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An Instrument to Measure Turbulent Fluxes in the Atmosphere of Mars and other Planets

S. Rafkin (1), D. Banfield (2), J. Silver (3), K. Nowicki (1), R. Dissly (4), A. Stanton (3)

(1) Southwest Research Institute (rafkin@boulder.swri.edu), Colorado, USA, (2) Cornell University, New York, USA, (3) Southwest Sciences, Inc., New Mexico, USA, (4) Ball Aerospace Corporation, Boulder, USA

Abstract

A newly developed instrument capable of simultaneously measuring turbulent fluxes of energy, momentum, and key photochemical and tracer gas species in planetary atmospheres has been developed. The focus to date has been for Mars, but the instrument can be adapted to other atmospheres such as Venus, Titan, and those of the gas or ice giants. The instrument consists of a vertical cavity emitting laser source and photodetector, and a multi-pass optical cell integrated directly into an acoustic anemometer (Fig. 1). The design for Mars allows it to operate over all relevant conditions and is not substantially degraded by dust accumulation. The instrument systems will undergo Mars environment testing to bring it to TRL-6 by the end of summer 2013. Current best estimates of total instrument mass and power are 4 W and 2 kg, respectively.

1. Introduction

Turbulent eddies in the planetary boundary layer of the terrestrial planet atmospheres are the primary mechanism by which energy, momentum, gasses, and aerosols are exchanged between the surface and the atmosphere [1]. One way to make a major rather than incremental leap in the understanding of the Mars climate system is to measure eddy fluxes, because these are part of the forcings that drive the atmosphere.

Although turbulent eddies are critically important to understanding climate systems, volatile cycles, dust and aerosol cycles, chemical cycles, aeolian activity, and the entire energy and momentum budget within atmospheres, these eddy fluxes have never been directly measured on a planet other than Earth. .

Models of the Martian atmosphere are used to simulate the climate and provide atmospheric predictions for entry, descent, and landing of spacecraft incorporate parameterizations of eddies, but have yet to be validated [2,3,4,5]. Model estimates of eddy fluxes vary by factors of two or more [6], and these differences can result in different predictions about the safety of landing sites, as well as general scientific results (e.g., convective updrafts and boundary layer heights).

We are developing an instrument that combines sonic anemometry and tunable laser spectroscopy to obtain the needed eddy flux measurements. We are focusing our attention on Mars as a proof-of-concept, but the resulting instrument can be adapted to Venus, Titan, or the atmospheres of the ice giants (Figure 1).

2. Instrument Description

On Earth, turbulent fluxes are often obtained by combining independent measurements from an acoustic anemometer (AA) and tunable laser spectrometer (TLS). The technique of using an AA and TLS should be effective in other planetary atmospheres, but the implementation must be different due to a variety of key issues that make the measurements less straightforward than on Earth. These issues include: 1) Importance of sensor collocation for measuring small eddies and minimizing sensor flow distortion; 2) Compositional changes in the atmosphere over time; 3) Contamination of temperature and wind measurements due to solar heating of a TLS structure; and 4) Limited resources typically available to instruments; 5) Environmental factors (e.g., dust on Mars, H_2SO_4 on Venus or cryogenic temperatures on Titan). Due to the expected scale of eddies near the surface, an instrumentation implementation that integrates AA and TLS sensors is a strict requirement. Conceptually, our integrated instrument is shown in 1.

2.1 Anemometer Description

The instrument has advanced from a proof of concept based on commercially available terrestrial AAs to a breadboard prototype instrument. The AA transducers have been tested in a Mars-like environment in a thermal-vacuum chamber, and the full sensor capabilities have been demonstrated on a stratospheric balloon to further replicate Mars-like atmospheric conditions.

To couple well to the thin Martian atmosphere, we used customized acoustic transducers that are designed with very light electrically driven membranes that can both produce and sense sound waves at Mars with relatively high efficiency. The high attenuation and challenges in coupling to Martian atmospheric density is tackled with sophisticated signal processing techniques (i.e., Pulse Compression borrowed from RADAR techniques).

The AA consists of a computer back-end that controls the initiation of the measurement sequence, as well as the computational processing required to perform the sophisticated digital signal processing needed to extract as much information as possible from the received signals.

2.2 TLS Description

Our TLS used as a starting point a compact and low-power field-quality TLS hygrometer. Versions of this instrument function in the laboratory and field environment on Earth [7,8], and have been flown on high-altitude balloons, sounding rockets and on aircraft. The instrument consists of a vertical cavity emitting laser (VCSEL) source and photodetector, a multi-pass optical cell to provide a long absorption path in a compact design, and laser driving and digital signal processing electronics. The sensor takes advantage of two key technological developments: 1) a patented multiple-pass optical cell design that uses small mirrors and dense spot patterns to give a long optical path with a small footprint; and 2) a low power and compact electronics system. The capability for four simultaneous laser channels using a single optical cell were also added. The light source for the TLS is a fiber-pigtailed VCSEL 2 μm thick and 5 μm in diameter.

3. Other Planetary Atmospheres

Although focused on Mars, we fully intend for this instrument to be applicable to various other atmospheres after only very minor modifications. Beyond Earth and Mars, three additional issues must be considered: 1) TLS wavelength selection to match gases of interest; 2) AA transducers matched to the acoustic environment; and 3) the specific environmental conditions in different atmospheres. Importantly, besides a trivial change in TLS wavelength and appropriate selection of a transducer, the rest of the instrument system remains unchanged.

4. Figures

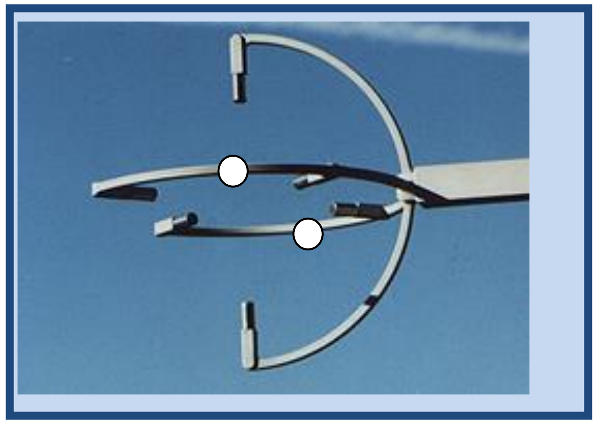

Figure 1. Conceptual model of integrated AA and TLS. TLS mirrors are schematically shown as circles. The acoustic and optical path length is ~15 cm. Mirrors are ~2.5 cm in diameter. An image (not to scale with AA) of an actual mirror with laser spot patterns is shown in the upper left. Close up of a Mars transducer (~1.5 cm) is shown in the bottom left.

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