# Environmental Qualification of the ACE-FTS Instrument

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## ABSTRACT

The Atmospheric Chemistry Experiment (ACE) is the mission selected by the Canadian Space Agency (CSA) for its next science satellite, SCISAT-1. ACE consists of a suite of instruments in which the primary element is an infrared Fourier Transform Spectrometer (FTS) coupled with an auxiliary 2-channel visible (525 nm) and near infrared imager (1020 nm). A secondary instrument, MAESTRO, provides spectrographic data from the near ultra-violet to the near infrared, including the visible spectral range. In combination the instrument payload covers the spectral range from 0.25 to 13.3 micron. A comprehensive set of simultaneous measurements of trace gases, thin clouds, aerosols and temperature will be made by solar occultation from a satellite in low earth orbit. The ACE mission will measure and analyse the chemical and dynamical processes that control the distribution of ozone in the upper troposphere and stratosphere. A high inclination (74 degrees), low earth orbit (650 km) allows coverage of tropical, mid-latitude and polar regions.

This paper describes the results of the environmental qualification campaign of the ACE-FTS instrument flight model. Performance test results during thermal-vacuum (TVAC) testing are presented. Stability of the instrument at various temperatures under thermal and vacuum environment are discussed. Qualification of the ACE-FTS under vibrations at instrument and spacecraft levels are covered.

**Keywords:** ACE, FTS, SCISAT-1, Spectrometer, FEA, Random Vibration, TVAC, Environmental Qualification

## 1. INTRODUCTION

Before being qualified at spacecraft level, the ACE-FTS instrument had been tested taking a protoflight approach. This means that no qualification hardware was built. Instead, the Flight Model (FM) was tested at a qualification level but with the same duration of an acceptance test. Of course, a higher level of confidence in the Finite Element Model (FEM) and experimental tests at sub-system level is thus required.

Opto-mechanical aspects were extensively tested (vibrations, adhesive strength, pressure clamping, bolt pre-loading, tension test, drop test and Zygo measurements) at sub-system level in order to correlate engineering calculations and/or Finite Element Analysis (FEA). The vibration qualification testing at instrument level was performed at the CSA's David Florida Laboratory (DFL) between July 2nd and July 4th, 2002. The vibration qualification testing at spacecraft level was performed at the DFL between August 16th and August 18th, 2002.

A detailed Thermal Mathematical Model (TMM) was the baseline of the FEM which was then experimentally correlated. The Thermal-Vacuum Chamber (TVAC) acceptance test at ACE-FTS level was performed at ABB Inc. between September 3rd and September 14th, 2002. On-orbit temperature distributions within the instrument were predicted from FEA/TVAC test correlation. The Thermal-Vacuum Chamber (TVAC) acceptance test at spacecraft level was performed at the DFL between November 5th and November 22nd, 2002.

More information on the ACE-FTS design can be found in "*ACE-FTS Instrument Detailed Design*"[1].

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## 2. PROTOFLIGHT QUALIFICATION VIBRATION LEVELS

Initial random vibration input levels for the ACE-FTS instrument were based on the requirement SES.IRV.1[2]. As the mechanical design was being refined, the instrument overall mass Current Best Estimate (CBE) was getting more precise. That allowed, at one point of the design, to lower the Power Spectral Density (PSD) levels according to GEVS-SE[3]. Also, following ACE-FTS-spacecraft coupled FEA, Bristol Aerospace proposed an update for the qualification random input level, which significantly reduced PSD in the mid-frequency range. Finally, a specific conference board review on launch vehicle (Pegasus XL) input PSD level was held at the DFL involving the CSA, Bristol Aerospace, Terry D. Scharton and ABB Inc. After discussion on acoustic issues, it was agreed to lower PSD levels in some of the frequency ranges.

| **Frequency (Hz)** | **X direction PSD Level ($G^2$/Hz)** | **Frequency (Hz)** | **Y, Z directions PSD Level ($G^2$/Hz)** |
|---|---|---|---|
| 20 | 0.018 | 20 | 0.018 |
| 50 | 0.14 | 50 | 0.1135 |
| 115 | 0.14 | 100 | 0.1135 |
| 160 | 0.04 | 160 | 0.018 |
| 540 | 0.04 | 440 | 0.018 |
| 700 | 0.04 | 700 | 0.04 |
| 800 | 0.04 | 800 | 0.04 |
| 2000 | 0.018 | 2000 | 0.018 |
| **Overall** | **8.45 Grms** | **Overall** | **7.61 Grms** |
| **Duration** | **60 s/axis** | **Duration** | **60 s/axis** |

Table 1: ACE-FTS Instrument Protoflight Random Vibration Test Levels.

A few weeks before the ACE-FTS vibration qualification test, the CSA accepted that Force Limited Vibration[4] (FLV) technique could be the applicable method rather than a low level demonstration. The FLV method was initially planned to be performed as a complement to the protoflight vibration qualification. FLV testing was developed at NASA JPL and was successfully used during the last decade in several space missions. In addition to controlling the input acceleration, the FLV testing measures and limits the reaction force between the test article and the shaker. This force limiting technique results in acceleration notching at predominant natural frequencies of the test article.

## 3. VIBRATION TESTS BEFORE QUALIFICATION

Even though the ACE-FTS instrument involved large amount of FEA (static, modal, Gaussian reduction, non linear, random vibration and enforced dynamic), the FEM had to be correlated with the test results. One major point was to extract the modal damping ratio of the whole instrument from test/FEA correlation. With this validated known data, a more realistic stress and strain results could be attained from the random vibration FEA.

The ACE-FTS structural detailed FEM is a 150,000 degrees of freedom model including 29,000 nodes and 28,000 elements (solid, beam, shell, spring and lumped mass elements). All interface fasteners were modeled using tri-axial and tri-rotational spring elements with K constant values tuned with sub-system test correlations. For example, the eight ACE-FTS to spacecraft G10 sleeves and Ti 6Al-4V bolts were tested in detail, because of their critical damping and modal effects on the instrument dynamic responses. To cover the Power Spectral Density (PSD) frequency range of 20 to 2000 Hz, 360 modes were processed with normalized effective mass of 99% in each direction.

### 3.1. EM-1 First Random Vibration Test Campaign

The first vibration of the Engineering Model-1 (EM-1) was performed at the David Florida Laboratory (DFL) in February 2001. Some important aspects had to be verified during these tests: mechanical strength of the flex pivots, test fixture validation, miscellaneous logistic aspects and FLV force sensors manipulation and procedures. The instrument structure frame was at this time very similar to the Flight Model (FM) which was being manufactured in parallel. Inside the instrument, most of the sub-system modules were approximated by mounted aluminum dummy blocks with mass and inertia very closed to the predicted properties.

Even though some components were missing (top and bottom covers and ACE-FTS end wall), some deficiencies had to be corrected that could not have been anticipated from passed experience or FEA. For example, flex pivots could not sustain the launch vibration while keeping their initial location. There were evidences of micro-slipping. Slight modifications were required on the test fixture to accommodate the FLV force sensors. The ACE-FTS to spacecraft interface sleeves made in G10 material demonstrated weakness. Finally, one of the two EM retro-reflectors broke during a sine sweep test ran at moderate level.

Regarding the FLV technique, the purpose of this test was to repeat the force sensor manipulation and set-up done previously on a Structural Model (SM) developed and built at the CSA Space Technologies Sector[4]. Eight force sensors were inserted between the test article and the fixture that had to be adapted to support them.

Lessons learnt from this early testing were determinant for the future of the ACE-FTS instrument design.

### 3.2. EM-1 Second Random Vibration Test Campaign

The second vibration test of the Engineering Model-1 (EM-1) was performed at the CSA Space Technologies Vibration Laboratory in St-Hubert, Quebec in August 2001 with all dummy components. The main purpose this time was to tune the FEA viscous damping ratio from dynamic responses at specific critical nodes. Then, a detailed FEA/Test correlation allowed to set an average of 1.25 % viscous damping ratio for the FEM for the whole frequency range 20-2000 Hz. However, this assumption was still conservative considering that at some response nodes there were almost 4-5 % viscous damping ratios while 0.5 % at others with no major structural contribution. In fact, it would have been too long and costly to set-up a specific damping value for different frequency ranges between 20 and 2000 Hz. However, this variable damping ratio effect on FEA modal results was studied but finally not applied because of frequency resonances at similar level for different sub-systems. For FLV technique, this test was a more realistic run[5] than the first one because the EM-1 was then much closer to the FM.

Following this test campaign, a detailed FEA/test correlation allowed to point out the importance of the FEM set-up of the interface spring constants (translational and rotational). The G10 ACE-FTS to spacecraft sleeves and Ti 6Al-4V bolts were modeled with these kinds of elements. From correlation, it was learned that by increasing translational spring stiffness in lateral direction, the frequency response from FEA results was actually increased. Also, stiffening rotational spring at the G10 interface, the G's responses at structural FEA nodes slightly increased.

### 3.3. Flex Pivots Optimization during Test Campaign

Tremendous efforts have been given to optimize the interferometer rotary arm flex pivots strength. More than a dozen of random vibrations tests with dummies rotary arm, retro-reflectors, and pin-puller (active caging for launch) were performed. The optimized engineering solution safely sustained 35 Grms, with positive safety margins. In July 2002, during the ACE-FTS vibration qualification test, a maximum value of 23 Grms was monitored at rotary arm flex pivots. Flex pivots final design is Electro Discharge Manufactured, made of stainless steel 17-7 CH900 and mounted with an in-house robust and accurate clamping method. The commercial FEA programs used, I-DEAS and ANSYS, did not allow to model the exact phenomena supposed to be a dynamic buckling coupled with accelerated fatigue. The main difficulty was to model dynamic (modal and random vibration) with large displacements. This is why this specific mechanism was optimized by test rather than by too complex and possibly unreliable FEA.

Finally, the robust configuration which had been vibrated was then cycled during several weeks on a test bench to simulate fatigue of the orbital life. The flexures survived to the vibration tests and cycling and kept their nominal characteristics.

## 4. VIBRATION TEST QUALIFICATION AT INSTRUMENT LEVEL

The vibration qualification testing at instrument level was performed at the David Florida Laboratory (DFL) between July 2nd and July 4th, 2002 (Figure 1). All along these tests, extra attention was put in protecting the ACE-FTS instrument against dust and molecular contamination. In addition of being hermetically covered with two layers of ESD bags, the instrument was constantly purged with filtered dry nitrogen to create a positive internal pressure.

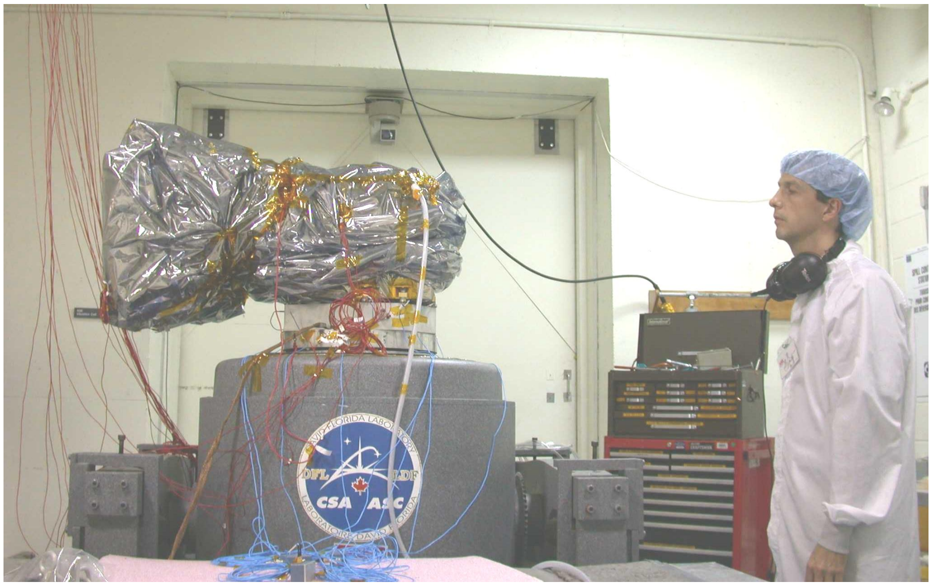


Figure 1: ACE-FTS Vibration Test Qualification at Instrument Level.

A summary of the FLV test procedure is listed below and was applied to each axis:

1. Low level random vibration run with flat input (1 Grms, 20-2000 Hz, 30s.) to calibrate the FLV force sensors and to obtain the apparent mass.
2. Low level random vibration run with the same relative frequency spectrum as full level without force limiting (−18 dB, 30s.) used as a reference dynamic signature.
3. Low level random vibration run with the same relative frequency spectrum as full level with force limiting (−12 dB, 60s.).
4. Full level random vibration run with force limiting (0 dB, 60s.).
5. Low level random vibration run with the same relative frequency spectrum as full level without force limiting (−18 dB, 60s.) used for comparing with the first reference dynamic signature.

Z axis was the first to be tested because it presented the most potential FLV notching. For practical considerations, the next axis was Y because the instrument was already mounted on the shaker slip table. Last axis was the vertical excitation X. For all axis the ACE-FTS instrument was monitored with seven accelerometers located at the following critical components:

- Cryo-cooler Earth Shield End Tip in Y direction.
- Cryo-cooler Earth Shield End Tip in X direction.
- Rotary Arm in Y/Z direction.
- Beam Splitter Wall at Flex Pivot in Y/Z direction.
- Input Optics Plate in X/Y direction.
- Electronic Box in X direction.
- Electronic Box in Z direction.

As previously mentioned in section 3.3, extreme attention was paid to the rotary arm transducer response. The Grms level at which the flex pivots would have been damaged was known very precisely. Also, the acceptable maximum PSD response ($G^2$/Hz) at frequency resonance of 1200 Hz was known.

In Figures 2 and 3, curve correlations (Rotary Arm and Input Optics Plate) are presented between test and FEA at −18 dB of the full level without FLV. Test results at −18 dB without FLV were not extrapolated since the ACE-FTS demonstrated non-linear dynamic comportment. An easier way to present correlation was to run a simple FEA at this lower PSD input.

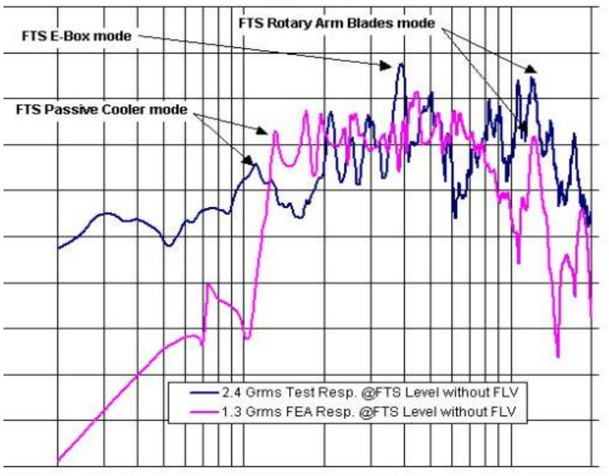


Figure 2: Rotary Arm Response without FLV (−18 dB, 60 s.).

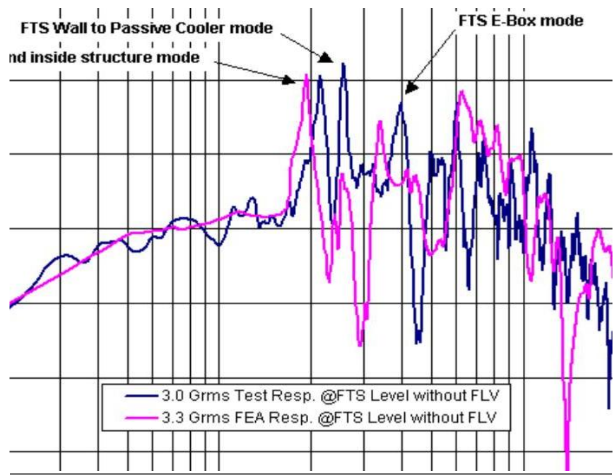


Figure 3: Input Optics Plate Response without FLV (−18 dB, 60 s.).

In Table 2, some correlations (Rotary Arm, Input Optics Plate, Earth Shield) are summarized between test and FEA at −18 dB of the full level. Detailed analysis demonstrates that the frequency modes, at their expected frequency ranges and the output PSD values, are all within 15% except for the Rotary Arm where test shows almost twice as the FEA (section 3.3).

| Accelerometer | Event Direction | FEA Responses @−18 dB (Grms) | Test Responses @−18 dB (Grms) | Grms Responses Ratios (FEA)/(Test) |
|---|---|---|---|---|
| Earth Shield X | X | 3,0 | 2,6 | 14% |
| Earth Shield Y | Y | 3,0 | 2,8 | 7% |
| Rotary Arm | X | 1,3 | 2,4 | -47% |
| Input Optics Plate | X | 3,3 | 3,0 | 10% |

Table 2: Summary of the FEA and Test Responses without FLV (−18 dB, 60 s.).

No damage was observed on the instrument following the three full level axis vibration tests. All substrates and flex pivots were closely inspected and finally spectra acquisitions confirmed that the instrument had kept its structural and functional integrities. In addition to the spectra acquisitions, the alignments of critical optical interfaces were measured and were within the allowed values.

## 5. VIBRATION TEST QUALIFICATION AT SPACECRAFT LEVEL

The vibration qualification testing at spacecraft level was performed at the DFL between August 16th and August 18th, 2002. (Figure 4). During these tests, the ACE-FTS instrument was also protected against dust and molecular contamination. The instrument mounted on the spacecraft deck plate was constantly purged with filtered dry nitrogen to create a positive internal pressure.


Figure 4: ACE-FTS Vibration test Qualification at Spacecraft Level.

The Table 3 below shows the spacecraft protoflight random vibration test levels:

| Frequency (Hz) | Spacecraft X, Z directions PSD Level (G²/Hz) | Spacecraft Y direction PSD Level (G²/Hz) |
|---|---|---|
| 20 | 0.008 | 0.008 |
| 35 | 0.008 | 0.008 |
| 40 | 0.008 | 0.016 |
| 55 | 0.008 | 0.016 |
| 65 | 0.008 | 0.008 |
| 1500 | 0.008 | 0.008 |
| 2000 | 0.002 | 0.002 |
| **Overall** | **3.73 Grms** | **3.79 Grms** |
| **Duration** | **60 s/axis** | **60 s/axis** |

Table 3: Spacecraft Protoflight Random Vibration Test Levels.

These tests were conducted by Bristol Aerospace engineers. The ACE-FTS instrument was monitored with seven accelerometers located at the same locations as during instrument level qualification test. The whole spacecraft was monitored with a total of fifty-one transducers. In Figures 5 and 6, test responses are presented (Rotary Arm and Input Optics Plate) at ACE-FTS and spacecraft levels at full level respectively with and without FLV. The most important verification was of course to ensure that no under-testing, using the FLV method, had been performed at instrument level.

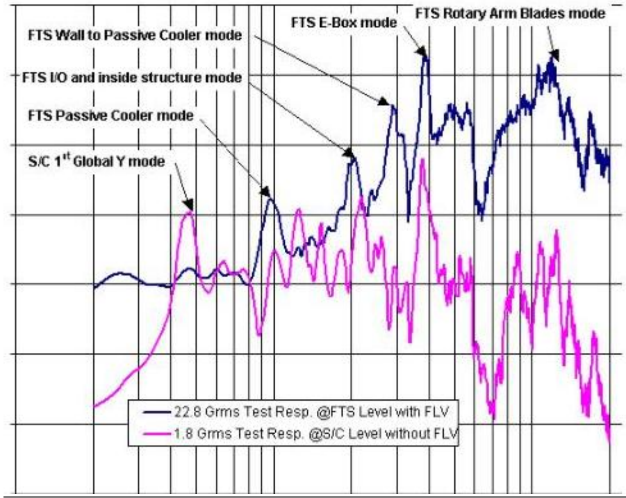


Figure 5: Rotary Arm at Instrument and Spacecraft Levels (0 dB, 60 s.).

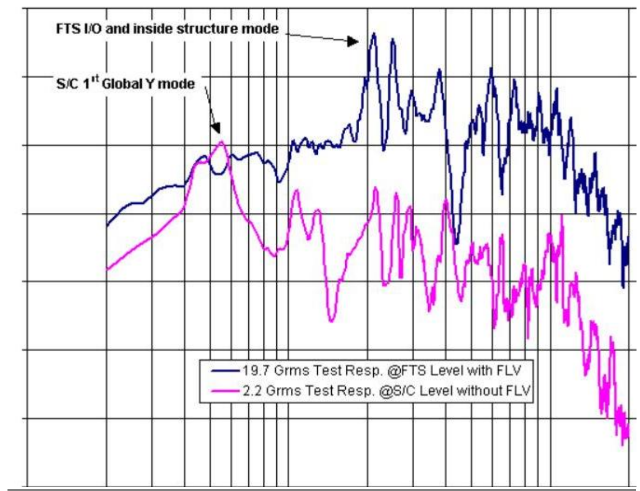


Figure 6: Input Optics Plate at Instrument and Spacecraft Levels (0 dB, 60 s.).

Key results are summarized in Table 4. It appears that no under-testing has occurred, and that the Rotary Arm has been largely over-tested at instrument level. However, this can be explained by flex pivot frequency resonance occurring at 1200 Hz (Figure 5) and FLV notching applied at a lower frequency range. Also, in Figure 6, there is a peak at 55 Hz in the spacecraft response curve that overlaps the ACE-FTS response curve. This frequency corresponds to the spacecraft first global Y mode and therefore should be discarded for the instrument level results analysis.

| Accelerometers | Event | Responses @ Instrument Level @ 0 dB (Grms) | Responses @ Spacecraft Level @ 0 dB (Grms) | Responses Level Ratios Instrument / Spacecraft |
|---|---|---|---|---|
| Earth Shield Y | X | 13 | 4 | 4 |
| Earth Shield X | X | 22 | 11 | 2 |
| Rotary Arm | X | 23 | 2 | 13 |
| Input Optics plate | X | 20 | 2 | 9 |
| Earth Shield Y | Y | 20 | 3 | 6 |
| Earth Shield X | Y | 9 | 2 | 5 |
| Rotary Arm | Y | 13 | 3 | 5 |
| Input Optics plate | Y | 14 | 1 | 11 |
| Earth Shield Y | Z | 6 | 3 | 2 |
| Earth Shield X | Z | 10 | 5 | 2 |
| Rotary Arm | Z | 17 | 1 | 15 |
| Input Optics plate | Z | 13 | 2 | 6 |

Table 4: Summary of the Test Responses for ACE-FTS at Instrument and Spacecraft Levels (0 dB, 60 s.).

Considering the overall Grms responses, the following sub-systems were over-vibrated during the instrument level qualification test:

- Cryo-cooler (Earth Shield) by at least a factor 2 (and up to 6)
- Rotary Arm (flex pivots are one of the most sensitive parts) by at least a factor of 5 (and up to 15)
- Input Optics Plate by at least a factor of 6 (and up to 11)

Even with over-testing, no damages were observed on the instrument following the three full level axis vibration tests. Again, after close inspection of all substrates and flex pivots, and running spectra acquisitions, the instrument had kept its structural and functional integrities.

## 6. ACE-FTS THERMAL MODEL

The ACE-FTS detailed thermal model was modeled to represent accurately the TVAC surroundings and internal powers. TVAC results of two cases were compared with the TVAC Thermal Model to determine if the model was enough accurate to predict on-orbit temperatures for critical operation and survival modes: Cold and Hot Cases.

### 6.1. The Thermal Mathematical Model

The ACE-FTS instrument Thermal Mathematical Model (TMM) is summarized in Figure 7. The TMM, which schematizes the thermal resistance between major components, is the baseline of the Thermal FEM.

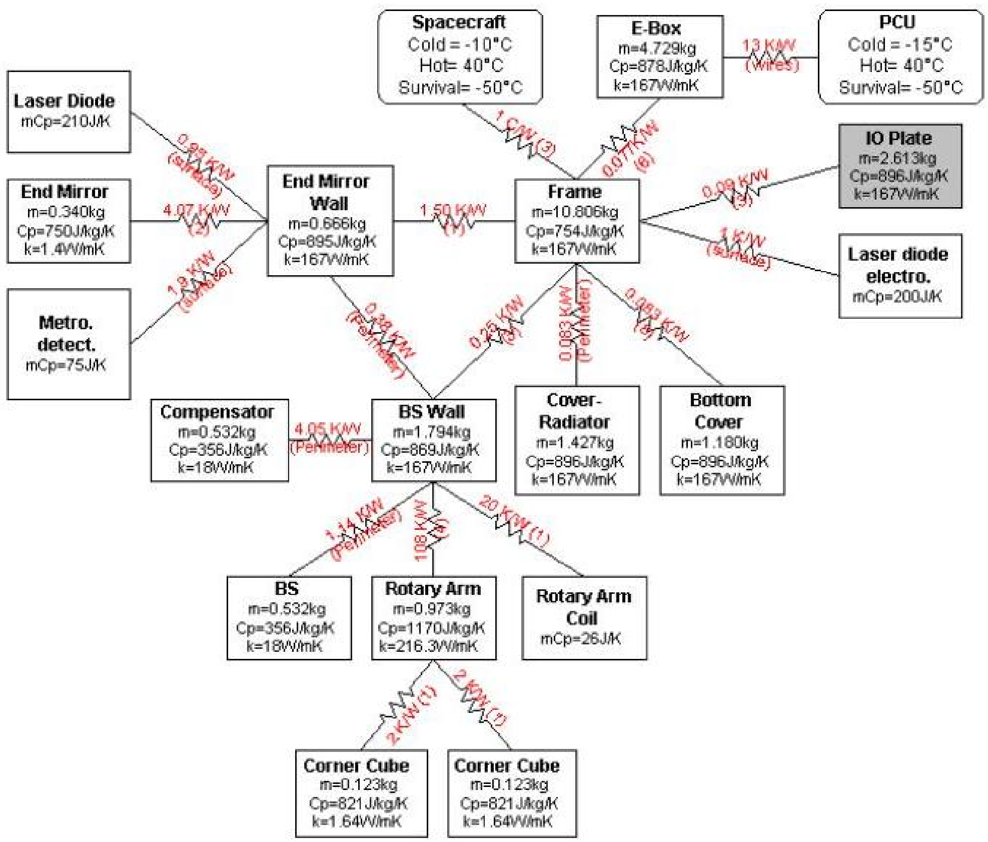


Figure 7: Thermal Mathematical Model.

### 6.2. The Thermal Finite Element Model

The Thermal FEM includes 6670 elements and 5998 nodes. The Input Optics substrates are modeled with 3D elements for a more precise temperature distributions. The Suntracker (developed by Ball Aerospace) model is done with a few shell elements since it has a considerable isolation from the coupled unit. The interferometer substrates are modeled using shell elements since they have a simple circular shape.

### 6.3. The FEA Thermal Model Environment

The radiation to space has been replaced by a radiation calculation between all the exterior surfaces of the instrument (four sides and base plate covered with MLI and radiator) and the inside surfaces of the TVAC shroud (Figures 8 and 9). The shroud was set to fixed temperatures has described below:

- Cold Case: 200.35 K constant on 4 sides and top – emissivity of 0.9;
  263.15 K constant on base plate – emissivity of 0.15
- Hot Case: 198.58 K constant on 4 sides and top – emissivity of 0.9;
  313.15 K constant on base plate – emissivity of 0.15.

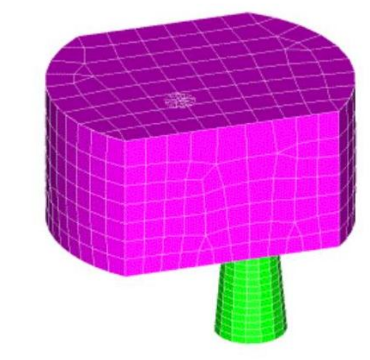

Figure 8: ABB TVAC Shroud outside view.

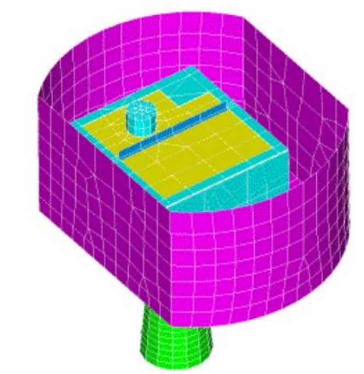

Figure 9: ABB TVAC Shroud inside view with ACE-FTS.

### 6.4. The FEA Thermal Model Radiation

The radiation was evaluated using the following parameters:

- The baffle was set to a fixed temperature of 270 K and an emissivity of 0.15 for both Hot and Cold Cases.
- The patch was set to a fixed temperature of 293 K and an emissivity of 1.0 for both Hot and Cold Cases.
- The radiation calculations occurring inside the ACE-FTS was kept as the detailed model.

The following components are included in the internal radiation: Electronic Box, Structure Frame (inside surfaces), Covers (inside surfaces), Interferometer with substrates, Rotary Arm, Retro-Reflectors, Back of Primary Mirror, Suntracker Bracket, Suntracker Isolated Unit and Input Optics Plate.

# 7. ACE-FTS THERMAL MODEL VALIDATION FROM TVAC TEST RESULTS

The TVAC instrument level characterization was performed at ABB Inc. between September 3rd and September 14th, 2002 (Figure 10). The model and the results allowed to predict FEA on-orbit temperatures distribution in the instrument.


Figure 10: ACE-FTS TVAC Qualification at Instrument Level.

The twelve days acceptance test[6] at instrument level is summarized in Figure 11. During all the test, the internal pressure of the TVAC was maintained lower than $1x10^{-5}$ Torr. The first of the two thermal vacuum cycles was made of a Survival Hot Case, an Operational Hot Case and an Operational Cold Case.

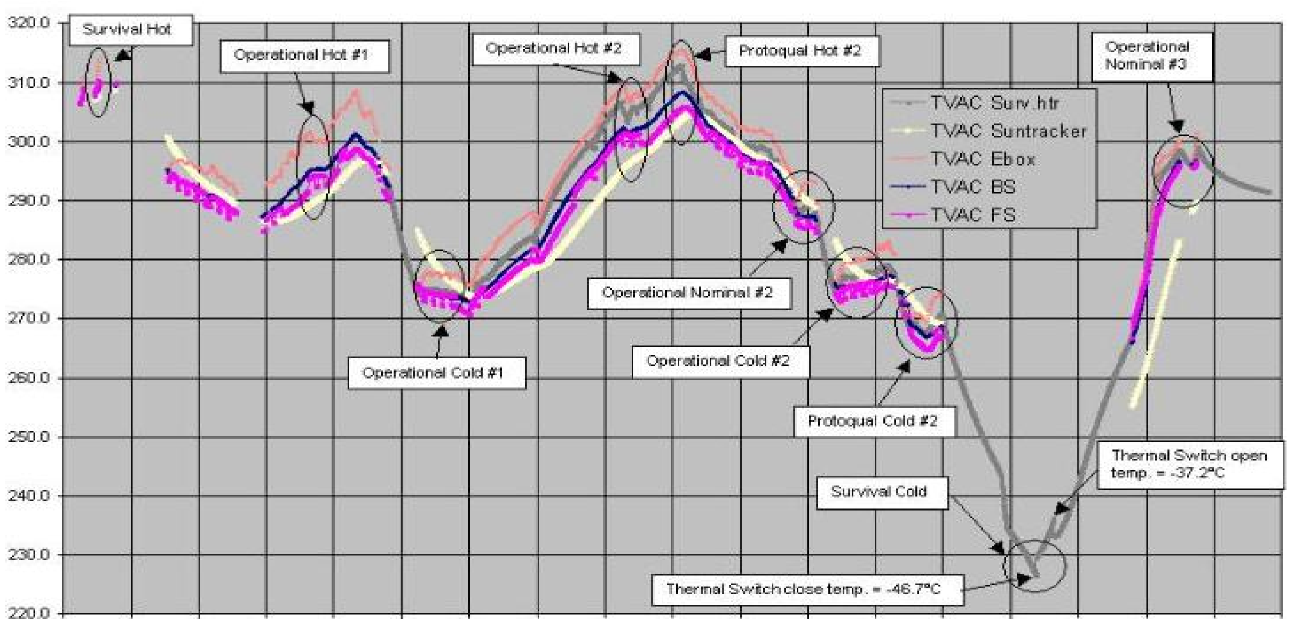


Figure 11: ACE-FTS TVAC Qualification at Instrument Level.

The Operational Hot and Cold Cases #1 were taken to validate the thermal model in respectively a Hot and Cold Case scenario:

- Beam Splitter
  Hot Case temperature was within 2.5 K of the thermal model;
  Cold Case temperature was not well stabilized but the curve extrapolation gives a stabilization at approximately 273 K which is within 2.5 K of the thermal model.

- Field Stop
  Hot and Cold Cases temperatures were within 2.5 K of the thermal model

- Electronic Box
  Hot and Cold Cases temperatures were about 5 K colder than the thermal model. This can be explained by a better conductivity at the Electronic Box/Frame interface than in the thermal model.

- Survival Heater Sensor
  Hot Case temperature was not available;
  Cold Case temperature was not well stabilized but the curve extrapolation gives a stabilization at approximately 274 K which is within 2.5 K of the thermal model.

- Suntracker Mirror
  Hot Case temperature was not well stabilized but the curve extrapolation gives a stabilization at approximately 294 K which is within 2.5.K of the thermal model;
  Cold Case temperature was not well stabilized but the curve extrapolation gives a stabilization at approximately 274 K which is within 2.5 K of the thermal model

The conclusion is that the ACE-FTS Thermal Model is mainly within 2.5 K of the TVAC tests. The model was then considered enough accurate to predict on-orbit environmental conditions of the mission.

## 8. ACE-FTS ON-ORBIT THERMAL MODEL

The ACE-FTS on-orbit detailed thermal model is the same than TVAC model except for radiation with surroundings, space environment and internal power. This model was used to predict the extreme temperatures in the optical substrates at various simulated orbits and scenarios (Table 5):

- Operation Cold Case $\beta = 0$;
- Operation Hot Case $\beta = 53$;
- Survival Cold Case $\beta = 90$ (no heater);
- Survival Cold Case $\beta = 90$ (Survival heater at 9.5 W);
- Turn-on Case $\beta = 0$.

| | Right Ascension of Ascending Node | FTS Radiator Silver-Teflon Tape Emissivity | FTS Radiator Silver-Teflon Tape Solar Aborptivity | MLI Effective Emissivity | Kapton Outer Layer Emissivity | Kapton Outer Layer Solar Absorptivity | Electrical Mean power (with heater power) | Input Optics Absorbed Solar Mean power | Solar Intensity | Albedo | Earth IR | Baseplate Temperature | PCU Temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta$ (Degree) | $\varepsilon_{Radiator}$ | $\alpha_{Radiator}$ | $\varepsilon^*_{MLI}$ | $\varepsilon_{Kapton}$ | $\alpha_{Kapton}$ | $P_E$ (W) | $P_s$ (W) | S (W/m$^2$) | A (%) | $E_{IR}$ (W/m$^2$) | $T_{Base}$ (°C) | $T_{PCU}$ (°C) |
| Operation Cold Case | 0 | 0.79 | 0.05 | 0.05 | 0.78 | 0.45 | 19.8 | 7.4 | 1290 | 31.6 | 213.9 | -10 | -15 |
| Operation Hot Case | 53 | 0.79 | 0.20 | 0.01 | 0.78 | 0.55 | 21.1 | 9.5 | 1420 | 39.6 | 239.1 | 40 | 40 |
| Survival Cold Case | 90 | 0.79 | 0.05 | 0.05 | 0.78 | 0.45 | 0 | 0 | 1290 | 31.6 | 213.9 | -50 | -50 |
| Survival Cold Case | 90 | 0.79 | 0.05 | 0.05 | 0.78 | 0.45 | 9.5 | 0 | 1290 | 31.6 | 213.9 | -50 | -50 |
| Turn-on Case | 0 | 0.79 | 0.05 | 0.05 | 0.78 | 0.45 | 0.0 | 7.4 | 1290 | 31.6 | 213.9 | -10 | -15 |

Table 5: Thermal parameters at various simulated orbits and scenarios.

In the actual instrument, the bottom cover has a hole in it to give the Suntracker a view to space. This view is restricted by a cylindrical baffle. Efforts have been made to include the effects of the incoming fluxes from space through that hole and the effect the baffle temperature. The baffle was then added to the thermal model, and a temperature profile was imposed on it for each beta angle case. Since the solar fluxes entering by the baffle opening are already included in the power tables of the thermal model, only the albedo is calculated with space radiation.

- The Cold Case time averaged power is 27.2 W
- The Hot Case time averaged power is 30.7 W
- The Survival Cold Cases time averaged power is 0 W, 9.5 W and 15.6 W
- The turn on Case time averaged power is 7.4 W

| | β Angle (°) | Mean Frame Temperature (°C) | Coldest Point Temperature in Optics (°C) | Hottest Point Temperature in Optics (°C) | Temperature at Radiator (°C) |
|---|---|---|---|---|---|
| Operation Cold Case | 0 | 4.5 to 5.3 | 1.88 to 2.42 at Retro-Reflector | 8.9 to 12.8 at Primary mirror | -4.0 to 0.4 |
| Operation Hot Case | 53 | 33.4 to 33.8 | 29.14 to 29.66 | 39.18 to 42.88 | 22.1 to 25.6 |
| Survival Case (no heater) * | 90 | -65.0 | -65.2 | -64.8 | -66.1 |
| Survival Case (heater 9.5W) * * | 90 | -42.6 | -44.1 | -43.5 | -45.8 |
| Survival Case (heater 15.6W) * @ | 90 | -28 | -30 | -29 | -32 |
| Turn-on Case * | 0 | -27.2 | -27.70 | -20.10 | -30.5 |

| | β Angle (°) | Beam Splitter (°C) | E-Box (°C) | Field Stop (°C) | Survival Heater Sensor (°C) |
|---|---|---|---|---|---|
| Operation Cold Case | 0 | 5.7 to 6.1 | 10.5 to 11.7 | 4.1 to 7.1 at Primary mirror | 4.9 to 5.9 |
| Operation Hot Case | 53 | 33.9 to 34.2 | 40.5 to 41.8 | 32.7 to 35.7 | 33.9 to 34.5 |

Table 6: On-Orbit anticipated results.

The On-Orbit ACE-FTS Thermal Model was validated by the TVAC ACE-FTS Thermal Model and the TVAC test results and was used to predict the extreme temperatures in the optics at various simulated orbits and scenarios.

The On-Orbit Hot Case temperatures are higher than TVAC test and thermal model results because the TVAC shroud temperature was calculated eighteen months before and was too cold to perfectly represent a real averaged orbital environment. The On-Orbit Hot Case temperatures are higher than the actual design because the power absorption have significantly increased especially on the primary mirror. The temperatures are nevertheless considered accurate enough to consider thermal and distortion analysis sufficient to validate the design.

## 9. CONCLUSION

The ACE-FTS Flight Model instrument has successfully passed the Protoflight Qualification Vibration and Thermal Tests. Even though FLV method was successfully applied at instrument level, the ACE-FTS sustained at least twice the G's responses at spacecraft vibration level, which also demonstrates a very robust design adapted to space environment. In the near future, FLV method should be considered earlier in the opto-mechanical design process in order to minimise over-design in addition to over-testing and mission cost.

Thermal Qualification was a success with a very accurate TVAC/FEA correlation within 2.5 K, considering that the minimum thermal margin was plus or minus 10 °C.

Post-qualification spectra acquisition have shown that the instrument kept all its structural and functional integrities. SCISAT-1 is scheduled for launch by NASA in August, 2003.

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## REFERENCES

1. M.-A. Soucy, F. Chateauneuf, C. Deutsch, N. Étienne, ABB Bomem Inc., Radiometry Division, "*ACE-FTS Instrument Detailed Design*", Proceedings of SPIE 2002, Vol. 4814.
2. Bristol Aerospace Limited, "*ER 990082/B SCISAT Environmental Specification (SES)*".
3. GEVS-SE, "*General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components, GEVS-SE, Rev.A, June 1996*".
4. Y. Soucy, R. Singhal, D. Lévesque, R. Poirier, T. Scharton, T.D. (2002). "*Force Limited Vibration Testing Applied to the FTS instrument of SCIAST-1*", ASTRO 2002-12$^{th}$ CASI Conference on Astronautics, Ottawa, On., Canada, Nov.12-14.
5. R. Sedaghati, Y. Soucy, N. Étienne. "*Efficient Estimation of Effective Mass for Complex Structures under Base Excitations*", Canadian Aeronautics and Space Institute, Canadian Aeronautics.
6. F. Chateauneuf, S. Fortin, C. Frigon and M.-A. Soucy, ABB Bomem Inc., Radiometry Division, "*ACE-FTS Test Results and Performances*", Proceedings of SPIE 2002, Vol. 4814.