

# **EFLIGHT 2003 – The Umbra on Ice from 35,000 ft.<sup>1</sup>**

## **The QANTAS/CROYDON QF 2901 Total Solar Eclipse Flight 23 November 2003 UT**

### **Mission Planning & Definition Overview REQUIREMENTS for Assisted Real-Time Computation and Navigation**

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#### **Abstract**

Until the austral summer of 2003 no total solar eclipse had ever been observed from Antarctica both because of the infrequency of occurrence and the logistical complexities associated with Antarctic operations. The total solar eclipse of 23 November 2003 U.T. (TSE2003), the first in the Antarctic since 12 November 1985, was no less challenging and may similarly have gone unobserved due to the geographic remoteness of the path of totality. Yet, interest in securing phenomenological observations of, and associated with, the eclipse by members of the scientific research communities engaged in astronomy, solar physics, astrodynamics, aeronomy and upper atmospheric physics, as well as educators and amateur astronomers has been extremely high and provided the impetus for breaking this paradigm of elusivity regarding Antarctic eclipses in the historical record of science and exploration. The development of a flight concept to enable airborne observations, using a dedicated aircraft chartered from QANTAS Airlines, permitted the previously unobtainable to be accomplished. Doing so, successfully, required detailed preparatory planning for the execution of such a flight. The technical groundwork to achieving this goal had been pursued with diligence for four years prior to TSE2003 and was predicated on a legacy and computational infrastructure capability founded on more than three decades of eclipse planning for ground, sea, and airborne venues. Given the geometrical circumstances of the eclipse, the uncertainties associated with weather, and the constraints of operations of the Boeing 747-400 ER aircraft, the requirements for the successful execution an intercept flight with the base of the Moon's shadow over the Antarctic are reviewed. The unequivocal need for real-time, in-situ re-computation of an executable flight plan in response to in-flight conditions is discussed. The mechanism for fulfilling that need, through the expert operation of EFLIGHT, a well-tested highly specialized software package of unique pedigree designed specifically for this purpose by the author of this report, working in concert with the flight crew on the flight deck is elaborated upon in the specific context of the requirements of this unprecedented flight.

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<sup>1</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLIPSE\\_03/SEC2004\\_SCHNEIDER\\_QF2901.pdf](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_03/SEC2004_SCHNEIDER_QF2901.pdf)

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### The 23 November 2003 Antarctic Total Solar Eclipse

On the long-term average, a total solar eclipse is visible somewhere in the world about once every sixteen months. However, the overlap between the cycles of solar eclipses is complex. The most recent solar eclipse occurred on 23 November 2003. Its immediate predecessor, the 4 December 2002 total solar eclipse, occurred only 354 days earlier. The next one (which has a maximum total phase duration of only 42 seconds) will not happen until 8 April 2005. Also on average, any given spot on the Earth will see a total solar eclipse about once every 360 years. However, eclipse paths can cross specific locations more frequently (e.g., the 2001 and 2002 eclipse paths crossed in South Africa, and those living in the right location saw both of them). The last total solar eclipse in the Antarctic occurred on 12 November 1985, but was unobserved.

The 23 November 2003 total solar eclipse (TSE2003) was visible only from a small portion of the Eastern Antarctic (see Figure 1; from NASA TP 2002-211618). The “path of totality”, the region on the Earth's surface which was swept by the Moon's umbral shadow, and where the total phase of the eclipse could have been seen, began off the coast in the Antarctic (Great Southern) Ocean. The umbral shadow touched down on the Earth at 22h 24m Universal Time (U.T.). At that time, the total phase of the eclipse become visible at sunrise at a latitude of 52.5°S, southeast of Heard Island and the Kerguelen archipelago. The lunar shadow then moved southward toward Antarctica and traversed an arc-like sector of the continent, from approximately longitudes 95°E to 15°E, where it then lifted off into space only 51 minutes later at 23h 15m U.T.

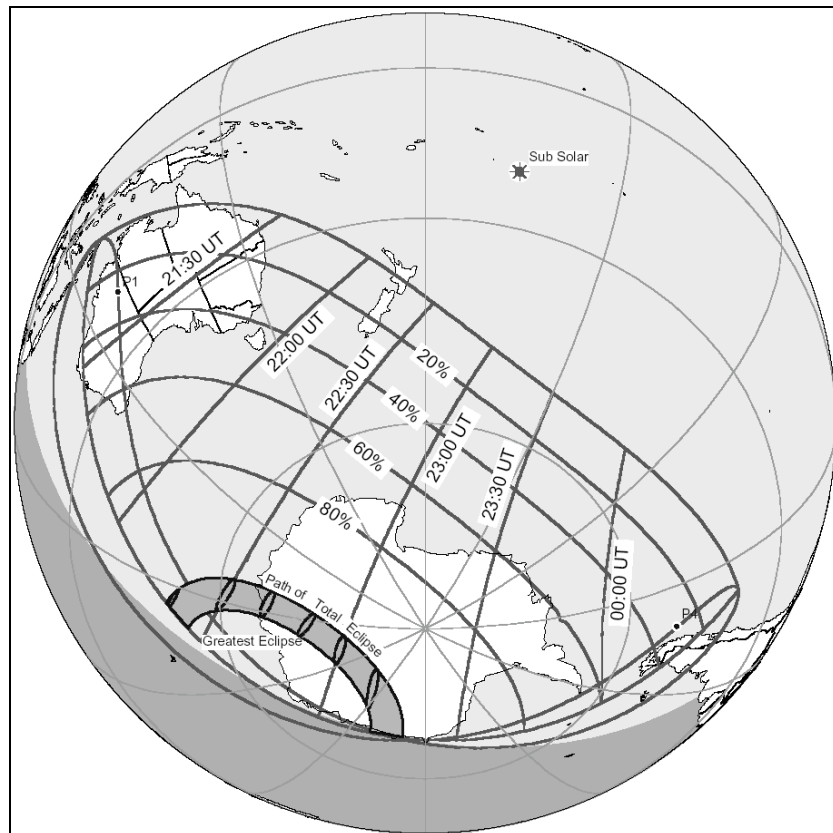


Fig. 1 – TSE2003 visibility. Partial eclipse seen in the region of the overlaid grid. Total eclipse seen within gray arc over Antarctica (path of totality). Ellipses indicate instantaneous surface projection of umbral shadow.

Total solar eclipses in the Polar Regions can have unusual geometries, and TSE2003 was no exception. In this case, the Moon's shadow passed “over the pole” before reaching the Earth. So, the path of totality advanced across Antarctica opposite the common direction of the Earth's rotation and the lunar orbit. The eclipse occurred in the hemisphere of the Earth which, except at southern polar latitudes, was experiencing nighttime. Hence, mid-totality occurred very close to local midnight. Antarctic total solar eclipses are infrequent, but not particularly rare, the last occurring (but unobserved) eighteen years earlier in 1985 (the Saros 152 predecessor to TSE2003).

Until this juncture in time and technology Antarctic total solar eclipses had been elusive targets and never before had one been observed. Accessibility to, and mobility in, the path of totality on the Antarctic continent was severely limited. As anticipated, coastal locations were hampered with less-than cooperative weather, and inland regions within the path of totality were unreachable. A Russian icebreaker, challenged by off-coastal weather that is often cloudy and potentially accompanied by high winds and ice fog, made its way to the path of totality finding observing conditions for the eclipse marginal, at best. A ground-based expedition to the Russian Antarctic station at Novolazarevskaya, located very close to the end of the eclipse path at sunset, persevered through hours-earlier threats of blowing snow and whiteout conditions, and observed the totally eclipsed Sun partially obscured by the horizon. If ever there was a clear-cut case for the necessity of using an airborne platform to observe a total solar eclipse, TSE2003 was it.

### **QF 2901: The QANTAS/Croydon Boeing 747-400 ER Total Solar Eclipse Flight**

TSE2003 presented the first opportunity in the history of science, (and indeed of humanity) to conduct high-altitude airborne observations of the a total solar eclipse over Antarctica. Until that day no total solar eclipse has ever been witnessed from the Antarctic. To fill this previous void in the experience base of humankind, while enabling compelling and otherwise unobtainable observations furthering a wide variety of astronomical, solar dynamical, and aeronomic studies, a truly unique QANTAS B747-400 ER flight – QF 2901 – departed Melbourne, Australia on 23 November 2003 under the command of Captain John Dennis to intercept the lunar umbra as planned by the author. After a poleward journey to a latitude of  $\sim 70^\circ\text{S}$ , the flight centrally rendezvoused with the Moon's shadow at 22:44:00 UT at an altitude 11 km above the Earth's surface as the shadow rapidly and obliquely swept over the eastern end of the White Continent.

Sightseeing flights over the Antarctic had been implemented over the preceding decade on a fairly regular basis by Croydon Travel, an Australian based company, in concert with QANTAS Airlines. Croydon Travel periodically chartered Boeing 747-400 aircraft from QANTAS Airlines for that purpose, and had done so with great success 60 times over the dozen years prior to TSE2003. Given that experience base, the concept of developing an eclipse observation flight was a natural “variant”, but with many special needs and requirements which were absent on their Antarctic sightseeing flights<sup>4</sup>. Here, the requirements levied upon QF 2901, as developed and approved in concert with QANTAS airlines flight, technical, operations, security and general management personnel, are discussed in the context of the 23 November 2003 total solar eclipse.

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<sup>4</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLUPSE\\_03/FAQ\\_747.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLUPSE_03/FAQ_747.html)

### Shadow Dynamics and the Duration of Totality

The dynamics of solar eclipses are driven by the inexorable laws of Newtonian celestial mechanics, as naturally applied to the orbital configurations of the Earth/Moon/Sun system. The long slender conic of the TSE2003 lunar umbral shadow,  $1/2^\circ$  in angular extent at the distance of the moon, was only 34 nautical miles in radius at 11 km above the Earth's surface and tapered to a geometrical point below. The umbral shadow sliced through the Earth's atmosphere at very high speed with a non-linear acceleration profile (see Figure 2), decelerating to its slowest instantaneously velocity of 2109 nautical miles per hour with respect to the rotating surface of the Earth at 22:49:17 UT. At that instant, the instant of "greatest eclipse", a ground-based observer concentrically located along the shadow axis would have experienced 1m 59s of totality, the maximum possible for this eclipse. Elsewhere within the path of totality the achievable ground-based duration was reduced. Time in totality is a highly precious commodity. Given the intrinsically short maximum duration of TSE2003, and the very limited opportunities to position observers within the path of totality, extreme care was taken in the planning and execution of an airborne shadow intercept to avoid unnecessarily shortening the achievable duration due to targeting and/or navigation errors.

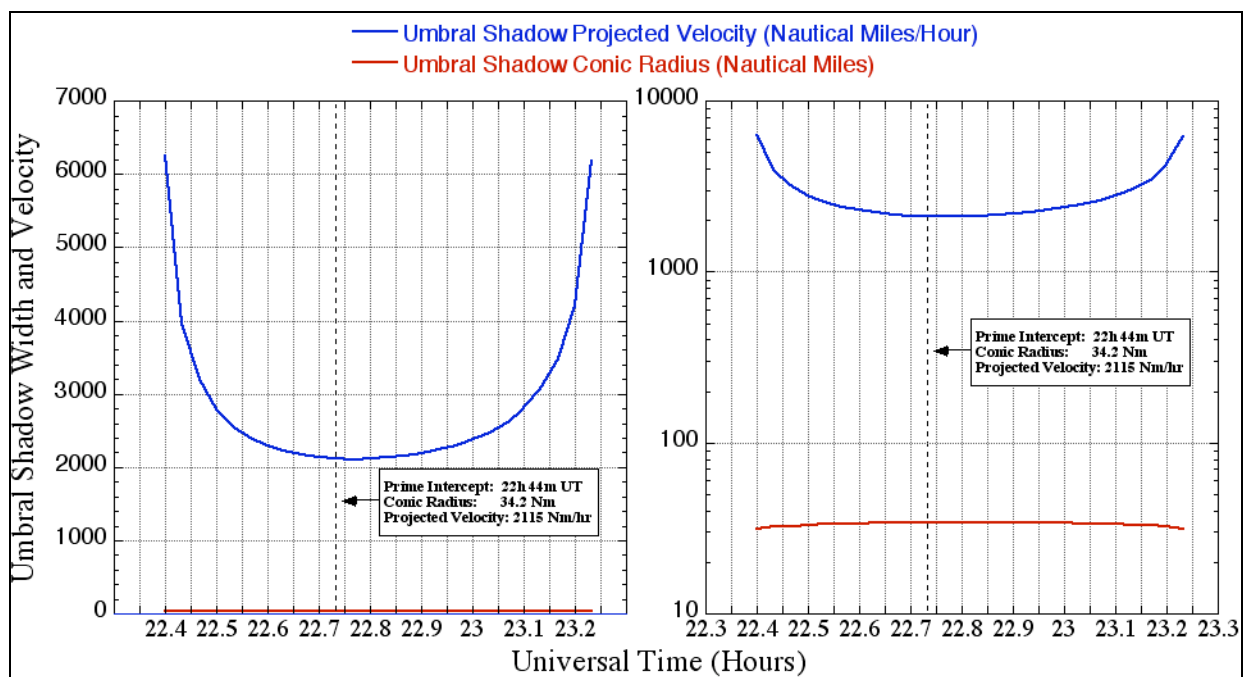


Fig. 2 – Instantaneous speed (blue) and radius (red) of the umbral shadow as a function of time.

As is typical for any total solar eclipse, the maximum duration of totality *along* centerline declines very slowly (except near the points of sunrise and sunset) but reduces significantly and non-linearly (to zero) *across* the direction of the shadow's velocity vector at the extrema of the shadow. For a ground-based observer, the duration of the total phase as seen at some particular location within the umbral shadow declines, to first order, as  $(1 - [1 - \text{abs}\{x/R\}]^2)^{1/2} / D$ ; where  $R$  is the radius of the umbral shadow where it intersects a surface of constant elevation,  $x$  is the distance of the observer from the shadow axis perpendicular to its instantaneous direction of motion, and  $D$  is the duration of totality on centerline at the same Universal Time of mid-eclipse.

For TSE2003, the duration of totality achievable by a ground-based observer (co-rotating with the Earth) with two degrees of positioning freedom (X, Y [or longitude & latitude]) as a function of the  $(X^2+Y^2)^{1/2}$  perpendicular displacement from the shadow axis is illustrated in Figure 3.

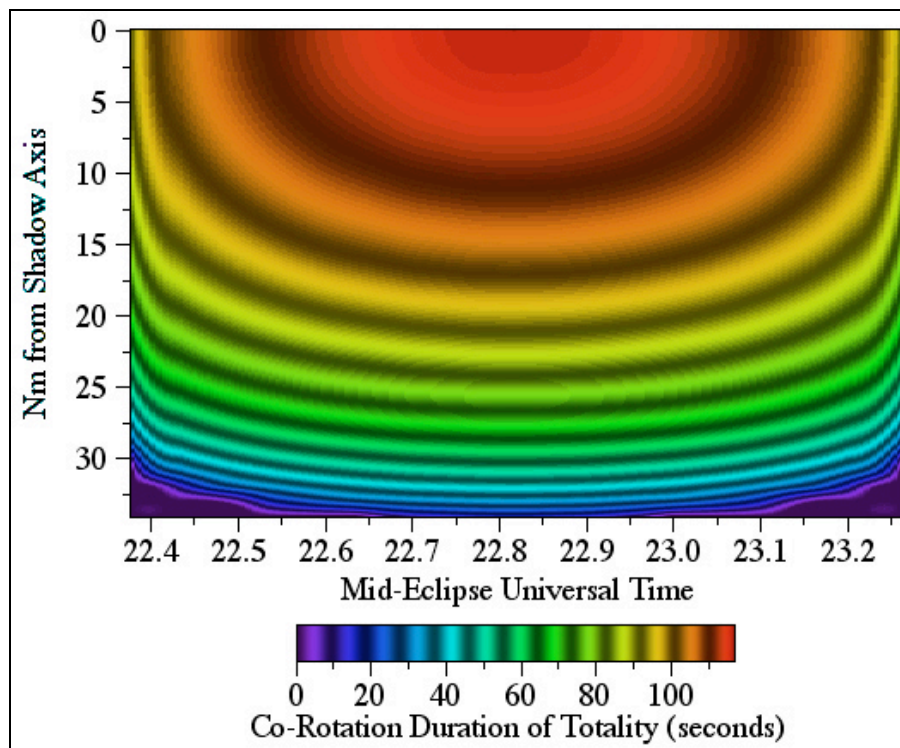


Fig. 3 – Duration of totality for perpendicular off-axis position displacements along the path of totality.

### **The Modifying Effects of the Aircraft Velocity Vector**

Figure 3 does not consider the effect of an aircraft's velocity vector on the absolute achievable duration of totality, and is directly applicable only for a stationary (Earth co-rotating) observer. For *any* aircraft trajectory the maximum duration of totality declines with an aircraft/shadow axis centration error as illustrated in Figure 3, but the duration will additionally be modified by the aircraft's motion relative to the lunar shadow.

The nominal at-altitude cruise speed of a B747-400 ER (with a no-wind condition) is 470 Nm/hr. The TSE2003 lunar shadow moved across the Earth with a minimum speed (near the point of greatest eclipse) approximately 4-1/2 times faster than the aircraft's speed. Hence, with the aircraft properly positioned at the critical time, and with the heading adopted for QF 2901's mid-eclipse intercept, the lunar shadow overtook the aircraft more slowly than for a stationary observer. An *increase* in the duration of totality is realized for an aircraft with a net velocity component in the direction of motion of the lunar shadow axis. Without the necessary consideration of other constraining factors, a maximum theoretical gain of 37s was possible for TSE2003 using an aircraft with a *ground* speed of 470 Nm/hr following the trajectory of the lunar shadow axis and precisely co-aligned with axis at the instant of greatest eclipse. Such a

fully duration-optimized aircraft trajectory may not be tenable, as the goal of maximizing the duration of totality cannot be taken in isolation.

### **Primary Factors for Simultaneous Optimization**

A) AXIAL CONCENTRICITY: At the selected instant of mid-eclipse, QF 2901 was required to be concentrically located along the lunar shadow axis. To the requisite degree of targeting precision, (discussed below) this is complicated because the photocentric location (i.e., the “center of figure”) of the Moon’s shadow is not coincident with its dynamical center (i.e., its “center of mass”) due to irregularities along the lunar limb (selenographic features such as mountains, ridges, and valleys). It is these features that give rise to the “diamond ring” and “Baily’s Beads” phenomenon at second and third contacts of the eclipse. The “lunar limb profile”, (for example see Figure 4; from NASA TP 2002-211618), changes with topocentric physical and optical librations and will differ with an observer’s latitude, longitude, and altitude along and across the path of totality, and hence, must be applied dynamically (and differentially) with changes in aircraft position and targeting.

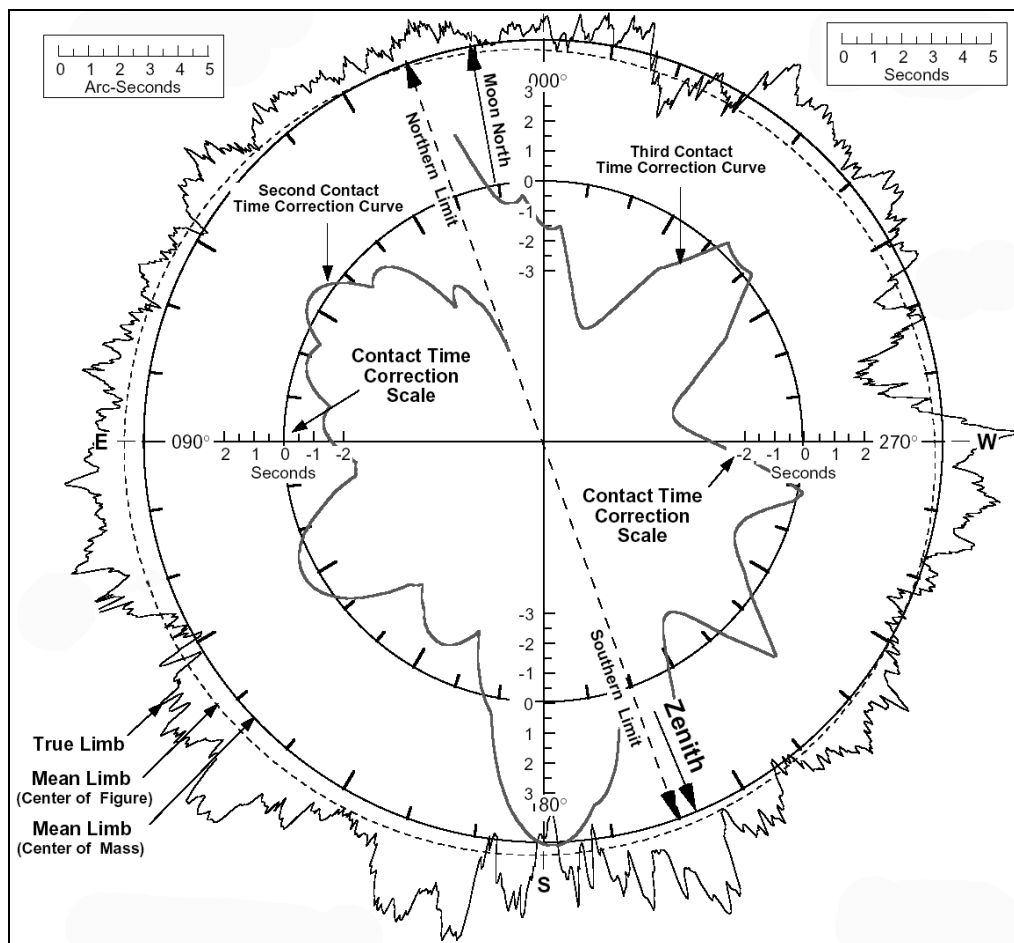


Fig. 4 – Representative lunar limb profile for mid-eclipse at 22:40 UT for an observer at sea level on centerline. The scale-height of the features along the lunar limb as seen at this location has been vertically amplified for illustrative purposes. One arcsecond at the distance of the moon is approximately 1.8 kilometers.

B) MID-ECLIPSE APPROACH/DEPARTURE SYMMETRY: Observation and analyses of the spectrally decomposed brightness and “color” gradients of the sky, illuminated by light scattered into the umbral shadow by upper atmospheric particulates (as planned to be executed on QF 2901), can provide unique insights into the bulk aerosol content over the Antarctic. In-situ measures by Antarctic ground stations rely on back-scattered LIDARs, whereas aerosol scattering of sunlight *into* the lunar shadow is uniquely front-scattered and can be used to break degeneracies in particle scattering models applied to the upper atmosphere. Quantitative calibration of aeronometric studies of the bulk physical properties of the upper atmosphere, particularly due to airborne contaminants, require sampling the scattering properties of the atmosphere in a symmetrical manner with respect to concentric shadow illumination, and hence immersion and emersion of the aircraft’s penetration through the umbral shadow.

(A) and (B), above, defined a temporal shadow concentricity/symmetry requirement for the aircraft trajectory, i.e., how close to the geometrical shadow axis the aircraft must be at the instant of mid-eclipse and where it must be positioned as it transitioned through the umbral boundary at second and third contacts. An offset in time would produce a time and position error not only reducing the duration of totality but causing a temporal shift in the expected absolute (U.T.) contact times of the eclipse which is counter to the needs of planned imaging and photographic experiments were conducted.

C) MID-ECLIPSE HEADING ALIGNMENT: For the purpose of observing, photographing, and providing a proper field-of-view for those on-board the aircraft observing the eclipse, the line-of-sight to the Sun through the cabin windows was constrained to be in a plane very close to perpendicular to the aircraft heading throughout the “totality run”. Such an orientation was required to provide an unimpeded, stable, and nearly optimal viewing opportunity through the cabin windows. Such orientations will generally yield aircraft crossing geometries with respect to centerline, and thus preclude a full maximization of the duration of totality. Thus, the aircraft heading alignment and totality duration must be simultaneously optimized.

D) MINIMIZE INTRA-“TOTALITY RUN” HEADING RE-ALIGNMENTS. The azimuth of the Sun varies continuously depending upon the absolute (U.T.) time and aircraft position. To fully optimize (C) would require near-continuous differential course corrections, which cannot be accommodated at high temporal cadence due to CDU/FMS command input granularity and operational procedures constraints. Additionally, large discrete corrections during totality would cause a sudden displacement in the positioning of the Sun with respect to the line-of-sight, which were contraindicated and constrained to be avoided.

### **Derived Navigation Requirements and Error Tolerance**

Taken together, the primary factors for simultaneous optimization (A – D, above) applied to the topocentric circumstances of the eclipse, give rise to a defining set of navigational precision requirements that are summarized in Table 2. Adherence to these requirements was of fundamental necessity to assure the success of the time-critical in-flight eclipse observation programs and the realization of the goals of those programs.

The Boeing 747-400 ER is exceptionally well suited to this task given the operational capabilities and characteristics of the aircraft. The experience base of the QANTAS flight crews in conducting previous Antarctic overflights, though less demanding in navigational specificity and compliance than the 23 November 2003 flight, is unparalleled in commercial aviation. Hence, the choice of QANTAS B747-400 ER platform for this purpose was unequivocally clear.

TABLE 1  
REAL-TIME NAVIGATION/TARGETING REQUIREMENTS

- 1) **Absolute Position Error Tolerance:**
  - a) Maximum Aircraft lateral (cross track) position error  $\pm 1$  km at mid-eclipse, contact II, and contact III.
  - b) Maximum Aircraft vertical position error  $\pm 100$  meters.
- 2) **Absolute Timing Error Tolerance :**  $\pm 6$ s in time w.r.t. U.T. predictions\* at CII and CIII.
- 3) **Heading Constraint: Portside Orthogonality:**

Absolute:  $\pm 1.5^\circ$  from mid-eclipse  $\pm 5$  minutes.  
Differential:  $\pm 0.5^\circ$  from mid-eclipse  $\pm 5$  minutes.
- 4) **CDU/FMS Way Point Input Updates During Totality Run:**
  - a) Precluded within 2 minutes of mid-eclipse, except for mid-eclipse update.
  - b) Avoided if possible within 5 minutes of mid-eclipse.
  - c) Desired Granularity: 5-minute intervals at relative mid-eclipse times of -15, -10, -5, (0), +5 minutes.
- 5) **Aircraft Altitude:**

Maximum possible altitude for least air-mass along line of sight to Sun.

\* Exclusive of delta-T correction based upon pre-eclipse IERS updates (see: <http://www.iers.org/iers/> )

### **Navigation Requirements: Constraints & Restrictions**

The requirements for previous QANTAS Antarctic flights, carried out with great success, were driven by the more casual needs to provide a suitable downward looking venue for sightseeing. These flights were unconcerned with the specific and highly demanding external constraints imposed by the unique needs of a solar eclipse intercept (see Table 2). For the 23 November 2003 eclipse flight the necessary responsiveness to uncontrollable, but anticipated, atmospheric variables (Table 2, section A) were fettered and constrained by defining astrodynamical geometry of the eclipse (section B) and coupled to the performance restrictions and characteristics of the B747-400 ER aircraft (sections C & D).



TABLE 2  
PRIMARY FLIGHT DEFINITION VARIABLES, CONSTRAINTS & RESTRICTIONS

**A ATMOSPHERICS: METEROROLOGICAL CONDITIONS**

Local obscuration by cloud: monolithic and multi-layer along the line-of-sight to the Sun.  
 Wind speed and direction and vector gradients.  
 Atmospheric turbidity along the line-of-sight to the Sun.  
 Flight-level turbulence (platform stability).

**B ASTRO-DYNAMICS: TIME/POSITION DEPENDENT FUNDEMENTAL GEOMETRY**

Non-linear motions (absolute & relative) of Earth, Moon, and Sun.  
 Shadow Velocity and instantaneous acceleration profile.  
 Shadow axis (X,Y,Z) position loci as functions of altitude above geodial surface (MSL), differentially corrected through atmospheric refraction models based upon Temperature/Pressure scale-height profiles.  
 Shadow boundary loci as a functions topocentric lunar limb profile and atmospheric refraction corrections.  
 Conic shadow projection on the elevated oblate geoidal surface.

**C AIRCRAFT PERFORMCE CONSIDERATIONS**

Maximum range for gross weight at eclipse intercept.  
 Maximum service ceiling for gross weight at eclipse intercept.  
 Nominal/Maximum cruise speed for required range and payload.  
 Take-off or In-flight delay.

**D AIRCRAFT OPERATIONS CONSIDERATIONS**

Minimum/Maximum Airspeed.  
 FMS Targeting Compliance (input granularity and precision).

**A "Baseline" Flight Concept for Plan Evaluation**

Maintaining flexibility in the execution of the shadow intercept, within the previously delineated constraints, was paramount in permitting the critical optimization of the spatial and temporal positioning of the aircraft to allow an unprecedented set of observations to be conducted to the greatest possible advantage that the circumstances of the eclipse allowed. With some decoupling, the outer envelopes of the flight definition parameter spaces can be evaluated and in doing so were used to define preliminary flight intercept profiles for evaluation and early planning purposes. A "baseline" totality run was then developed and called for: (a) a mid-eclipse intercept at 22:44:00 U.T at, (b) a flight altitude of 35,000 ft with, (c) a direction of flight to orient the sun orthogonal to the port-side windows and (d) waypoint pre-loads into the 747 Command Data Unit/Flight Management System (CDU/FMS) requiring no more frequent than 5 minute updates. This baseline plan is shown graphically in Figure 5 and tabulated in Table 3. This particular point of mid-eclipse intercept, and its corresponding baseline flight trajectory of approach and recession, simultaneously satisfy the optimization criteria previously discussed.

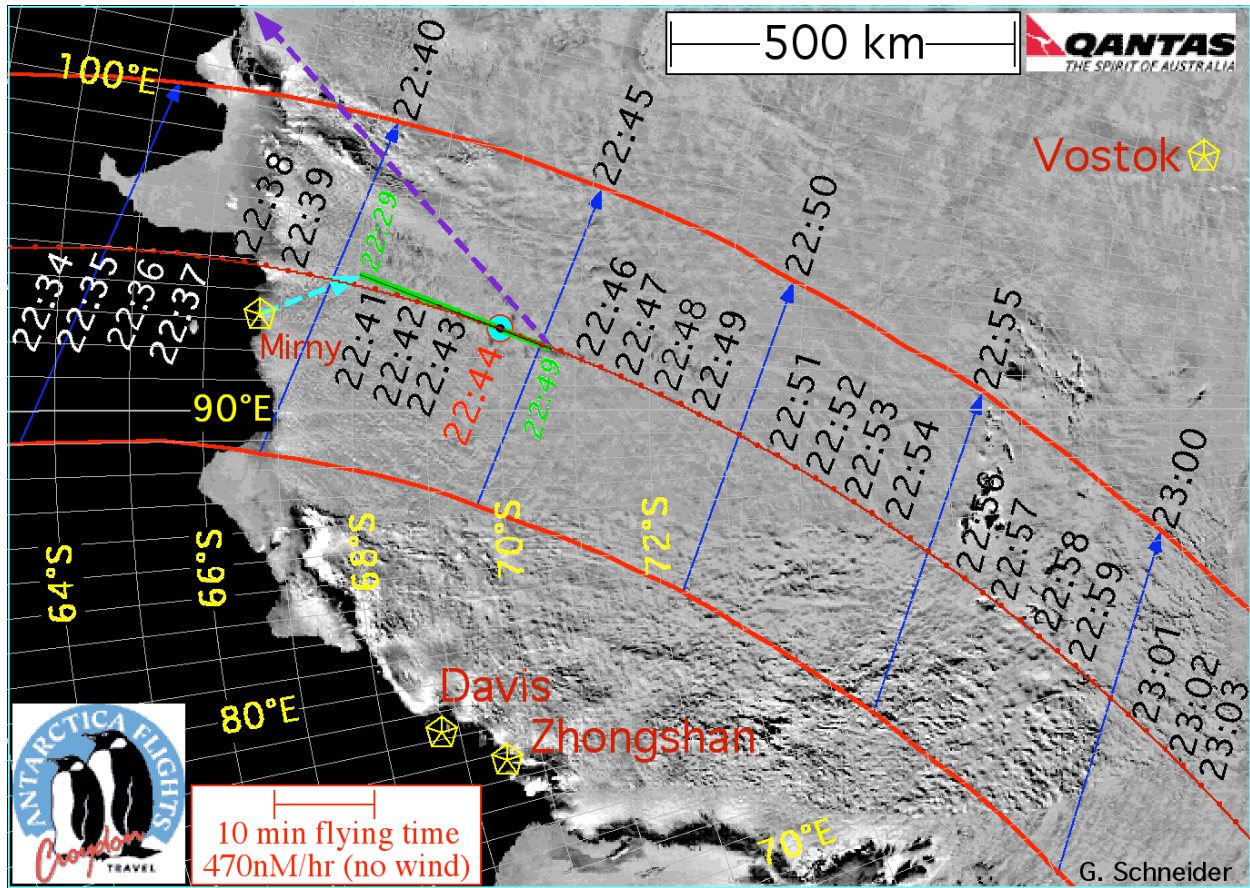


Fig. 5 – Schematic representation of the “baseline” flight used for planning purposes. Dotted red line: Centerline at 35,000 ft in 30-second intervals (1 minute annotation). Solid red lines: Projection of the shadow conic major axis extrema onto a geoidal surface of 11 km constant elevation. Blue arrows: Lines of sight to Sun.

This specific “baseline” scenario, when executed in this form, achieves:

- a) a 2m 34.7s extended duration totality, 36s longer than on ground at the same mid-eclipse U.T., and only 0.6s shorter than the theoretical maximum for this eclipse.
- b) a line-of-sight viewing geometry deviating in offset angle by only (+0.3°, -0.1°) from optimal orthogonality to the flight vector throughout the totality run. And,
- c) a solar elevation of 14.8° at mid-eclipse, only 0.2° lower than theoretically possible.

Additionally, at this point the lunar shadow velocity (2115 nM/hr) is very nearly at its minimum for this eclipse (2109 nM/hr) providing a greater temporal margin for tolerable positioning error than most other locations along the path of totality.

The possibility of executing of this baseline plan, unaltered in detail as shown in Table 3, was wholly dependent upon the imponderable in-flight state of the multi-parametric set of input variables noted in sections A/C of Table 2, which then drove those in section B/. The likelihood that the speculative set of (optimized) conditions postulated for planning purposes would actually arise identically in flight was, indeed, vanishingly small.

TABLE 3  
 BASELINE INTERCEPT PROFILE FOR PLAN EVALUATION

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=====
U.T. Intercept: 22:44:00          TOTALITY DURATION = 2m 34.7s
Flight Altitude: 35000ft
Heading: 198.80°
Air Speed: 470.0nm/h
Wind Speed: 0.0nm/h
Wind Direction: 0.0°
=====
                Cnt hh:mm:ss.f  Alt°  Az°  P° Cnt  Cnt  hh:mm:ss.f  Alt°  Az°  P°
                2ND 22:42:42.7 +14.8 109.0 109.3  3RD 22:45:17.4 +15.0 108.6 289.7
                LATITUDE: -069° 49' 09.4''  LATITUDE: -070° 08' 17.2''
                LONGITUDE: +093° 09' 59.0''  LONGITUDE: +092° 51' 6.8''
=====
HMMSS  Umbra Lon Umbra Lat  WidKM  Uaz°  Ual°  AC Long  AC Lat  MidAT  MidAD  LOS  Bearng  ACaz  Acal
222900  9321.788E 6031.704S  541.8  113.7  10.2  9442.029E 6807.104S  -900s  117.5nm  +0.3  197.22  108.5  14.6
222930  9334.818E 6053.937S  540.9  113.4  10.5  9438.915E 6810.838S  -870s  113.6nm  +0.3  197.27  108.5  14.6
223000  9346.587E 6115.758S  539.9  113.1  10.8  9435.783E 6814.571S  -840s  109.7nm  +0.3  197.32  108.5  14.6
223030  9357.178E 6137.205S  538.8  112.7  11.0  9432.635E 6818.303S  -810s  105.8nm  +0.3  197.37  108.5  14.7
223100  9406.659E 6158.313S  537.6  112.4  11.3  9429.470E 6822.034S  -780s  101.8nm  +0.3  197.42  108.5  14.7
223130  9415.088E 6219.109S  536.3  112.2  11.5  9426.287E 6825.764S  -750s  -97.9nm  +0.3  197.47  108.5  14.7
223200  9422.514E 6239.618S  535.1  111.9  11.8  9423.086E 6829.493S  -720s  -94.0nm  +0.3  197.52  108.5  14.7
223230  9428.976E 6259.863S  533.7  111.6  12.0  9419.868E 6833.221S  -690s  -90.1nm  +0.3  197.56  108.5  14.7
223300  9434.508E 6319.862S  532.4  111.4  12.2  9416.632E 6836.947S  -660s  -86.2nm  +0.2  197.62  108.6  14.7
223330  9439.140E 6339.632S  531.0  111.1  12.4  9413.378E 6840.673S  -630s  -82.3nm  +0.2  197.67  108.6  14.7
223400  9442.892E 6359.188S  529.6  110.9  12.6  9410.106E 6844.398S  -600s  -78.3nm  +0.2  197.72  108.6  14.7
223430  9445.786E 6418.544S  528.1  110.7  12.8  9406.815E 6848.122S  -570s  -74.4nm  +0.2  197.77  108.6  14.7
223500  9447.834E 6437.712S  526.7  110.5  13.0  9403.507E 6851.845S  -540s  -70.5nm  +0.2  197.82  108.6  14.8
223530  9449.051E 6456.701S  525.3  110.3  13.1  9400.179E 6855.567S  -510s  -66.6nm  +0.2  197.87  108.6  14.8
223600  9449.442E 6515.523S  523.8  110.1  13.3  9356.833E 6859.287S  -480s  -62.7nm  +0.2  197.92  108.6  14.8
223630  9449.013E 6534.185S  522.4  109.9  13.4  9353.468E 6903.007S  -450s  -58.8nm  +0.2  197.98  108.6  14.8
223700  9447.769E 6552.695S  521.0  109.8  13.6  9350.084E 6906.725S  -420s  -54.8nm  +0.2  198.03  108.6  14.8
223730  9445.707E 6611.060S  519.6  109.6  13.7  9346.681E 6910.442S  -390s  -50.9nm  +0.2  198.08  108.6  14.8
223800  9442.827E 6629.286S  518.2  109.5  13.9  9343.258E 6914.158S  -360s  -47.0nm  +0.2  198.13  108.6  14.8
223830  9439.124E 6647.379S  516.8  109.3  14.0  9339.816E 6917.873S  -330s  -43.1nm  +0.1  198.19  108.7  14.8
223900  9434.591E 6705.344S  515.4  109.2  14.1  9336.354E 6921.587S  -300s  -39.2nm  +0.1  198.24  108.7  14.8
223930  9429.218E 6723.185S  514.0  109.1  14.2  9332.872E 6925.300S  -270s  -35.3nm  +0.1  198.30  108.7  14.8
224000  9422.996E 6740.906S  512.7  109.0  14.3  9329.370E 6929.011S  -240s  -31.3nm  +0.1  198.35  108.7  14.9
224030  9415.910E 6758.510S  511.4  109.0  14.4  9325.847E 6932.722S  -210s  -27.4nm  +0.1  198.41  108.7  14.9
224100  9407.947E 6816.000S  510.1  108.9  14.5  9322.305E 6936.430S  -180s  -23.5nm  +0.1  198.46  108.7  14.9
224130  9359.087E 6833.379S  508.8  108.8  14.6  9318.742E 6940.138S  -150s  -19.6nm  +0.1  198.52  108.7  14.9
224200  9349.314E 6850.648S  507.5  108.8  14.7  9315.157E 6943.845S  -120s  -15.7nm  +0.1  198.57  108.7  14.9
224230  9338.603E 6907.811S  506.3  108.8  14.7  9311.552E 6947.551S  -90s  -11.8nm  -0.0  198.63  108.8  14.9
224300  9326.933E 6924.866S  505.1  108.8  14.8  9307.926E 6951.255S  -60s  -7.8nm  -0.0  198.69  108.8  14.9
224330  9314.278E 6941.816S  503.9  108.8  14.9  9304.278E 6954.958S  -30s  -3.9nm  -0.0  198.73  108.8  14.9
224400  9300.609E 6958.660S  502.7  108.8  14.9  9300.609E 6958.663S  +0s  +0.0nm  -0.0  198.71  108.8  14.9
224430  9245.896E 7015.398S  501.6  108.8  15.0  9256.939E 7002.362S  +30s  +3.9nm  -0.0  198.53  108.8  14.9
224500  9230.106E 7032.030S  500.5  108.9  15.0  9253.292E 7006.064S  +60s  +7.8nm  -0.0  198.37  108.8  14.9
224530  9213.204E 7048.556S  499.4  109.0  15.1  9249.666E 7009.769S  +90s  +11.8nm  -0.0  198.22  108.8  15.0
224600  9155.152E 7104.972S  498.4  109.1  15.1  9246.061E 7013.474S  +120s  +15.7nm  -0.1  198.06  108.9  15.0
224630  9135.910E 7121.279S  497.4  109.2  15.1  9242.476E 7017.181S  +150s  +19.6nm  -0.1  197.91  108.9  15.0
224700  9115.435E 7137.472S  496.4  109.3  15.2  9238.913E 7020.889S  +180s  +23.5nm  -0.1  197.75  108.9  15.0
224730  9053.680E 7153.551S  495.4  109.5  15.2  9235.371E 7024.598S  +210s  +27.4nm  -0.1  197.60  108.9  15.0
224800  9030.598E 7209.511S  494.5  109.6  15.2  9231.848E 7028.309S  +240s  +31.3nm  -0.1  197.45  108.9  15.0
224830  9006.134E 7225.348S  493.6  109.8  15.2  9228.346E 7032.020S  +270s  +35.3nm  -0.1  197.30  108.9  15.0
224900  8940.235E 7241.057S  492.7  110.0  15.2  9224.864E 7035.732S  +300s  +39.2nm  -0.1  197.16  108.9  15.0
=====
    
```

Notes: Bold line is instant of mid-eclipse. See Appendix for definition of column headers.

Deviations and variations from the baseline plan were unquestionably expected. Numerous “solution sets” for alternate scenarios had considered, and evaluated by QANTAS flight operations personnel. But, the sheer nature of the number of dynamical variables was far from exhaustive and the need for in-flight recomputation was fully anticipated.

The baseline flight plan, alternate plans with significant deviations due to possible variations in winds aloft, other non-nominal exceedences, and real-time replanning and interface procedures using EFLIGHT (discussed below) were tested at QANTAS Jet Base in Sydney, Australia using the QANTAS/Boeing 747 high fidelity simulator normally used for pilot training. As a result of those test and simulation exercises EFLIGHT (see below) was recommended by the assigned pilot in command (and subsequently approved) for use on the flight deck to provide the time-critical navigational inputs required for the QF 2901 umbral shadow intercept.

### **Real-Time Responsivity: A Necessary Pathway to Success**

The experience, skills, and capabilities of the QANTAS personnel were unquestionable in aircraft operations and “conventional” navigation. The demands of the computation and evaluation of real-time astrodynamical differential and simultaneous optimization calculations essential to the success of the flight mission objectives, however, was outside of the scope of that experience base and augmentation to their essential expertise was required. Such augmentation could only be provided by real-time collaborative interaction and consultation on the flight deck with an expert in astrodynamical navigation and the planning and executing airborne eclipse intercept flights.

The dynamical variables, which ultimately define both the characteristics of the umbral intercept and the resulting executable eclipse flight plan, are not independent. The analytic forms they assume are correlated and the trade spaces to be evaluated are complex. The actual execution of a detailed multi-variate and dynamic flight plan must be amenable to in situ modification as required by meteorological and other conditions encountered in flight. Such flexibility is required to assure the success of an optimal intercept such that the requisite differentially corrected flight vectors throughout the totality run are properly determined and achieved. Ultimately, this translates into computing and defining highly constrained sets of time-correlated target “way points” which must be determined iteratively in real-time, and with convergence toward mid-eclipse, based upon actual changing conditions in flight.

The differential numerical processes and algorithmic procedures required to yield an optimized solution to satisfy the simultaneous criteria required for a successful eclipse intercept expressed as an executable flight plan have been codified in a highly specialized software package called EFLIGHT. EFLIGHT was designed specifically for this purpose. EFLIGHT has a long and significant pedigree and has been put to the test in flight, with great success, during previous total solar eclipse intercept missions. EFLIGHT has matured into a fully integrated interactive eclipse flight planning and navigation S/W package, and is fully described in the *Appendix* to this report to which the reader is referred for further understanding and detail.

Inherent in EFLIGHT’s operation and utilization, particularly under the stress and pressure of real-time demands in flight, is an intimate familiarity with its underpinnings. Such familiarity is essential in order to effectively and rapidly supply parametric inputs most germane to and best representing evolving conditions in flight and to evaluate EFLIGHT’s computational astrodynamical results. This is a task fully demanding of uninterrupted attention and is inappropriate for a member of the flight crew whose responsibilities (and necessary expertise) lay elsewhere and whose attention cannot be so diverted and consumed. It was strongly suggested to QANTAS operations management that the real-time analyses and transformation of EFLIGHT results into flight plan updates, directly and subsequently implemented by the QANTAS B747-400 flight crew, would be carried out with the greatest degree of effectiveness and highest efficiency by the program’s creator, and author of this report. Unimpeded multi-directional communication and information flow in the in situ operational environment of the B747-400 flight deck between the pilot in command, the first (flight) officer, and myself serving as an astrodynamics navigator, was deemed and recognized as essential to the successful realization of the primary goals of this historic, and unique flight opportunity.

## **EFLIGHT Pedigree**

The planning and execution of the QF 2901 eclipse flight (and also the contemporaneous planning of the Lan Chile 8001 eclipse flight) was accomplished with the use of EFLIGHT. EFLIGHT was created specifically to address the optimization problem of intercepting the moon's shadow from a moving aircraft. EFLIGHT's core algorithms were developed in the planning effort for a historically unique, and highly technically challenging and navigationally critical, intercept of a near-instantaneous total/annular eclipse using a Citation II over the North Atlantic on 3 October 1986<sup>5</sup>. EFLIGHT was augmented and provided with a graphical user interface for the 1992 south Atlantic eclipse flight<sup>6</sup> to provide greater flexibility for real-time use on the DC-10 flight deck. The S/W was modified in preparation for a 2001 Concorde eclipse flight<sup>7,8</sup> for consideration of an intercept in the supersonic regime, where the instantaneous speed of the aircraft was greater than that of the lunar umbra, and capable of yielding an hour long totality. EFLIGHT was again modified in preparation for TSE2003, specifically for the "over the pole" approach geometry of the lunar shadow which occurred for the 23 Nov 2003 eclipse, and tailored for real-time use given the manual input requirements of the Boeing 747-400 FMS. More detailed information on the history of EFLIGHT may be found the *Appendix* to this report.

## **Summary**

The success of QF 2901, realized as it was plunged into darkness and concentrically enveloped by the lunar shadow at 22:44 UT, was not assured by reliance on pre-planned flight trajectories though such "baseline" plans were necessary to the planning effort. Detailed pre-planning, while essential, was predicated upon the inherently unrealistic simplification of presumptively static, but in actuality highly dynamic, input variables. While the likely states of those variables could be probabilistically bounded, their values could not be a priori ascertained. Such foreknowledge with the requisite degree of specificity was, in fact, unobtainable and unpredictable.

The real-time evolutionary development of an optimal flight plan, built in situ on the aircraft flight deck based upon changing in-flight conditions, was absolutely essential. The path toward successfully accomplishing the QF 2901 eclipse flight objectives, while computationally extensive and algorithmically complex, were enabled by EFLIGHT. This highly specialized software application facilitating an optimal and executable solution to this practical problem in astrodynamical navigation problem was developed and tested over many years. It has emerged in its current incarnation to provide the requisite computational resources, codified and integrated into its infrastructure, to solve the highly complex and multiply constrained optimization problem at hand. Yet, EFLIGHT it is merely a tool that can only be used effectively by skilled practitioners of the highly specialized art (and science) of astrodynamical navigation.

The 23 November 2003 total solar eclipse, the first ever observed from the Antarctic, was a milestone not only for eclipse chasers, but also of human endeavor. The Boeing 747-400 ER, a

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<sup>5</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLIPSE\\_86/ECLIPSE\\_86.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_86/ECLIPSE_86.html)

<sup>6</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLIPSE\\_92/ECLIPSE92\\_REPORT.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_92/ECLIPSE92_REPORT.html)

<sup>7</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLIPSE\\_01/CONCORDE\\_ECLIPSE.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_01/CONCORDE_ECLIPSE.html)

<sup>8</sup> [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/ECLIPSE\\_01/ECLIPSE\\_2001\\_REPORT.html#MEMORIUM](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_01/ECLIPSE_2001_REPORT.html#MEMORIUM)

truly remarkable aircraft, flying above 80% of the Earth's atmosphere in the pristine, nearly particulate-free, and uncompromisingly clear skies over inland Antarctica provided an unparalleled venue for a dedicated band of more than 120 eclipse chasers and "accidental tourists" (some anticipating only a scenic flight over "the ice") to view, photograph, and hold in the mind's eye the indescribable majesty of TSE2003. With QF 2901, and TSE2003, EFLIGHT has proven itself as an invaluable tool by enabling an optimized umbral intercept over, perhaps, the most extreme and logistically-challenging region of the Earth. EFLIGHT now awaits a future opportunity to serve umbraphiles again at the next total solar eclipse over otherwise climatologically hostile or virtually inaccessible terrain.

Got an airplane? We are ready...

### **Acknowledgements**

The degree of maturity which had been reached in the technical planning and execution of the QF 2901 eclipse flight could not have been achieved without the most welcome and necessary assistance and collaborative efforts of the pilot in command, QANTAS Senior Check Captain John Dennis. The author is also most grateful for the diligence and professional commitment of the other members of the QF 2901 flight crew, Capt. B. Meade and F/O's P. Ward and C. Alderton. Insights and assistance provided by other members of the QANTAS family: Captains P. Elston, J. Black, P. Hunter, I. Getley, and I. Barnet were most appreciated and proved extremely helpful in both the planning and implementation of the QF 2901 eclipse intercept and the separately reported flight deck imaging program. The most cooperative assistance of other elements of QANTAS airlines, particularly by security, flight operations and general management personnel, are also gratefully recognized and acknowledged. The author also is extremely thankful for the labors of Croydon Travel, and in particular Phil Asker and Gayle Brown, without whom the QF 2901 eclipse flight would not have been possible. Figures 1 and 4 in this document have been adapted from NASA TP 2002-211618 by Espenak & Anderson.

### **Dedication**

This report, and indeed all of my work on the planning and execution of QF 2901, is dedicated to the memory of crew and passengers of the ill-fated Air France Concorde flight 4590. As our hopes for an hour long totality tragically vanished on 25 July 2000 along with the lives of all 113 persons on board, let us reflect that there are indeed things of far greater import which transcend our passion for eclipse chasing, and take a moment of remembrance for those who will never again have a chance to see the glory of Totality.

### **Postscript**

The airborne observations of the 23 November 2003 Antarctic total solar eclipse, enabled by QF 2901, were reported at the second (2004) international solar eclipse conference in Milton Keynes, England. The complete digital content of that presentation is provided as an electronic supplement to this report to be made available with the conference proceedings.

# APPENDIX



## *EFLIGHT 2003 X - Eclipse Flight Planning & Navigation S/W*



Updated: 04 Apr 2003 for [MacOS X](#)

(embedded links resolved in) [http://nicmosis.as.arizona.edu:8000/ECLIPSE\\_WEB/EFLIGHT/EFLIGHT.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/EFLIGHT/EFLIGHT.html)

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### **Prelude on the Art of Eclipse Chasing**

The "art" of eclipse chasing sometimes poses difficult and complex logistical, technical (and financial) problems. Unless you are one of the very fortunate < 1% of the world's population which, by pure luck, has a Total Solar Eclipse fall in your backyard sometime during your life, then getting to the path of totality often becomes a challenge, if not an obsession. I suppose I am one of the obsessed. At the risk of redundancy, but for necessary background, elsewhere I had previously written: *"Glenn Schneider is an UMBRAPHILE. Literally a "shadow lover", but properly applied, one who is addicted to the glory and majesty of total solar eclipses. Those who have basked in the moon's shadow will know what I mean without further explanation. Those who have not may have difficulty in understanding that umbraphillia is not only an addiction, but an affliction, and a way of life. The real raison d' etre for many of us. The more common and prolific term "solar eclipse chaser" is nearly synonymous, but somehow does not convey the depth of commitment to this lifelong endeavor. Once every 16 months, or so, (on average) umbraphiles will drop whatever they are doing and trek by plane, ship, train, foot, and camel-back to gather along a narrow strip in some remote God- forsaken corner of the globe defined by the inexorable laws of celestial mechanics. Newtonian physics heeds no national boundaries, and neither do umbraphiles. Wherever the solar photosphere will be extinguished, enshrouded by the ashen lunar disk, umbraphiles will revel in the quasi-twilight darkness."*

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## Why EFLIGHT?

Occasionally, the path of totality (i.e., the region on or above Earth's surface where a total eclipse may be viewed) is so elusive that an airborne observation of such an eclipse is by far the preferable, if not the only, viable alternative. Such was the case on [03 October 1986](#), and again on [30 June 1992](#). And, the very fortuitous geometrical circumstances associated with the [21 June 2001](#) total solar eclipse could have given rise to an [hour long totality](#) if fate had not [tragically intervened](#). Hitting a moving target (the moon's shadow) from a moving platform (a high speed aircraft) may not intrinsically seem like too complex a problem, though it certainly is non-trivial. To do this successfully, while optimizing a flight intercept to strike a desired balance between duration, observability (i.e., line-of-sight requirements due to aircraft windows), other dynamical and programmatic constraints and restrictions, and cost, must be approached with both care and rigor. The circumstances of the 03 October 1986 eclipse were so constrained (see the above linked page), that virtually no deviation from a very laboriously pre-constructed flight intercept could be tolerated. By 1992, however, the availability and capabilities of portable (aka "laptop") computers had so rapidly evolved, that eclipse flight *re*-planning in reaction to situ conditions became possible. As a result, [EFLIGHT 92](#) - an integrated eclipse flight planning and navigation S/W package - was engineered for the then fledgling Macintosh PowerBook 100 series laptop computers, and then successfully used to navigate a DC-10 through the path of the 30 June 1992 eclipse. (As it begs the question... No. I did not have to "turn off and put away" my Powerbook 170 during take-off for that flight, though I suppose it helped that I was occupying the navigator's seat in the cockpit).

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## The 23 November 2003 total Solar Eclipse

With the advent of the [23 November 2003](#) total solar eclipse, a prime candidate for an airborne eclipse observation, I have dusted off **EFLIGHT** after the tragic accident on 25 July 2000 canceling its planned use, in its [2001 incarnation](#), on the Concorde for the 21 June 2001 eclipse. Given the large degree of "inaccessibility" to nearly all of the 23 November 2003 eclipse path, such a flight was crying to be flown. This eclipse has met with considerable interest, likely due to the added enticement of its remoteness, and planning for such a flight has actually been underway for some time. Two Antarctic over-flights have evolved which have (and continue) to use **EFLIGHT** to develop their flight concepts, requirements, specifications, and plans:

- 1) [Croydon Travel](#)/QANTAS: Using a Boeing 747-400 from Melbourne, Australia.
- 2) [TravelQuest](#) (Sky & Telescope)/LanChile: Using an Airbus A340 from Punta Arenas, Chile.

The baseline Eclipse Flight Centerline Intercepts and Totality Runs for these flights are illustrated and summarized [HERE](#).

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## **EFLIGHT 2003 X (and UMBRAPHILE) and their predecessors**

On the "technical" side, many have queried me about **EFLIGHT** (which I have recently ported to run under MacOS X and is now a native Jaguar/Aqua application). So, here I provide an overview of what it is, and what it can (and will) do. But first...

**HISTORY:** The core algorithms for **EFLIGHT** have a long history. The computations of the astronomical ephemerides and eclipse circumstances performed by **EFLIGHT** were originally implemented in 1974 in APL on a Xerox Sigma 9 computer under the UTS (and later CP-V) operating system. These core algorithms have been used for planning ground-based and/or airborne observations every total solar eclipse since. Early in its history, the software was migrated to other mainframe computers and operating systems (including the IBM/360, Ahmdahl/470VM and Harris 500). By 1979 the software had also been implemented in a combination of BASIC and 6502 assembly code and "packaged" for use on an APPLE II computer. The eclipse predication and planning software was integrated into a end user oriented system called **CENTERLINE** and migrated to the microAPL desktop environment (in the Waterloo language system) on the Commodore SuperPet SP9000 in 1982. By 1985 **CENTERLINE** had again moved, to a VAX/VMS environment, implemented in APL11 under RSX. **CENTERLINE** was then augmented with some rather special purpose algorithms to aid in the planning of the airborne eclipse observation of the October, 1986 eclipse in the north Atlantic near Iceland. By 1988, **CENTERLINE** was transformed to the paradigm of the graphical user interface under (Mac) OS 6, implemented first on a Macintosh SE in APL/68000. Contemporaneously, following the 1988 eclipse, a real-time automated camera controller called **ROSE** (the Reprogrammable Observer for Solar Eclipses) was developed for the Rockwell AIM-65 (6502) environment as a machine/assembly language program, which relied on computationally derived inputs from **CENTERLINE**. **ROSE**, supported computationally by **CENTERLINE**, was used successfully during the exceptionally long total solar eclipse of 1991. With the advent of the Macintosh Powerbook, in 1992, **ROSE** and **CENTERLINE** were symbiotically merged into a single APL/68000 application running under (Mac) OS 7, the first prototype of **UMBRAPHILE**. But **UMBRAPHILE** would not be field-tested (quite successfully) until the total solar eclipse of 1995 in Ghanoli, India.

Contemporaneous with the early development of **UMBRAPHILE**, a separate (Mac) OS APL/68000 application, **EFLIGHT** predicated on the same core algorithms, was born to plan and assist in the real-time navigation of a VASP airlines DC-10 to observe the total solar eclipse of June 1992 over the South Atlantic. **UMBRAPHILE** evolved in the late 1990's to a user friendly MacOS application and was subsequently used for the 1997 (Siberian) 1999 (Black Sea), total solar eclipses. **EFLIGHT** was upgraded and modified for MacOS 9 nativity as an APL Level II for Power Macintosh application in 2000, in preparation for a planned nearly one-hour airborne observation of the June 2001 eclipse with an Air France Concorde. The tragic event of 25 June 2000, which lead to the subsequent grounding of the Concorde fleet, resulted in the upgraded **EFLIGHT** being put "on the shelf". Observing instead from the ground, the June 2001 eclipse in Zambia was photographed with **UMBRAPHILE**, for the first time by multiple eclipse photographers and at different locations along the path of totality (e.g., see results from

D. McGlaun). And, **UMBRAPHILE** was used again for the 4 December 2002 eclipse, with an three Macintosh Powerbooks spanning 10 years of technology (68K Series 100 by J. Friedland, to G4 by J. Moskowitz and myself) within 5 meters of each other in the middle of the Australian outback.

In preparation for the 23 November 2003 eclipse, which will be viewed by two aircraft over Antarctica, **EFLIGHT** underwent additional modifications and a port to run natively under MacOS X. The current version of **EFLIGHT** (2003 X version 2.0.0), described here, is written in APLX for Macintosh (version 1.1.5) from mcicroAPL Ltd. (UK). Though designed for MacOS X it will run in "Classic" mode under MacOS X, and a release can be prepared to run "native" under MacOS 9.

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## An Umbraphillic Derivative

**EFLIGHT** is an eclipse circumstance calculator - but one specifically designed to address the problem of intercepting the moon's shadow from a moving aircraft. The core algorithms for the computation of at-altitude local and centerline eclipse circumstances are the same as those employed in [UMBRAPHILE](#). What? You aren't familiar with [UMBRAPHILE](#)? Then please read about that freeware application to fill in the necessary background details, which I won't repeat here. **EFLIGHT** actually co-evolved with **UMBRAPHILE**, so much so that it uses the same input data file structure, and both shares many common "user" interface elements. However, **UMBRAPHILE** was designed as a more generic application for unrestricted distribution (and hence, "user proofed"). **EFLIGHT** requires a bit more hand-holding and intimate familiarization with embedded concepts, so you won't find a down-loadable application here. For those seriously interested please [contact me](#), but I suggest a likely necessary sentient accessory to have with it on your airplane if you plan to use it there. At least, some think I am sentient. Indeed, I will be using **EFLIGHT** in situ on 23 November 2003 QANTAS/Croydon (Boeing 747-400) eclipse flight over the Antarctic to help guide the aircraft to a seamless and optimized high precision time-critical intercept with the conic axis of the lunar umbral shadow.

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## Starting up and Running EFLIGHT 2003 X

To start up **EFLIGHT** just double-click the **EFLIGHT** ICON: . **EFLIGHT** will then :

1) Bring up an introductory message in a dismissible dialog (Figure 1), indicating the software version release number. Ephemeris data is pre-loaded with the application for a specific total solar eclipse, though ephemeris data may be imported (as described later) for other eclipses. The eclipse for which eclipse ephemeris data is provided by default as part of the application is also noted at startup in the introductory dialog.

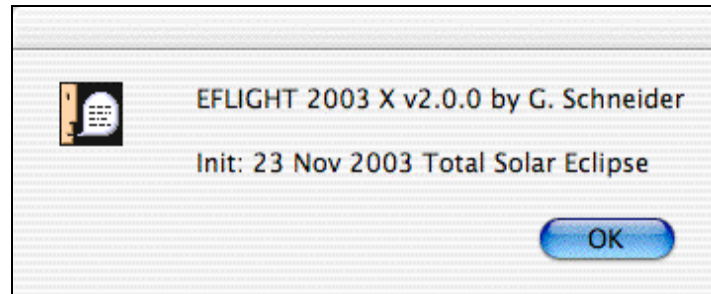


Figure 1. EFLIGHT Introductory Dialog.

2) Pop up an "Info Window" (Figure 2) providing contact information and where to obtain the latest **EFLIGHT** documentation. By design, this window cannot be closed or minimized while running EFLIGHT, but it can be moved "out of the way", or behind other windows.

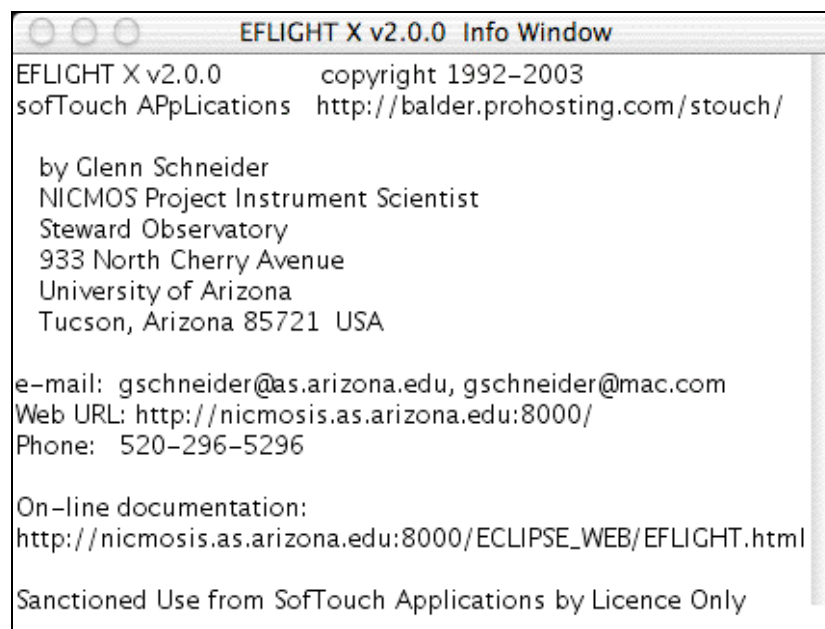


Figure 2. EFLIGHT Info Window

3) Create a text "Output Window" (Figure 3), which **EFLIGHT** will use for displaying textual information and data generated by **EFLIGHT**. The text output window will initially display basic information germane to the operation of the current **EFLIGHT** release:

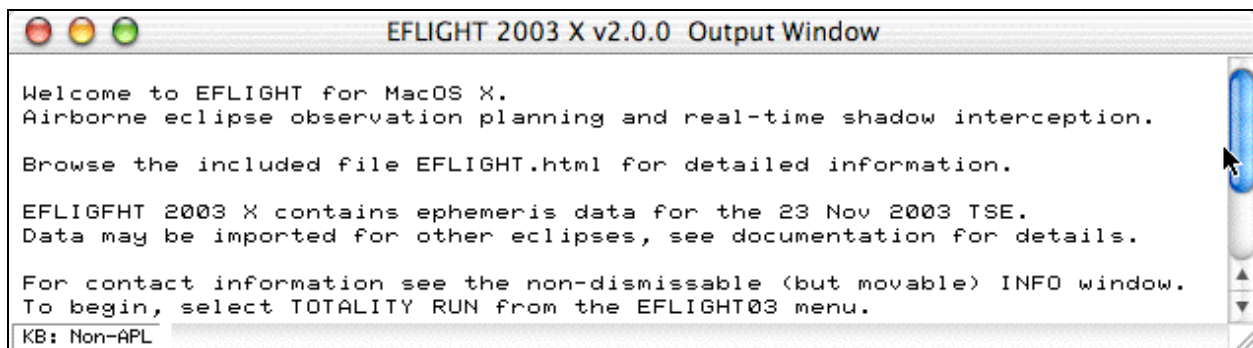


Figure 3. EFLIGHT Output Window

The introductory notes (which may be release dependent) will be cleared when **EFLIGHT** subsequently produces a text display in the output window, but these messages may be refreshed by selecting **HELP** from the **EFLIGHT** menu.

The text output window is scrollable, as the tabular output produced by **EFLIGHT** can be quite lengthy (depending upon the input parameters supplied by the user). The output window, initially, may be smaller than the width of the **TABULATE TOTALITY RUN** table (describe later), but it may be maximized to the full screen size or resized, as usual, by clicking and dragging the lower right edge of the window.

The title bar of the text output window will change name to reflect the current window content, and to display computational status messages for computationally intensive operations in progress.

## **EFLIGHT 2003 X Menus**

The following menus and associated menu items will appear to the right of the Apple menu after starting up **EFLIGHT**:

<b><u>EFLIGHT{release #}</u></b>	(MacOS system servicesmenu)
Note: The About... and Preferences... menu items are not used by EFLIGHT	
<b><u>FILE</u></b>	(Active only for the text output window)
<b>Save Window Content...</b>	(Export entire window context to ASCII file)
<b>Page Setup...</b>	[to specify printing parameters as usual]
<b>Print...</b>	[to print the content of the output window]
<b><u>EDIT</u></b>	(Active only for the text output window)
Provides usual Copy, Paste, Find, etc.	
<b><u>OPTIONS</u></b>	(Active only for the text output window)
<b>Font Size</b>	[Select font size for text output window]
<b><u>EFLIGHT##</u></b> {## indicates year of TSE ephemeris data included}	
<b>HELP</b>	[Refreshes/provides EFLIGHT start-up advisory messages]
<b>COMPUTE TOTALITY RUN</b>	[Input flight parameters, compute circumstances]
<b>TABULATE TOTALITY RUN</b>	[Tabular (text) display of flight profile & circumstances]
<b>SELECT WAYPOINTS</b>	[Waypoints for FMS entry, track info & local circumstances]
<b>DISPLAY TOTALITY RUN</b>	[Real-time synchronized or time compressed graphical simulation]
<b>COMPUTE COURSE</b>	[Generate pre/post totality run flight profile]
<b>INTERRUPT</b>	[Terminate Totality Run in progress]
<b>QUIT</b>	[Exit from EFLIGHT]

---

## **The EFLIGHT Menu**

The items under the **EFLIGHT** menu perform the computational and display tasks for planning, optimizing, and executing an eclipse flight totality run. Those items, are described in detail below. The other menus provide standard system services, and so, are not discussed here.

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### **1) COMPUTE TOTALITY RUN**

An **EFLIGHT** "totality run" is fundamentally parametrized by specifying a Universal Time (U.T.) at which the aircraft is to be co-axially located in the umbral shadow (i.e., the instant of mid-eclipse). This is combined with the flight altitude, aircraft speed, and several other parameters to develop a set of time-ordered and time-dependent way points (latitude and longitude tuples) which can, for example, be loaded into an aircraft's navigation/autopilot and/or CDU/FMS systems. Importantly, **EFLIGHT** can re-compute a "corrected" flight plan *in situ* given changing wind conditions en route to the eclipse intercept. The set of parameters and selectable options which control the computation, and later tabulation and display of the totality run, is entered through the **EFLIGHT** "flight definition dialog" (Figure 4) which is presented when the **COMPUTE TOTALITY RUN** item is selected from the **EFLIGHT** menu.

#### **Concepts:**

1) For planning purposes, **EFLIGHT** can be run in a U.T. synchronous, or asynchronous time-compressed manner. I.e., a flight plan can be developed and "simulated" without regard to the actual U.T. (system) clock time or rate of time-flow. The flight plan can be tested at a sped up (or slowed down) pace, and enabled for real-time use on-board the aircraft (via the **RT SIMULATION** check box). In that case, **EFLIGHT** will synchronize to the computer's internal clock (with a fixed time offset, if desired), and provide position/navigation information in real-time.

2) **EFLIGHT** develops a set of time-correlated way points, in 1, 5, 10, or 30 second intervals, to be targeted within a specified range of times before and after the instant of mid-eclipse. At each instant of time along the flight path, **EFLIGHT** reports on the circumstances of the eclipse, the aircraft position, its flight vector, and related information.

3) Currently **EFLIGHT** builds the "totality run" in one of three ways by specifying/selecting:

a) A user-input fixed aircraft heading to be flown fly through the point of mid-eclipse.

b) A fixed aircraft heading to put the sun perpendicular to the aircraft heading at the instant of mid-eclipse (to put the Sun "straight out the cabin windows" at mid-eclipse) as determined by **EFLIGHT** based upon the circumstances of the eclipse.

c) A flight path parallel to the direction of the velocity vector of the moon's umbral shadow.

U. T. Mid-Eclipse =	hhmmss		
	224400		
Intercept CL	0	<input type="radio"/> km <input type="radio"/> mi toward Sun <input checked="" type="radio"/> nm	
Time Window =	5	3	Min.
True Air Speed =	470	/hr	
<input type="radio"/> Fly Aircraft Heading = 200 Deg. <input checked="" type="radio"/> Fly Perpendicular to Sun <input type="radio"/> Fly Parallel to Shadow			
Altitude in feet AMSL =	35000		
WIND from	0	Deg., Speed =	0
Autoscale +	2	Deg	
Display Time Resolution:	<input type="radio"/> 1s <input checked="" type="radio"/> 5s <input type="radio"/> 10s <input type="radio"/> 30s	Output Format:	<input type="radio"/> DDD.xxxxx <input type="radio"/> DDDMMSS.x <input checked="" type="radio"/> DDDMM.xxx
Display Frame Delay =	.1	s	
<input type="checkbox"/> Export Waypoint Table <input type="checkbox"/> RT SIMULATION			
Graphics Scale =	100	°/°	
			CANCEL
			OK

Figure 4. A centerline-intercept flight profile is created in compliance with a set parameters specified through the EFLIGHT flight definition dialog.

### Inputs:

**U.T. Mid-Eclipse:** Specifies the Universal Time (with one second granularity) at which the aircraft is to be concentrically located in the moon's shadow.

**Time Window:** Specifies how many minutes before and after mid-eclipse the aircraft is to fly on the to-be-computed "totality run".

**INTERCEPT CL:** For some eclipses a non-central intercept through the umbra might be desirable, and such an offset can be specified through the INTERCEPT CL option. *This option has been disabled for the 23 November 2003 total solar eclipse.*

**(True) AIRcraft Speed:** This is the true AIR speed (not the GROUND speed, which EFLIGHT will compute based upon windage and course). The true AIRcraft speed may be entered in kilometers/hour, (statute) miles/hour or nautical miles/hour.

**(True) Aircraft Heading:** True Heading (not magnetic\*) may be entered (in degrees) - but is used only if "Use Entered Heading" is selected.

**Choice of Flight Vectors:** As defined in (3) a, b, and c, above. Flying perpendicular to the Sun will present an optimized view of the eclipse out the aircraft cabin windows, and will typically be necessary anywhere along the path except relatively near the points of local noon or midnight. Flying parallel to the shadow will maximize the duration of totality - but would likely not be practical near the beginning or end of the path (as the aircraft would then fly "across the shadow" and the sun would not be visible through the cabin windows, or would be a real neck-craner).

**Altitude in feet:** Fixed altitude of the aircraft above MSL.

**Wind Speed/Direction:** Specify direction wind is FROM in degrees, and the Wind Speed. Note: Wind Speed is taken to be in same units selected for AIRcraft speed.

**Autoscale:** The EFLIGHT graphical output (discussed below) is scaled to exactly fit the most constrained end-points along the path of totality at the boundaries of the graphics window. In setting up the output display an optional "buffer" to move the endpoints from the closer end of the window (in degrees of latitude, or longitude) may be entered.

**Time Resolution:** Specifies the temporal granularity (in seconds) for the computation of eclipse circumstance and navigation data. (see Tabulate and presented graphically, but also affects the [precision of the times of contacts](#) as seen from the moving aircraft. For computation speed, use coarse time intervals, for initial flight planning and evaluation. For high precision contact times and circumstances use 1s granularity.

**Export Way point Table:** Check this box to automatically also write the information presented in the output window to an ASCII file.

**RT SIMULATION:** Check this box display a Real Time (i.e., system clock time synchronous) graphical simulation when the **DISPLAY TOTALITY RUN** item is subsequently selected from the EFLIGHT03 menu. .

**OUTPUT FORMAT:** Three output formats are available for aircraft and umbral shadow coordinates (latitude and longitude) as displayed in the text window (but not in the graphics window) and/or exporting the content of the text output window to an ASCII file. Select from: decimal degrees; degrees, minutes, seconds (and fractional seconds to the nearest 0.1"); or degrees and minutes (and fractional minutes to the nearest 0.001').

\* **EFLIGHT** uses true, not magnetic headings. For most locations on the Earth the difference can be computed by a magnetic field model such as the [NGDC/NOAA](#) model. Near the magnetic poles both the magnetic declination and gradient of the declination can be very large. The South magnetic pole is at 66°S latitude, 139°E longitude. For the intercept location given in the Figure 1 example the magnetic declination is -64° 57', and would be -93° 44' for an intercept near maximum eclipse at 22h 49m U.T.

After entering the desired parametric values and selectable options in the Flight Definition Dialog, clicking **[OK]** will prepare **EFLIGHT** to pre-compute the local circumstances and navigational information along flight path of the totality run.

---

### **Note on Coordinate Systems and Geodetic Reference:**

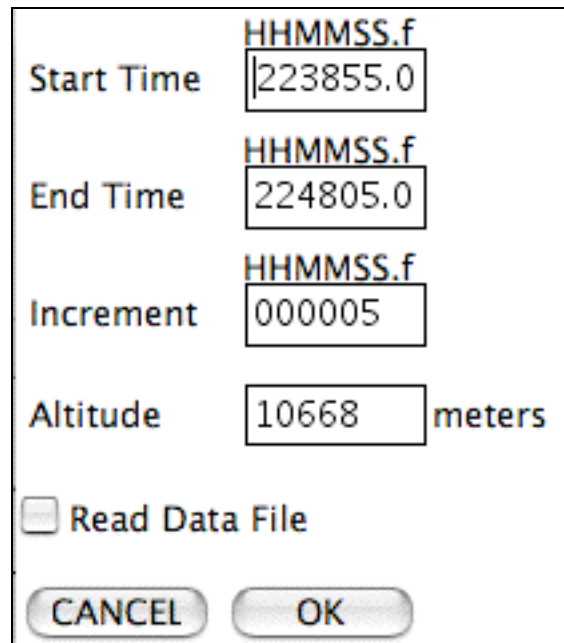
Many different geodetic reference systems are in use around the world. Thus, for high precision position determinations it is important to know which system is being used, and how to transform topocentric coordinates from one to another. **EFLIGHT** adopts the aspherical definition of the geoid suggested by the International Astronomical Union (see [UMBRAFILE](#) documentation) and adds a fixed constant to the topocentrically dependent radius vector when determining the (X,Y, Z) instantaneous positions of the aircraft. The International Terrestrial Reference System is defined by the [Earth Orientation Rotation Service](#). There are many resources available for transforming between commonly used, but different, map reference data (such as WGS 84, NAD 27, etc.). For more information let me refer a [comprehensive introductory summary](#) prepared by Pete Dana at the University of Texas Dept. of Geography.

---

### **When you click [OK] in the Flight Definition Dialog:**

Before the computation proceeds, **EFLIGHT** will bring up a confirmatory dialog (figure 5) indicating the UT start, end, and increment times and flight altitude (converted to meters) for the totality run. The actual computation spans an interval which is one time step longer, at the start and end of the run, then the time window specification for which the totality run is developed. This dialog is presented to allow you to **[CANCEL]** the computation before it begins in the event an input error is made in the flight definition dialog. Click **[OK]** to proceed. Unless you are intimately familiar with **EFLIGHT**, **DO NOT** alter the information in the confirmatory dialog. (You may adjust the start, and end times and increment - but this **MUST** be done with care. The **ONLY** allowable increments are 1, 5, 10, and 30s, and the start and end times **MUST** differ by an integral number of increments.) It is suggested that if you wish to make any adjustments at this point you **[CANCEL]** the confirmatory dialog, and re-enter any changes in the Flight Definition dialog, otherwise click **[OK]**.





Start Time	HHMMSS.f
End Time	HHMMSS.f
Increment	HHMMSS.f
Altitude	meters

Read Data File

CANCEL OK

Figure 5 - Totality Run Confirmation Dialog.

Note: **EFLIGHT 2003X v2.0.0** is "pre-loaded" with ephemeris data specifically for the 23 November 2003 eclipse. The data file from which these data were pre-imported in **EFLIGHT 2003X v2.0.0** is included with the **EFLIGHT S/W**. Ephemeris data for other solar eclipses may be imported by checking Read Data File in the flight definition confirmation dialog. Ephemeris data is imported from ASCII files of specific format and content and are of the same form used for the **UMBRAPHILE** camera controller software. Please contact Glenn Schneider for additional information on data files other eclipses. If Read Data File is checked a file requester dialog will be presented, and after importation of ephemeris data, the data values read from the file will be displayed in the main text output window.

**EFLIGHT** then pre-computes all of the eclipse circumstances and aircraft related information before anything is display or tabulated. Generation of eclipse circumstances and navigation data proceeds in temporally increasing order for the totality run and is a computationally extensive task. While these data are being computed, a status message, indicating the instantaneous U.T. of the computation in progress, will be displayed in the title bar of the main window. During the computation some diagnostic information may be presented in the main window. This information can generally be ignored and will be cleared from the display when the computation completes. A message informing of the completion of the **COMPUTE TOTALITY RUN** task will be presented when the computation has finished.

When the pre-computations are completed, if the Display Graphics box was checked in the Flight Definition dialog, a graphics output window will be built (if it hadn't been from a previous Totality Run).

---

## 2) TABULATE TOTALITY RUN

The results of the totality run computation may be tabulated in a scrollable text window (and exported to an ASCII file). The format of the tabular display is shown in Figure 6.

The screenshot shows a window titled "EFLIGHT03:TABULATE TOTALITY RUN" with the following content:

```

U.T. Intercept: 22:44:00 | TOTALITY DURATION = 2m 34.7s
Flight Altitude: 35000ft |
Heading: 198.80° |
Air Speed: 470.0nm/h | 2ND 22:42:43.1 +14.8 109.0 109.3 3RD 22:45:17.8 +15.0 108.6 289.7
Wind Speed: 0.0nm/h | LATITUDE: -069° 49' 24.2'' | LATITUDE: -070° 08' 32.0''
Wind Direction: 0.0° | LONGITUDE: +093° 09' 44.5'' | LONGITUDE: +092° 50' 52.3''
-----
HHMMSS  Umbra Long  Umbra Lat  WidKM  Uaz*  Ual*  AirCr Long  AirCr Lat  MidΔT  MidΔD  LOS  Bearing  ACaz  ACal
223200  9422.514E  6239.618S  535.1  111.9  11.8  9423.086E  6829.493S  -720s  -94.0nm  +0.3  197.52  108.5  14.7
223205  9423.657E  6243.010S  534.8  111.8  11.8  9422.551E  6830.114S  -715s  -93.3nm  +0.3  197.52  108.5  14.7
223210  9424.773E  6246.395S  534.6  111.8  11.8  9422.015E  6830.736S  -710s  -92.7nm  +0.3  197.53  108.5  14.7
223215  9425.863E  6249.772S  534.4  111.7  11.9  9421.479E  6831.357S  -705s  -92.0nm  +0.3  197.54  108.5  14.7
223220  9426.927E  6253.143S  534.2  111.7  11.9  9420.942E  6831.978S  -700s  -91.4nm  +0.3  197.55  108.5  14.7
223225  9427.964E  6256.506S  533.9  111.7  12.0  9420.405E  6832.599S  -695s  -90.7nm  +0.3  197.56  108.5  14.7

```

KB: Non-APL

Figure 6 - Totality Run Tabular Output Window

The text output is organized in two sections: a header and a table. The left side of the header region echoes back the input parameters from the Flight Definition dialog. The right section provides the duration of totality and information on second and third contact\*. The U.T. of each contact, along with the solar altitude, azimuth, and contact position angle is given, as is the location (latitude and longitude) of the aircraft at the instants of the contacts. The tabular section is presented in time order at the temporal resolution specified in the Flight Definition Dialog.

\*NOTE: For very high precision contact determinations, a 1s temporal granularity should be used in computing the totality run.

The time-ordered table section is as follows:

```

HHMMSS = Universal Time (Hours, Minutes, Seconds)
Umbra Long = Longitude of the Center of the Umbra
Umbra Lat = Latitude of the Center of the Umbra
WidKM = Width of the Umbral Shadow Projection in KM
Uaz = Altitude of the Sun (degrees) from that point
Ual = Altitude of the Sun (degrees) from that point
AirCr Long = Longitude of the Aircraft at the corresponding time
AirCr Lat = Latitude of the Aircraft at the corresponding time
MidΔT = Time in seconds until/since mid-eclipse
MidΔD = Distance to be flown (in units requested) to/from mid-eclipse
LOS = LOS deviation angle to the Sun w.r.t. aircraft windows (degrees)
Bearing = Instantaneous Bearing of the Aircraft (degrees)
ACaz = The azimuth angle of the sun from the Aircraft (degrees)
ACal = The altitude of the Sun from the Aircraft (degrees)

```

The geographical co-ordinates for the instantaneous center of the umbra and position of the aircraft are formatted as specified in the Flight Definition Dialog.

### 3) SELECT WAYPOINTS

The totality run is defined by a series of time correlated waypoints to which the aircraft trajectory must conform both in position and time. COMPUTE TOTALITY RUN determines a set of target points with a temporal granularity that is generally much denser than is required for a flight path specification. The Totality Run may be very closely approximated by extracting a subset of waypoints from the more densely computed values. For nearly all eclipses (except for those with very narrow shadows or very close to the points of sunrise/set) waypoint densities on the order of several minutes in time will not limit the accuracy achieved in the actual targeting of the aircraft.

SELECT WAYPOINTS provides a simple mechanism for extracting target position waypoints from the computed totality run. The selected waypoints and associated local eclipse circumstances are displayed in a pop-up window (the Selected WAYPOINTS window) and are used for incremental relative position updates in the EFLIGHT graphical display of the totality run. The SELECT WAYPOINTS menu item should be used after COMPUTE TOTALITY RUN completes. Select Waypoints will allow you to extract a subset of waypoints from a time-ordered list with granularities of 5, 10, 30, or 60 seconds via the Waypoint Selection Time Granularity dialog (Figure 7)

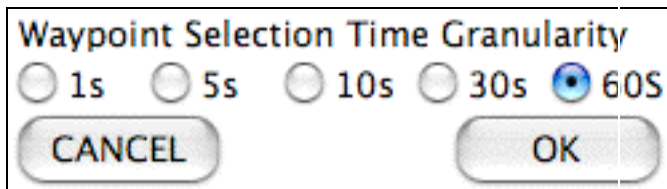


Figure 7 - Waypoint Selection Time Granularity dialog

After specifying the Selection Time Granularity, a Waypoint Extraction Dialog (Figure 8) will be presented. This dialog will contain a list of Universal Times corresponding to positions along the totality run within the computed time window at the selection granularity specified. The instant of mid-eclipse is pre-selected. Additional points (by time) along the totality run may be selected (or deselected) by checking (or unchecking) the boxes adjacent the list of Universal Times. After clicking [OK] the extracted waypoints will be displayed in a Selected WAYPOINTS window (Figure 9).

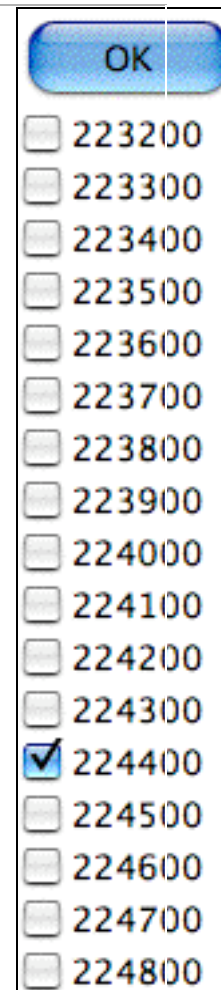


Figure 8 – Way Point Extraction Dialog

Selected WAYPOINTS															
#	HHMMSS	UMbra Long	UMbra Lat	WidKM	Uaz°	Ual°	AirCr Long	AirCr Lat	MidAT	MidAD	LOS	Bearng	ACaz	ACal	
A	223200	9422.514E	6239.618S	535.1	111.9	11.8	9423.086E	6829.493S	-720s	-94.0nm	+0.3	197.52	108.5	14.7	
B	223600	9449.442E	6515.523S	523.8	110.1	13.3	9356.833E	6859.287S	-480s	-62.7nm	+0.2	197.92	108.6	14.8	
C	224000	9422.996E	6740.906S	512.7	109.0	14.3	9329.370E	6929.011S	-240s	-31.3nm	+0.1	198.35	108.7	14.9	
D	224400	9300.609E	6958.660S	502.7	108.8	14.9	9300.609E	6958.663S	+0s	+0.0nm	-0.0	198.88	108.8	14.9	
E	224800	9030.598E	7209.511S	494.5	109.6	15.2	9231.848E	7028.309S	+240s	+31.3nm	-0.1	197.54	108.9	15.0	

Figure 9 - Selected WAYPOINTS Window

#### 4) DISPLAY TOTALITY RUN

Selecting **DISPLAY TOTALITY RUN** from the EFLIGHT menu creates a graphical output window, which provides a continually updating display showing the topocentric geographical circumstances of the total phase of the eclipse, and the computed track of the aircraft throughout the duration of the totality run.

#### TIME SYNCHRONIZATION

The totality run graphics display will update in one of three ways.

1. If **RT SIMULATION** was *NOT* selected in the **COMPUTE TOTALITY RUN** Flight Definition dialog, then the graphical output will update asynchronously with respect to the computer's clock. In that case, each successive graphic frame will be displayed with an inter-frame cadence specified by Flight Definition dialog's **Display Frame Delay** without regard to the system clock time.

If **RT SIMULATION** was selected, then a Clock Synchronization Dialog (Figure 10) will be presented before the totality run graphic output begins.

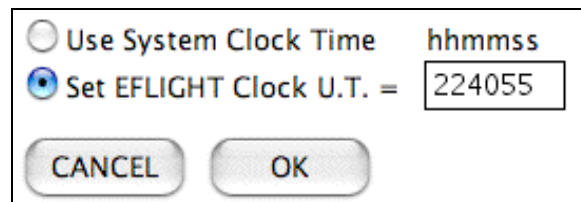


Figure 10 - EFLIGHT Clock Synchronization Dialog

2. If **Use System Clock Time** is selected the Totality Run display will commence when the System Clock reaches the Universal Time of the first point computed for the totality run. After clicking [**OK**], the subsequent graphic output of the totality run will then be synchronized to the computer's system clock time.

*In flight, it is imperative that the computer's internal clock has been accurately set and synchronized to a Coordinated Universal Time (e.g., through a network time server or GPS time reference).*

3. You may set an "EFLIGHT U.T. Clock", independent of the computer's system clock but running at a real-time cadence, to which the graphical output can be synchronized by selecting **Set EFLIGHT Clock U.T.** The "EFLIGHT Clock" will be set to the U.T. as specified (in HHMMSS format) in the Clock Synchronization Dialog. This time will automatically be pre-set to one graphics frame delay period (as specified through the Flight Definition Dialog) before the U.T. of the first point computed for the totality run, but may be over-ridden to any legal value by user input. After clicking [**OK**], the subsequent graphic output of the totality run will then be synchronized to the "EFLIGHT Clock". This is particularly useful for simulating a real-time

lapse-rate totality run, without the necessity of adjusting the computer's system clock to achieve synchronization with a "simulated" Universal Time.

### DISPLAY GRAPHIC OUTPUT FORMAT

The **EFLIGHT** graphical output window is divided into a Map region (left) and a Text region (right). Five clocks in the title bar provide absolute and relative time references. A sample "snapshot", frozen from the graphical output window, is shown in Figure 11 one instant of time.

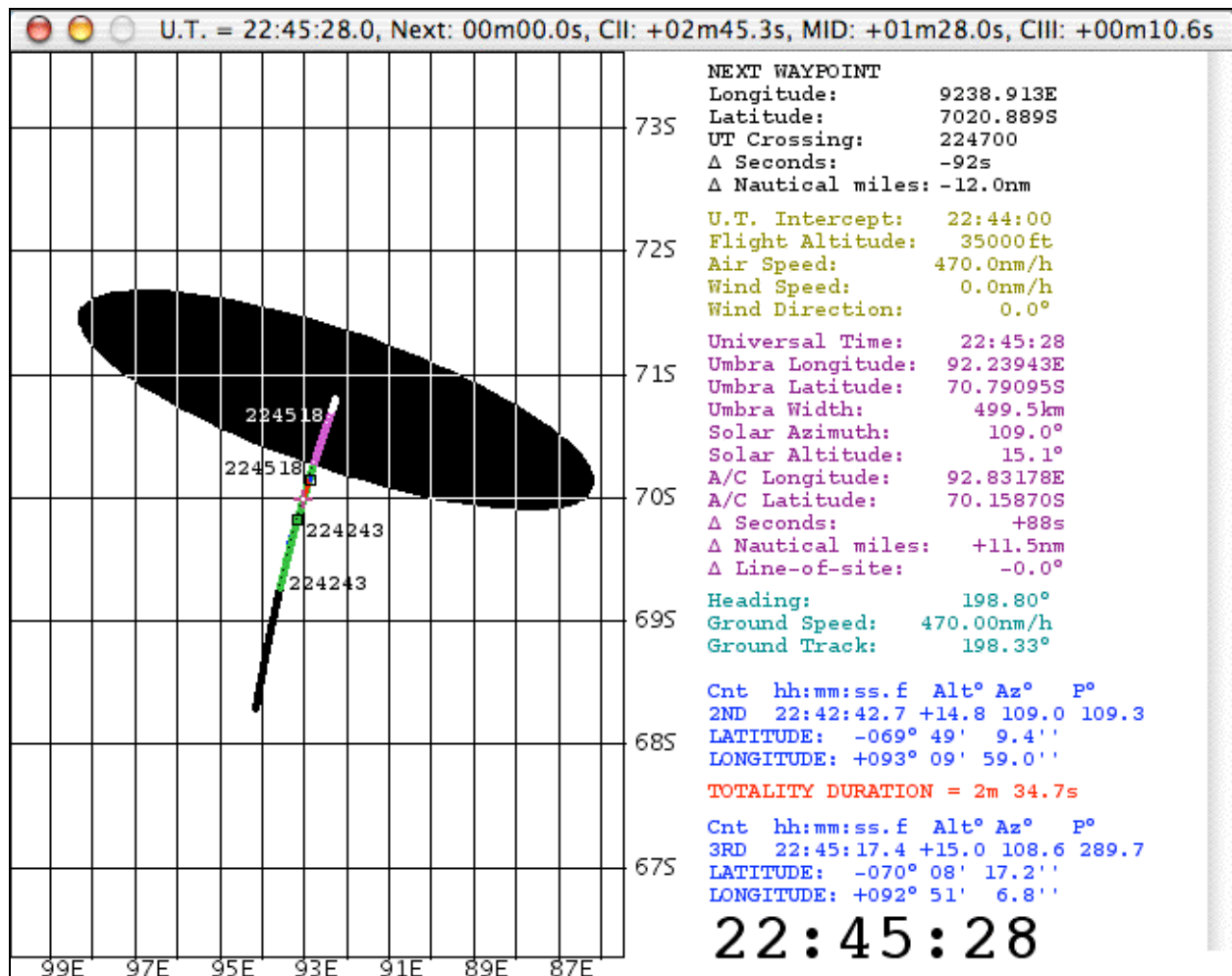


Figure 11. EFLIGHT totality run graphical output window

This particular example, corresponds a Universal Time of 22:45:27 UT (as indicated both by the large UT clock at the bottom right of the text region, and at the left of the graphics window title bar. In the title bar are four other incrementing clocks which indicate:

- (1) Next how long until the next graphics display update
- (2) CII how long until (or since) Contact II
- (3) MID how long until (or since) mid-eclipse
- (4) CIII how long until (or since) Contact III

**Map Region (Left):**

The intersection of the shadow center with the geoidal surface (see [note on geodetic reference](#)) at the altitude of the aircraft (i.e., the path of centerline at flight-altitude) is shown along with the path of the aircraft, and an approximate representation umbral shadow on a Mercator projection.

**Umbral Shadow:** The projection of the umbral shadow, showing the instantaneous region on the at-altitude geoidal surface in totality, sweeps across the map region over the duration of the totality run. As a visualization tool, and for display purposes only, the shadow boundary is approximated as an ellipsoid. Shadow axis (and aircraft) positions, contact times, and other numerical quantities are derived with high precision independent of this approximation. The shadow boundary display approximation loses high fidelity at very low solar elevations (e.g., near sunrise or sunset), but this does not affect the efficacy of any of the more rigorously computed quantities which are displayed and tabulated. The umbral shadow projection is not shown for instants of time (also near sunrise and sunset) when the eclipse is non-central (i.e., when the apex of the shadow cone does not reach the flight-level elevated geoidal surface).

**Mid-Eclipse Intercept Point:** The location of the point of mid-eclipse intercept, where the aircraft is instantaneously co-axially located in the umbral shadow (on centerline), is marked by a [purple cross +](#).

**Centerline:** The instantaneous positions of the center of the lunar umbra (defined by the lunar center of figure, not the dynamical center of mass) are shown for each instant of time throughout the totality run. As time progresses the locus of these points discretely maps out the centerline of the path of totality. At any instant of time each point (retained in sequential frames) is displayed as a black dot (inverted as white when a point is immersed in the umbra). Points along the centerline through which the umbra passes while totality is visible from the aircraft as it moves along its track are circumscribed in green (or purple when within the umbra). In the example above, which is for a time very soon after sunrise, the non-linearity of the point spacing due to the deceleration of the shadow in projection on the geoidal surface is readily apparent.

**Aircraft Ground Track:** The ground track of the aircraft is shown throughout the totality run. Before the aircraft enters the umbra (or, more generally as the umbra overtakes the aircraft [except in some circumstances for supersonic flight]) these positions are marked in dark blue (inverted to yellow as the umbra later passes over). Points along the ground track corresponding to times when the aircraft is flying through the umbral shadow are marked in light blue (inverted to red when those points are outside of the umbra).

**Contact Times:** The instants and locations of second and third contact, marking the start and end of totality as seen from the moving aircraft, are annotated along the aircraft ground track as the aircraft passes those points. The locations are marked by small black squares (inverted to yellow with the passage of the umbra over those positions) along with the Universal Times at which the contacts occur. In addition, the points along the centerline corresponding to the instants when the aircraft enters and exits the umbra are also annotated with the Universal Times of those instants.

### Notes on Contact Times:

- 1) Due to the approximate nature of the representation of the shadow ellipsoid, the shadow boundary, at the instants of contact may not appear exactly at the aircraft location by may be discrepant by a few kilometers.
- 2) Contact times and circumstances are determined by interpolative fitting of discrete values associated with the temporal spacing (intervals) selected. When the Display Time Resolution is set to 1s, the internal uncertainty (not including the limb profile, changes in delta-T, etc.) in the times of contact on the order of a few tenths of a second seconds, but takes longer to compute. If a large area is mapped at low temporal resolution (e.g., 30 seconds), contact times (and totality duration) will not be as accurately computed. Such coarse temporal granularities are useful for evaluating centerline flight options over large positions of the path of totality, but must be re-evaluated with a finer time resolution after selection.
- 3) For a moving platform, times of contacts are estimated numerically (to the noted precision), not analytically, by computing the local circumstances for each discrete point along the (at-altitude) ground track. A determination is then made, for each instant of U.T., as to which side of the umbral boundary the aircraft is on. When two contiguous instantaneous positions straddle a boundary crossing the instant (and hence position) of the boundary crossing is estimated by interpolation, and local circumstances are then computed for those points.

### Text Region (Right):

To the right of the map region, the circumstances of the eclipse and the aircraft flight parameters are updated at each incrementing time step, presented in five color coded sections:

#### 1. (Black, Top). NEXT WAYPOINT.

Longitude of the next targeted waypoint  
 Latitude of the next targeted waypoint  
 UT Crossing = UT at which aircraft will reach next waypoint  
 $\Delta$  Seconds = Time in seconds until next waypoint crossing  
 $\Delta$  Nautical Miles = Distance in Nm to next waypoint crossing

#### 2. (Light green). Static echo of input parameters.

Universal Time of Mid-Eclipse Intercept (HH:MM:SS).  
 Flight Altitude (in feet) above MEan Sea Level  
 True Air Speed in user-specified units  
 Wind Speed in user-specified units specified

#### 3. (Purple). Dynamic. Umbra Path Circumstances & AC Positions.

Current Universal Time  
 Longitude of the center of the umbra at flight altitude  
 Latitude of the center of the umbra at flight altitude  
 Umbral shadow width in km (see UMBRAPHILE for definition)  
 Solar Azimuth (degrees E of N) on centerline at current UT  
 Solar Altitude (degrees) on centerline wrt astronomical horizon  
 Aircraft Longitude  
 Aircraft Latitude  
 Time in seconds to/from mid-eclipse intercept  
 Flight distance (ground track) in Nm to mid-eclipse intercept  
 Deviation of LOS angle to sun orthogonal to flight direction

**4 (Light Blue). Dynamic/Static. Instantaneous Flight Vector.**

Aircraft Heading

Aircraft Ground Speed in units specified for Air/Wind Speed

Ground Track Direction

**5. (Dark Blue/Red). Static. Contact Information.**

U.T. of second and third contacts

Solar Altitude {elevation} (degrees) above the astronomical horizon at contacts

Position angles of contacts (east from north) along solar limb

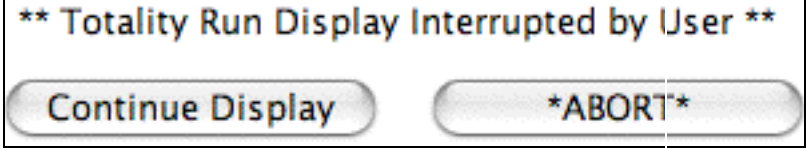
Aircraft Position (Latitude/Longitude) at contact times

Duration of Totality (minutes and seconds)

**5) INTERRUPT(ing a Totality Run Graphic Display)**

**To interrupt a TOTALITY RUN in progress, select the INTERRUPT item from the EFLIGHT03 menu.**

*Accidentally* interrupting a totality run would be very undesirable in flight! Therefore, after an INTERRUPT is requested a confirmatory dialog (Figure 11) will be presented which must be positively acknowledged before the temporally incrementing graphical display is terminated. Clicking [**Continue Display**] will resume the graphical output. If **RT SIMULATION** was selected in the Flight Definition dialog, the display will advance (to compensate for the time lapse during the temporary suspension) to time re-synchronize the graphical output).



11. INTERRUPT Confirmation Dialog

Clicking [**\*ABORT\***] will terminate the graphical display at the current time step. The graphical display window will remain opened (but can be closed if desired), and the clocks in the title bar will freeze at the moment of the interrupt request.



---

## Sample Dynamic Graphical Display

The **EFLIGHT** dynamic graphic display for a 40,000 ft., 22h23m15s UT intercept of the 23 November 2003 total eclipse may be viewed, as an example, to gain a better understanding of the graphical output format. This "movie" was actually generated with an earlier version of **EFLIGHT** (and thus the graphics display is somewhat different) but is shown to illustrate the concept.

[View/Download the sample EFLIGHT Display as a QuickTime Movie \(4.2Mbytes\)](#)

[View/Download the sample EFLIGHT Display as an animated .gif file \(4.0 Mbytes\)](#)

This example is "played" at 4-times the real-time rate at four one-second updates per second of elapsed time.

In this example an intercept profile spanning (-1.5, +2) minutes centered on 22:23:15s U.T, (shortly after sunrise) is developed to fly a course of constant heading over those three minutes to have the sun "straight out" the aircraft sun-side windows at mid-eclipse. As the animation/movie opens at 22:21:45 U.T. the center of umbra has not yet "touched down" 40,000 ft. above the surface of the Earth. Hence, as the first time steps are displayed only the changing location of the aircraft (and the intercept point) is annotated in the map region, and parametric values associated with the umbra in the text region are blanked out. Eight seconds later at 22:21:53 U.T. the umbra-center reaches 40,000 feet above the surface of the Earth, and that location is marked inside the approximate projection of the shadow which then appears. At that point the aircraft is 10.7 nautical miles from mid-eclipse intercept which it will reach in 82 seconds by flying a true heading of  $209.6^\circ$  at a ground speed of 470 nM/hr (with no wind). Second contact has been computed to occur 17 seconds later at 22:22:10 U.T. Over those 17 seconds, as the shadow moves to the south east, the umbral projection on the geoidal surface decelerates as can be seen by the decreasing point spacing along the developing centerline. At 22:22:10 U.T. the position of the aircraft is annotated (as is the corresponding point along the centerline) as totality begins for in situ observers. The evolving path of the eclipse, and flight of the aircraft can then be followed through mid-eclipse, to third contact, and beyond to the end of the requested time window.

---

## 6) COMPUTE COURSE

For developing a time constrained pre-totally run intercept flight plan, **EFLIGHT** provides a facility for easy producing the time-critical routing to approach the first point on the **TOTALITY RUN** from some pre-run location. This is done through the **COMPUTE COURSE** menu item and dialog as shown in Figure 12.

<input checked="" type="radio"/> DECIMAL DEGREES	<input type="radio"/> km
<input type="radio"/> DDMSS	<input type="radio"/> mi
	<input checked="" type="radio"/> nm
LATITUDE	LONGITUDE
P1: <input type="text" value="-37.7"/>	<input type="text" value="+144.95"/>
P2: <input type="text" value="-69.60717"/>	<input type="text" value="+93.37175"/>
COURSE= +204.4075	
DISTANCE= 2505.798 nm	
Number of Points	<input type="text" value="10"/>
U.T. of Last	<input type="text" value="224100.0"/>
Ground Speed (/hr)	<input type="text" value="470.0"/>
<input type="checkbox"/> Export Table	
Click [ENTER] Before Generating Table	
<input type="button" value="ENTER"/>	<input type="button" value="CANCEL"/> <input type="button" value="TABLE"/>

Figure 12. COMPUTE COURSE dialog.

**COMPUTE COURSE** will produce a set of time-ordered way points to be followed to get from point 1 (P1) to point 2 (P2). As a matter of convenience, after generating a **TOTALITY RUN**, the aircraft coordinates of the first point for the run is transferred to P2 in the **COMPUTE COURSE** dialog. The time at which the aircraft *must* be at P2 is the time corresponding to the first point in the totality run, and is the U.T. for the last point (U.T. of Last) in the **COMPUTE COURSE** waypoint table. This time is also automatically transferred to the **COMPUTE COURSE** dialog after generating a **TOTALITY RUN**. It is likely desirable to approach this point sometime prior to the critical "must be at" time, to allow for any unanticipated delays in route, and to execute a hold pattern at that position until the requisite release time. The U.T. Last field may be entered manually, to build in as long a hold time as desired. These co-ordinate fields, as well, may be manually over-written by entering whatever coordinates are desired. Coordinates may be entered in decimal degrees or DDMSS format as specified.

After the coordinates are entered *first* click the [ENTER] button. This will update the **COURSE =** and **DISTANCE =** values shown in the dialog. The course is the great circle heading in degrees from P1 to P2 (flown from P1), and the distance is in the units that were selected (upper right). To generate a table of intermediate way points (e.g., figure 13), then click [TABLE].

```

Great Circle Track and Penumbra Crossing: 22:41:00
Mid-Eclipse Intercept: 224400 U.T., Totality Run Start at -3 minutes
U.T. Start = 171938.5 Course = +204.1381* Ground Speed = 470.0nm/hr
U.T. End = 224100.0 Distance = 2517.302nm Number of Segments = 10
1ST Contact = 21:43:18 4TH Contact = xxxxxx.x

HHMMSS Latitude Longitude Latitude Longitude Course NEXTnm TOTALnm Elapsed Remaining
171938.5 37 42.0S 144 57.0E 37.7000S 144.9500E 204.14 249.52 000000.0 052121.5
175129.8 41 32.4S 142 53.3E 41.5402S 142.8889E 205.67 249.15 249.52 003151.2 044930.2
182318.1 45 20.5S 140 35.7E 45.3422S 140.5944E 207.54 248.68 498.67 010339.6 041741.9
185502.9 49 05.7S 138 00.0W 49.0952S 138.0006E 209.86 248.07 747.35 013524.4 034557.1
192643.0 52 47.0S 135 01.1E 52.7837S 135.0184E 212.78 247.27 995.42 020704.5 031417.0
195817.0 56 23.2S 131 31.4E 56.3862S 131.5239E 216.52 246.25 1242.69 023838.5 024243.0
202943.2 59 52.2S 127 20.4E 59.8704S 127.3397E 221.44 245.04 1488.94 031004.7 021116.8
210100.1 63 11.1S 122 12.1E 63.1857S 122.2015E 228.17 243.93 1733.98 034121.6 013959.9
213208.5 66 14.7S 115 41.7E 66.2455S 115.6952E 238.05 244.23 1977.92 041230.0 010851.5
220319.2 68 52.8S 107 06.3E 68.8797S 107.1058E 255.11 227.77 2222.14 044340.7 003740.8
223223.8 70 37.0S 94 48.5E 70.6162S 094.8086E 255.11 67.39 2449.91 051245.3 000836.2
224100.0 69 36.4S 93 22.3E 69.6072S 093.3718E 2517.30 052121.5 000000.0

```

Figure 13. COMPUTE COURSE Text Window output.

The title bar of the text window containing the COMPUTE COURSE table indicates the Universal Time at the completion of the computed track from P1 to P2.

The first line of the table header gives the U.T. of mid-eclipse intercept, and the time before that intercept (in minutes) the Totality run begins.

The second line gives the U.T. the aircraft would have to leave P1 and the great circle heading to fly, given the ground speed (as computed based upon earlier airspeed and wind information entered in the **COMPUTE TOTALITY RUN** Flight Definition dialog).

The third line gives the arrival time at the end of the great circle track (and start of the totality run), and the total distance flown, as the number of segments in the table which then follows.

IF the aircraft crosses the penumbral shadow boundary along the track from P1 to P2 the estimated crossing time, which is the instant of 1st or 4th contact is indicated (as appropriate).

For each instant of Universal Time in the table, the Latitude and Longitude of the aircraft is given (in two formats as shown), as well as the course from that point (in degrees), and the distance to the next segment is indicated. Also shown is the running distance and time from start, and time remaining to the end of the course.

**COMPUTE COURSE** *critically* seams together the approach to the Totality Run and the start of the Totality Run. For the actual Croydon/QANTAS flight, the plans developed have the aircraft reaching a "hold" point ahead of the start of the totality run before the critical time (by nominally 15 - 20 minutes) to allow for any unforeseen in-flight delays.

## 7) QUIT

To terminate **EFLIGHT** select QUIT from the **EFLIGHT** menu.

---

## Summary

This page is intended to briefly introduce you to **EFLIGHT**, and to give you an idea as to how it was used to develop baseline flight scenarios for the Croydon/QANTAS and TravelQuest(Sky & Telescope)/LanChile Antarctic eclipse overflights. This is not intended to be a fully comprehensive user's guide, since I suspect the number of potential users (other than myself) are rather small. However, if you consider yourself a smitten umbraphile, I suspect the **EFLIGHT** concept might be of interest to you (particularly if you have read this far down the page). So... now you know.

What's next? **EFLIGHT** continues to evolve to support the 23 Nov 2003 eclipse flight planning and execution. Indeed, baseline test scenarios developed with **EFLIGHT** were recently tested in a three-hour session in the QANTAS B747-400 simulator in Sydney by QANTAS Senior Check Captain John Dennis (who will be the pilot in command for the Croydon/QANTAS flight) as he dry ran the eclipse flight. As a result of that simulator session, a few "tweaks" were made to the user and display interfaces (which are now as documented here), to make its real-time use in conjunction with the requirements of the 747 Flight Management System more seamless.

If you are seriously contemplating an airborne observation of this, or of a future eclipse and would like to take advantage of **EFLIGHT** as a planning and in situ execution tool then [contact me](#). Unlike [UMBRAPHILE](#), however, I am not freely giving **EFLIGHT** away, primarily because to use it properly requires a fair amount of detailed familiarity. I would, however, be very happy to work with like-minded eclipse chasers in defining and planning future airborne eclipse observations using **EFLIGHT** - maybe in exchange for an opportunity observe and fly with you into the bottom of the lunar umbral cone.

Glenn Schneider

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