

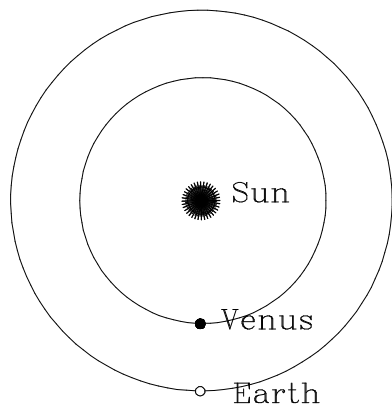
CAPTAIN COOK AND THE TRANSIT OF VENUS

Most Australian's will know that the purposes of the first voyage of Lieutenant James Cook RN were to observe the Transit of Venus and then to search for the great south land, Terra Australis. But what was the Transit of Venus and why would you go to so much trouble to observe it.

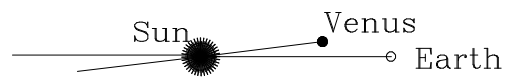
What is the Transit of Venus

When, in the course of its orbit around the sun, the planet Venus passes between the Earth and the Sun, Venus can be seen as a black dot moving across the disc of the sun. This is known as a transit.

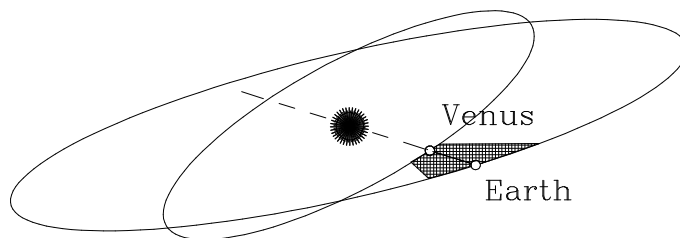
If the orbits of Venus and Earth were coplanar, Venus would come between the Earth and the Sun when both planets lay on the same radial from the Sun. This is known as a conjunction. It can happen anywhere in the orbits of Venus and Earth. Venus catches up to and passes the Earth every 586 days. However, because of the relative inclination of the orbital planes, Venus only appears in front of the Sun when the conjunction takes place near the intersection of the orbital planes of Venus and Earth. That happens very infrequently.



Inferior Conjunction



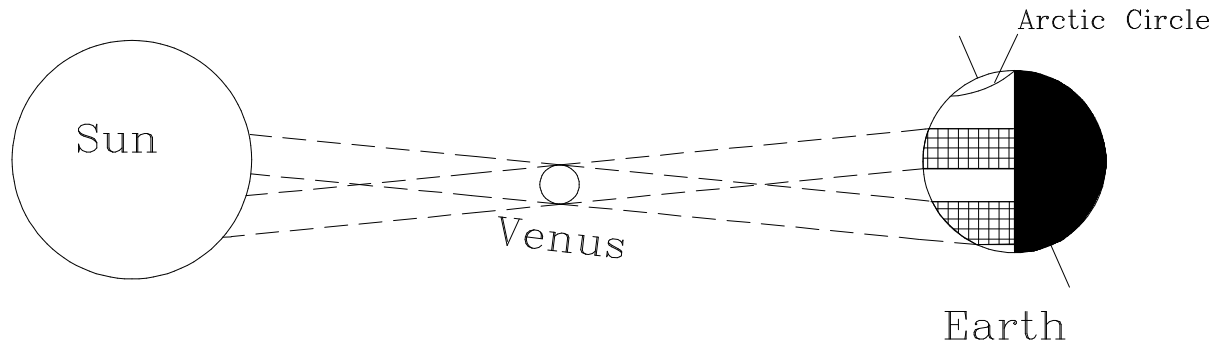
Orbital Inclination



Orbital Location of Conjunction for Visible Transit

Transits occur in pairs separated by eight years, after which there are no more for over 100 years. The next transits will be in 2004 and 2012.

The Transit takes about six hours. It cannot, of course, be seen from those places on the Earth where the Sun cannot be seen at the time of the Transit. That is, it cannot be seen at night time when the sun is below the horizon. All of the Transit can only be seen either from within one of the polar circles or from places within a particular band of longitude at each latitude.



Why Measure It

For the following account I am indebted to Lt Cdr R.T. Gould RN (ret), navigator, cartographer, and historian of the chronometer - writing some 75 years ago.

In 1716, Edmund Halley (Professor of Geometry and later Astronomer Royal) pointed out that there would be a Transit of Venus in 1761. He predicted that such a phenomenon might recur in 1769, but would certainly not be seen thereafter until 1874. He theorized that, by observing the whole duration of such transits from two stations differing widely in latitude, one could deduce the distance from the earth to the sun. The significance of this distance was that all the equations for the orbits in the solar system were known from observation of comparative movements observed from the Earth, but they were perforce written in terms of the single variable the "astronomical unit" or au. This was the distance from the Earth to the Sun.

Thus by observing the Transit a solution could be found for the most fundamental problem which then confronted astronomers.

Then aged 60, Halley knew that he personally could no more hope to see this Transit of 1761 than the return of his famous comet in 1758. Nevertheless he proposed arrangements for observing the Transit. Halley suggested that observers should occupy various stations, such as Benkulen (in Sumatra) and the shores of Hudson Bay, which seemed well adapted to his method (now called 'Halley's method').

Halley said, *"I could wish that many observations of this famous phenomenon might be taken by different persons at separate places, both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of clouds, of a sight which I know not whether any man living in this or the next age will ever see again, and on which depends the certain and adequate solution of a problem the most noble, and at other times not to be attained to. I recommend it therefore again and again to those curious astronomers who, when I am dead, will have an opportunity of observing these things, that they would remember this my admonition. . . and I earnestly wish them all imaginable success"*

In 1742 Halley was laid to rest in Lee churchyard. On Christmas Day, 1758 his comet reappeared; and on June 3rd, 1761, Venus was duly seen creeping across the face of the sun in the form of a small black dot. But while his prediction had been accurate enough in the main, it failed in detail - as later astronomers had anticipated. His method and his station proved ill-suited to this particular occasion. However, with fine official pertinacity, English observers were despatched to Benkulen - and others would probably have also

been sent to Hudson Bay if definite proof had not been forthcoming that the Transit would not be visible there at all. Luckily, the ship bound for Benkulen was forced to put in at the Cape of Good Hope, where excellent observations were secured. These results were combined with those taken elsewhere on 'Delisle's method', which used pairs of stations differing widely in longitude.

To calculate the distance to the sun one needed to know the latitude and longitude, of the observing stations. Owing to the formidable difficulties which then stood in the way of ascertaining longitude accurately, the 1761 observations did not determine the sun's distance with any great precision. On the other hand they demonstrated (Halley had only surmised) that there would unquestionably be another Transit in 1769 - after which there would be none for more than a century. Furthermore, at this second transit the easier method - Halley's - would be available *if suitable stations could be found*.

The selection of a northern observation station for 1769 presented no difficulty. The Transit would occur in June when the north pole of the earth is tilted towards the sun; an observer anywhere inside the Arctic Circle could therefore, given fine weather, have the sun continuously in view day and night. But at the southern station it was necessary that the sun should be at least visible - and, preferably, well above the horizon - for the whole six hour duration of the Transit. In the circumstances of the case, this meant that the station should be on, or fairly near, 155° W longitude. Calculations made by Maskelyne, the Astronomer Royal, indicated that the station ought to lie within an area bounded by lines joining the following points; 5°S 173°E, 5°S 124°W, 35°S 139°W, and 35°S 172°W.

Astronomically then, the object of Cook's voyage was to transport qualified persons to some suitable station within Maskelyne's coordinates in the South Pacific; from which they could observe the Transit of Venus which was due to occur on June 3rd 1769.

The plan of the voyage was materially affected, on May 20th 1768, by the return to England of the *Dolphin* - fresh from a voyage of exploration, in the 'South Seas'. *Dolphin's* captain brought news of a group of islands - part of the Low Archipelago - which he had discovered in about 18° S. He had made a long stay at the largest, "King George III Island" (now Tahiti), and his account of its amenities, coupled with its advantageous position (almost in the centre of the area laid down by Maskelyne) at once led the Royal Society to select it for their southern station.

Cook joined the *Endeavour*, in the Downs, on August 3, 1768, and sailed next day for Plymouth. From here, he sent word to Banks, still in London, that he was ready for sea. By August 20 the naturalists had made their way to Plymouth, and were embarked, with their baggage.

And baggage there was! Sir Joseph Banks OBE, aged 35, baronet, privy councillor, President of the Royal Society and *ex officio* member of the Board of Longitude, had a personal income of some £6,000 per annum from estates he had inherited. In today's terms that is about \$3 million. He had given £10,000 to outfit Cook's expedition. In addition to a mountain of luggage, there was Banks' entourage of a botanist, two illustrators, a draughtsman, a landscapist, a secretary, four personal servants and two greyhounds.

Then on Thursday, August 25, Cook's journal records:

"... At 2 p.m. got under Sail and put to Sea, having on board 94 Persons, including Officers, Seamen, Gentlemen, and their Servants; near 18 Month's Provisions, 10 Carriage Guns, 12 Swivels, with good Store of Ammunition and Stores of all kinds."

The Gentlemen included Charles Green, the Assistant to the Astronomer Royal at Greenwich and whose part in the voyage is so often overlooked.

Where on Earth are We?

For his expedition to be successful, Cook needed a method of determining longitude. For his expedition to be safe, he needed a method of determining longitude while actually at sea.

In principle, determining one's longitude is simple. If one knows the local time, and also knows the time at 0° longitude, then because the earth rotates 360° in 24 hours

$$\text{Local longitude} = \frac{\text{Time difference in hours}}{24\text{hrs}} \times 360^\circ$$

Now local time may be discovered in one of several ways. The problem was how to know what time it was back home at Greenwich or the 0° of longitude.

By 1768 this famous "problem of the longitude" had, actually, been solved. John Harrison, the Yorkshire carpenter, had produced a timekeeper whose performance more than complied with the terms of the Act of Parliament that offered a reward of £20,000 for a practicable method of finding longitude. Half the reward had already been paid to him, and an account of his timekeeper published. On his second voyage, Cook's ships were to carry no fewer than four marine chronometers. But in 1768 no seaman could hope to obtain such a timekeeper for love or money.

However, there were methods for determining when it was a particular time at Greenwich by direct observation of the heavens. Many visible astronomical events, such as eclipses or stars passing behind the sun, had been recorded over the centuries. The time at which they occurred at Greenwich was being documented with increasing accuracy. Tables of these times were carried by mariners. However, the tabulated events were mostly infrequent and sporadic.

But, two sorts of events happened frequently enough to be a useful indicator of time at Greenwich.

The first was that proposed by Galileo soon after his discovery of four of Jupiter's satellites in the year 1610. These little moons, as they circle round their huge primary, are frequently eclipsed. The times at which these eclipses occur can be predicted a long time in advance. They are seen simultaneously at all longitudes.

That is all very well on dry land. But at sea, in any weather except a flat calm, the ship's motion prevents Jupiter and its satellites from being held in the view of the telescope long enough to observe an eclipse. Secondly, the eclipses are not instantaneous, and any alteration in the state of the atmosphere or in the telescope affects the observation. Lastly, Jupiter is often so near the Sun that the eclipses cannot be observed.

Nevertheless, later in the voyage, Cook and Green, using the mean of two observations of Jupiter's first satellite, determined the longitude of their encampment (now the mouth of the Endeavour River, Cooktown) as 145° 12'E. - the present Cooktown aerodrome is actually at 145° 13.5'E.

Now the moon, with its comparatively rapid motion in the heavens, has always attracted those who wish to find standard time by celestial observations. Its motion - some 12° in twenty-four hours is quite obvious, and many plans have been proposed for making use of it.

If the moon's motion is known with sufficient accuracy, tables can be drawn up forecasting its position in the heavens at any time for years in advance. The position is expressed as the moon's angular distance from suitable stars. These distances can be measured on board ship by means of the sextant and the Greenwich time corresponding with the measured distance can be taken out of the tables.

The possibilities of this method were seen early in the history of the problem. The method was proposed

by Werner as early as 1514, by Morin in 1633, and by St. Pierre in 1674. But at that period, and until much later, the theory of the moon's motion was far too rudimentary to allow the accurate prediction of lunar distances. As Newton pointed out in 1713, it would permit a ship's place being found within two or three degrees, but not nearer. Such accuracy was little better than that of reckoning by ship's speed and time travelled. King Charles II then established Greenwich Observatory, "*for rectifying the tables of the motion of the heavens, and the places of the fixed stars, so as to find out the so-much desired longitude of places for perfecting the art of navigation.*"

So, the method of lunar distances had been suggested, but it remained inapplicable for lack of fundamental data. After thousands of hours of observation and recording and mathematical analysis by himself and others, the German astronomer and mathematician Tobias Mayer compiled a set of tables of data which he submitted to the Board of Longitude in 1755.

The French were the first to apply Mayer's tables. However, it was Astronomer-Royal, Maskelyne, who brought the lunar method into general use. Maskelyne had experimented with this method, using Mayer's tables during his voyage to St. Helena to observe the Transit of 1761. In 1763 he published his *British Mariners' Guide*, giving data from which, after some four hours' calculation, a ship's longitude might be found within about 1°. In 1767, as Astronomer Royal, he instituted the *Nautical Almanac* in which he gave, for the first time in the history of navigation, lunar distances of the sun and seven selected stars, computed for every three hours at Greenwich. The *Nautical Almanac* continued to publish such distances uninterruptedly, and several years in advance, until 1907, when they were discontinued, as no longer worth the trouble of computing.

But at no time during that period had they been an entirely satisfactory solution of the problem. In the hands of a good observer and computer they were excellent, but for general use they were unreliable. The reason was twofold. In the first place, the observations had to be extremely accurate. Owing to the moon's comparatively slow motion, an error of only 1' of arc produced an error of 30' or so of longitude in the result. The best observer could hardly be certain of avoiding errors of 1' of arc. Secondly, the calculations were long and intricate, and although many efforts were made to simplify them, there remained many pitfalls and chances of committing some slight error which might easily pass unnoticed, and yet convert the result from a safeguard to a source of fearful danger. The combination of a good observer and a good computer was not very usual, while even those expert at both branches could not guarantee, however favourable the observing conditions, that the mean results of several sets of distances would not exhibit considerable discrepancies.

Charles Green, Cook's astronomical colleague, had studied the new method under Maskelyne at the Observatory, and was probably its most able living exponent. Cook, naturally, was eager to learn it - and throughout the voyage he and Green lost no opportunity of doing what most navigators, a few years earlier, would have said was impossible - obtaining their ship's longitude, at sea, by direct observation.

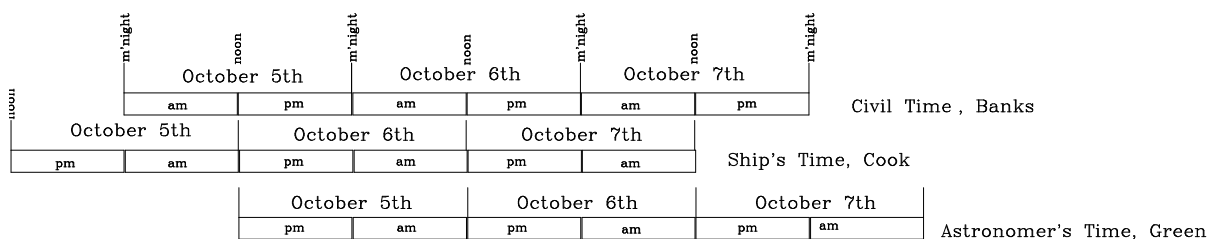
Cook and Green were exceptional navigators. In general, their observations were correct within 1°, and often much nearer still. This was a great advantage. It meant that Cook could navigate freely on the high seas without the ever-present fear of 'losing the longitude'. He could fix his discoveries accurately, and correct those of bygone navigators; and he could re-visit any spot he had once fixed by a course as direct as the winds would allow.

And What Day Is It?

There are some confusing things about dates in the record of the *Endeavour's* voyage. In Cook's journal the entries relating to the afternoon of any particular day invariably precede those dealing with the morning. Moreover, the dates in Banks' journal frequently differ by one day from those in Cook's; and while the dates in Green's astronomical journal sometimes, but not always, agree with Banks, they never agree with Cook.

There were three different systems of dating in use in *the Endeavour*. Cook kept his journal, and the ship's log, in Ship Time - now obsolete. In this system, the day begins at noon, not at midnight, and twelve hours *before* the ordinary Civil Day. Thus for Cook October 6th began at noon on Oct 5th Civil Time, and ended at noon Oct 6th Civil Time. Events which happened in the afternoon and evening of October 6 Civil Time (which Banks used all through his journal) would be noted by Cook as happening in the p.m. of October 7. After midnight Cook {and, of course, Banks also) would write of them as happening in the a.m. of October 7.

On the other hand Green kept his journal in Astronomical Time - a system discontinued in 1925. Like Cook, he reckons his day from noon to noon - but instead of beginning twelve hours *before* the Civil day, his day is twelve hours *behind* it; and, consequently, a whole day behind Cook's. He would agree with Banks in the date of any event which happened between noon and midnight: he would be a day behind him if it happened between midnight and the following noon - for which period Banks' date would agree with Cook's. Cook's dates would always be a day ahead of Green's: their journals would only agree in always making the p.m. of any day precede the a.m.



Nowadays, Cook would have pushed his dates still further ahead by dropping a day when he crossed the Date-Line. Actually, he did not do so until he reached Batavia - where he notes in his journal 'Wednesday 10th, according to our reckoning, but by the people here Thursday 11th', and he continues his journal with the amended date.

On to Tahiti

On January 30th 1769, the *Endeavour* reached its furthest south point of the voyage - 60° 04' S., in approximately 74° W. Thereafter Cook steered N W. On March 31st they were nearly in the latitude of their destination, and course was altered to the westward. On April 4th they sighted their first atoll, low-lying and inhabited. It was the modern Vahitahi, in the Low Archipelago. Proceeding westward they sighted and coasted several similar islands. Finally, after a day's delay caused by the wind's failing, they anchored in Matavai Bay, Tahiti, at 7 a.m. on April 13th 1769.

There were seven weeks to spare before the Transit. Cook's first care was to select a site and build a fort - Fort Venus - from which the long awaited event could be securely observed. This done, the instruments were landed. Immediately one of them, the quadrant, was stolen. Banks recovered it, piece by piece, but undamaged.

To minimize the chance of missing the Transit through bad weather, Cook sent out two auxiliary observing parties - one to York Island, the other to the eastern coast of Tahiti.

The great day - June 3rd - was cloudless, and almost unbearably hot. Cook and Green, exposed to a temperature which rose at one time to 119° F., watched the Transit throughout its whole duration - almost six hours. They were using identical telescopes - reflectors made by the celebrated James Short - but they

found, to their surprise, that their observed times for the two internal and two external contacts - times which, for the successful application of Halley's method, ought to have been in almost exact agreement - differed quite widely (15-20 seconds). However, they counted themselves fortunate that, after coming so far, and waiting so long, they had at least seen the Transit.

Although Green never knew it, and Cook not till long afterwards, another observer had waited *eight years* in the East to witness that phenomenon - and had missed it after all ! He was a Frenchman named Le Gentil, who had sailed for Pondicherry in 1760 to observe the Transit of 1761. By a chapter of accidents, including the outbreak of the Seven Years' war, his arrival was delayed, and he had the mortification of trying in magnificent weather to get what observations of the Transit he could from the heaving deck of his ship. Nothing daunted, he formed the heroic resolve of exiling himself at Pondicherry, and waiting for the 1769 Transit. This he did - and while the weather was perfect for weeks both before and after that event, the actual day was overcast, and he saw nothing. Unable to wait for the Transit of 1874, he returned to France - and found that, during his long absence, his heirs had obtained legal permission to presume his death and divide his property among them.

The Answer

After an epic voyage of discovery, Cook arrived back in England on Friday July 12th 1771.

The biographies of Cook seem to ignore the effect of the *Endeavour's* observations of the 1769 Transit upon the problem which they were designed to solve - the determination of the earth's distance from the sun. As this was the original objective of the whole expedition, the omission seems inexcusable.

The observations secured at the northern-hemisphere stations proved to be no more consistent than those of Cook and Green. This was due to a source of error which could hardly have been foreseen or removed. Owing to "irradiation", the disc of Venus was distorted when apparently approaching or breaking contact with the edge of the sun, and seemed to be connected with it by a narrow ligament. In such circumstances, the actual instant of contact could not be observed - and the time of its occurrence was a matter of estimation, varying with each observer.

Some of the northern observations also seem to have been spoiled by additional errors. Much was expected from those taken at Wardhuus, in Lapland, by a leading German astronomer, one Father Hell. The Transit began, at Wardhuus, about 9.30 p.m. and ended about 3.30 a.m. - the sun being visible at midnight. But these were so discordant as to give rise to dark suspicions that the good Father had fallen asleep and had missed the end of the Transit altogether !

Nevertheless, before the end of 1771, over two hundred independent computations of the sun's distance, based upon the 1769 observations, had been received by the Academy of Paris alone. The results ranged from 87,890,780 miles to 108,984,560 miles - yet nearly all the computers were perfectly confident that their particular value could not possibly be far wrong. The value accepted today is a mean of 92,957,200 miles.

Encke in 1824, and Stone in 1869, "cooked" the observations into some sort of agreement - but such proceedings have no fundamental value, and are essentially unscientific. The Transits of 1874 and 1882 showed clearly that, even with the help of photography, such phenomena do not afford a sufficiently accurate measure of the distance to the sun.