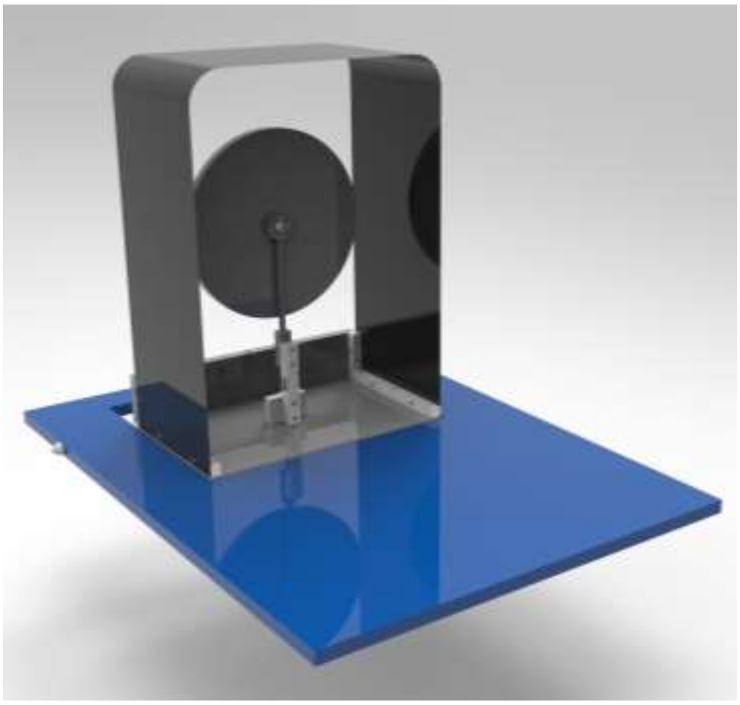


H11

DRONE PROPELLER THRUST MEASUREMENT

1. Aim of the measurement

The measurement task is to measure the thrust generated by a propeller driven by a drone motor. The rpm of the motor can be set, and it can be equipped with several types of propellers. The speed distribution of the propeller's flow field is determined by measurement, from which the thrust force, the delivered volume flow rate, and the effective power can be calculated by integration.

2. Description of the measuring bench/equipment

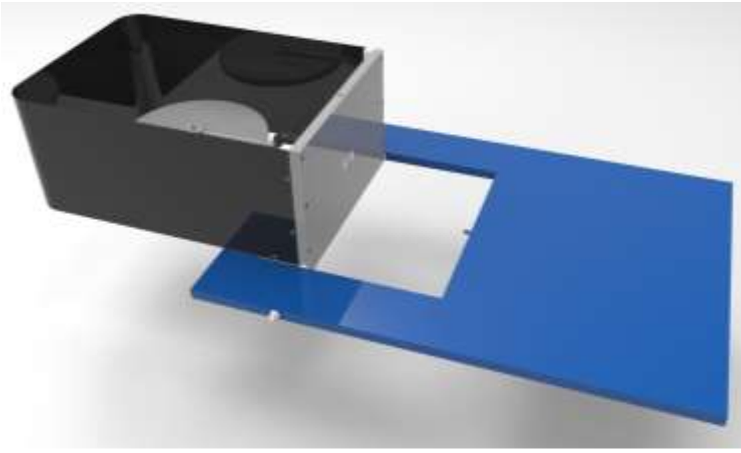
The measuring device is built on a solid steel plate and is easy to move. A load cell measuring the thrust of the propeller is screwed onto the sheet. A pilon is connected to the other side of the load cell, which holds the motor in position. The propeller is fixed by a threaded nose cone on the motor shaft. A 12V laboratory power supply unit and a drone speed control unit provide the electric drive of the motor.
Various propellers can be mounted on the shaft:

7” diameter, two-bladed propeller
6” diameter, two-bladed propeller
5” diameter, two-bladed propeller
4” diameter, three-bladed propeller

3. Measurement process

Step 1: Calibration of the load cell

At the start of the measurements, it is necessary to zero and calibrates the load cell.
For calibration, the central, rotatable part of the testbench must be turned so that the pilon holding the motor is in a horizontal position (see the following figure). It is worth disconnecting the motor's electrical connections for calibration.



Test bench in the calibration position

After that, the force measurement must be zeroed. Zeroing is done with the red button of the processing and display unit of the load cell. After pressing once, the force measuring cell resets itself 4 seconds later. It is recommended to repeat this operation several times during the measurements when the motor is stopped.
After that, calibration weights must be hung on the engine mounting element, and the value measured by the load cell must be noted down. The measurements must be carried out up to the measuring limit of the load cell, i.e., 9.81 N, in at least 5-10 steps. When the measurement limit has been reached, it is worth performing a control measurement at two points, reducing the placed weight on the console. It is important not to overload the load cell with too much weight or pressure! The calibration equation of the force measuring cell must be determined from the measurement results during the home evaluation, and the measured values of the force measurement must be corrected using it during thrust force measurements.

Step 2: Connecting and starting of the motor

After calibration, the electrical wires must be connected again. The order of the 3 cables does not matter. If the motor does not rotate in the correct direction, two wires must be swapped.
Care must be taken that the the electrical wires do not overload the load cell!
Two banana plugs of the control unit must be connected to the laboratory power supply, and the laboratory power supply must be initially set to 6.5V. The number displayed on the display of the lab power supply can be the current or the voltage. Changing between the displayed values can be set with the button next to the display.

We can start the motor with the potentiometer of the control unit. Regardless of the previous position, the potentiometer must be turned down to its minimum position, and by winding it up from there, the motor can be started first. Then its speed can be increased/decreased.

Step 3: Measurement of thrust as a function of rpm

The next step in the measurement is to measure the thrust by setting different rpm (revolutions per minute) values. There are 2 ways to change the speed. It is possible to change the terminal voltage on the lab power supply. The minimum voltage is 6V, if the terminal voltage is below this, the motor will not start. The maximum value is 12V.
The other possibility is to change the PWM (phase width modulation) regulation of the brushless motor. This is possible by turning the potentiometer of the control unit.

The rpm can be measured in two ways. The equipment includes a built-in optical measuring device, which can be used to measure the speed of rotation of the motor side. The measured rpm value can be seen on the control unit's display. The built-in sensor works on the optical principle and counts the black stripe passage on the motor's side. The sensor is currently operating in test mode, its operation must be checked with another speed-measuring procedure.
Another possible method is to use a stroboscope. When using the stroboscope, the device flashes light with a known frequency. This light should be used to illuminate the propeller. If the flashing frequency of the light is the same as the rpm of the propeller, then the light flashes when the propeller is in the same specific position, and the propeller appears to be still. The rpm can be read on the stroboscope display. It is important to check the double and half frequencies during the stroboscopic measurements because the propeller seems to stop at those as well.

During the measurements, 12 different rpm values must be set, and the rpm and thrust values must be read.

Step 4: Velocity distribution

At several rpm points, the air speed distribution on the exit side of the propeller has to be measured. For this purpose, a 3D, manually adjustable positioner with a Pitot tube can be used. The velocity distribution should be measured along symmetry axes. In the wake of the positioning pylon, it is not worth measuring in the lower part of the vertical axis of symmetry.So a velocity distribution measurement is required in the horizontal axis of symmetry across the entire width and a velocity distribution measurement in the vertical axis of symmetry from the center of the engine up to the top edge of the stream.

Step 5: Recording of the measurement arrangement

The following data must be recorded before or after the measurement:

- environmental data (air pressure, temperature)
- propeller data (diameter, pitch, number of blades, etc.)
- velocity measurement positions (x, z positions, distance to the propeller)

4. Processing

Calculation of air jet volume flow rate, mass flow rate and momentum flux

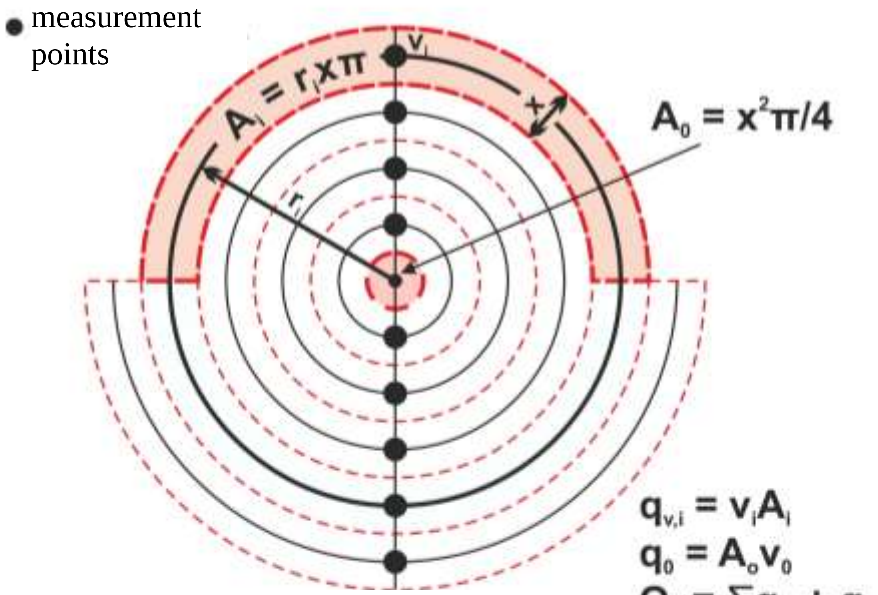
During processing, the 3 measured velocity distributions (2 horizontal halves and the vertical half) must be shifted along the measurement axis so that the curves overlap as best as possible. After that, the volume flow rate, mass flow rate and momentum flux of the air stream must be determined. The calculated momentum flux should match the thrust of the propeller. The volume flow is required for the efficiency calculation.
We can assume that the velocity distributions (after shifting the profiles) are circularly symmetric. The 3 velocity values (2 from the horizontal, 1 from the vertical profile) from the measured velocity profiles must be averaged for each radius. Multiplying the area of the circular ring for a given radius by the average velocity gives the volumetric flow rate of the air flowing through the circular ring. If the square of the velocity is multiplied by the area and the density, the impulse flow of the surface of the ring is the result. The volume flow rates and the momentum flux of the annular surfaces must be summed up.

$$dq_V = v \cdot dA = v \cdot \pi \cdot \left[\left(r_i + \frac{dr}{2} \right)^2 - \left(r_i - \frac{dr}{2} \right)^2 \right] \tag{1}$$

$$d\dot{I} = v^2 \cdot \rho \cdot dA = v^2 \cdot \rho \cdot \pi \cdot \left[\left(r_i + \frac{dr}{2} \right)^2 - \left(r_i - \frac{dr}{2} \right)^2 \right] \tag{2}$$

To calculate the mass flow rate, the volume flow rate must be multiplied by the density.

Calculation of volume flow rate by numerical integration (center-point method)



v_i [m/s] – velocity in point –„i"
r_i [m] – middle radius of point –„i"
x [m] – spacing of the measuremnt points

Efficiency calculation

To calculate the efficiency, the input electrical power is required, which is the product of the supply voltage and the current. These data can be read from the power supply.

$$P_{input} = U \cdot I \tag{3}$$

To calculate the efficient power, the volume flow must be known, which must be integrated from the velocity measurement. Furthermore, it is necessary to calculate the created pressure change, which is the dynamic pressure calculated from the average velocity on the outflow side. The product of the two values is efficient power:

$$P_{eff} = q_V \cdot \Delta p_{din} \tag{4}$$

Remember that during the labs:

Before turning any measurement device on or in general during the lab, ensure safe working conditions. The other participants have to be warned of the starting of the machines and any changes that could endanger the lab members.
The atmospheric pressure and room temperature should be recorded before and after every measurement.
The measurement units and other important factors (e.g., data sampling frequency, data of calibration) of every recorded value of the applied measurement devices should be recorded.
The type and construction number of the applied measuring instrument should be included in the final report.
Checking the units of the recorded values with those used in further calculations.
The digital manometer must be calibrated.
The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
If inlet or outlet tubes are to be assembled with fans, connections should be airtight, as escaping/entering air can significantly modify the measurement results.
The students should consult with their instructor before submitting the report.

Literature

[1] Lajos Tamás: Áramlástan alapjai (2004) 9.9.3 és 11.1.2 fejezet
[2] Lajos Tamás: Áramlástan alapjai (2004) 423.oldal
[3] Lajos Tamás: Áramlástan alapjai (2004) 488.oldal