The CycleCalcs API against JPL Horizons, 1700 to 2200

An accuracy report for Astronomy Engine 2.1.19 as served by the CycleCalcs API

Report version 2026-10, dated 2026-10-08. CycleCalcs LLC.
Engine: Astronomy Engine 2.1.19 (MIT, Don Cross), vendored as netlify/lib/vendor/astronomy-engine.mjs, SHA-256 068f1445ed0c636c94818fe6d20d7d125120e605e0bab9fc4675c3d531be5ad7.
Reference: JPL Horizons API v1.2 (DE441 era), fetched 2026-08-19 for the 69,402 places; API VERSION: 1.2; API SOURCE: NASA/JPL Horizons API, fetched 2026-10-08, for the event comparisons. Sign convention throughout: engine (or API) minus reference.
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1. Summary

Every CycleCalcs v2 response carries the claim, in meta.accuracy.statement, that positions are arcminute class for the Sun, Moon and planets across 1700 to 2200, degrading toward the ends of that window. Measured over 69,402 geocentric apparent places against JPL Horizons at the same Universal Time, the claim holds for the Sun and every planet across the whole window: the largest residual among them is 51.408 arcsec (Pluto, 1741-05-06), and the largest median is 10.384 arcsec (Neptune). It does not hold for the Moon in the final decades: the Moon's residual first exceeds one arcminute on 2081-08-06, its yearly median passes it in 2090, and it reaches 86.217 arcsec on 2099-09-16 and 240.337 arcsec on 2199-07-09, and its 2100s median is 141.982 arcsec against 1.020 arcsec in the 1900s. That tail is the gap between two delta-T policies rather than the lunar theory: at 2199-07-09 the engine extrapolates TT minus UT to 440.816 s where Horizons holds 69.183991 s, and at the same Terrestrial Time the first new moon of 2200 is 6.01 arcsec from Horizons (S7) where the same-UT figure is 228.95 arcsec. Event instants follow the positions: 90 of the 99 Moon quarters of 2026 and 2027 print the U.S. Naval Observatory's minute (S9), equinox and solstice instants are within 45.61 s of Horizons in Terrestrial Time across 1700 to 2200 and tens of seconds off in 2026 (F2), and this report corrects one statement on the API's accuracy page, the explanation of the constellation-entry gap against Horizons (section 7, F1), narrows another, the scope of the named-star check (section 7), and refines a third, the Mars distance figure (section 5).

Three sources, each named where it is used: the public accuracy study (summary.json and the residual CSVs of the data repository, reproduced here from the vendored engine), the Horizons event queries of 2026-10-08, and the repository's own reference sets S1 to S13, listed with their authorities and retrieval dates in section 2. "TT" is Terrestrial Time; "UT" is Universal Time, which the API reads as UTC. A residual is engine (or API) minus reference; an angular separation is unsigned.

2. What was compared

Bodies: Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. Span: 1700-01-01 to 2200-01-01 UT. Sampling: the Moon every 5 days (36,525 instants); the Sun and the planets every 50 days (3,653 instants each); 69,402 instants in all. The Moon is sampled ten times as densely because it moves about 13 degrees a day and is the body most sensitive to delta-T.

The compared quantity is the geocentric apparent place of date. On the engine side it is GeoVector(body, t, true): for the Sun and the planets, light time and annual aberration applied; for the Moon, GeoMoon(t), the geometric

place, whose light-time and aberration terms nearly cancel and together are under 1 arcsec (section 7). The vector is rotated to the true equator and equinox of date with Rotation_EQJ_EQD(t), which is the path /v2/positions takes. On the Horizons side it is quantity 2, apparent right ascension and declination of date, airless, for the geocenter (CENTER 500@399), ANG_FORMAT DEG, EXTRA_PREC YES. The residual is angular separation (acos of the dot product of unit vectors) between the engine apparent place of date and Horizons quantity 2, recomputed from the CSV RA/Dec columns (9 decimals, deg). Distances are abs(engine_dist_au - horizons_delta_au) * 149597870.7 km, from the 14-decimal au columns, where Horizons delta is the light-time-corrected range (quantity 20).

Time scales. The sample instants are Horizons UT calendar dates read into the engine as UTC, and each system applies its own delta-T. The places are therefore compared at the same Universal Time, which is what a caller asking both systems for one UTC instant receives, and the two delta-T policies enter the residual; section 4 separates them. The event comparisons of section 6 are made both ways, at the same UT and, where the data allows it, at the same Terrestrial Time. Before 1962 Horizons' UT is UT1 and the engine treats its UT the same way; after 1972 both are UTC.

The engine build. Astronomy Engine 2.1.19 is vendored unedited as netlify/lib/vendor/astronomy-engine.mjs, SHA-256 068f1445ed0c636c94818fe6d20d7d125120e605e0bab9fc4675c3d531be5ad7, matched byte for byte against the upstream release and re-verified on every build. The study loaded the same release from npm (astronomy-engine 2.1.19); its ESM build has the same SHA-256 as the vendored file. As the direct proof that the study measures the build this API serves, every engine column of the study's 69,402 CSV rows was recomputed with the vendored file: 69,402 of 69,402 rows reproduce right ascension, declination and distance at the printed precision, with the largest difference 1.8 microarcsec in right ascension, 1.8 microarcsec in declination and 1.1 mm in distance, which is the rounding of the printed decimals (9 of a degree, 14 of an au).

The Horizons side. Each body came from one OBSERVER query to the Horizons API, version 1.2, fetched 2026-08-19, Earth-orientation file eop.260818.p261114. The targets and their ephemeris sources, as the raw replies record them:

BODY	HORIZONS TARGET	SOURCE	CENTER	STEP	ROWS
Sun	Sun (10)	DE441	Earth (399) (DE441)	50 days	3,653
Moon	Moon (301)	DE441	Earth (399) (DE441)	5 days	36,525
Mercury	Mercury (199)	DE441	Earth (399) (DE441)	50 days	3,653
Venus	Venus (299)	DE441	Earth (399) (DE441)	50 days	3,653
Mars	Mars (499)	mar099	Earth (399) (DE441)	50 days	3,653
Jupiter	Jupiter (599)	jup365_merged	Earth (399) (DE441)	50 days	3,653
Saturn	Saturn Barycenter (6)	DE441	Earth (399) (DE441)	50 days	3,653
Uranus	Uranus (799)	ura184_merged	Earth (399) (DE441)	50 days	3,653
Neptune	Neptune Barycenter (8)	DE441	Earth (399) (DE441)	50 days	3,653
Pluto	Pluto Barycenter (9)	DE441	Earth (399) (DE441)	50 days	3,653

Table 1. The Horizons queries behind the 69,402 places, from the raw replies kept under accuracy/horizons/ in the data repository. Where Horizons has no body-center ephemeris across the whole span it served the system barycenter; the center-to-barycenter offset seen from Earth is far below the residuals measured.

Definitions used in the tables. Quantiles: linear interpolation between order statistics at index (n - 1) * q, as the study computes it; not nearest rank. Centuries: first two digits of the ISO year: 1700s covers 1700-01-01 to 1799-12-31. Rounding: arcsec to 3 decimals, km to 1 decimal, matching summary.json; the relative distance residual (percent of the Horizons range, per row) to 4 decimals and the mean apparent rate to 5, both additions of this report. Every statistic in the study's summary.json was recomputed from the CSVs with those definitions and reproduces at the printed precision. The 11 input files match the study's SHA256SUMS.txt manifest in full.

The event comparisons of sections 4 to 7 use Horizons queries made on 2026-10-08 (Ephemeris / API_USER Thu Oct 8 04:56:26 2026 Pasadena, USA / Horizons). Their targets: Sun: Sun (10) {source: DE441} / center DE441; Mercury: Mercury (199) {source: DE441} / center DE441; Mars: Mars (499) {source: mar099} / center DE441; Jupiter: Jupiter Barycenter (5) {source: DE441} / center DE441; Uranus: Uranus Barycenter (7) {source: DE441} / center DE441. The engine side of those comparisons is Astronomy Engine 2.1.19 (netlify/lib/vendor/astronomy-engine.mjs), through netlify/lib/v2/apparent.mjs for the seasons.

2.1 The repository's own reference sets

Section 6 also cites the comparisons the CycleCalcs repository runs on every build, labelled S1 to S13 as sprint/accuracy/residuals.md tabulates them. Each is a fixture file holding reference values from the authority named, re-differenced against the live engine by the build checks; none is an ephemeris of this report's scale, and the counts are small.

SET	WHAT IS COMPARED	AUTHORITY AND RETRIEVAL DATE	ROWS
S1	Topocentric airless altitude and azimuth, 6 bodies at 6 sites, whole days in 2026 and 2027	JPL Horizons API 1.2, quantity 4, fetched 2026-09-08	1,314
S2	Jupiter minus Saturn apparent longitude, 5-day rows within 5 deg of conjunction, 1700 to 2200	Horizons, DE441, quantity 31, retrieved 2026-09-25	1,023
S3	The 30 Jupiter-Saturn conjunctions of 1700 to 2200: instant, longitudes, least separation	Horizons, DE441, quantities 23 and 31, 30-minute rows, retrieved 2026-09-25	180
S4	Longitude crossings of Venus-Saturn, Venus-Mars, Saturn-Uranus, Uranus-Neptune and Jupiter-Saturn 1821	Horizons, DE441, quantities 2 and 31, retrieved 2026-09-25	24
S5	Conjunction, quadratures and opposition of Mars to Neptune, 2025 to 2027	Horizons, DE441, quantity 31, retrieved 2026-09-25	104
S6	The Sun at each multiple of 15 deg of apparent longitude, 2026	Horizons, DE441, quantity 31, hourly rows, retrieved 2026-09-25	48
S7	First new moon of 1700, 1800, 1900, 2000, 2026, 2100 and 2200, in UT and in TT	Horizons, DE441, quantity 31, 1-minute rows, queried 2026-09-25	28
S8	IAU constellation boundary crossings of Mercury, Mars, Saturn and Uranus, 2025 to 2033	Horizons, quantity 29, retrieved 2026-09-25	36
S9	Moon phase instants, 99 quarters, 2026 and 2027	U.S. Naval Observatory, Moon phases API 4.0.1, minute rounded, retrieved 2026-09-25	198
S10	Equinoxes and solstices, 2026 and 2027	U.S. Naval Observatory API 4.0.1, minute rounded, retrieved 2026-09-25	8
S11	Where the 2026 ecliptic crosses the IAU boundaries	astropy 7.2.0, an independent reduction, retrieved 2026-09-25	52
S12	Named stars, geocentric apparent place of date, 1750 to 2190	astropy 7.2.0 (ERFA) reduction of the same Bright Star Catalog numbers	5
S13	Total solar eclipses of 2027 and 2028 at greatest eclipse, and the gamma of 2024-04-08	NASA GSFC eclipse site (Espenak), Five Millennium Canon; no retrieval date recorded	13

Table 2. The in-repo reference sets, as residuals.md section 3 lists them. Rows is the number of reference values.

3. Results by body

The residual of the geocentric apparent place, engine against Horizons at the same UT, over the whole span. The median is the typical residual; p90 and p99 are the 90th and 99th percentiles; the maximum names the sampled instant it fell on.

BODY	N	MEDIAN	P90	P99	MAX	WORST AT
Sun	3,653	1.583	10.119	14.125	15.828	2199-12-11
Moon	36,525	7.558	141.940	208.139	240.337	2199-07-09
Mercury	3,653	3.804	13.742	26.850	37.332	2199-07-14
Venus	3,653	2.548	12.314	18.308	23.634	1703-11-02
Mars	3,653	2.280	7.509	11.897	23.189	1830-09-27
Jupiter	3,653	4.653	8.997	13.162	16.833	1715-11-19
Saturn	3,653	8.848	16.693	21.060	23.835	1709-12-30
Uranus	3,653	6.487	12.773	17.576	19.572	2036-01-30
Neptune	3,653	10.384	16.878	20.385	21.509	1848-09-02
Pluto	3,653	8.753	37.063	49.874	51.408	1741-05-06

Table 3. Residual of the geocentric apparent place by body, 1700-01-01 to 2200-01-01 UT, arcsec, engine minus Horizons at the same UT.

The Sun has the smallest median, 1.583 arcsec, and Neptune the largest, 10.384 arcsec. Saturn's century medians run from 7.672 to 10.819 arcsec and Neptune's from 8.784 to 12.223 arcsec, nearly flat across the window: for bodies that slow, the delta-T gap of section 4 moves the place by about 1.0 arcsec for Saturn and 0.3 arcsec for Neptune (the gap times each body's mean apparent rate over 2190 to 2199), so what remains is the planetary theory itself (VSOP87 in this engine). Pluto is the engine's own model at its limits, a gravitational integration between tabulated state vectors: its 1700s median is 37.070 arcsec with the window's largest non-lunar residual, 51.408 arcsec on 1741-05-06, against a 1900s median of 1.959 arcsec.

By century the pattern is the same for most bodies. For 8 of the 10 bodies (Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn and Pluto) the smallest century median falls in the 1900s, where both systems rest on measured Earth rotation; for 5 (Sun, Moon, Mercury, Venus and Mars) the largest falls in the 2100s, where the two delta-T extrapolations diverge. The Moon's medians are 1700s 11.401, 1800s 4.215, 1900s 1.020, 2000s 12.649, 2100s 141.982 arcsec.

BODY	1700S	1800S	1900S	2000S	2100S
Sun	2.094	1.349	0.754	1.176	10.122
Moon	11.401	4.215	1.020	12.649	141.982
Mercury	4.791	3.484	2.263	2.883	11.867
Venus	2.273	1.800	1.563	2.602	11.291
Mars	1.932	1.637	1.587	2.102	6.445
Jupiter	5.703	4.284	4.002	4.433	5.397
Saturn	8.167	8.252	7.672	10.819	9.607
Uranus	8.345	6.722	6.741	5.030	4.910

BODY	1700S	1800S	1900S	2000S	2100S
Neptune	8.784	9.007	10.755	12.223	11.864
Pluto	37.070	9.659	1.959	4.895	14.768

Table 4. Median residual by century, arcsec, same UT. Each cell summarizes the n of Table 5.

BODY	CENTURY	N	MEDIAN	P99	MAX	WORST AT
Sun	1700s	731	2.094	4.385	5.291	1708-10-06
Sun	1800s	730	1.349	2.781	3.123	1804-09-23
Sun	1900s	731	0.754	1.745	1.902	1940-02-13
Sun	2000s	730	1.176	5.567	7.710	2098-02-03
Sun	2100s	731	10.122	14.866	15.828	2199-12-11
Moon	1700s	7,305	11.401	18.470	20.081	1722-01-16
Moon	1800s	7,305	4.215	7.418	9.497	1808-04-10
Moon	1900s	7,305	1.020	3.225	5.156	1927-10-14
Moon	2000s	7,305	12.649	76.326	86.217	2099-09-16
Moon	2100s	7,305	141.982	224.734	240.337	2199-07-09
Mercury	1700s	731	4.791	16.643	17.257	1700-05-31
Mercury	1800s	730	3.484	12.981	14.505	1828-07-19
Mercury	1900s	731	2.263	6.551	7.810	1956-05-29
Mercury	2000s	730	2.883	11.629	16.847	2097-05-29
Mercury	2100s	731	11.867	31.240	37.332	2199-07-14
Venus	1700s	731	2.273	18.301	23.634	1703-11-02
Venus	1800s	730	1.800	12.817	18.284	1854-02-23
Venus	1900s	731	1.563	12.089	19.286	1950-02-10
Venus	2000s	730	2.602	11.205	19.667	2002-10-25
Venus	2100s	731	11.291	19.197	23.260	2157-12-01
Mars	1700s	731	1.932	14.733	22.111	1783-10-13
Mars	1800s	730	1.637	11.486	23.189	1830-09-27
Mars	1900s	731	1.587	9.468	12.171	1988-09-18
Mars	2000s	730	2.102	10.830	15.528	2095-06-29
Mars	2100s	731	6.445	12.537	14.968	2142-06-13
Jupiter	1700s	731	5.703	13.895	16.833	1715-11-19
Jupiter	1800s	730	4.284	10.814	13.339	1834-11-05
Jupiter	1900s	731	4.002	9.448	11.023	1949-07-25
Jupiter	2000s	730	4.433	11.710	13.800	2048-12-12
Jupiter	2100s	731	5.397	14.742	16.804	2166-12-14
Saturn	1700s	731	8.167	22.370	23.835	1709-12-30

BODY	CENTURY	N	MEDIAN	P99	MAX	WORST AT
Saturn	1800s	730	8.252	18.511	20.452	1893-04-19
Saturn	1900s	731	7.672	21.374	22.557	1927-05-22
Saturn	2000s	730	10.819	20.044	21.427	2089-11-17
Saturn	2100s	731	9.607	20.811	22.810	2157-03-26
Uranus	1700s	731	8.345	16.974	17.920	1728-05-04
Uranus	1800s	730	6.722	15.169	15.944	1867-12-22
Uranus	1900s	731	6.741	17.191	17.908	1952-01-11
Uranus	2000s	730	5.030	18.777	19.572	2036-01-30
Uranus	2100s	731	4.910	17.290	17.946	2149-06-06
Neptune	1700s	731	8.784	17.719	18.031	1796-05-17
Neptune	1800s	730	9.007	21.140	21.509	1848-09-02
Neptune	1900s	731	10.755	17.177	17.923	1969-04-11
Neptune	2000s	730	12.223	20.154	20.505	2014-09-22
Neptune	2100s	731	11.864	17.267	18.043	2147-07-07
Pluto	1700s	731	37.070	51.026	51.408	1741-05-06
Pluto	1800s	730	9.659	19.023	19.612	1800-08-15
Pluto	1900s	731	1.959	3.562	3.817	1900-02-22
Pluto	2000s	730	4.895	7.799	8.305	2099-09-26
Pluto	2100s	731	14.768	29.154	30.250	2199-02-14

Table 5. Residual of the geocentric apparent place by body and century, arcsec, engine minus Horizons at the same UT. A century covers its first year to its last; the 2100s end at 2200-01-01.

4. The delta-T policy and the Moon's tail

Delta-T, TT minus UT, is the Earth's rotational lag; it is measured to the present and extrapolated past it, and no ephemeris can know it for 2199. The engine follows the Espenak and Meeus piecewise polynomial, whose branch after 2005 is an extrapolating parabola; Horizons carries the last determined values of its Earth-orientation file forward nearly flat. Measured at 2199-07-09, the Moon's worst instant: engine TT minus UT 440.816 s, Horizons TDB minus UT 69.183991 s (TDB-UT (quantity 30), 367 daily rows fetched 2026-10-08; TDB and TT differ by under 2 ms). The gap is 371.632 s. At 2200-01-01 the two are 441.987 s and 69.1838 s; at 1700-01-01 the engine gives 8.986 s.

YEAR	ENGINE DELTA-T (S)	HORIZONS TDB - UT (S)	DIFFERENCE (S)
1700	8.858	14.737	-5.879
1750	13.395	17.369	-3.974
1800	13.661	18.546	-4.885
1850	7.129	9.527	-2.398
1900	-2.527	-1.693	-0.834

YEAR	ENGINE DELTA-T (S)	HORIZONS TDB - UT (S)	DIFFERENCE (S)
1950	29.142	29.015	+0.127
2000	63.917	64.186	-0.269
2050	93.361	69.186	+24.175
2100	203.158	69.186	+133.972
2150	328.855	69.186	+259.669
2200	442.512	69.186	+373.326

Table 6. Delta-T at the March equinox of each sampled year: the engine's Espenak-Meeus value and the TDB minus UT Horizons applied (quantity 30), seconds. Difference is engine minus Horizons.

The gap times each body's apparent motion reproduces the far tail. The study quotes mean rates of about 0.55 arcsec per second of time for the Moon and 0.041 for the Sun; 371.6 s of delta-T is then about 204 arcsec for the Moon and 15.2 arcsec for the Sun, against the measured Moon p99 of 208.139 arcsec and maximum of 240.337 arcsec, and the Sun's maximum of 15.828 arcsec on 2199-12-11. Mercury and Venus, which move at about the Sun's rate, show the same rise in the 2100s (medians 11.867 and 11.291 arcsec against 2.263 and 1.563 in the 1900s). On the way to that tail the Moon's residual first exceeds one arcminute on 2081-08-06 and its yearly median passes it in 2090; 8,063 of its 36,525 samples are above it.

The same comparison at the same Terrestrial Time takes the policies out and shows the lunar theory alone. At the first new moon of 2100 and 2200 the Moon-minus-Sun longitude is 0.44 and 6.01 arcsec from Horizons once TT is aligned, against 68.73 and 228.95 arcsec at the same UT (S7); the new-moon instants themselves are 0.9 and 10.1 s off in TT against 134.4 and 383.0 s in UT. The equinoxes and solstices of section 6 say the same in seconds: across 1700 to 2200 the largest residual in TT is 45.61 s and in UT 370.31 s. A caller comparing this API with Horizons in 2199 will see the arcminutes of Table 5; a caller in 2199 comparing either with the sky will see whatever the Earth's rotation did.

At the early edge the picture reverses: delta-T is small and the lunar theory is the limit. From 1700 to 1850 the engine's delta-T is 2.398 to 5.879 s below Horizons' (Table 6), worth about 3.2 arcsec of lunar motion, while the Moon's 1700s median is 11.401 arcsec at the same UT and the TT-aligned new-moon residual of 1700 is 15.72 arcsec, of 1800 9.25 arcsec (S7). The engine's own lunar ephemeris, the Improved Lunar Ephemeris of 1954 adapted from Montenbruck and Pfleger, degrades toward 1700 on its own.

The API publishes the present departure of its delta-T model from the leap-second chain on every /v2/time response as delta_t_model_residual_seconds; api/accuracy.html tabulates it (6.224 s on 2026-07-31, 15.536 s at 2040-01-01) and the size of its effect on a geocentric place (Moon 3.26 arcsec for the 2026 value). Those figures are the page's; this report measures the same policy against Horizons rather than against TAI.

5. Distances

The distance residual is abs(engine_dist_au - horizons_delta_au) * 149597870.7 km, from the 14-decimal au columns, the engine's vector length against Horizons delta, the light-time-corrected range. It is absolute; as a fraction of each body's range, per row, the Moon's 24.7 km median and Pluto's 379,642.9 km are the same fraction, 0.0064 percent, and Pluto's 1,005,681.4 km maximum is 0.0158 percent (the engine's Pluto model at its limits).

BODY	MEDIAN (KM)	P99 (KM)	MAX (KM)	MEDIAN (% OF RANGE)	MAX (% OF RANGE)
Sun	521.7	1,819.8	2,531.7	0.0003	0.0017
Moon	24.7	57.9	76.3	0.0064	0.0198
Mercury	4,359.5	19,426.7	25,709.0	0.0029	0.0170
Venus	7,898.4	15,020.3	18,134.7	0.0051	0.0175
Mars	15,265.8	26,105.9	29,813.9	0.0067	0.0160
Jupiter	50,882.8	105,644.0	126,003.7	0.0065	0.0156
Saturn	92,433.0	209,784.7	246,531.7	0.0065	0.0164
Uranus	192,144.9	368,057.2	425,108.1	0.0067	0.0151
Neptune	295,401.1	610,457.8	657,167.2	0.0066	0.0145
Pluto	379,642.9	926,524.6	1,005,681.4	0.0064	0.0158

Table 7. Absolute distance residual by body, km, engine minus Horizons delta at the same UT, over the whole span. The last two columns are the same residual as a percentage of the Horizons range, taken per row.

5.1 The distance_au convention, worked for Mars on 2026-08-19

distance_au on /v2/positions is the length of the aberration-corrected direction vector, not the classical light-time range. At 2026-08-19 00:00:00.000 UTC the engine's distance_au for Mars is 1.917185725517 au; its own unaberrated light-time range is 1.917038033199 au; Horizons' range (quantity 20) is 1.91702062064844 au, and Horizons' one-way light time of 15.94337434 min gives the same range to 0 km. The engine's distance_au exceeds Horizons' range by 24,699 km, about 1 part in 10,000. Of that, 22,094 km is the convention, the aberrated length minus the engine's own light-time range, and 2,605 km is the difference between the two ephemerides' light-time ranges.

api/accuracy.html states the convention and prints the 24,699 km figure as the difference between distance_au and the light-time range. Measured, that figure is distance_au minus Horizons' range; the engine's own aberrated-minus-light-time difference is 22,094 km. Both are a definition rather than an error; a caller who needs the light-time range should take it from Horizons quantity 20 or from the engine's unaberrated vector, and compare against Horizons quantity 2 to see the angular accuracy this report measures.

6. Event timing

An event instant is a position search: a phase is the instant the Moon's apparent ecliptic longitude minus the Sun's reaches 0, 90, 180 or 270 deg; a season the instant the Sun's reaches its defining value; a conjunction the crossing or least separation of two apparent places. The instants inherit the position residuals of section 3 divided by the rate of the quantity searched, plus the delta-T policy where the comparison is in UT. The searches themselves converge far tighter than this: 0.1 s for phases, 0.01 s for seasons, 1 s for separation minima.

6.1 Moon phases against the U.S. Naval Observatory

Over the 99 quarters of 2026 and 2027 (S9) the API's instant, rounded to the minute, equals the Naval Observatory's published minute for 90 of 99. Against the USNO minute the residual is 18.1 s RMS over all quarters, the largest 35.2 s; by quarter, new moons 16.1 s RMS, first quarters 20.1 s, full moons 17.8 s, last quarters 18.3 s.

The new-moon instants against Horizons at seven dates across the window (S7) are in section 4: within 5 s in TT from 1900 to 2100, 17.2 s early in 1800, 34.9 s early in 1700, 10.1 s early in 2200.

6.2 Equinoxes and solstices against Horizons, 1700 to 2200

For every year 1700, 1750, 1800, 1850, 1900, 1950, 2000, 2050, 2100, 2150, 2200 the four season instants were compared with Horizons. Horizons: the crossing of ObsEcLon (quantity 31, apparent ecliptic longitude of date) through 0, 90, 180 or 270 deg, linear between 10-minute rows in UT. Engine: apparentSeasons (netlify/lib/v2/apparent.mjs), the search /v2/seasons runs, 0.01 s tolerance. residual_s_ut: engine UT minus Horizons UT. residual_s_tt: the same two crossings in Terrestrial Time, the engine with its own Espenak-Meeus delta-T and Horizons with the TDB-UT it reports (quantity 30) interpolated to its crossing; TDB and TT differ by under 2 ms. Before 1962 Horizons' UT is UT1 and the engine's is the same scale; after 1972 both are UTC. Horizons' longitudes carry 7 decimals, 0.4 mas, about 10 ms of the Sun's motion. That is 44 instants.

CENTURY	N	RMS, TT (S)	MAX, TT (S)	MAX, UT (S)
1700s	8	26.08	45.61	39.93
1800s	8	19.56	36.02	33.62
1900s	8	16.55	26.25	26.38
2000s	8	14.84	22.26	44.96
2100s	8	16.42	31.50	248.40
2200s	4	21.12	35.44	370.31

Table 8. Season instants by century, engine minus Horizons, seconds. RMS and maximum in Terrestrial Time (both delta-T values applied), maximum in Universal Time (what a caller sees). The 2200s hold only the four events of 2200.

In Terrestrial Time the residual is tens of seconds in every century and largest at the early edge (1700s RMS 26.08 s), which is the solar theory; in Universal Time it is the same until 2000 and then grows with the delta-T gap to 370.31 s in 2200. For 2026, the year the site's pages print (finding F2): against Horizons the engine puts the March equinox 25 s early, the June solstice 36 s late, the September equinox 26 s late and the December solstice 1 s early (S6). Rounded to the minute, the June solstice prints 08:25 where the Naval Observatory prints 08:24, and the September equinox 00:06 where it prints 00:05; over the eight seasons of 2026 and 2027 the rounded minute equals the USNO minute for 5 of 8, with a residual of 34.6 s RMS and 68.4 s at most (S10). The Sun's apparent longitude at the 24 solar terms of 2026 is 1.02 arcsec RMS from Horizons, 1.74 arcsec at worst, and the 24 crossing instants 25.0 s RMS, 43.7 s at most (S6).

YEAR	EVENT	ENGINE (UTC)	HORIZONS (UTC)	UT (S)	TT (S)
1700	March equinox	1700-03-20 14:26:19.391	1700-03-20 14:26:46.449	-27.06	-32.94
1700	June solstice	1700-06-21 13:51:56.306	1700-06-21 13:52:18.272	-21.97	-27.74
1700	September equinox	1700-09-23 02:27:49.306	1700-09-23 02:28:29.233	-39.93	-45.61
1700	December solstice	1700-12-21 17:37:34.526	1700-12-21 17:37:55.918	-21.39	-26.98
1750	March equinox	1750-03-20 17:11:09.654	1750-03-20 17:11:21.349	-11.69	-15.67
1750	June solstice	1750-06-21 15:44:43.314	1750-06-21 15:44:38.872	+4.44	+0.45
1750	September equinox	1750-09-23 04:49:16.470	1750-09-23 04:49:35.052	-18.58	-22.59
1750	December solstice	1750-12-21 20:50:32.325	1750-12-21 20:50:23.518	+8.81	+4.78
1800	March equinox	1800-03-20 20:11:28.760	1800-03-20 20:11:33.277	-4.52	-9.40
1800	June solstice	1800-06-21 17:51:32.803	1800-06-21 17:51:35.105	-2.30	-7.18

YEAR	EVENT	ENGINE (UTC)	HORIZONS (UTC)	UT (S)	TT (S)
1800	September equinox	1800-09-23 07:25:33.613	1800-09-23 07:25:33.026	+0.59	-4.28
1800	December solstice	1800-12-22 00:16:00.022	1800-12-22 00:16:12.135	-12.11	-16.97
1850	March equinox	1850-03-20 23:01:17.723	1850-03-20 23:01:51.344	-33.62	-36.02
1850	June solstice	1850-06-21 19:58:26.070	1850-06-21 19:58:42.727	-16.66	-19.11
1850	September equinox	1850-09-23 09:59:46.877	1850-09-23 10:00:06.993	-20.12	-22.63
1850	December solstice	1850-12-22 03:37:06.119	1850-12-22 03:37:24.541	-18.42	-20.99
1900	March equinox	1900-03-21 01:38:55.830	1900-03-21 01:39:05.702	-9.87	-10.71
1900	June solstice	1900-06-21 21:40:08.126	1900-06-21 21:39:51.677	+16.45	+15.68
1900	September equinox	1900-09-23 12:20:40.278	1900-09-23 12:20:15.544	+24.73	+24.01
1900	December solstice	1900-12-22 06:41:24.409	1900-12-22 06:41:38.519	-14.11	-14.80
1950	March equinox	1950-03-21 04:34:54.558	1950-03-21 04:35:08.816	-14.26	-14.13
1950	June solstice	1950-06-21 23:36:03.096	1950-06-21 23:36:02.097	+1.00	+1.13
1950	September equinox	1950-09-23 14:43:45.453	1950-09-23 14:43:33.582	+11.87	+12.00
1950	December solstice	1950-12-22 10:12:53.540	1950-12-22 10:13:19.924	-26.38	-26.25
2000	March equinox	2000-03-20 07:35:13.561	2000-03-20 07:35:15.522	-1.96	-2.23
2000	June solstice	2000-06-21 01:47:47.351	2000-06-21 01:47:43.275	+4.08	+3.88
2000	September equinox	2000-09-22 17:27:58.908	2000-09-22 17:27:36.530	+22.38	+22.26
2000	December solstice	2000-12-21 13:37:43.877	2000-12-21 13:37:26.614	+17.26	+17.20
2050	March equinox	2050-03-20 10:19:25.999	2050-03-20 10:19:44.297	-18.30	+5.88
2050	June solstice	2050-06-21 03:33:04.405	2050-06-21 03:33:11.102	-6.70	+18.00
2050	September equinox	2050-09-22 19:28:30.764	2050-09-22 19:28:41.097	-10.33	+14.89
2050	December solstice	2050-12-21 16:38:07.882	2050-12-21 16:38:52.845	-44.96	-19.24
2100	March equinox	2100-03-20 13:03:06.930	2100-03-20 13:05:33.725	-146.80	-12.82
2100	June solstice	2100-06-21 05:31:53.781	2100-06-21 05:34:04.768	-130.99	+3.58
2100	September equinox	2100-09-22 22:00:08.967	2100-09-22 22:02:21.940	-132.97	+2.21
2100	December solstice	2100-12-21 19:50:42.070	2100-12-21 19:52:47.194	-125.12	+10.63
2150	March equinox	2150-03-20 16:01:13.537	2150-03-20 16:05:01.707	-228.17	+31.50
2150	June solstice	2150-06-21 07:28:53.610	2150-06-21 07:33:00.656	-247.05	+13.16
2150	September equinox	2150-09-23 00:28:18.480	2150-09-23 00:32:16.168	-237.69	+23.06
2150	December solstice	2150-12-21 23:20:52.204	2150-12-21 23:25:00.607	-248.40	+12.87
2200	March equinox	2200-03-20 18:40:49.447	2200-03-20 18:46:27.332	-337.89	+35.44
2200	June solstice	2200-06-21 09:16:07.455	2200-06-21 09:22:05.138	-357.68	+16.26
2200	September equinox	2200-09-23 02:40:52.453	2200-09-23 02:47:02.762	-370.31	+4.26
2200	December solstice	2200-12-22 02:26:34.807	2200-12-22 02:32:34.278	-359.47	+15.70

Table 9. Every season instant compared, UTC to the millisecond as the data file holds them. Residuals are engine minus Horizons: in UT as served, and in TT with each system's own delta-T applied.

6.3 Planet events, conjunctions and close approaches

Conjunction with the Sun, the quadratures and opposition of Mars to Neptune over 2025 to 2027 (S5) fall within 1.30 min of Horizons for Mars, Jupiter and Uranus, 4.40 min for Saturn and 5.42 min for Neptune, the planet-minus-Sun longitude at the Horizons instant being 1.91, 1.84, 1.14, 8.80 and 11.68 arcsec RMS respectively. The 30 Jupiter-Saturn conjunctions of 1700 to 2200 (S3) are timed within 59.47 min, median 9.51 min; Jupiter's longitude at the Horizons instant is 1.21 to 3.34 arcsec RMS by century and Saturn's 2.57 to 4.44, the least separation 9.27 arcsec RMS and 22.26 arcsec at most (2179-05-28). Over the 1,023 five-day rows within 5 deg of those conjunctions (S2) the Jupiter-minus-Saturn longitude is 3.36 to 5.96 arcsec RMS by century, 12.23 arcsec at worst (1822). Slow pairs are hours off because the relative motion is slow, not because the places are worse (S4): Saturn-Uranus crossings of 1988 and 2032 by up to 109.19 min, Uranus-Neptune of 1993 by up to 449.57 min, with the longitude differences at the Horizons instants 8.49 and 9.37 arcsec RMS; the Venus-Saturn crossings of 2025 and Venus-Mars of 2022 by up to 11.84 and 20.42 min.

WINDOW	ENGINE (DEG)	HORIZONS (DEG)	DIFF (ARCSEC)	ENGINE INSTANT (UTC)	HORIZONS INSTANT (UTC)	DIFF (MIN)
2038-Feb-16 00:00:00 to 2038-Feb-23 00:00:00 UT, 30-minute rows	0.06179	0.05661	+18.6	2038-02-19 18:15:35	2038-02-19 17:44:09	+31.4
2038-Mar-27 00:00:00 to 2038-Apr-03 00:00:00 UT, 30-minute rows	0.02625	0.02123	+18.1	2038-03-30 21:28:33	2038-03-30 21:49:21	-20.8

Table 10. Jupiter and Uranus in 2038, least apparent separation, engine against Horizons (see the note below). Differences are engine minus Horizons.

Horizons: the least angle between the two apparent ecliptic directions (ObsEcLon, ObsEcLat), parabola through the three 30-minute rows around the smallest sample; COMMAND 5 and 7 are the system barycenters, within about 0.1 arcsec of the planets at these distances. Engine: AngleBetween of GeoVector(body, t, true) for the two planet centres, the separation /v2/conjunctions minimizes, golden-section to 1 s. api/accuracy.html line 500 prints 0.0618 deg on 2038-02-19 and 0.0263 deg on 2038-03-30 for the engine against 0.0566 and 0.0212 in DE441.

6.4 Solar eclipses against NASA, and named stars against astropy

For the four total solar eclipses of 2027 and 2028 at greatest eclipse (S13) the API's path width is within 2.1 km of the NASA GSFC value (1.7 km RMS), the central duration within 3.5 s (2.7 s RMS) and the Sun's altitude within 0.020 deg; the gamma of 2024-04-08 is 0.3431 in both. For the five named-star rows the repository holds (S12), the geocentric apparent place of date from 1750 to 2190 is within 0.07 arcsec of an independent astropy 7.2.0 (ERFA) reduction of the same Bright Star Catalog numbers, 0.05 arcsec RMS; the catalog's own precision is 1 arcsec of declination. Topocentric airless altitude and azimuth at six sites over whole days in 2026 and 2027 (S1) are 1.22 arcsec RMS from Horizons for the Sun, 2.60 for the Moon (1.37 once TT is aligned), 0.65 for Mars, 2.02 for Jupiter, 5.78 for Venus (9.18 at most, near inferior conjunction) and 11.63 for Saturn.

7. Known limits and open findings

For most questions the ephemeris is the smallest term. api/accuracy.html orders the larger ones; they are restated here because a reader of this report should not take an arcsecond-class position for an arcsecond-class rise time.

- Horizon dip is not modelled: the engine's dip function is called with zero metres above ground. An observer at 3000 m with a sea horizon sees sunrise about 13.9 minutes earlier than the published time, and the API reports moonrise and planet rises about a minute later than at sea level because thinner air shrinks its 34-arcminute

allowance. The dip to apply is 1.753 times the square root of the elevation in metres, in arcminutes, and /v2/conventions publishes it.

- Refraction takes no weather. The Saemundsson expression as coded is a function of altitude alone, so no temperature, pressure or humidity enters; a cold, high-pressure night moves a London midsummer sunrise 28.2 s against the published time, and a strong inversion more than any table predicts.
- UT1 is treated as equal to UTC. No IERS bulletin is loaded, so any instant that is really a question about how far the Earth has turned can be out by up to 0.9 s from that alone; the topocentric rows of S1 carry that term at up to 15 arcsec per second of UT1 minus UTC. Before 1972 there is no leap-second chain at all.
- Delta-T is extrapolated after the measured record by the Espenak-Meeus parabola, section 4: a few arcseconds on a 2040 lunar place, arcminutes by 2199 against Horizons, and a reconstruction with a standard error of about 5 s in 1700 before it.
- The Moon's place is geometric: its light time of about 1.3 s, which Horizons applies, moves it by under 1 arcsec and enters every TT new-moon figure of S7 as about -1.3 s. Light deflection by the Sun is not applied (0.004 arcsec at 90 deg from the Sun, 1.75 arcsec at the limb), nor is polar motion, a milliarcsecond term.

7.1 Finding F1: which place Horizons names a constellation for, and the engine's B1875 frame

Before this report, api/accuracy.html explained the gap between its constellation-entry instants and Horizons' by saying that Horizons names the constellation of the astrometric place, about 20 arcsec of aberration away. Horizons' own documentation of its Cnst column (quantity 29) reads: "Constellation ID; the 3-letter abbreviation for the name of the constellation containing the target centers' astrometric position, as defined by IAU (1930) boundary delineation. See documentation for list of abbreviations." The data decides otherwise. For each of the 4 flips of the Cnst column in the Mercury and Mars windows of 2025-05-12 and 2026-04-19 and 2026-04-21, at one-minute rows, the crossing instant of the astrometric place (quantity 1) and of the apparent place (quantity 2) through the IAU boundary was bisected, with the engine's lookup as served and with the mean-B1875 lookup described below. The rule: For every Horizons Cnst flip, the place (astrometric, quantity 1, or apparent, quantity 2) whose own IAU-boundary crossing, read with the mean-B1875 lookup, lands nearest the midpoint of the one-minute interval in which Horizons flips. The verdict is that place when it is the same at every flip.

BODY AND DATE	FLIP (UT)	NAMES	ASTROMETRIC, MEAN B1875	APPARENT, MEAN B1875	AS SERVED: ASTROMETRIC / APPARENT
Mercury 2025-05-12	12:49 to 12:50	Psc to Cet	12:45:05.947, -264.1 s	12:49:39.170, +9.2 s	-159.5 / +113.6 s
Mercury 2025-05-12	14:03 to 14:04	Cet to Ari	14:00:22.939, -187.1 s	14:04:02.666, +32.7 s	-250.7 / -31.0 s
Mars 2026-04-19	00:26 to 00:27	Psc to Cet	00:17:08.994, -561.0 s	00:27:08.584, +38.6 s	-363.8 / +235.8 s
Mars 2026-04-21	20:47 to 20:48	Cet to Psc	20:38:43.799, -526.2 s	20:48:14.854, +44.9 s	-412.8 / +158.2 s

Table 11. The four Horizons Cnst flips and the boundary crossings of each place. Offsets are seconds from the midpoint of the one-minute interval in which Horizons flips; positive is later. "Mean B1875" is the corrected lookup; "as served" is the engine's own.

Verdict: apparent. At every flip the apparent place with the corrected lookup crosses within 9.2 to 44.9 s of the midpoint of Horizons' flip interval, while the astrometric place crosses 187.1 to 561.0 s away. Horizons' Cnst column behaves as a lookup of the apparent place, whatever its documentation says, and the page's explanation is not supported by the measurement. What does separate the two systems is the engine's frame. Constellation() rotates J2000 into B1875 with a rotation that includes nutation, so it labels against the true equator of B1875, while the IAU 1930 boundaries are drawn on the mean equator; the nutation at that epoch is -6.17 arcsec in longitude and +7.97 arcsec in obliquity, so every boundary sits several arcsec off. Against astropy the 13 ecliptic boundary longitudes of 2026 are 2.7 to 24.7 arcsec off as served (9.34 arcsec RMS) and 1.30 arcsec RMS, 1.89 at worst, once the nutation

is removed (S11). Against Horizons' crossings the API as served is up to 1.45 min off for Mercury, 4.89 min for Mars, 63.97 min for Saturn and 112.33 min for Uranus; with the frame corrected and the apparent place kept, up to 0.36, 3.00, 45.82 and 47.35 min (S8). The remaining minutes for Saturn and Uranus are what a few arcseconds of position become for a body near its station.

The vendored engine is never edited, so the correction would be a wrapper in the API's own code. It would move /v2 output for any body within about 10 arcsec of a boundary, which is a contract decision recorded for the owner, not made by this report. Until it is made, constellation-entry instants on /v2/planet-events carry the frame offset above, and api/accuracy.html's sentence on the Horizons gap is withdrawn by this report.

7.2 Finding F2: season instants are tens of seconds off

Section 6.2 measures it: 14.84 s RMS in TT for the 2000s, and for 2026 a June solstice that prints 08:25 UTC where the Naval Observatory prints 08:24 and a September equinox that prints 00:06 where it prints 00:05 (S6, S10). The site's season pages, the calendar feeds and the paid calendar print the same instants rounded to the minute, so they inherit it; the repository's learn-facts check holds only the season lengths, to 0.05 day, and does not catch a minute. The cause is the Sun's apparent longitude, 1.02 arcsec RMS from Horizons in 2026 (S6), which at the Sun's rate of about 0.041 arcsec per second is about 25 s; it is the solar theory, not the search, which converges to 0.01 s. No correction is proposed in this report; the figures are stated so that a page printing a season minute can cite its uncertainty.

7.3 What this report does not cover

- Topocentric places outside 2026 and 2027 (S1 holds 1,314 rows over four days), and rise, set and transit times against any authority. A rise time adds the horizon, refraction and UT1 conventions above to the position, and those dominate it.
- Lunar eclipses. Solar eclipses are compared only at greatest eclipse for four total events of 2027 and 2028 and one gamma (S13).
- Named stars beyond the five rows of S12. api/accuracy.html states a median of 0.04 arcsec for every named star at eight instants from 1700 to 2200; that run is not in the repository, so this report certifies only the five rows it can recompute, which agree to 0.07 arcsec. The page's wider claim is not contradicted; it is not reproduced here either.
- The Moon's ecliptic latitude and distance by century other than through the apparent-place separation and the distance residual of Tables 5 and 7; the Moon-minus-Sun longitude is sampled at only seven new moons (S7).
- Anything the API does not compute: minor planets, comets and Chiron (the engine has no minor-planet ephemeris and CycleCalcs adds no copyleft or paid one), satellite passes, polar motion, and interpretation of any kind. /v2/conventions publishes the list as data.

8. How to reproduce

The 69,402 places, the raw Horizons replies and the two scripts that made them are public in the CycleCalcs data repository, https://github.com/cyclecalcs/astronomy-data, under accuracy/, archived with the concept DOI 10.5281/zenodo.21905241 (the record that DOI resolves to carries accuracy/ since v1.1.0). The files: accuracy/summary.json, every overall statistic of section 3 and the Table 7 distances in km of section 5 (the by-century p99 and worst instants of Table 5, the arcminute crossings, the relative distances and the mean rates are recomputed from the CSVs by sprint/accuracy/build-places.mjs); accuracy/residuals/<body>.csv, both systems' places, the separation and both distances at every sampled instant; accuracy/horizons/<body>.txt, the replies as fetched; accuracy/SHA256SUMS.txt, the manifest.

```
# the public study, in the data repository
git clone https://github.com/cyclecalcs/astronomy-data.git && cd astronomy-data
npm ci
node scripts/accuracy/fetch-horizons.mjs   # the 10 queries of Table 1 -> accuracy/horizons/
node scripts/accuracy/compare.mjs          # -> accuracy/residuals/*.csv, accuracy/summary.json
(cd accuracy && sha256sum -c SHA256SUMS.txt)   # the manifest paths are relative to accuracy/
```

Two scripts in the CycleCalcs repository built the tables of this report from those files and from the Horizons replies of 2026-10-08; both run offline from the saved replies and the vendored engine, and both are deterministic. sprint/accuracy/build-places.mjs reads the study's CSVs, recomputes every figure of summary.json with the definitions of section 2, recomputes every engine column with the vendored file, checks the manifest and writes report-data-places.json; with --check it exits non-zero on any difference. sprint/accuracy/build-events.mjs reads the raw replies that sprint/accuracy/fetch-horizons.mjs saved (the season windows, the constellation windows, the 2038 windows, the Mars day and the daily delta-T of 2199) and writes report-data-events.json. tools/build-accuracy-report.mjs typesets the two data files into this document; building twice gives byte-identical output.

```
# in the CycleCalcs repository, with astronomy-data checked out beside it
node sprint/accuracy/build-places.mjs ../astronomy-data/accuracy/residuals --check
node sprint/accuracy/fetch-horizons.mjs     # only re-fetches a reply that is missing
node sprint/accuracy/build-events.mjs
node sprint/accuracy/build-residuals.mjs --write   # the in-repo sets S1 to S13
node tools/build-accuracy-report.mjs --out accuracy-report.pdf
```

The engine columns of the CSVs reproduce with the vendored file to 1.8 microarcsec (section 2); the CSV separation column reproduces from its own RA and Dec columns to within the rounding of the printed decimals; summary.json reproduces in full. The Horizons replies carry their own version, source and Earth-orientation lines, quoted in Table 1 and section 2; a re-fetch after a Horizons ephemeris or EOP update may differ from them at the level of the delta-T figures in section 4.

9. How to cite

Suggested citation: CycleCalcs LLC (2026). The CycleCalcs API against JPL Horizons, 1700 to 2200: an accuracy report for Astronomy Engine 2.1.19 as served by the CycleCalcs API. Report version 2026-10, 2026-10-08. https://www.cyclecalcs.com/api/accuracy-report-2026-10.pdf (add your access date).

This report has no DOI. Cite the PDF URL above with your access date, and cite the underlying study by its concept DOI, 10.5281/zenodo.21905241, which always resolves to the newest version of the data repository; the version used here is the one whose summary.json and manifest are reproduced in section 2. The summary block on https://www.cyclecalcs.com/api/accuracy.html carries the same figures and links to this report.

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