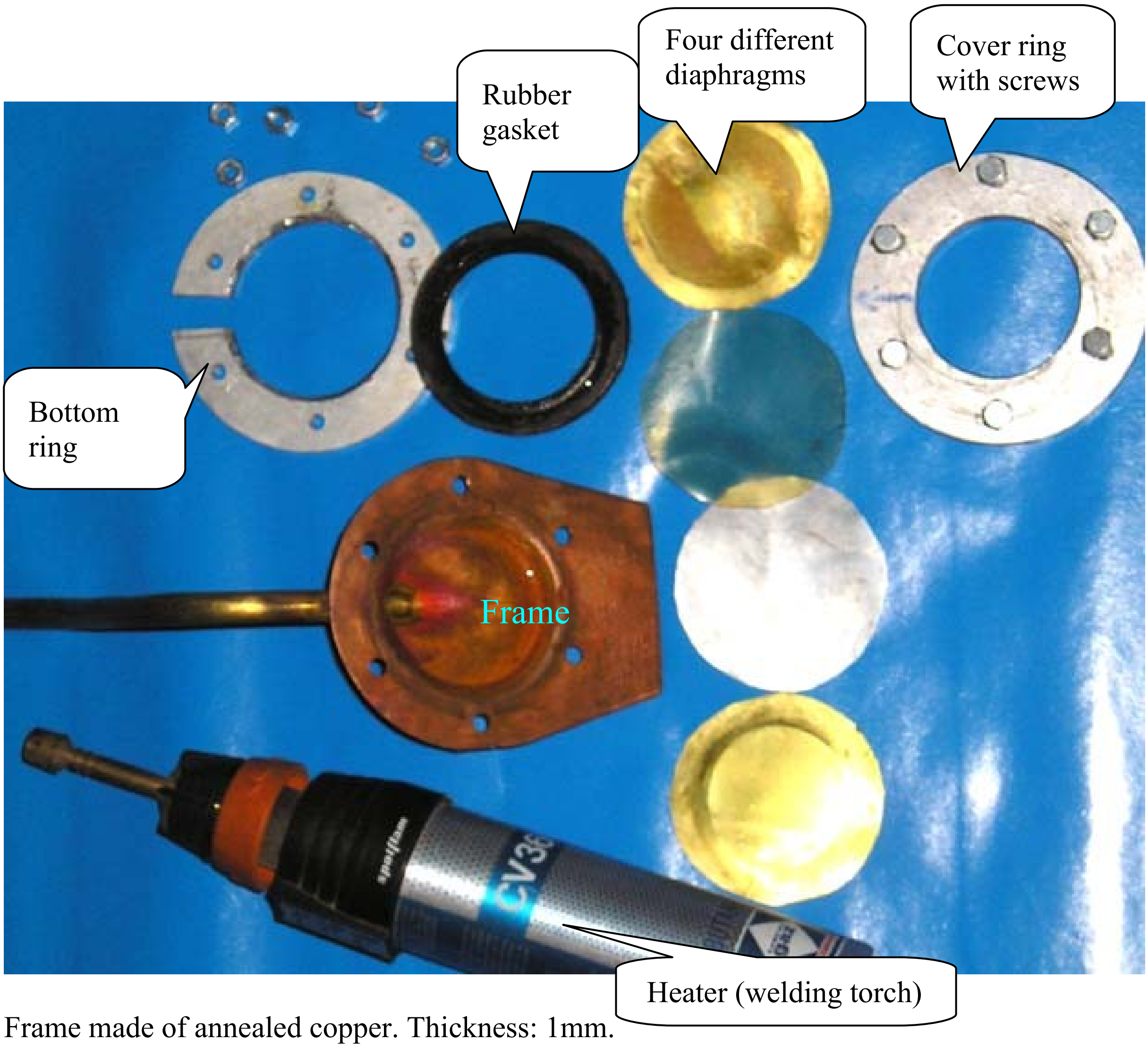
Diaphragm pop-pop engine

By Jean-Yves

Based on some knowledge got from previous engines we decided to build a new one in order to test various diaphragms. Therefore, where the diaphragm is usually pinched in a fold of the frame here the assembling is made by means of screws and nuts.



Frame made of annealed copper. Thickness: 1mm.
Bottom ring and cover ring made of duralumin (AG4). Thickness: 4mm.
Pipe made of brass. Internal diameter: 6.0mm. Length: 480mm.

1. Conventional tests

First diaphragm tested: brass. 13/100mm.
Observations: Frequency: 3.0 Hz. Thrust: up to 22mN.

With the pipe prolonged by a smaller one (ID 4mm) the frequency became 1.4 Hz.
Back to the previous arrangement. New frequency: 2.1 Hz.
Leakage. Repair. New test. Frequency: 2.05 Hz.

Second diaphragm tested: brass 13/100mm slightly deformed to increase the noise.
Observations: Frequency: 2.4 Hz. Thrust: up to 22mN.

After removal of the flame the engine ran for 26 seconds due to overheating.

Third diaphragm tested: mylar.
Observations: Frequency: 1.65 Hz. Thrust: up to 12mN but the heating power (of a candle) seemed insufficient to reach the maximum thrust.

Fourth diaphragm tested: aluminium. 10/100mm.
Observations: Frequency: 2.2 Hz. Thrust: up to 14mN. Then burnout due to overheating. Engine cooled down by pouring some water on it.

New test. 3 Hz. 14mN.

Engine tested upside down. Frequency 3.9 Hz.

The engine has been tested at various angles, and various heights. Whatever the position, the engine worked satisfactorily, but the frequency and thrust were different.

Comments:

The low frequency (1.65 Hz) got with the mylar diaphragm can be explained because it is very soft and the volume of the chamber differs.

The relatively high frequency (3.9 Hz) got with the engine upside down can be explained by the small gas volume, the vaporizer being heated from the top. The diaphragm was covered with liquid water.

One thing is unclear. Why is there a sudden change from approximately 2 Hz to approximately 3 Hz? For all these tests the sound was loud and clear. We couldn't be wrong when counting the pulses.

2. PPVG engine (PopPop Variable Geometry !!)

There we come to the main purpose of this engine.

- Study of thrust and frequency versus drum volume
- Measurement of the maximum high pressure in the cycle
- Measurement of the minimum low pressure in the cycle

To reach these goals the PPVG engine has been designed and built. PP for pop-pop and VG for variable geometry. It uses a special diaphragm.

This diaphragm (in the middle of the picture) is made of rubber with a rigid part in the middle. A screw at the centre allows to adjusting the vertical position of the diaphragm, i.e. the volume.

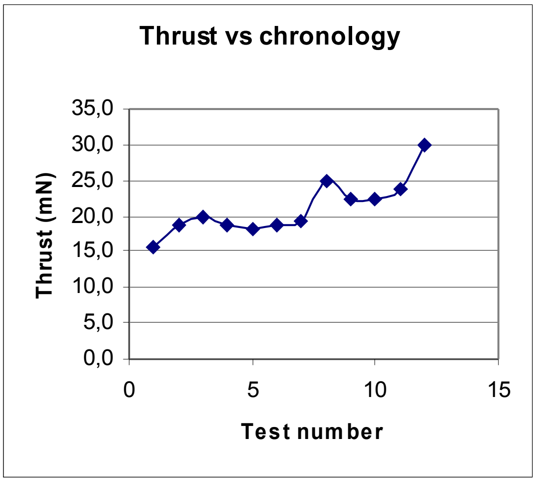
The volume is adjusted by means of the nuts on the central screw (or on the two lateral screws). One complete turn of the nuts (nut and counter-nut) means 0.7mm up or down.
The piston diameter is 40mm.

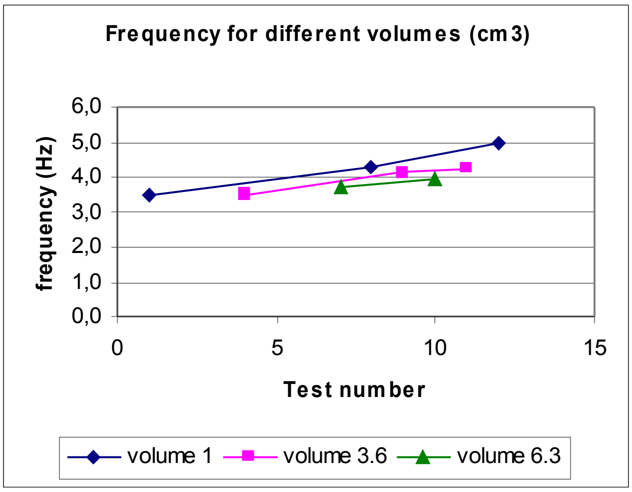
2.1. Thrust and frequency versus drum volume

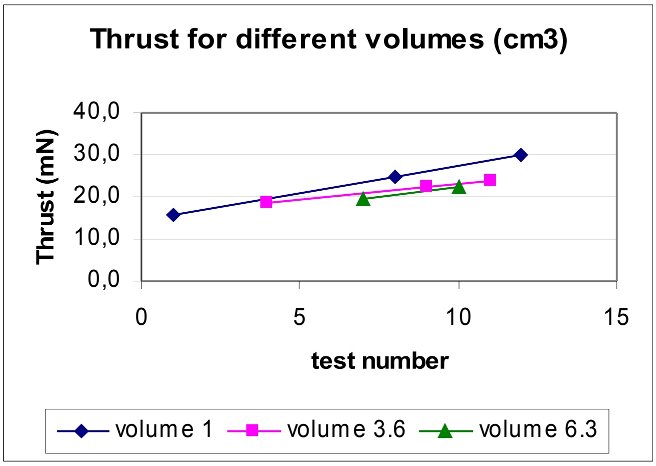
12 consecutive tests were run with volume change.

Chronology	Volume (cm3)	frequency (Hz)	thrust (mN)
1	1,0	3,5	15,6
2	1,9	3,5	18,8
3	2,8	3,8	20,0
4	3,6	3,5	18,8
5	4,5	3,7	18,1
6	5,4	3,5	18,8
7	6,3	3,7	19,4
8	1,0	4,3	25,0
9	3,6	4,1	22,5
10	6,3	3,9	22,5
11	3,6	4,2	23,8
12	1,0	5,0	30,0

The analysis of the record gives the following curves:

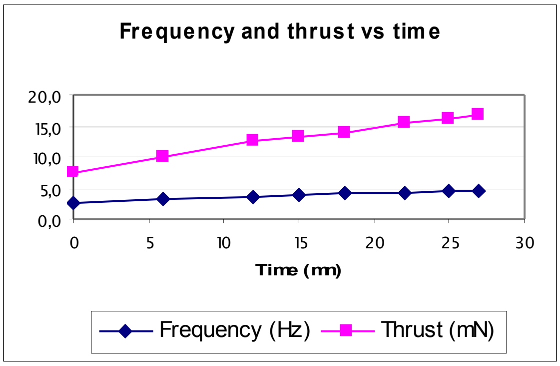


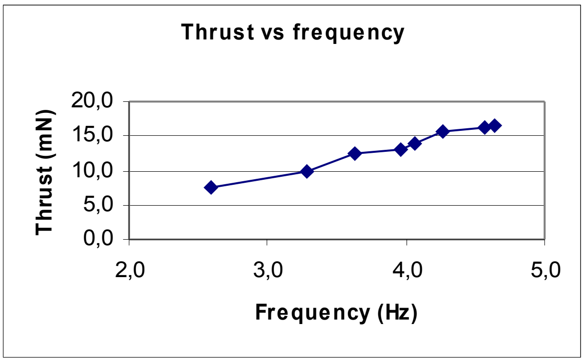




From these graphs we get confirmation of “rumors” or assumptions: **for a given surface of the heating chamber, the thrust increases when the volume decreases.**

Another series of tests without change in volume gave the following curves:





Unfortunately the test was stopped by lack of butane in the burner. However, we can draw the following laws:

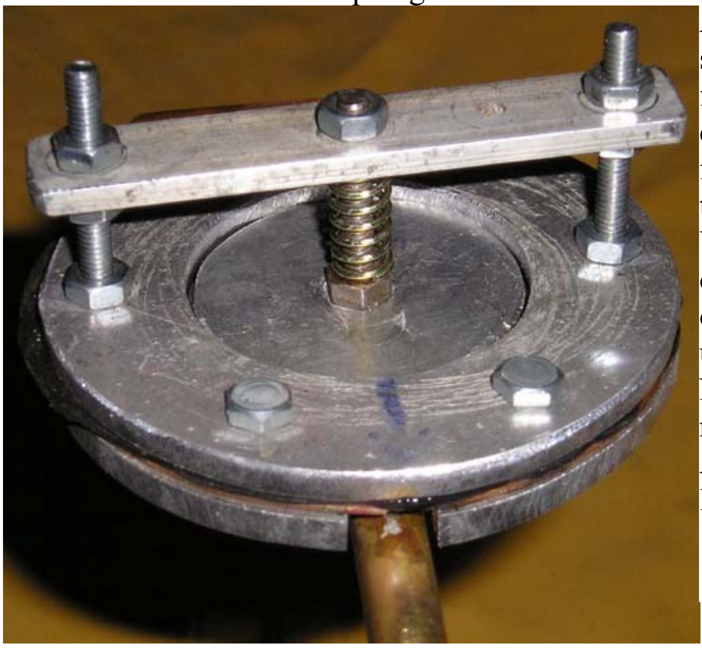
1°) **The thrust increases with time.** This is a confirmation of what we observed with coil engines. It would be due to some gasses inside the engine. There was no gas when we started the test. After 27 minutes the volume of gas was 2cm^3.

2°) **Thrust and frequency increase when the drum volume decreases.**

3°) **The thrust increases** (linear relation?) **with frequency.**

2.2. Maximum high pressure in the cycle

To determine (for this particular engine) the maximum HP in the cycle we modified the connection between the diaphragm and the frame.



A spring has been added. At rest the spring is compressed. The compression force is adjusted by means of the central nut. The diaphragm is in a fixed position adjustable by means of the lateral nuts on both sides.

When the pressure is high enough to develop a force bigger than the spring one, the screw with its central nut goes up and this is visible.

Note: the diaphragm weight is negligible compared with spring load. And its inertia is negligible at such low frequencies.

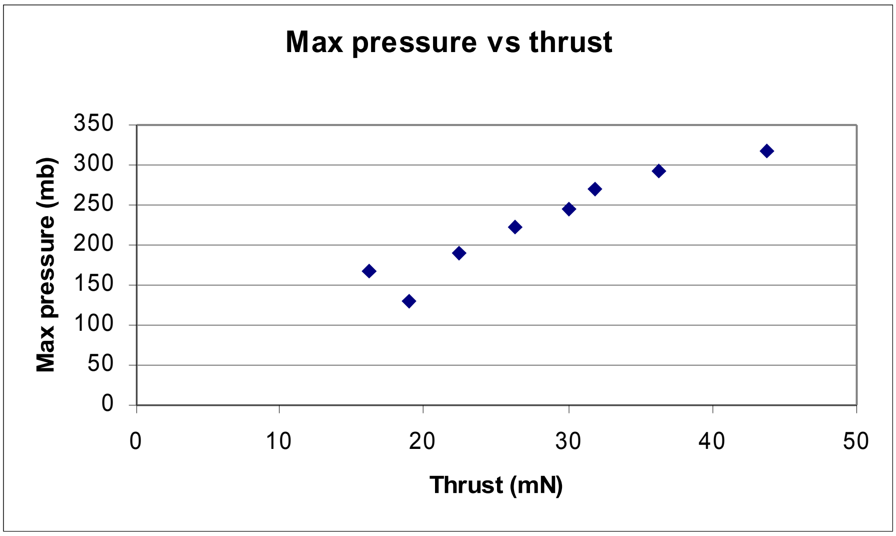
During the first test the screw lifted up slightly for a thrust of 19mN. On one hand we measured the length of the spring (16.95mm) and then its corresponding force. We loaded the spring with 1,620kg i.e. 15,9N. As the area of the diaphragm is 12.56cm^2, it means the highest pressure was 12700Pa. On the other hand, we sent a hydrostatic pressure in the drum just to lift the nut. The height of the water column was 135cm which corresponds to 13200Pa.

Both measurements are consistent: approx 0.13bar.

Later, we ran a series of tests and for every working condition we adjusted the spring length so that the nut was just free at max thrust.

We got the following results:

Spring length (mm)	Scale reading (mm)	Max force (N)	Max pressure (Pa)	Thrust (mN)
16	130	20,937	16661	16
15,3	180	23,9526	19061	23
14,4	210	27,8298	22146	26
13,7	240	30,8454	24546	30
13	255	33,861	26946	32
12,3	290	36,8766	29345	36
11,6	350	39,8922	31745	44



Then, we improved the precision by adding a thin plastic tape between the transverse beam and the nut. Thus, any play between the beam and the nut was easy to detect because the plastic sheet was loose and could be moved.

Note: At low pressures the accuracy is not very good because the diaphragm which is made of rubber has also a spring effect.

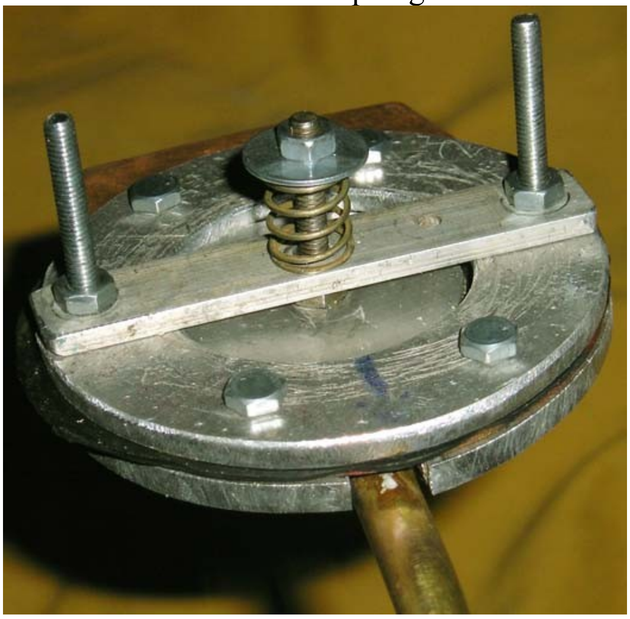
We recorded the following data:

Spring length (mm)	Scale reading (mm)	Max force (N)	Max pressure (Pa)	Thrust (mN)
15	60	9,05	7202	8
14,3	60	10,429	8299	8
13,6	72	11,808	9397	9
12,9	105	13,187	10494	13
12,2	140	14,566	11591	18
11,5	155	15,945	12689	19
10,8	172	17,324	13786	22
10,1	215	18,703	14883	27
9,4	295	20,082	15981	37
14,3	65	10,429	8299	8
15	55	9,05	7202	7
15,7	47	7,671	6104	6
16,4	21	6,292	5007	3

Note 1: the volume of the chamber was not exactly the same as during the first series of tests.
Note 2: we used another spring (visible on the picture).

2.3. Minimum low pressure in the cycle

To determine (for this particular engine) the minimum LP in the cycle we modified again the connection between the diaphragm and the frame.

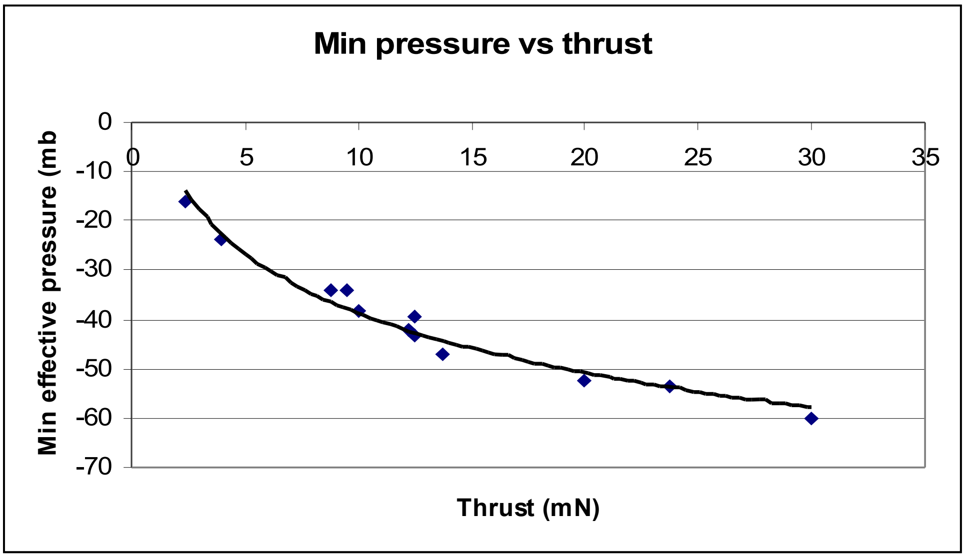


Another spring (softer) has been used. At rest the spring is compressed. The compression force is adjusted by means of the central nut. The diaphragm is in a fixed position. Its lower nut is against the transverse bar. When the pressure is low enough to develop a force bigger than the spring one, the screw with its central nut goes down and the movement is visible (and audible).

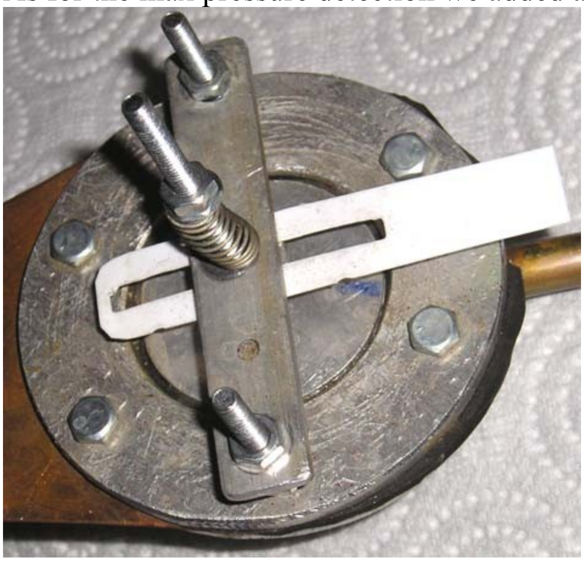
Note: In addition to the spring force, there is another (small) one coming from the rubber of the diaphragm. It could have a relatively high influence at very small pressure.

Records:

Spring length (mm)	Scale reading (mm)	Max force (N)	Min pressure (Pa)	Thrust (mN)
23	100	4,947	-3937	13
20	110	5,925	-4715	14
15	240	7,555	-6012	30
18	160	6,577	-5234	20
21,5	100	5,436	-4326	13
23,5	80	4,784	-3807	10
25	70	4,295	-3418	9
29	32	2,991	-2380	4
32	19	2,013	-1602	2
17,5	190	6,74	-5364	24
22	98	5,273	-4196	12
25	76	4,295	-3418	10



As for the max pressure detection we added a plastic tape to improve the accuracy.



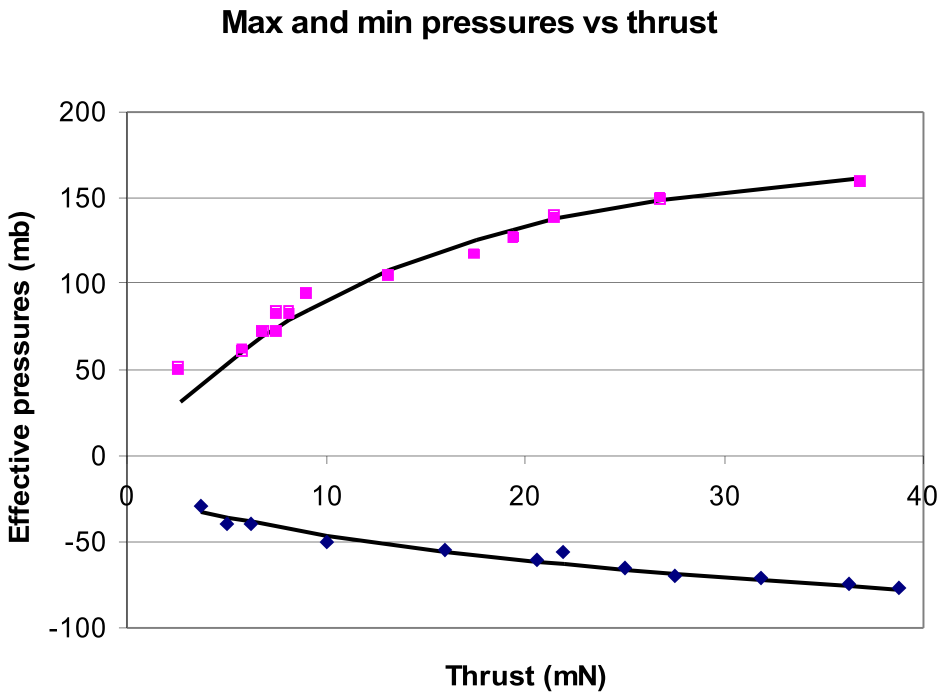
And we ran a series of tests (with a volume which was not exactly the same as for the first series).

Records:

Spring length (mm)	Scale reading (mm)	Max force (N)	Min pressure (Pa)	Thrust (mN)
11,5	220	8,696	-6920	28
8,5	310	9,674	-7698	39
15	165	7,555	-6012	21
19	80	6,251	-4974	10
23	40	4,947	-3937	5
27	30	3,643	-2899	4
13	200	8,207	-6531	25
16,5	175	7,066	-5623	22
23	50	4,947	-3937	6
9,7	290	9,2828	-7387	36
11	255	8,859	-7050	32
17	128	6,903	-5493	16

2.4. Compilation

Both curves (max and min pressures) can be drawn on a common diagram.



There, we see that **the absolute value of the max pressure** (positive) **is bigger than the one of the min pressure** (negative)**.**

Consequences:

1°) Our model (refer to "Pop-pop engine and electrical analogy") is to be revised. The pressure doesn't evolve as a sine function.
2°) Our hydraulic test benches are to be revised accordingly. (refer to "Hydraulic test bench" and "Thrust measuring test bench").
3°) Due to the asymmetry of the pressure the use of a converging nozzle should improve the efficiency.