MICRO/NANOSATELLITE MARS NETWORK FOR GLOBAL LOWER ATMOSPHERE CHARACTERIZATION. M. L. Tinker, NASA Marshall Space Flight Center; Systems Development, Integration and Test Division/ES60, Huntsville, AL 35812; mike.tinker@nasa.gov.

Overview: To address multiple key challenge areas for robotic exploration of Mars, to achieve scientific goals and reduce risk for future human missions, a micro/nanosatellite constellation for lower atmosphere characterization is proposed. A microsatellite design is discussed that can operate (1) in tandem with another microsat or (2) as a "mother-ship" to deploy a network of nanosatellites (CubeSats). Either configuration of the network would perform radio occultation-based atmospheric measurements. Advantages of the proposed network are low development cost based on an existing microsatellite bus, and proven performance of the bus to date. Continued efforts in miniaturization of instruments are needed to fully enable the mother-ship/nanosat version of the proposed network.

Science Goals and Human Exploration Risk Reduction: Global measurement of lower atmosphere winds, densities, and additional characteristics will not only address major Mars science goals but also reduce risk for human missions to the surface. For example, understanding and prediction of lower atmosphere winds and large-scale dust events could greatly enhance successful/safe execution of crewed landings. Further, goals for Mars atmospheric science in the coming decade include (1) wind structure from the surface to upper atmosphere, (2) dust distribution, particularly during dust storms, and causes of global dust events, (3) water distribution, (4) trace gas chemistry, and others [1]. To help answer these questions, high vertical resolution observations of the atmosphere from orbit to determine global variations of pressure, temperature, winds, and other components from the surface to upper atmosphere are needed.

Description of Micro/Nanosatellite Network: The proposed architecture shown in Figs. 1-2 is based on development and flight experience with a microsat bus (FASTSAT) and deployed payloads that are currently in operation in low earth orbit. A Mars orbiter version of the microsatellite would provide average power of at least 100W, to accommodate the sensor suite required for atmospheric profile measurements.

The proposed micro/nanosat constellation could be configured in two different mission architectures for Mars atmospheric measurements using satellite-to-satellite radio occultations (RO), depending on progress in miniaturized instrument technology in the near future: (1) network of two or more microsatellites using existing technology (Fig. 1), or (2) network of microsat (mother-ship)-deployed CubeSats with advanced technology RO system (Fig. 2).

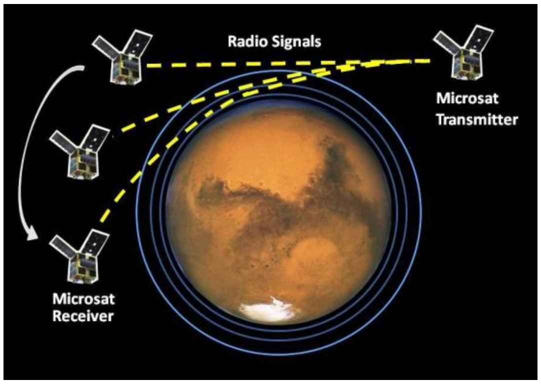

Figure 1. Dual Microsatellite Version of Proposed Network Performing Radio Occultation Measurements

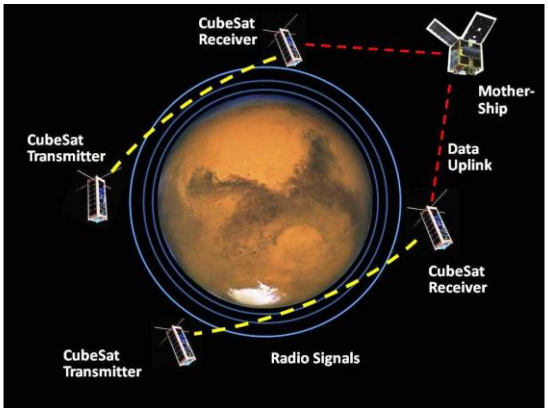

Figure 2. Mother-Ship/Nanosat Network Performing Radio Occultation Measurements

Radio Occultation Measurements and Feasibility of Micro/Nanosat Network: The RO measurement technique has been proven in previous missions (Mariner 4 and Mars Global Surveyor) [2]. Additionally, occultation sounding has been demonstrated for earth climate monitoring [3-5]. The RO method is based on refraction of radio waves passing through a planetary atmosphere (Figs. 1-2). Atmosphere refractivity gradients depend on gradients of density, temperature, pressure, and water vapor, and electron density [5], and can be processed to determine atmospheric variables.

Feasibility of Architecture 1: Dual or Multiple Microsat Network. Comparison of the mass and power requirements for science instruments required for Mars RO atmospheric measurements shows that the first architecture appears feasible using existing technology. Example calculations are presented for the enhanced FASTSAT described in Fig. 3 and Table 1. Instruments described in [2] for a Mars climate mission are (1) 300GHz RO system (estimated 30kg, 38W), (2) thermal IR limb emission ice/dust sounder (est. 9kg, 2W), (3) near-IR solar occultation instrument (est. 7kg, 17W), and (4) thermal emission spectrometer (est. 15kg, 18W). The total estimated mass and power budget for these instruments (divided between two microsats) is 61 kg and 73W, and comparison with Table 1 suggests feasibility of the multiple microsat architecture for RO atmospheric measurements.

Larger numbers of satellites increase the number of possible occultation profiles per day, but also increase complexity and cost of the mission. A mission with 2-4 microsatellites and potential nanosatellite payloads appears feasible for a single launch platform.

Figure 3. Enhanced Microsat with CubeSat Deployers

Feasibility of Architecture 2: Mother-Ship/Nanosat Network. The second proposed architecture for Mars atmospheric measurements is a network of microsat-deployed nanosats, as shown in Fig. 2. One FASTSAT -type microsat can deploy 12 1U or four 3U CubeSats. This architecture as shown for CubeSat-to-CubeSat radio occultation to the Martian surface is expected to require continued technology advancement for miniaturization of transmitters and receivers, and improved signal-to-noise ratios. As described in [6], the use of nanosatellites for science applications is still in its infancy. In the examples for CubeSat earth atmospheric missions that follow, it is recognized that the instruments would require different designs and specifications for application to Mars missions.

As a first example that suggests feasibility of CubeSats for Mars radio occultation atmospheric measurements, [6] describes a unique mission to determine variations of several key constituents and parameters in earth's lower thermosphere (90-320 km) with a network of 50 double CubeSats having identical sensors. Observables could include total mass density, densities of atmospheric constituents, temperature or wind speed, and signal sounding using GPS L-band signals.

Total Mass (kg)	180
Stabilization	3-Axis
Attitude Control/Knowledge	0.1°, 0.02°
S-Band Downlink (Mbps)	5
S-Band Uplink (kbps)	19.2
Mission Life	2 yr
Payload Mass (kg)	60
Payload Power (W)	100 - 120 W Avg 250 - 350 W Peak
Payload Volume (cc)	120,000
Payload Data (MB)	7,800

Table. 1. Properties of Enhanced Microsat

The second example potentially demonstrating feasibility of CubeSats for Mars atmospheric measurements is the CanX-2 mission [7], which utilized a miniaturized (100x60x16mm, 60g, 1.6W) GPS receiver. The CanX-2 mission accomplished ionospheric radio occultations, but the current system was not able to deliver tropospheric occultation measurements due to low carrier-to-noise-density ratios. The operation of the CanX-2 GPS receiver is also limited to short data takes, due to power and onboard data storage constraints. Use of the mother-ship shown in Figs. 2-3 for communication and data uplinks from CubeSats could relieve such operational concerns.

Mission Cost and Launch/Transportation Concepts: The proposed micro/nanosat network could be transported to Mars using a low-cost system such as the Russian Zenit launch vehicle and Phobos-Grunt probe, which carried the Chinese Yinghuo-1 microsatellite. Total cost of the failed Phobos-Grunt mission was reported as approximately $160M.

Costs for micro/nanosatellite development are reduced based on existing platforms such as FASTSAT and CubeSats. Considering the launch/transportation system costs, total mission cost could be as low as $330M for Architecture 1 with dual microsats and $250M for Architecture 2 with microsat mother-ship and four 3U nanosats. Improved redundancy of satellite systems could increase these costs more than 50%.

References: [1] Mischna M. A. et al. (2009) *Planet. Sci. Dec. Surv. White Paper.* [2] Kursinski E.R. et al. (2009) *Planet. Sci. Dec. Surv. White Paper*. [3] Steiner A. K. et al. (2001) *Phys. Chem. Earth (A), 26*, 113–124. [4] Wickert J. et al. (2005) *Annal. Geoph. 23*, 653-658. [5] Luntama J.-P. et al. (2008) *BAMS, Am. Meteor. Soc.*, 1863-1876. [6] Gill E. et al. (2010) *IWSCFF-2010-Paper-4-2, 6th Intl. Workshop on Sat. Constell. and Form. Flying.* [7] Kahr E. et al. (2011) *GNC 2011, 8th Intl. ESA Conf. on Guid., Nav. and Ctrl. Sys.*