Mass Flux Sensor for Aircraft Jet Engines

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Motivation

The air flow entering into a jet engine is traditionally measured one of two ways: either directly by using a total pressure probe or indirectly from temperature and pressure data within the engine. A promising non-intrusive measurement method is to use absorption spectroscopy to measure both the velocity and density of the incoming oxygen in the air, using a single tunable diode laser.

Overview

Figure 1 shows the P branch spectra of the oxygen A-band at 763nm. Due to the properties of the ground and excited electronic states, there are two rotational quantum numbers, N and J. Thus, absorption features appear in pairs of PQ and PP states. The feature chosen for this sensor, a P11Q10 transition at 764.17nm (13086.13 cm^{-1}), has properties which are well-matched for measuring density at atmospheric temperatures. Figure 2 shows a typical linear scan across the oxygen absorption feature using a DFB diode laser, as measured by a photodetector. The right panel shows the absorbance of this scan as a function of frequency given in wavenumbers (cm^{-1}). For the temperature range 225 – 330K, the integrated absorbance, i.e. area under the curve, is directly proportional to the gas density to within ±1% for this particular feature.

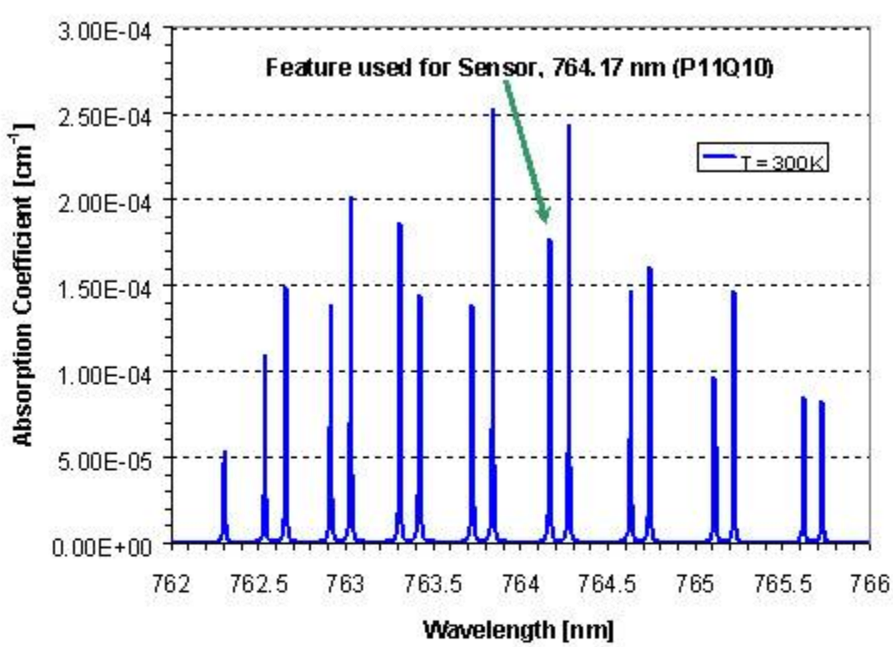

Figure 1: Spectral absorption coefficient vs. wavelength for P-branch of O2 A-band, T = 300K.

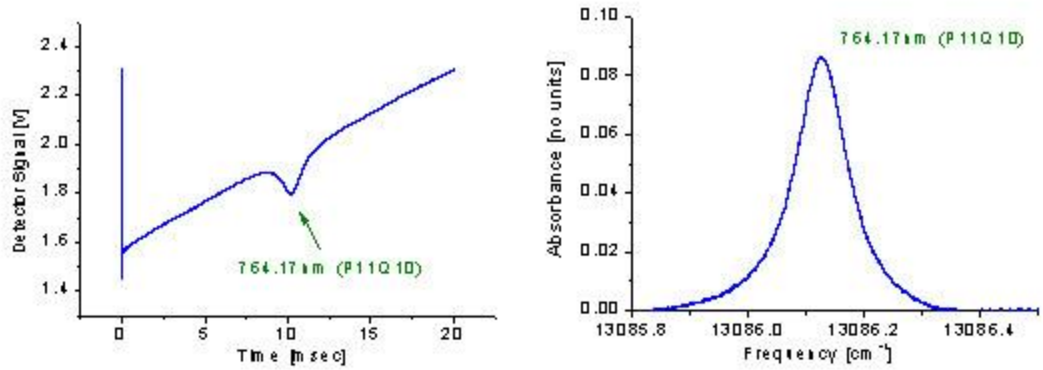

Figure 2: Linear diode laser scan across O2 absorption feature (left). Absorbance of same scan using absorbance = -ln(I/I0) (right).

The velocity of the air flow is measured using Doppler velocimetry. The location of the center of the absorption feature shifts if the gas has a bulk velocity in the direction of the laser path. If a laser bean is split into separate channels which point upstream and downstream into the flow path, the Doppler frequency shift between the two absorbance curves is directly proportional to the gas velocity. Figure 3 shows a schematic of a sensor using optical fibers to split the beam. In this case, the measured velocity would be determined from u = [c(v_1-v_2)] / [2sin(theta($v_{0,0}$))] , where v_1 and v_2 are the linecenter frequencies of the two shifted features, $v_{0,0}$ is the non-shifted linecenter, theta is the half-angle between the beams, and c is the speed of light. In order to obtain good measurement resolution, it is desirable for theta to be as large as possible.

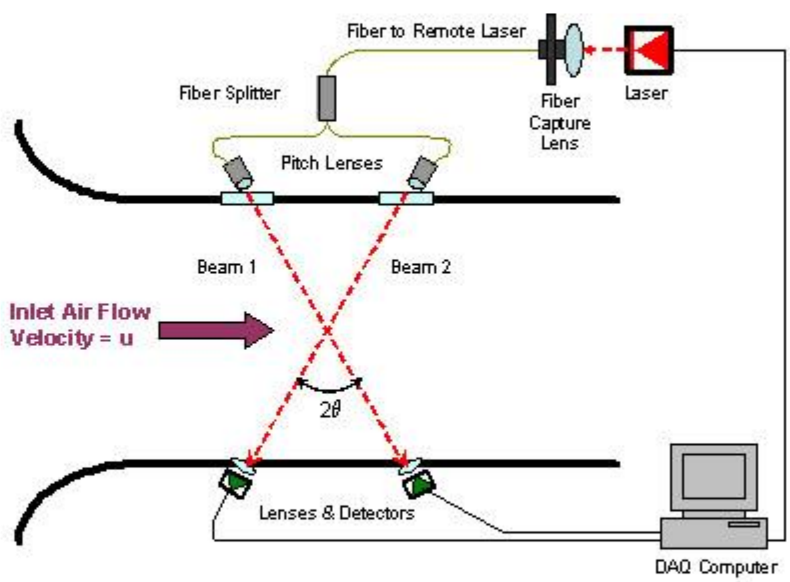

Figure 3: Schematic of mass flux sensor using split paths to measure Doppler shift for velocity measurement.

This sensor makes use of wavelength modulation (WM) spectroscopy for its measurements, a method closely related to Fourier analysis. A high frequency sine wave is added to the linear ramp shown in Fig. 2, and a lock-in amplifier captures the 2f component of the signal. Doing this rejects much of the low frequency noise of the system and reduces the background signal from the slanted line in Fig. 2 to a flat line at zero. Figure 4 shows a typical 2f lineshape, with its Doppler-shifted twin corresponding to a velocity of 100 m/s (theta = 30 deg). The density can be determined by comparing the 2f peak height to an initial calibration point. Note how narrow the shift is compared to the width of the feature, about 2% of the full width at half max (FWHM) in Fig. 2; obtaining an accurate subsonic velocity measurement is the primary challenge for this sensor.

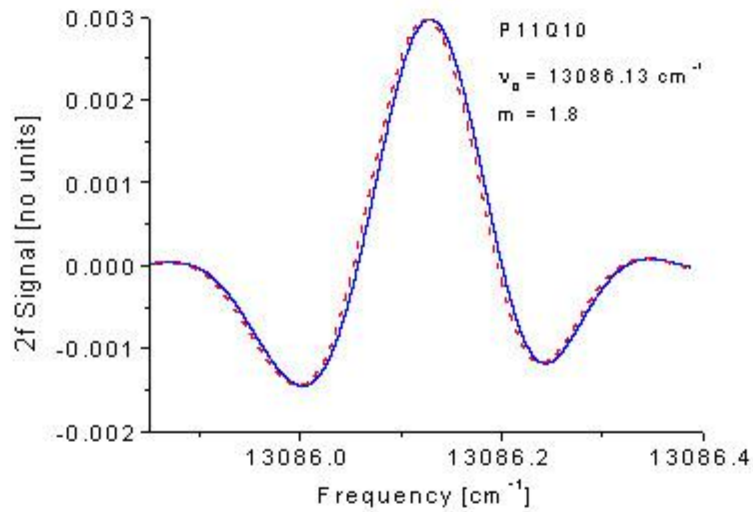

Figure 4: Two 2f lineshapes Doppler shifted by a velocity of 100 m/s (theta = 30°).

Figure 5 shows a timeline of some velocity measurements performed in a low-speed wind tunnel. The sensor was operated with a real-time readout rate of 1 Hz. The velocity was increased from zero to 1 m/s, 2 m/s, and finally 3 m/s before being reduced to zero at the end. The sensor was able to measure the velocity to within 1 m/s, and the differences between velocities are clearly evident. This shows promise for achieving accuracies ~ ±1% for engine flows. Future work consists of higher speed wind tunnel tests, and eventually testing in a Pratt & Whitney engine.

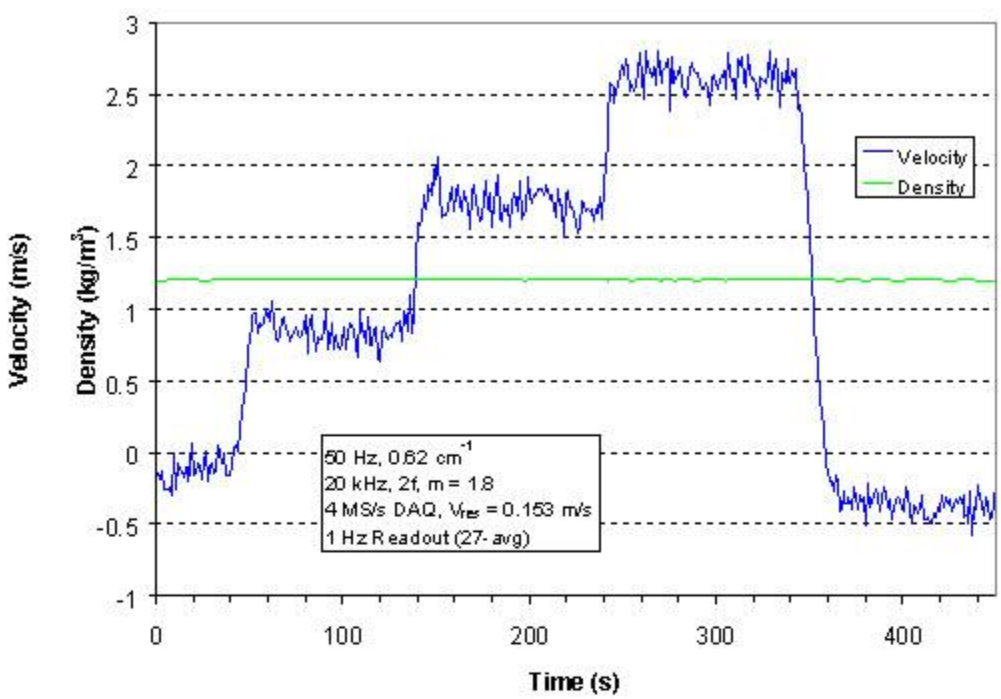

Figure 5: Timeline of velocity in a low speed wind tunnel, with real-time readout rate of 1 Hz.

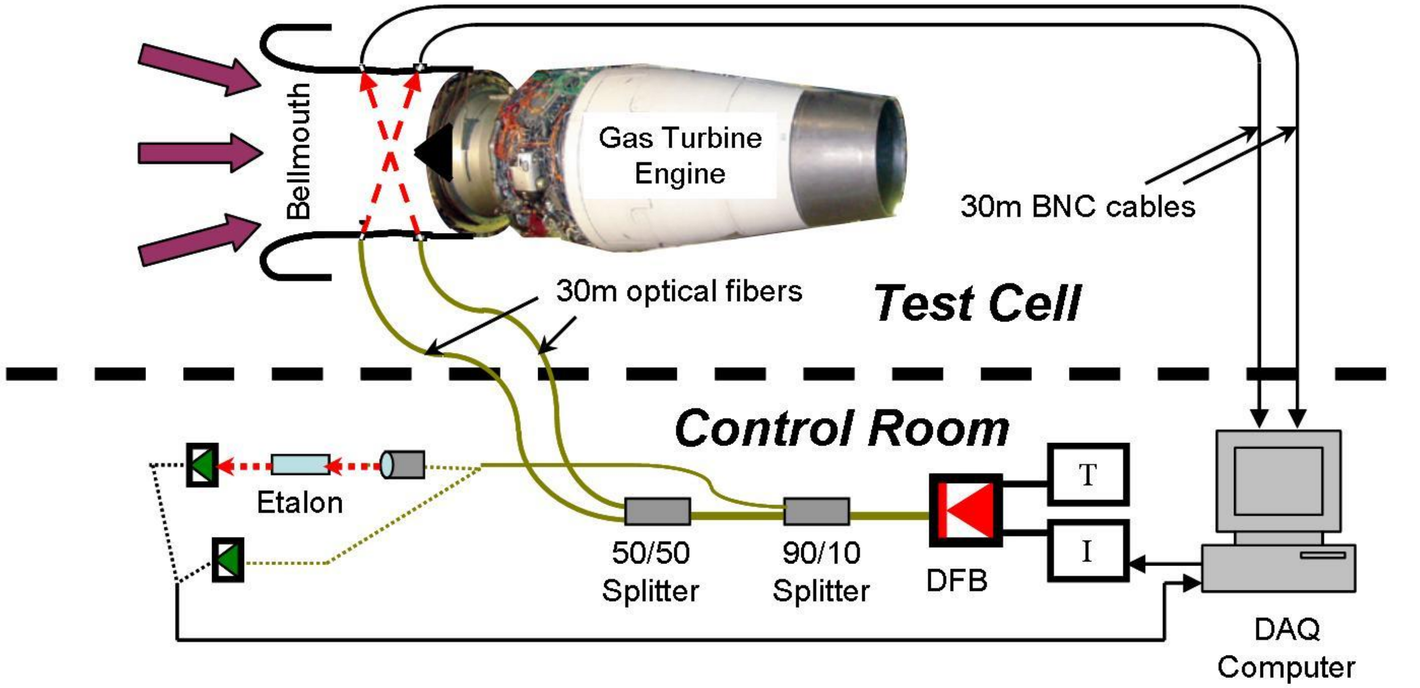

Figure 6: Schematic of an air mass flux sensor installed on the inlet of a commercial jet engine, (Airbus 318).

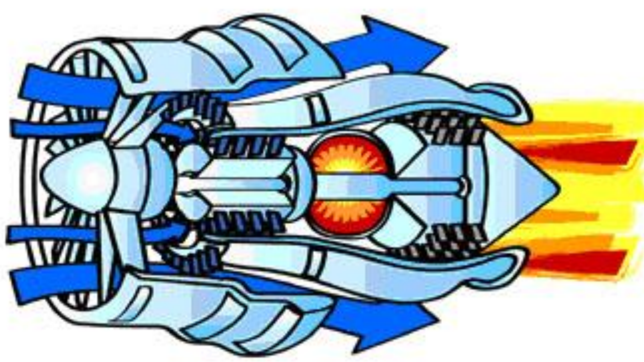

Figure 7: Jet engine cartoon