# Field Aligned Current Experiment in the Ionosphere and Thermosphere – FACE-IT

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*Summary*

*FACE-IT will observe the field aligned currents in the magnetosphere using two different instruments: The well-known vector magnetometer and a new instrument the 'Faraday Current Meter'. The 'Faraday Current Meter' will allow direct measurements of very fine spatial structures in the field aligned current patterns while the vector magnetometer gives superior measurements of larger spatial structures. The current measurements will be used to develop a more detailed understanding of the interaction between the solar wind and the energy transfer processes to the magnetosphere-ionosphere system. The nominal mission lifetime to reach the scientific objectives is 1 year. The international interest in the field aligned current measurements is very high.*

## 1. The Scientific Objectives

The field-aligned currents carry the major energy input to the ionosphere from the magnetosphere and solar wind. Direct observations of the magnitude and structures of these current systems will be a major breakthrough in the understanding and interpretation of the interaction processes taking place between the solar wind and the upper ionized part of the atmosphere, dominated by the Earth magnetic field.

Presently, electric currents in space are detected by observing their integrated magnetic characteristics or by counting the net amount of charge carriers flowing in any given direction. Both methods suffer from serious drawbacks. The interpretation of existing magnetic measurements is geometry-dependent and becomes less sensitive for small-scale structures in known current signatures, dominating a range of ionosphere and magnetosphere processes. Detectors counting streaming charged particles miss the populations of particles with energies above and below the instrument's measurement range. Furthermore, they also require a good spatial coverage of all pitch angles for extended integration times to form the total particle distributions of the species observed.

The main scientific objective of this mission is to perform observations of the ionosphere/magnetosphere field-aligned current system with an unprecedented accuracy to reveal the spatial small-scale structure and magnitude of these currents during different geophysical conditions. It has recently been shown [2] that the current contribution from these small-scale structures is substantial (up to 300 $\mu A/m^2$) and higher than previously reported.

Electric currents flowing in the plasma surrounding the Earth constitute the decisive part of the energy transport and conversion processes taking place between the Sun and the Earth's ionized atmosphere. Some of the more prominent consequences of this energy exchange are the spectacular northern and southern auroral displays, the magnetic storms regularly perturbing the Earth's otherwise quiet magnetic field, and the occasional abnormally large absorption of electromagnetic waves in the polar regions.

The solar wind drives the magnetosphere dynamo, which leads to the system of field-aligned currents (FACs) connecting the energy dissipation in the ionosphere with the plasma flows in the magnetosphere. At high latitudes FACs feed the mainly Hall current electrojets, revealing from ground, observations of the interaction processes between the magnetosphere and the solar wind. The current patterns in the bottom of the ionosphere are very sensitive to the magnetosphere conditions. During magnetic storm conditions large changes in the FAC distribution of the polar cap and the auroral regions lead to a range of processes, which still are not well understood and established due to the limitations in the existing satellite observations.

*Global high latitude currents.* The bulk flow of the quiet time field-aligned currents is carried by charged particles of energies less than 1 keV. The average estimates of large scale FACs in the high latitude region 1 [4] give magnitudes of the order of 1-30 $\mu A/m^2$. While region 2 FACs [4] have been estimated to be up to 80 $\mu A/m^2$. The horizontal extents of the FAC filaments are reported to be less than 10 km.

*Auroral FACs.* To study the processes taking place in auroras, it is important to be able to observe the structures of the FACs and their magnitude, to determine other auroral phenomena as the plasma waves, field-aligned electric fields, electron and ion beams, emerging during these events. The thin sheet FACs in auroras has horizontal extents sometimes less than 1 km with peak current densities along the direction of the magnetic field of up to 100-300 $\mu A/m^2$. See reference [2]. The 1-10 keV parts of the particle population carry the FACs, often in pairs of upward and downward flowing currents. Thus it is important to establish an alternative method of measuring FAC in order to resolve the large variability and the small-scale structure in FACs. Additionally, a more direct method of FAC observations will lead to a spatial and temporal resolution needed to verify the predicted structures of simulation studies.

*Global ionosphere conductivity distribution.* Many large-scale interpretations of the physics of the ionosphere rely on models of the spatial and temporal conductivity. Tomographic representations of the mission's observations can describe the conductivity distribution and thereby complement the derivations of other observations with less a priori knowledge of the ionosphere structures.

*Space weather and magnetic storms.* We are becoming increasingly dependent on technologies that are affected by the space environment and the physical phenomena dominating the space around our planet. Observations from this mission are suited to address forecasting goals by, direct measurement of electron density, currents and electric fields for assimilation into a physical models designed for space weather predictions. Because of the dynamical coupling in the thermosphere-ionosphere, a physical model that assimilates these data will provide solutions to other physical parameters related to composition and winds of the species of the medium.

## 2. The Space segment

The main science instrument on the field-aligned current mission is a new instrument called the 'Faraday Current Meter' (FCM), which is particularly well suited for measurements of small-scale space plasma currents, without the inherent uncertainties of the existing methods. The sensor consists of a circular loop of optical fiber guiding a polarized beam of laser light. The change in polarization direction of the laser light is a direct measure of the circular magnetic field along the closed fiber, attributed to the current flowing through the plane of the loop. The figure below shows the proposed satellite in a schematic drawing.

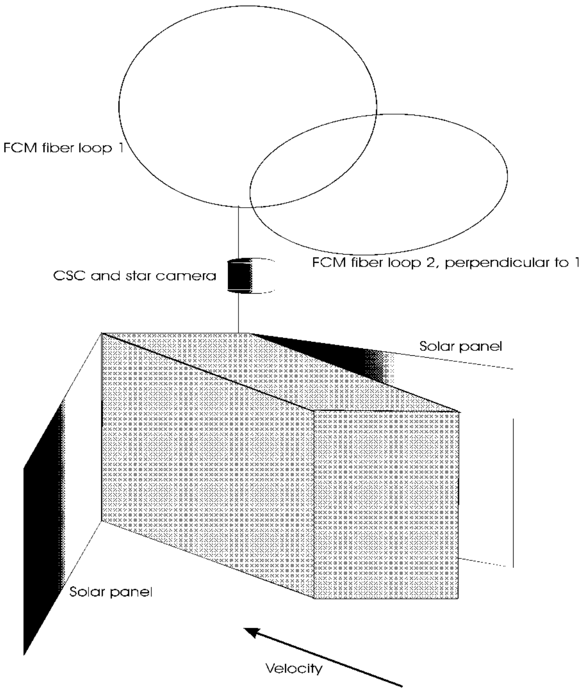


Figure 1. A schematic drawing of the FACE-IT satellite.

The FCM will be complemented with a fluxgate vector magnetometer (CSC) to monitor the larger scale variations in the field-aligned currents. DC electric field sensors will assist in the interpretation of the resistivity and diffusion characteristics of the plasma, together with the GPS instrument's monitoring of the changes in the total electron content of the medium.

The payload concept for the mission can be summarized to consist of:

Main scientific instruments

- 1 FCM instrument consisting of 2 perpendicular 10 m loops
- 1 CSC vector magnetometers
- 4 DC electric field sensors
- 1 GPS instrument

The main specifications of the FCM instrument are expected to be:

| | |
|---|---|
| Coil size diameter: | 10 m |
| Fiber length: | 4.2 km |
| Laser wavelength: | 1.55 µm |
| Mass: | < 1 kg |
| Electronics, mass | 2.0 kg |
| Power: | 5 W |
| Sensitivity: | < 15 $\mu A/m^2$ |
| Data sampling rate: | 20 Hz |

Other necessary basic instruments

- 1 Star camera, integrated to the CSC magnetometer
- 3 magnetic torquers
- 4 solar panels
- 4 batteries
- 1 S-band communication unit
- 2 receive only omnidirectional antennas
- 2 transmit helix antennas

The star camera will perform the primary attitude determination. This information will be used by three magnetic coils to active control the attitude of the satellite. The GPS receiver will continuously determine the spacecrafts attitude by combining GPS signal phases from 3 antennas. The output will be a 3D-orientation knowledge to within ±2°, with an attitude rate change of <1°/sec. FACE-IT will also have coarse miniature sun sensors at the corners of the satellite, which can provide a ±10° attitude knowledge. Thus the attitude control subsystem will maintain the platform stability and pointing accuracy to better than 10°.

The main body of the satellite is expected to be of the same size as the Ørsted satellite. The vector magnetometer is expected to be placed on the boom supporting the FCM coils. The mass of the satellite is estimated to be about 35 kg. The electrical power consumption for the full spacecraft will be around 60 W. A more detailed mass and power budget is given below together with a list of the organizations with the potential to develop the different parts of the satellite.

| Satellite system element | Mass (kg) | Power (W) | Developed by |
|---|---|---|---|
| Solar panels and structure | 3.0 | 90.0 (Peak), 60 (Avg.) | Danish Industry |
| FCM | 3.0 | 5 | DMI/DTU |
| CSC | 1.0 | 4 | DRI/DTU |
| Star camera | 1.0 | 5 | DRI/DTU |
| E-field sensors | 1.0 | 1 | Uni of Texas |
| GPS receiver | 3.0 | 6 | JPL |
| Communication | 1.0 | 10 | Danish Industry |
| CDH system | 1.0 | 10 | Danish Industry |
| Attitude control | 1.5 | 3 | Danish Industry |
| Power system | 2.5 | 2 | Danish Industry |
| Satellite structure | 7.0 | | Danish Industry |
| Boom/boom motor | 3.0 | 5 | Danish Industry |
| Power margin | | 9 | |
| Total | 28 | 60 | |

## 3. Launch

The FACE-IT satellite will contain four types of science instruments, and a set of supporting satellite platform subsystems including a deployable boom. The satellite is suitable for a secondary payload launch on a Delta-II rocket, depending somewhat on the compactness of the booms for the FCM instrument in the launch configuration. The main body of the satellite is shaped as a box of the size of ØRSTED with modular electronic boxes and configured with the subsystems given above.

## 4. Mission Requirements

The orbit for the FACE-IT satellite is envisioned to be polar with a high inclination (> 80°), precessing slowly to cover all local times within six months. The altitude of the circular orbit has to be around 470 km in the initial phase of the mission. Assuming the same drag-forces for high solar maximum conditions as for the CHAMP mission, it is conceivable to expect more than one-year of lifetime of the mission. For lower solar activity the duration could be much longer.

If the satellite could be launched during the lifetime of the ESA's CLUSTER mission it could contribute significantly to the CLUSTER mission. For the CLUSTER mission it would scientifically be very important to be able to describe the FAC structures of the ionosphere and magnetosphere.

The nominal mission life time to reach the scientific objectives is 12 months. The designed orbit life time of all satellite elements has to match 36 months.

## 5. Science Partners

The *primary users* of the data products are entities, which normally receive scientific ionosphere data mostly for research activities. The group of data users consists of:

- Ionosphere research community
- Space weather monitoring centers
- Defense space weather services

The mission will draw considerable international interest due to the uniqueness of the observations and the potential for new interpretation and verification of FAC models.

If launched parallel to the CLUSTER mission the impact of FACE-IT will be unprecedented.

Ground based observations from radars and magnetometer chains all over the world will certainly be a major activity in the exploitation of the observations. The science partners and users for this mission include:

Jet Propulsion Laboratory, Los Angeles
Oslo University, Oslo
Swedish Institute of Space Physics, Uppsala
Geophysical Research Laboratory, Boston
Naval Research Laboratory, Washington
Stanford Research International, San Francisco
University of Texas, Houston
John Hopkins University, Maryland

## 6. Relation to other Missions

The FACE-IT mission will have relations to several European and US missions scheduled for future Earth observation programs. They consist of:

CLUSTER, (ESA)
NPOESS, (USA)
DMSP, (USA)
CHAMP, (Germany)
GRACE, (USA/Germany)
SAC-C, (Argentina/ USA/Denmark)

## 7. Technical Challenges

While many technical issues are settled, various design tradeoffs and options need still to be examined in greater detail. The principal ones include:

- *FCM design* – The FCM instrument has been verified in the laboratory and flown on sounding rockets. But is not yet developed for space applications. Thus it will be important to start an instrument study of all aspects of the design concept.
- *Deployment mechanisms* – The deployment ideas used in the sounding rockets needs to be further refined for satellite applications of this kind. The process will not be decisive for the success of the mission, but will have an impact on the size and design of the satellite.
- *Solar Panels* – The solar panels consist of gallium arsenide cells with high individual peak power specifications. Each panel is planned to hold 40 cells in four strings. It needs to be investigated if other types of solar cells/arrays would have a higher sensitivity for larger zenith angles than the ones chosen, to omit the large variations in the power input along the orbits of the satellite and to reduce the battery capacity.
- *Orbit* – To maintain the low orbit a more detailed study is required to evaluate the need for propulsion as part of the payload.

## 8. References

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[4] *Introduction to Space Physics*, M. Kivelson and C. Russell, *Cambridge University Press*, 1995.