AN IMPROVED RAND-USGS CONTROL NETWORK AND SIZE DETERMINATION FOR IO.

B. A. Archinal[1], M. E. Davies[2], T. R. Colvin[2], T. L. Becker[1], R. L. Kirk[1], and A. R. Gitlin[1], [1]U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA), [2]RAND (1700 Main Street, Santa Monica, CA 90401, USA).

Introduction: We present here the results of a recent new photogrammetric triangulation solution for the size and shape of Jupiter's moon Io. It is compared to previous such solutions, and on-going work to further improve these results is described. This work is also being done as part of a cooperative process of transferring software, data, and expertise on the subject of planetary control determination from RAND to USGS Flagstaff.

Significance: A good determination of a control network and shape model for Io is desirable for a number of reasons, including the practical one that it is needed in order to project spacecraft imagery in order to derive controlled mosaics of the surface of Io. In addition, such a network and shape model can be used to assist with current and future spacecraft operations in the vicinity of Io, and also serves to constrain various models on the internal structure of Io and its evolution.

Previous Results: There have been a number of solutions, obtained via various techniques, for the mean radius and axis lengths for Io over the past few years. These include the results of photogrammetric solutions using both Voyager and Galileo SSI image measurements, both by RAND-USGS and the DLR [1], solutions by Thomas et al. [2] obtained via absolute limb measurements from Galileo imagery, and a solution by Schubert et al. [3] derived entirely from Galileo spacecraft tracking data during four encounters with Io. However, the results of previous photogrammetric control network solutions for Io (e.g. from [1]) have been in question because the ellipsoidal axes differ significantly (e.g. are several km shorter) in length from those obtained via the limb measurement results of [2]. The latter, using a best-fit equilibrium shape, gives axis length determinations of a=1829.6±0.6 km, b=1819.2±0.5 km, and c=1815.8±0.4 km. In the former RAND-USGS solution, a=1826.5 km, b=1815.7 km, and c=1812.2 km. It is thought from geometrical arguments that the Thomas et al. values should be more accurate than those obtained via a control network solution. A more recent RAND-USGS solution, incorporating additional measurements of Galileo SSI images, gives axis lengths that are different from the other types of determinations by even larger values. This situation implied that there might be some fundamental problem in mixing the measurements from both Voyager and Galileo in the same solution.

A New Solution: A new photogrammetric solution has been derived, this time using only measurements from Galileo imagery. This has become possible only within the last year or so as additional images of Io have been obtained, extending longitude coverage of that body. The new solution includes 2148 measurements of 432 control points from 116 Galileo SSI images. Although the imagery provides for good longitudinal coverage of Io, there is currently a lack of control points in the region of 320º to 20º (east) longitude. Solved-for parameters include the control point positions (latitude and longitude), spacecraft camera angles (3 per image), and the 3 best fitting semi-axes for Io. The camera focal length and orbits were assumed known, and other constants were held at the IAU 1994 [4] values. The *a posteriori* mean measurement error of the solution was 7.7 micrometers (e.g. in the Galileo SSI camera image plane). This solution yielded a best-fit ellipsoid of a=1828.8±1.0 km, b=1820.8±0.5 km, and c=1816.9±1.3 km. The mean radius derived from these values is r=1822±1.3 km. These results are in line with those obtained by the other methods. However, this leaves the mystery unresolved as to why the solutions including Voyager measurements give such different results.

Comparison of solutions: There is no obvious reason why there would be a problem with the Voyager imagery of Io in particular. No similar problems have been seen with RAND-USGS control solutions for the other Galilean satellites [1], which included both Voyager and Galileo SSI imagery. However, there are a number of reasons why problems may result in the case of Io as opposed to the other satellites. First, the appearance of Io can vary dramatically between images of different colors or different phase angles, making the selection or at least measurement of control points difficult. The best fitting regular shape for Io is a triaxial ellipsoid, as opposed to a rotational ellipsoid or even a sphere in the case of the other moons. Io is also essentially unique in the solar system in that many features have changed between the Voyager and Galileo missions and even between individual encounters by Galileo, due to the ongoing resurfacing by volcanic processes – so the control points themselves can come and go – or even move between images. Finally, the image coverage from all three spacecraft (Galileo and particularly Voyager 1 and 2) of the sub-Jovian area of Io (at 0º degrees longitude) is rather poor. In order to try to determine which control points or (presumably) Voyager imagery is causing the discrepant results, a new solution was done using all the data, but with the axis lengths fixed at their Galileo SSI-derived values. Differencing the control point positions from their previously determined positions showed a number of large positional changes (up to 14 km), but only over a specific region of Io, i.e. near and to the west of the sub-Jovian point (0º longitude). A further solution was done with all the data holding everything fixed to the previous solution's values, except that the control point radii were solved for. The radii themselves showed only the differences between the original and newly determined ellipsoidal surfaces, but their standard deviations again showed a number of extreme values (up to 58 km) in the same area where the large horizontal changes occurred. In conclusion, it appears that there are simply problems with a number of control point measurements from the Voyager images covering this area. This has been partially confirmed by examining some of these images, and finding that the coverage of this area of Io by the two Voyager spacecraft was indeed rather poor, with most of the control points here occurring near the limb (i.e. at high emission angles) on the Voyager imagery. There are also some indications that these images and even the measurements (apparently done circa 1980 - by matching pin-pricked points on prints of the images) are of lower quality than for other areas of Io.

Continuing work: Further work is planned in order to continue to improve the results with both the Galileo and Voyager data. A few Galileo images obtained in 1999 and 2000 provide even better coverage of the sub-Jovian area of Io, and these will be used to add Galileo image control point measurements over this area, thus completing uniform coverage of these measurements over the entire surface. We expect this to provide some slight improvement in the control network and axis determinations for Io, and more specifically to provide additional images, with well-determined camera angles, for use in making a controlled Galileo image mosaic. Many of the Voyager control point measurements will also be examined, particularly in the region where there are now known to be problems, and problem measurements will be deleted or remeasured. It is also planned to use new capabilities in the USGS ISIS [5] software, which facilitates the measurement and automatic matching of control points at the sub-pixel level. This new method of point measurement alone should provide for significantly improved Voyager image measurements. Software work is also continuing to allow for the complete output of parameter variance-covariance information from the photogrammetric solutions, and the development of statistical tools to examine this information, the measurement residuals, and other products of these solutions.

Expected products: The outcome of this work will be a "final" improved control network and axis length determinations, based on Galileo SSI image measurements, with control points spaced relatively uniformly on Io's surface. We also plan to achieve a compatible solution (e.g. with respect to axis lengths and common control points) using Voyager measurements as well. These control networks and the associated camera angle information will then be used to project imagery to make at least two controlled mosaics, one with Galileo, and the other with Voyager images, so that the surface changes during the ~18 year period between these missions can be examined. This is as described in more detail elsewhere by Becker et al. [6] at this conference. A significant byproduct of this work will be the new availability of the RAND software and data at USGS Flagstaff, so that the use of this software and work to improve it can continue there. All of the RAND software and data available for planetary control work has already been copied for use at USGS and discussions regarding its use are ongoing between RAND and USGS personnel. Finally, the basic RAND software used to preprocess data and perform various triangulation solutions has been converted for use on a Linux platform, modified further, and used in this current study.

Summary: A new photogrammetric triangulation solution has been performed, using only Galileo SSI image measurements, which gives Io triaxial ellipsoid semi-axis estimates consistent with determinations by other methods. These estimates are: a=1828.8±1.0 km, b=1820.8±0.5 km, and c=1816.9±1.3 km, with a derived mean radius of r=1822±1.3 km. Work is continuing to improve this solution and to resolve problems with Voyager imagery measurements. Expertise, data, and software for doing planetary control solutions has also been transferred from RAND to USGS, and software improvements, particularly to develop statistical tools to analyze these photogrammetric solutions, are continuing at USGS.

References: [1] Davies et al., *Icarus*, 135, 372-376. [2] Thomas et al., *Icarus*, 135, 175-180. [3] Schubert et al., DPS2000 abstract. [4] Davies et al., *Cel. Mech. & Dyn. Ast.*, 63, 127-148. [5] Torson J. and Becker K. J, LPSC XXVIII, 1443-1444. [6] Becker, T. et al. this conference.