

Dispersion Interferometry for Relative Atmospheric Pressure Measurement

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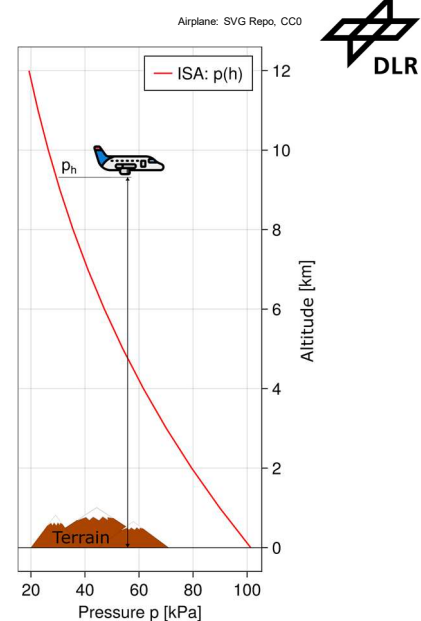
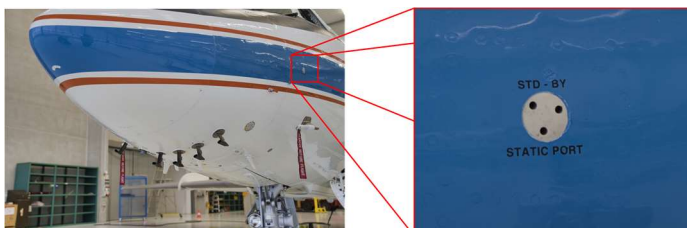
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Motivation - state of the art

Static pressure measurement

- Pitot tube and pressure ports
 - Static pressure p_0
 - Dynamic pressure
- p_0 is reference value for aircraft altitude
- Static pressure curve $p_0(h)$ "defined" by ISA equations
 - Good approx. within troposphere (< 12 km)



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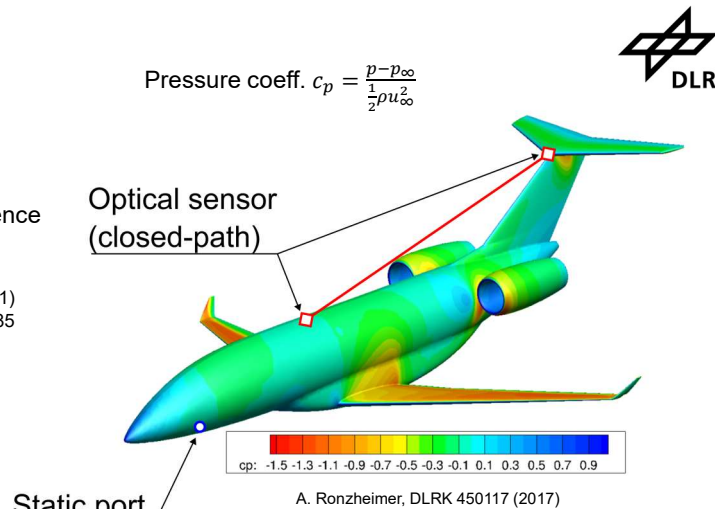
Motivation

Issues

- Measurement within aerodynamic influence
 - Extensive calibration required
- Risk of undetected sensor failure (icing)
 - R. Jäckel et al., Flow. Meas. Instrum. **81** (2021)
 - Y. Cao et al., Aerosp. Sci. Technol. **75**, 353-385 (2018)

Optical measurement

- Detection of sensor failure
 - Active emission of radiation
- Measurement of p_0 outside of boundary layer
- Spectroscopy (i.e. TDLAS)
 - R. A. Lorbeer et al., Optical Sensors, SM1B-6 (2020)



Aeronautical requirements

- Dependent on height and airspeed
- Low altitude: $\Delta p \approx 30 \text{ Pa}$

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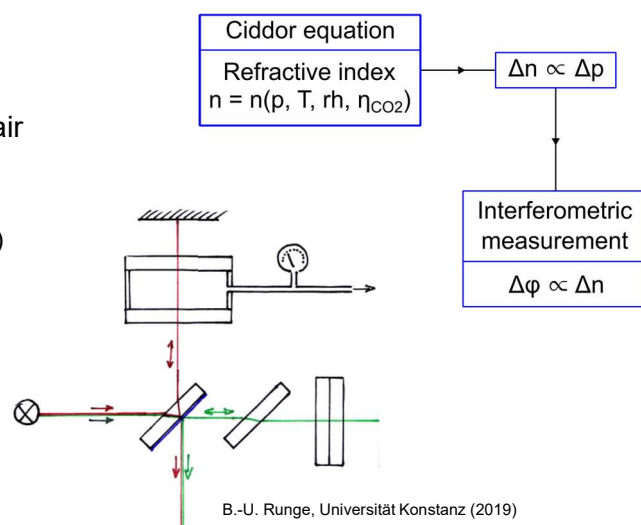
Interferometric approach to pressure measurement

Principle

- Interferometric measurement of changes in the refractive index of air
- Change in phase corresponds to change in pressure
 - P. E. Ciddor, Appl. Opt. **35**(9) (1996)

Challenges

- Vibrations
- Absolute measurement
 - 2π - ambiguity



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Synthetic Dispersion Interferometry (SDI)

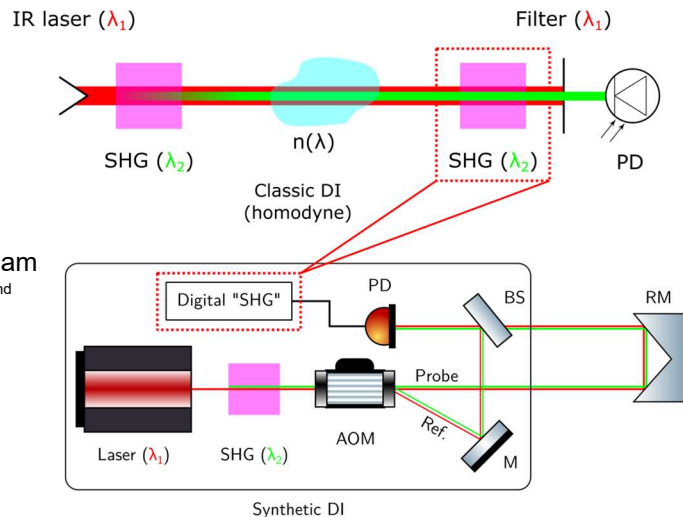


Approach

- Two-arm, two-color heterodyne interferometer
- Nd:YAG DPSS with intracavity SHG
 - Phase-locked relation between
 - $\lambda_1 = 1064 \text{ nm}$
 - $\lambda_2 = 532 \text{ nm}$
- AOM is used to generate reference beam
 - 1st diffraction order of λ_1 collinear with 2nd diffraction order of λ_2
- Digital "frequency-doubling" after photodetection $\rightarrow$ synthetic

Related publications:

- J. Irby et al., Rev. Sci. Instrum. **70**, 699 (1999)
- D.-G. Lee et al., Rev. Sci. Instrum. **92**, 033536 (2021)



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Synthetic Dispersion Interferometry

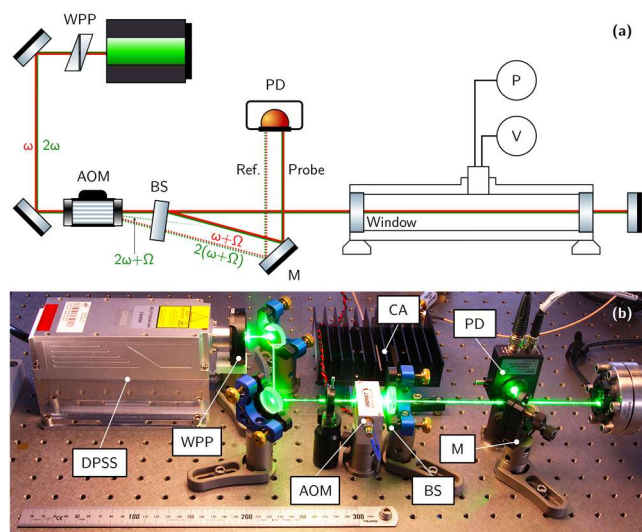


Approach

- Two-tone PD signal around
 - $\Omega = 80 \text{ MHz}$
 - $2\Omega = 160 \text{ MHz}$
 - Downmixing to 125 and 250 kHz
- Digital demodulation is used to obtain φ_ω and $\varphi_{2\omega}$
- $\Delta\varphi = \varphi_{2\omega} - 2 \cdot \varphi_\omega$

Pressure-phase relation

$$\Delta\varphi = \frac{2\pi}{\lambda_{2\omega}} \cdot [n(\lambda_{2\omega}, p) - n(\lambda_\omega, p)] \cdot l$$



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H. Uittenbosch et al., Opt. Express **31**, 6356-6369 (2023)

Proof of concept – pressure measurement

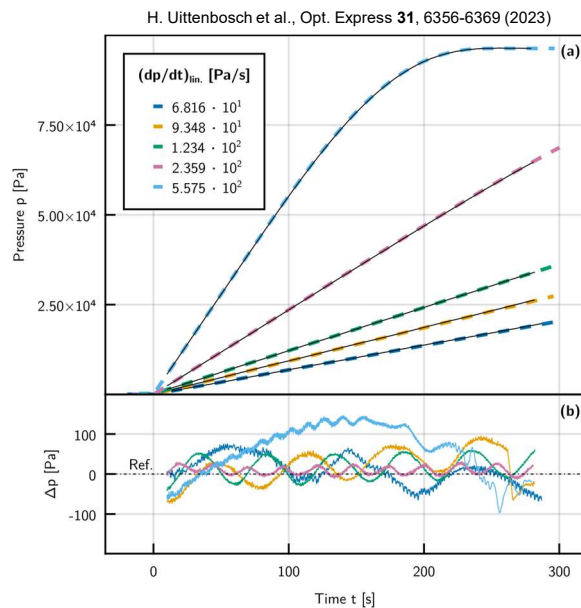


Conditions

- Probe path length ~ 2 m
- Probe path optical power (cw)
 - 1064 nm: 11.5 mW
 - 532 nm: 2.3 mW
- Reference Sensor
 - Piezoresistive pressure transceiver
 - ± 50 Pa accuracy
- SDI data downsampled to 10 Hz

Related publications:

- V. P. Drachev, Meas. Tech. **33**, 1125–1127 (1990)
- F. Brandi et al., Opt. Lett. **32**, 2327–2329 (2007)



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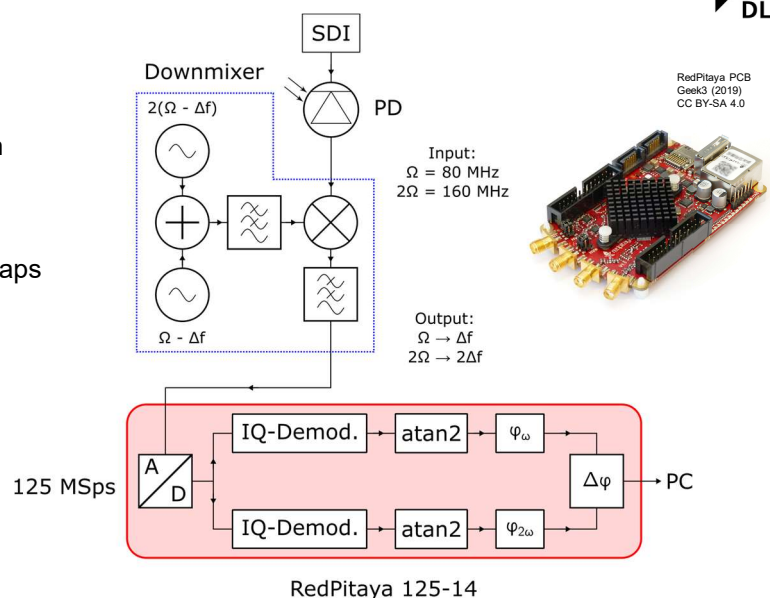
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Field programmable gate array (FPGA)-based digital demodulation



Concept

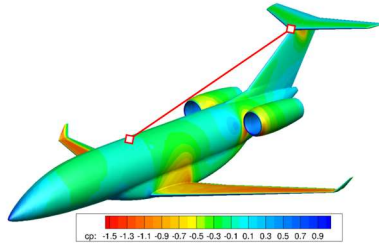
- Real-time phase demodulation
 - PLL referenced signals
- High digital bandwidth
 - Robustness against 2π wraps
- Downmixing to intermediate frequencies
 - ADC/FPGA bandwidth
- Compact physical footprint



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Summary

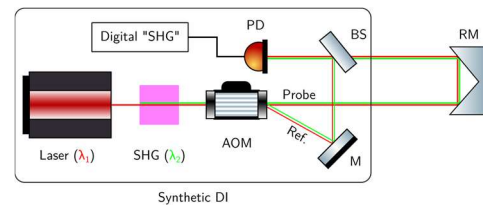


Optical, contact-free variometer in aviation

- Self-diagnosis capability
- Measurement outside of aerodynamic influence
- Low optical power (eye-safety)
- Closed beam-path

Outlook

- Laboratory proof-of-concept
 - Opt. Express **31**, 6356-6369 (2023)
 - Lower pressure deviation required
- Simple setup with good prospect for integration
- Vibrations
 - Longitudinal → suppressed
 - Transversal → further research

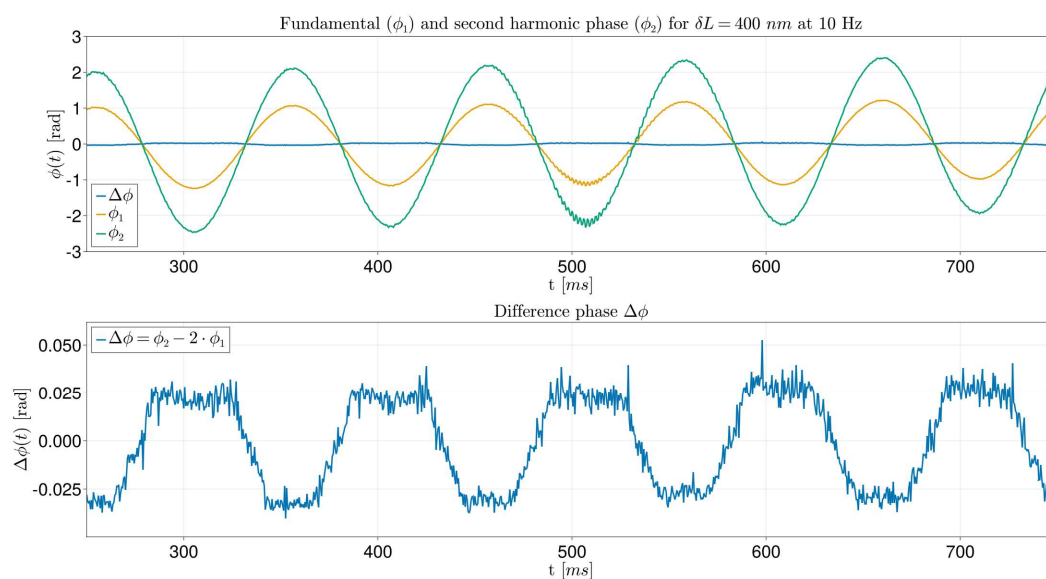


Thank you for your attention!

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Vibrational resistance



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