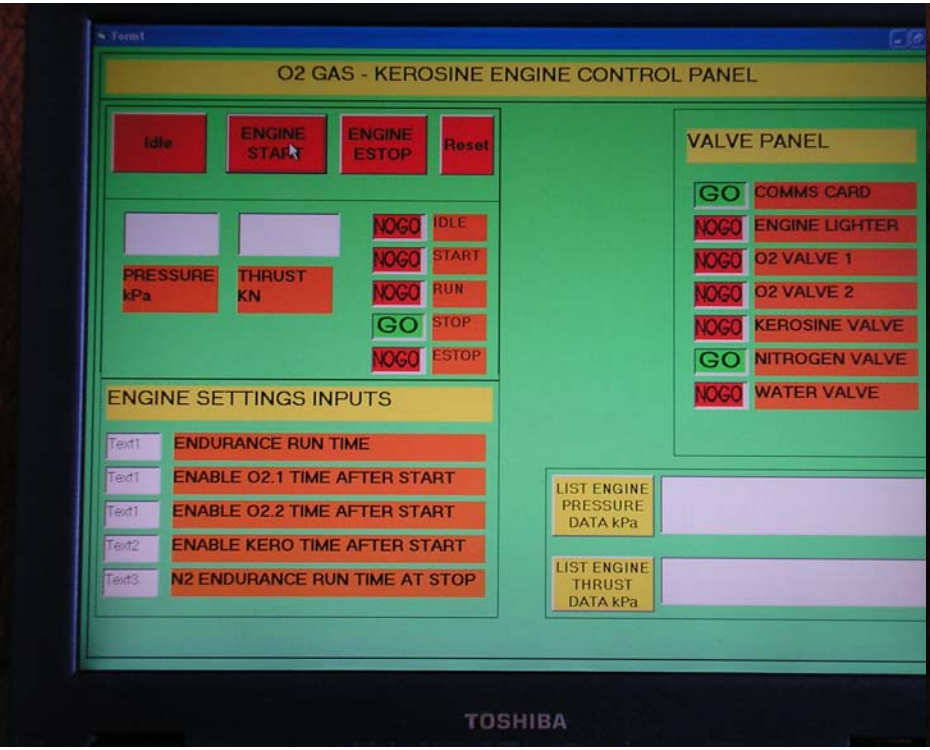


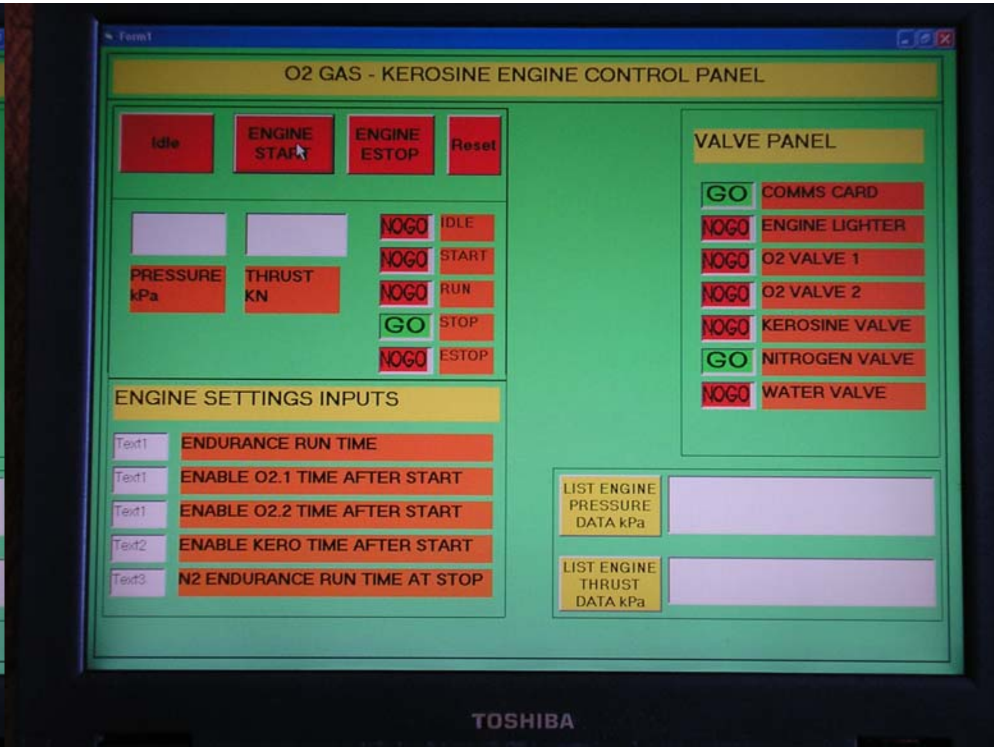
Engine Design - Control

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

The Ignition lighter, O_2 in-feed valves Kerosene in-feed valves and N_2 purge valve was controlled sequentially.

In essence O_2 is fed into the combustion chamber first before the kerosene fuel to prevent a ‘hard start’ or explosion.





The First Test- Setting Up

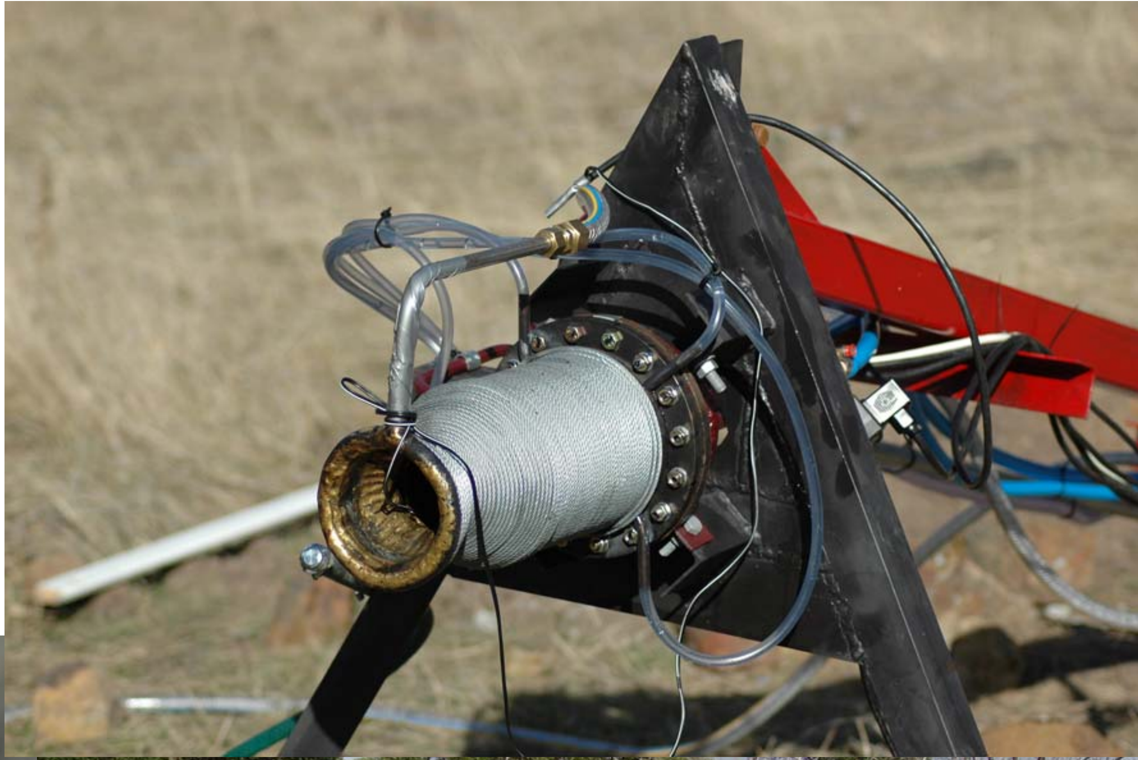
The aim of this test was to trial the equipment in the areas of:

-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.

Difficult fuel loading and monitoring of the mass burned.

-Safe start, run and shut down;

Safe. The runs provided confidence in system

-Software control;

Could not read input data. Output to field OK

-Monitoring of the loads and pressures.

Required to read gauges using camera.

Engine performance.

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.