

# Astro-navigation goes artificial

High accuracy in navigation and positioning is now obtained not from fixed stars but fast moving satellites. Navstar, a new satellite navigation system, is being readied to provide astonishing accuracies of a few metres in "blind" navigation

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When the first Sputnik bleeped its solitary way through the heavens, so the story goes, some US physicists remembered the variations

in the pitch of the signal as the satellite passed overhead. These doppler shifts could enable them, on the ground, to calculate very accurately the satellite's orbit relative to a known position on Earth.

That trick was quickly turned on its head. If a satellite broadcast to a ground-based listener who didn't know his location, and the satellite's orbit was known, the listener could calculate his position from doppler shifts. Thus, reputedly, was Transit, the US Navy's Navigational Satellite System, born of Sputnik.

The first Transit satellite was launched, but failed to orbit, just two years later in 1959. Two were launched in 1960 and, by the end of 1963, the Transit system was fully operational—intended to provide precise position "fixing" for Polaris submarine commanders, so that their missiles could be accurately launched. Three years later, the secrecy was lifted, allowing the Transit system to be used commercially. It has found wide application in geophysical and oceanographic research. In London this week, an international conference on Satellite Communication and Navigation is discussing the ways that Transit, and its successor Navstar, may be used for ships and aircraft.

Five Transit type satellites are now in orbit, travelling over the poles at a height of about 1000 km, once every 100 minutes or so. Each broadcasts VHF and UHF radio signals continuously to ground receivers. In the satellite signals are coded data specifying its orbital parameters. The data signals and bleeps transmitted by the satellites are timed to within a few microseconds of GMT, so that the position on the predicted orbit of each is precisely known. The two frequency bands used allow compensation

for distortion of the doppler effect by the ionosphere.

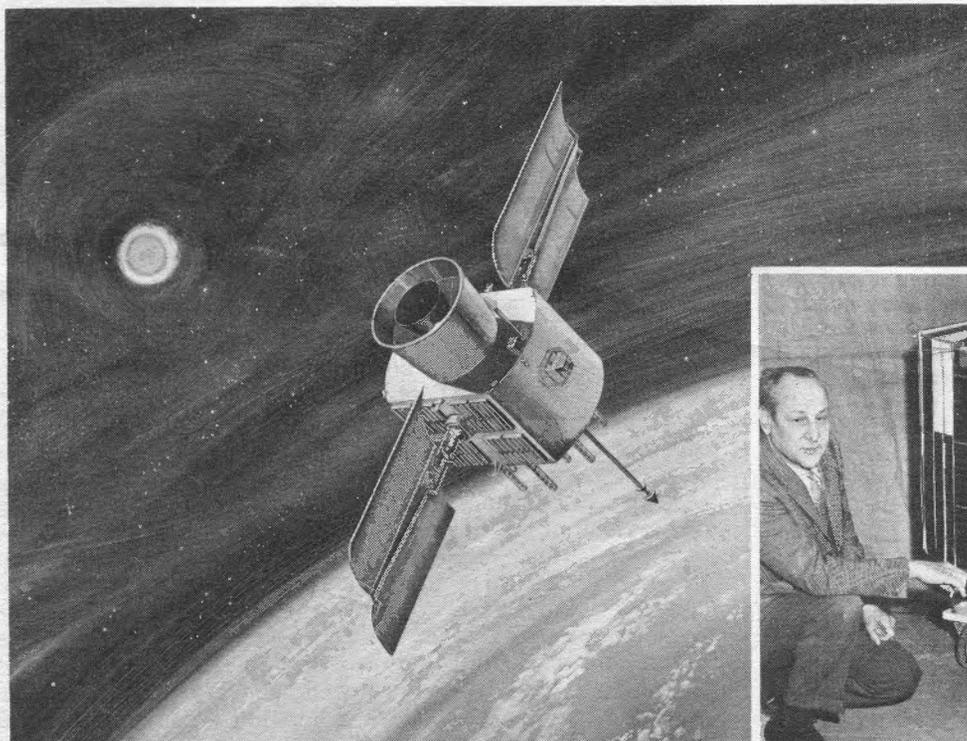
As the Transit makes its "pass" over the Earth, the frequencies received fluctuate according to the relative speed—higher as it approaches, lower as it passes and sinks below the horizon. The ground "satnav" receiver records and counts the doppler shifts. It stores the transmitted data, and computes a position when the pass is finished. The computation requires a digital computer, one of the reasons for the hitherto substantial expense of satnav equipment.

A single satellite pass will define position to within 50 metres or less. Cheaper receivers use only one of the satellite channels, and may be three or four times less accurate. But real accuracy can be obtained by averaging 30 or more passes taken over a day, which will reduce the possible error to a few metres. The ability to do this is vital in, say, carving up the relative shares of Britain and Norway in North Sea oil and gas fields, some of which straddle the dividing median line.

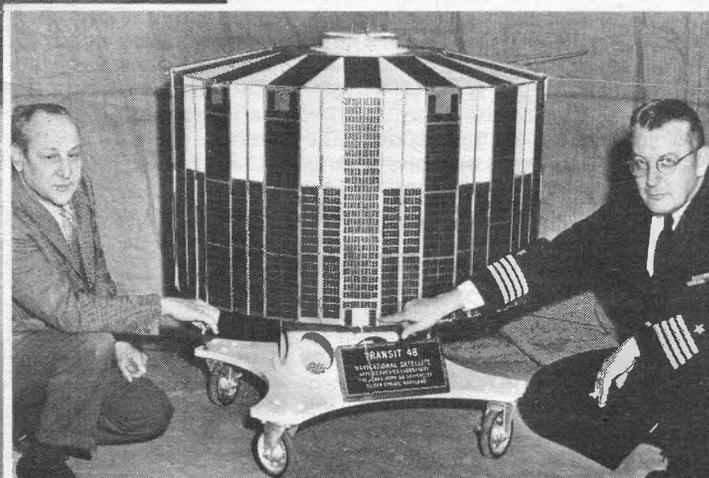
## But where is the Earth?

Satellite navigation and geodesy has resulted in fundamental changes in surveying. It is no good having satnav receivers capable of computing positions accurate to within five metres if the surface of the world is plotted to an accuracy 100 times poorer. Even now, however, this problem still exists.

Until the late 1960s, survey networks relied on sightings and triangulation across continents. Within one country high accuracies are achievable. But linking together the survey nets of Britain and Norway, which means using precarious sightings to the European survey network from across the English Channel and the Kattegat, could give rise to sizeable errors in the relative positions of Scotland and Norway. Satellite positioning can eliminate them.



Navstar, a new satellite navigation system making use of 24 satellites such as this one, will provide navigational accuracy to within five metres in "blind" conditions. Inset, one of the earlier Transit satellites, six of which are now in orbit, travelling 1000 kilometres above the poles every 100 minutes or so



But there is another more fundamental problem. The Earth is not truly round, nor is its gravitational field even across the surface. Maps of different continents and countries are based on two approximations to the real Earth; one is the spheroid, which represents the general shape of the Earth; the other is the datum, which fits the spheroid as well as possible to the surface of a particular continent. And each place has as many different sets of latitude and longitude coordinates as there are spheroid/data models in use. Errors up to one kilometre between different continental data such as the European datum and the North American datum, were not uncommon.

### Earth's gravity field "pear-shaped"

The very first Transit satellites started uncovering unsuspected oddities of the Earth's surface and gravity. It quickly ceased to be round and became pear-shaped—bulging in the southern hemisphere. It was oblate rather than spherical in shape, 20 kilometres fatter around the equator. Work to improve understanding and accuracy in survey is still continuing. Last May, some 39 receivers were used all over Europe to reconcile three different measuring systems as accurately as possible.

Such improvements in positional precision naturally mattered greatly to the US military, whose missile accuracy in travelling between continents was clearly a prime example of the problems of varying reference systems.

High accuracy commercial receivers still cost around \$20 000. The major UK use of satnav has been for rig positioning in the North Sea, where the search for oil and gas requires very high precision. The Transit system has two problems, though, which will not affect Navstar. With Transit, satellite passes are intermittent—about every 40 minutes at typical British latitudes, but rather more than an hour apart in equatorial regions. If a vessel is moving, accuracy is greatly reduced unless the ship's velocity is accurately known. For aircraft, which could travel anything up to 1000 kilometres between satnav fixes, the system is clearly useless.

The Transit satellite navigation system clearly depends on knowing the satellite orbits to a high accuracy. This is done by a network of receiving stations including Lasham in southern England, where data from satellites are relayed

### Soviets follow suit

Amateur observers in Britain have discovered that a Soviet satellite navigation system has been operating since about 1970. The Soviet system uses virtually identical radio frequencies and patterns of transmission to the US Transit series, on 150 and 400 MHz. These frequencies are reserved for space navigation.

The system, which started with Cosmos 385, was detected by the Kettering Space Observer Group, who noticed that there were three satellites orbiting in planes 120° apart to give the best coverage of the Earth's surface. Since then the system has been expanded to six satellites in planes separated by 60° and, within the last two years, other satellites at 30° intervals have been added. The coverage provided by the Cosmos satellites is now more frequent than that by Transit.

Like Transit, the Cosmos navigation series transmit orbital data and other data modulated onto the basic doppler shifted signals. The Kettering group analysis of the data suggests that it contains a broadcast of the status of the entire system—valuable to users, especially submarines, who then know when the next pass is likely.

Other British observers, using converted Transit receivers, were able to discover the control stations for the Cosmos series, by monitoring the change in orbital parameters, after new information was "injected" into the satellites. The USSR has, however, shown no wish to exploit its system commercially. D.C.

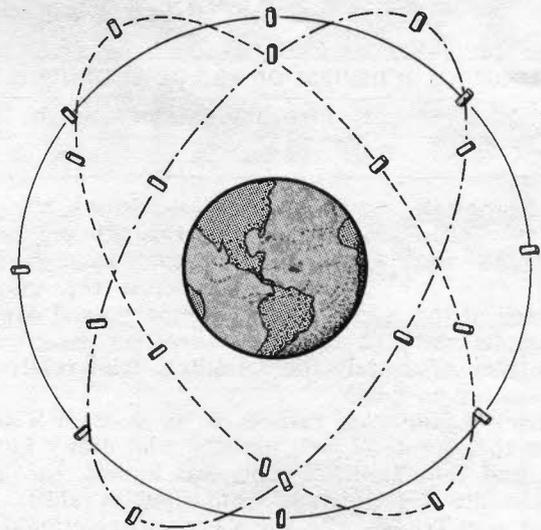


Fig 1. When the Navstar system is in full operation, in 1984 if all goes well, there will be 24 satellites orbiting the earth with 12-hour periods

to a US computer centre. The precise timing needed is provided from a Universal Time Standard (UT2) at the US Naval Observatory. From these two centres, time and orbit data is periodically injected into the memories on board the satellite, for rebroadcast to all users.

The Transit system is likely to last into the 1990s. Late last month, a contract was placed with RCA for three Nova satellites, which are the latest in a series of improved Transits; others were NNSS, TIP and Triad. Many of the improvements are intended to reduce the satellite's vulnerability to attack by killer satellites, or jamming. They include removing the vulnerable solar panels and using a radioisotope power source instead. Since Transit satellites have become extremely reliable, functioning for up to 10 years, it is likely that the system will still work well after Navstar is introduced. Such guarantees clearly matter to commercial satnav users, who could be left with defunct equipment.

### New stars in space

To provide the information that Transit could not supply—height, velocity, or continuous position—the US Navy and Air Force began competing projects for a new series of navigation satellites. The Navy wanted more accurate and continuous information, which could possibly also provide guidance to missiles in flight. The US Air Force wanted the system usable in highly manoeuvrable aircraft, and the possibility of steering "smart" weapons on to predetermined targets. For these systems, the doppler shift measurements of Transit satellites have been shelved, and a system of timing and ranging introduced.

The competing USAF and Navy systems were merged in 1973 into the Navstar Global Positioning System (GPS). The basic principle of Navstar satellites is the calculation of distance between the satellite transmitter and a navigation receiver, based on the propagation time. If signals are received simultaneously from three satellites, then timing the arrival of each signal enables the calculation of the user's position receiver, using the known radiowave velocity,  $c$ . The three measured distances effectively define a sphere around each satellite—the position of the receiver is at the intersection of the three spheres. But to do the calculating accurately requires that the timing of all three satellites be highly synchronised; an error of one microsecond in timing would give a position error of about 300 metres. Each Navstar will carry a caesium atomic clock to

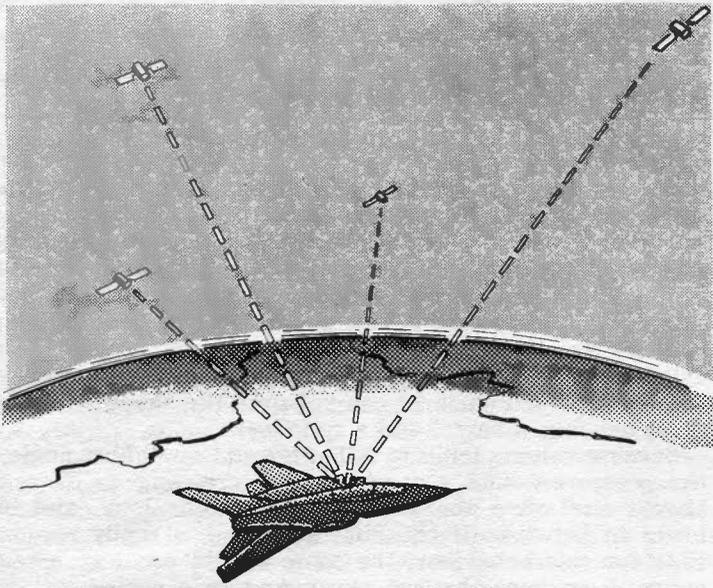


Fig 2. Each Navstar carries a very accurate Caesium clock. By solving four equations relating position and time the receiving station, the aircraft in this case, does not need itself to carry a precise timing device, whereas with earlier systems like Transit it does

keep timing perfectly synchronised.

Ingeniously, the need for each ground receiver to have a clock of similar accuracy is avoided by using instead signals from four satellites. The solution of four relative position and time equations instead of three enables time to be calculated as well as position. Thus not only is an accurate ground clock unnecessary—the Navstar satellites distribute highly accurate time signals, as a by-product of their operation.

#### Four satellites continually in view

There is a drawback—the need to have four satellites continually in view, all over the Earth's surface. To do this, a grand total of 24 satellites will be needed for the system when it becomes fully operational in 1984. The 24 satellites will orbit with 12-hour periods, and are dispersed in three planes of eight spacecraft, each plane being inclined at 63° to the equator (see Diagram). This ensures that at least four, and often more, Navstars will be continually in view. A preliminary group of six Navstars was planned for launch in the early part of this year. So far, however, only NTS-2, the final Navstar test satellite, has been placed in orbit, in July 1977.

In full operation, Navstar fixes will have a horizontal accuracy of 5 metres, and a vertical accuracy of 7 metres. Velocity, in three dimensions, can be measured to about 5 cm/s. The title of Global Positioning System was chosen, according to the project director, "to reflect better its principal mission for weapons delivery and the high accuracy potential of the system". Navstar will obviously facilitate further accuracy in cruise missiles and similar weapons; remotely piloted vehicles (RPVs) will also benefit, and there are plans to develop missile-based receivers which could increase nuclear missile accuracy further by providing mid-course guidance.

The availability from Navstar of precise time will improve battlefield communications by enabling anti-jamming radio systems to operate more readily. Navigational use may also extend to other space vehicles—the space shuttle, certainly, but possibly also killer-satellite systems now being developed by both the US and the USSR. Navstar planners anticipate about 30 000 receivers being in use when the full system starts operating in 1984

—among these is a hand-held receiver not much larger than early pocket calculators.

Each Navstar will transmit information both "in clear" and in code on the same basic frequencies of around 1200 and 1500 MHz. The coded transmissions use a cryptographic technique called "pseudo-random noise" (PRN) which modulates the signal in a way indistinguishable from simple "white" noise. But the PRN signal can also be generated at the receiving end and, by suitable processing, the information is extracted. The advantage of the PRN technique is that there is no easy or obvious way to jam the signal and the information will get through, even past jamming signals many times stronger than the original.

The PRN signal will give private information with the highest possible accuracy to US military users. But there is also a public signal which is not coded or jam-proofed, and which will be open to commercial use. Because of the simplicity, it will also be used for less costly or less demanding military receivers.

Navstar, like Transit or the worldwide Omega VLF navigation system (*New Scientist*, vol 68, p 164), will undoubtedly find civil use in Britain and elsewhere. Some work at UK research establishments is reported at this week's conference. They are undoubtedly helped by the fact that, according to Navstar project director Col Brad Parkinson, "we have made this system as unclassified as we can". The precision of Navstar is such that even vehicles in cities could locate or relay their positions from its signals. Civil receivers for simple two-dimensional tasks such as harbour navigation are already being planned. The doubts as to whether the global precision of Navstar—with its "principal mission for weapons delivery"—is really in everyone's interest is evaporating fast. □

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