In the coming years pilots flying over the Indian air space need no longer depend solely upon the conventional ground-based radar systems for receiving navigational instructions. They will be guided by a more accurate and seamless satellite-based navigation system to be installed jointly by the Indian Space Research Organization (ISRO) and the Airports Authority of India (AAI).

Presently, air traffic management over the Indian sky is carried out with the aid of ground-based radar sites. The aircraft has to pass over these sites, which form “highways in the sky”, to receive navigational instructions via radio signals on the position, speed, altitude, route, etc. With increasing air traffic, these highways become congested, slowing down traffic movement. Radar control also restricts air route availability. Further, dissimilar procedures and standards from airport to airport result in changes in flight profiles at the boundaries. In case of congestion, the system cannot provide alternative route structures to the pilots.

With the satellite-based navigation system, the pilot is provided with on-board position for precision and non-precision landing approaches as well as for en route applications. This will result in the opening up of air connections to a large number of small Airports that lack the conventional full-fledged navigational facilities.

The basic requirement for a satellite-based navigation system is a constellation of satellites with known orbits, which can be used as reference. Satellite-based navigation system is not new. The US government launched a satellite constellation known as Global Positioning System (GPS) in the 1980s for use by the military. It is also available for civilian use. World over, rail, road and ocean traffic and even individuals have been using it to know their exact position anywhere on the globe and also to chart out the route for their destination.

The International Civil Aviation Organization (ICAO) has endorsed GPS as the core satellite constellation to provide worldwide seamless navigation for civil aviation.

What is GPS?
GPS consists of three main segments: 1) the satellite constellation, 2) the ground control network and 3) the user equipment.

The satellite constellation is made up of 30 solar-powered satellites, which revolve around the earth in six orbital planes at a radius of about 26,600 km from the center of the earth. Their main function is to continually broadcast ranging and navigational signals. These are in the form of pseudo random codes (PRC), transmitted as low power radio waves in the L band carrying information on their position in space and time. Each satellite is identified with a unique PRN code and equipped with an atomic clock for precise timing.

The ground control network consists of six stations across the globe. They constantly monitor the satellites for their health and fine-tune their orbital data, which is transmitted back to them.

The user equipment is a GPS receiver. It captures the ranging and navigational signals from the satellites in view and computes the user’s position (latitude, longitude and altitude), velocity and time (PVT). Any one with a suitable GPS receiver—an individual hiker, a vehicle on road, a ship or an aircraft—can receive the signals for navigation purposes.

The position accuracy of the GPS is about 20 and 30 meters in the horizontal and vertical directions respectively. Though this may be adequate for ocean and road transport navigation, aircraft navigation requires much greater accuracy. For example, the ICAO stipulates that the navigation system should provide a horizontal and vertical position accuracy of 16 meters and 6 meters respectively. The integrity or the correctness of the information should be 1 to 2 X 10^{-7} which means correct to more than one out of ten million times. It should quickly alert the receiver within 6 seconds, if the navigation system is out of tolerance and cannot be used. It should also be capable of continuous operation without interruption.

Sources of Error
Thus, the accuracy and integrity of the GPS is not sufficient for air traffic management and navigation, particularly during precision approach. Inaccuracies arise from several sources such as the ionosphere, drift in the satellite orbits (ephemeris), clock drift and signal degradation. These have to be corrected in order to augment the GPS signals to make them suitable for civil aviation navigation.

Ionospheric correction: The upper part of the atmosphere, from about 85 km to 1000 km from the surface of the Earth, is called ionosphere. Here, solar radiation ionizes air molecules by knocking out electrons out of them. This layer of ionized air has important practical applications. It makes possible the propagation of radio waves to distant places on the globe. However, electrons in the ionosphere scatter the GPS signals as they pass through the ionosphere, causing delay in their passage. Since position determination is based on the time taken by the signal to travel from the satellite to the GPS receiver, this delay introduces inaccuracies in range calculations.
The extent of delay in signal transmission is not the same at all locations on earth at all times. This is because the ionization in the ionosphere varies with a number of factors like the time of the day, the season, and solar activity. It also depends upon the geographical location such as poles, auroral zones, mid-latitudes, and equatorial regions. India is situated near the equator where the ionospheric variation is very high resulting in range inaccuracies of the order of 25 to 50 m.

This can be corrected by suitably modeling the ionosphere over the Indian airspace. To do this, a grid of 25 ground-based ionospheric reference stations, separated by 500 km, has been set up across the country. Each station is equipped with a dual frequency GPS receiver, which collects raw pseudorange measurements from all the visible satellites. These are then converted to what are known as "total electron content" in the ionosphere and further analyzed to generate a suitable ionospheric model to determine the signal delay over the Indian sky.

The Indian team at ISRO has been successful in the development of the region specific ionospheric model for the region. The implementation of this model along with the modification of the Grid Ionospheric Vertical Error confidence steps at the grid points is expected to provide the required performance levels. This effort in the Final Operational Phase is very creditable and will bring to focus our achievements in the area. It should be noted that this is a very difficult task given the various International standards to be adhered to, the need to be backward compatible and the vigorous testing and the certification process that is involved.

Ephemeris correction: The orbital positions of the satellites change due to natural phenomena such as gravitational force from the Sun and moon and due to pressure from solar winds. It is necessary to know the exact positions of the satellites for accurate range measurement. The order of precision required is several orders higher for Navigation Satellites than what is required for other applications. This is achieved through the use of precision ranging using the radio frequency signals as well as laser. There is always some error introduced due to the difference in the actual Ephemeris and the estimated one. This introduces some error in the location.

Clock drift correction: Highly stable Atomic Clocks are used in the Navigation Satellites for ensuring precision in the position accuracy. Even then, the minute drift of the onboard Atomic Clock introduces errors. Fortunately the errors are systematic in nature and it is possible to correct it to a large extent.

Multiple path correction: The signals coming from the satellites may also undergo multiple reflections and diffractions by objects like mountains, water bodies, tall buildings, etc on their path. This leads to degradation in their quality resulting in errors in range measurements. The error can be reduced by suitable choice of antennae and receivers.

GAGAN The ISRO and the AAI signed a MoU to install a space-based augmentation system (SBAS) to render the GPS signal suitable for civil aviation over the Indian airspace. An interesting aspect of the project is the name chosen for this system, which is strikingly Indian. It is called GAGAN (GPS Aided GEO Augmented Navigation).

As with GPS, SBAS also consists of three segments: the space segment, the ground segment and the user segment.

The space segment of GAGAN consists of three geosynchronous communication satellites. The first one, GSAT-8, was launched by ISRO on 21 May 2011 from Kourou, French Guiana. The satellite, weighing about 3100 kg, has been positioned in a geostationary orbit at 55-degree east longitude on the Indian Ocean. It carries a dual frequency L1 and L5 navigation payload compatible with the GPS. Since a minimum of three satellites are required to meet the availability specifications applicable for civil aviation, two more satellites will be added in due course.

The ground segment consists of 15 Indian Reference Stations (INRESs), an Indian Master Control Center (INMCC) and an Indian Navigation Land Uplink Station (INLUS), all suitably augmented. In the Final Operational Phase, which is currently being carried out, the Reference Stations are located at Ahmedabad, Bangalore, Thiruvananthapuram, Port Blair, Delhi, Kolkata, Guwahati, Jammu, Dibrugarh, Patna, Bhubaneswar, Nagpur, Goa, Porbandar and Jaisalmer. They are connected to the INMCC at Bangalore. Each station is provided with a minimum of two identical GPS receivers/antennae subsystems to receive GPS signals.

The INMCC processes the data received from all the 15 INRESs. It also estimates the availability and the integrity of the GPS satellites and transmits the corrections and confidence parameters to the INLUS.

The INLUS, also located at Bangalore, formats these messages consisting of ionospheric, ephemeris and clock drift corrections and transmits them to the satellites’ navigation payload for broadcasting to the user segment.

The user segment is a modified GPS receiver installed in the aircraft. It receives these signals and determines the aircraft's
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The exact location in the sky. The pilot can use this information for the navigation en route and for landing. The pilot can also broadcast this information, along with other aircraft-specific data to other planes and to the air traffic control facilities to obtain seamless navigation service for all phases of flight from takeoff to landing over the Indian airspace.

Implementation: All the ground systems consisting of the 15 INREs, the Master Control Center, and the uplink stations are already in place. As of October 2008 final site acceptance test of the ground segment, their integration and connectivity have been completed. These tests have demonstrated that GAGAN is capable of better than 7.6 meters accuracy in both vertical and horizontal, and time to alert better than 6.2 seconds, meeting the ICAO standards.

The satellite-based navigation system, after all the three satellites are in position, is expected to be made fully operational and certified in the coming years. ISRO provides the technology support, maintenance and replenishment of the space segment of the system. The Airports Authority of India is working along with ISRO for the successful implementation of GAGAN as a partner.

Interoperability and compatibility: GAGAN is not the only SBAS for navigation of civil aviation. The USA commissioned its SBAS version known as Wide Area Augmentation System (WASS) in the early 1990s. All the above mentioned systems are designed to ensure mutual compatibility.

GAGAN, although being built primarily for civil aviation, can cater to other applications. All the GPS applications could advantageously use the GAGAN signal that will ensure not only accuracy but also integrity. Such applications in future may include Railways and Maritime vessels.

Individual users in our country can also benefit from GAGAN since the higher positional accuracy will enable them to navigate themselves through the narrow lanes in both urban and rural areas which otherwise will be difficult.

GAGAN service is free of charge. Anybody in the coverage area and possessing the commercially available special GPS receivers can get the benefits of GAGAN.

The experience gained during GAGAN implementation will lead us to the successful completion of the tasks related to the establishment of the indigenous Indian Regional Navigation Satellite System (IRNSS). When that happens in a couple of years, our country will have firmly established itself in the field of satellite navigation.

Dr M.S.S. Murthy retired as Head, Radiological Physics Division, Bhabha Atomic Research Centre (BARC). Address: B-104, Terrace Garden Apartments, 2nd Main Road, BSK IIIrd Stage, Bangalore-560085

Dr K.N. Suryanarayana Rao is Former Project Director, GAGAN, ISRO