Overview

In January 2000 an 80 cm solar telescope flew for 17 days suspended from a balloon in the stratosphere, 35 km above Antarctica. The goal was to acquire long time series of high spatial resolution images and vector magnetograms of the solar photosphere and chromosphere. Such observations will help to advance our basic scientific understanding of solar activity. Flare Genesis’s principal advantage over ground-based telescopes is in its uninterrupted high-resolution coverage.

When the telescope was in line of sight with the ground station, communications were guaranteed via a two ways low-speed radio link for commanding and telemetry, and a high-speed downlink for receiving images. During the rest of the flight, only limited telemetry and commanding capability was available via INMARSAT and ARGOS satellites.

The telescope landed safely on the Ross Ice Shelf at about 340 km from the McMurdo station, after 409 hours of flight around the Antarctic continent. Due to landing late in the season and to bad weather only the data tapes were recovered from the ice. The rest of the instrument will be recovered in early November 2000. FGE recorded about 50,000 images of solar active regions which are now under analysis. In particular it was able to observe the evolution of a young region with magnetic flux emergence, and the occurrence of a flare.

Web site:  http://sd-www.jhuapl.edu/FlareGenesis/
The basic design of the FGE gondola was derived from a payload developed by the Harvard/Smithsonian Center for Astrophysics (CFA). The frame is bolted together from standard aluminum angle. The structure is strong enough to support the 4400-lb weight of the instrumentation even under a design load of 10 g, and is rigid enough to allow stable pointing to at least 10 arcsec.

A key component, at the top of the gondola, is the Momentum Transfer Unit (MTU). It provides (1) the means for pointing in azimuth (a motor provides torque between the frame and a reaction wheel, simultaneously accelerating the frame in one direction and the wheel in the other); (2) a means for transferring momentum from the frame+reaction wheel system into the flight train; and (3) the support and attachment point between the gondola and the flight train.

An Image Motion Compensation system (IMC) is used to stabilize the image at the CCD focal plane to about 1". It is composed by a sun sensor capable of detecting pointing errors down to 0.05 " and a fast tip-tilt mirror.

Main Telescope, Pointing Telescope, and a pressure vessel housing the optical analysis stages are mounted together and pivoted around the elevation axis, driven by a torque motor.

The main scientific instrument an Imaging Vectormagnetograph. Its main components are:
- Polarization analyzer: 2 liquid-crystal polarization modulators + 1 linear polarizer
- 3 thin-film 1.25 Å prefilters for wavelength selection.
- 0.16 Å lithium-niobate Fabry-Perot etalon filter coated for 6000 - 6600 Å operation.
- 1024 x 1024-pixel Kodak Megaplus CCD camera - 20 MByte/s read rate.

Gondola dimensions (width x depth x height): 512 cm x 240 cm x 480 cm
Instrument description

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Momentum Transfer Unit

- balloon cable
- reaction wheel
- momentum dump motor
- torque motor
- thrust bearing
- titanium shaft
- gondola frame
FGE capability

- **Spatial resolution:** Limited by diffraction to 0.2" (145 km at Sun center)
- **Spectral resolution:** 0.016 nm passband tunable over spectral line profiles with repeatability to 1x10^-4 nm
- **Wavelength range:** 610 - 660nm
- **Field of view:** 100" x 100"
- **Detector:** Charge Coupled Device (CCD), 1024 x 1024 pixels, 10 bits
- **Exposure interval:** About 70 s for one vector magnetogram (12 images)
- **Data products:** Time series of vector magnetograms at various wavelengths, vector velocity & intensity in the photosphere and chromosphere
- **Data storage capacity:** 54,000 images = 9 tape cassettes with ~ 6000 images each
- **Telemetry downlink:** 0.5 Mbit/s for images, 1 kbit/s for commands & status check
- **Detectable magnetic field:** $B_z = 10 - 100$ G, $B_{x,y} = 50 - 200$ G (depending on tradeoffs in data processing); $B_z$ is the line-of-sight component
- **Spectral lines:**
  1) Ca I 612.2 nm, Landè-Factor $g = 1.75$
  2) H I (Hα) 656.3 nm
  3) 624.9 nm (continuum)
Command, Control & Communications

- **2 on-board main computers:**
  - Autonomous Control Executive (ACE): controls instrument operations, observations scheduling.
  - Instrument Control Computer (ICC, APL/JHU - design): handles communications between ACE and instrument subsystems & with ground.

- **First 24 hours: Line-Of-Sight communication with ground station**
  - Send telemetry via low speed downlink
  - Send images from CCD + real time video camera via high speed downlink
  - Receive commands

- **Rest of flight: communications via INMARSAT and ARGOS satellites through NSBF Support Instrument Package (SIP)**
  - Communications are sporadic.
  - ACE autonomously commands operations of instrument according to observing program & Region of Interest table prepared before flight.
  - Tables can be modified in flight through Over the Orison Commands
Pointing System

- **Track-state 0: No tracking.** Used only during ascent

- **Track-state 1: Coarse tracking.**
  - Azimuth pointing using 4 photodiode sensors on each corner of the gondola.
  - Elevation calculated through ephemeris and real time GPS position.

- **Track-state 2: Intermediate tracking.**
  - 2 photodiodes with cylindrical lenses in front are mounted on the front of the guider telescope to measure azimuth and elevation errors.
  - Field of view = ±20°; pointing accuracy ≅ 0.25°

- **Track-state 3: Fine Tracking.** Used to point at specific locations on the Sun
  - A guiding telescope rigidly mounted to the main telescope projects a full solar disk image onto a Lateral Effect Diode (LED).
  - LED mounted on X-Y motion stage, that moves it in azimuth and elevation.
  - Servo loop maintains the solar image on the LED center.
  - LED has metal disk occulting 90% of Sun’s image to improve error sensitivity.
  - Field of view ≅ 1°; pointing accuracy ≅ 0.05” RMS.
Pointing System & IMC

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  - LED has a metal disk occulting 90% of Sun’s image to improve error sensitivity.
  - Field of view $\approx 1^\circ$; pointing accuracy $\approx 0.05”$ RMS.
- An Image Motion Compensation system (IMC) is used to stabilize the image at the CCD focal plane to about 1”.
  - A fast tip-tilt mirror located at the entrance pupil (see optical schematic) is tilted to compensate the residual image motion. The mirror is coupled to 2 voice-coil actuators via thin rods that bend.
  - Actuators are driven by signals formed from LED fine pointing error measurements.
The FGE Flight Path
January 10-27, 2000

Launch site: Ross Ice Shelf near McMurdo Station

Landing site: Ross Ice Shelf 340 km from McMurdo 17 days later

Flight trajectory at an average altitude of 35 km.

50,000 images recorded. The payload survived the landing without suffering significant damage. Due to bad weather only the data tapes have been recovered so far. The instrument will be recovered in early November 2000.
The Flare Genesis Telescope Ready For Launch in Antarctica, January 10, 2000
Flight performance

- **Optical system & scientific data:**
  - **Image resolution:** variable between 0.5" and 1".
  - **Polarimeter:** Worked well during the entire flight.
  - **Observations:** Very long time series of photospheric and chromospheric images + vectormagnetograms on various active regions, and one flare observed on January 22. See the examples below.

- **Image stability:** Good but not optimal. The tip-tilt active Image Motion Compensation mirror (IMC see optical setup) was able to compensate for pointing errors as big as 15". The residual RMS image offset at the CCD focus was about 1.1", and the peak image offset was 2.0".

- **Telescope pointing:** Jitter about 10" (see graph below). Fine pointing at the Sun was lost only once, for 10 h, during the entire flight.

- **Computer system:** Operated fairly well throughout the entire flight. Occasionally the command control computer stopped and required a computer reset commanded manually from the ground.

- **Communications:**
  - **Line Of Sight:** maintained for the first 24 h, and for the last 15 h prior termination.
  - **Over The Orison:** Satellite link was very sporadic but sufficient to guarantee adequate telemetry and commanding capabilities during most of the flight.

- **Thermal performance:** All components operated within the expected temperature ranges with the exception of the heat dump mirror, whose temperature gradually rose up to 90° C
The Flare Genesis Experiment probes rapidly growing sunspots - January 25, 2000

FGE filtergram at 6122.428 Å
image size: 92" x 92"
spatial resolution: ~ 0.5"
Example of a vectormagnetogram of the active region 8841, recorded on January 25, 2000

Photospheric filtergram with Fabry-Perot passband centered at 6122.428 Å, on the blue wing of the CaI 6122.5 Å. Field of view is 90" x 90", with a spatial resolution of about 0.5". Distance between minor tick marks is 1".

Map of the longitudinal photospheric magnetic fields (parallel to the line of sight). The field strength is indicated by the bar on the left. White, positive fields point towards the observer.
Direction of the transversal magnetic field component

The orientation of the transverse component is indicated by the pixel color, as in the color wheel at the lower left. Note that there is a 180-degree ambiguity in the direction.

The same data as in the figure on the left, but with the transverse field direction indicated by lines superimposed to the 6122.428 Å filtergram.
Conclusions

- **FGE had a successful flight of 409 hours**, with precise solar pointing throughout.

- **Achieved ~1 arcsec image stability.**

- **Image resolution lower than expected, but remained constant over long periods.**
  Proven very difficult to perform high precision optical alignment in Antarctica, without appropriate facilities and tools.

- **Obtained unprecedented observations of evolution of solar magnetic fields.**
  Data acquired will provide valuable insight in structure and evolution of solar magnetic fields in active regions during flares.