A Tool for Aerodynamic Analysis of Flexible Kites

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Introduction

Energy production of a pumping kite system can be improved with respect to the kite with better lift-to-drag ratio[1] and/or increased de-power range[2]. Current kite design methods derived from the kitesurf industry rely on trail and error qualitative design process. In search of an improved kite design, this study aimed at identifying shortcomings of current design procedures, with a special focus on the aerodynamics. As a result, little is known of the kite while in-flight, such as shape, angle of attack, and pressure distribution. Knowledge of these parameters is essential for the quantification and identification of design improvements. These values are furthermore crucial for the validation of numerical models. In order to provide a solution for the lack of experimental data of in-flight kites, a system for in-situ measurement of the surface pressure distribution was developed and validated.

System

The developed system consists of two main components, a surface pressure measuring component named the pressure strip and a pitot-static unit. The later unit is required to determine the dynamic pressure in order to compute the pressure coefficient.

MEMS pressure strip

The pressure strip is based on Micro-Electro-Mechanical-System(MEMS) barometric pressure sensors, the LPS25H by STMicroelectronics was used for this prototype. A set of sensors are mounted on a flexible circuit board printed on PEN (Polyethylene naphthalate) produced by Holst Centre. To allow the control of multiple sensors on the same bus additional IO-expanders are also incorporated in the circuit.

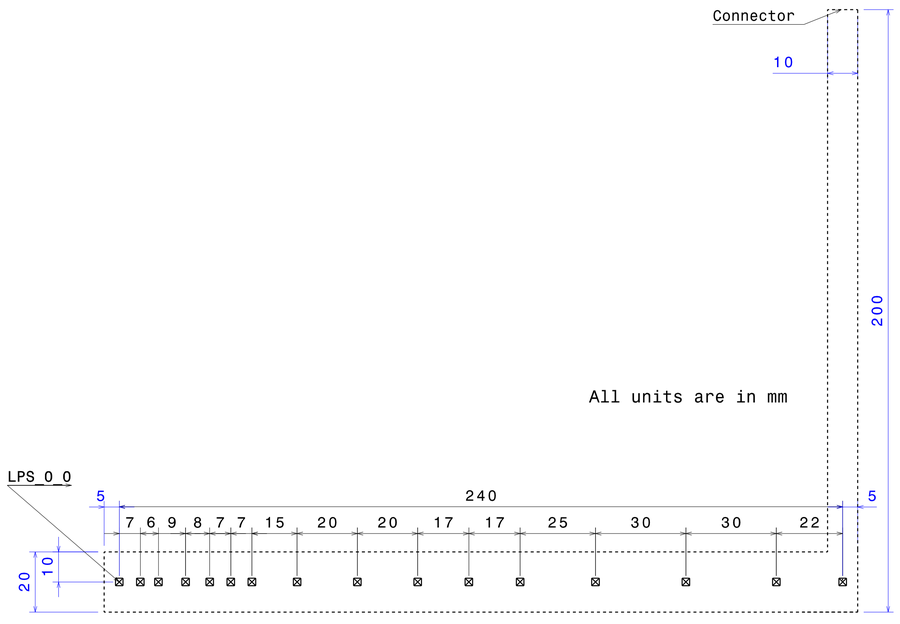


Figure 1: Pressure strip design

Table 1: Pressure strip specifications

Sensors	16
Output rate (128 sample internal average)	40 Hz
Standard deviation σ	5 Pa
LPS25H lxbxh	2.5x2.5x1 mm

Pitot-static tube

The pitot-static unit is also used to determine the free stream static pressure required due to the barometric nature of the LPS25H sensors, this is done by adding an additional LPS25H sensor on the static pressure line and the dynamic pressure is measured by differential the pressure sensor SDP2000 by Sensirion selected based on minimum error indicated in Figure 2.

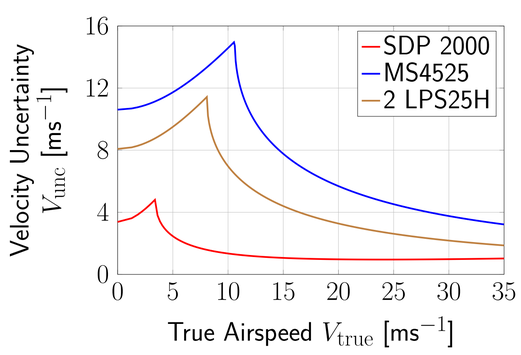


Figure 2: Comparison of different sensors on indicated velocity.

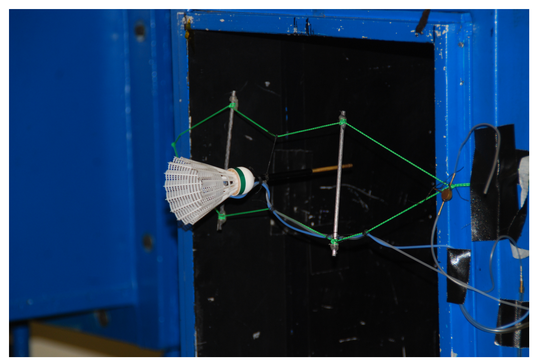
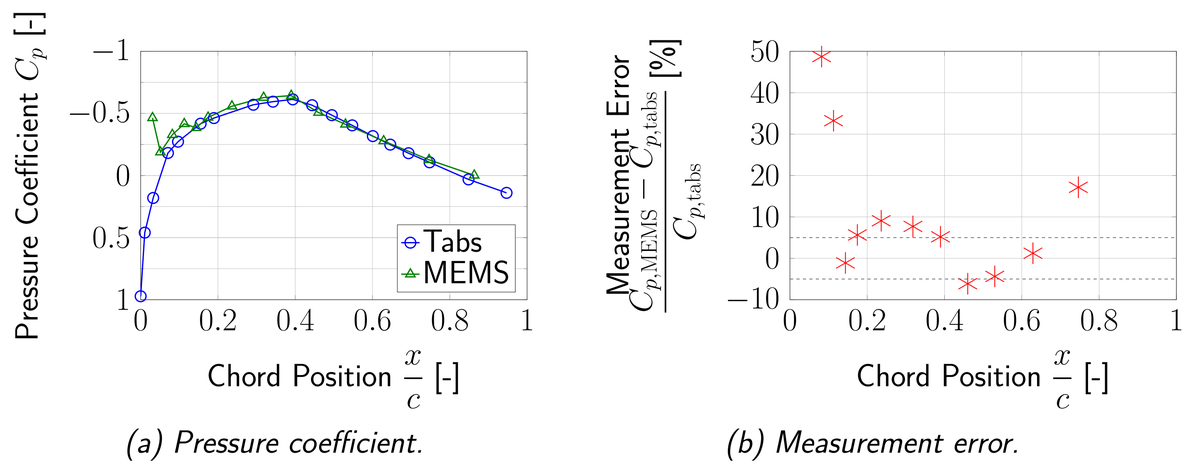


Figure 3: Pitot tube calibration in the wind tunnel

The pitot-static tube includes a badminton shuttle mounted on a gimbal to allow flow alignment while suspended in the kite bridles (Figure 3).

Results

The strip is placed on a fixed wing section with pressure tabs for validation. The results of the strip covered with cellophane to reduce surface roughness are given in Figures 4.



(a) Pressure coefficient. *(b) Measurement error.*

Figure 4: MEMS and pressure tabs measurement in the low speed wind tunnel, including a 0.40mm trip strip at 0.03-0.05 chord.

Future research

- Use next generation sensor LPS22HB[3] instead of LPS25H[4], smaller package, higher accuracy and lower noise
- Multiple strip system
- Strip package/cover for smooth surface
- Reduce pitot dynamic behavior
- Expand system with other sensors for angle of attack or side slip

Sponsors

Holst Centre Open Innovation by imec and TNO

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References

[1] Loyd, M. L., "Crosswind Kite Power," *Journal of Energy*, Vol. 4, No. 3, 1980, pp. 106–111.

[2] Noom, M. N., *Theoretical Analysis of Mechanical Power Generation by Pumping Cycle Kite Power Systems*, Master's thesis, Delft University of Technology, 2013.

[3] STMicroelectronics, *LPS22HB, MEMS nano pressure sensor: 260-1260 hPa absolute digital output barometer*, rev 3 ed., June 2015, retrieved from `http://www.st.com/st-web-ui/static/active/en/resource/technical/document/datasheet/DM00140895.pdf`.

[4] STMicroelectronics, *LPS25H, MEMS pressure sensor: 260-1260 hPa absolute digital output barometer*, rev 3 ed., June 2015, retrieved from `http://www.st.com/st-web-ui/static/active/en/resource/technical/document/datasheet/DM00066332.pdf`.

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