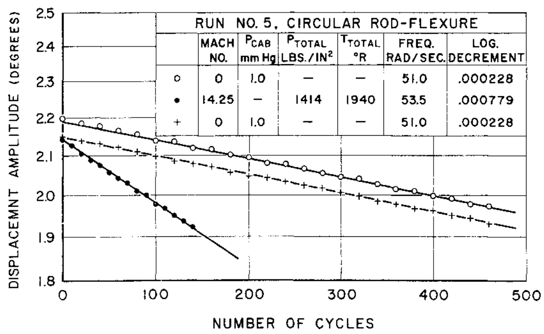


**Fig. 3 Amplitude decay of cone model mounted to flexure C.**

The reason for the obviously low damping derivatives will be investigated further. It is intended to investigate the effects of nose bluntness, oscillation amplitudes, and frequencies on the damping. A quasi-steady analysis is planned, based on the experimentally determined normal force distribution along the model. The investigation will be extended to various trim angles of attack.

### References


[1] Gregorek, G. M. and Lee, J. D., "Design performance and operational characteristics of the ARL twenty-inch hypersonic wind tunnel," Aerospace Research Labs. Rept. 62-392 (1962).

[2] Gregorek, G. M., "Initial calibration and performance of the ARL twenty-inch hypersonic wind tunnel," Aerospace Research Labs. Rept. 62-393 (1962).

[3] Daum, F. L., "Air condensation in a hypersonic wind tunnel," AIAA J. **1**, 1043–1046 (May 1963).

[4] Goddard, R., "Liquefaction tests in the ARL twenty-inch hypersonic wind tunnel," unpublished data (1963).

[5] Gemant, A., *Frictional Phenomena* (Chemical Publishing Co., Inc., New York, 1950), Chap. XVI, p. 328.

[6] Welsh, C. J. and Ward, L. K., "Structural damping in dynamic stability testing," Arnold Engineering Development Center TR 59-5 (1959).

[7] Whitfield, J. D. and Wolny, W., "Hypersonic static stability of blunt slender cones," Arnold Engineering Development Center TDR 62-166 (1962).

[8] Jaffee, P., Preslin, R. H., and Dayman, B., *Space Programs Summary*, JPL Rept. 37-24 (Jet Propulsion Laboratories, California Institute of Technology, Pasadena, Calif., 1963), Vol. IV, pp. 72–78.


# Approximate Payload Capabilities of Boosters for Planetary Missions


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### Nomenclature

- $E$ = injection energy, joules
- $g$ = gravitational constant, 9.81 m/sec²
- $I_{spj}$ = specific impulse of the $j$th stage, sec
- $m_1$ = escape mass, kg
- $n$ = number of booster stages
- $P$ = weight of payload, lb
- $R$ = radius of Earth, 6.38 ($10^6$) m
- $r_0$ = parking orbit radius, 6.57($10^6$) m
- $W_{ij}$ = weight of vehicle at beginning of $j$th stage, lb
- $W_{fj}$ = weight of vehicle at end of $j$th stage, lb
- $V$ = actual terminal velocity at injection, m/sec
- $V_L$ = velocity loss because of drag and gravity, 1524 m/sec (5 kft/sec)


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THE payload capability of any chemical booster depends primarily on its ascent trajectory and the injection energy required for the particular mission. At the end of the ascent phase, the spacecraft must have a final velocity and orientation to permit escape from the earth's gravitational field and to rendezvous, at the proper time and place, with the target planet. There are two alternative ascent paths: a direct-ascent trajectory, where the booster stages burn successively, with only short coast periods to permit separation of the stages; and a parking-orbit trajectory, where the burning time is divided into two periods, separated by a coasting interval in a circular orbit. The parking-orbit trajectory is much preferred to the direct ascent, although the latter has shorter flight time.[2] The major disadvantage of the latter is that it must satisfy both the energy requirements and the geometrical constraints simultaneously, which results in a narrow launch window, an inefficient ascent path, and a loss in payload capability. Parking orbit trajectories permit higher payloads and more flexibility in launching time because the in-orbit time and launch azimuth can be varied for the same mission. The lowest possible parking-orbit altitude permits the greatest payload capability, and this capability decreases as the altitude is increased. A 100-naut-mile parking orbit ascent trajectory was assumed in all calculations.

The optimum type-I transfer characteristics for the planets under consideration are listed in Table 1, abstracted from Clarke's tables.[1] These optimum conditions are cyclic and each occurs once during the planet's metonic cycle.† Mars' metonic cycle is 15 yr. The characteristics for the period listed for Mars will repeat for the period 1977 through 1992. No transfer characteristics are listed for Venus beyond 1970, since its metonic cycle is ~8 yr; the conditions listed will repeat for the period 1970 through 1978 and again during 1978 through 1986. Jupiter's metonic cycle is ~12 yr, but because of its nearly circular orbit and relatively large distance from Earth, there is very little variation in these characteristics from year to year—the required geocentric injection energy ranges from 0.77($10^8$) to 1.1($10^8$)m²/sec² for 1968 through 1973, and launch windows occur every 13 months. Mercury's metonic cycle is ~1 yr; hence, the conditions shown occur annually.

Geocentric injection energy is the vehicle's remaining kinetic energy after it escapes from the Earth's gravitational field. It is independent of the heliocentric flight path and is defined by the equation

$$E = \tfrac{1}{2}m_1V^2 - gR^2m_1/r_0 \qquad (1)$$

or

$$2E/m_1 = V^2 - 1.216(10^8) \qquad (2)$$

Values of $2E/m_1$ are tabulated in Table 1.

It is theoretically possible to travel from Earth to a planet on several different ballistic paths at any given moment, but only a small number of these paths have a sufficiently low injection energy requirement to be usable with currently available or planned boosters. Of these, the most practical paths are those that require less than one revolution about the sun. Type I trajectories make less than one-half of one revolution about the sun and type II trajectories make between one-half and one revolution around the sun. Within each type there are two possible trajectories, class I and class II. Class I has a smaller heliocentric central angle and hence a shorter flight time than class II.[3]

The value of $2E/m_1$ listed in Table 1 for a particular launch period is the greatest value that might be required to launch the vehicle at any time within that period. The launch date requiring the minimum energy occurs at some time within the smallest launch interval. These listings show that a

† The period of cyclic occurrence of the same absolute fixed geometry between Earth and the planet. The length of this cycle depends on the planet's orbital velocity relative to Earth.

Table 1 Type I transfer characteristics[a]

| Launch dates | $t_L$, days | $2E/m_1$, $m^2(10^8)/sec^2$ | Class I trajectories $t_f$, days | Class I $S_{com}$, $10^6$ km | Class I $V_{hxs}$, km/sec | Class I $\delta_g$, deg | Class II trajectories $t_f$, days | Class II $S_{com}$, $10^6$ km | Class II $V_{hxs}$, km/sec | Class II $\delta_g$, deg |
|---|---|---|---|---|---|---|---|---|---|---|
| MARS | | | | | | | | | | |
| 10/23/62-11/7/62 | 15 | 0.1612 | 206/224 | 214/244 | 4.03/5.24 | 40.2/45.7 | 235/260 | 242/281 | 2.88/4.11 | 45.4/54.8 |
| 10/18/62-11/17/62 | 30 | 0.1821 | 188/288 | 193/313 | 2.55/6.30 | 21.3/49.1 | 224/292 | 221/315 | 2.53/4.88 | 6.6/61.5 |
| 10/11/62-11/25/62 | 45 | 0.232 | 163/279 | 167/312 | 2.66/7.94 | 23.3/46.1 | 221/294 | 208/320 | 2.80/5.40 | -5.2/70.4 |
| 11/12/64-11/27/64 | 15 | 0.094 | 233/246 | 214/225 | 4.05/4.46 | 9.7/16.2 | 240/248 | 220/229 | 3.95/4.20 | -1.8/8.5 |
| 11/10/64-12/10/64 | 30 | 0.1257 | 196/243 | 182/213 | 4.39/6.24 | 17.8/35.9 | 243/253 | 216/244 | 3.59/4.56 | -20.9/37.8 |
| 11/5/64-12/20/64 | 45 | 0.1759 | 167/224 | 157/199 | 5.37/8.16 | 14.9/30.4 | 226/259 | 189/257 | 3.41/5.54 | -32.1/50.1 |
| 12/28/66-1/12/67 | 15 | 0.0962 | 189/201 | 149/159 | 5.58/6.25 | -23.1/-14.3 | 202/212 | 159/171 | 4.87/5.53 | -29.3/-17.8 |
| 12/21/66-1/20/67 | 30 | 0.1120 | 173/206 | 138/155 | 5.86/7.23 | -27.1/-9.3 | 203/220 | 152/182 | 4.38/5.98 | -37.7/-14.6 |
| 12/13/66-1/27/67 | 45 | 0.1397 | 158/203 | 127/164 | 5.25/8.41 | -24.3/-5.6 | 194/227 | 148/194 | 4.01/6.23 | -44.6/-8.4 |
| 2/24/69-3/11/69 | 15 | 0.092 | 165/178 | 108/119 | 4.92/5.88 | -51.9/-43.6 | 180/189 | 115/129 | 4.34/5.22 | -56.1/-46.7 |
| 2/16/69-3/18/69 | 30 | 0.1049 | 151/181 | 98/128 | 4.40/6.91 | -55.1/-38.1 | 183/201 | 109/145 | 3.79/5.70 | -63.3/-43.3 |
| 2/9/69-3/26/69 | 45 | 0.1235 | 140/193 | 92/151 | 3.66/7.86 | -51.5/-34.3 | 188/212 | 109/163 | 3.62/5.72 | -68.9/-44.2 |
| 5/16/71-5/31/71 | 15 | 0.0815 | 186/212 | 130/175 | 2.83/2.99 | -27.2/-15.6 | 214/230 | 160/191 | 2.82/3.04 | -22.5/-6.7 |
| 5/8/71-6/7/71 | 30 | 0.0896 | 164/201 | 106/169 | 2.86/3.64 | -30.0/-18.0 | 203/240 | 137/208 | 2.84/3.24 | -29.5/5.8 |
| 5/1/71-6/15/71 | 45 | 0.1033 | 147/208 | 90/188 | 2.91/4.52 | -30.6/-13.3 | 208/242 | 135/223 | 2.88/3.51 | -33.6/16.2 |
| 7/21/73-8/5/73 | 15 | 0.1507 | 176/186 | 154/169 | 3.22/3.53 | 23.8/38.0 | 202/209 | 184/206 | 2.71/2.97 | 30.9/35.6 |
| 7/13/73-8/12/73 | 30 | 0.166 | 159/185 | 132/184 | 2.96/4.26 | 19.9/27.8 | 204/223 | 176/233 | 2.54/3.11 | 2[illegible].2/42.6 |
| 7/5/73-8/19/73 | 45 | 0.1903 | 143/194 | 114/185 | 2.96/5.10 | 16.9/30.9 | 199/235 | 153/259 | 2.45/3.44 | 28.1/49.1 |
| 9/7/75-9/22/75 | 15 | 0.1964 | 186/226 | 191/209 | 4.17/4.68 | 41.7/47.0 | 216/226 | 227/254 | 3.10/3.68 | 47.3/54.9 |
| 8/31/75-9/30/75 | 30 | 0.2237 | 165/194 | 164/215 | 4.01/5.78 | 37.2/47.5 | 215/245 | 214/285 | 2.62/4.03 | 42.4/62.6 |
| 8/23/75-10/7/75 | 45 | 0.2683 | 147/192 | 143/198 | 4.64/6.99 | 33.7/47.3 | 212/264 | 198/315 | 2.39/4.46 | 45.0/69.7 |
| 10/11/77-10/26/77 | 15 | 0.1806 | 198/216 | 209/230 | 4.54/5.33 | 42.5/50.8 | 223/247 | 232/275 | 3.10/4.42 | 48.5/57.7 |
| 10/4/77-11/3/77 | 30 | 0.2122 | 176/207 | 182/240 | 4.18/6.66 | 38.0/47.6 | 226/273 | 228/308 | 2.49/4.59 | 45.7/66.0 |
| 9/30/77-11/4/77 | 45 | 0.2376 | 164/306 | 170/339 | 2.46/7.44 | 25.1/47.6 | 222/309 | 218/340 | 2.51/4.95 | 12.2/70.2 |
| VENUS | | | | | | | | | | |
| 8/13/62-8/28/62 | 15 | 0.09 | 108/122 | 54/59 | 5.40/5.92 | -7.8/-0.6 | 110/123 | 57/62 | 5.20/5.58 | -1.5/5.9 |
| 8/4/62-9/3/62 | 30 | 0.0985 | 101/127 | 50/59 | 5.41/6.49 | -13.5/-1.7 | 106/130 | 56/66 | 4.98/5.63 | 0.2/12.6 |
| 7/26/62-9/9/62 | 45 | 0.112 | 94/135 | 47/57 | 5.62/7.18 | -18.0/-4.2 | 104/138 | 53/69 | 4.78/5.79 | -4.1/18.3 |
| 3/22/64-4/6/64 | 15 | 0.128 | 104/115 | 55/60 | 6.06/6.82 | -3.6/0.7 | 108/119 | 60/66 | 5.39/6.12 | -11.1/-5.2 |
| 3/14/64-4/13/64 | 30 | 0.142 | 96/122 | 51/59 | 6.30/7.74 | -3.6/5.8 | 106/125 | 57/72 | 4.82/6.50 | -17.1/-5.7 |
| 3/5/64-4/19/64 | 45 | 0.1645 | 88/128 | 48/60 | 6.19/8.71 | -1.2/9.8 | 102/132 | 55/78 | 4.34/6.79 | -22.2/-3.8 |
| 11/5/65-11/20/65 | 15 | 0.1370 | 99/108 | 54/58 | 5.05/5.75 | 9.2/13.7 | 111/115 | 60/69 | 3.73/4.70 | 13.9/19.0 |
| 10/27/65-11/26/65 | 30 | 0.1537 | 91/115 | 48/63 | 4.33/6.94 | 4.9/15.8 | 111/121 | 55/81 | 3.02/5.49 | 9.6/24.1 |
| 10/19/65-12/3/65 | 45 | 0.1750 | 84/121 | 45/89 | 2.99/7.92 | 2.0/16.7 | 118/126 | 51/96 | 2.99/6.03 | 7.2/27.8 |
| 6/8/67-6/23/67 | 15 | 0.0842 | 128/144 | 81/91 | 2.81/3.42 | -18.5/9.1 | 133/146 | 93/96 | 2.96/4.90 | -16.0/35.9 |
| 5/30/67-6/29/67 | 30 | 0.1065 | 110/127 | 60/93 | 3.31/5.15 | -23.7/15.2 | 127/145 | 72/98 | 2.88/5.61 | -27.3/44.4 |
| 5/21/67-7/5/67 | 45 | 0.1344 | 96/132 | 51/96 | 3.45/6.96 | -27.4/20.0 | 122/146 | 61/100 | 3.13/6.27 | -33.7/48.0 |
| 1/4/69-1/19/69 | 15 | 0.0805 | 119/132 | 66/69 | 4.53/4.73 | 2.2/8.8 | 123/134 | 70/74 | 4.49/4.62 | -8.4/-0.4 |
| 12/27/68-1/26/69 | 30 | 0.0894 | 111/140 | 61/68 | 4.45/5.22 | 2.5/15.4 | 119/141 | 68/78 | 4.44/4.88 | -16.3/3.5 |
| 12/17/68-1/31/69 | 45 | 0.1035 | 103/148 | 56/70 | 4.26/5.92 | -0.9/20.3 | 113/149 | 67/82 | 4.39/5.26 | -23.1/3.7 |
| 8/9/70-8/24/70 | 15 | 0.088 | 109/120 | 54/58 | 5.51/5.88 | -8.2/-2.8 | 112/124 | 59/62 | 5.17/5.44 | 1.8/6.3 |
| 8/1/70-8/31/70 | 30 | 0.0965 | 102/126 | 51/58 | 5.47/6.42 | -13.6/-2.7 | 107/131 | 57/66 | 4.98/5.57 | 1.5/12.4 |
| 7/23/70-9/6/70 | 45 | 0.1105 | 95/134 | 48/54 | 5.87/7.13 | -18.3/-8.1 | 109/139 | 55/70 | 4.79/5.73 | 0/18.6 |
| MERCURY | | | | | | | | | | |
| 11/16/67-12/1/67 | 15 | 0.4415 | 99/112 | 125/130 | 15.04/15.62 | -15.6/-3.9 | 99/113 | 130/132 | 15.02/15.44 | -21.6/-16.4 |
| 11/11/67-12/11/67 | 30 | 0.5685 | 88/118 | 114/131 | 13.52/20.15 | -18.6/12.3 | 91/131 | 128/156 | 13.78/17.81 | -39.0/12.3 |
| 11/5/67-12/20/67 | 45 | 0.8195 | 76/114 | 103/124 | 16.88/27.96 | -14.9/11.2 | 87/119 | 121/144 | 15.10/20.07 | -48.2/22.0 |
| 11/8/68-11/23/68 | 15 | 0.5902 | 91/103 | 127/139 | 13.90/16.74 | -13.7/7.0 | 94/105 | 134/147 | 12.52/16.93 | -43.8/8.0 |
| 10/31/68-11/30/68 | 30 | 0.7825 | 81/105 | 112/145 | 13.93/25.00 | -23.3/9.3 | 87/107 | 123/151 | 13.81/18.86 | -51.2/16.7 |
| JUPITER | | | | | | | | | | |
| 12/27/70-1/11/70 | 15 | 0.7882 | 810/1035 | 641/866 | 5.72/6.65 | -7.7/4.4 | 902/1043 | 633/876 | 5.72/6.00 | -16.1/8.6 |
| 12/21/70-1/20/70 | 30 | 0.8612 | 675/1077 | 638/940 | 5.74/8.69 | -7.1/4.7 | 820/1122 | 636/920 | 5.81/6.64 | -24.6/16.9 |

[a]Reproduction of this table was authorized by the Jet Propulsion Laboratories, Pasadena, Calif.
[b]All double values are min/max values for the specified launch period.

spacecraft with a particular injection energy can fly a variety of missions.

Also listed are the following, where $t_L$ is the launch period, $t_f$ the flight time, $S_{\text{com}}$ the communication distance at the time of planetary encounter, $V_{\text{hxs}}$ the hyperbolic excess velocity of the vehicle with respect to the target planet, and $\delta_g$ the declination of the geocentric asymptote, which places restrictions on the ascent trajectory. The minimum/maximum values of these parameters bracket the interval containing the value for any given launch within the time interval.

The boosters in this study are compared in Fig. 1 by generating curves of payload vs $2E/m_1$. The *actual terminal velocity* $V$ of the vehicle is given by[4]:

$$(V + V_L)/g = \sum_{j=1}^{n} I_{\text{sp}j} \ln(W_{ij} + P)/(W_{fj} + P) \qquad (3)$$

Note that the "payload" $P$ includes any required guidance equipment and other support subsystems in addition to the scientific payload. A computer program based upon Eqs. (2) and (3) was used to find $2E/m_1$ as a function of payload weight for Atlas-Centaur, three-stage Saturn 1B, and Saturn 5 boosters, using the specifications in Table 2 as inputs. The results appear in Fig. 1 for $V_L$ = to 1524 m/sec (5 kft/sec). The actual value of $V_L$ will vary slightly for each booster and mission, but this value is within $\pm 10\%$ for planetary missions.[5] For example, for the three-stage Saturn 1B with a 5000-lb payload, substitution of the appropriate $I_{\text{sp}}$, $W_i$, and $W_f$ for each stage from Table 2 into Eq. (3) gives $V + V_L$ = 13,564 m/sec. Using $V_L$ = to 1524 m/sec, $V$ = 12,040 m/sec. Substituting into Eq. (2), $2E/m_1 = 0.234(10^8)\text{m}^2/\text{sec}^2$.

The *planning sequence* for any planetary mission can be summarized in the following four steps: 1) choose a planet and a mission objective (flyby, orbiter, etc.); 2) choose transfer characteristics, including the launch date and the required injection energy from Table 1; 3) determine the payload weight based on the objectives; and 4) choose a suitable booster. Assuming that the destination and the primary mission objectives are fixed, tradeoffs among booster capabilities, payload weight, launch date, and secondary mission objectives must be made so that the final payload weight conforms to the capability of the boosters available at the chosen launch time. The choice of a launch date involves tradeoffs among the tabulated transfer characteristics. Short flight time is desirable to minimize the probability of a failure in the spacecraft and the susceptibility to injection errors. For orbiter and lander missions, it is desirable to minimize the hyperbolic excess speed to permit the heaviest possible payload. However, the minimum values of $V_{\text{hxs}}$ do not correspond with the minimum values of $2E/m_1$, so a compromise must be made. Finally, $\delta_g$ places restrictions on the ascent trajectory; values between $\pm$ 34° must be chosen for launches for the Atlantic Missile Range.

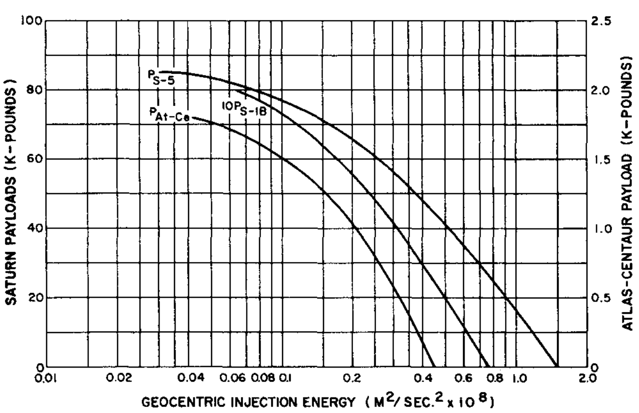


**Fig. 1 Payload vs geocentric injection energy for Atlas-Centaur, three-stage Saturn 1B, and Saturn 5.**

**Table 2 Booster specifications**

| Booster | Stage | $I_{\text{sp}}$, sec | $W_i$, klb | $W_f$, klb |
|---|---|---|---|---|
| Atlas-Centaur | 1 | 257 | 292 | 44 |
| | 2 | 420 | 32 | 3 |
| Saturn 1-B | 1(S-1) | 257 | 1250 | 404 |
| | 2(S-4B) | 420 | 285 | 54.7 |
| | 3(S-6) | 420 | 26.7 | 6.4 |
| Saturn 5 | 1(S-1C) | 257 | 5951 | 1551 |
| | 2(S-2) | 420 | 1263 | 333 |
| | 3(S-4B) | 420 | 258 | 28 |

***Example***

It is desired to launch a flyby probe to Mars at an appropriate time during 1966 or 1967. Table 1 shows that a launch between December 28, 1966 and January 12, 1967 would require $2E/m_1 = 0.0962(10^8)\text{m}^2/\text{sec}^2$, and $\delta_g$ for this trajectory is within the $\pm$ 34° required for launch at the Atlantic Missile Range. Payload capabilities for this value of $2E/m_1$ are obtained from Fig. 1 as follows: Atlas-Centaur, 1510 lb; Saturn 1B, 7400 lb; Saturn 5, 76,000 lb.

**References**

[1] Clarke, V. C., Jr., "A summary of the characteristics of ballistic interplanetary trajectories, 1962–1977," Jet Propulsion Lab., Calif. Institute of Technology, TR 32-209 (January 15, 1962).

[2] Clarke, V. C., Jr., "Design of lunar and interplanetary ascent trajectories," Jet Propulsion Lab., Calif. Institute of Technology, TR 32-30 (March 15, 1962).

[3] Clarke, V. C., Jr., Bollman, W. E., Roth, R. Y., and Scholey, W. J., "Design parameters for ballistic interplanetary trajectories, Part 1. One-way transfers to Mars and Venus," Jet Propulsion Lab., Calif. Institute of Technology, TR 32-77 (January 16, 1963).

[4] Koelle, H. H. (Ed.), *Handbook of Astronautical Engineering* (McGraw-Hill Book Co., Inc., New York, 1961), Chap. 6, pp. 6-2–6-6.

[5] Koelle, H. H. (Ed.), *Handbook of Astronautical Engineering* (McGraw-Hill Book Co., Inc., New York, 1961), Chap. 9, pp. 9-35–9-37.

# Orbital Elements from Doppler Tracking of Three Satellites

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THREE satellites, 1961 o1, 1961 $\alpha\eta$1, and 1962 $\beta\mu$1, have each transmitted four coherent frequencies controlled by highly stable oscillators and have been tracked by Doppler methods. The orbital elements resulting from this tracking are of research interest in two different ways. First, their secular and long-term periodic perturbations can be analyzed to yield equations of condition connecting the zonal harmonics in the earth's gravitational field. Second, because of the unique nature of the radio signals from these satellites, they have been used in studies of radio propagation through the ionosphere and troposphere and in studies of the reflections of radio signals from the earth's surface.

This paper presents three tables of the orbital elements of these satellites which are adequate for either of these types of

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