A Close Flyby of *Tiangong-1* by X-37B on 10 January 2012

The first X-37B robotic space plane completed a 225-day mission in low Earth orbit (LEO) with a Vandenberg Air Force Base runway landing on 3 December 2010. Its successor, known as Orbital Test Vehicle 2 (OTV-2), launched from Cape Canaveral Air Force Station (CCAFS) on 5 March 2011 atop an Atlas V (see Figure 1). Based on NASA's X-37 design, the X-37B is operated by the USAF on classified missions thought to be evaluating onboard photoreconnaissance and other intelligence-gathering systems.

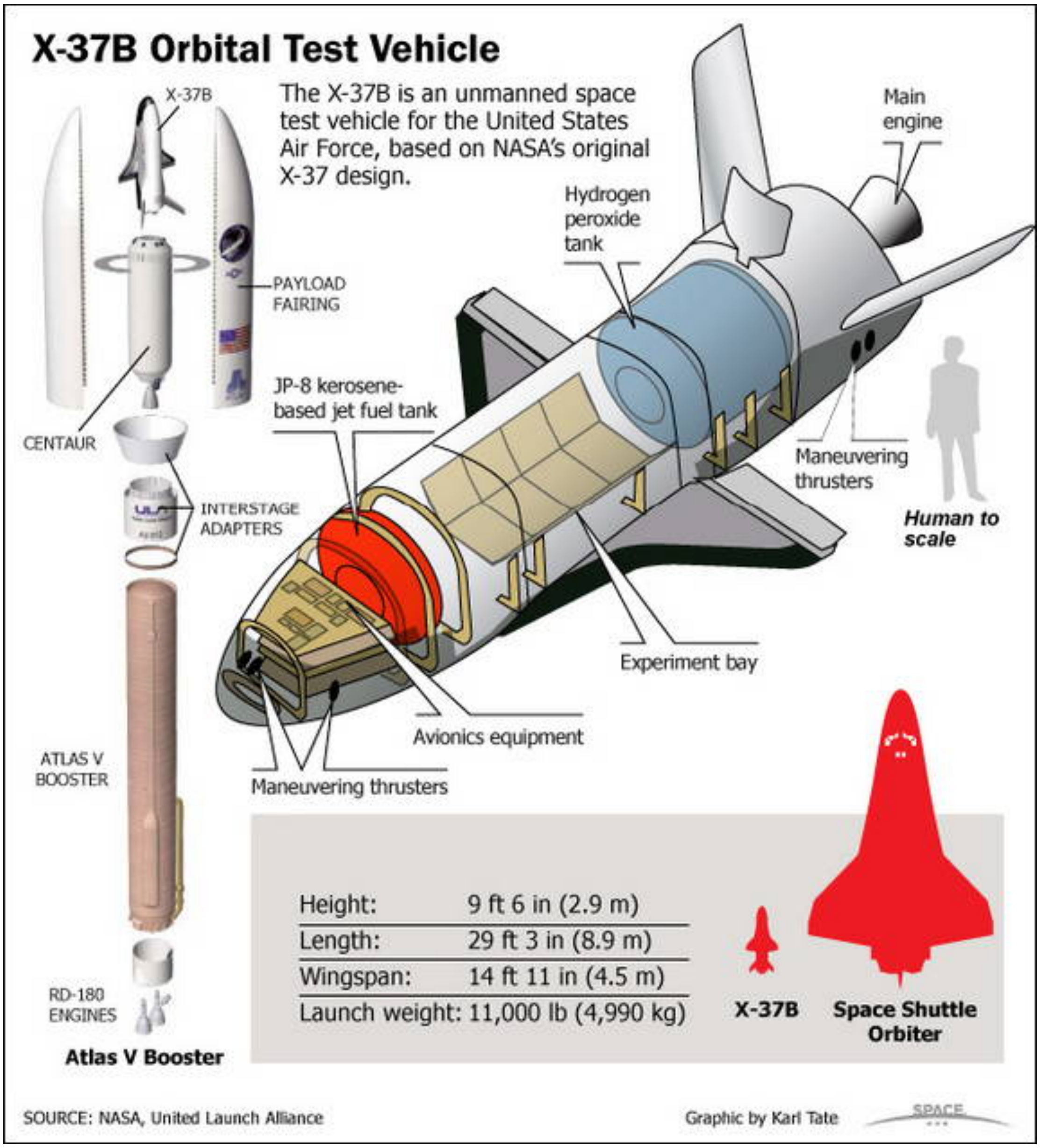

Figure 1. The X-37B robotic space plane and its Atlas V launch vehicle are illustrated in a diagram obtained from Space.com.

Maximum mission duration for X-37B is rated at 270 days, and OTV-2 had logged 302 days in LEO as 2011 drew to a close. In an interview with Leonard David published 4 October 2011 by Space.com, X-37B Systems Program Director, USAF Lt. Col. Tom McIntyre, indicated OTV-2 had been planned as a 9-month mission, "but [controllers] will try to extend it as circumstances allow."

As 2012 began, public speculation arose that motivation for an extended OTV-2 mission might be observations of China's nascent space station module *Tiangong-1*. Launched without a crew by a Long March 2F/G on 29 September 2011, *Tiangong-1* achieved China's first docking with the robotic *Shenzhou-8* spacecraft on 2 November 2011. This milestone presumably clears the way for planned initial crewed dockings with *Tiangong-1* by *Shenzhou-9* and *Shenzhou-10* in 2012.

Although OTV-2 and *Tiangong-1* are currently in orbits whose inclinations to Earth's equator are both near 42.8°, the two orbit planes cross Earth's equator from south-to-north at distinctly differing geocentric right ascensions[*]. As of 6.1 January 2012 UTC, the two geocentric orbit planes were inclined to each other by a 65° "wedge angle", making rendezvous and extended inspection of *Tiangong-1* by OTV-2 impossible in the near term.

But brief, high-speed flybys at close ranges between OTV-2 and *Tiangong-1* are possible because they orbit at similar heights above Earth. These flybys can only occur along the geocentric line of nodes where the two orbit planes intersect. If OTV-2 crosses the *Tiangong-1* orbit plane at either end of this line when *Tiangong-1* is also nearby, a close flyby can occur. Assuming no orbit changes, the time interval T between successive flybys can be computed from the mean motion for OTV-2 (ω_C = 15.78606 revolutions per day) and for *Tiangong-1* (ω_T = 15.68845 revolutions per day) using the simple formula $T = 1 / |\omega_C - \omega_T|$. This technique estimates a flyby opportunity will arise once every 10.24 days.

Per Figure 2's "top view" centered on *Tiangong-1*, the next flyby occurs on 10 January 2012 at 19:44 UTC with OTV-2 passing from north to south of *Tiangong-1*'s orbit plane just before overtaking it from behind. Figure 3 provides a complimentary "side view" of the flyby, showing OTV-2 will pass 34 km below *Tiangong-1* at closest approach[†].

Figures 4 and 5 are world maps illustrating flyby locations of OTV-2 and *Tiangong-1*, respectively, along with their ground tracks before and afterward. These maps indicate the flyby will occur immediately east of CCAFS with its potentially supportive communications and sensor resources. Also evident from the maps is the flyby's afternoon local solar time. Under this lighting geometry, OTV-2 will view primarily the lit side of *Tiangong-1* if it trails *Tiangong-1* during the flyby. Figures 2 and 3 confirm OTV-2 will indeed trail *Tiangong-1* at 19:44 UTC. Note that the next flyby, at the line of nodes' other end, will occur with OTV-2 leading *Tiangong-1* and both spacecraft in Earth's shadow.

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[*] Because OTV-2's mission is classified, so are its high-accuracy orbit elements. Surrogate, but usable, orbit elements are obtained from dedicated amateur observers via http://heavens-above.com/. High-accuracy *Tiangong-1* orbit elements are unclassified and are obtained from http://www.space-track.org/perl/login.pl.

[†] Figures 2 and 3 utilize a local vertical spherical (LVS) coordinate system to eliminate geometric distortion of OTV-2 motion relative to *Tiangong-1*. These distortions arise in conventional Cartesian systems when two orbit planes have an appreciable wedge angle. The LVS system is described in D. R. Adamo, "A Meaningful Relative Motion Coordinate System For Generic Use", Paper AAS 05-306, *Volume 123 of the Advances in the Astronautical Sciences Series*, Univelt, Inc., San Diego, pp. 837-856, 2006.

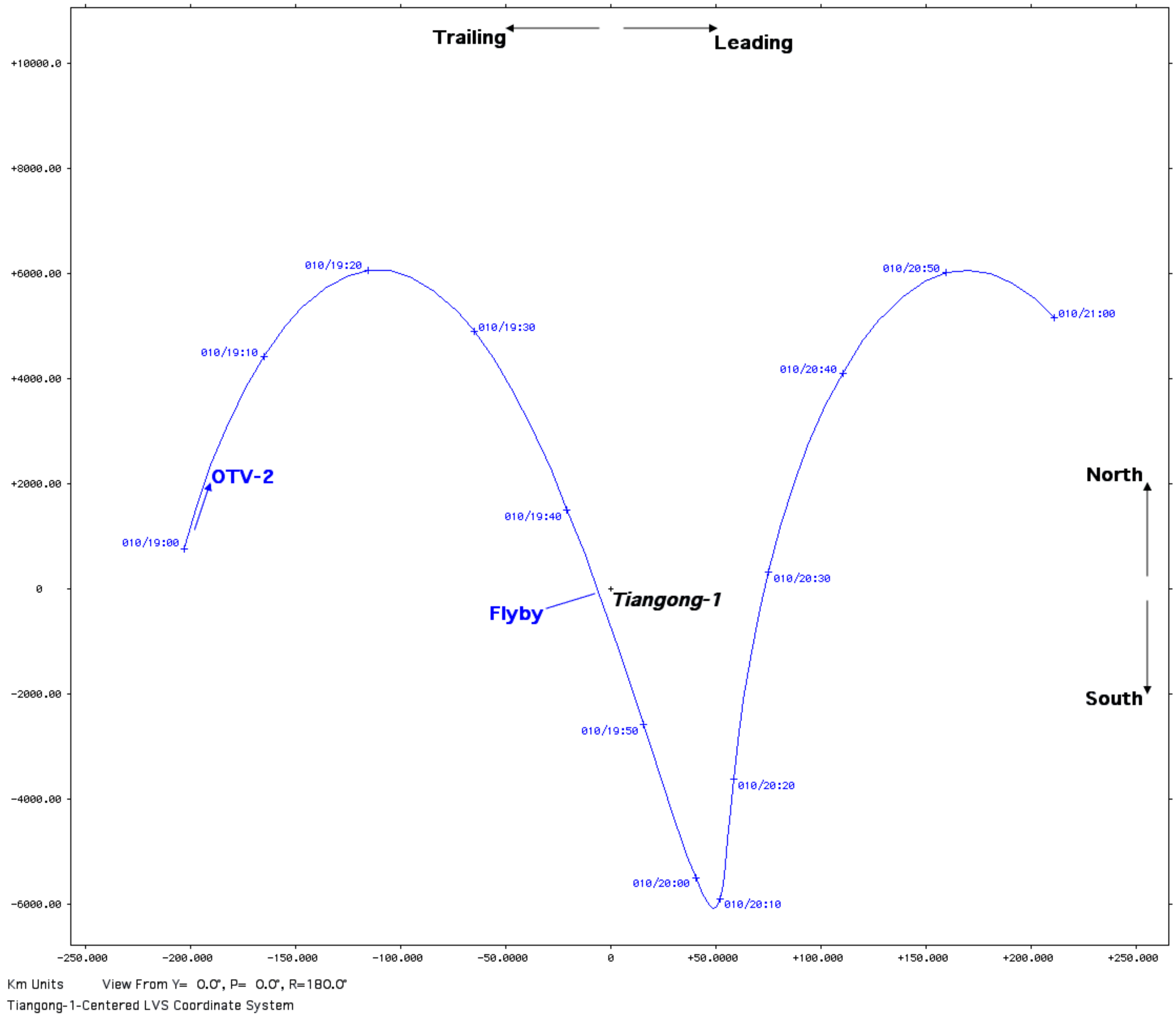

Figure 2. This "top view" illustrates OTV-2 motion with respect to *Tiangong-1* during the 10 January 2012 flyby. The viewpoint is from above *Tiangong-1* looking toward the geocenter. Note the North/South vertical scale is 40 times larger than the Leading/Trailing horizontal scale. Time ticks are labeled in DOY/hh:mm UTC at 10-minute intervals.

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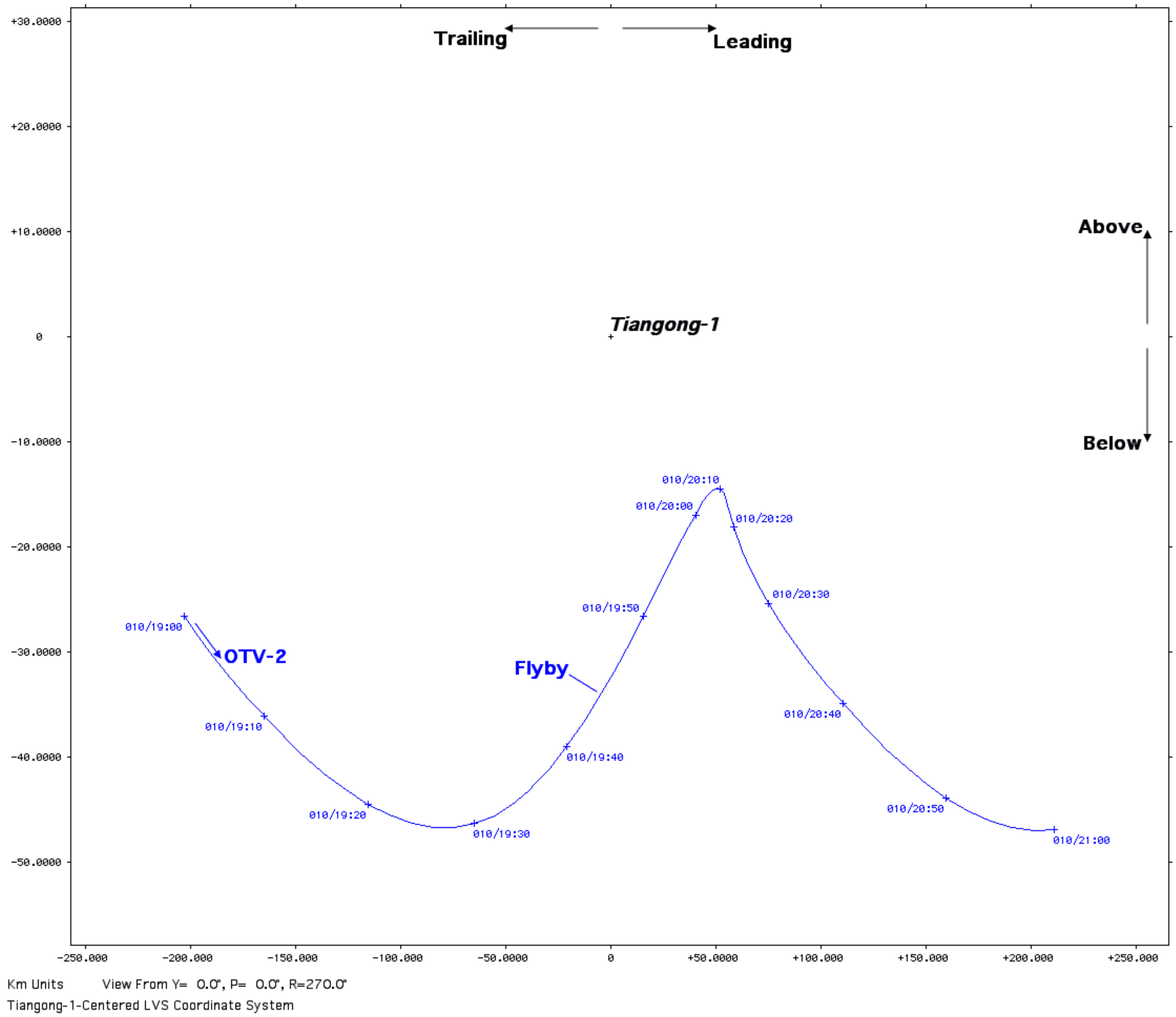

Figure 3. This "side view" illustrates OTV-2 motion with respect to *Tiangong-1* during the 10 January 2012 flyby. The viewpoint is from south of the *Tiangong-1* orbit plane looking north. Note the Above/Below vertical scale is 5 times smaller than the Leading/Trailing horizontal scale. Time ticks are labeled in DOY/hh:mm UTC at 10-minute intervals.

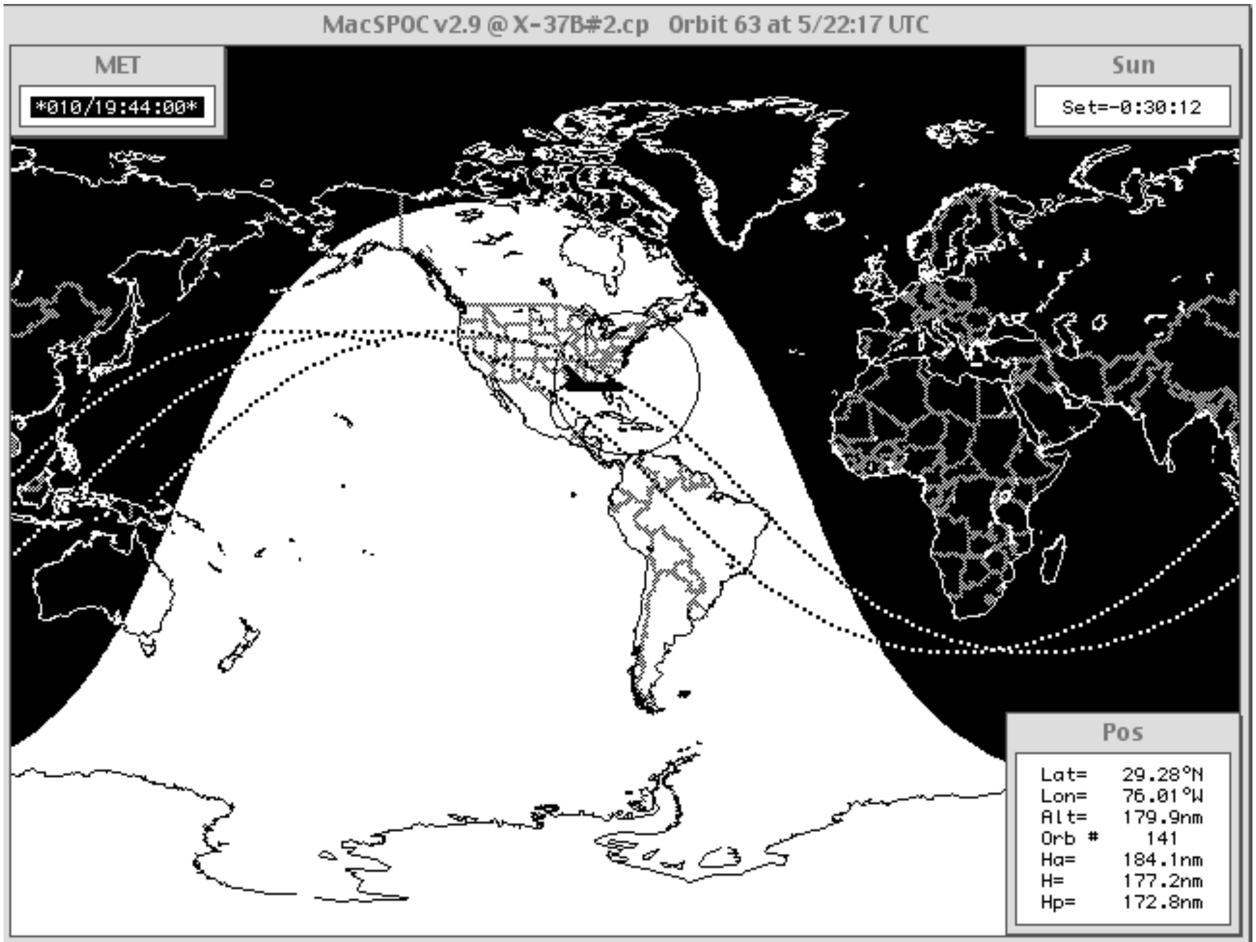

Figure 4. The Space Shuttle silhouette's nose on this world map denotes OTV-2's location at the 10 January 2012 *Tiangong-1* flyby. A circumscribing circle maps the OTV-2 horizon at this time, and the Sun window shows OTV-2 will enter Earth's shadow 30 min 12 sec after the flyby. Earth's nightside is reverse-field on the map.

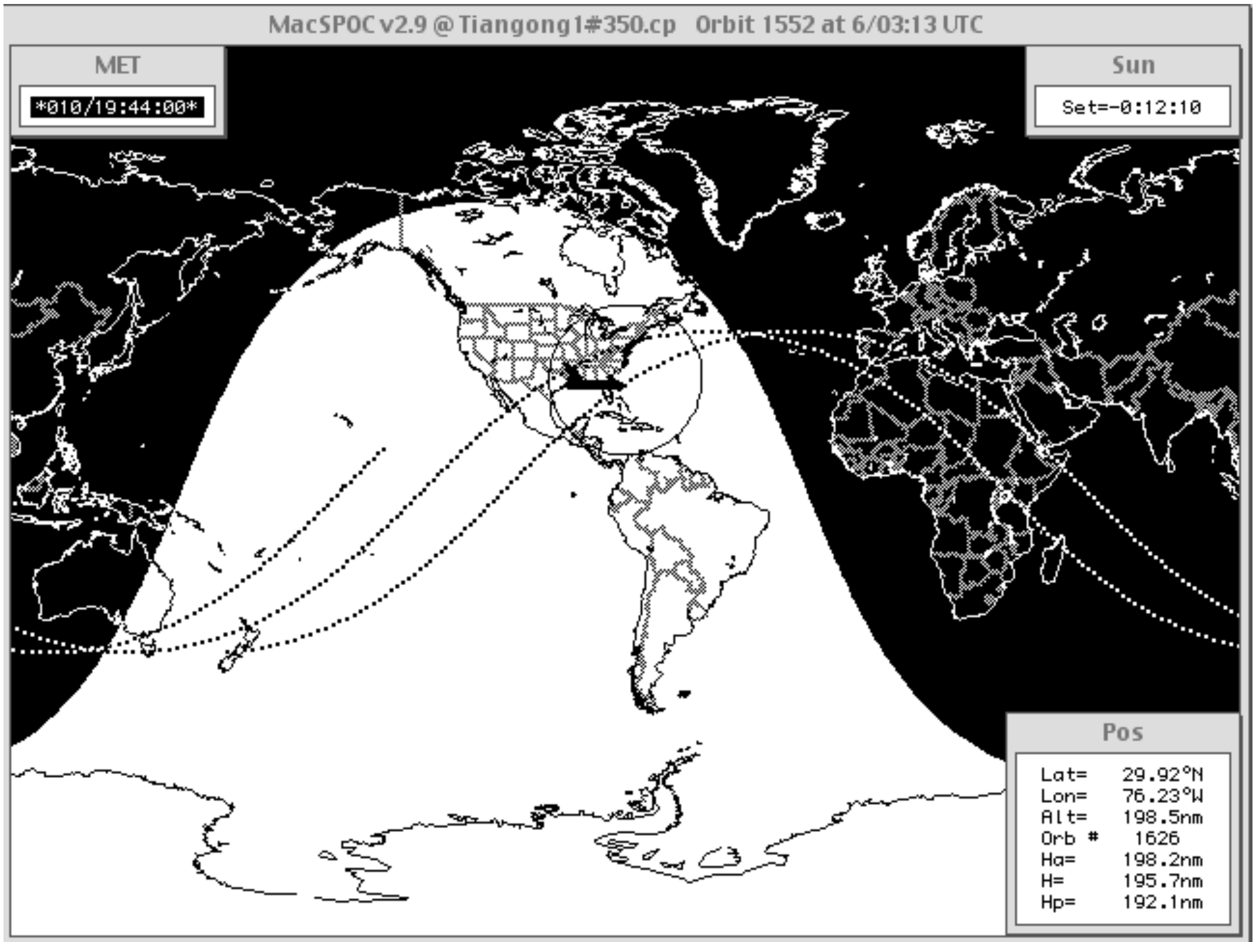

Figure 5. The Space Shuttle silhouette's nose on this world map denotes *Tiangong-1*'s location at the 10 January 2012 OTV-2 flyby. A circumscribing circle maps the *Tiangong-1* horizon at this time, and the Sun window shows *Tiangong-1* will enter Earth's shadow 12 min 10 sec after the flyby. Earth's nightside is reverse-field on the map.

The best OTV-2 orbit elements are classified and enjoy a pedigree supported by the U.S. Strategic Command's impressive Space Surveillance Network resources. Predictions based on these orbit solutions would typically coast over days of prediction with but a few to a few tens of km in position error. But such OTV-2 solutions are inaccessible to the foregoing analysis, and the flyby documented here may suffer from prediction errors amounting to hundreds of km or more. This error will magnify still further if either OTV-2 or *Tiangong-1* changes its orbit during the prediction interval.

Nevertheless, salient features reported for the 10 January 2012 flyby will occur unless one or more orbit maneuvers are performed sufficiently in advance. With the possible exception of the flyby's proximity to CCAFS, the event predicted here is certainly typical of other OTV-2/*Tiangong-1* flybys occurring multiple times per month. Whether or not these flyby opportunities are relevant to OTV-2's mission can only be a matter of speculation to the public. Perhaps this paper will help better inform that speculation.