# INSAT Master Control Facility: An insight

*S. Rangarajan*

*An overview of the activities at the INSAT Master Control Facility (MCF) located at Hassan is presented. After a brief account of the INSAT services, the major subsystems of the spacecraft and their interrelationships are brought out. Important operations in different phases of the mission are described. The maintenance of these satellites in the geostationary orbit calls for periodic station keeping manœuvres. Facilities exist at MCF for carrying out these operations and also to provide support for the satellite users. A bird's eye view of the facilities is also included in the article.*

The Master Control Facility (MCF) is the only mission control centre for the INSAT satellites – past, present and future. It is located about 8 km north of Hassan town on way to the historic monuments of Halebeedu. What immediately catches the eye for a newcomer is the number of antennae looking like giant-sized cups propping up over a green line of trees. Unlike the sunflowers in the fields around, these antennae at MCF seem to be pointed for ever into the vast emptiness of space. Actually they are looking towards and communicating with those satellites which have come to revolutionize our life-styles in the last decade. INSAT satellites are placed in the geostationary orbit, a circular one in the equatorial plane, at an altitude of around 36,000 km, a height at which the period of revolution synchronizes with that of earth's rotation. From there about 42% of earth's surface is accessible for line-of-sight communication using an antenna pointed in a fixed direction.

The services provided by INSAT satellites have grown steadily both in terms of quantity and in terms of new services. In addition to traditional applications in the areas of telecommunication, TV and radio broadcasting and imaging for meteorological purposes, INSAT has several unconventional services like the collection of local meteorological data from remote unattended platforms, relay of zone-specific disaster warning messages, standard time and frequency distribution, tele-education, search and rescue system, etc. In fact, some of the services are not widely known, for example, the high-quality sky radio channels which are being distributed as an add-on to the regional language TV transmissions.

## Spacecraft subsystems

To understand how these multidimensional services are provided and what MCF's role is in controlling the satellite, it is essential to have a broad understanding of the satellite's subsystems and the orbit. A satellite can be visualized as being composed of its payload and the mainframe or a platform to operate the payload, comprising many interlinked subsystems. The payload is that part of the satellite which specifically caters to the application. For example, the communication payload on INSAT provides the necessary functional capabilities to receive a radio signal from a ground station in a specified frequency band, amplify and retransmit back to ground in a different frequency band. There are a number of subsystems which are essential for any operational spacecraft. Electric power subsystem is generally composed of solar arrays for generating power, rechargeable chemical batteries for storing power and power control electronics for load regulation. The attitude and orbit control system (AOCS) is composed of a set of attitude sensors to sense the current orientation of the body, processing electronics and set of actuators to generate control torques to orient the payload in the desired direction. The thermal subsystem provides the required thermal environment for the different components/subsystems. Active control using heaters is usually available. The propulsion subsystem provides the capability to carry out orbit transfers, orbit maintenance, and provides for attitude control torques. The subsystem directly interfacing with the mission control centre is the telemetry, tracking and command (TT&C) subsystem. The communication is in specific RF frequencies in the GHz range. The telemetry subsystem centralizes the encoding of information from all the onboard subsystems and transmits them as a telemetry signal, probably the ever-running commentary about the on-board activities. Command subsystem provides the capability for receiving, decoding and distributing commands from the ground. Turn-around ranging provides the tracking data for orbit determination.

## Orbit maintenance

A geostationary satellite has a designated longitudinal position in the equatorial plane over which it is placed.

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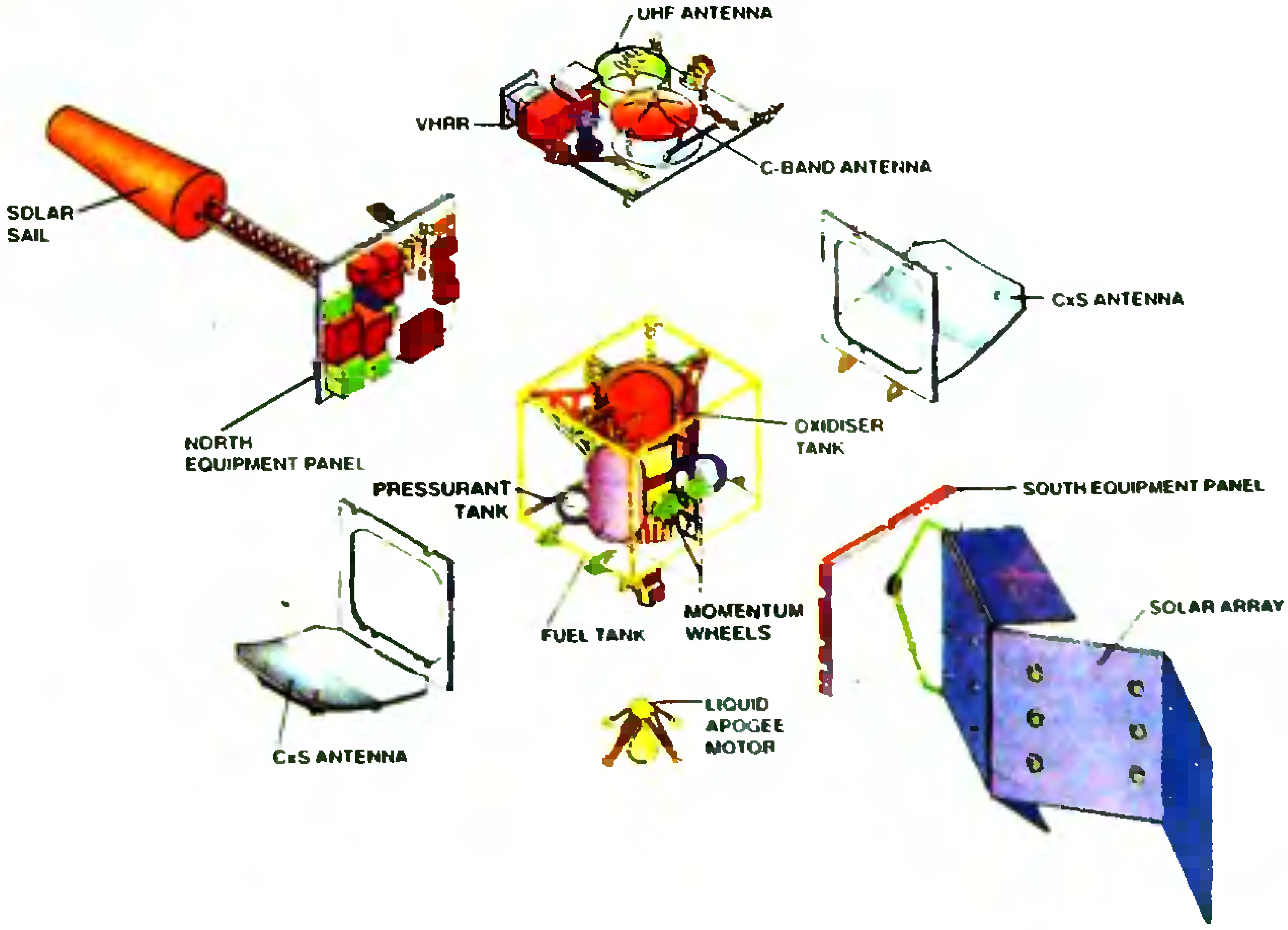
A view of the Master Control Facility, Hassan.




INSAT-2B disassembled view.

However, perturbations such as luni-solar gravitational effects, nonsphericity of the earth and solar radiation pressure cause deviations from the ideal orbit. These affect, respectively, the inclination, semimajor axis and eccentricity of the orbit. If there is any departure from the ideal geostationarity, the direction to the satellite will show a variation. Bigger antennae have a smaller beam width and hence this effect is more pronounced in them. The deviations are expressed in terms of the excursions in the latitude and the longitude of the subsatellite point (vertically below the satellite). It is MCF's responsibility to maintain the orbit such that these deviations are less than 0.1°.

For this purpose the orbit is determined by sending a set of sinusoidal tones from MCF to the satellite, modulating it on a suitable uplink carrier. The tones are turned around by the satellite on a downlink carrier. By measuring the phase difference between the transmitted and the received tones, the distance to the satellite is calculated. This, coupled with the direction information as determined from the antenna pointing angles, provides the instantaneous position in three dimensions. Similar measurements carried out several times a day are sufficient for reconstructing the orbit. From the determined orbit, it is possible to work out the optimal date and time of orbit correction manœuvres. The inclination of the orbit, which affects the latitudinal excursions, must be limited to 0.1° in case of INSAT. This calls for an out-of-plane thruster firing once in about 80 days. The propellant consumed in each of these manœuvres is about 4 kg for INSAT, which has an on-orbit mass in the range of 1000 kg. Once there is insufficient fuel for this correction, the inclination of the orbit will build up, marking the end of mission life. The control of semi-major axis and eccentricity calls for in-plane thruster firing and the fuel requirements are an order of magnitude less. However, the frequency of corrections can be as high as once in two weeks. These manœuvres are critical activities carried out with the participation of subsystem specialists on a real-time basis. A typical manœuvre operation lasts about 4 h and the user services remain unaffected.

## Orbital events

Precise orbit determination of satellite's orbit has other uses for preventive measures. If an observer views the celestial bodies from the satellite, he would naturally see them going around the satellite in various orbits, sometimes one occulting the other. Some of the orbit-related events are earth shadow, lunar shadow, sun/moon intrusion into the field of view of sensors, etc. As the evolution of the orbit is predictable to a reasonable accuracy, many of these events can be predicted well in advance and suitable actions planned. Some of the events greatly dictate the overall design of the satellite itself. For example, satellites in the geostationary orbit pass through the shadow of the earth around midnight local time for 45 days centred around the equinox. The longest eclipse is for 72 min and during this period the onboard battery supports the loads. Depending on the battery capacity, some loads may have to be shut off for the duration of the eclipse. The battery is to be charged using the solar power once the satellite comes out of eclipse and be ready for next day's eclipse. One can imagine the constraints put on the thermal subsystem of the satellite to maintain an equilibrium temperature for the critical subsystems in the absence of solar input for about an hour and to operate any heater, if at all, with tight power budget.

## Link between control centre and satellite

It may be true that the design methods go on improving constantly to keep the satellite going, but still space environment is not yet completely understood to make the systems error-free. For the payload as well as the other subsystems of the satellite, it is essential to monitor the proper functioning. If ever a fault is detected, immediate correction is called for not only from the point of view of user services, but also for preventing the fault from worsening and propagating to other subsystems. For this purpose, it is essential to have knowledge of the current status of the satellite. A number of parameters pertaining to the different subsystems such as the temperature at different locations, operating status of equipment, pressure of fuel tanks, voltage, current and power consumed of selected units, angular information with respect to solar and other bodies, etc., are measured onboard and transmitted to the control centre. Some of these parameters are analog which are converted to digital data by sampling and quantizing. The sampling rates are different for different parameters. For example, temperatures which are generally slowly varying are sampled less frequently compared to attitude information, which is sampled more often.

The different parameters are multiplexed to form a composite telemetry stream. INSAT-2 satellite has about 400 analog parameters and 400 status parameters to be monitored. These are organized into a telemetry masterframe which repeats every 8 s. The slowly varying parameters occur only once in a masterframe. Each masterframe has 8 frames and each frame has 128 eight-bit words. Including the overheads required to identify the start of frame and the subframe within the masterframe, the telemetry has a bit rate of 1 kbps. As the transmission from the satellite is at a very high frequency, the telemetry data are first modulated on a subcarrier which, in turn, modulates the RF beacon. INSAT uses PSK modulation on a 32 kHz subcarrier and PM modulation on a 4 GHz carrier. On ground, the entire sequence has to be undone, namely, receive the beacon, recover the subcarrier, obtain the bit stream, synchronize the frame, identify the words and bits, convert to engineering units, and display the data. Besides being useful for mission control, the telemetry data also provide important feedback to the designers.

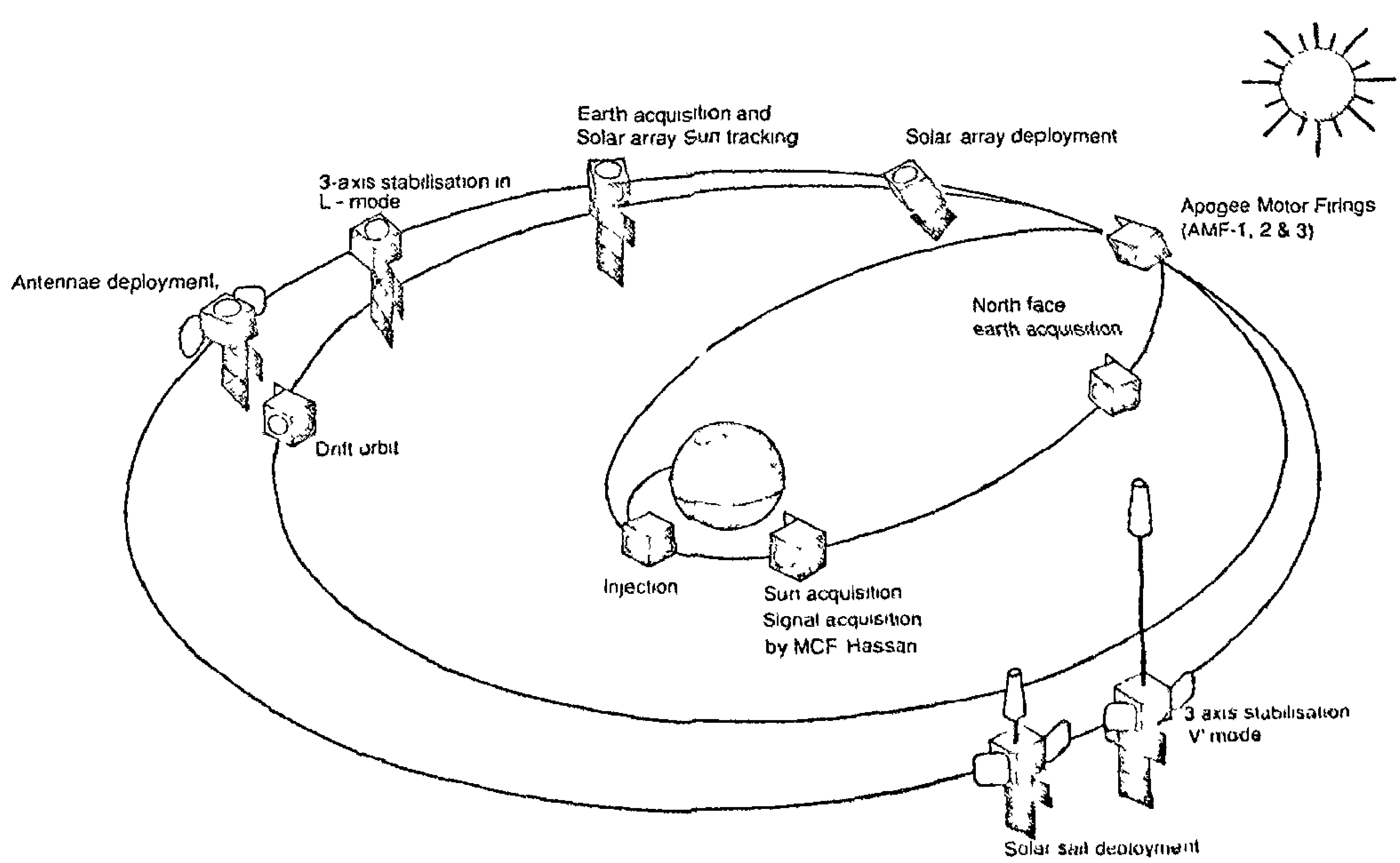
As the number of parameters is large, continuous surveillance of the data is carried out by the mission computer, which can present the data in graphical and tabular forms and also alert the operator in case of any abnormality. Even one bit of data being abnormal will be a nerve-racking experience to the operating crew.

The telecommand system provides the capability for receiving, decoding and distributing commands sent from the control centre. Commands are required for operating payloads, switching on/off heaters, firing thrusters, selecting a redundant system, etc. Here again the command code is a set of bits which are to be transmitted on a RF carrier. INSAT uses a 100 bps data with FSK/FM modulation on a 6 GHz carrier. Unlike telemetry, it is important to guard against even a single bit error in the transmission. For this purpose forward error control coding is used.

## Launch phase operations

In today's technologies, satellites are not just thrown in space. They are designed and built on ground but transported to the destination in space. Before reaching the final slot, each satellite, like INSAT, goes through a launch phase wherein many critical activities are undertaken. The launch and early orbit phase is full of excitement and MCF bubbling with activities. In the first one or two weeks, the major operations include firing of big rocket engines for orbit raising, opening out of antennae and solar panels, an elaborate testing of payloads, etc. In INSAT the transfer to the geostationary orbit is carried out by using a liquid apogee motor which gives a thrust of 450 N. This motor has to be fired in three parts for about 100 min in all, resulting in a propellant consumption of about 1000 kg. This must be compared with the propellant requirement for the next ten years of on-orbit operation, which will be around 200 kg. Deployment of the appendages is also critical as any failure will result in a total loss of mission.

So far MCF has supported six launches and in each case the signal from the satellite was received minutes after the satellite was put into orbit by the launch vehicle. This orbit is a highly eccentric one with perigee as close as 200 km from the ground and apogee at the geosynchronous height. Consequently, there is a large motion of the satellite relative to the ground calling for tracking antennae. Also, a given earth station cannot have continuous radio contact in successive orbits. For this purpose, additional tracking stations are deployed and a communication interface established with the tracking network. The launcher agency is also linked by dedicated communication channels so as to monitor




Mission sequence.

carefully the prelaunch operations which go on for 7–8 weeks. Prior to the launch the entire hardware at MCF undergoes revalidation. The mission control software is tested extensively and the operations crew are trained to carry out the sequence of events (SoE) pertaining to the mission. The simulation and rehearsals are conducted in several stages and last a few months.

## Normal phase operations

At the end of launch phase operations a satellite and its payloads are tested for their functioning and declared operational from its slot in space. Then onwards, the mission life of the satellite begins and the operations undertaken in this period are called normal phase operations. Spacecraft operations call for considerable planning and critical analysis so as to ensure flawless execution of commands and a fast response in the event of any contingency, pinpointing the problem area in case of a malfunction. Based on the user requirements nominal operations are detailed as an event schedule on a time line. Unforeseen behaviour is taken care of by issuing operations directives generated by the subsystem engineers. Equal importance is given for trend analysis and performance monitoring to detect even minor anomalies at the earliest. Emphasis is also laid on generating periodical reports as well as anomaly reports.

Though the operations may look quite routine for a casual observer during the normal on-orbit phase, the stakes involved are so high that it is important to monitor continuously the state of health of the satellite. A careless command or unwatchful operator can bring the end of life to a mission. The parameters pertaining to attitude control are rather important in this context. The attitude and orbit control system (AOCS) of INSAT in the normal on-orbit phase is designed around the concept of biased angular momentum. By spinning two flywheels an angular momentum of about 130 N m s is maintained, giving gyroscopic stiffness to the body. The disturbance torques are taken care of by adjusting the wheel speeds, making use of the principle of conservation of angular momentum. Unidirectional disturbances may result in the wheel speeds going to extreme values and hence at such times thrusters are fired (typically for 16 ms) to bring the wheel speed within the operating range. Even though the attitude control system works based on a closed-loop onboard control, it is important to monitor the system parameters from ground. Even a small error of 1° in the pointing will result in a shift of antenna beam by about 600 km on the surface of the earth, affecting all the user services. Such misorientations can arise for a variety of reasons like an anomalous thruster firing, a single event upset in the processor code, attitude sensor failure, etc. If any of these were to occur, quick corrective actions are called for. Depending on how high the body rates are, the recovery process may take anywhere from 15 min to 10 h. At such times of loss of attitude lock, the experts assemble at the control centre within 15 min irrespective of the time of occurrence of the anomaly.

## MCF facilities

MCF is an integrated control facility with multiple earth stations co-located with mission control centre. It presently has three full-motion antennae with trans-receive capability in C-band (6/4 GHz). There are a number of limited-motion antennae to support payload test in C-band, extended C-band, S-band (2 GHz) and UHF (400 MHz). It also has a boresite facility for zero range calibration and RF testing. The interface between earth stations and satellite control centre (SCC) is at 70 MHz. SCC houses the base-band equipment for telemetry, tracking and command, data processing system, timing systems, recording facilities and communication systems. The computer systems include PDP 11/70s and VAX systems. In keeping with the present-day trend, the future missions will be supported on distributed processing system. Besides the workstations, telemetry is being processed on PCs with suitable add-on cards developed in-house. The mission control software can be broadly divided into two categories – one for real-time data acquisition, processing, health monitoring and trend analysis, and the other for processing the tracking data, determining the orbit, predicting the orbital events and planning correction manœuvres.

A centralized power system provides uninterrupted power supply for each functional area. The captive generating system consists of six generators of 310 kVA capacity each. A variety of air-conditioning systems provide the required environmental control. It is a matter of great pride that all these systems are maintained in-house.

Initially it was a necessity to grow a garden around the facility to avoid collection of dust all around. Over the years the garden has been developed so well that it won a prize in the horticultural competition at the State level.

The facility started with just about 40 persons in the year 1980. Now even the security staff belonging to the CISF exceed this number! The present staff strength of MCF is around 300, drawn from different engineering disciplines, technical branches and administrative areas. At any time 18 persons are on round-the-clock shift duty headed by an Operations Manager. He or she will coordinate with the users on real time as required. The spacecraft controllers undergo a well-structured training programme for six weeks followed by on-the-job training for a similar duration. It is noteworthy that MCF was asked to organize a course for such controllers working for Arabsat, a multinational organization controlling similar satellites. If MCF has been able to achieve smooth and flawless operations for all these years, it is only due to the personal involvement of everyone of the staff members who takes pride in his or her job with an excellent team spirit.

MCF has been responsible for several innovations such as the survival of INSAT-1B through the eclipse season in spite of the loss of both the onboard batteries, use of attitude control thruster firings for orbit adjustment, detailed on-orbit measurement of antenna footprint, etc. MCF has also taken the lead in indigenization programmes as well as technology transfer to the industry.

### Into the future

INSAT system is still in the stage of growth in terms of introduction of newer payloads and newer services. Correspondingly, the augmentation of the facilities at MCF will go on for the next few years. For example, presently, new earth stations are being built for testing Ku-band (11/14 GHz) communication payload and Mobile Satellite Service (MSS) payload. In the next three years a launch of INSAT is planned every year. There will also be experimental missions carried on the test flights of GSLV. Each launch calls for calibrating, checking and revalidating the performance of every subsystem to ensure fail-safe operation. The launch seasons are so hectic that the MCF personnel have very little time for other activities. However, the routine operations tend to be less glamorous, but provide useful feedback to the designers. ISRO is one of the few organizations in which the satellite design and operations are carried out under the same umbrella. This is sure to pay rich dividends in the long term.

# Vegetarianism: A nutritional appraisal

*K. T. Achaya*

*Vegetarianism in India is perhaps 3000 years old. What is the extent of flesh consumption at present? How do vegetarian diets stand up to scrutiny in the light of modern nutritional knowledge? What of the future? These are the questions addressed in this paper.*

NOWHERE in the world except in India is the concept of vegetarianism really commonplace, or accepted without explanation. Nor is this surprising, since the vegetarian ethos was propounded here by the Vedic Indians as early as about 1000 BC. There are many today who are a product of total vegetarian eating for as long as hundred generations, and survive, reproduce and live full and satisfying lives, both physically and mentally. So it has been done, and can be done. There is room, however, to review the current trends in the use of animal foods, and the practice of vegetarianism, in relation to the knowledge of scientific nutrition that has been unravelled over the last century or so.

### Proportions and causes

Census figures of 1971 record the proportions of vegetarians that exist in the various states of India. Among the high-vegetarian-population states (expressed as percentages of the population) are Gujarat 69, Rajasthan 60, Punjab–Haryana 54 and Uttar Pradesh 50. At medium levels come Madhya Pradesh 45, Karnataka 34, Maharashtra 30 and Bihar 24, while the low-vegetarian-population states are Tamil Nadu 21, Andhra Pradesh 16, Assam 15, and Kerala, Orissa and West Bengal 6 each. The overall figure for vegetarianism in the whole country in 1971 was 28%.

What is the nature of this vegetarianism? Reliable dietary data have been collected for the years 1979–81 by the National Nutrition Monitoring Bureau, Hyderabad, in 10 states spread all over India[1]. In the rural areas of these 10 states, the consumption figures for fish and other flesh foods (including eggs)[1] are shown in Table 1. Everywhere, fish intake is much higher than that of meat, the averages for each of these for the 10 states being about 10 g of fish and just 3 g of meat a day. Since vegetarians form about one-quarter of the popula-

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