A Brief Discourse Concerning Velocity Corrections for IUE Data

Lyla L. Taylor
IUE RDAF

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Introduction

Since 10 November 1981 (at GSFC), high dispersion extracted data have been routinely corrected for the geocentric and heliocentric motion of IUE using algorithms described by Harvel (1980). Comparisons with the Goddard Trajectory Determination System's software and the IUE Telescope Operations Center's software have shown that VELSAT, the routine that calculates the geocentric velocity, is accurate to within 0.1 km/s when up-to-date orbital elements are used (Gass 1990). The results of the VELSUN algorithm, which calculates the heliocentric velocity, are also believed to be valid (Gass 1990). As discussed in Harvel (1980), it is possible to measure a radial velocity to an accuracy of about two kilometers per second with high dispersion IUE data.

IUE's orbital elements are osculating elements calculated by the Flight Dynamics facility at Goddard. The epochs given in the tables herein are for 0^h UT. The inclination is given with respect to the equator. The right ascension of the ascending node is measured along the equator from the vernal equinox. The argument of perigee is the angle between the ascending node and perigee, measured along the satellite's orbit. The mean anomaly is measured from perigee. The rectangular coordinate system for the velocity vector is such that the Z component points north, the X component points to the vernal equinox, and the Y component points ninety degrees from X and Z. The system is righthanded. This is shown in Figure 1.

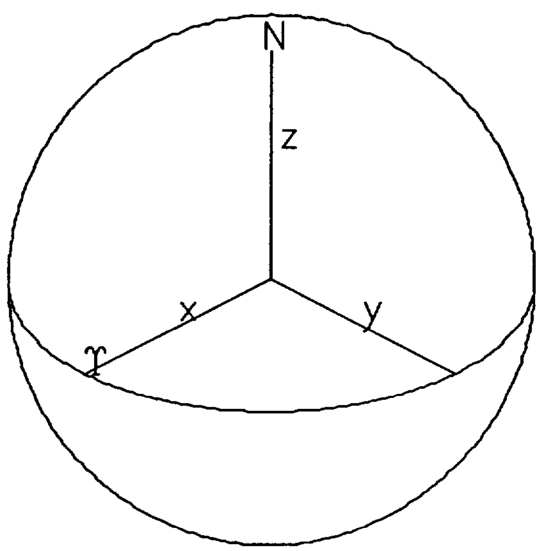

Figure 1: Coordinate System

Since the IUESIPS software uses a hardcoded (and therefore time-independent) set of orbital elements (epoch 22 November 1979), users who want accurate radial velocities may wish to correct their data. The maximum systematic error introduced by using the 1979 elements, while initially accurate to better than 1 km/s, has grown with time to worse than 3 km/s in the Z component. Figures 2, 3, and 4 show the difference between the velocity components calculated using every set of orbital elements available since launch and the velocities as calculated by IUESIPS for every day between 15 February 1978 and 13 February 1993, inclusive, at 0^h UT. Figure 5 shows the magnitude of the total difference, using the Pythagorean Theorem, for the same days.

Discussion

The error in the Z component is primarily caused by the evolution of the argument of perigee with time. This causes the Z component calculated with current elements to differ from that of IUESIPS not only in magnitude, but in frequency as well.

A sidereal day is almost four minutes shorter than a solar day. This means that there are nearly 366 sidereal days during one 365-day solar year. Since IUE's orbital period is approximately one sidereal day, there is a beat frequency of about one year for the mean anomaly. The eccentric anomaly as calculated by IUESIPS has about the same beat frequency as that calculated using current elements. IUESIPS uses a hardcoded period of one sidereal day.

This frequency is also approximately the same for the components of the velocity vectors of IUESIPS. Unfortunately, when current elements are used, the frequency (of the velocity vectors) is higher, obviously resulting in an error that has been increasing with time. Each of the three components has a different beat frequency, and thus a different daily period. The daily period for the Y component happens to be approximately one sidereal day, so it's not surprising that IUESIPS does a fairly good job with it. The period of Vx is several seconds shorter, and Vz has the shortest period of the three.

During a given day, the components of the velocity vectors may each vary by as much as six kilometers per second. The difference between vectors calculated with current elements and those calculated with IUESIPS will peak at various times of the day, depending on their relative phases. Figure 5 shows the magnitude of the velocities calculated for the same time of day (0 hours). Therefore, the maximum difference for any given day will only be depicted when it takes place at 0 hours, which should happen approximately once per year. An estimate of the maximum resulting systematic error for a particular day can be obtained by fitting an envelope to the peaks, since the peaks simply shift if the velocities are calculated for other times of day.

When the argument of perigee used by IUESIPS is substituted for the current argument of perigee, using current values for all other elements, the frequency of the Z component is very close to that calculated by IUESIPS. The X and Y components are also affected by the evolution of the right ascension of the ascending node, which is evolving in the opposite direction from the argument of perigee.

The station-keeping delta-V maneuvers which are done once or twice a year primarily affect the semimajor axis length, and thus the period of revolution. The evolution of all of the orbital elements with time is depicted in Fireman (1991). An extension of the table of elements published in the same article is given in Tables 2 and 3. As of this writing, three delta-V maneuvers have been performed since the last one listed in Fireman; they have been listed in Table 1.

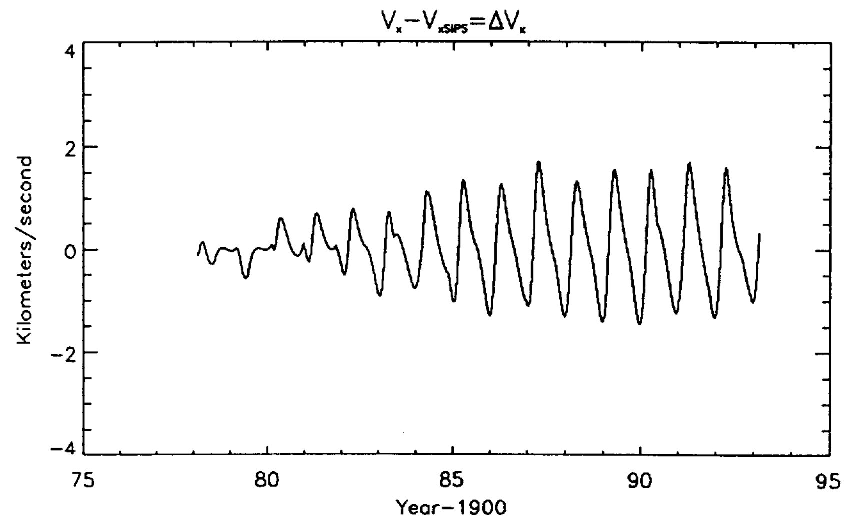

Figure 2: Difference in X Velocity

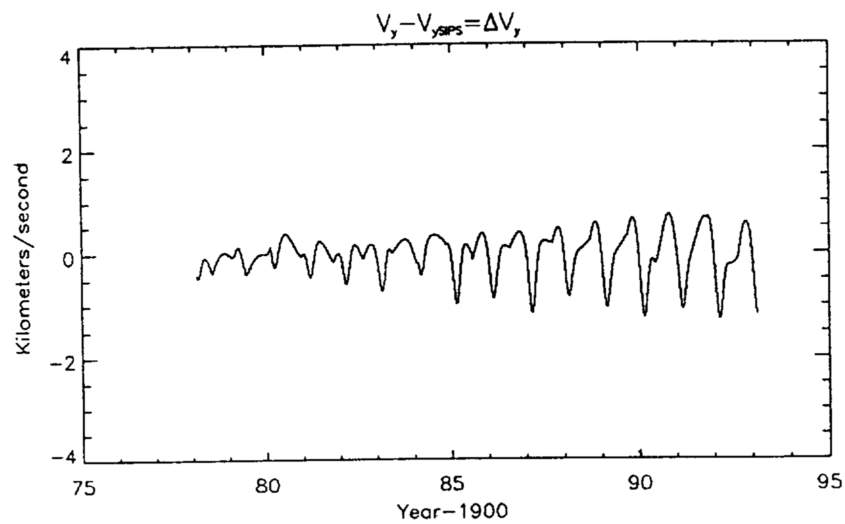

Figure 3: Difference in Y Velocity

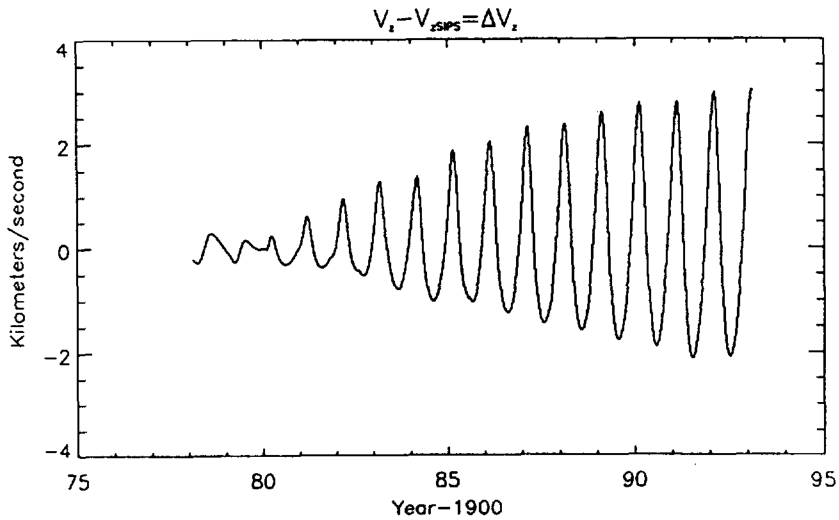

Figure 4: Difference in Z Velocity

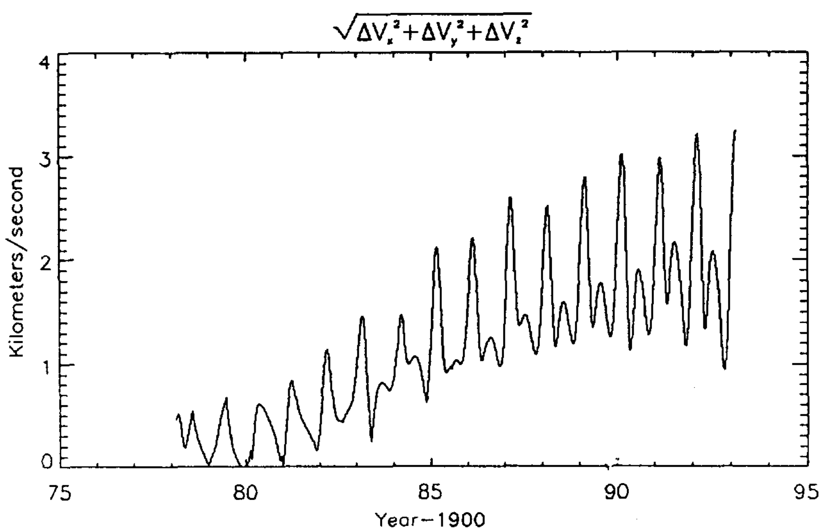

Figure 5: Magnitude of Velocity Difference

Data Correction Procecures

The IUE RDAF has implemented a routine (IUEVEL) to calculate the radial velocity corrected for both the heliocentric and geocentric motion of IUE. This routine has been in the experimental library for over a year. It uses Harvel's algorithm to calculate the geocentric velocity, but reads the orbital elements from a table and selects the set nearest in time to the observation date where no delta-V maneuver intervenes. The period is calculated using Kepler's third law. The program calls ann IDL version of VELSUN to calculate the heliocentric velocity. The right ascension and declination of the target are extracted from the scale factor record (or the VICAR label if not found) so that the net velocity toward the target can be determined as follows:

$$VNET = V_x \cos\alpha \cos\delta + V_y \sin\alpha \cos\delta + V_z \sin\delta$$

where α and δ are the right ascension and declination of the target, respectively, and V_x, V_y, and V_z are the sums of the components of the geocentric and the heliocentric velocity vectors.

For very recent observations, there may not yet be an entry in the table of orbital elements. In such cases, IUEVEL will extract the elements contained in line 83 of the VICAR label using a program called ORBEL. These are the most recent previous elements, regardless of possible subsequent delta-V maneuvers.

The midtime of exposure is assumed by IUESIPS to be the end-time minus half the total exposure time. This time is written in the image processing portion of the VICAR label and in the scale factor record. Along with the right ascension and declination of the target, the midtime will be extracted using a program called GETRADEC. If the midtime is not available from the sources mentioned above, the round-robin portion of the VICAR label (lines 10-32) will be read in and searched for EXPOBC and MODTIME commands using a routine called EXPOFIN. The total exposure time will be calculated, and the mid-time of observation will be obtained by finding the midpoint between the beginning of the first segment and the end of the last segment of the exposure. If no READ or PREP command for the previous image for that camera is found, the user will be warned, since not all segments of the exposure may be present. Users should exercise caution if the exposure time is a large fraction of a day, due to the variation in the geocentric velocity over one orbit.

How to Apply the Correction

The calling sequence of IUEVEL is as follows:

IUEVEL,IMAGET,v,vnet,vdc

where "imaget" is the filename of your data file, "v" will be your total velocity vector, "vnet" will be the net velocity of IUE toward your target, and "vdc" will be equal to "vnet" divided by the speed of light. Optionally, you can replace "imaget" with a null string, and IUEVEL will prompt you for the Julian date of observation and the coordinates of your target. The RDAF procedure JULDATE is available if you need to calculate the Julian date.

If your wavelengths have already been corrected by IUESIPS (*e.g.*, if your image was processed after 10 November 1981 at GSFC), you will need to un-correct them before applying the new correction. You can find the net velocity used by IUESIPS near the bottom of the label or in the scale factor record. If you've used IUE RDAF routines to extract your data vectors, element 54 of your "H" vector will contain the net velocity multiplied by ten. The net velocity should be divided by the speed of light.

Remove the correction of IUESIPS as follows: $w = (1 - h(54)/10./2.99792501^5) * w$

Correct your wavelength vector as follows: $w = (1 + vdc) * w$

The difference between the net velocity generated by IUEVEL and that generated by IUESIPS will depend on the location of your target in the sky and the phases of the components of the velocity vectors at the time of observation.

Note:

IUEVEL and its subroutines were not used to create the figures in this paper, because they were written with the goal of calculating one set of velocity vectors at a time. Instead, I wrote programs that would allow me to perform those calculations on as many sets of elements, and as many observation dates, as I wanted. These programs are not in the RDAF libraries, but I have them on the IUE Vax if anyone is interested in them. They use the same equations as IUEVEL.

REFERENCES

Fireman, G. F. 1991 *NASA IUE Newsletter*, **45**,13

Gass, J. E. 1990 *Record of the Meeting of the IUE User's Committee*, 19 October 1990, Appendix H.

Harvel, C. 1980 *NASA IUE Newsletter*, **10**, 32

Table 1: Recent Station-keeping Maneuvers

Date (yymmdd)	Time (hh:mm:ss)
911018	15:02:26
920819	16:16:29
921120	16:32:41

Table 2: IUE Orbital Elements

Epoch (yymmdd)	Semimajor Axis (km)	Eccentricity	Inclination (degrees)	Ascending Node (degrees)	Arg. of Perigee (degrees)	Mean Anomaly (degrees)
910311	42160.3	0.1408717	32.734	114.631	0.735	2.136
910326	42161.0	0.1404732	32.737	114.363	1.159	17.903
910405	42161.0	0.1401875	32.732	114.168	1.310	28.458
910418	42161.2	0.1399881	32.751	113.910	1.627	41.903
910501	42161.8	0.1398780	32.766	113.693	1.889	55.178
910513	42163.7	0.1398168	32.775	113.465	2.210	67.217
910527	42162.9	0.1398327	32.816	113.215	2.616	81.080
910607	42164.9	0.1398497	32.859	113.058	2.936	91.756
910619	42165.5	0.1398982	32.890	112.842	3.336	103.269

Table 3: IUE Orbital Elements Continued

Epoch (yymmdd)	Semimajor Axis (km)	Eccentricity	Inclination (degrees)	Ascending Node (degrees)	Arg. of Perigee (degrees)	Mean Anomaly (degrees)
910702	42166.1	0.1397836	32.932	112.656	3.776	115.548
910715	42167.4	0.1396413	32.963	112.449	4.245	127.612
910727	42168.7	0.1393527	32.986	112.290	4.658	138.625
910809	42170.8	0.1390231	33.005	112.084	5.130	150.355
910821	42172.0	0.1385551	33.009	111.900	5.523	161.089
910903	42173.3	0.1381378	33.011	111.681	5.939	172.541
910916	42173.9	0.1376466	33.014	111.460	6.302	183.894
910928	42172.8	0.1372582	33.005	111.254	6.662	194.214
911019	42156.7	0.1367374	33.030	110.874	6.970	212.304
911023	42155.6	0.1366583	33.025	110.789	7.024	216.761
911105	42156.9	0.1365689	33.048	110.547	7.335	230.995
911118	42157.7	0.1364684	33.080	110.318	7.670	245.016
911130	42158.5	0.1365520	33.119	110.105	8.000	257.774
911213	42159.3	0.1365578	33.164	109.897	8.374	271.380
911226	42160.1	0.1365983	33.201	109.695	8.784	284.752
920108	42160.8	0.1364827	33.245	109.499	9.233	297.936
920121	42161.2	0.1363681	33.274	109.316	9.685	310.917
920203	42162.4	0.1360487	33.299	109.132	10.138	323.753
920214	42165.8	0.1358634	33.298	108.944	10.428	334.586
920227	42166.9	0.1354555	33.286	108.745	10.821	347.176
920310	42167.4	0.1350641	33.305	108.537	11.177	358.672
920322	42168.4	0.1347342	33.295	108.317	11.514	10.045
920404	42169.3	0.1344922	33.297	108.084	11.843	22.240
920417	42169.8	0.1343819	33.314	107.842	12.157	34.300
920429	42170.9	0.1343648	33.336	107.627	12.457	45.251
920512	42171.8	0.1344907	33.363	107.394	12.766	56.954
920523	42171.7	0.1345777	33.406	107.206	13.032	66.718
920605	42171.9	0.1347453	33.440	106.989	13.406	77.993
920618	42173.8	0.1347615	33.483	106.791	13.800	89.039
920701	42175.1	0.1348010	33.510	106.591	14.272	99.816
920708	42176.7	0.1346181	33.516	106.490	14.576	105.455
920727	42178.7	0.1345136	33.554	106.214	15.248	120.702
920808	42179.8	0.1341947	33.570	106.020	15.703	130.104
920820	42156.7	0.1334511	33.568	105.838	16.069	139.523
920902	42157.5	0.1330800	33.575	105.623	16.522	153.376
920914	42158.3	0.1327642	33.574	105.429	16.903	166.036
920929	42159.2	0.1323896	33.581	105.142	17.332	181.798
921010	42160.7	0.1321714	33.591	104.970	17.639	193.165
921025	42161.4	0.1320074	33.608	104.683	17.990	208.585
921105	42163.2	0.1319615	33.639	104.493	18.270	219.681
921122	42150.5	0.1322390	33.673	104.177	18.520	237.006
921130	42151.1	0.1323675	33.712	104.061	18.768	246.171
921213	42151.5	0.1325521	33.751	103.855	19.134	260.955
921229	42152.9	0.1325182	33.793	103.629	19.684	278.734
930120	42155.3	0.1325165	33.841	103.298	20.375	302.794
930201	42157.4	0.1323371	33.851	103.115	20.802	315.618
930213	42159.0	0.1320948	33.854	102.929	21.235	328.277