

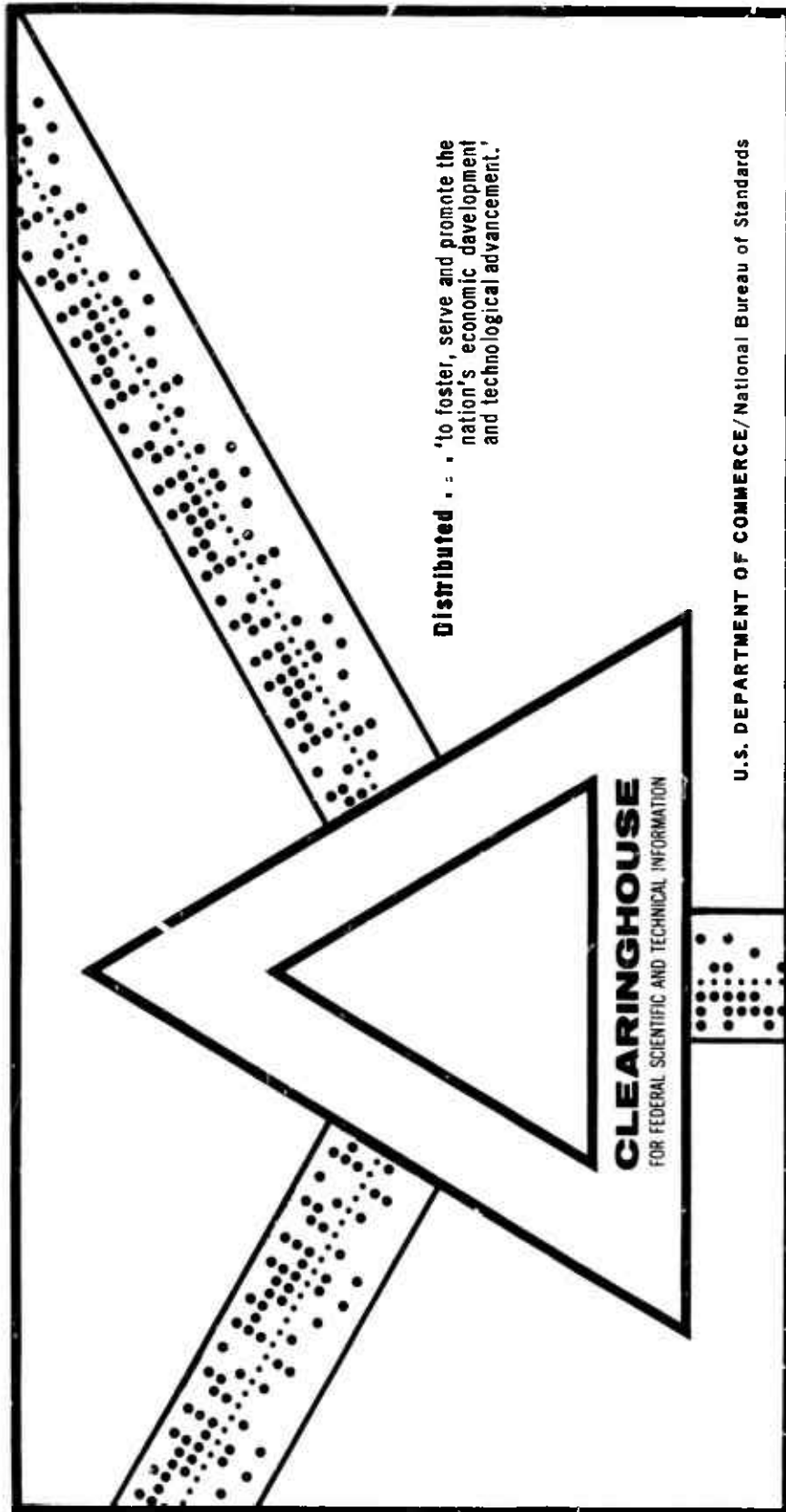
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ADVANCED ORBIT/EPHEMERIS SUBSYSTEM (AOES) TIME TRANSFORMATION  
REVIEW

Charles M. Randall

Aerospace Corporation  
El Segundo, California

30 July 1969



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## Advanced Orbit/Ephemeris Subsystem (AOES) Time Transformation Review

Prepared by CHARLES M. RANDALL  
Space Physics Laboratory  
Laboratory Operations

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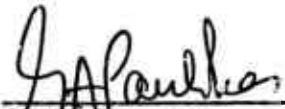
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## FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract F04701-69-C-0066.

This report, which documents research carried out from 1 September, 1968 through 30 June, 1969, was submitted on 22 August 1969 for review and approval to Col. Arthur A. Banister, Acting Director for Development, Air Force Satellite Control Facility.

Approved

  
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Publication of this report does not constitute Air Force Approval of the report's finding or conclusions. It is published only for the exchange and stimulation of ideas.

  
ARTHUR W. BANISTER, Col, USAF  
Acting Director for Development  
AF Satellite Control Facility

## ABSTRACT

The time transformations and time dependent inputs for spatial transformations in the Advanced Orbit/Ephemeris Subsystem (AOES) presently being implemented by the Air Force Satellite Control Facility have been reviewed. The principle results are:

1. The relations described in the Milestone 2 documents describing the computer routines include all relations required to satisfy the accuracy design goals of AOES.
2. If future systems require higher accuracy the present time-related transformations will not be adequate. The improvements must involve the following:
  - a. Wander of the pole of rotation with respect to the crust of the earth can no longer be ignored.
  - b. The empirical relations between earth rotation time scales (UT2, UT1) and atomic time scales (A1, UTC, etc.) must be improved, probably by fitting over shorter periods of time.
  - c. Nutation terms of amplitude less than 0.2 arc second must be included.
3. A best set of constants to be employed by the AOES relating UT2 to UTC for the period 1 January 1961 to 30 June 1969 have been calculated. A procedure is suggested for the continuous review of the applicability of these and subsequent constants, with provisions for updating them as required.
4. Values for comparison with computer routine results are presented for many of the quantities under study.

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## I. INTRODUCTION

The space-time reference frame most convenient for the calculations of satellite ephemerides is not, because of the earth's motion, the most convenient reference frame in which satellite positions may be measured by an observer on the earth. Integration of the equations of motion describing the satellite motion is most conveniently carried out in an inertial coordinate system, while observation is most conveniently carried out in a coordinate system fixed with respect to the surface of the earth.

Both inertial coordinate systems and earth fixed systems are to some extent arbitrary in their definitions of origins and fixed directions. However, once these definitions are established, transformation from the inertial to the earth fixed systems and vice-versa is a straightforward, though often tedious, computational exercise. This transformation requires a knowledge of the earth's motion with accuracy commensurate with the accuracy required from the transformation.

The present report will concentrate attention on the coordinate systems and transformation schemes employed by the Advanced Orbit/Ephemeris Subsystem (AOES) computer programs presently being implemented by the Air Force Satellite Control Facility. The relations between the time scales employed by it and the computation of time dependent inputs to the spatial transformation procedures of AOES will be reviewed. The basic equations will be presented and the numerical constants appearing in the programs will be evaluated. Where possible, test values, against which computer routines may be checked, will be presented.

## II. AOES SPACE-TIME COORDINATE SYSTEMS

There are two space-time reference systems used in AOES. The atomic time and inertial system is employed for orbit calculations while the earth fixed system with a precisely defined civil time (UTC) is employed in the rest of the Satellite Control Facility. In this section we discuss the basis for each of the two spatial reference frames used and separately the basis for the two time systems.

### A. SPATIAL COORDINATE SYSTEMS

#### 1. INERTIAL COORDINATE SYSTEM

An inertial coordinate system may be defined as one in which Newton's second law of motion (force equals rate of change of momentum) holds. The AOES inertial coordinate system is defined with its origin at the center of mass of the earth and the orientation of its axes defined by the mean equator of the year 1950.0, and the intersection of this equator with the mean ecliptic of 1950, i.e., the mean equinox of 1950.0.

Actually the "inertial" reference frame with origin fixed in the moving earth used by AOES is only an approximation to an inertial reference frame. It will be a satisfactory approximation so long as the acceleration of the satellite due to gravitational attraction by the earth is large compared with the acceleration of the origin of the coordinate system. This requirement is satisfied for earth orbits well beyond synchronous altitudes. This encompasses the uses that will be made of AOES. Therefore we follow the convention of calling a coordinate system with origin fixed at the center of the earth and with its directions fixed in space, an inertial coordinate system.

## 2. EARTH FIXED COORDINATE SYSTEM

The AOES earth fixed reference frame has its origin at the center of mass of the earth and its orientation specified by the equator and prime meridian of the earth. The AOES actually uses several different coordinate systems which are related to this one by non-time-dependent relations; for example: position determined as azimuth, elevation, and range from a known spot on the surface of the earth. Because we are at present emphasizing only time dependent relations, all of these earth fixed coordinate systems will be regarded as equivalent.

### B. TIME SCALES

"Time is not physically tangible; it has no unique physical property that permits its laboratory examination. Time is essentially metaphysical; there is no direct way of measuring it, even in principle. Nonetheless, our lives are ordered by it and, more importantly, our physics is also ordered by it. Therefore time must be measured. The foundations of physical science include the article of faith that a 'uniform' time exists that corresponds identically with the variable called time in dynamics. Even Isaac Newton suspected (Ref. 1, page 8) the impossibility of determining 'uniform' time, and he commented upon the necessity of distinguishing between this construct of faith and the physical measures of time. The failure to reconcile observations with dynamical theories may lead one to amend or discard the laws of dynamics or the means of determination of time, but the faith in a 'uniform' supertime is untouched" (Ref. 2, page 14). In the following we review the specific definitions of the two time scales employed in AOES.

#### 1. ATOMIC TIME, A1

Because the calculation of satellite ephemerides is based on this faith in the existence of a "uniform" supertime, it is convenient to use a practical time scale which agrees as far as is known with the uniform time. The A1 atomic time scale is the one presently available that meets this requirement and has been chosen as the time scale for the inertial space-time coordinate system in AOES. We briefly review the development of this time scale.

The positions of astronomical objects have been, until recently, the basis for the practical determination of uniform time. These positions have been employed because they could be measured quite precisely and because classical dynamics, which was the first branch of physics to develop a precise mathematical formalism, was adequate to predict most of these positions with high precision. Since the chief cause for apparent motion of astronomical objects is the motion of the earth, these time measuring schemes were in fact based on the motion of the earth.

As more precise independent measurements of time became possible by means of quartz oscillators and atomic beam systems, irregularities were discovered in time based on earth motion which could not be quantitatively predicted but could be qualitatively described and were attributed to such things as tidal motions, and seasonal changes in the polar ice masses. It thus became necessary to define the unit of time, the ephemeris second, as a certain fraction of a particular year near the beginning of this century (Refs. 3, 4). The ephemeris time defined in this way can in principle always be found from the reduction of a sufficient number of star position observations but the determination is tedious and can be done only after an event has happened.

The development of the cesium beam clock in the early 1950's introduced a means of keeping time more precise than ephemeris time and with greater convenience. The ephemeris second was measured to be 9 192 631 770 periods of the microwave transition between the hyperfine levels  $F = 4, m_F = 0$  and  $F = 3, m_F = 0$  of the  $^2S_{1/2}$  ground state of the unperturbed  $\text{Cs}^{133}$  atom (Ref. 5). A new time scale (A1) has been defined with the above number of oscillations defined as one second and  $0^h 0^m 0^s$  of 1 January 1958 defined as  $0^h 0^m 0^s$  of the atomic time scale. This causes A1 to differ from ephemeris time by 32.15 second.\* Up to the present this difference has remained

---

\*The best and most recent value of ET - A1 is 32.15 seconds (Ref. 17). Earlier measurements, however, gave a value of 32.25 seconds. This value is still used in the calculation of many Jet Propulsion Laboratory ephemerides (Ref. 2). Since the only use of ephemeris time in AOES is believed to be obtaining quantities from these JPL ephemerides it is desirable that the same constant be used to relate ET and A1. This requires that ETTOAT, the only entry in CBLK, 'AURLK2, be 32.25 seconds. If JPL changes the value used in their ephemeris computations then ETTOAT should be changed.

constant indicating that, within the precision of measurements made to date, ephemeris time and atomic time are equivalent. Recognizing this and the convenience with which time can be determined from atomic standards the second was redefined in 1967 as 9 192 631 770 periods of the above mentioned  $\text{Cs}^{133}$  resonance line. It is this atomic time (A1) which is used in the AOES as the best approximation to uniform time and thus the time variable of integration for determining satellite position.

## 2. UNIVERSAL TIME

Although atomic time is the most convenient for orbital calculations, a time scale related to the rotation of the earth is employed by the Air Force for observations and communication with other Satellite Control Facility Systems.

The time, using the earth as the clock, may be determined from the observed position of some known point among the stars. More specifically the angle along the celestial equator from the great circle through the observer's zenith west to the great circle through the known point is used. These angles, usually measured in units of hours, are called hour angles. The local time, XT, on the x scale, where x is the accepted reference point in the sky, is then the hour angle of reference point;  $XT = ha_{(x)}$ . By this definition only observers at the same longitude will have the same time, which is inconvenient. Therefore a single meridian is defined by convention as the time keeping meridian. Then the local time,  $XT_{loc} = XT + \text{longitude}$ , where XT is the time at the prime meridian and longitude is measured increasing to the west from the prime meridian.

Two reference points and their related time scales are required in AOES. One point is the equinox of date and the associated time scale is called sidereal time (ST). This time (or angle) is required to relate the "inertial" coordinate system to the earth fixed one. The second reference point, which defines the universal time scale, the basis for civil time keeping, is always very nearly directly opposite the sun. Because of the earth's motion about

the sun, the second reference point is in constant motion with respect to the first. A relation between them is required. By definition:

$$ST = ha_{\text{equinox}}$$

The angle from the equinox to the universal time point is defined (Ref. 6) to be 12 hours +  $R_u$  where

$$R_u = 18^h 38^m 45.836 + 8640184.542 T + 0.0929T^2$$

and T is the number of Julian centuries of 36525 days which have elapsed since 12<sup>h</sup> UT on 0 January 1900.

$$UT = ha_u = ha_{\text{eq}} - R_u - 12^h$$

$$UT = ST - R_u - 12^h \quad (1)$$

UT is thus determined by means of Eq. 1 from sidereal time obtained by observing the zenith transit of stars whose position with respect to the equinox is accurately known.

When this time scale is compared with an independent precise time scale, such as atomic time, UT is observed to have a varying difference from the atomic time. There appears to be 1) changes which depend on the observer's location and result from the wandering of the earth's pole of rotation with respect to the crust of the earth; 2) charges which are seasonal; and 3) gradual slowing down of the earth rotation rate. None of these can be completely predicted on a theoretical basis and are the subject of study due

to their intrinsic interest (Refs. 7, 8). Three time scales in use reflect these various differences: UT0 is the time scale which results from applying Eq. 1 to measured star positions. UT1 is the result of correcting UT0 for polar motion, UT2 is the result of correcting UT1 for seasonal variations. The only effect left in UT2, then is the gradual slowing down of the earth.

The UTC time scale is designed to provide a convenient time scale with the stability of atomic clocks and still be a close approximation to UT2. Because of the measurements and corrections required, UT2 can be determined only long after an event, and is therefore inconvenient for many purposes. The ratio of the length of the UTC second to the AI second length is held constant at a value such that the UTC second is approximately the same length as the UT2 second. The value of this ratio is decided upon and announced in advance by an international bureau on the basis of recent trends in UT2. When the difference between UT2 and UTC becomes larger than about 100 milliseconds, a step is put in UTC to bring the two closer together. UTC is the time scale used by AOES for communication with other Satellite Control Facility systems.

It is important to recognize that UTC and AI have a mathematically defined relation between them. Given one the other can always be found to within the accuracy of constants in a formula. Similarly UT0 and sidereal time have a mathematically defined relationship. On the other hand the relations between UT0 UT1, UT2, and UTC are basically empirical, though they can be estimated with fair accuracy on the basis of past experience.

### III. COORDINATE SYSTEM TRANSFORMATIONS

Relating the position of a object as expressed in inertial coordinates to the position in earth fixed coordinates requires only a knowledge of the orientation of one coordinate system with respect to the other at any given time. Since the largest part of the change in orientation is due to the earth's motion, which is for the most part quite predictable, the most logical way to obtain the required transformation would seem to be to compute the relative orientation at any specific time, to apply this to relate the position vector in the two coordinate systems, and finally to apply small corrections, predicted as best as possible by statistical means on the basis of recent empirical data on the motion of the earth.

This is generally the procedure actually followed in AOES although the detailed way in which the corrections are made reflects the traditional coordinate systems of the astronomer. The transformation is broken into several parts, some of which (precession and nutation) are introduced as changes in the inertial coordinate system, others (rotation of earth about its axis, seasonal and random variations in the rotation rate) are introduced via the time, and some, such as polar wander are applied directly. In addition to the spatial transformations there is a time transformation between A1 and UTC.

The steps in the transformations between the inertial system of AOES and the earth fixed systems of AOES are indicated schematically in Fig. 1. The mathematical formulation of the transformations is described in detail in Ref. 9 and will not be repeated in its entirety here. The purpose of the present report is 1) to review the inputs to these transformations which are time dependent, and 2) to review the transformations between the A1 time scale used in the inertial system and the UTC time scale used in communicating with the world outside the AOES. These are the operations taking place within the broken line in Fig. 1.

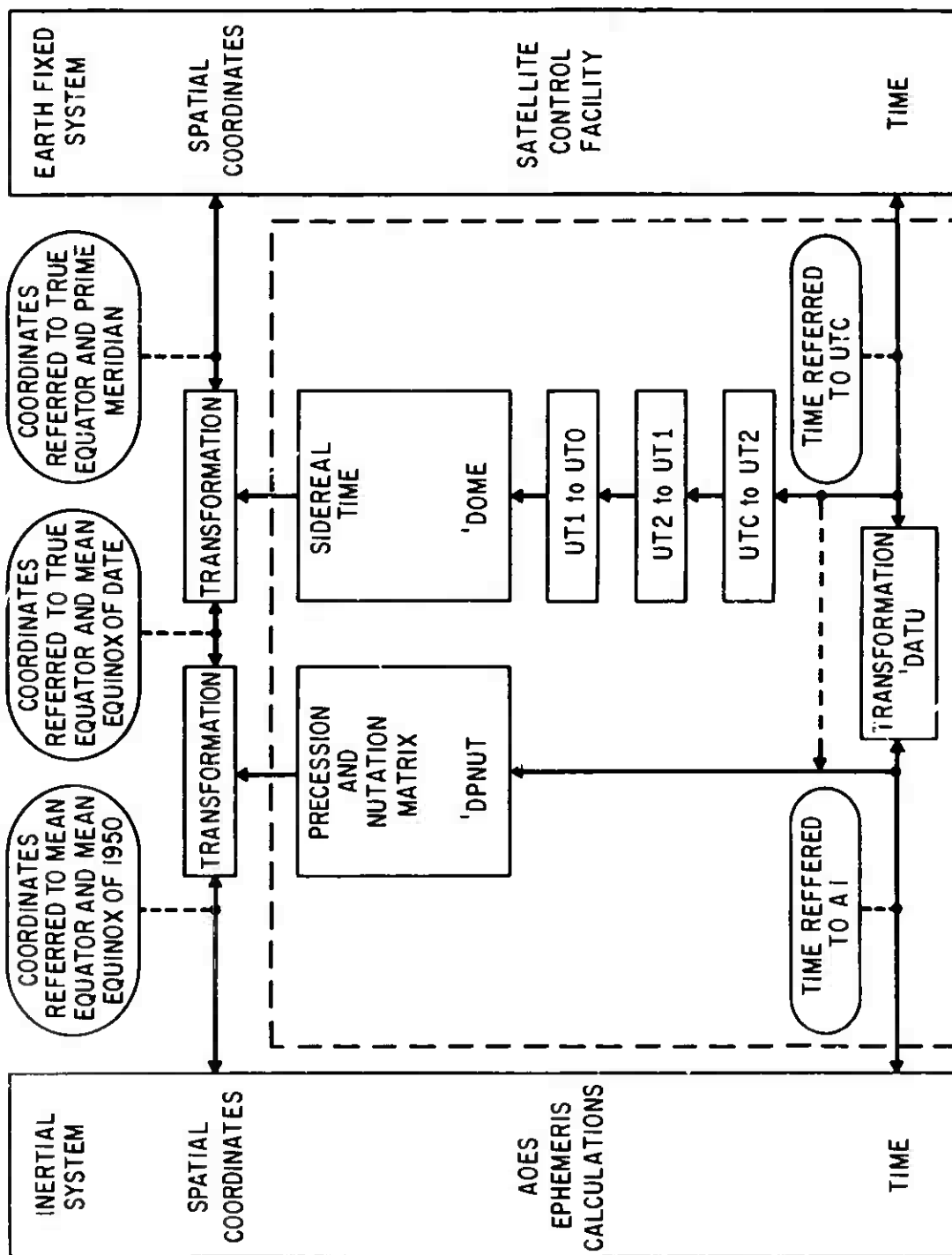


Figure 1. Schematic Representation of Space-Time Reference Systems in AOES Emphasizing Transformations Between Them which are Time Dependent. Those Computations Referred to within the Broken Line are the Detailed Concern of this Report.

The AOES computer routines which perform these calculations are: 'DATU (Atomic to Universal Time), 'DOME (Sidereal Time), and 'DPNUT (Precession Nutation Matrix). A fourth routine, 'DATIME, performs housekeeping functions such as converting the time between two dates into minutes. Since it introduces no new time scales or transformations, it will not be reviewed here. The physical constants required for 'DATU and 'DOME are found in the system data base as a constant block 'AUBLK. In the following sections numerical values of all the constants in 'AUBLK will be calculated. This information is summarized in Appendix D, which, for every entry in 'AUBLK, either lists the value calculated in this report or refers to the tabulation of that value elsewhere in the report. The constants required for 'DPNUT are part of the code for that routine.

The accuracy of the transformation should meet and exceed the design goals of AOES. In terms of a nominal 90 minute orbit "nothing in the computer program shall preclude the attainment of these accuracies:" 50 ft cross track, 200 ft in track and 100 ft radial distance (Ref. 10). In angular measure the 50 ft requirement for a satellite at 185 miles with a 90 minute period requires an angular accuracy of 0.47 arc sec or 30 milliseconds time.

#### A. TIME DEPENDENT SPATIAL TRANSFORMATION INPUTS

Referring to Fig. 1, there are two time dependent inputs to the spatial transformations. These are the sidereal time (computed by 'DOME) and the precession-nutation matrix (computed by 'DPNUT).

##### 1. SIDEREAL ANGLE

The most important quantity required for transformation between the earth fixed and the AOES inertial system is the angle between the prime meridian of the earth fixed system and the meridian through the mean equinox of date. This, however, is just the hour angle of the equinox, or the sidereal time. From Eq. 1 of the earlier discussion of time bases, this is:

$$\theta = ST = UT + R_u + 12^h$$

Converting to degrees and AOES base time, this becomes:

$$\theta = UT + 100^{\circ}0755415 + 0^{\circ}9856473458 d + 2.90 \times 10^{-13} d^2 \quad (2)$$

where  $d$  is the universal time in days since AOES reference time.\* Some checks of the computer routine for sidereal angle have been conducted (Ref. 11). Values for additional checks may be obtained from the ephemeris (Ref. 12) for any year under the heading Mean Sidereal Time.

## 2. PRECESSION AND NUTATION

Because of the gravitational attraction of other bodies in the solar system the rotation axis of the earth does not remain fixed in space, but slowly, over a period of about 26000 years, describes a circle of about  $23.5^{\circ}$  radius. Furthermore the combined effects of the planets serve to slowly change the plane of the earth's orbit (the ecliptic). The combined motion is known as general precession of the mean pole. In addition, there are various shorter period motions of the true pole about the mean pole position described as nutation.

We are principally concerned here that the angular arguments used to compute the nutation and precession matrices are correct. In order to be specific about the arguments, however, it is necessary to give the way in which they are used, which means specifying the transformation matrices. Assume we wish to transform a vector specified by its position with respect to the mean equinox and true equator of date, (center of Fig. 1) to a position vector in the AOES inertial reference frame which is referred to the mean equinox and equator of 1950 (left side of Fig. 1). Transformation from

---

\* To avoid very large numbers in some calculations all times in AOES are, by convention, measured from a reference time of  $0^h$  1 January 1950.

The first two constants in Eq. 2, expressed as fractions of a revolution, are THK1 and THK2 in constant block 'AUBLK in the AOES data base. For some purposes the rate of change of sidereal time with respect to UT2 is needed. This may be obtained by differentiating the above equation. The result is THDK1 in 'AUBLK. In all cases the quadratic term is ignored.

mean equinox and true equator of date to mean equinox and mean equator of date is accomplished by the nutation matrix  $N$ . Transformation from mean equinox and equator of date to mean equinox and equator of 1950.0 is then accomplished by the precession matrix,  $P$ .

$$\vec{r}_0 = PN \vec{r}$$

We look at each matrix in some detail now.

#### a. Nutation

Nutation is specified by two angles:  $\Delta\psi$ , the angular separation measured along the ecliptic between the mean and true equinoxes ( $K$  and  $K'$  in Fig. 2), and  $\Delta\epsilon$ , the difference in angle between the equatorial planes and the ecliptic plane for the true equator  $\epsilon_1$  and the mean equator  $\epsilon_2$ . The transformation is first  $\Delta\psi \cos \epsilon$  about  $z$ , then  $\epsilon_1$  about the new  $x$  axis, then  $\Delta\psi$  about the latest  $z$  axis, and finally  $(-\epsilon_2)$  about the latest  $x$  axis. Combining all these operations into one matrix, using the small angle approximation and keeping terms only to the first order in  $\Delta\epsilon$  and  $\Delta\psi$ , the resulting nutation matrix  $N$  is

$$N = \begin{pmatrix} 1 & 0 & \Delta\psi \sin \epsilon \\ 0 & 1 & \Delta\epsilon \\ -\Delta\psi \sin \epsilon & -\Delta\epsilon & 1 \end{pmatrix}$$

The arguments required are  $\Delta\psi$  and  $\Delta\epsilon$  which are given by trigonometric series, the constants of which have been determined partially theoretically and partially empirically.

$$\Delta\psi = \sum_{i=1}^N a_i(t) \sin [\alpha_i(t)]$$

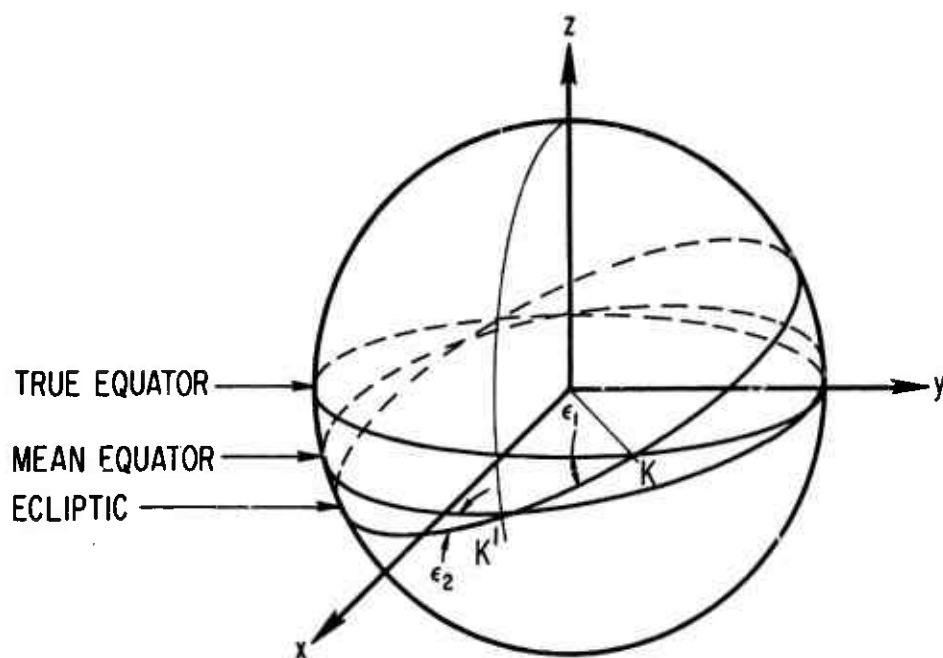


Figure 2. Geometry Relating the True Equator and Mean Equator of Date from which the Nutation Matrix may be Computed. The Angle  $KK'$  is the Nutation in Longitude,  $\Delta\psi$ . The Difference Between the Inclination of the True Equator to the Ecliptic ( $\epsilon_1$ ) and the Mean Equator to the Ecliptic ( $\epsilon_2$ ) is the Nutation in Obliquity,  $\Delta\epsilon$ .

$$\Delta\epsilon = \sum_{i=1}^N b_i(t) \cos[\alpha_i(t)] \quad (13)$$

where  $t$  is time. The  $\alpha_i = \sum_{j=1}^4 \beta_{ij} F_j(t)$ , are various linear combinations of  $F_j(t)$  which are in turn polynomials in  $t$ . Listed in the Explanatory Notes to Ephemeris (Ref. 6) are 69 terms with  $a_i \geq 0.0002$  arc sec and 40 with  $b_i \geq 0.0002$  arc sec. The 0.47 arc sec accuracy required by AOES suggests that not nearly all of these terms are required. Table 1a lists the coefficients of the functions which have either  $a_i$  or  $b_i$  greater than 0.1 arc sec. Table 1b lists the coefficients in the  $F(t)$  polynomials. The time arguments ( $d_n$  and  $T_n$ ) to be used with the coefficients of Table 1 are measured from the beginning of the present Julian Century while the time arguments in AOES are measured in days,  $d$ , since AOES base time. The relations between these quantities are:  $d_n = d + 18262.5$  and  $T_n = d_n/36525$ .

Computer calculations may be checked by comparison with the values listed in Table 2. For 10 day intervals during 1968, the nutation in longitude ( $\Delta\psi$ ) and nutation in obliquity ( $\Delta\epsilon$ ) are listed as obtained both from the limited series of Table 1 and from the full series as tabulated in the 1968 ephemeris (Ref. 12). The nontrivial matrix elements,  $N_{13} = \Delta\psi \sin \epsilon$ , and  $N_{23} = \Delta\epsilon$  corresponding to the limited series calculation are also listed. The maximum difference between the ephemeris and the calculated values is 0.171 arc sec. The average difference without regard to sign, is 0.059 arc sec, well within the accuracy requirement of AOES.\*

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\*'DPNUT does not include the  $i = 4$  term from Table 1a. When this term is not included, the same comparison over 1968 gives a maximum difference of 0.261 arc sec and an average without regard to sign of 0.083 arc sec. The maximum error is within a factor of two of the AOES design limit.

The Data Dynamics Inc. literature on 'DPNUT chose to test the nutation matrix on 1.30 January 1980. The values calculated on the basis of Table 1 for this date are  $\Delta\psi = -7''.958$ ,  $N_{13} = -1.5350 \times 10^{-5}$ , and  $N_{23} = -4.2547 \times 10^{-5}$ . If  $i = 4$  term of Table 1a is not included, we then calculate  $\Delta\psi = 7''.952$ ,  $\Delta\epsilon = -8''.776$ ,  $N_{13} = -1.5338 \times 10^{-5}$ , and  $N_{23} = -4.2547 \times 10^{-5}$ . These latter values are in good agreement with the test number published in the 8/15/07 Milestone 4, revision B, of 'DPNUT.

Table 1. Coefficients and Functions for Nutation Calculations

a. Coefficients of nutation trigonometric series.

| Index, i | $\beta_{i1}$ | $\beta_{i2}$ | $\beta_{i3}$ | $\beta_{i4}$ | $a_i$<br>( $\Delta\psi$ longitude)<br>(arc sec) | $b_i$<br>( $\Delta\epsilon$ obliquity)<br>(arc sec) |
|----------|--------------|--------------|--------------|--------------|-------------------------------------------------|-----------------------------------------------------|
| 1        | 0            | 0            | 0            | 1            | $-17.2327 - 0.01737 T_n$                        | $+9.21 + 0.00091 T_n$                               |
| 2        | 0            | 0            | 0            | 2            | $+0.2088 + 0.00002 T_n$                         | $-0.0904 + 0.00004 T_n$                             |
| 3        | 0            | 2            | -2           | 2            | $-1.2729 - 0.00013 T_n$                         | $+0.5522 - 0.00029 T_n$                             |
| 4        | 1            | 0            | 0            | 0            | $+0.1261 - 0.00031 T_n$                         |                                                     |
| 5        | 0            | 2            | 0            | 2            | $+0.2037 - 0.00002 T_n$                         | $+0.0884 - 0.00005 T_n$                             |

b. Coefficients of nutation polynomials

$$F_j = f_{j0} + f_{j1}d_n + f_{j2}d_n^2 + f_{j3}d_n^3$$

| Index, j | $f_{j0}$<br>(deg) | $f_{j1}$<br>(deg) | $f_{j2}$<br>(deg)        | $f_{j3}$<br>(deg)      |
|----------|-------------------|-------------------|--------------------------|------------------------|
| 1        | 358.475833        | 0.9856002669      | $-1.12 \times 10^{-13}$  | $-6.8 \times 10^{-20}$ |
| 2        | 11.250889         | 13.2293504490     | $-2.407 \times 10^{-12}$ | $-7.0 \times 10^{-21}$ |
| 3        | 350.737486        | 12.1907491914     | $-1.076 \times 10^{-12}$ | $3.9 \times 10^{-20}$  |
| 4        | 259.183275        | -0.0529539222     | $1.557 \times 10^{-12}$  | $4.6 \times 10^{-20}$  |

Table 2. Nutation Matrix Values for 1968

| Julian Day | Nutation in Longitude |                        | Nutation in Obliquity |                        | Off-Axis Matrix Elements |           |
|------------|-----------------------|------------------------|-----------------------|------------------------|--------------------------|-----------|
|            | $\Delta\psi$          |                        | $\Delta\epsilon$      |                        | (Units of $10^{-5}$ )    |           |
|            | Calculated            | Ephemeris<br>(Ref. 13) | Calculated            | Ephemeris<br>(Ref. 13) | $N_{1,3}$                | $N_{2,3}$ |
| 2439855.5  | -6.477                | -6.401                 | 7.736                 | 7.708                  | -1.2494                  | 3.7507    |
| 65.6       | -6.149                | -6.132                 | 7.946                 | 7.949                  | -1.1861                  | 3.8521    |
| 75.5       | -5.457                | -5.428                 | 8.203                 | 8.224                  | -1.0527                  | 3.9768    |
| 85.5       | -4.949                | -4.822                 | 8.299                 | 8.320                  | -0.9546                  | 4.0236    |
| 95.5       | -5.027                | -5.089                 | 8.457                 | 8.472                  | -0.9697                  | 4.1001    |
| 2439905.5  | -5.098                | -5.150                 | 8.791                 | 8.832                  | -0.9835                  | 4.2622    |
| 15.5       | -4.901                | -4.891                 | 9.008                 | 9.046                  | -0.9454                  | 4.3674    |
| 25.5       | -5.058                | -5.209                 | 9.014                 | 8.996                  | -0.9757                  | 4.3699    |
| 35.5       | -5.630                | -5.683                 | 9.085                 | 9.064                  | -1.0859                  | 4.4044    |
| 45.5       | -5.890                | -5.948                 | 9.227                 | 9.223                  | -1.1361                  | 4.4734    |
| 2439955.5  | -5.839                | -5.927                 | 9.150                 | 9.107                  | -1.1264                  | 4.4359    |
| 65.5       | -6.096                | -5.992                 | 8.918                 | 8.874                  | -1.1760                  | 4.3233    |
| 75.5       | -6.423                | -6.444                 | 8.826                 | 8.797                  | -1.2390                  | 4.2789    |
| 85.5       | -6.178                | -6.182                 | 8.776                 | 8.775                  | -1.1918                  | 4.2549    |
| 95.5       | -5.696                | -5.525                 | 8.538                 | 8.543                  | -1.0988                  | 4.1392    |
| 2440005.5  | -5.532                | -5.542                 | 8.307                 | 8.292                  | -1.0671                  | 4.0272    |
| 15.5       | -5.249                | -5.292                 | 8.316                 | 8.345                  | -1.0125                  | 4.0316    |
| 25.5       | -4.450                | -4.362                 | 8.355                 | 8.389                  | -0.8584                  | 4.0506    |
| 35.5       | -3.745                | -3.793                 | 8.267                 | 8.261                  | -0.7225                  | 4.0079    |
| 45.5       | -3.496                | -3.542                 | 8.311                 | 8.303                  | -0.6744                  | 4.0294    |
| 2440055.5  | -3.117                | -3.119                 | 8.585                 | 8.592                  | -0.6013                  | 4.1619    |
| 65.5       | -2.478                | -2.525                 | 8.788                 | 8.782                  | -0.4780                  | 4.2604    |
| 75.5       | -2.271                | -2.213                 | 8.861                 | 8.833                  | -0.4381                  | 4.2958    |
| 85.5       | -2.522                | -2.533                 | 9.075                 | 9.046                  | -0.4865                  | 4.3996    |
| 95.5       | -2.546                | -2.567                 | 9.383                 | 9.383                  | -0.4912                  | 4.5490    |
| 2440105.5  | -2.452                | -2.329                 | 9.478                 | 9.477                  | -0.4730                  | 4.5953    |
| 15.5       | -2.842                | -2.835                 | 9.437                 | 9.407                  | -0.5483                  | 4.5754    |
| 25.5       | -3.391                | -3.378                 | 9.520                 | 9.516                  | -0.6540                  | 4.6153    |
| 35.5       | -3.464                | -3.375                 | 9.575                 | 9.601                  | -0.6683                  | 4.6419    |
| 45.5       | -3.426                | -3.436                 | 9.376                 | 9.375                  | -0.6608                  | 4.5458    |
| 2440155.5  | -3.723                | -3.649                 | 9.142                 | 9.142                  | -0.7183                  | 4.4323    |
| 65.6       | -3.811                | -3.804                 | 9.078                 | 9.103                  | -0.7352                  | 4.4013    |
| 75.5       | -3.309                | -3.370                 | 8.961                 | 8.989                  | -0.6383                  | 4.3446    |
| 85.5       | -2.827                | -2.729                 | 8.681                 | 8.701                  | -0.5454                  | 4.2086    |
| 95.5       | -2.627                | -2.667                 | 8.531                 | 8.529                  | -0.5067                  | 4.1362    |
| 2440205.5  | -2.088                | -2.196                 | 8.598                 | 8.629                  | -0.4028                  | 4.1686    |
| 15.5       | -1.173                | -1.092                 | 8.599                 | 8.624                  | -0.2263                  | 4.1689    |
| 25.5       | -0.609                |                        | 8.530                 |                        | -0.1175                  | 4.1354    |

b. Precession

The precession is described by the three angles shown in Fig. 3.  $\alpha = 90^\circ - \zeta_0$  is the right ascension of the ascending node ( $\eta$ ) of the equator of epoch  $t$  on the equator of  $t_0$  reckoned from the equinox of  $t_0$ .  $\beta = 90^\circ + z$  is the right ascension of the node ( $\eta$ ) reckoned from the equinox of  $t$  on the equator of  $t$  and  $\theta$  is the inclination of the equator of  $t$  to the equator of  $t_0$ . To transform  $X, Y, Z$  components of one system to  $X_0, Y_0,$  and  $Z_0$  of the other requires first a rotation  $+\beta$  about  $Z$ ,  $-\theta$  about the new  $X$ , and finally  $-\alpha$  about the latest  $Z$  axis. The  $P$  matrix elements then result from straightforward trigonometry.

$$P_{11} = \cos \zeta_0 \cos \theta \cos Z - \sin \zeta_0 \sin Z$$

$$P_{21} = -\sin \zeta_0 \cos \theta \cos Z - \cos \zeta_0 \sin Z$$

$$P_{31} = -\sin \theta \cos Z$$

$$P_{12} = \cos \zeta_0 \cos \theta \sin Z + \sin \zeta_0 \cos Z$$

$$P_{22} = -\sin \zeta_0 \cos \theta \sin Z + \cos \zeta_0 \cos Z$$

$$P_{32} = -\sin \theta \sin Z$$

$$P_{13} = \cos \zeta_0 \sin \theta$$

$$P_{23} = -\sin \zeta_0 \sin \theta$$

$$P_{33} = \cos \theta$$

The angles are given by (Ref. 6):

$$\zeta_0 = (2304''250 + 1''396 T_{0p}) T_p + 0''302 T_p^2 + 0''018 T_p^3$$

$$z = \zeta_0 + 0''791 T_p^2$$

$$\theta = (2004''682 - 0''853 T_{0p}) T_p - 0''426 T_p^2 - 0''042 T_p^3$$

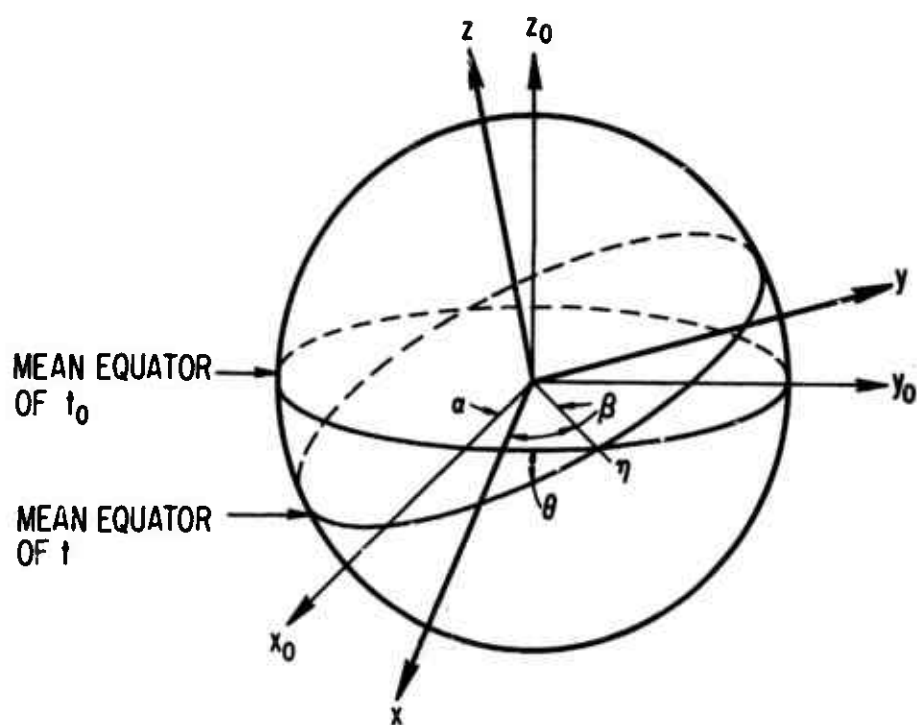


Figure 3. Geometry Relating the Mean Equator of  $t_0$  to the Mean Equator of Time  $t$ , from which the Precession Matrix may be Computed.

$T_p$  is the time interval between the two epochs measured in tropical centuries of 36524.22 days.  $T_{Op}$  is the time since Besselian year 1900.0, also measured in tropical centuries. Changing to AOES base time, which is 0.077 day into Besselian year 1950,  $T_{Op} = 0.5$  and  $T_p = (0.077 + d)/36524.22$ , where  $d$  is the number of days since AOES reference time. The equations then become:

$$\zeta_o = 2304''948 T_p + 0''302 T_p^2 + 0''018 T_p^3$$

$$z = \zeta_o + 0''791 T_p^2$$

$$\theta = 2004''2555 T_p - 0''426 T_p^2 - 0''042 T_p^3$$

The results of calculating the angles and the matrix elements for a few selected times are tabulated in Table 3. Also tabulated are results for approximately the same times taken from Tables 2.1 and 2.2 of the Explanatory Notes to the Ephemeris (Ref. 6). The differences in the angles are due to the calculation being made for 0<sup>h</sup> on January 1 while the ephemeris tables were computed for the beginning of the Besselian Year.\*

#### B. TIME TRANSFORMATIONS

The time transformations required are between UTC, used in earth fixed system, and A1 used in the inertial system. Since sidereal time is directly proportional to UT0, the relation between UT0 and A1 or UTC must also be accurately known. Universal time is required to calculate the precession-nutation matrix but since this is a small correction the differences between UTC and A1 are insignificant. This section reviews these transformations between time scales.

\*The times for which values are presented in Table 3 are the times used for testing the P matrix in 'DPNUT. The values in Table 3 for the off axis matrix elements differ slightly but significantly from the values published in 'DPNUT, Milestone 4, Revision B, 8/15/67. It is suspected this is due to roundoff error in the Milestone 4 values but this is not definitely known.

Table 3. Calculated Precession Matrix Values

|                    | 0 <sup>h</sup> 1 Jan 1960 |                       |  | 0 <sup>h</sup> 1 Jan 1970 |                       |  | 0 <sup>h</sup> 1 Jan 1980 |                       |  |
|--------------------|---------------------------|-----------------------|--|---------------------------|-----------------------|--|---------------------------|-----------------------|--|
|                    | Calculation               | Ephemeris<br>(Ref. 6) |  | Calculation               | Ephemeris<br>(Ref. 6) |  | Calculation               | Ephemeris<br>(Ref. 6) |  |
| $\xi_0$ (sec)      | 15.3651                   | 15.367                |  | 30.7344                   | 30.733                |  | 46.1000                   | 46.101                |  |
| $\zeta$ (sec)      | 15.3656                   | 15.367                |  | 30.7365                   | 30.736                |  | 46.1047                   | 46.106                |  |
| $\sigma$ (sec)     | 13.3601                   | 13.361                |  | 26.7231                   | 26.722                |  | 40.0818                   | 40.082                |  |
| $P_{11}$           | .99999703                 | .99999702             |  | .99998812                 | .99998807             |  | .99997327                 | .99997324             |  |
| $P_{12} = -P_{21}$ | .00223479                 | .00223479             |  | .00447028                 | .00447028             |  | .00670526                 | .00670526             |  |
| $P_{13} = P_{31}$  | .00097153                 | .00097157             |  | .00194335                 | .00194335             |  | .00291481                 | .00291480             |  |
| $P_{22}$           | .99999750                 | .99999749             |  | .99999001                 | .99998997             |  | .99997752                 | .99997749             |  |
| $P_{23} = P_{32}$  | -.00000109                | -.00000109            |  | -.00000434                | -.00000436            |  | .00000977                 | .00000979             |  |
| $P_{33}$           | .99999953                 | .99999953             |  | .99999811                 | .99999810             |  | .99999575                 | .99999574             |  |

1. A1 TO UTC

The UTC time scale is related to the A1 scale as follows:

$$A1 = UTC + a_1 - s_1 (UTC - UTC_1)$$

The  $s_1$  are frequency offsets decided in advance and announced by an international bureau to keep the rate of change of UTC with respect to A1 about equal to the average rate of change of UT2 with respect to A1. The  $s_1$  are changed only on the beginning of a year. The  $a_1$  are also decided upon and announced in advance by the same international bureau, when UTC and UT2 differ by more than about 0.1 sec. The  $a_1$  may be changed at the beginning of any month.

Values of the frequency shifts,  $s_1$  and offsets,  $a_1$ , have been calculated for all the changes which have taken place in UTC between 1 January 1961 and 30 June 1969. These are presented in the first three columns of Table 4. The values of  $UTC_1$  appearing in the first column are given in units of days since AOES base time. (The 1 August 1963 entry is an exception in that no defined change in UTC took place at this time. This entry was introduced to reduce the maximum difference between UTC and UT2 (See Appendix C).

During the early part of this time period the clocks used could not be held at precisely the nominal announced frequency offset,  $s_1$ . This is reflected in Table 4 by the  $s_1$  which do not have a simple value. The values for  $s_1$  which are specified to 3 decimal places are the results of least squares fitting to the time scale established by the National Bureau of Standard Radio Station (WWV) broadcasts. The UTC values calculated from the constants differ in all cases by less than one millisecond from the UTC time scale established by WWV. The advances in frequency control at U.S. Naval Observatory (USNO) and within the Satellite Control Facility should make corrections to the nominal offset,  $s_1$ , unnecessary in the future.

Table 4. AUTAB from Least Squares Fit to US Naval Observatory Data

| Notation in this report | UTC <sub>1</sub> | s <sub>1</sub>                             | s <sub>1</sub>                              | c <sub>1</sub>                               | d <sub>1</sub>                             | Maximum<br> UT2 <sub>calc</sub> - UT2 <sub>USNO</sub>  <br>(msec) |
|-------------------------|------------------|--------------------------------------------|---------------------------------------------|----------------------------------------------|--------------------------------------------|-------------------------------------------------------------------|
| AUTAB item              | UTC <sub>1</sub> | FRQSHF<br>(units of<br>10 <sup>-10</sup> ) | UCTAA<br>(units of<br>10 <sup>-2</sup> min) | UCTU2C<br>(units of<br>10 <sup>-4</sup> min) | UCTU2D<br>(units of<br>10 <sup>-10</sup> ) |                                                                   |
| Dates                   | (days)           |                                            |                                             |                                              |                                            |                                                                   |
| 1 Jan 61 to 1 Aug 61    | 4018             | -148.958                                   | 2.4353                                      | 2.8909                                       | 32.505                                     | 10.0                                                              |
| 1 Aug 61 to 1 Jan 62    | 4230             | -150.0                                     | 2.8067                                      | 2.3291                                       | 6.5518                                     | 2.0                                                               |
| 1 Jan 62 to 1 Aug 63    | 4383             | -129.778                                   | 3.1370                                      | 5.3254                                       | -21.245                                    | 16.0                                                              |
| 1 Aug 63 to 1 Nov 63    | 4960             | -129.485                                   | 4.2157                                      | -14.203                                      | -85.571                                    | 0.3                                                               |
| 1 Nov 63 to 1 Jan 64    | 5052             | -130.0                                     | 4.5538                                      | -8.9828                                      | -80.324                                    | 0.6                                                               |
| 1 Jan 64 to 1 Apr 64    | 5113             | -150.0                                     | 4.6677                                      | -16.084                                      | -64.699                                    | 1.0                                                               |
| 1 Apr 64 to 1 Sep 64    | 5204             | -149.768                                   | 5.0310                                      | -7.4724                                      | -68.523                                    | 3.0                                                               |
| 1 Sep 64 to 1 Jan 65    | 5357             | -150.0                                     | 5.5288                                      | -6.4912                                      | -85.260                                    | 7.0                                                               |
| 1 Jan 65 to 1 Mar 65    | 5479             | -150.0                                     | 5.9593                                      | -4.7161                                      | -72.321                                    | 0.4                                                               |
| 1 Mar 65 to 1 Jul 65    | 5538             | -150.0                                     | 6.2533                                      | 5.3646                                       | -95.223                                    | 5.0                                                               |
| 1 Jul 65 to 1 Sep 65    | 5660             | -150.0                                     | 6.6835                                      | 4.8843                                       | -118.35                                    | 0.6                                                               |
| 1 Sep 65 to 1 Jan 66    | 5722             | -150.0                                     | 6.9840                                      | 10.053                                       | -128.91                                    | 8.0                                                               |
| 1 Jan 66 to 1 Feb 68    | 5844             | -300.0                                     | 7.2476                                      | -8.9162                                      | 20.398                                     | 22.0                                                              |
| 1 Feb 68 to 9 Jul 69    | 6605             | -300.0                                     | 10.3665                                     | -1.1220                                      | 9.1113                                     | 18.0                                                              |

## 2. A1 TO UT0

### a. Timing Polynomials, A1 to UT1

As discussed under time scales, the relationship between atomic based time scales, such as UTC or A1, and earth motion time scales such as UT0 is, when considered at their highest accuracy, a relation which is known precisely only after an event has occurred. A most straightforward way to obtain UT0 from A1 would be a power series fit to obtain UT1, then the station peculiar correction to get UT0. The constants in the formula would be changed whenever the fit became unsatisfactory. This is the approach taken by the Jet Propulsion Laboratory (Refs. 14, 15) and the coefficients of their timing polynomials are readily available (Table 3, Ref. 2). From these coefficients "the value of A1-UT1 is known to  $\pm 0.005$  sec. after the fact and to  $0.0002 \text{ sec/day}^2$  additional when predicting ahead." To accomplish this accuracy requires 41 different sets of polynomials to cover the period from 1 January 1961 through June 1969.

### b. Successive Corrections, UTC to UT2

Another approach is to take advantage of AOES's use of UTC, which is already a first approximation to UT2 and apply in reverse the corrections used to get UTC from UT1. This is the approach followed by AOES. A linear relation between UTC and UT2 is assumed.

$$UT2 = UTC + C_1 + d_1 (UTC - UTC_1)$$

As a programming convenience the same  $UTC_1$  used for the UTC to A1 conversion are used here. Tabulated in Table 4 are the constants resulting from a least squares fit of this formula to the USNO determined UT2 scale. (Ref. 16). The maximum values of  $|UT2(\text{calculated}) - UT2(\text{USNO})|$  are also tabulated in Table 4-- the absolute difference between the UT2 calculated from the constants and the UT2 established by the US Naval Observatory.

The largest errors are around 20 msec, some four times larger than the JPL timing polynomials errors, but only 14 different sets of constants are required to cover the 1961 to 1969 period compared with the 41 required for JPL polynomials. The 22 msec is still well within the 30 msec accuracy requirement of AOES. In Appendix A, all of the USNO time data employed are tabulated along with the calculated values of UTC and UT2 obtained from the constants of Table 4 for each input time.

c. UT2 to UT1

After determining UT2, the seasonal correction, S, must be applied to obtain UT1.  $UT1 = UT2 - S$ . The assumed form of S is:

$$S = u_1 \sin(2\pi t) + u_2 \cos(2\pi t) + u_3 \sin(4\pi t) + u_4 \cos(4\pi t)$$

where t is the fraction of a Julian year of 365.25 days since 1 January of the year. The  $u_i$  are chosen for an entire year.\* Values found by a least squares fit to the USNO data (Ref. 16) are listed in Table 5. The complete USNO data and the fit for all input values is shown in Appendix B. For all years except 1962 the errors are less than the 1 msec accuracy with which the USNO values are stated.

Table 5. Seasonal Time Variation Coefficients

| Year    | $u_1$<br>(sec) | $u_2$<br>(sec) | $u_3$<br>(sec) | $u_4$<br>(sec) |
|---------|----------------|----------------|----------------|----------------|
| 1961    | 0.0221         | -0.0169        | -0.0069        | 0.0059         |
| 1962    | 0.0210         | -0.0135        | -0.0074        | 0.0067         |
| 1963-68 | 0.0220         | -0.0120        | -0.0059        | 0.0070         |

\*The  $u_i$  are the U1K1, U1K2, U1K3, U1K4 of the constant block 'AUBLK in the AOES data base.

d. UT1 to UT0

The correction from UT1 to UT0 is really another coordinate change which should be applied to relate earth fixed coordinates referred to a point on the earth to earth fixed coordinates referred to the pole of rotation. If  $\vec{r}$  is a vector determined with respect to a system of coordinates defined by the mean pole of 1903 and  $\vec{r}'$  is a vector determined with respect to a system of coordinates defined by the current pole of rotation then

$$\vec{r}' = R \vec{r}$$

where

$$R = \begin{pmatrix} 1 & 0 & x \\ 0 & 1 & y \\ -x & -y & 1 \end{pmatrix}$$

And  $x$  and  $y$  are shifts from the mean pole in radian measure. If  $\lambda$  is the longitude and  $\phi$  the latitude, this same change can be represented as a change of latitude,  $\Delta\phi$  and longitude,  $\Delta\lambda$ .

$$\Delta\lambda = \lambda' - \lambda = \tan \phi (x \sin \lambda + y \cos \lambda)$$

$$\Delta\phi = \phi' - \phi = x \cos \lambda - y \sin \lambda$$

The values of  $x$  and  $y$  are presented as a polar plot for the 1962 to 1968 time period in Fig. 4 (Ref. 2). It will be noted that over a period of 6 months the values have changed by as much as 0.5 arc sec. This is approximately equal to the design goal of AOES and is not corrected for in AOES transformations since the correction is station peculiar.

e. Accuracy

The largest single error source is the polar motion which is not corrected for and may amount to  $\pm 0.020$  sec time. The next largest source of error is the conversion from UTC to UT2 which may at times be in error nearly as much. The other corrections are never in error by more than 0.1 of these amounts. If these two sources of error were independent and random (neither of which is probably true) then one might expect the total error to be  $(2)^{1/2}$  times the error from either of the two sources of equal magnitude or about  $\pm 0.030$  sec time--just about the AOES design goal.

Thus the present AOES transformation achieves the design accuracy goals. Improvement in accuracy of other parts of the system beyond the present goals is not useful unless the transformations are also improved. For greater accuracy the relation between AI (or UTC) and UT2 must be improved, perhaps by using something like the JPL timing polynomials, and the polar motion must be included.

3. PARAMETER UPDATE

Most of the parameters occurring in the various time transformation equations are not varying, and except to review them occasionally to assure that the best currently available values are in use, they do not need to be changed. Exceptions to this are the constants relating AI to UTC to UT1. These constants must be updated to reflect the most recent available information. A convenient source of this current information is the weekly bulletin of the US Naval Observatory, "Preliminary Times and Coordinates of the Pole, Series 7", which gives information on UTC, UT2, UT1, UT0 and should it be useful sometime in the future x, and y coordinates of the pole. Appendix C outlines a possible systematic way to incorporate this data as it becomes available, while at the same time making a minimum number of changes in the computer data base.

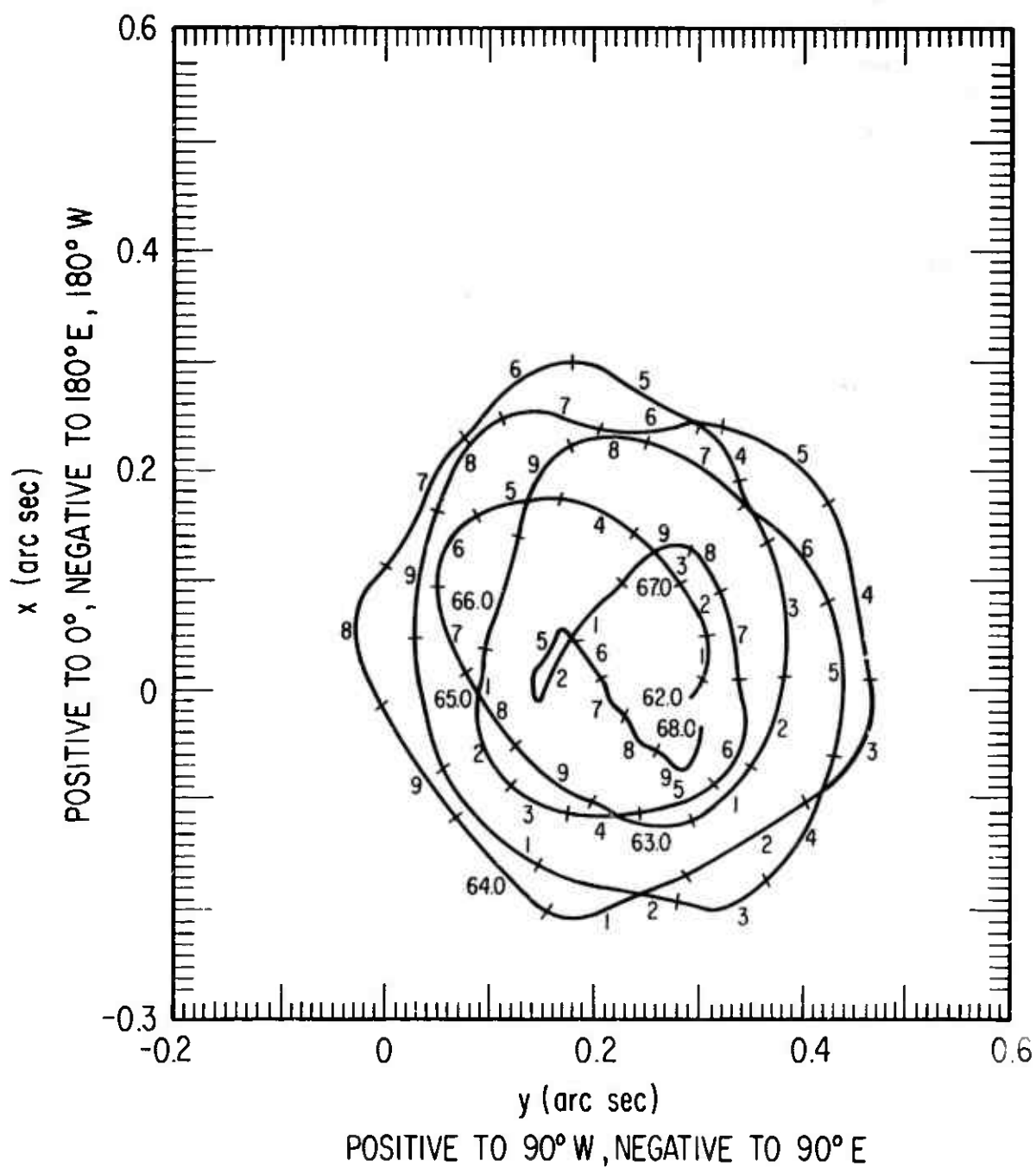


Figure 4. Polar Orbit Plot of the Coordinates of the Pole of Rotation of the Earth for the Period 1962 to 1968 (Ref. 2).

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13.  $\Delta\epsilon$  is tabulated in the Sun Table, pages 18-33, reference 12.  $\Delta\epsilon$  is tabulated in -B in the Besselian Day Numbers, pages 260-275 reference 12.
14. P. M. Muller, "Timing Data and Orbit Determination Process at JPL" Space Program Summary No. 37-41, Volume III, page 18, Jet Propulsion Laboratory, 30 September 1966.
15. P. M. Muller, "A Method of Constrained Least-Squares Polynomial Fitting with Application to Analysis of A.1 - WWV from 1955 to 1968," Space Program Summary No. 37-49, Volume II, Page 2, Jet Propulsion Laboratory, 31 January 1968.

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\* Not available for distribution outside Aerospace Corporation.

16. U. S. Naval Observatory Time Signals, Bulletins 188 thru 215, 15 May, 1961 to 20 June 1968. U. S. Naval Observatory, Preliminary Times and Coordinates of the Pole, Series 7, No. 1 (January 1968) to No. 79 (3 July 1969).
17. U. S. Naval Observatory Time Signals, Bulletin 215, 20 June 1968, paragraph 13.

## APPENDIX A

Comparison of UTC and UT2 as computed from the constants of Table 4 as compared with the US Naval Observatory established scales, which are labelled "EXP".

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 JANUARY 1961 TO 1 AUGUST 1961 07/16/69  
 A1 + UTC + UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC01S = 4.018000000E+03  
 FRQSHF = -1.489580000E-08  
 UCTAA = 2.435300000E-02  
 UCTU2C = 2.890900000E-04  
 UTCU20 = 3.250500000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2437309.5     | 1.472763                | .019873                  | 1.452890                | 1.472800               | .037               | 1.459700               | 6.810              | 10 JAN 61 |
| 2437319.5     | 1.485633                | .022681                  | 1.462952                | 1.485800               | .167               | 1.469300               | 6.348              | 20 JAN 61 |
| 2437329.5     | 1.498503                | .025490                  | 1.473013                | 1.498700               | .197               | 1.476900               | 3.887              | 30 JAN 61 |
| 2437339.5     | 1.511373                | .028298                  | 1.483075                | 1.511600               | .227               | 1.483400               | .325               | 9 FEB 61  |
| 2437349.5     | 1.524243                | .031107                  | 1.493136                | 1.524500               | .257               | 1.490300               | -2.836             | 19 FEB 61 |
| 2437359.5     | 1.537113                | .033915                  | 1.503198                | 1.537300               | .187               | 1.499300               | -3.898             | 1 MAR 61  |
| 2437369.5     | 1.549983                | .036724                  | 1.513259                | 1.550200               | .217               | 1.510700               | -2.559             | 11 MAR 61 |
| 2437379.5     | 1.562853                | .039532                  | 1.523321                | 1.563100               | .247               | 1.524200               | .879               | 21 MAR 61 |
| 2437389.5     | 1.575723                | .042340                  | 1.533382                | 1.576000               | .277               | 1.536000               | 2.618              | 31 MAR 61 |
| 2437399.5     | 1.588593                | .045149                  | 1.543444                | 1.588900               | .307               | 1.544900               | 1.456              | 10 APR 61 |
| 2437409.5     | 1.601463                | .047957                  | 1.553505                | 1.601700               | .237               | 1.551700               | -1.805             | 20 APR 61 |
| 2437419.5     | 1.614333                | .050766                  | 1.563567                | 1.614600               | .267               | 1.558300               | -5.267             | 30 APR 61 |
| 2437429.5     | 1.627203                | .053574                  | 1.573628                | 1.627500               | .297               | 1.566300               | -7.328             | 10 MAY 61 |
| 2437439.5     | 1.640073                | .056383                  | 1.583690                | 1.640400               | .327               | 1.576800               | -6.890             | 20 MAY 61 |
| 2437449.5     | 1.652943                | .059191                  | 1.593752                | 1.653200               | .257               | 1.588300               | -5.452             | 30 MAY 61 |
| 2437459.5     | 1.665813                | .061999                  | 1.603813                | 1.666100               | .287               | 1.600500               | -3.313             | 9 JUN 61  |
| 2437469.5     | 1.678683                | .064808                  | 1.613875                | 1.678900               | .217               | 1.612800               | -1.075             | 19 JUN 61 |
| 2437479.5     | 1.691552                | .067616                  | 1.623936                | 1.691700               | .148               | 1.625400               | 1.464              | 29 JUN 61 |
| 2437489.5     | 1.704422                | .070425                  | 1.633998                | 1.704500               | .078               | 1.638100               | 4.112              | 9 JUL 61  |
| 2437499.5     | 1.717292                | .073233                  | 1.644059                | 1.717300               | .008               | 1.651000               | 6.941              | 19 JUL 61 |
| 2437509.5     | 1.730162                | .076042                  | 1.654121                | 1.730200               | .038               | 1.664000               | 9.879              | 29 JUL 61 |
| A1UT2 37300   | COM37512 4018           | 2.4353E-02               | -148.958E-10            | +2.8909E-04            | +32.505E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAR CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 AUGUST 1961 TO 1 JANUARY 1962 07/16/69  
 A1 & UTC & UT2 TESTING USING OATU FORMULAS

PARAMETERS  
 UTC015 = 4.23000000E+03  
 FRQSHF = -1.50000000E-08  
 UCTAA = 2.80670000E-02  
 UCTU2C = 2.32910000E-04  
 UTCU20 = 6.55180000E-10

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2437519.5     | 1.693092                | .014371                  | 1.678721                | 1.693103               | .008               | 1.677600               | -1.721             | 8 AUG 61  |
| 2437529.5     | 1.706052                | .014937                  | 1.691115                | 1.706000               | -.052              | 1.690000               | -1.115             | 18 AUG 61 |
| 2437539.5     | 1.719012                | .015503                  | 1.703509                | 1.719000               | -.012              | 1.703000               | -.509              | 28 AUG 61 |
| 2437549.5     | 1.731972                | .016069                  | 1.715903                | 1.732100               | .128               | 1.716000               | .097               | 7 SEP 61  |
| 2437559.5     | 1.744932                | .016635                  | 1.728297                | 1.745100               | .168               | 1.728900               | .603               | 17 SEP 61 |
| 2437569.5     | 1.757892                | .017201                  | 1.740691                | 1.758000               | .108               | 1.741600               | .909               | 27 SEP 61 |
| 2437579.5     | 1.770852                | .017767                  | 1.753085                | 1.770900               | .048               | 1.754200               | 1.115              | 7 OCT 61  |
| 2437589.5     | 1.783812                | .018333                  | 1.765479                | 1.783800               | -.012              | 1.766600               | 1.121              | 17 OCT 61 |
| 2437599.5     | 1.796772                | .018899                  | 1.777873                | 1.796700               | -.072              | 1.779000               | 1.127              | 27 OCT 61 |
| 2437609.5     | 1.809732                | .019466                  | 1.790266                | 1.809700               | -.032              | 1.791300               | 1.034              | 6 NOV 61  |
| 2437619.5     | 1.822692                | .020032                  | 1.802660                | 1.822600               | -.092              | 1.803500               | .840               | 16 NOV 61 |
| 2437629.5     | 1.835652                | .020598                  | 1.815054                | 1.835600               | -.052              | 1.815500               | .446               | 26 NOV 61 |
| 2437639.5     | 1.848612                | .021164                  | 1.827448                | 1.848600               | -.012              | 1.827300               | -.148              | 6 DEC 61  |
| 2437649.5     | 1.861572                | .021730                  | 1.839842                | 1.861600               | .028               | 1.838700               | -1.142             | 16 DEC 61 |
| 2437659.5     | 1.874532                | .022296                  | 1.852236                | 1.874500               | .068               | 1.849200               | -2.436             | 26 DEC 61 |
| ALUT2 37512   | COM37665 4230           | 2.8067E-02               | -150.000E-10            | +2.3291E-04            | +6.5518E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM #AU7A8 CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 JANUARY 1962 TO 1 AUGUST 1963 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC01S = 4.38300000E+03  
 FRO5HF = -1.29778000E-08  
 UCTAA = 3.13700000E-02  
 UTCU2C = 5.32540000E-04  
 UTCU2D = -2.12450000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2437669.5     | 1.886685                | .031218                  | 1.855467                | 1.886900               | .215               | 1.871900               | 16.433             | 5 JAN 62  |
| 2437679.5     | 1.897898                | .029383                  | 1.868515                | 1.898100               | .202               | 1.882800               | 14.285             | 15 JAN 62 |
| 2437689.5     | 1.909111                | .027547                  | 1.881564                | 1.909300               | .189               | 1.893500               | 11.936             | 25 JAN 62 |
| 2437699.5     | 1.920324                | .025711                  | 1.894612                | 1.920500               | .176               | 1.903800               | 9.188              | 4 FEB 62  |
| 2437709.5     | 1.931536                | .023876                  | 1.907661                | 1.931700               | .164               | 1.914800               | 7.139              | 14 FEB 62 |
| 2437719.5     | 1.942749                | .022040                  | 1.920709                | 1.942900               | .151               | 1.923700               | 4.991              | 24 FEB 62 |
| 2437729.5     | 1.953962                | .020205                  | 1.933757                | 1.954100               | .138               | 1.936800               | 3.043              | 6 MAR 62  |
| 2437739.5     | 1.965175                | .018369                  | 1.946806                | 1.965400               | .225               | 1.948100               | 1.294              | 16 MAR 62 |
| 2437749.5     | 1.976388                | .016534                  | 1.959854                | 1.976700               | .312               | 1.959300               | -.554              | 26 MAR 62 |
| 2437759.5     | 1.987601                | .014698                  | 1.972902                | 1.987900               | .299               | 1.970400               | -2.502             | 5 APR 62  |
| 2437769.5     | 1.998813                | .012862                  | 1.985951                | 1.999200               | .387               | 1.982300               | -3.651             | 15 APR 62 |
| 2437779.5     | 2.010026                | .011027                  | 1.998999                | 2.010400               | .374               | 1.994700               | -4.299             | 25 APR 62 |
| 2437789.5     | 2.021239                | .009191                  | 2.012048                | 2.021600               | .361               | 2.007500               | -4.548             | 5 MAY 62  |
| 2437799.5     | 2.032452                | .007356                  | 2.025096                | 2.032800               | .348               | 2.020900               | -4.196             | 15 MAY 62 |
| 2437809.5     | 2.043665                | .005520                  | 2.038144                | 2.044000               | .335               | 2.033800               | -4.344             | 25 MAY 62 |
| 2437819.5     | 2.054877                | .003685                  | 2.051193                | 2.055200               | .323               | 2.045900               | -5.293             | 4 JUN 62  |
| 2437829.5     | 2.066090                | .001849                  | 2.064241                | 2.066400               | .310               | 2.057200               | -7.041             | 14 JUN 62 |
| 2437839.5     | 2.077303                | .000014                  | 2.077290                | 2.077500               | .197               | 2.068300               | -8.990             | 24 JUN 62 |
| 2437849.5     | 2.088516                | -.001822                 | 2.090338                | 2.088700               | .184               | 2.079600               | -10.738            | 4 JUL 62  |
| 2437859.5     | 2.099729                | -.003658                 | 2.103386                | 2.099900               | .171               | 2.091400               | -11.986            | 14 JUL 62 |
| 2437869.5     | 2.110942                | -.005493                 | 2.116435                | 2.111100               | .158               | 2.104200               | -12.235            | 24 JUL 62 |
| 2437879.5     | 2.122154                | -.007329                 | 2.129483                | 2.122300               | .146               | 2.117700               | -11.783            | 3 AUG 62  |
| 2437889.5     | 2.133367                | -.009164                 | 2.142531                | 2.133500               | .133               | 2.131700               | -10.831            | 13 AUG 62 |
| 2437899.5     | 2.144580                | -.011000                 | 2.155580                | 2.144700               | .120               | 2.146300               | -9.280             | 23 AUG 62 |
| 2437909.5     | 2.155793                | -.012825                 | 2.168628                | 2.155900               | .107               | 2.161700               | -6.928             | 2 SEP 62  |
| 2437919.5     | 2.167006                | -.014671                 | 2.181677                | 2.167100               | .094               | 2.178900               | -2.777             | 12 SEP 62 |
| 2437929.5     | 2.178218                | -.016507                 | 2.194725                | 2.178300               | .082               | 2.195400               | -.675              | 22 SEP 62 |

|             |               |            |              |             |             |          |         |           |
|-------------|---------------|------------|--------------|-------------|-------------|----------|---------|-----------|
| 2437939.5   | 2.189431      | -.018342   | 2.207773     | 2.189400    | -.031       | 2.209300 | 1.527   | 2 OCT 62  |
| 2437949.5   | 2.200644      | -.020178   | 2.220822     | 2.200600    | -.044       | 2.222800 | 1.978   | 12 OCT 62 |
| 2437959.5   | 2.211857      | -.022013   | 2.233870     | 2.211900    | .043        | 2.237500 | 3.630   | 22 OCT 62 |
| 2437969.5   | 2.223070      | -.023849   | 2.246919     | 2.223100    | .030        | 2.252400 | 5.481   | 1 NOV 62  |
| 2437979.5   | 2.234283      | -.025684   | 2.259967     | 2.234300    | .017        | 2.266700 | 6.733   | 11 NOV 62 |
| 2437989.5   | 2.245495      | -.027520   | 2.273015     | 2.245500    | .005        | 2.281000 | 7.985   | 21 NOV 62 |
| 2437999.5   | 2.256708      | -.029356   | 2.286064     | 2.256700    | -.008       | 2.295500 | 9.436   | 1 DEC 62  |
| 2438009.5   | 2.267921      | -.031191   | 2.299112     | 2.267900    | -.021       | 2.310500 | 11.388  | 11 DEC 62 |
| 2438019.5   | 2.279134      | -.033027   | 2.312161     | 2.279100    | -.034       | 2.325000 | 12.839  | 21 DEC 62 |
| 2438029.5   | 2.290347      | -.034862   | 2.325209     | 2.290300    | -.047       | 2.338500 | 13.291  | 00 JAN 63 |
| 2438039.5   | 2.301559      | -.036698   | 2.338257     | 2.301500    | -.059       | 2.349100 | 10.843  | 10 JAN 63 |
| 2438049.5   | 2.312772      | -.038533   | 2.351306     | 2.312600    | -.172       | 2.358400 | 7.094   | 20 JAN 63 |
| 2438059.5   | 2.323985      | -.040369   | 2.364354     | 2.323800    | -.185       | 2.367100 | 2.746   | 30 JAN 63 |
| 2438069.5   | 2.335198      | -.042205   | 2.377402     | 2.335000    | -.198       | 2.375500 | -1.902  | 9 FEB 63  |
| 2438079.5   | 2.346411      | -.044040   | 2.390451     | 2.346200    | -.211       | 2.383900 | -6.551  | 19 FEB 63 |
| 2438089.5   | 2.357624      | -.045876   | 2.403499     | 2.357400    | -.224       | 2.392400 | -11.099 | 1 MAR 63  |
| 2438099.5   | 2.368836      | -.047711   | 2.416548     | 2.368700    | -.136       | 2.402500 | -14.048 | 11 MAR 63 |
| 2438109.5   | 2.380049      | -.049547   | 2.429596     | 2.379900    | -.149       | 2.416500 | -13.096 | 21 MAR 63 |
| 2438119.5   | 2.391262      | -.051382   | 2.442644     | 2.391200    | -.062       | 2.432100 | -10.544 | 31 MAR 63 |
| 2438129.5   | 2.402475      | -.053218   | 2.455693     | 2.402400    | -.075       | 2.447500 | -0.193  | 10 APR 63 |
| 2438139.5   | 2.413688      | -.055054   | 2.468741     | 2.413600    | -.088       | 2.461900 | -6.841  | 20 APR 63 |
| 2438149.5   | 2.424900      | -.056889   | 2.481790     | 2.424800    | -.100       | 2.475200 | -6.590  | 30 APR 63 |
| 2438159.5   | 2.436113      | -.058725   | 2.494838     | 2.436100    | -.013       | 2.489500 | -5.330  | 10 MAY 63 |
| 2438169.5   | 2.447326      | -.060560   | 2.507886     | 2.447300    | -.026       | 2.505400 | -2.486  | 20 MAY 63 |
| 2438179.5   | 2.458539      | -.062396   | 2.520935     | 2.458600    | .061        | 2.521600 | .665    | 30 MAY 63 |
| 2438189.5   | 2.469752      | -.064231   | 2.533983     | 2.469800    | .048        | 2.537300 | 3.317   | 9 JUN 63  |
| 2438199.5   | 2.480965      | -.066067   | 2.547031     | 2.481000    | .035        | 2.552700 | 5.669   | 19 JUN 63 |
| 2438209.5   | 2.492177      | -.067902   | 2.560080     | 2.492300    | .123        | 2.567900 | 7.620   | 29 JUN 63 |
| 2438219.5   | 2.503390      | -.069738   | 2.573128     | 2.503500    | .110        | 2.582600 | 9.472   | 9 JUL 63  |
| 2438229.5   | 2.514603      | -.071574   | 2.586177     | 2.514700    | .097        | 2.596900 | 10.723  | 19 JUL 63 |
| 2438239.5   | 2.525816      | -.073409   | 2.599225     | 2.526000    | .184        | 2.611100 | 11.875  | 29 JUL 63 |
| ALUT2 37665 | COM38242 4383 | 3.1370E-02 | -129.778E-10 | .5.3254E-04 | -21.245E-10 | 07/16/69 |         |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 AUGUST 1963 TO 1 NOVEMBER 1963 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC015 = 4.96000000E+03  
 FRQ5H5 = -1.29485000E-08  
 UTC7AA = 4.21570000E-02  
 UTCU2C = -1.42030000E-03  
 UTCU2D = -8.55710000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438249.5     | 2.537251                | -0.090393                | 2.627645                | 2.537200               | -0.051             | 2.627600               | -0.045             | 8 AUG 63  |
| 2438259.5     | 2.548439                | -0.097787                | 2.646225                | 2.548400               | -0.039             | 2.645900               | -0.325             | 18 AUG 63 |
| 2438269.5     | 2.559626                | -0.105120                | 2.664806                | 2.559500               | -0.126             | 2.664700               | -0.106             | 28 AUG 63 |
| 2438279.5     | 2.570814                | -0.112573                | 2.683387                | 2.570700               | -0.114             | 2.683400               | -0.013             | 7 SEP 63  |
| 2438289.5     | 2.582001                | -0.119967                | 2.701968                | 2.581900               | -0.101             | 2.702100               | -0.132             | 17 SEP 63 |
| 2438299.5     | 2.593189                | -0.127360                | 2.720549                | 2.593200               | -0.011             | 2.720700               | -0.151             | 27 SEP 63 |
| 2438309.5     | 2.604376                | -0.134753                | 2.739130                | 2.604300               | -0.076             | 2.739000               | -0.130             | 7 OCT 63  |
| 2438319.5     | 2.615564                | -0.142147                | 2.757710                | 2.615500               | -0.064             | 2.757600               | -0.110             | 17 OCT 63 |
| 2438329.5     | 2.626751                | -0.149540                | 2.776291                | 2.626700               | -0.051             | 2.776100               | -0.191             | 27 OCT 63 |
| A1UT2 38242   | CDM38334 4960           | 4.2157E-02               | -129.485E-10            | -14.203E-04            | -85.571E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USND VALUES      07/16/69  
 1 NOVEMBER 1963 TO 1 JANUARY 1964      07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC01S = 5.052000000E+03  
 PRQSHF = -1.300000000E-08  
 UCTAA = 4.553800000E-02  
 UCTU2C = -8.982800000E-04  
 UTCU2O = -8.032400000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438339.5     | 2.737896                | -.057367                 | 2.795263                | 2.737900               | .004               | 2.794800               | -.463              | 6 NOV 63  |
| 2438349.5     | 2.749124                | -.064307                 | 2.813435                | 2.749100               | -.028              | 2.813500               | .065               | 16 NOV 63 |
| 2438359.5     | 2.760360                | -.071247                 | 2.831607                | 2.760300               | -.040              | 2.831900               | .293               | 26 NOV 63 |
| 2438369.5     | 2.771592                | -.078187                 | 2.849779                | 2.771500               | -.092              | 2.850100               | .321               | 6 DEC 63  |
| 2438379.5     | 2.782824                | -.085127                 | 2.867951                | 2.782700               | -.124              | 2.867900               | -.051              | 16 DEC 63 |
| 2438389.5     | 2.794056                | -.092067                 | 2.886123                | 2.793900               | -.156              | 2.885500               | -.623              | 26 DEC 63 |
| 38334         | COM38395                | 5052                     | 4.5538E-02              | -130.000E-10           | -80.324E-04        | -8.9828E-10            | -80.324E-10        | 07/16/69  |
| A1UT2         |                         |                          |                         |                        |                    |                        |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 JANUARY 1964 TO 1 APRIL 1964 07/16/69  
 A1 - UTC - UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC015 = 5.113000000E+03  
 FRQSHF = -1.500000000E-08  
 UCTAA = 4.667700000E-02  
 UCTU2C = -1.608400000E-03  
 UTCU2D = -6.469900000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438399.5     | 2.805804                | -0.098740                | 2.904544                | 2.805800               | -0.004             | 2.903400               | -1.144             | 5 JAN 64  |
| 2438409.5     | 2.818764                | -0.104330                | 2.923094                | 2.818800               | .036               | 2.922900               | -.194              | 15 JAN 64 |
| 2438419.5     | 2.831724                | -0.109920                | 2.941644                | 2.831800               | .076               | 2.942100               | .456               | 25 JAN 64 |
| 2438429.5     | 2.844684                | -0.115510                | 2.960194                | 2.844700               | .016               | 2.961000               | .806               | 4 FEB 64  |
| 2438439.5     | 2.857644                | -0.121100                | 2.978744                | 2.857700               | .056               | 2.979600               | .856               | 14 FEB 64 |
| 2438449.5     | 2.870604                | -0.126690                | 2.997294                | 2.870700               | .096               | 2.997900               | .606               | 24 FEB 64 |
| 2438459.5     | 2.883564                | -0.132280                | 3.015844                | 2.883700               | .136               | 3.016000               | .156               | 5 MAR 64  |
| 2438469.5     | 2.896524                | -0.137870                | 3.034394                | 2.896600               | .076               | 3.034200               | -.194              | 15 MAR 64 |
| 2438479.5     | 2.909484                | -0.143460                | 3.052944                | 2.909600               | .116               | 3.052200               | -.744              | 25 MAR 64 |
| A1UT2 38395   | COM38486 5113           | 4.6677E-02               | -150.000E-10            | -16.084E-04            | -64.699E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 APRIL 1964 TO 1 SEPTEMBER 1964 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTCDS = 5.20400000E+03  
 FROSHF = -1.49768000E-08  
 UTAA = 5.03100000E-02  
 UTCU2C = -7.47240000E-04  
 UTCU2D = -6.45230000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438489.5     | 3.022482                | -0.046611                | 3.069093                | 3.022500               | .018               | 3.069400               | .307               | 4 APR 64  |
| 2438499.5     | 3.035422                | -0.052531                | 3.087953                | 3.035500               | .078               | 3.086500               | -1.453             | 14 APR 64 |
| 2438509.5     | 3.048362                | -0.058451                | 3.106813                | 3.048400               | .038               | 3.104300               | -2.513             | 24 APR 64 |
| 2438519.5     | 3.061302                | -0.064372                | 3.125674                | 3.061300               | -.002              | 3.123900               | -1.774             | 4 MAY 64  |
| 2438529.5     | 3.074242                | -0.070292                | 3.144534                | 3.074300               | .058               | 3.144500               | -.034              | 14 MAY 64 |
| 2438539.5     | 3.087182                | -0.076212                | 3.163394                | 3.087200               | .018               | 3.165000               | 1.606              | 24 MAY 64 |
| 2438549.5     | 3.100122                | -0.082133                | 3.182255                | 3.100200               | .078               | 3.185100               | 2.845              | 3 JUN 64  |
| 2438559.5     | 3.113062                | -0.088053                | 3.201115                | 3.113100               | .038               | 3.204300               | 3.185              | 13 JUN 64 |
| 2438569.5     | 3.126002                | -0.093974                | 3.219975                | 3.126000               | -.002              | 3.222800               | 2.825              | 23 JUN 64 |
| 2438579.5     | 3.138942                | -0.099894                | 3.238836                | 3.139000               | .058               | 3.240300               | 1.464              | 3 JUL 64  |
| 2438589.5     | 3.151882                | -0.105814                | 3.257696                | 3.151900               | .018               | 3.256700               | -.996              | 13 JUL 64 |
| 2438599.5     | 3.164821                | -0.111735                | 3.276556                | 3.164900               | .079               | 3.274300               | -2.256             | 23 JUL 64 |
| 2438609.5     | 3.177761                | -0.117655                | 3.295417                | 3.177800               | .039               | 3.293600               | -1.817             | 2 AUG 64  |
| 2438619.5     | 3.190701                | -0.123576                | 3.314277                | 3.190700               | -.001              | 3.313500               | -.777              | 12 AUG 64 |
| 2438629.5     | 3.203641                | -0.129496                | 3.333137                | 3.203600               | -.041              | 3.333000               | -.137              | 22 AUG 64 |
| 2438639.5     | 3.216581                | -0.135416                | 3.351998                | 3.216600               | 100.019            | 3.352400               | .402               | 1 SEP 64  |
| A1UT2 38486   | COM38639 5204           | 5.0310E-02               | -149.768E-10            | -7.4724E-04            | -68.523E-10        |                        |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USNO VALUES  
 1 SEPTEMBER 1964 TO 1 JANUARY 1965  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

07/16/69  
 07/16/69

PARAMETERS

UTCUIS = 5.35700000E+03  
 FRQSHF = -1.50000000E-08  
 UCTAA = 5.52880000E-02  
 UCTU2C = -6.49120000E-04  
 UTCU20 = -8.52600000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438639.5     | 3.317280                | -0.038947                | 3.356227                | 3.316600               | -0.680             | 3.352400               | -3.827             | 1 SEP 64  |
| 2438649.5     | 3.330240                | -0.046314                | 3.376554                | 3.329500               | -0.740             | 3.372800               | -3.754             | 11 SEP 64 |
| 2438659.5     | 3.343200                | -0.053680                | 3.396880                | 3.342500               | -0.700             | 3.394800               | -2.080             | 21 SEP 64 |
| 2438669.5     | 3.356160                | -0.061047                | 3.417207                | 3.356500               | .340               | 3.416600               | -0.607             | 1 OCT 64  |
| 2438679.5     | 3.369120                | -0.068413                | 3.437533                | 3.369400               | .280               | 3.440600               | 3.067              | 11 OCT 64 |
| 2438689.5     | 3.382080                | -0.075780                | 3.457860                | 3.382400               | .320               | 3.464400               | 6.540              | 21 OCT 64 |
| 2438699.5     | 3.395040                | -0.083146                | 3.478186                | 3.395300               | .260               | 3.483300               | 5.114              | 31 OCT 64 |
| 2438709.5     | 3.408000                | -0.090512                | 3.498512                | 3.408300               | .300               | 3.501000               | 2.488              | 10 NOV 64 |
| 2438719.5     | 3.420960                | -0.097879                | 3.518839                | 3.421200               | .240               | 3.519400               | .561               | 20 NOV 64 |
| 2438729.5     | 3.433920                | -0.105245                | 3.539165                | 3.434200               | .280               | 3.537700               | -1.465             | 30 NOV 64 |
| 2438739.5     | 3.446880                | -0.112612                | 3.559492                | 3.447100               | .220               | 3.556500               | -2.992             | 10 DEC 64 |
| 2438749.5     | 3.459840                | -0.119978                | 3.579818                | 3.460100               | .260               | 3.577800               | -2.018             | 20 DEC 64 |
| 2438759.5     | 3.472800                | -0.127345                | 3.600145                | 3.473000               | .200               | 3.599700               | -0.445             | 30 DEC 64 |
| A1UT2         | COM38761 5357           | \$ .5288E-02             | -150.000E-10            | -6.4912E-04            | -85.260E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USND VALUES 07/16/69  
 1 JANUARY 1965 TO 1 MARCH 1965 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTCDIS = 5.47900000E+03  
 FRQSHF = -1.50000000E-08  
 UCTAA = 5.95930000E-02  
 UCTU2C = -4.71610000E-04  
 UCTU2D = -7.23210000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438769.5     | 3.585948                | -0.033295                | 3.619243                | 3.585900               | -.048              | 3.619400               | .157               | 9 JAN 65  |
| 2438779.5     | 3.594908                | -0.039544                | 3.634452                | 3.598900               | -.008              | 3.638100               | -.352              | 19 JAN 65 |
| 2438789.5     | 3.611868                | -0.045792                | 3.657660                | 3.611800               | -.068              | 3.657500               | -.160              | 29 JAN 65 |
| 2438799.5     | 3.624828                | -0.052041                | 3.676869                | 3.624800               | -.028              | 3.677100               | .231               | 8 FEB 65  |
| 2438809.5     | 3.637788                | -0.058290                | 3.696078                | 3.637700               | -.088              | 3.696100               | .022               | 18 FEB 65 |
| 2438819.5     | 3.650748                | -0.064538                | 3.715286                | 3.650700               | -.048              | 3.715100               | -.186              | 28 FEB 65 |
| A1UT2 38761   | COM38H20                | 5479                     | 5.9593E-02              | -150.000E-10           | -4.7161E-04        | -72.321E-10            | 07/16/69           |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 MARCH 1965 TO 1 JULY 1965 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTC01S = 5.538000000E+03  
 FRQSHF = -1.50000000E-08  
 UCTAA = 6.25330000E-02  
 UTCU2C = 5.36460000E-04  
 UTCU2D = -9.52230000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438829.5     | 3.763644                | .024783                  | 3.738861                | 3.763700               | .056               | 3.735900               | -2.961             | 10 MAR 65 |
| 2438839.5     | 3.776604                | .016556                  | 3.760048                | 3.776600               | -.004              | 3.758100               | -1.948             | 20 MAR 65 |
| 2438849.5     | 3.789564                | .008329                  | 3.781235                | 3.789600               | .036               | 3.782000               | .765               | 30 MAR 65 |
| 2438859.5     | 3.802524                | .000101                  | 3.802423                | 3.802600               | .076               | 3.807400               | 4.977              | 9 APR 65  |
| 2438869.5     | 3.815484                | -.008126                 | 3.823610                | 3.815500               | .016               | 3.827700               | 4.090              | 19 APR 65 |
| 2438879.5     | 3.828444                | -.016353                 | 3.844797                | 3.828500               | .056               | 3.845200               | .403               | 29 APR 65 |
| 2438889.5     | 3.841404                | -.024581                 | 3.865985                | 3.841500               | .096               | 3.864700               | -1.283             | 9 MAY 65  |
| 2438899.5     | 3.854364                | -.032808                 | 3.887172                | 3.854400               | .036               | 3.885200               | -1.972             | 19 MAY 65 |
| 2438909.5     | 3.867324                | -.041035                 | 3.908359                | 3.867400               | .076               | 3.906400               | -1.959             | 29 MAY 65 |
| 2438919.5     | 3.880284                | -.049262                 | 3.929546                | 3.880300               | .016               | 3.928200               | -1.346             | 8 JUN 65  |
| 2438929.5     | 3.893244                | -.057490                 | 3.950734                | 3.893300               | .056               | 3.950800               | .066               | 18 JUN 65 |
| 2438939.5     | 3.906204                | -.065717                 | 3.971921                | 3.906200               | -.004              | 3.973600               | 1.679              | 28 JUN 65 |
| A1U72 38820   | COM38942 5538           | 4.2533E-02               | -150.000E-10            | +5.3646E-04            | -95.223E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES      07/16/69  
 1 JULY 1965 TO 1 SEPTEMBER 1965      07/16/69  
 A1 \* UTC \* UT2    TESTING USING DATU FORMULAS

PARAMETERS

UTC0IS = 5.66000000E+03  
 FROSHF = -1.50000000E-08  
 UCTAA = 6.68350000E-02  
 UTCU2C = 4.89430000E-04  
 UTCU2D = -1.18350000E-08

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2438949.5     | 4.019172                | .022148                  | 3.997024                | 4.019200               | .028               | 3.996900               | -.124              | 8 JUL 65  |
| 2438959.5     | 4.032132                | .011923                  | 4.020209                | 4.032200               | .068               | 4.020600               | .391               | 18 JUL 65 |
| 2438969.5     | 4.045092                | .001697                  | 4.043395                | 4.045100               | .008               | 4.043700               | .305               | 28 JUL 65 |
| 2438979.5     | 4.058052                | -.008528                 | 4.066580                | 4.058100               | .048               | 4.066200               | -.380              | 7 AUG 65  |
| 2438989.5     | 4.071012                | -.018754                 | 4.089766                | 4.071000               | -.012              | 4.089200               | -.566              | 17 AUG 65 |
| 2438999.5     | 4.083972                | -.028979                 | 4.112951                | 4.084000               | .028               | 4.113500               | .549               | 27 AUG 65 |
| A1UT2         | 38942                   | CDM34004 5660            | 6.6835E-02 -150.000E-10 | 4.8843E-04             | -118.35E-10        | 4.113500               |                    | 07/16/69  |

A1-UTC AND A1-UT2 CALCULATED FROM #AUTAB CONSTANTS COMPARED WITH USNO VALUES 07/16/69  
 1 SEPTEMBER 1965 TO 1 JANUARY 1966 07/16/69  
 A1 \* UTC \* UT2 TESTING USING DATU FORMULAS

PARAMETERS

UTCDIS = 5.72200000E+03  
 FRQSHF = -1.50000000E-08  
 UCTAA = 6.98400000E-02  
 UCTU2C = 1.00530000E-03  
 UTCU2D = -1.28910000E-08

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | OATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2439009.5     | 4.196880                | .054749                  | 4.142131                | 4.196900               | .020               | 4.138200               | -3.931             | 6 SEP 65  |
| 2439019.5     | 4.209840                | .043611                  | 4.166229                | 4.209900               | .060               | 4.163200               | -3.029             | 16 SEP 65 |
| 2439029.5     | 4.222800                | .032473                  | 4.190327                | 4.222900               | .100               | 4.188600               | -1.721             | 26 SEP 65 |
| 2439039.5     | 4.235760                | .021336                  | 4.214424                | 4.235800               | .040               | 4.214900               | .476               | 6 OCT 65  |
| 2439049.5     | 4.248720                | .010198                  | 4.238522                | 4.248800               | .080               | 4.240700               | 2.178              | 16 OCT 65 |
| 2439059.5     | 4.261680                | -.000940                 | 4.262620                | 4.261700               | .020               | 4.265900               | 3.280              | 26 OCT 65 |
| 2439069.5     | 4.274640                | -.012078                 | 4.286718                | 4.274700               | .060               | 4.291200               | 4.482              | 5 NOV 65  |
| 2439079.5     | 4.287600                | -.023216                 | 4.310816                | 4.287600               | .000               | 4.315800               | 4.984              | 15 NOV 65 |
| 2439089.5     | 4.300560                | -.034354                 | 4.334914                | 4.300600               | .040               | 4.339100               | 4.186              | 25 NOV 65 |
| 2439099.5     | 4.313520                | -.045491                 | 4.359011                | 4.313600               | .080               | 4.359900               | .889               | 5 DEC 65  |
| 2439109.5     | 4.326480                | -.056629                 | 4.383109                | 4.326500               | .020               | 4.380000               | -3.109             | 15 DEC 65 |
| 2439119.5     | 4.339440                | -.067767                 | 4.407207                | 4.339500               | .060               | 4.399100               | -8.107             | 25 DEC 65 |
| AIUT2 39004   | COM39126 5722           | 6.9840E-02               | -150.000E-10            | *10.053E-04            | -128.91E-10        | 07/16/69               |                    |           |

A1-UTC AND A1-UT2 CALCULATED FROM AUTAP CONSTANTS COMPARED WITH USNO VALUES  
 1 JANUARY 1966 TO 1 FEBRUARY 1968  
 A1 UTC UT2 TESTING USING DATU FORMULAS

07/16/69  
 07/16/69

PARAMETERS

UTCDIS = 5.84000000E+03  
 FRQSHF = -3.00000000E-08  
 UCTAA = 7.24760000E-02  
 UCTU2C = -8.91620000E-04  
 UCTU2D = 2.03380000E-09

| JULIAN<br>DAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-UTC<br>(SEC) | CALC<br>A1-UT2<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-UT2<br>(SEC) | EXP-CALC<br>(MSEC) | DATE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2439129.5     | 4.356336                | -0.052968                | 4.409304                | 4.356300               | -0.036             | 4.415100               | 5.796              | 4 JAN 66  |
| 2439139.5     | 4.382256                | -0.051206                | 4.433462                | 4.382200               | -0.056             | 4.438000               | 4.538              | 14 JAN 66 |
| 2439149.5     | 4.408176                | -0.049444                | 4.457620                | 4.408100               | -0.076             | 4.461200               | 3.580              | 24 JAN 66 |
| 2439159.5     | 4.434096                | -0.047681                | 4.481777                | 4.434100               | .004               | 4.485100               | 3.323              | 3 FEB 66  |
| 2439169.5     | 4.460016                | -0.045919                | 4.505935                | 4.460000               | -0.016             | 4.508500               | 2.565              | 13 FEB 66 |
| 2439179.5     | 4.485936                | -0.044157                | 4.530093                | 4.485900               | -0.036             | 4.530800               | .707               | 23 FEB 66 |
| 2439189.5     | 4.511856                | -0.042394                | 4.554250                | 4.511800               | -0.056             | 4.552400               | -1.850             | 5 MAR 66  |
| 2439199.5     | 4.537776                | -0.040632                | 4.578408                | 4.537700               | -0.076             | 4.573000               | -5.408             | 15 MAR 66 |
| 2439209.5     | 4.563696                | -0.038869                | 4.602565                | 4.563600               | -0.096             | 4.594300               | -8.265             | 25 MAR 66 |
| 2439219.5     | 4.589616                | -0.037107                | 4.626723                | 4.589600               | -0.016             | 4.616100               | -10.623            | 4 APR 66  |
| 2439229.5     | 4.615536                | -0.035345                | 4.650881                | 4.615500               | -0.036             | 4.638200               | -12.681            | 14 APR 66 |
| 2439239.5     | 4.641456                | -0.033582                | 4.675038                | 4.641400               | -0.056             | 4.661700               | -13.338            | 24 APR 66 |
| 2439249.5     | 4.667376                | -0.031820                | 4.699196                | 4.667300               | -0.076             | 4.686100               | -13.096            | 4 MAY 66  |
| 2439259.5     | 4.693296                | -0.030057                | 4.723353                | 4.693200               | -0.096             | 4.710800               | -12.553            | 14 MAY 66 |
| 2439269.5     | 4.719216                | -0.028295                | 4.747511                | 4.719200               | -0.016             | 4.736400               | -11.111            | 24 MAY 66 |
| 2439279.5     | 4.745136                | -0.026533                | 4.771669                | 4.745100               | -0.036             | 4.761900               | -9.769             | 3 JUN 66  |
| 2439289.5     | 4.771056                | -0.024770                | 4.795826                | 4.771000               | -0.056             | 4.787200               | -8.626             | 13 JUN 66 |
| 2439299.5     | 4.796976                | -0.023008                | 4.819984                | 4.796900               | -0.076             | 4.812000               | -7.984             | 23 JUN 66 |
| 2439309.5     | 4.822896                | -0.021246                | 4.844142                | 4.822900               | .004               | 4.836600               | -7.542             | 3 JUL 66  |
| 2439319.5     | 4.848816                | -0.019483                | 4.868299                | 4.848800               | -0.016             | 4.861300               | -6.999             | 13 JUL 66 |
| 2439329.5     | 4.874736                | -0.017721                | 4.892457                | 4.874700               | -0.036             | 4.885700               | -6.757             | 23 JUL 66 |
| 2439339.5     | 4.900656                | -0.015958                | 4.916614                | 4.900600               | -0.056             | 4.910000               | -6.614             | 2 AUG 66  |
| 2439349.5     | 4.926576                | -0.014196                | 4.940772                | 4.926600               | .024               | 4.935100               | -5.672             | 12 AUG 66 |
| 2439359.5     | 4.952496                | -0.012434                | 4.964930                | 4.952500               | .004               | 4.961100               | -3.830             | 22 AUG 66 |
| 2439369.5     | 4.978416                | -0.010671                | 4.989087                | 4.978400               | -0.016             | 4.987800               | -1.287             | 01 SEP 66 |
| 2439379.5     | 5.004336                | -0.008909                | 5.013245                | 5.004300               | -0.036             | 5.015000               | 1.755              | 11 SEP 66 |
| 2439389.5     | 5.030256                | -0.007146                | 5.037402                | 5.030200               | -0.056             | 5.042300               | 4.898              | 21 SEP 66 |

|           |          |          |          |          |       |          |        |    |     |    |
|-----------|----------|----------|----------|----------|-------|----------|--------|----|-----|----|
| 2439399.5 | 5.056176 | -.005384 | 5.061560 | 5.056200 | .024  | 5.070000 | 8.440  | 1  | OCT | 66 |
| 2439409.5 | 5.062096 | -.003622 | 5.085718 | 5.082100 | .004  | 5.097600 | 11.882 | 11 | OCT | 66 |
| 2439419.5 | 5.108016 | -.001859 | 5.109875 | 5.108000 | -.016 | 5.124900 | 15.025 | 21 | OCT | 66 |
| 2439429.5 | 5.133936 | -.000097 | 5.134033 | 5.133900 | -.036 | 5.151900 | 17.867 | 31 | OCT | 66 |
| 2439439.5 | 5.159854 | .001666  | 5.158190 | 5.159900 | .044  | 5.178400 | 20.210 | 10 | NOV | 66 |
| 2439449.5 | 5.185776 | .003428  | 5.182348 | 5.185600 | .024  | 5.203900 | 21.552 | 20 | NOV | 66 |
| 2439454.5 | 5.211696 | .005190  | 5.206506 | 5.211700 | .004  | 5.228100 | 21.594 | 30 | NOV | 66 |
| 2439469.5 | 5.237616 | .006953  | 5.230663 | 5.236900 | -.716 | 5.251200 | 20.537 | 10 | DEC | 66 |
| 2439479.5 | 5.263536 | .008715  | 5.254821 | 5.262800 | -.736 | 5.272800 | 17.979 | 20 | DEC | 66 |
| 2439489.5 | 5.289456 | .010477  | 5.278979 | 5.288600 | -.856 | 5.292500 | 13.521 | 30 | DEC | 66 |
| 2439499.5 | 5.315376 | .012240  | 5.303136 | 5.314600 | -.776 | 5.310900 | 7.764  | 9  | JAN | 67 |
| 2439509.5 | 5.341296 | .014002  | 5.327294 | 5.340500 | -.796 | 5.331900 | 4.606  | 19 | JAN | 67 |
| 2439519.5 | 5.367216 | .015765  | 5.351451 | 5.366400 | -.816 | 5.354700 | 3.249  | 29 | JAN | 67 |
| 2439529.5 | 5.393136 | .017527  | 5.375609 | 5.392300 | -.836 | 5.378400 | 2.791  | 08 | FEB | 67 |
| 2439539.5 | 5.419056 | .019289  | 5.399767 | 5.418200 | -.856 | 5.402300 | 2.533  | 18 | FEB | 67 |
| 2439549.5 | 5.444976 | .021052  | 5.423924 | 5.444100 | -.876 | 5.425900 | 1.976  | 28 | FEB | 67 |
| 2439559.5 | 5.470896 | .022814  | 5.448082 | 5.470100 | -.796 | 5.448800 | .718   | 10 | MAR | 67 |
| 2439569.5 | 5.496816 | .024577  | 5.472239 | 5.496000 | -.816 | 5.471300 | -.939  | 20 | MAR | 67 |
| 2439579.5 | 5.522736 | .026339  | 5.496397 | 5.521900 | -.836 | 5.495000 | -1.397 | 30 | MAR | 67 |
| 2439589.5 | 5.548656 | .028101  | 5.520553 | 5.547800 | -.856 | 5.519700 | -.855  | 09 | APR | 67 |
| 2439599.5 | 5.574576 | .029844  | 5.544712 | 5.573700 | -.876 | 5.544700 | -.012  | 19 | APR | 67 |
| 2439609.5 | 5.600496 | .031626  | 5.568870 | 5.599700 | -.796 | 5.569700 | .830   | 29 | APR | 67 |
| 2439619.5 | 5.626416 | .033388  | 5.593028 | 5.625600 | -.816 | 5.594600 | 1.572  | 09 | MAY | 67 |
| 2439629.5 | 5.652336 | .035151  | 5.617185 | 5.651500 | -.836 | 5.619300 | 2.115  | 19 | MAY | 67 |
| 2439639.5 | 5.678256 | .036913  | 5.641343 | 5.677400 | -.856 | 5.642900 | 1.557  | 29 | MAY | 67 |
| 2439649.5 | 5.704176 | .038676  | 5.665500 | 5.703300 | -.876 | 5.665300 | -.200  | 08 | JUN | 67 |
| 2439659.5 | 5.730096 | .040438  | 5.689658 | 5.729700 | -.796 | 5.686800 | -2.858 | 18 | JUN | 67 |
| 2439669.5 | 5.756016 | .042200  | 5.713816 | 5.755200 | -.816 | 5.708200 | -5.616 | 28 | JUN | 67 |
| 2439679.5 | 5.781936 | .043963  | 5.737973 | 5.781100 | -.836 | 5.730300 | -7.673 | 08 | JUL | 67 |
| 2439689.5 | 5.807856 | .045725  | 5.762131 | 5.807000 | -.856 | 5.753700 | -8.431 | 18 | JUL | 67 |
| 2439699.5 | 5.833776 | .047488  | 5.786288 | 5.832900 | -.876 | 5.777800 | -8.488 | 28 | JUL | 67 |
| 2439709.5 | 5.859696 | .049250  | 5.810446 | 5.858900 | -.796 | 5.802700 | -7.746 | 07 | AUG | 67 |
| 2439719.5 | 5.885616 | .051012  | 5.834604 | 5.884800 | -.816 | 5.827600 | -7.004 | 17 | AUG | 67 |
| 2439729.5 | 5.911536 | .052775  | 5.858761 | 5.910700 | -.836 | 5.852400 | -6.361 | 27 | AUG | 67 |
| 2439739.5 | 5.937456 | .054537  | 5.882919 | 5.936600 | -.856 | 5.877100 | -5.819 | 06 | SEP | 67 |
| 2439749.5 | 5.963376 | .056300  | 5.907074 | 5.962500 | -.876 | 5.901100 | -5.976 | 16 | SEP | 67 |
| 2439759.5 | 5.989296 | .058062  | 5.931234 | 5.988500 | -.796 | 5.924600 | -6.634 | 26 | SEP | 67 |
| 2439769.5 | 6.015216 | .059824  | 5.955392 | 6.014400 | -.816 | 5.948000 | -7.392 | 06 | OCT | 67 |
| 2439779.5 | 6.041136 | .061587  | 5.979549 | 6.040300 | -.836 | 5.972700 | -6.849 | 16 | OCT | 67 |
| 2439789.5 | 6.067056 | .063349  | 6.003707 | 6.066200 | -.856 | 5.999400 | -4.307 | 26 | OCT | 67 |
| 2439799.5 | 6.092976 | .065111  | 6.027865 | 6.092100 | -.876 | 6.026200 | -1.665 | 05 | NOV | 67 |
| 2439809.5 | 6.118896 | .066874  | 6.052022 | 6.118000 | -.896 | 6.052300 | .278   | 15 | NOV | 67 |

|           |          |          |          |            |              |             |             |          |        |
|-----------|----------|----------|----------|------------|--------------|-------------|-------------|----------|--------|
| 2439819.5 | 5.144816 | .068636  | 6.076180 | 6.144000   | --.816       | 6.076900    | .720        | 25       | NOV 67 |
| 2439829.5 | 6.170736 | .070394  | 6.100337 | 6.169900   | --.836       | 6.098100    | -2.237      | 05       | DEC 67 |
| 2439839.5 | 6.176656 | .072161  | 6.124495 | 6.195800   | --.856       | 6.121200    | -3.295      | 15       | DEC 67 |
| 2439849.5 | 6.212576 | .073923  | 6.148653 | 6.221700   | --.876       | 6.144300    | -4.353      | 25       | DEC 67 |
| 2439859.5 | 6.245904 | .075510  | 6.170394 | 6.245400   | --.504       | 6.171400    | 1.006       | 03       | JAN 68 |
| 2439865.5 | 6.264048 | .076743  | 6.187305 | 6.263400   | --.648       | 6.187400    | .095        | 10       | JAN 68 |
| 2439872.5 | 6.282192 | .077977  | 6.204215 | 6.281400   | --.792       | 6.203400    | -.815       | 17       | JAN 68 |
| 2439879.5 | 6.300336 | .079211  | 6.221125 | 6.299400   | --.936       | 6.220400    | -.725       | 24       | JAN 68 |
| 2439886.5 | 6.314480 | .080444  | 6.238035 | 6.317400   | -1.080       | 6.237400    | -.636       | 31       | JAN 68 |
| ALUT2     | 39126    | COM39887 | 5644     | 7.2475E-02 | -300.000E-10 | -8.9162E-04 | +20.398E-10 | 07/16/69 |        |

A1-UTC AND A1-U72 CALCULATED FROM #A07A8 CONSTANTS COMPARED WITH USNO VALUES  
 1 FEBRUARY 1968 TO 12 FEBRUARY 1969  
 A1 U7C U72 TESTING USING OATU FORMULAS

07/16/69  
 07/16/69

# PARAMETERS

UTC01S = 6.605000000E+03  
 FRQSHF = -3.000000000E-08  
 UTC7AA = 1.036650002E-01  
 UTCU2C = -1.122000000E-04  
 UTCU2O = 9.111300000E-10

| JULIAN<br>OAY | CALC<br>A1-UTC<br>(SEC) | CALC<br>UT2-U7C<br>(SEC) | CALC<br>A1-U72<br>(SEC) | EXP<br>A1-UTC<br>(SEC) | EXP-CALC<br>(MSEC) | EXP<br>A1-U72<br>(SEC) | EXP-CALC<br>(MSEC) | OAYE      |
|---------------|-------------------------|--------------------------|-------------------------|------------------------|--------------------|------------------------|--------------------|-----------|
| 2439893.5     | 6.235452                | -0.006260                | 6.241712                | 6.235400               | -.052              | 6.253400               | 11.688             | 07 FEB 68 |
| 2439900.5     | 6.253596                | -0.005709                | 6.259305                | 6.254400               | .804               | 6.270400               | 11.095             | 14 FEB 68 |
| 2439907.5     | 6.271740                | -0.005158                | 6.276898                | 6.272400               | .660               | 6.289400               | 12.502             | 21 FEB 68 |
| 2439914.5     | 6.289884                | -0.004607                | 6.294491                | 6.290210               | .326               | 6.306400               | 11.909             | 28 FEB 68 |
| 2439921.5     | 6.308028                | -0.004255                | 6.312083                | 6.308350               | .322               | 6.321400               | 9.317              | 6 MAR 68  |
| 2439928.5     | 6.326172                | -0.003504                | 6.329676                | 6.326490               | .318               | 6.337400               | 7.724              | 13 MAR 68 |
| 2439935.5     | 6.344316                | -0.002953                | 6.347269                | 6.344640               | .324               | 6.353400               | 6.131              | 20 MAR 68 |
| 2439942.5     | 6.362460                | -0.002402                | 6.364862                | 6.362780               | .320               | 6.370400               | 5.538              | 27 MAR 68 |
| 2439949.5     | 6.380604                | -0.001851                | 6.382455                | 6.380930               | .326               | 6.386400               | 3.945              | 03 APR 68 |
| 2439956.5     | 6.398748                | -0.001300                | 6.400048                | 6.399070               | .322               | 6.400400               | .352               | 10 APR 68 |
| 2439963.5     | 6.416892                | -0.000749                | 6.417641                | 6.417210               | .318               | 6.413400               | -4.241             | 17 APR 68 |
| 2439970.5     | 6.435036                | -0.000198                | 6.435234                | 6.435360               | .324               | 6.427400               | -7.834             | 24 APR 68 |
| 2439977.5     | 6.453180                | -0.000353                | 6.452827                | 6.453500               | .320               | 6.444400               | -8.427             | 01 MAY 68 |
| 2439984.5     | 6.471324                | -0.000904                | 6.470420                | 6.471650               | .326               | 6.462400               | -8.020             | 08 MAY 68 |
| 2439991.5     | 6.489468                | -0.001455                | 6.488013                | 6.489790               | .322               | 6.481400               | -6.613             | 15 MAY 68 |
| 2439998.5     | 6.507612                | -0.002006                | 6.505606                | 6.507930               | .318               | 6.502400               | -3.206             | 22 MAY 68 |
| 2440005.5     | 6.525756                | -0.002557                | 6.523199                | 6.526080               | .324               | 6.520400               | -2.799             | 29 MAY 68 |
| 2440012.5     | 6.543900                | -0.003108                | 6.540792                | 6.544220               | .320               | 6.537400               | -3.392             | 05 JUN 68 |
| 2440019.5     | 6.562044                | -0.003659                | 6.558385                | 6.562370               | .326               | 6.554400               | -3.985             | 12 JUN 68 |
| 2440026.5     | 6.580188                | -0.004210                | 6.575978                | 6.580510               | .322               | 6.573400               | -2.578             | 19 JUN 68 |
| 2440033.5     | 6.598332                | -0.004761                | 6.593571                | 6.598650               | .318               | 6.590400               | -3.171             | 26 JUN 68 |
| 2440040.5     | 6.616476                | -0.005312                | 6.611164                | 6.616800               | .324               | 6.606400               | -4.764             | 03 JUL 68 |
| 2440047.5     | 6.634620                | -0.005863                | 6.628757                | 6.634940               | .320               | 6.621400               | -7.357             | 10 JUL 68 |
| 2440054.5     | 6.652764                | -0.006415                | 6.646349                | 6.653090               | .326               | 6.637400               | -8.949             | 17 JUL 68 |
| 2440061.5     | 6.670908                | -0.006966                | 6.663942                | 6.671230               | .322               | 6.654400               | -9.542             | 24 JUL 68 |
| 2440068.5     | 6.689052                | -0.007517                | 6.681535                | 6.689370               | .318               | 6.672400               | -9.135             | 31 JUL 68 |
| 2440075.5     | 6.707196                | -0.008068                | 6.699128                | 6.707520               | .324               | 6.689400               | -9.728             | 07 AUG 68 |

|           |          |         |          |          |      |          |         |           |
|-----------|----------|---------|----------|----------|------|----------|---------|-----------|
| 2440082.5 | 6.725340 | .008619 | 6.716721 | 6.725660 | .320 | 6.705400 | -11.321 | 14 AUG 68 |
| 2440089.5 | 6.743484 | .009170 | 6.734314 | 6.743810 | .326 | 6.723400 | -10.914 | 21 AUG 68 |
| 2440096.5 | 6.761628 | .009721 | 6.751907 | 6.761950 | .322 | 6.744400 | -7.507  | 28 AUG 68 |
| 2440103.5 | 6.779772 | .010272 | 6.769500 | 6.780090 | .318 | 6.755400 | -4.100  | 04 SEP 68 |
| 2440110.5 | 6.797916 | .010823 | 6.787093 | 6.798240 | .324 | 6.787400 | 307     | 11 SEP 68 |
| 2440117.5 | 6.816060 | .011374 | 6.804686 | 6.816380 | .320 | 6.811400 | 6.714   | 18 SEP 68 |
| 2440124.5 | 6.834204 | .011925 | 6.822279 | 6.834530 | .326 | 6.834400 | 12.121  | 25 SEP 68 |
| 2440131.5 | 6.852348 | .012476 | 6.839872 | 6.852670 | .322 | 6.855400 | 15.528  | 02 OCT 68 |
| 2440138.5 | 6.870492 | .013027 | 6.857465 | 6.870810 | .318 | 6.873400 | 15.935  | 09 OCT 68 |
| 2440145.5 | 6.888536 | .013578 | 6.875058 | 6.888960 | .324 | 6.891400 | 16.342  | 16 OCT 68 |
| 2440152.5 | 6.906780 | .014129 | 6.892651 | 6.907100 | .320 | 6.906400 | 13.749  | 23 OCT 68 |
| 2440159.5 | 6.924924 | .014680 | 6.910244 | 6.925250 | .326 | 6.922400 | 12.156  | 30 OCT 68 |
| 2440166.5 | 6.943068 | .015231 | 6.927837 | 6.943390 | .322 | 6.939400 | 11.563  | 06 NOV 68 |
| 2440173.5 | 6.961212 | .015782 | 6.945430 | 6.961530 | .318 | 6.957400 | 11.970  | 13 NOV 68 |
| 2440180.5 | 6.979356 | .016333 | 6.963023 | 6.979680 | .324 | 6.976400 | 13.377  | 20 NOV 68 |
| 2440187.5 | 6.997500 | .016884 | 6.980616 | 6.997820 | .320 | 6.993400 | 12.784  | 27 NOV 68 |
| 2440194.5 | 7.015644 | .017436 | 6.998208 | 7.015970 | .326 | 7.010400 | 12.192  | 04 DEC 68 |
| 2440201.5 | 7.033788 | .017987 | 7.033394 | 7.034110 | .322 | 7.026400 | 10.599  | 11 DEC 68 |
| 2440208.5 | 7.051932 | .018538 | 7.050987 | 7.052250 | .314 | 7.041400 | 8.006   | 18 DEC 68 |
| 2440215.5 | 7.070076 | .019089 | 7.070400 | 7.070400 | .324 | 7.056400 | 5.413   | 25 DEC 68 |
| 2440222.5 | 7.088220 | .019640 | 7.088580 | 7.088540 | .320 | 7.057400 | -11.180 | 01 JAN 69 |
| 2440229.5 | 7.106364 | .020191 | 7.086173 | 7.106690 | .326 | 7.071400 | -14.773 | 08 JAN 69 |
| 2440236.5 | 7.124508 | .020742 | 7.103766 | 7.124830 | .322 | 7.086400 | -17.366 | 15 JAN 69 |
| 2440243.5 | 7.142652 | .021293 | 7.121359 | 7.142970 | .318 | 7.103400 | -17.959 | 22 JAN 69 |
| 2440250.5 | 7.160796 | .021844 | 7.138952 | 7.161120 | .324 | 7.120400 | -18.552 | 29 JAN 69 |
| 2440257.5 | 7.178940 | .022395 | 7.156545 | 7.179260 | .320 | 7.139400 | -17.145 | 05 FEB 69 |
| 2440264.5 | 7.197084 | .022946 | 7.174138 | 7.197410 | .326 | 7.157400 | -16.738 | 12 FEB 69 |
| 2440271.5 | 7.215228 | .023497 | 7.191731 | 7.215550 | .322 | 7.176400 | -15.331 | 19 FEB 69 |
| 2440278.5 | 7.233372 | .024048 | 7.209324 | 7.233690 | .318 | 7.195400 | -13.924 | 26 FEB 69 |
| 2440285.5 | 7.251516 | .024599 | 7.226917 | 7.251840 | .324 | 7.213400 | -13.517 | 05 MAR 69 |
| 2440292.5 | 7.269660 | .025150 | 7.244510 | 7.269980 | .320 | 7.232400 | -12.110 | 12 MAR 69 |
| 2440299.5 | 7.287804 | .025701 | 7.262103 | 7.288130 | .326 | 7.250400 | -11.703 | 19 MAR 69 |
| 2440306.5 | 7.305948 | .026252 | 7.279496 | 7.306270 | .322 | 7.269400 | -10.296 | 26 MAR 69 |
| 2440313.5 | 7.324092 | .026803 | 7.297289 | 7.324410 | .318 | 7.289400 | -7.889  | 02 APR 69 |
| 2440320.5 | 7.342236 | .027354 | 7.314882 | 7.342560 | .324 | 7.308400 | -6.482  | 09 APR 69 |
| 2440327.5 | 7.360380 | .027905 | 7.330067 | 7.378850 | .326 | 7.349400 | -6.67   | 23 APR 69 |
| 2440334.5 | 7.378524 | .028457 | 7.367660 | 7.396990 | .322 | 7.372400 | 4.740   | 30 APR 69 |
| 2440341.5 | 7.396668 | .029008 | 7.385253 | 7.415130 | .318 | 7.393400 | 8.147   | 07 MAY 69 |
| 2440348.5 | 7.414812 | .029559 | 7.402846 | 7.433280 | .324 | 7.412400 | 9.554   | 14 MAY 69 |
| 2440355.5 | 7.432956 | .030110 | 7.420439 | 7.451420 | .320 | 7.430400 | 9.961   | 21 MAY 69 |
| 2440362.5 | 7.451100 | .030661 | 7.438032 | 7.469570 | .326 | 7.446400 | 8.368   | 28 MAY 69 |
| 2440369.5 | 7.469244 | .031212 | 7.455625 | 7.487710 | .322 | 7.463400 | 7.775   | 04 JUN 69 |
| 2440376.5 | 7.487388 | .031763 |          |          |      |          |         |           |

### APPENDIX 3

Comparison of seasonal correction  $S = UT2 - UT1$  as obtained from the parameters of Table 5 with the correction established by the US Naval Observatory and indicated by "EXP".

1961 SEASONAL VARIATION CORRECTION  
PROJECTION AND COMPARISON OF CALCULATED VALUES  
CALC = 2.210E-02\*SIN(ARG) + -1.690E-02\*COS(ARG) + -6.900E-03\*SIN(2\*ARG) + 5.900E-03\*COS(2\*ARG)  
RMS DEVIATION = 2.54993E-04

04/08/69.

| JULIAN<br>DAY | TIME<br>FROM BEG<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | OATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2437300.5     | 9                       | -.01000                 | -.00977                  | -.2269           | 10 JAN 61 |
| 2437319.5     | 19                      | -.00800                 | -.00842                  | .4223            | 20 JAN 61 |
| 2437329.5     | 29                      | -.00700                 | -.00687                  | -.1344           | 30 JAN 61 |
| 2437339.5     | 39                      | -.00500                 | -.00488                  | -.1216           | 9 FEB 61  |
| 2437349.5     | 49                      | -.00200                 | -.00228                  | .2754            | 19 FEB 61 |
| 2437359.5     | 59                      | .00100                  | .00106                   | -.0452           | 1 MAR 61  |
| 2437369.5     | 69                      | .00500                  | .00513                   | -.1263           | 11 MAR 61 |
| 2437379.5     | 79                      | .01000                  | .00984                   | .1614            | 21 MAR 61 |
| 2437389.5     | 89                      | .01500                  | .01498                   | .0193            | 31 MAR 61 |
| 2437399.5     | 99                      | .02000                  | .02024                   | -.2444           | 10 APR 61 |
| 2437409.5     | 109                     | .02500                  | .02525                   | -.2517           | 20 APR 61 |
| 2437419.5     | 119                     | .03000                  | .02959                   | .4079            | 30 APR 61 |
| 2437429.5     | 129                     | .03300                  | .03287                   | .1341            | 10 MAY 61 |
| 2437439.5     | 139                     | .03500                  | .03473                   | .2730            | 20 MAY 61 |
| 2437449.5     | 149                     | .03500                  | .03492                   | .0766            | 30 MAY 61 |
| 2437459.5     | 159                     | .03300                  | .03333                   | -.3268           | 9 JUN 61  |
| 2437469.5     | 169                     | .03000                  | .02995                   | .0486            | 19 JUN 61 |
| 2437479.5     | 179                     | .02500                  | .02496                   | .0431            | 29 JUN 61 |
| 2437489.5     | 189                     | .01900                  | .01864                   | .3629            | 9 JUL 61  |
| 2437499.5     | 199                     | .01100                  | .01139                   | -.3938           | 19 JUL 61 |
| 2437509.5     | 209                     | .00400                  | .00370                   | .3000            | 29 JUL 61 |
| 2437519.5     | 219                     | -.00400                 | -.00394                  | -.0550           | 8 AUG 61  |
| 2437529.5     | 229                     | -.01100                 | -.01106                  | .0414            | 18 AUG 61 |
| 2437539.5     | 239                     | -.01700                 | -.01723                  | .2337            | 28 AUG 61 |
| 2437549.5     | 249                     | -.02200                 | -.02215                  | .1464            | 7 SEP 61  |
| 2437559.5     | 259                     | -.02600                 | -.02561                  | -.3908           | 17 SEP 61 |
| 2437569.5     | 269                     | -.02800                 | -.02757                  | -.4318           | 27 SEP 61 |
| 2437579.5     | 279                     | -.02800                 | -.02810                  | .1012            | 7 OCT 61  |
| 2437589.5     | 289                     | -.02700                 | -.02740                  | .3999            | 17 OCT 61 |
| 2437599.5     | 299                     | -.02600                 | -.02574                  | -.2599           | 27 OCT 61 |
| 2437609.5     | 309                     | -.02300                 | -.02344                  | .4433            | 6 NOV 61  |
| 2437619.5     | 319                     | -.02100                 | -.02084                  | -.1648           | 16 NOV 61 |
| 2437629.5     | 329                     | -.01800                 | -.01821                  | .2065            | 26 NOV 61 |
| 2437639.5     | 339                     | -.01600                 | -.01578                  | -.2215           | 6 DEC 61  |
| 2437649.5     | 349                     | -.01400                 | -.01368                  | -.3198           | 16 DEC 61 |
| 2437659.5     | 359                     | -.01200                 | -.01194                  | -.0425           | 26 DEC 61 |

1962 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC =  $2.100E-02 \cdot \sin(\text{ARG}) + -1.350E-02 \cdot \cos(\text{ARG})$   
 RMS DEVIATION =  $1.46891E-03$

04/08/69.

$+ -7.400E-03 \cdot \sin(2 \cdot \text{ARG}) + 6.700E-03 \cdot \cos(2 \cdot \text{ARG})$

| JULIAN<br>DAY | TIME<br>FROM RFG<br>DAY | U72-U71<br>(EXP)<br>SEC | U72-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | DATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2437669.5     | 4                       | -.01000                 | -.00640                  | -3.5973          | 5 JAN 62  |
| 2437679.5     | 14                      | -.00900                 | -.00559                  | -3.4080          | 15 JAN 62 |
| 2437689.5     | 24                      | -.00800                 | -.00484                  | -3.1437          | 25 JAN 62 |
| 2437699.5     | 34                      | -.00600                 | -.00386                  | -2.1407          | 4 FEB 62  |
| 2437709.5     | 44                      | -.00400                 | -.00240                  | -1.5998          | 14 FEB 62 |
| 2437719.5     | 54                      | -.00100                 | -.00026                  | -.7440           | 24 FEB 62 |
| 2437729.5     | 64                      | .00300                  | .00268                   | .3155            | 6 MAR 62  |
| 2437739.5     | 74                      | .00700                  | .00642                   | .5837            | 16 MAR 62 |
| 2437749.5     | 84                      | .01200                  | .01081                   | 1.1909           | 26 MAR 62 |
| 2437759.5     | 94                      | .01600                  | .01561                   | .3867            | 5 APR 62  |
| 2437769.5     | 104                     | .02000                  | .02048                   | -.4417           | 15 APR 62 |
| 2437779.5     | 114                     | .02400                  | .02500                   | -1.0036          | 25 APR 62 |
| 2437789.5     | 124                     | .02700                  | .02875                   | -1.7482          | 5 MAY 62  |
| 2437799.5     | 134                     | .03000                  | .03131                   | -1.3124          | 15 MAY 62 |
| 2437809.5     | 144                     | .03000                  | .03237                   | -2.3666          | 25 MAY 62 |
| 2437819.5     | 154                     | .03000                  | .03169                   | -1.6947          | 4 JUN 62  |
| 2437829.5     | 164                     | .02800                  | .02922                   | -1.2216          | 14 JUN 62 |
| 2437839.5     | 174                     | .02400                  | .02503                   | -1.0270          | 24 JUN 62 |
| 2437849.5     | 184                     | .01800                  | .01934                   | -1.3421          | 4 JUL 62  |
| 2437859.5     | 194                     | .01200                  | .01253                   | -.5301           | 14 JUL 62 |
| 2437869.5     | 204                     | .00400                  | .00505                   | -1.0926          | 24 JUL 62 |
| 2437879.5     | 214                     | -.00300                 | -.00257                  | -.4256           | 3 AUG 62  |
| 2437889.5     | 224                     | -.01000                 | -.00983                  | -.1696           | 13 AUG 62 |
| 2437899.5     | 234                     | -.01700                 | -.01624                  | -.7593           | 23 AUG 62 |
| 2437909.5     | 244                     | -.02200                 | -.02142                  | -.5797           | 2 SEP 62  |
| 2437919.5     | 254                     | -.02600                 | -.02511                  | -.8912           | 12 SEP 62 |
| 2437929.5     | 264                     | -.02600                 | -.02719                  | -.8094           | 22 SEP 62 |
| 2437939.5     | 274                     | -.02900                 | -.02770                  | -1.3014          | 2 OCT 62  |
| 2437949.5     | 284                     | -.02800                 | -.02680                  | -1.1972          | 12 OCT 62 |
| 2437959.5     | 294                     | -.02600                 | -.02478                  | -1.2165          | 22 OCT 62 |
| 2437969.5     | 304                     | -.02300                 | -.02199                  | -1.0074          | 1 NOV 62  |
| 2437979.5     | 314                     | -.02000                 | -.01881                  | -1.1900          | 11 NOV 62 |
| 2437989.5     | 324                     | -.01600                 | -.01560                  | -.4034           | 21 NOV 62 |
| 2437999.5     | 334                     | -.01300                 | -.01265                  | -.3470           | 1 DEC 62  |
| 2438009.5     | 344                     | -.01000                 | -.01019                  | .1861            | 11 DEC 62 |
| 2438019.5     | 354                     | -.00700                 | -.00829                  | 1.2491           | 21 DEC 62 |
| 2438029.5     | 364                     | -.00500                 | -.00694                  | 1.9165           | 00 JAN 63 |

1963 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC =  $2.200E-02 \cdot \sin(\text{ARG}) + -1.200E-02 \cdot \cos(\text{ARG}) + -5.900E-03 \cdot \sin(2 \cdot \text{ARG}) + 7.000E-03 \cdot \cos(2 \cdot \text{ARG})$   
 RMS DEVIATION =  $3.15795E-04$

04/08/69.

| JULIAN DAY | TIME FROM REF DAY | UT2-UT1 (EXP) SEC | UT2-UT1 (CALC) SEC | EXP-CALC MSEC | DATE      |
|------------|-------------------|-------------------|--------------------|---------------|-----------|
| 2438039.5  | 9                 | -.00400           | -.00359            | -.4053        | 10 JAN 63 |
| 2438049.5  | 19                | -.00200           | -.00233            | .3325         | 20 JAN 63 |
| 2438059.5  | 29                | -.00100           | -.00117            | .1740         | 30 JAN 63 |
| 2438069.5  | 39                | -0.               | .00012             | -.1210        | 9 FEB 63  |
| 2438079.5  | 49                | .00200            | .00178             | .2230         | 19 FEB 63 |
| 2438089.5  | 59                | .00400            | .00396             | .0351         | 1 MAR 63  |
| 2438099.5  | 69                | .00700            | .00677             | .2285         | 11 MAR 63 |
| 2438109.5  | 79                | .01000            | .01018             | -.1792        | 21 MAR 63 |
| 2438119.5  | 89                | .01400            | .01406             | -.0586        | 31 MAR 63 |
| 2438129.5  | 99                | .01800            | .01818             | -.1760        | 10 APR 63 |
| 2438139.5  | 109               | .02200            | .02221             | -.2140        | 20 APR 63 |
| 2438149.5  | 119               | .02600            | .02580             | .1958         | 30 APR 63 |
| 2438159.5  | 129               | .02900            | .02857             | .4332         | 10 MAY 63 |
| 2438169.5  | 139               | .03000            | .03015             | -.1543        | 20 MAY 63 |
| 2438179.5  | 149               | .03000            | .03029             | -.2927        | 30 MAY 63 |
| 2438189.5  | 159               | .02900            | .02882             | .1436         | 9 JUN 63  |
| 2438199.5  | 169               | .02600            | .02569             | .3083         | 19 JUN 63 |
| 2438209.5  | 179               | .02100            | .02103             | -.0272        | 29 JUN 63 |
| 2438219.5  | 189               | .01500            | .01507             | -.0687        | 9 JUL 63  |
| 2438229.5  | 199               | .00800            | .00818             | -.1788        | 19 JUL 63 |
| 2438239.5  | 209               | .00100            | .00080             | .1952         | 29 JUL 63 |
| 2438249.5  | 219               | -.00700           | -.00656            | -.4368        | 8 AUG 63  |
| 2438259.5  | 229               | -.01400           | -.01344            | -.5609        | 18 AUG 63 |
| 2438269.5  | 239               | -.02000           | -.01939            | -.6142        | 28 AUG 63 |
| 2438279.5  | 249               | -.02400           | -.02406            | .0564         | 7 SEP 63  |
| 2438289.5  | 259               | -.02800           | -.02722            | -.7759        | 17 SEP 63 |
| 2438299.5  | 269               | -.02900           | -.02880            | -.2006        | 27 SEP 63 |
| 2438309.5  | 279               | -.02900           | -.02883            | -.1480        | 7 OCT 63  |
| 2438319.5  | 289               | -.02700           | -.02750            | .4987         | 17 OCT 63 |
| 2438329.5  | 299               | -.02500           | -.02508            | .0766         | 27 OCT 63 |
| 2438339.5  | 309               | -.02200           | -.02191            | -.0922        | 6 NOV 63  |
| 2438349.5  | 319               | -.01800           | -.01836            | .3568         | 16 NOV 63 |
| 2438359.5  | 329               | -.01500           | -.01477            | -.2313        | 26 NOV 63 |
| 2438369.5  | 339               | -.01100           | -.01143            | .4302         | 6 DEC 63  |
| 2438379.5  | 349               | -.00800           | -.0085A            | .5407         | 16 DEC 63 |
| 2438389.5  | 359               | -.00600           | -.00619            | .1938         | 26 DEC 63 |

1964 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC =  $2.200E-02 \cdot \sin(\text{ARG}) - 1.200E-02 \cdot \cos(\text{ARG}) - 5.900E-03 \cdot \sin(2 \cdot \text{ARG}) + 7.000E-03 \cdot \cos(2 \cdot \text{ARG})$   
 RMS DEVIATION =  $3.02754E-04$  04/08/69.

| JULIAN<br>DAY | TIME<br>FROM RFG<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | OATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2438399.5     | 4                       | -.00400                 | -.00433                  | .3346            | 5 JAN 64  |
| 2438409.5     | 14                      | -.00300                 | -.00294                  | -.0639           | 15 JAN 64 |
| 2438419.5     | 24                      | -.00200                 | -.00176                  | -.2448           | 25 JAN 64 |
| 2438429.5     | 34                      | -.00100                 | -.00056                  | -.4416           | 4 FEB 64  |
| 2438439.5     | 44                      | .00100                  | .00089                   | .1085            | 14 FEB 64 |
| 2438449.5     | 54                      | .00300                  | .00280                   | .2033            | 24 FEB 64 |
| 2438459.5     | 64                      | .00500                  | .00529                   | -.2493           | 5 MAR 64  |
| 2438469.5     | 74                      | .00800                  | .00841                   | -.4057           | 15 MAR 64 |
| 2438479.5     | 84                      | .01200                  | .01207                   | -.0723           | 25 MAR 64 |
| 2438489.5     | 94                      | .01600                  | .01611                   | -.1057           | 4 APR 64  |
| 2438499.5     | 104                     | .02000                  | .02023                   | -.2272           | 14 APR 64 |
| 2438509.5     | 114                     | .02400                  | .02409                   | -.0891           | 24 APR 64 |
| 2438519.5     | 124                     | .02700                  | .02731                   | -.3120           | 4 MAY 64  |
| 2438529.5     | 134                     | .03000                  | .02953                   | .4732            | 14 MAY 64 |
| 2438539.5     | 144                     | .03000                  | .03042                   | -.4179           | 24 MAY 64 |
| 2438549.5     | 154                     | .03000                  | .02976                   | .2382            | 3 JUN 64  |
| 2438559.5     | 164                     | .02800                  | .02746                   | .5434            | 13 JUN 64 |
| 2438569.5     | 174                     | .02400                  | .02354                   | .4604            | 23 JUN 64 |
| 2438579.5     | 184                     | .01300                  | .01819                   | -.1495           | 3 JUL 64  |
| 2438589.5     | 194                     | .01200                  | .01171                   | .2462            | 13 JUL 64 |
| 2438599.5     | 204                     | .00500                  | .00452                   | .4778            | 23 JUL 64 |
| 2438609.5     | 214                     | -.00300                 | -.00291                  | -.0490           | 2 AUG 64  |
| 2438619.5     | 224                     | -.01000                 | -.01009                  | .0917            | 12 AUG 64 |
| 2438629.5     | 234                     | -.01600                 | -.01655                  | .5528            | 22 AUG 64 |
| 2438639.5     | 244                     | -.02200                 | -.02190                  | -.1021           | 1 SEP 64  |
| 2438649.5     | 254                     | -.02600                 | -.02584                  | -.1629           | 11 SEP 64 |
| 2438659.5     | 264                     | -.02800                 | -.02821                  | .2109            | 21 SEP 64 |
| 2438669.5     | 274                     | -.02900                 | -.02900                  | .0002            | 1 OCT 64  |
| 2438679.5     | 284                     | -.02800                 | -.02832                  | .3207            | 11 OCT 64 |
| 2438689.5     | 294                     | -.02600                 | -.02640                  | .4034            | 21 OCT 64 |
| 2438699.5     | 304                     | -.02400                 | -.02356                  | -.4372           | 31 OCT 64 |
| 2438709.5     | 314                     | -.02000                 | -.02016                  | .1576            | 10 NOV 64 |
| 2438719.5     | 324                     | -.01700                 | -.01655                  | -.4523           | 20 NOV 64 |
| 2438729.5     | 334                     | -.01300                 | -.01305                  | .0534            | 30 NOV 64 |
| 2438739.5     | 344                     | -.01000                 | -.00992                  | -.0791           | 10 DEC 64 |
| 2438749.5     | 354                     | -.00700                 | -.00730                  | .2979            | 20 DEC 64 |
| 2438759.5     | 364                     | -.00500                 | -.00522                  | .2231            | 30 DEC 64 |

1965 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 $CALC = 2.200E-02 \cdot \sin(ARG) + -1.200E-02 \cdot \cos(ARG) + -5.900E-03 \cdot \sin(2 \cdot ARG) + 7.000E-03 \cdot \cos(2 \cdot ARG)$   
 RMS DEVIATION = 2.94839E-04

04/08/69.

| JULIAN<br>DAY | TIME<br>FROM BEG<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | DATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2438769.5     | 8                       | -.00400                 | -.00374                  | -.2646           | 9 JAN 65  |
| 2438779.5     | 16                      | -.00200                 | -.00245                  | .4501            | 19 JAN 65 |
| 2438789.5     | 28                      | -.00100                 | -.00129                  | .2920            | 29 JAN 65 |
| 2438799.5     | 36                      | -0.                     | -.00002                  | .0213            | 8 FEB 65  |
| 2438809.5     | 46                      | .00200                  | .00159                   | .4103            | 18 FEB 65 |
| 2438819.5     | 58                      | .00400                  | .00372                   | .2911            | 28 FEB 65 |
| 2438829.5     | 68                      | .00600                  | .00646                   | -.4626           | 10 MAR 65 |
| 2438839.5     | 78                      | .01000                  | .00981                   | .1958            | 20 MAR 65 |
| 2438849.5     | 88                      | .01400                  | .01366                   | .3447            | 30 MAR 65 |
| 2438859.5     | 98                      | .01800                  | .01776                   | .2380            | 9 APR 65  |
| 2438869.5     | 108                     | .02200                  | .02182                   | .1759            | 19 APR 65 |
| 2438879.5     | 118                     | .02600                  | .02548                   | .5237            | 29 APR 65 |
| 2438889.5     | 128                     | .02800                  | .02834                   | -.3382           | 9 MAY 65  |
| 2438899.5     | 138                     | .03000                  | .03006                   | -.0570           | 19 MAY 65 |
| 2438909.5     | 148                     | .03000                  | .03035                   | -.3498           | 29 MAY 65 |
| 2438919.5     | 158                     | .02900                  | .02904                   | -.0387           | 8 JUN 65  |
| 2438929.5     | 168                     | .02600                  | .02608                   | -.0763           | 18 JUN 65 |
| 2438939.5     | 178                     | .02200                  | .02156                   | .4430            | 28 JUN 65 |
| 2438949.5     | 188                     | .01600                  | .01571                   | .2968            | 8 JUL 65  |
| 2438959.5     | 198                     | .00900                  | .00890                   | .1025            | 18 JUL 65 |
| 2438969.5     | 208                     | .00100                  | .00155                   | -.5502           | 28 JUL 65 |
| 2438979.5     | 218                     | -.00600                 | -.00584                  | -.1592           | 7 AUG 65  |
| 2438989.5     | 228                     | -.01300                 | -.01279                  | -.2133           | 17 AUG 65 |
| 2438999.5     | 238                     | -.01900                 | -.01884                  | -.1563           | 27 AUG 65 |
| 2439009.5     | 248                     | -.02400                 | -.02365                  | -.3457           | 6 SEP 65  |
| 2439019.5     | 258                     | -.02700                 | -.02698                  | -.0213           | 16 SEP 65 |
| 2439029.5     | 268                     | -.02900                 | -.02871                  | -.2869           | 26 SEP 65 |
| 2439039.5     | 278                     | -.02900                 | -.02889                  | -.1060           | 6 OCT 65  |
| 2439049.5     | 288                     | -.02800                 | -.02769                  | -.3138           | 16 OCT 65 |
| 2439059.5     | 298                     | -.02500                 | -.02536                  | .3584            | 26 OCT 65 |
| 2439069.5     | 308                     | -.02200                 | -.02225                  | .2479            | 5 NOV 65  |
| 2439079.5     | 318                     | -.01900                 | -.01872                  | -.2911           | 15 NOV 65 |
| 2439089.5     | 328                     | -.01500                 | -.01512                  | .1204            | 25 NOV 65 |
| 2439099.5     | 338                     | -.01200                 | -.01175                  | -.2536           | 5 DEC 65  |
| 2439109.5     | 348                     | -.00900                 | -.00881                  | -.1941           | 15 DEC 65 |
| 2439119.5     | 358                     | -.00600                 | -.00640                  | .4037            | 25 DEC 65 |

1966 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC = 2.200E-02\*SIN(ARG) + -1.200E-02\*COS(ARG) + -5.900E-03\*SIN(2\*ARG) + 7.000E-03\*COS(2\*ARG)  
 RMS DEVIATION = 3.19140E-04

04/08/69.

| JULIAN<br>DAY | TIME<br>FROM RFG<br>OAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | OATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2439129.5     | 3                       | -.00500                 | -.00449                  | -.5057           | 4 JAN 66  |
| 2439139.5     | 13                      | -.00300                 | -.00306                  | .0625            | 14 JAN 66 |
| 2439149.5     | 23                      | -.00200                 | -.00187                  | -.1300           | 24 JAN 66 |
| 2439159.5     | 33                      | -.00100                 | -.00069                  | -.3143           | 3 FEB 66  |
| 2439169.5     | 43                      | .00100                  | .00073                   | .2710            | 13 FEB 66 |
| 2439179.5     | 53                      | .00300                  | .00258                   | .4187            | 23 FEB 66 |
| 2439189.5     | 63                      | .00500                  | .00501                   | -.0118           | 5 MAR 66  |
| 2439199.5     | 73                      | .00800                  | .00807                   | -.0472           | 15 MAR 66 |
| 2439209.5     | 83                      | .01200                  | .01169                   | .3148            | 25 MAR 66 |
| 2439219.5     | 93                      | .01600                  | .01569                   | .3068            | 4 APR 66  |
| 2439229.5     | 103                     | .02000                  | .01982                   | .1794            | 14 APR 66 |
| 2439239.5     | 113                     | .02400                  | .02373                   | .2747            | 24 APR 66 |
| 2439249.5     | 123                     | .02700                  | .02703                   | -.0292           | 4 MAY 66  |
| 2439259.5     | 133                     | .02900                  | .02936                   | -.3402           | 14 MAY 66 |
| 2439269.5     | 143                     | .03000                  | .03040                   | -.3956           | 24 MAY 66 |
| 2439279.5     | 153                     | .03000                  | .02990                   | .0090            | 3 JUN 66  |
| 2439289.5     | 163                     | .02800                  | .02776                   | .2386            | 13 JUN 66 |
| 2439299.5     | 173                     | .02400                  | .02400                   | .0002            | 23 JUN 66 |
| 2439309.5     | 183                     | .01900                  | .01878                   | .2189            | 3 JUL 66  |
| 2439319.5     | 193                     | .01200                  | .01240                   | -.4009           | 13 JUL 66 |
| 2439329.5     | 203                     | .00500                  | .00526                   | -.2403           | 23 JUL 66 |
| 2439339.5     | 213                     | -.00200                 | -.00217                  | .1709            | 2 AUG 66  |
| 2439349.5     | 223                     | -.00900                 | -.00940                  | .3987            | 12 AUG 66 |
| 2439359.5     | 233                     | -.01600                 | -.01595                  | -.0489           | 22 AUG 66 |
| 2439369.5     | 243                     | -.02100                 | -.02142                  | .4228            | 01 SEP 66 |
| 2439379.5     | 253                     | -.02500                 | -.02551                  | .5120            | 11 SEP 66 |
| 2439389.5     | 263                     | -.02800                 | -.02805                  | .0456            | 21 SEP 66 |
| 2439399.5     | 273                     | -.02900                 | -.02899                  | -.0098           | 1 OCT 66  |
| 2439409.5     | 283                     | -.02800                 | -.02845                  | .4490            | 11 OCT 66 |
| 2439419.5     | 293                     | -.02700                 | -.02664                  | -.3576           | 21 OCT 66 |
| 2439429.5     | 303                     | -.02400                 | -.02388                  | -.1216           | 31 OCT 66 |
| 2439439.5     | 313                     | -.02100                 | -.02051                  | -.4869           | 10 NOV 66 |
| 2439449.5     | 323                     | -.01700                 | -.01691                  | -.0917           | 20 NOV 66 |
| 2439459.5     | 333                     | -.01400                 | -.01339                  | -.6101           | 30 NOV 66 |
| 2439469.5     | 343                     | -.01000                 | -.01021                  | .2128            | 10 DEC 66 |
| 2439479.5     | 353                     | -.00800                 | -.00754                  | -.4447           | 20 DEC 66 |
| 2439489.5     | 363                     | -.00600                 | -.00541                  | -.5930           | 30 DEC 66 |

1967 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC =  $2.200E-02 \cdot \sin(\text{ARG}) + -1.200E-02 \cdot \cos(\text{ARG}) + -5.900E-03 \cdot \sin(2 \cdot \text{ARG}) + 7.000E-03 \cdot \cos(2 \cdot \text{ARG})$   
 RMS DEVIATION =  $2.90073E-04$

04/08/69.

| JULIAN<br>DAY | TIME<br>FROM BFO<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | OATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2439499.5     | 8                       | -.00400                 | -.00374                  | -.2646           | 9 JAN 67  |
| 2439509.5     | 18                      | -.00200                 | -.00245                  | -.4501           | 19 JAN 67 |
| 2439519.5     | 28                      | -.00100                 | -.00129                  | .2920            | 29 JAN 67 |
| 2439529.5     | 38                      | 0.                      | -.00002                  | .0213            | 08 FEB 67 |
| 2439539.5     | 48                      | .00200                  | .00159                   | .4103            | 18 FEB 67 |
| 2439549.5     | 58                      | .00400                  | .00372                   | .2811            | 28 FEB 67 |
| 2439559.5     | 68                      | .00600                  | .00646                   | -.4426           | 10 MAR 67 |
| 2439569.5     | 78                      | .01000                  | .00981                   | .1458            | 20 MAR 67 |
| 2439579.5     | 88                      | .01400                  | .01366                   | .3447            | 30 MAR 67 |
| 2439589.5     | 98                      | .01800                  | .01776                   | .2380            | 09 APR 67 |
| 2439599.5     | 108                     | .02200                  | .02182                   | .1759            | 19 APR 67 |
| 2439609.5     | 118                     | .02600                  | .02548                   | .5237            | 29 APR 67 |
| 2439619.5     | 128                     | .02800                  | .02834                   | -.3382           | 09 MAY 67 |
| 2439629.5     | 138                     | .03000                  | .03006                   | -.0570           | 19 MAY 67 |
| 2439639.5     | 148                     | .03000                  | .03035                   | -.3498           | 29 MAY 67 |
| 2439649.5     | 158                     | .02900                  | .02904                   | -.0387           | 08 JUN 67 |
| 2439659.5     | 168                     | .02600                  | .02608                   | -.0763           | 18 JUN 67 |
| 2439669.5     | 178                     | .02200                  | .02156                   | .4430            | 28 JUN 67 |
| 2439679.5     | 188                     | .01600                  | .01571                   | .2868            | 08 JUL 67 |
| 2439689.5     | 198                     | .00900                  | .00890                   | .1025            | 18 JUL 67 |
| 2439699.5     | 208                     | .00200                  | .00155                   | .4498            | 28 JUL 67 |
| 2439709.5     | 218                     | -.00600                 | -.00584                  | -.1592           | 07 AUG 67 |
| 2439719.5     | 228                     | -.01300                 | -.01279                  | -.2133           | 17 AUG 67 |
| 2439729.5     | 238                     | -.01900                 | -.01884                  | -.1563           | 27 AUG 67 |
| 2439739.5     | 248                     | -.02400                 | -.02365                  | -.3457           | 06 SEP 67 |
| 2439749.5     | 258                     | -.02700                 | -.02698                  | -.0213           | 16 SEP 67 |
| 2439759.5     | 268                     | -.02900                 | -.02871                  | -.2869           | 26 SEP 67 |
| 2439769.5     | 278                     | -.02900                 | -.02889                  | -.1060           | 06 OCT 67 |
| 2439779.5     | 288                     | -.02800                 | -.02769                  | -.3138           | 16 OCT 67 |
| 2439789.5     | 298                     | -.02500                 | -.02536                  | .3584            | 26 OCT 67 |
| 2439799.5     | 308                     | -.02200                 | -.02225                  | .2479            | 05 NOV 67 |
| 2439809.5     | 318                     | -.01900                 | -.01872                  | -.2811           | 15 NOV 67 |
| 2439819.5     | 328                     | -.01500                 | -.01512                  | .1204            | 25 NOV 67 |
| 2439829.5     | 338                     | -.01200                 | -.01175                  | -.2536           | 05 DEC 67 |
| 2439839.5     | 348                     | -.00900                 | -.00881                  | -.1941           | 15 DEC 67 |
| 2439849.5     | 358                     | -.00600                 | -.00640                  | .4037            | 25 DEC 67 |

1968 SEASONAL VARIATION CORRECTION  
 PROJECTION AND COMPARISON OF CALCULATED VALUES  
 CALC = 2.200E-02\*SIN(ARG) + -1.200E-02\*COS(ARG) + -5.900E-03\*SIN(2\*ARG) + 7.000E-03\*COS(2\*ARG)  
 RMS DEVIATION = 4.27421E-04

04/08/69.

| JULIAN<br>DAY | TIME<br>FROM 8G<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXF-CALC<br>MSEC | DATE      |
|---------------|------------------------|-------------------------|--------------------------|------------------|-----------|
| 2439859.5     | 2                      | -.00500                 | -.00466                  | -.3416           | 03 JAN 68 |
| 2439865.5     | 9                      | -.00300                 | -.00359                  | .5947            | 10 JAN 68 |
| 2439872.5     | 16                     | -.00300                 | -.00269                  | -.3104           | 17 JAN 68 |
| 2439879.5     | 23                     | -.00200                 | -.00187                  | -.1300           | 24 JAN 68 |
| 2439886.5     | 30                     | -.00200                 | -.00105                  | -.9454           | 31 JAN 68 |
| 2439893.5     | 37                     | -0.                     | -.00016                  | .1602            | 07 FEB 68 |
| 2439900.5     | 44                     | -0.                     | .00089                   | -.6915           | 14 FEB 68 |
| 2439907.5     | 51                     | .00200                  | .00217                   | -.1679           | 21 FEB 68 |
| 2439914.5     | 58                     | .00300                  | .00372                   | -.7189           | 28 FEB 68 |
| 2439921.5     | 65                     | .00600                  | .00557                   | .4268            | 6 MAR 68  |
| 2439928.5     | 72                     | .00700                  | .00773                   | -.7344           | 13 MAR 68 |
| 2439935.5     | 79                     | .01000                  | .01018                   | -.1792           | 20 MAR 68 |
| 2439942.5     | 86                     | .01200                  | .01286                   | -.8573           | 27 MAR 68 |
| 2439949.5     | 93                     | .01600                  | .01569                   | .3068            | 03 APR 68 |
| 2439956.5     | 100                    | .01900                  | .01859                   | .4109            | 10 APR 68 |
| 2439963.5     | 107                    | .02200                  | .02143                   | .5700            | 17 APR 68 |
| 2439970.5     | 114                    | .02400                  | .02409                   | -.0891           | 24 APR 68 |
| 2439977.5     | 121                    | .02600                  | .02643                   | -.4348           | 01 MAY 68 |
| 2439984.5     | 128                    | .02800                  | .02834                   | -.3382           | 08 MAY 68 |
| 2439991.5     | 135                    | .03000                  | .02968                   | .3200            | 15 MAY 68 |
| 2439998.5     | 142                    | .03000                  | .03036                   | -.3579           | 22 MAY 68 |
| 2440005.5     | 149                    | .03100                  | .03029                   | .7073            | 29 MAY 68 |
| 2440012.5     | 156                    | .03000                  | .02943                   | .5665            | 05 JUN 68 |
| 2440019.5     | 163                    | .02800                  | .02776                   | .2386            | 12 JUN 68 |
| 2440026.5     | 170                    | .02500                  | .02529                   | -.2915           | 19 JUN 68 |
| 2440033.5     | 177                    | .02200                  | .02207                   | -.0734           | 26 JUN 68 |
| 2440040.5     | 184                    | .01800                  | .01819                   | -.1895           | 03 JUL 68 |
| 2440047.5     | 191                    | .01400                  | .01375                   | .2481            | 10 JUL 68 |
| 2440054.5     | 198                    | .00900                  | .00890                   | .1025            | 17 JUL 68 |
| 2440061.5     | 205                    | .00400                  | .00378                   | .2184            | 24 JUL 68 |
| 2440068.5     | 212                    | -.00100                 | -.00143                  | .4288            | 31 JUL 68 |
| 2440075.5     | 219                    | -.00700                 | -.00656                  | -.4368           | 07 AUG 68 |
| 2440082.5     | 226                    | -.01100                 | -.01146                  | .4554            | 14 AUG 68 |
| 2440089.5     | 233                    | -.01600                 | -.01595                  | -.0489           | 21 AUG 68 |

|           |     |         |         |        |           |
|-----------|-----|---------|---------|--------|-----------|
| 2440094.5 | 246 | -.02000 | -.01992 | -.0850 | 28 AUG 68 |
| 2440103.5 | 247 | -.02300 | -.02324 | .2372  | 04 SEP 68 |
| 2440110.5 | 254 | -.02600 | -.02584 | -.1429 | 11 SEP 68 |
| 2440117.5 | 261 | -.02700 | -.02767 | .6670  | 18 SEP 68 |
| 2440124.5 | 268 | -.02800 | -.02871 | .7131  | 25 SEP 68 |
| 2440131.5 | 275 | -.02900 | -.02900 | -.0047 | 02 OCT 68 |
| 2440138.5 | 282 | -.02800 | -.02856 | .5645  | 09 OCT 68 |
| 2440145.5 | 289 | -.02800 | -.02750 | -.5013 | 16 OCT 68 |
| 2440152.5 | 296 | -.02600 | -.02590 | -.1019 | 23 OCT 68 |
| 2440159.5 | 303 | -.02400 | -.02388 | -.1216 | 30 OCT 68 |
| 2440166.5 | 310 | -.02200 | -.02156 | -.4361 | 06 NOV 68 |
| 2440173.5 | 317 | -.01900 | -.01908 | .0804  | 13 NOV 68 |
| 2440180.5 | 324 | -.01700 | -.01655 | -.4523 | 20 NOV 68 |
| 2440187.5 | 331 | -.01400 | -.01407 | .0732  | 27 NOV 68 |
| 2440194.5 | 338 | -.01200 | -.01175 | -.2536 | 04 DEC 68 |
| 2440201.5 | 345 | -.01000 | -.00963 | -.3658 | 11 DEC 68 |
| 2440208.5 | 352 | -.00800 | -.00778 | -.2217 | 18 DEC 68 |
| 2440215.5 | 359 | -.00600 | -.00619 | .1938  | 25 DEC 68 |

1969 SEASONAL VARIATION CORRECTION  
PROJECTION AND COMPARISON OF CALCULATED VALUES  
CALC =  $2.200E-02 \cdot \sin(\text{ARG}) + -1.200E-02 \cdot \cos(\text{ARG}) + -5.900E-03 \cdot \sin(2 \cdot \text{ARG}) + 7.000E-03 \cdot \cos(2 \cdot \text{ARG})$   
RMS DEVIATION = 3.80692E-04

| JULIAN<br>DAY | TIME<br>FROM BEG<br>DAY | UT2-UT1<br>(EXP)<br>SEC | UT2-UT1<br>(CALC)<br>SEC | EXP-CALC<br>MSEC | OATE      |
|---------------|-------------------------|-------------------------|--------------------------|------------------|-----------|
| 2440222.5     | 0                       | -.00500                 | -.00500                  | -.0000           | 01 JAN 69 |
| 2440229.5     | 7                       | -.00300                 | -.00388                  | .0796            | 08 JAN 69 |
| 2440236.5     | 14                      | -.00300                 | -.00294                  | -.0639           | 15 JAN 69 |
| 2440243.5     | 21                      | -.00200                 | -.00210                  | .1001            | 22 JAN 69 |
| 2440250.5     | 28                      | -.00100                 | -.00129                  | .2920            | 29 JAN 69 |
| 2440257.5     | 35                      | -.00100                 | -.00043                  | -.5715           | 05 FEB 69 |
| 2440264.5     | 42                      | -0.00000                | .00057                   | -.5708           | 12 FEB 69 |
| 2440271.5     | 49                      | .00100                  | .00178                   | -.7770           | 19 FEB 69 |
| 2440278.5     | 56                      | .00300                  | .00325                   | -.2456           | 26 FEB 69 |
| 2440285.5     | 63                      | .00500                  | .00501                   | -.0118           | 05 MAR 69 |
| 2440292.5     | 70                      | .00700                  | .00709                   | -.0865           | 12 MAR 69 |
| 2440299.5     | 77                      | .01000                  | .00945                   | .5458            | 19 MAR 69 |
| 2440306.5     | 84                      | .01200                  | .01207                   | -.0723           | 26 MAR 69 |
| 2440313.5     | 91                      | .01500                  | .01487                   | .1279            | 02 APR 69 |
| 2440320.5     | 98                      | .01800                  | .01776                   | .2380            | 09 APR 69 |
| 2440327.5     | 105                     | .02100                  | .02336                   | .6444            | 16 APR 69 |
| 2440334.5     | 112                     | .02400                  | .02580                   | .1958            | 23 APR 69 |
| 2440341.5     | 119                     | .02600                  | .02785                   | .1533            | 30 APR 69 |
| 2440348.5     | 126                     | .02800                  | .02936                   | .13602           | 07 MAY 69 |
| 2440355.5     | 133                     | .02900                  | .03024                   | -.2370           | 14 MAY 69 |
| 2440362.5     | 140                     | .03000                  | .03039                   | .6093            | 21 MAY 69 |
| 2440369.5     | 147                     | .03100                  | .02976                   | .2382            | 28 MAY 69 |
| 2440376.5     | 154                     | .03000                  | .02832                   | -.3219           | 04 JUN 69 |
| 2440383.5     | 161                     | .02800                  | .02608                   | -.0763           | 11 JUN 69 |
| 2440390.5     | 168                     | .02600                  | .02306                   | -.0650           | 18 JUN 69 |
| 2440397.5     | 175                     | .02300                  | .01936                   | -.3611           | 25 JUN 69 |
| 2440404.5     | 182                     | .01900                  | .01507                   | -.0687           | 02 JUL 69 |
| 2440411.5     | 189                     | .01500                  | 0.0220                   | -.0120           | 09 JUL 69 |
| UT2UT1        | 40222COM 40586          |                         |                          | 0.0070           | 07/15/69  |

## APPENDIX C

### Time conversion constant update procedure.

All of the parameters required to convert from A1 to UTC, from UTC to UT2 and from UT2 to UT1 are included in a constant block (CBLK) called 'AUBLK in the AOES System II Data Base. The constants for the first two conversions are contained in Table 'AUTAB within this block. The correlation between the symbols used in this report and the item names in this table are indicated by the headings in Table 4. 'AUTAB has space for a maximum of 10 entries. Table 4 already has 14 entries so not all of Table 4 can be used as 'AUTAB. Because of the way 'AUTAB is employed by the computer routine 'DATU, the entries must occur in consecutive order with no omissions. Thus to support currently flying missions the last ten entries in Table 4 would be used.

New entries must be made in 'AUTAB whenever a step change is made in UTC or whenever the frequency offset is changed. It may be advantageous to make additional entries when it is impossible to fit UTC to UT2 within the required accuracy over the time period between UTC changes with a single set of constants. In the eight year period covered by Table 4 this has been necessary only once, namely the entry of 1 August 1963.

In addition to adding new entries to 'AUTAB the values in the last (most recent) entry should reflect as large an amount of data as is available on the relation between UTC, UT2. The most convenient source of this information is the "Preliminary Times and Coordinates of the Pole. Series 7" published by the US Naval Observatory. The method by which this information is incorporated in the base involves tradeoffs between frequent changes in the data base, level of management authority which should permit changes in the data base, auxiliary computer programs required, etc., all considerations outside the scope of this report. We suggest one scheme simply to indicate the type of procedure which might be used.

This updating procedure is outline as a flow chart in Fig. C-1. The criteria for making a change in 'AUTAB is that for some input day there is a greater than 30 msec difference between UT2 as calculated from the constants in 'AUTAB and UT2 as obtained from the Naval Observatory. If a change is necessary the first attempt is to change the constants relating UTC to UT2 to better values. If elimination of the troublesome time difference is not possible this way then a new entry should be made in 'AUTAB.

A new entry is made in 'AUTAB whenever the  $|UT2_{cal} - UT2_{USNO}|$  is too large or whenever a UTC discontinuity occurs. For either cause the new entry is always the last one in the table and if one must be dropped to keep within the table size it must be the first entry in the table. The items in the new entry are determined as shown in Table C-1. When a new entry is made there will be no further need to update the old last entry. Therefore the best values of UCTU2C and UCTU2D for that time period should be inserted even if the old values were giving acceptable answers.

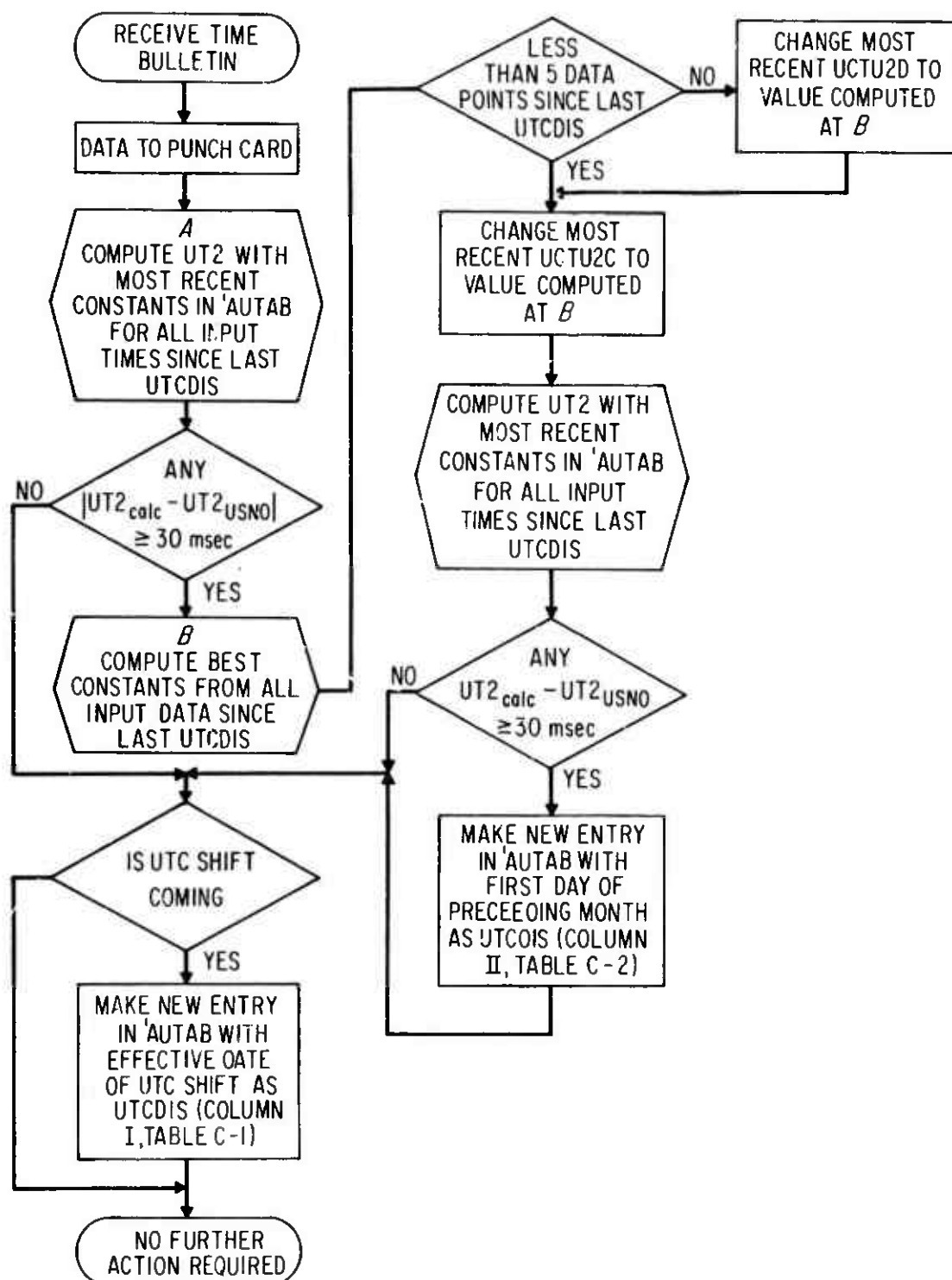


Figure C-1. Flow Chart of a Possible Procedure for Updating 'AUTAB'.

Table C-1. Source for Values of Items in New Entry in 'AUTAB

| ITEM                                                           | 1                                                                                    |                                                                                                                                |
|----------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
|                                                                | 1                                                                                    | II                                                                                                                             |
|                                                                | New entry because of change in UTC constants                                         | New entry because $ UT2_{calc} - UT2_{USNO} $ has grown too large                                                              |
| Next to last entry in 'AUTAB (last entry before the new entry) |                                                                                      |                                                                                                                                |
| UTCDIS                                                         | Unchanged from old last entry                                                        | Unchanged from old last entry                                                                                                  |
| FRQSHF                                                         |                                                                                      |                                                                                                                                |
| UCTAA                                                          |                                                                                      |                                                                                                                                |
| UCTU2C                                                         | Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry. | Best least squares fit to data between UTCDIS of this entry and UTCDIS of new entry.                                           |
| UCTU2D                                                         |                                                                                      |                                                                                                                                |
| New last entry in 'AUTAB                                       |                                                                                      |                                                                                                                                |
| UTCDIS                                                         | Effective date of change in days from AOES base time.                                | First day of month preceding date when $UT2_{calc} - UT2_{USNO}$ first exceeded 30 msec, measured in days from AOES base time. |
| FRQSHF                                                         | As defined by USNO for new period                                                    | Same as FRQSHF in preceding entry                                                                                              |
| UCTAA                                                          | Al-UTC USNO at UTCDIS as determined by interpolation in USNO time bulletins          | Al-UTC USNO at UTCDIS as determined by interpolation in USNO time bulleting                                                    |
| UCTU2C                                                         | UCTU2C of preceding entry $\pm$ step change announced for UTC                        | Calculated from least squares fit to data since last discontinuity.                                                            |
| UCTU2D                                                         | Same as UCTU2D in preceding entry                                                    |                                                                                                                                |

# APPENDIX D

## Summary of Constant Block AUBLK Data Values.

| Name   | Description                        | Value or Source               |
|--------|------------------------------------|-------------------------------|
| AUTAI  | UTC to A1 and A1 to UTC Conversion | Table 4 and Appendix C        |
| UTCIND | Internal Flag                      |                               |
| A1IND  | Internal Flag                      |                               |
| U1K1   | Seasonal Variation Constants       | Table 5                       |
| U1K2   |                                    |                               |
| U1K3   |                                    |                               |
| U1K4   |                                    |                               |
| THK1   | Conatant for Sidereal Time Comp.   | 0.2779876155                  |
| THK2   | Constant for Sidereal Time Comp.   | $0.2737909294 \times 10^{-2}$ |
| THDK1  | Sidereal Rate Conatant             | 1.002737909294                |

} Eq. 2

UNCLASSIFIED

Security Classification

| DOCUMENT CONTROL DATA - R&D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                             |                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| (Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                             |                                                                                        |
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| ADVANCED ORBIT/EPHEMERIS SUBSYSTEM (AOES)<br>TIME TRANSFORMATION REVIEW                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                             |                                                                                        |
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| 5. AUTHOR(S) (Last name, first name, initial)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                             |                                                                                        |
| Randall, Charles M.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |                                                                                        |
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| c.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                             |                                                                                        |
| d.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                             |                                                                                        |
| 10. AVAILABILITY/LIMITATION NOTICES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |                                                                                        |
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| 11. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                             | 12. SPONSORING MILITARY ACTIVITY                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                             | Space and Missile Organization<br>Air Force Systems Command<br>Los Angeles, California |
| 13. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                             |                                                                                        |
| <p>The time transformations and time dependent inputs for spatial transformations in the Advanced Orbit/Ephemeris Subsystem (AOES) presently being implemented by the Air Force Satellite Control Facility have been reviewed. The principle results are:</p> <ol style="list-style-type: none"><li>1. The relations described in the Milestone 2 documents describing the computer routines include all relations required to satisfy the accuracy design goals of AOES.</li><li>2. If future systems require higher accuracy the present time-related transformations will not be adequate. The improvements must involve the following:<ol style="list-style-type: none"><li>a. Wander of the pole of rotation with respect to the crust of the earth can no longer be ignored.</li><li>b. The empirical relations between earth rotation time scales (UT2, UT1) and atomic time scales (AI, UTC, etc.) must be improved, probably by fitting over shorter periods of time.</li><li>c. Nutation terms of amplitude less than 0.2 arc second must be included.</li></ol></li></ol> |                                                                             |                                                                                        |

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14.

KEY WORDS

Atomic Time  
Universal Time  
Time Transformations

Abstract (Continued)

3. A best set of constants to be employed by the AOES relating UT2 to UTC for the period 1 January 1961 to 30 June 1969 have been calculated. A procedure is suggested for the continuous review of the applicability of these and subsequent constants, with provisions for updating them as required.
4. Values for comparison with computer routine results are presented for many of the quantities under study.

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