SMALL APERTURE AIRBORNE TELESCOPES FOR PLANETARY SCIENCE. C.C.C. Tsang[1], D.D. Durda[1], K.A. Ennico[2], J. Less[3], T. Propp[4], C.B. Olkin[1], S.A. Stern[1], [1]Southwest Research Institute, Department of Space Studies, 1050 Walnut Street, Suite 300, Boulder, CO, 80302, USA, [2]NASA Ames Research Center, Moffett Field, CA 94035, USA, [3]NASA Armstrong Flight Research Center, Edwards, CA 93523 USA, [4]NASA Johnson Space Center, Ellington Field, Houston, TX 77034 USA

Introduction: Airborne observatories fly high above the tropopause (~38,000 f.t.) and avoid many detrimental telluric effects of Earth's opaque atmosphere. This is especially true at wavelengths near or greater than 1 µm where the transmission is > 80% at 14 km (45,000 ft) and above 99.8% of the water vapor in the Earths atmosphere. Currently, NASA's Stratospheric Observatory For Infrared Astronomy (SOFIA) is the premier platform to conduct airborne astronomy and planetary science. However, a number of planetary science investigations can be conducted using much smaller aperature telescopes (primary diameter ~ 11 – 15") currently onboard other airborne platforms [1]. We present these platforms, their capabilities and potential science investigations.

Background: NASA has invested significant amount of time and money on its new airborne platform, SOFIA. With its 2.7 m telescope, the modified Boeing 747-SP is capable of reaching 45,000 ft. Key advantages of SOFIA, and all aircraft platforms, are its mobility and access to parts of the EM spectrum unavailable on the ground. The ability to deploy to different sites across the world and over oceans allows SOFIA to catch transient celestial events, such as stellar occultations of planetary objects. These occultations can occur anywhere on the Earth, and since a substantial fraction of the Earth's surface is ocean, many of these unique events are impossible to observe without an airborne platform. Airborne platforms also allow guaranteed observations of important and rare events (e.g.: comet perihelion passes) above variable weather conditions. However, smaller aperature airborne telescopes allow 1) low solar phase angle observations, 2) relatively quick unscheuled deployments, and 3) simultaneous airborne observations, all of which are hard to achieve with SOFIA.

Small Aperature Platforms: There are a number of different platforms that currently host small aperature telescopes. The *F/A-18B "Hornet"* is a two-seat high performance aircraft based at NASA's Armstrong Flight Research Center (AFRC) used routinely for technical and scientific research and support (Fig 1). It flew regularly as a chase plane during SOFIA's flight evaluation test program. It has a top speed of ~1200 mph, giving it the ability to quickly redirect its position if a stellar occultation changes shadow paths with little notice. The Hornet is capable of reaching 50,000 ft., high in the dry stratosphere, as demonstrated recently when the Hornet supported NASA-JPL's Mars Science Laboratory tests of its descent radar prior to launch [2, 3]. The Hornet is also designed to carry the Forward Looking Infrared (FLIR) pod (Fig 2). The Raytheon AAS-38 NITEHAWK FLIR pod is a high fidelity telescopic and camera system. It has an 11" primary, a 2800 mm focal length with an infrared detector sensitive from 8 – 12 µm. The current field-of-view (FOV) is either 12º×12º or 3º×3º, with 2× and 4× magnification settings. The FLIR pod is normally used to acquire and track ground targets in the infrared, which scans and slaves to a specific target, presenting images to the crew. The pod can be moved from -150 to +30º in azimuth and has a 540º of roll freedom in either direction. Targets can be tracked at 75º/sec if needed [4]. The FLIR pod is designed with good pointing stability in mind, as can be seen in these in-flight images of the Moon (Fig 3).

The second platform is the *WB-57F "Canberra"*. The WB-57 is a two seater, high altitude research aircraft operated by NASA Johnson Space Flight Center (JSC) (Fig 4). There are three operational airframes, based primarily at Ellington Field, Houston TX. Since the early-1960's, their main purpose has been to conduct high altitude research, mainly in the fields of meteorology, terrestrial atmospheric and geophysical research. They are capable of reaching and maintaining an altitude in excess of 65,000 ft, and have a deployment range of 2,500 miles for a total mission duration of 6.5 hour. It has been successfully deployed to national and international airfields. The optical instrument is a 13" primary telescope called the Day Night Airborne Motion Imagery for Terrestrial Environments (DyNAMITE), gimbal mounted on the noise cone of the WB-57 (Fig 5). DyNAMITE is a full motion, two independent co-bore sighted system, with a visible color HD video camera systems, combined a mid-wave (3-5 µm bolometer) infrared video camera. The gimbal has a pointing stability of < 5 µRad @ 20 Hz RMS. Recent deployments of WB-57/DyNAMITE include observing the re-entry of SpaceX Falcon 9 first stage from Cape Canaveral FL (Fig 6).

In addition, there are also NASA's Predator "Ikhana" and the DC-8 Airborne Science Laboratory (max. alt. 52K ft and 41K ft respectively), both of which carry similar small optical gimbaled telescopes and have long endurances. All these platforms have the ability to reach the stratosphere and offer *unrestricted* pointing ability through all-sky fuselage and wing mounted instruments. They can fly to different airports across the continental US, as well as overseas, and can land at all major airports. The AFRC and JSC ground mission control rooms can provide monitoring of instruments and data from these aircraft.

Planetary Science Targets: A surprising number of planetary science investigations can be conducted using small aperature telescope facilities, including Venus observations of the surface, simulanteous multi-cord Pluto, KBO and asteroid stellar occulations for studying their atmospheres and size determinations, cometary atmosphere and leonid [5] studies. Suggestions welcome!

Conclusions: Small aperature telescopes, outfitted with appropriate cameras and filters are available to the planetary science community, deployed by NASA, that can conduct observations complementary to, and in some cases not possible by, SOFIA. We present these capabilities and discuss potential scientific targets, their investigations, and the practicalities and difficulties in conducting these observations.

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References: [1] Durda et al. (2000) SPIE, 4127. [2] Creech (2011), NASA Solar System News, 06.21.11 [3] Chapin et al. (2013), *Radar Conference IEEE*, 10.1109/RADAR.2013.6586044, 1-4, [4] Krebs et al. (1998), *Proc. SPIE* 3376, Sensor Fusion: Architectures, Algorithms, and Applications II, 129, [5] Stern et al. (1999) Leonid Thread Conference Abstract

Fig 1: NASA's two seat F/A-18B Hornet, carrying the FLIR pod (under left fuselage) based at the Armstrong Flight Research Center. Backseat observer can in real time control the 11" telescope 8 μm camera.

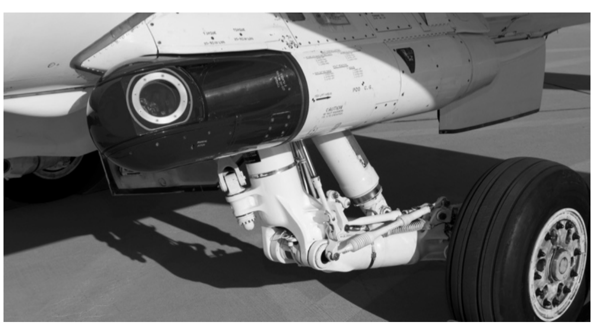

Fig 2: The FLIR pod under the F/A-18B Hornet, both of which are owned and operated at NASA ARFC

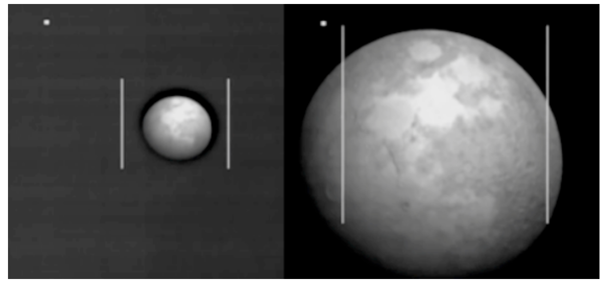

Fig 3: Two different FOV of the Moon from the FLIR pod at altitude at 8 μm. These images show little to no jitter.

Fig 4: NASA's WB-57 Canberra based at Ellington Field. Having greater range than the Hornet, the Canberra can highly complement SOFIA to catch remote stellar occulations.

Fig 5: The WB-57F/DyNAMITE telescope mounted on the nose cone. A dichroic allows simultaneous observations at visible and infrared wavelengths.

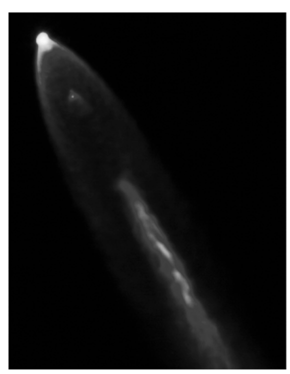

Fig 6: WB-57/DyNAMITE airborne thermal imaging of the SpaceX Falcon 9 re-entry in 2014.