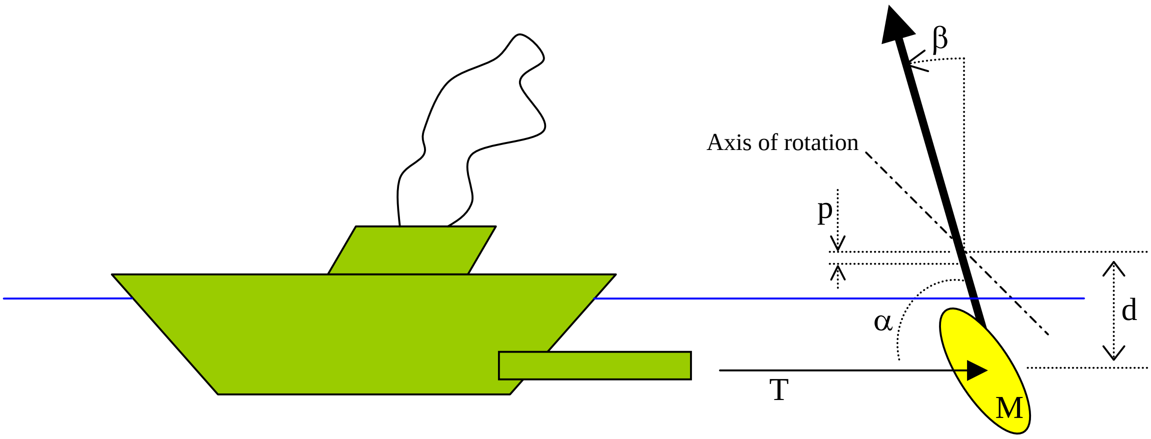
Test bench for pop-pop engines

Everybody can build his own test bench with the parts that are at his disposal. The purpose of the following description is just to give ideas.

To measure the thrust, we use Newton's third law: action = reaction. The thrust T of the pop-pop engine is exerted on a target on which we measure the reaction. According to the momentum theory, the force exerted by a jet on a flat surface is $F=qV(1-\cos\alpha)$, where q is the flow, V is the velocity of the jet and α is the angle between the jet and the flat target. F is equal to T when the target is perpendicular to the flow. Measuring this thrust can be done by using a mobile rotating around a horizontal axle and provided with a target located behind the pop-pop nozzle(s).



The deviation of the pendulum depends on its apparent weight (less than the real weight because of Archimedes' buoyancy) and the position of its centre of gravity.

If d is the vertical distance between the axis and the jet, the torque exerted by this latter is $C=T.d(1-\cos\alpha)$

If M is the mass of the pendulum and p the distance from the centre of gravity to the axis, and β the deviation angle, the counter-torque is $Q=M.g.p.\sin\beta$

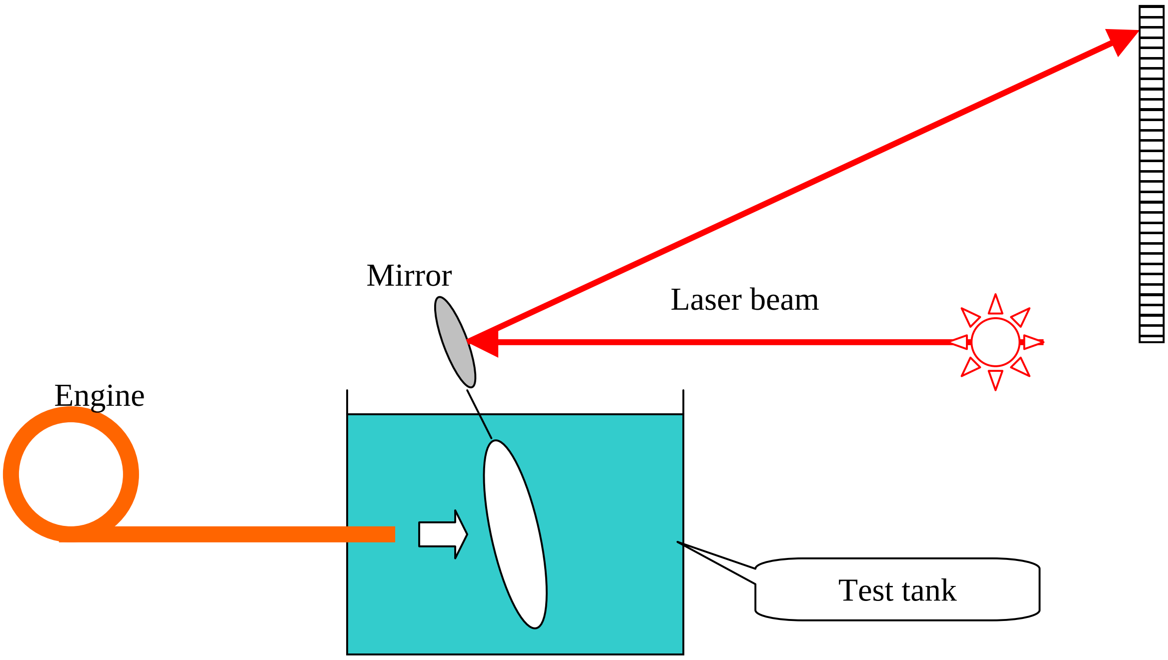
Therefore, $T.d(1-\cos\alpha)=M.g.p.\sin\beta$

Knowing β and α we could calculate the thrust of the jet. But, in order not to complicate things we will use the pendulum at small angles. Thus, $\cos\alpha$ will be approximately one and $\sin\beta$ will be approximately proportional to β. In these conditions the deviation will be proportional to the thrust.

We used this principle on several thrust measuring instruments. But, for every new test bench we had to modify the instrument or to build a new one. For this reason, and based on the knowledge from the various previous instruments we have decided to build a new one, a versatile one. Main goals:

- Adjustable height of the target to centre it behind the jet.
- Adjustable counter-torque (to keep small angles)
- Adjustable scaling factor to get direct thrust reading (in mN)
- Easy calibration.

There, we meet a problem: how to measure a deviation with accuracy when it is a small deviation? One way is to use a very long needle. Another way is to use an "optic needle". On the upper part of the pendulum there is a mirror where a laser beam is reflected and sent towards a board. Thus, the deviation can be amplified as much as wished. It is only a matter of distance between the mirror and the board. So, it is easy to use small angles.



Realization:

Main components:

Mirror (3€ with telescopic handle and magnetic support)

Laser emitter (9€ in a hardware store)

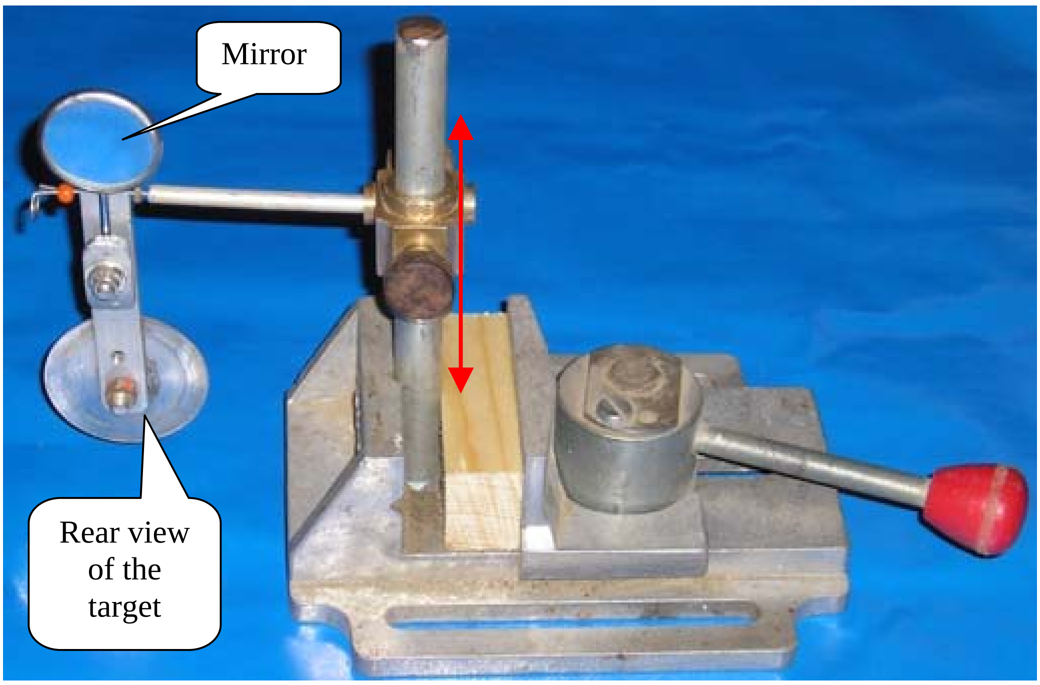
Target (stainless steel disk diameter 45mm)

Adjustable height slider (recovery)

Axle: A piano string in stainless steel of diameter 10/10

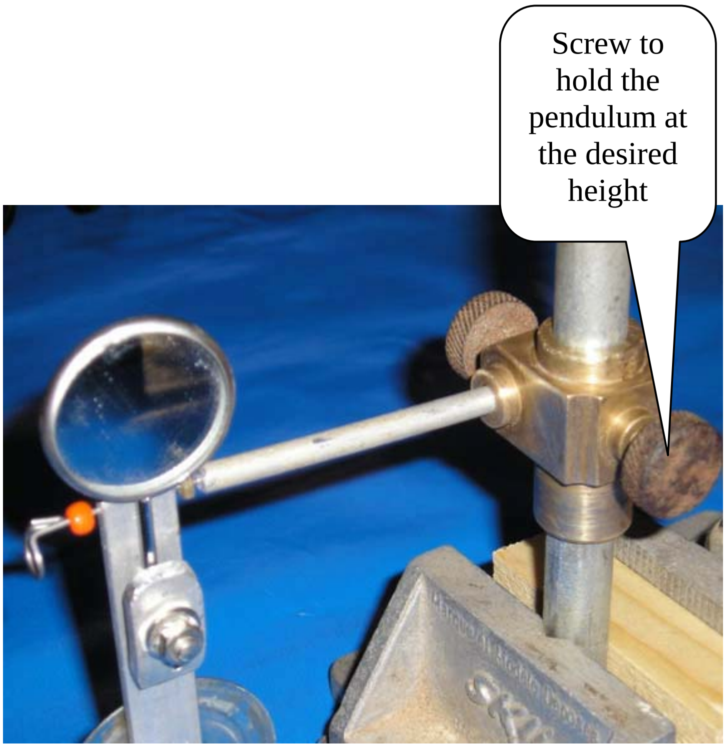
Left over components (screws, nuts, pearl, aluminum flat bar….)

Note: the dimensions and the shape of the target are not critical. The target must be flat and large enough to receive the whole jet(s).



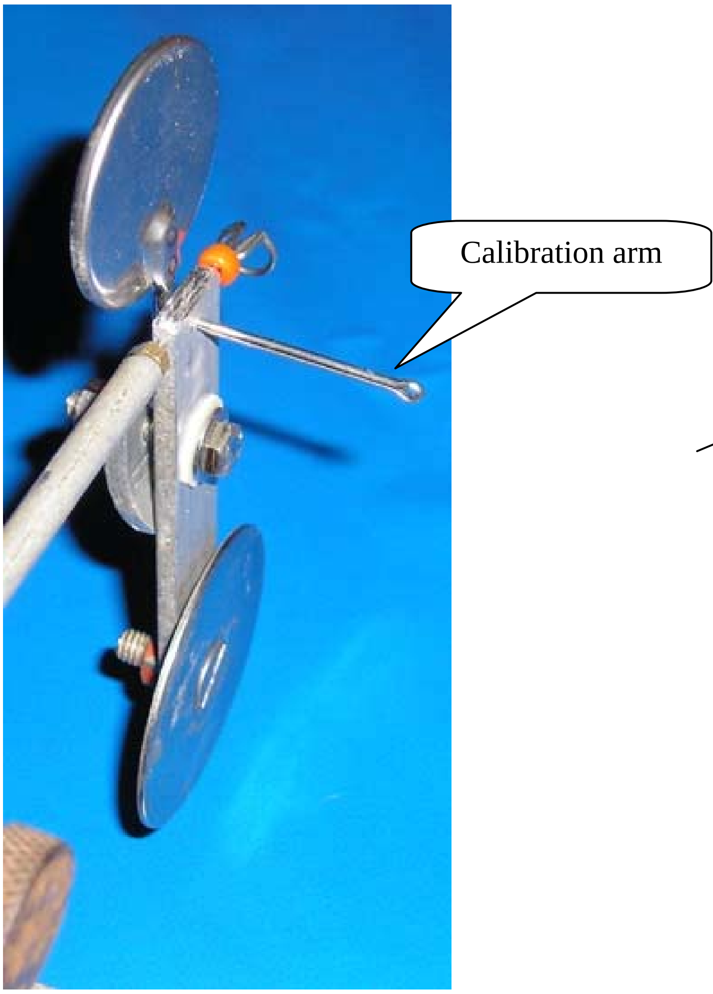
For the base frame, here we use a vice, but any heavy piece of metal can do it.

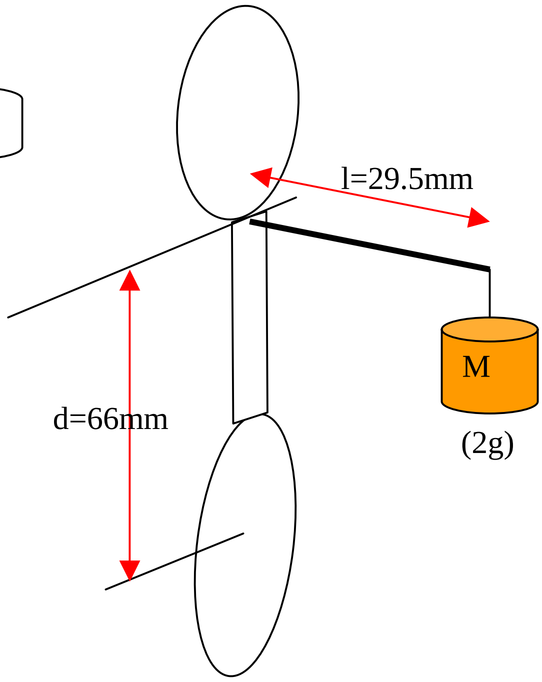
The screw at the back of the target allows to adding weights in order to keep small angles when measuring high thrusts.



On the left is a picture with a front view of the target. In the background is the laser emitter.

Below is a detail of the pendulum. The small horizontal arm is used for calibration. His length "l" is perfectly known. For the calibration we suspend a defined weight (2g or 5g).



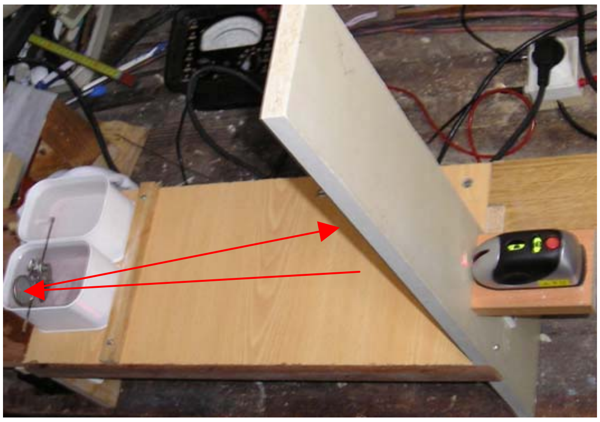


Calibration:

- Immerse the target in the test tank
- Place the laser emitter at the mirror height and facing it (see note 1)
- Note the zero (position of the light dot) on the vertical board
- Glue a meter tape onto the board with its zero where is the light dot
- Add a calibration weight "M". It simulates a thrust
- Note the position of the light dot and adjust the distance between mirror and board to get an easy correspondence.

Example: l=29.5mm d=66mm M=2g g=9,81
This gives T=8,8mN

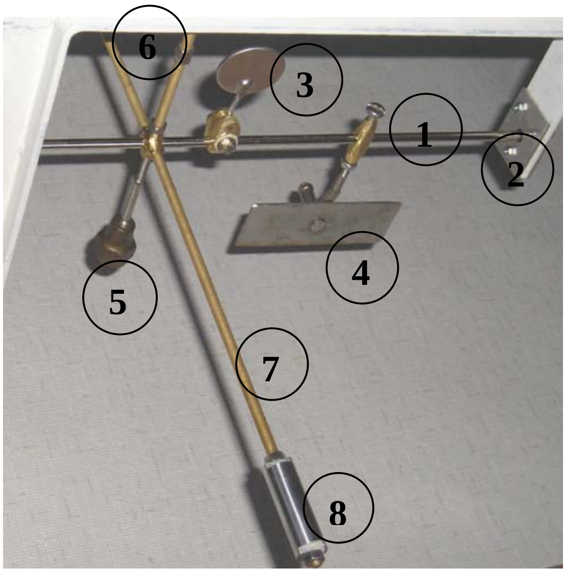
If the measured deviation is for instance 59mm, increase the distance between mirror and board to read a deviation of 88mm. Now, any indication in centimeters corresponds to a thrust in milliNewtons.



An other evolution:

Later we built a more sophisticated test bench. It is based on the same principle, but it includes two improvements:

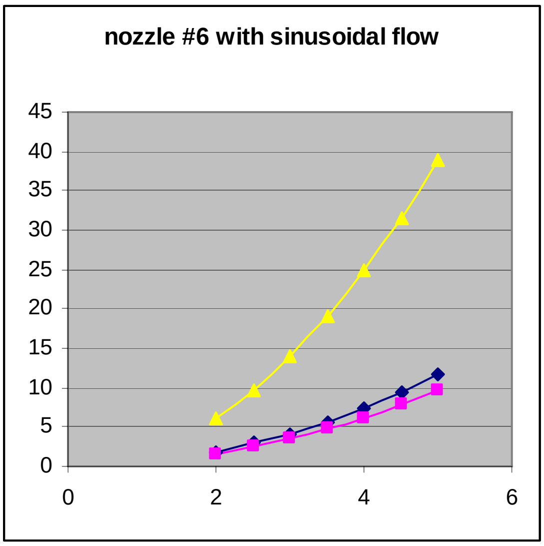
1°) 2 very small ball bearings (recovered from a hard disk drive).
2°) a balancing pole allowing to filtering the high frequencies.



1 = axle
2 = ball bearing
3 = mirror (back side)
4 = target
5 = loading weight (heavier for big engines)
6 = light counterweight for gain adjustment
7 = fore arm of the balancing pole
8 = weight at the end of the fore arm
(Same arm and weight on the back)

Why do we measure more than the theoretical thrust?

Example of measurement:



In purple the theoretical mean thrust versus frequency (see "Hydraulic simulator of pop-pop").

In blue the measured thrust.

In yellow (for information) the maximum theoretical thrust; i.e. the peak value.

Thrusts are in mN and frequencies in Hz

The thrust measuring test bench indicates always (we ran approx hundred tests) a thrust that is bigger (by 10 to 40%) than the theoretical mean value. This could be caused by at least two phenomena:

1°) Lack of filtration (frequency filter).

The thrust indication was fluctuating between 1 and 4mN, depending on the nozzle. (2mN for our example). We always used the arithmetic mean value, but doing that we introduced a small error. ===>The measuring pendulum is to be completed by a dash-pot or by inertia.

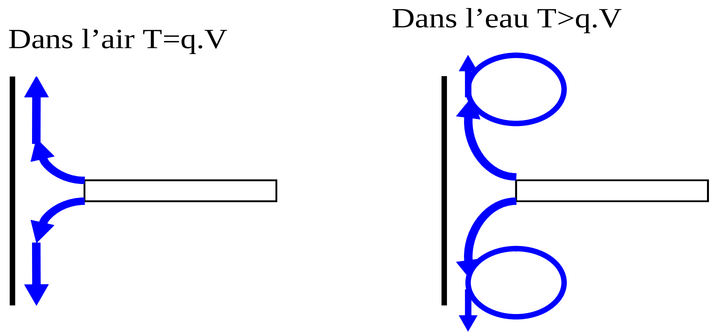
However, the lack of filtration cannot explain so big discrepancies between theory and practice.

2°) Recirculation of the water in the tank.

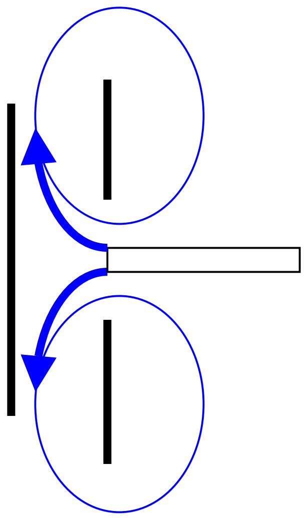
This phenomenon was evoked in a previous report. Here, we set it as evident.

a) First we observed vortexes thanks to (unexpected) impurities into the water.
b) Then we built a micro mooring buoy.

This device is made of a small weight (2g), a piece of sewing thread and a small polyurethane foam float (diameter 8mm) adjustable along the thread thanks to a little wedge. We placed this device in the tank at various places and we observed the inclination of the thread, and most of all the movements of the float. It was clearly visible that some water was re-circulated towards the target; therefore, the momentum was bigger than what it would have been in air.



c) Then we placed some screens (chicanes) at various places inside the tank (not on the direct jet flow) and we saw a decrease of the thrust indication. The *right* thrust was got with a screen arranged as shown on the following scheme.



Such a screen doesn't prevent vortexes, but they are large and the water which comes again towards the target has lost most of its velocity.
Our screen had a hole in the middle of approximately 3.5 times the nozzle diameter.

Another alternative could be to decrease the target size, but in that case you must be sure that the jet is well oriented.

Note: This recirculation phenomenon could be perfectly known by hydrodynamics specialists, but we didn't find it in the books we read.