



## Precision Arc-Second Pointing on Balloons Using WASP

**W**ASP (Wallops Arc-Second Pointer) is a NASA provided support system, developed at NASA's Wallops Flight Facility (WFF), which points science instruments on balloon gondolas at targets with arc-second accuracy and stability. WASP can support a variety of science-provided instruments and sensors, and multiple science disciplines, to meet specific mission performance requirements. Pointed masses over 600 kilograms and instrument dimensions over one meter in diameter and eight meters in length can be accommodated. Major components of WASP are reusable which reduces the overall costs to the BPO and to users. Collaborative design, analysis, integration and flight support services are available from WFF for proposers who want to use WASP.

WASP has successfully completed five test flights between 2011 and 2014 and has demonstrated positional stability at sub-arc-second levels during flight. In September of 2013, WASP supported its first pointed science instrument, the HyperSpectral Imager for Climate Science (HySICS), provided by the Laboratory for Atmospheric and Space Physics (LASP), which is an institute at the University of Colorado at Boulder (CU).

Figure 1 shows a view of the WASP gondola-mounted elements as configured for Test Flight 1 (TF1). Figure 2 shows the WASP TF1 system on the launch vehicle at the Fort Sumner, New Mexico launch site.

*WASP is a flexible system that points science instruments on balloon gondolas at targets with arc-second accuracy and stability*



**Figure 1 - WASP Test Flight One Gondola**

The WASP system points an instrument (modeled during TF1 by a 24-ft 1500-lb steel beam) using a gondola mounted pitch/yaw articulated gimbal. The range of motion of the yaw-gimbal is purposely minimized to reduce kinematic coupling during fine pointing. Thus, the gondola itself is suspended beneath a standard NASA Rotator to provide large angle azimuth targeting and coarse azimuth stabilization.

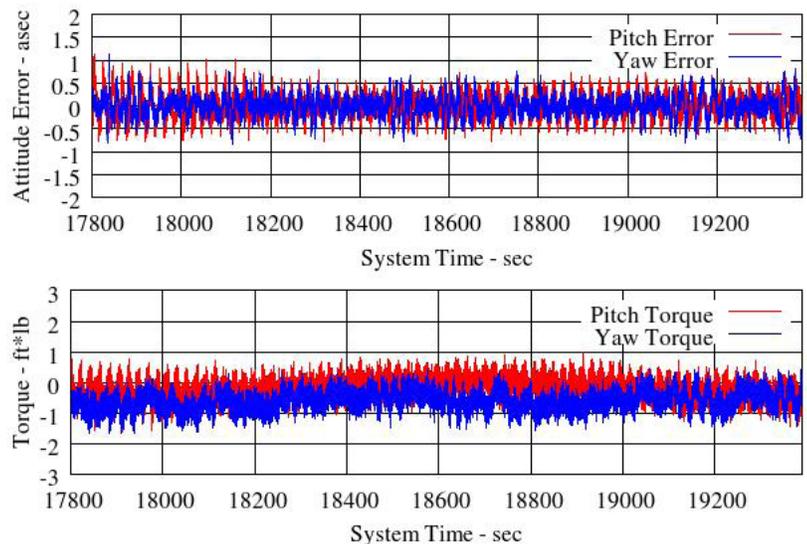
Sub-arc-second pointing is enabled by the design of the WASP gimbal hubs. A pair of hubs on opposing sides of the gimbal is used to establish each articulated axis of rotation. Each hub uses high-precision angular contact bearings to float the rotor side and stator side of the hub on a central shaft. The central shaft in each hub is constantly rotated by a small diameter torque motor to eliminate static friction. A large-diameter brushless DC torque motor is used to provide the torque for each control axis. The current in the three electrical phases in each of the control motors is commutated in software and set using power Op-Amps in a motor interface circuit.

Instrument attitude is computed by integrating incremental angles ( $\Delta\theta$ ) output from a LN251 system. While the LN251 is a fully capable GPS/INS navigation system, its use on the WASP system is limited to that of a relatively low-cost, high-quality inertial-rate-unit. Control torques are computed using a modified Proportional-Integral-Derivative control law in each axis.

WASP TF1 was flown in October 2011 and demonstrated the ability to point inertially with sub-arc-second stability. Figure 3 shows the pitch and yaw errors over a 20 minute period of inertial pointing.

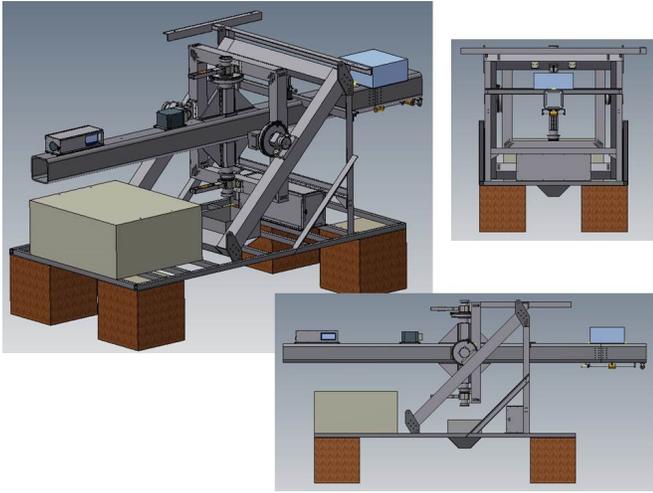


**Figure 2 - WASP Test Flight One  
Gondola on Launch Vehicle**



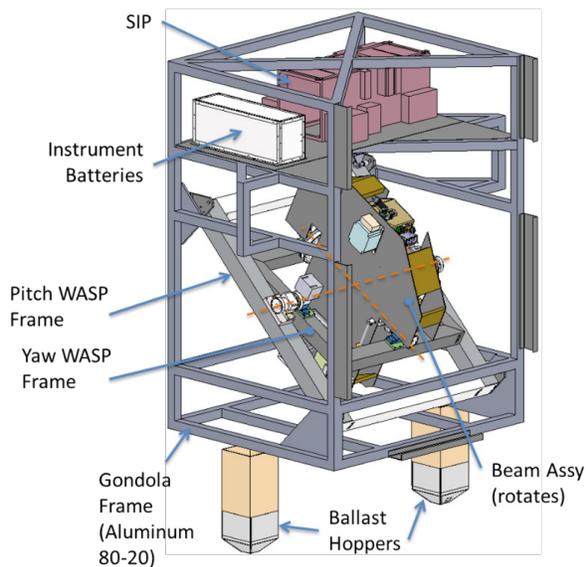
**Figure 3 - WASP Test Flight One  
Station-keeping Stability**

After the initial test flight of WASP, a number of system modifications and improvements were made, and a new gondola was built and flown in 2012. The system changes include incorporating a Star Tracker into the control system loop, changing the mock telescope from a 24 foot steel tube to a 16 foot tube with less inertia, moving the avionics deck from the outer frame to the mock telescope, and adding angular positional encoders to the Resolver Hubs. Figures 4 and 5 show the WASP Test Flight Two configuration, and Figure 6 shows the stability achieved during flight during a one hour station-keeping period.



**Figure 4 - WASP Test Flight Two Gondola Design**

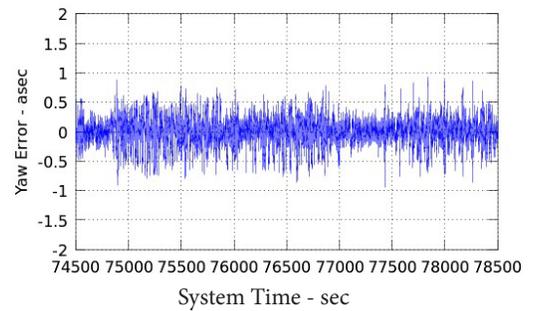
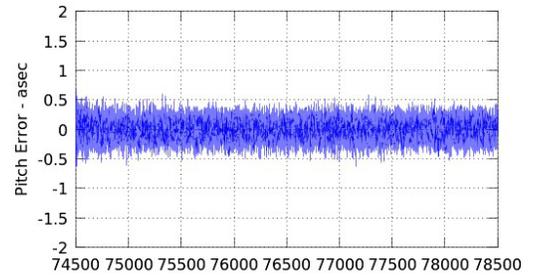
The third and fourth flights of WASP, which occurred in the fall of 2013 and 2014, included the HySICS science instrument provided by LASP, and successfully completed scan maneuvers of the sun and observations of the earth, moon and earth limb. These flights successfully tested several new WASP system enhancements, and demonstrated WASP's ability to be integrated with science and provide flight support. Figure 7 shows the WASP HySICS design and Figure 8 shows the integrated WASP HySICS gondola during integration.



**Figure 7 – WASP HySICS Gondola Design**



**Figure 5 - WASP Test Flight Two Gondola**

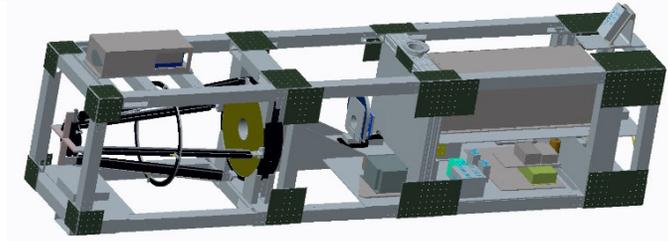


**Figure 6 – Test Flight Two Pointing Performance**



**Figure 8 – WASP HySICS Integrated Gondola**

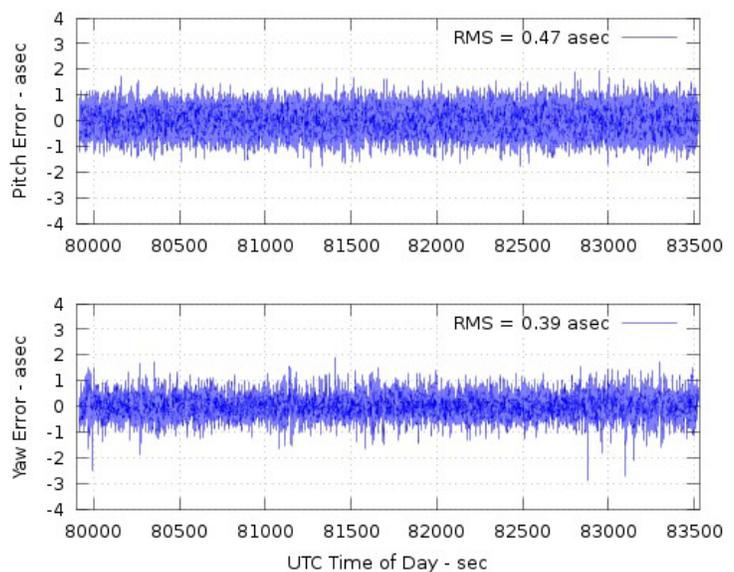
The fifth and final WASP test flight also occurred in 2014, and included an optical telescope and science detector provided by NASA Goddard Space Flight Center's Solar System Exploration Division. The flight demonstrated the WASP system's ability to support both planetary and exoplanet scientific studies, and achieved pitch RMS pointing errors of 0.47 arc-seconds and yaw RMS errors of 0.39 arc-seconds. The science instrument, the Observatory for Planetary Investigations from the Stratosphere (OPIS), successfully obtained images of Jupiter, and a number of stellar targets including Etamin, Procyon and Altair were acquired and tracked. Figure 9 shows the WASP OPIS pointed structure, which includes a counter-balanced design where the telescope's primary mirror is mounted in front of the WASP inner gimbal and yaw axis, which allows mirrors with diameters greater than one meter to be supported and flown. Figure 10 shows the integrated gondola during testing at the launch site in Fort Sumner, New Mexico, and Figure 11 shows the pointing errors achieved during the flight.



**Figure 9 – WASP OPIS Pointed Structure and Telescope**



**Figure 10 – WASP OPIS at Fort Sumner Launch Site**



**Figure 11 – WASP OPIS Performance Data**

*WASP has demonstrated excellent performance during the development test flights and is available for science groups to propose as a solution to their fine-pointing needs. The WFF WASP Team can provide collaborative design, simulation, analysis, integration, and flight support.*

For more information on WASP, please contact the NASA Project Manager at WFF, Mr. David Stuchlik, at [david.w.stuchlik@nasa.gov](mailto:david.w.stuchlik@nasa.gov).