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MSX Satellite Flight Measurements of Contaminant Deposition on a CQCM and on TQCMs*

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Abstract

The Midcourse Space Experiment (MSX) is a Ballistic Missile Defense Organization (BMDO) demonstration and validation satellite program that has both defense and civilian applications. MSX was launched April 24, 1996, and has UV, visible, and infrared instruments including the SPIRIT 3 (Space Infrared Imaging Telescope) cryogenic telescope. It also has several contamination measuring instruments for measuring pressure, gas species, water and particulate concentrations and condensable gas species. A cryogenic quartz crystal microbalance (CQCM) and four temperature-controlled microbalances (TQCMs) are part of this suite of contamination measuring instruments on board the satellite. This paper describes some of the flight QCM data obtained and analyzed to date. The CQCM is located internal to the SPIRIT 3 cryogenic telescope and is mounted adjacent to the primary mirror. Real-time monitoring of contaminant mass deposition on the primary mirror is being provided by the CQCM, which is cooled to the same temperature as the mirror -- ~20 K. The four TQCMs are mounted on the outside of the spacecraft and monitor contaminant deposition on the external surfaces. The TQCMs operate at ~ -50 C and are positioned strategically to monitor the silicone and organic contaminant flux arriving at specific locations, such as near to the UV instruments, or coming from specific contaminant sources such as the solar panels. Time histories of contaminant thickness deposition for each of the QCMs are presented. During the first week of flight operation, all QCMs recorded deposition in the 10-20 ng/cm^2-day (1-2 Å/day) range. These TQCM deposition rates have continuously decreased, and after 100 days into the mission the measured rates have fallen to values between 0 and 0.2 Å/day depending on TQCM location. Thermogravimetric analyses (TGAs) on the QCMs provided insight into the amount and species of contaminants condensed, especially for the CQCM.

Introduction

The Midcourse Space Experiment (MSX) satellite (Fig. 1) was launched on April 24, 1996, into a 903 km, 99.4-deg orbit. MSX is a Ballistic Missile Defense Organization (BMDO) demonstration/validation program which has both defense and civilian applications[1-4]. With telescopes and imagers operating in the wavelength range from the UV through the infrared spectrum, the spacecraft is able to identify and track ballistic missiles during midcourse flight, obtain data on test targets and space background phenomena, monitor in-flight contamination, and investigate the composition and dynamics of the Earth's atmosphere.

The SPIRIT 3 (Space Infrared Imaging Telescope) (Fig. 2) is a major part of the MSX spacecraft and has sensor system components cooled to temperatures varying between 10 and 65 K.

Contamination of the mirrors, windows, and detectors by condensed gases is of concern since the operational lifetime in space is projected to be

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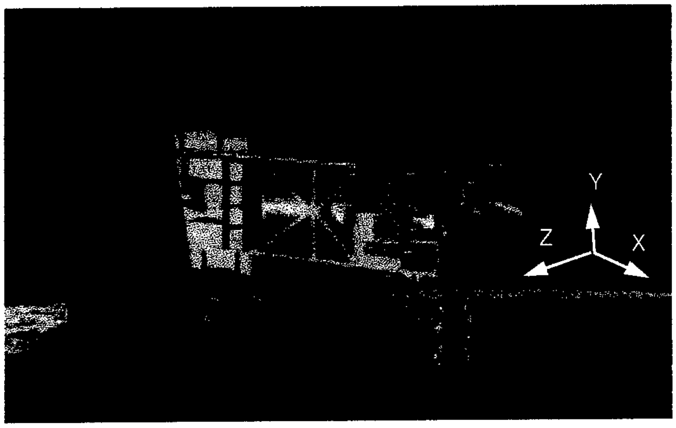

Figure 1. Artist's drawing of midcourse space experiment showing reference axis.

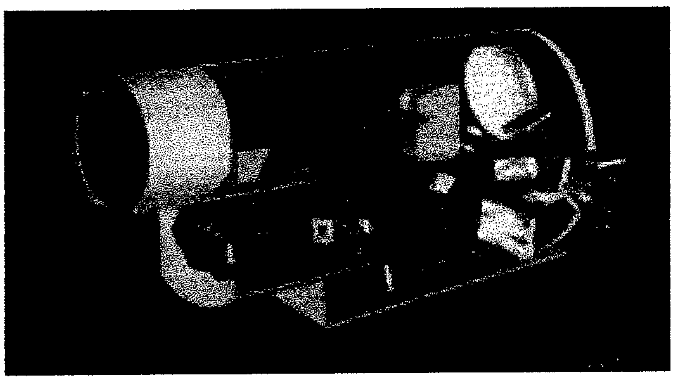

Figure 2. Artist's drawing of SPIRIT III telescope sensor system.

~ 12 months. Real-time, in-space monitoring of contaminant mass deposition on the telescope primary mirror is being provided through the use of a cryogenic quartz crystal microbalance (CQCM) which is located adjacent to the mirror. Performance of the infrared sensor optical surfaces can be impaired by contamination deposition. The deposition of contaminant films on critical surfaces can affect optical element performance by: (1) changing the reflectance/transmittance and (2) increasing scatter of the optical element. In the infrared region, the effects of condensed films on sensor surfaces can be particularly detrimental due to selective wavelength absorption. The CQCM has been extremely useful for monitoring contaminant deposition during ground testing operations, preflight, and now space.

The TQCMs are located externally on the spacecraft at locations chosen to best characterize ambient contamination. As expected, the TQCMs having view factors of the solar panels have shown the largest deposition rates. The TQCM looking in the same general direction as the science instruments (+X) has also indicated significant contaminant levels. Operating at ~-50°C, the TQCMs are too warm for deposition of water vapor but are cold enough to condense organic and silicone contaminants. Therefore, they provide a convenient method for monitoring these contaminants. The locations of the science instruments are shown in Fig. 3, and the orientations of the various contamination measuring instruments relative to the SPIRIT 3 and Space Based Visible (SBV) telescopes and the UV-Visible (UVISI) instruments are indicated. The SPIRIT 3 sunshade and the argon-cooled cover are shown in the center of Fig. 3.

Description

The effects of condensed gases on cold optics were previously investigated for the MSX program.[5,6] The primary mirror, shown in Fig. 2, is of most concern since it faces the entrance aperture through which most of the contaminants pass. Located adjacent to the primary mirror and operating at the same temperature (~20 K) is the cryogenic quartz crystal microbal-

Figure 3. Photograph of instrument section of MSX (+X direction).

ance (CQCM) which measures the condensed contaminant mass throughout the lifetime of the SPIRIT 3 sensor. By knowing the condensed mass, an estimate of the contaminant film thickness can be derived. Once the film thickness is known, the effect of the film on the mirror bidirectional reflectance distribution function (BRDF) and reflectance can be estimated from the laboratory measurements previously completed. Similarly, the effects of contaminants on the transmittance of optical elements can be deduced. The CQCM has been used to help identify the species of the contaminants condensed through thermogravimetric analysis (TGA) techniques. In the CQCM TGA mode, the sensing surface is allowed to warm up and the evaporated mass is measured as a function of temperature. By monitoring the temperatures at which the various gases evaporate (which depends on their vapor pressure), the gas species can be identified and their approximate thickness determined.

MSX stays in its parked mode orientation for most of the time. In this mode, the -Y face of MSX is facing towards the Sun for maximum power generation by the solar panels. The +Z face is into ram and the -X face is always facing Earth. The +X direction is always perpendicular to the Sun vector to minimize thermal loading on the SPIRIT 3 telescope. Generally, the spacecraft is in parked mode prior to spacecraft maneuvers for dedicated experiments which require other orientations.

2. INSTRUMENT DESCRIPTIONS

2.1 Cryogenic quartz crystal microbalance

The CQCM is a Mark 16 model[7] which was designed and fabricated by QCM Research of Laguna Beach, CA. The CQCM (Fig. 4) uses two quartz crystals (to minimize temperature effects) which oscillate at 10 MHz and are positioned such that the sense crystal is exposed to the environment external to the sensor, whereas the reference crystal is protected from any deposition. The difference frequency is directly proportional to the mass condensed on the sense crystal. The mass sensitivity is proportional to $1/F^2$ where F is the oscillation frequency of the crystal. It can detect condensed mass densities on the order of 10^{-9} g/cm^2 and was designed to operate at temperatures as low as 4 K. The quartz crystals were exposed to 100 krad (Si) from a cobalt-60 source at Johns Hopkins University Applied Physics Laboratory (JHU/APL) in order to minimize radiation-induced frequency change during the time in orbit.

The CQCM on MSX is located adjacent to, and thermally is coupled to, the cryogenically cooled primary mirror of the SPIRIT 3 telescope. It is being used to monitor the deposition of contaminants on the interior optics and, with associated optical data, will be used to forecast the degradation in performance of the mirror. The CQCMs were calibrated and characterized at temperatures as low as 10 K in a cryogenic calibration facility at the Air Force Arnold Engineering Development Center (AEDC) in Tullahoma, TN.[8] After installation in the SPIRIT 3 telescope, the CQCM was a valuable tool in monitoring the mirror status during cryogenic testing of SPIRIT 3 at Utah State University Space Dynamics Laboratory (USU/SDL), thermo-vacuum testing at the NASA Goddard Space Flight Center (GSFC), and pre-flight measurements at the launch site.

The sensitivity of the CQCM to mass deposition (for 10 MHz crystals) is given by[7]

$$\Delta m/A = 4.42 \times 10^{-9}\ (\text{g/cm}^2 \bullet \text{Hz})\ \Delta F\ (\text{Hz}) \quad (1)$$

where Δm = condensed mass, g

ΔF = change in CQCM frequency, Hz

A = active crystal surface area, 0.317 cm^2

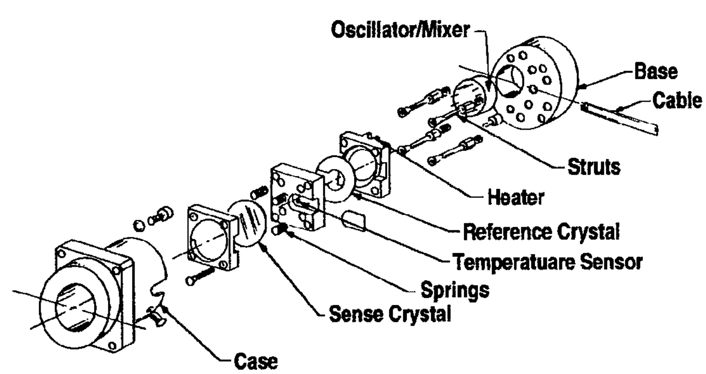

Figure 4. Mark 16 CQCM assembly diagram.

The contaminant film thickness, t, can be calculated from the equation

$$t(\text{cm}) = (\Delta m/A)/\rho = 4.42 \times 10^{-9}\ (\text{g/cm}^2 \bullet \text{Hz})\ \Delta F\ (\text{Hz})/\rho\ (\text{g/cm}^3) \quad (2)$$

where

$$\rho = \text{film density, g/cm}^3 \quad (3)$$

Typically, the film density is unknown, but it is usually assumed to be 1.0 g/cm^3 to facilitate film thickness calculations. The actual density range of typical spacecraft contamination is thought to be between 0.8 and 1.5, depending on the species. For unity density, the film thickness in Å is given by

$$t(\text{Å}) = 0.442\ (\text{Å/Hz})\ \Delta F\ (\text{Hz}) \quad (4)$$

= 0.442 for a frequency change of 1 Hz.

Similarly,

$$\Delta F(\text{Hz}) = 2.262 \text{ for a film thickness of 1 Å.} \quad (5)$$

2.2 Temperature controlled quartz crystal microbalance

The TQCMs were also designed and built by QCM Research to operate at temperatures as low as -70(C and as high as 70°C. Preflight calibration and operational characteristics of the TQCMs were determined in ground testing.[9] The temperatures are controlled by a Peltier cooler/heater unit (see Fig. 5) which is built into these Mark 10 TQCM units. As in the case of the CQCM, one of the two crystals is exposed to the environment while the other crystal is the reference crystal and is protected. The crystals operate at a frequency of 15 MHz. That makes the TQCM 2.25 times more sensitive than the CQCM. The mass sensitivity for the TQCMs is given by [10]

$$\Delta m/A = 1.96 \times 10^{-9}\ (\text{g/cm}^2 \bullet \text{Hz})\ \Delta F\ (\text{Hz}) \quad (6)$$

Using similar expressions to those derived for the CQCM results in the frequency versus thickness relationships (where again the density is assumed to be 1.0 g/cm^3),

$$t(\text{Å}) = 0.196\ (\text{Å/Hz})\ (F\ (\text{Hz}) \quad (7)$$

= 0.196 for a frequency change of 1 Hz.

Similarly,

$$\Delta F(\text{Hz}) = 5.102 \text{ for a film thickness of 1 Å.} \quad (8)$$

The four TQCMs are mounted on the exterior of MSX with the direction cosines indicated in Table 1 below

Table 1. TQCM Direction Cosines:

TQCM No.	X	Y	Z
1	-0.865	0.251	0.433
2	0.000	0.000	1.000
3	0.000	0.500	-0.865
4	0.896	-0.213	0.388

The satellite axes are indicated in Fig. 1. Thus, TQCM 1 is pointed with components in the (-X,Y,Z) directions, TQCM 3 has (Y,-Z) components, and TQCM 4 has (X,-Y,Z) components. TQCM 2 points in the +Z direction. The TQCM covers limit their fields of view (FOV) to a right cone with approximately 64-deg half angle. TQCMs 1 and 2 both have view factors which contain considerable area of the solar panels. TQCM #3 was positioned to look in a direction where minimal contamination would be seen. TQCM #4 was mounted on the +X face of the spacecraft and thus provided the deposition rate on the surfaces where all of the science instruments were located. The +X face of the spacecraft was predicted to cool to temperatures on the order of -20°C. Therefore, the deposition levels measured by the TQCMs at -50°C represent a "worst case" condition for the UV-Visible instruments of UVISI and SBV.

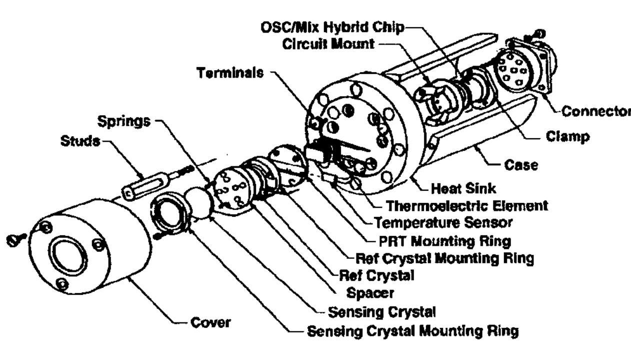

Figure 5. Mark 10 TQCM assembly diagram.

The TQCMs are mounted on individual radiators which are isolated from the main frame of the spacecraft to allow better thermal control. The heat from each Peltier thermoelectric device is radiated to space by the radiators. TQCMs 2-4 have maintained an operating temperature of -50°C whereas TQCM #1 has operated at a slightly warmer temperature, -43°C, due to being mounted on a smaller radiator. As the satellite rotates on the solar panel axis to achieve a commanded attitude, the projected area of solar panel within their fields of view (FOVs) varies. In addition to the solar panel, TQCM 1 views some of the spacecraft electronics module, which is to the left of the Z solar panels in Fig. 1. Furthermore, thermal blanketing of a UVISI box intrudes into TQCM 1's FOV. The degree to which the TQCMs can receive line-of-sight outgassed molecules from these surfaces has been calculated from spacecraft drawings.[11] The planned TQCM operational temperature range of -40 to -50°C was calculated to be cooler than all external contamination sources, such as the multilayer insulation, electronic boxes, and other non-cryogenically cooled surfaces of the spacecraft, and should be cold enough to condense many silicones and hydrocarbons outgassing from MSX materials.

2.3 Flight data processing

The QCM data consisted of normal and diagnostic telemetry frames. Normal frames contained science data while the diagnostic frames also contained instrument operational status information. The QCM telemetry output is 1 byte/sec into the MSX spacecraft housekeeping datastream in all spacecraft modes. The housekeeping data can be telemetered to the ground in any of three ways - real-time at 16 Kbps, tape recorded at 25 Mbps and downlinked, or tape recorded at 5 Mbps and downlinked. All three types of QCM satellite data were downlinked to the Mission Control Center at JHU/APL. During early Ops the Air Force Satellite Control Network was also used to collect MSX housekeeping data.

The 16 Kbps and 25 Mbps datastreams provided a normal frame of QCM data every 40 sec and, when commanded, a diagnostic frame every 52 sec. The 5-Mbps data provided a QCM normal data frame every 200 sec and, when commanded, a diagnostic frame every 260 sec. All three types of data were downlinked to the Mission Processing Center (MPC) as so-called Level 0 data. It was then processed and sent to the Contamination Experiment Data Processing Center (CEDPC) as Level 1 data, and finally, after further processing, sent to the Contamination Experiment Data Analysis Center (CEDAC) as Level 2 data. During early Operations (first week of flight and before SPIRIT 3 cover ejection) all of the data analysis by the principal investigators took place on location at the CEDAC. The 16-Kbps data provided an additional advantage in that they could be monitored real time during each ground station contact. This was especially important during early ops since expedited processing to Level 2 took about 12 hr, and SPIRIT III, UVISI, and SBV wanted reports more current than that. The real-time data were monitored by extracting the single byte per second of Level 0 data in the MPC data flow and sending them to a Mac Plus computer. The Mac recorded all the data and searched for the QCM frame synchronization bytes. It then determined the type of each frame telemetered, and converted the data to engineering units. The data were transferred to another computer and analyzed using Excel®. This nearly real-time data analysis capability was nominally for engineering assessment. Since all program certified data flow through the MPC-CEDPC-CEDAC pipeline, certified data were processed in the CEDAC using an Interactive Data Language (IDL) routine that was created specifically for displaying the Level 2 data.

2.4 Flight data uncertainty

The QCM mass calibration expressions were obtained from the vendor QCM Research. These values of 4.42×10^{-9}(g/cm^2 • Hz) for the CQCM and 1.96 x10^{-9}(g/cm^2 (Hz) are estimated to be accurate within 5percent based on earlier experiments in which density values for condensed gases were obtained. The CQCM frequencies are stable within + 1 Hz. The TQCM stability is strongly affected by incident solar flux and other thermal conditions. Based on the laboratory operation of some of these and similar units,[8,9] a stable thermal condition may still result in a TQCM frequency variability (noise level) as large as ~ 4 Hz.

Results

MSX Cryogenic Quartz Crystal Microbalance

The CQCM has played a major role in determining the contamination environment in space for the MSX SPIRIT 3 telescope. The CQCM is mounted adjacent to the telescope primary mirror and is maintained at the same temperature as the mirror (~20 K). The contaminant mass deposition rate measured by the CQCM is assumed to be the same as that on the primary mirror. By monitoring the deposited contaminant mass (or film thickness), a realistic estimate can be made of the health of the mirror.[12] The change in CQCM frequency with time is shown in Fig. 6 for the time period from launch (Day 115, April 24, 1996) until Day 294 (Oct. 20, 1996). The frequency-to-thickness conversion constant is 2.26 Hz/Å for an assumed film density of 1 g/cc. When launch occurred on Day 115 (April 24) the CQCM frequency was approximately 2,492 Hz which was 12 Hz (~ 5 Å) higher than the frequency for the completely clean CQCM – 2480 Hz. During the first 7 days after launch there was a gradual buildup of contaminant film on the CQCM, even though the cryogenically cooled SPIRIT 3 protective cover was still in place. Thermogravimetric analysis (TGA) of the CQCM contaminants provided a means for determining the species and amount of contaminant condensed at specified times.

From two TGAs performed prior to the cover release it was determined that the contaminant deposited inside was primarily oxygen.[1] When the cover was released on Day 122, there was a rise in CQCM frequency of about 163 Hz (72 angstroms). Nineteen days after the cover release another TGA was performed to determine the mass and species of the 72 Å-thick film. This TGA is shown in Fig. 7. Most of the condensate evaporated between 28-30 K and is believed to be argon which came from the solid argon used as the cover coolant. This evaporation temperature is consistent with that seen from the argon vapor pressure versus temperature curve. The small amount of deposit evaporated between 30 and 32 K is believed to be oxygen which was deposited prior to the cover release. The maximum evaporation rates were modeled using vapor pressure curves by treating the Fig. 7 CQCM cryofilm as an effusive source at an effective pressure in equilibrium with the CQCM temperature. The results were a good fit for the two expected species, argon and oxygen.

It is seen in Fig. 6 that very little film accumulation has occurred since the cover release. Most of the small incremental increases occurred when the spacecraft was maneuvered into positions in which radiation from the Earth irradiated portions of the telescope baffles, causing them to heat up, and causing some of the previously adsorbed gases to be redistributed within the telescope. Since the last TGA was performed on Day 149, there has been a CQCM frequency change of only 28 Hz (12 Å). As of October 21,1996, the total deposition on the CQCM since the telescope cooldown prior to launch is 154 Å.

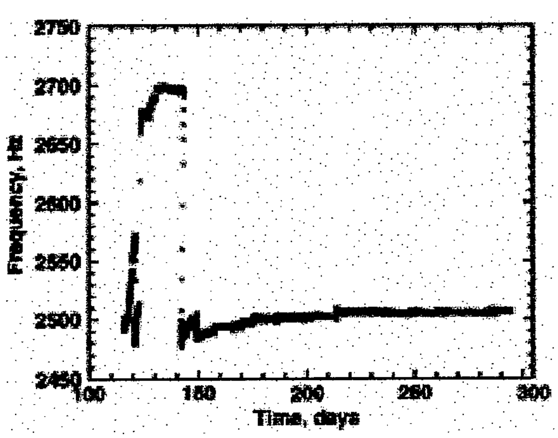

Figure 6. CQCM frequency versus time in days (1996).

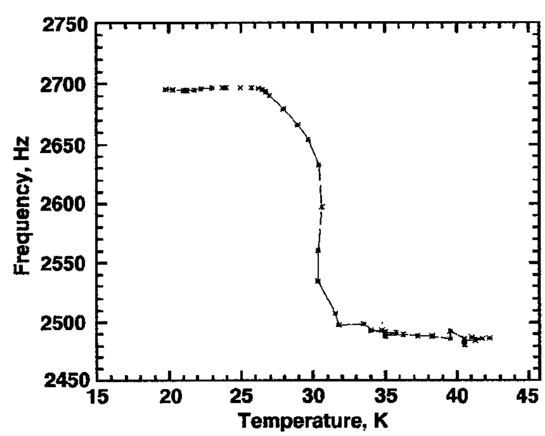

Figure 7. Thermogravimetric analysis (ΔF versus temp) plot of CQCM with accreted mass.

The TGAs have indicated that the condensed cryofilm on the primary mirror is composed of argon and oxygen, neither of which absorb in the infrared, and hence, have no effect on mirror reflectance. Even if it is assumed that the condensed species were either H_2O or CO (the infrared absorbing species most likely to be present), the change in mirror reflectance would be negligible. This is shown in Figs. 8 and 9 where the mirror reflectance is calculated assuming the species to be H_2O and CO, respectively. The bare gold-coated mirror reflectance was assumed to be 0.98. Even at the peak of absorption for each specie, the reflectance has only been reduced by ~ 0.002 (0.2%).

Similarly, Figs. 10 and 11 show the effects of condensed argon and oxygen films, respectively, on the mirror scatter at a wavelength of 10.6 µm. In these figures the data are for film thicknesses measured in micrometers, which are considerably greater than the 150 Å (0.015 µm) film on the primary mirror. The smallest thickness for each specie shown in Figs. 10-11 (~1.25 µm) indicates negligible scatter for these relatively thick films. As shown, then, in Figs. 8-11, a film thickness of 150 Å has had a negligible effect on both the BRDF of the mirror, which is a measure of surface scatter, and the mirror reflectance.

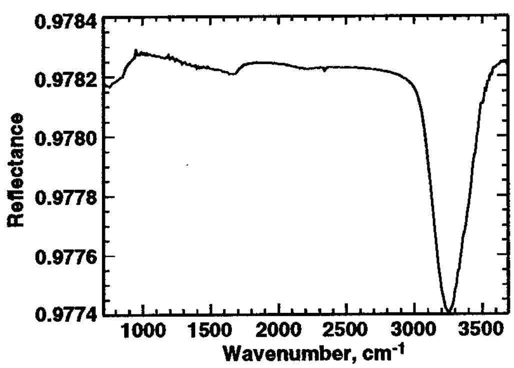

Figure 8. Calculated effect of 150 Å film of H_2O on 20K mirror reflectance.

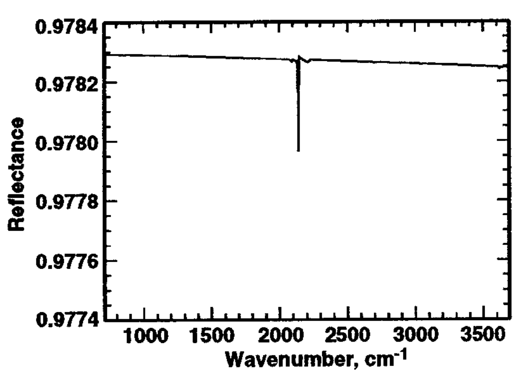

Figure 9. Calculated effect of 150 Å film of CO on 20K mirror reflectance.

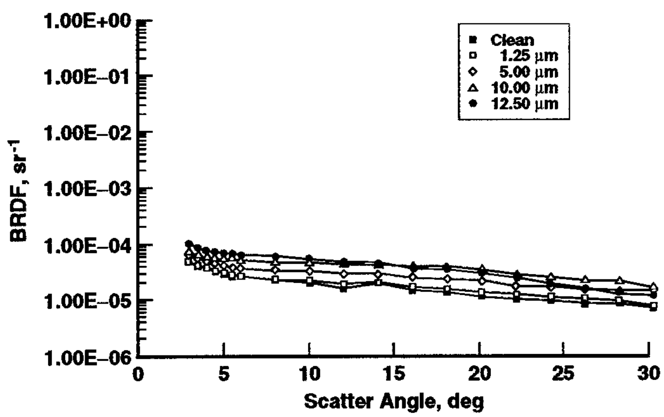

Figure 10. Mirror scatter due to argon films condensed at 16K and for 10.6 µm wavelength.

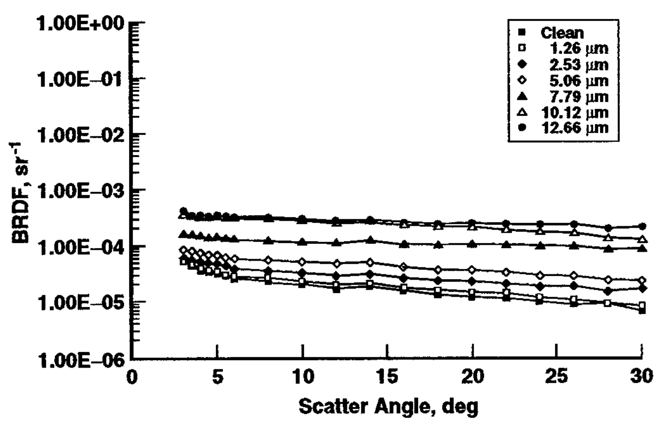

Figure 11. Mirror scatter due to oxygen films condensed at 16K and for 10.6 µm wavelength.

MSX Temperature Controlled Quartz Crystal Microbalances

The frequency versus time plots are shown in Figs. 12-15, respectively for TQCMs 1-4. The time covered is the same as that previously shown for the CQCM. The TQCMs have the disadvantage of being sensitive to incident solar flux. Negative shifts in frequencies (ΔF) from 300-450 Hz have been seen for the TQCMs used on MSX for the situations of no Sun or full Sun. In the satellite park mode only TQCM 4 sees full sun (or near full sun). The frequency of TQCM 4, Fig. 15, changed by ~ 330 Hz between the times of full sun and out of sun. The ΔF due to solar flux on the QCM external crystals also is variable as the ΔF has dropped from the 330 Hz seen in June to 240 Hz in October for TQCM #4. This decrease may be seasonal, or it may be due to precession of the spacecraft orbit. TQCMs 1-3 also show similar solar effects in Figs. 7-9, but to a much lesser extent. Even though they do not view the Sun directly in the spacecraft park mode, they do see a solar effect which is due primarily to reflected specular and scattered solar radiation from the solar panels and spacecraft blanketing.

The many spikes in the data of Figs. 12 - 15 are indicative of times when the spacecraft was maneuvered out of park mode in a manner that caused direct solar irradiance on the individual QCMS which normally did not view the Sun directly. This caused the TQCM frequency to drop 300 - 400 Hz depending on the TQCM and whether or not it was exposed to full or partial Sun. These solar effects complicate the data analysis on a short-term basis, but the data corresponding to TQCM darkness times can be used to determine the long-term deposition thickness and rates. Using the data points at the top of the curves, which correspond to the darkness times, a thickness plot for the condensate has been determined and is shown in Fig. 16. The thickness is plotted

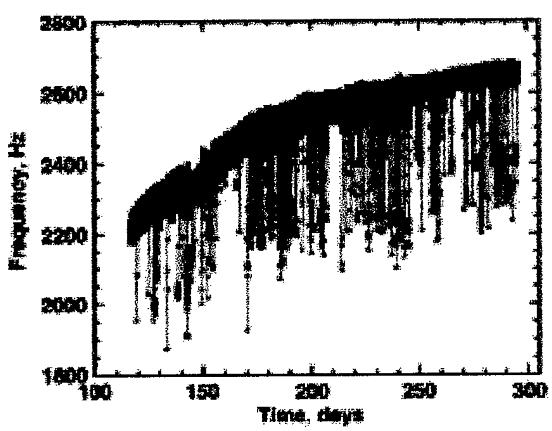

Figure 12. TQCM #1 plot showing increase in frequency due to accreted mass at (+Y, +Z) location.

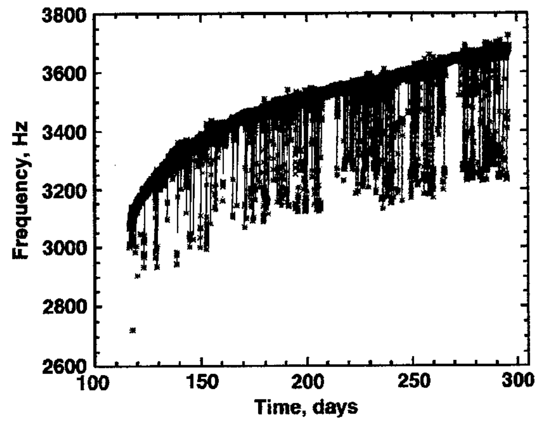

Figure 13. TQCM #2 plot showing increase in frequency due to accreted mass at (+Z) location.

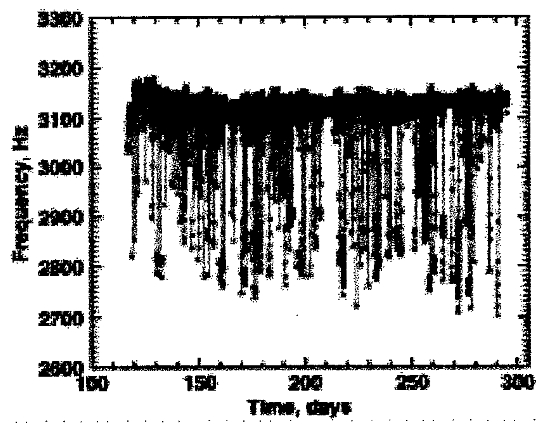

Figure 14. TQCM #3 plot showing increase in frequency due to accreted mass at (+Y, -Z) location.

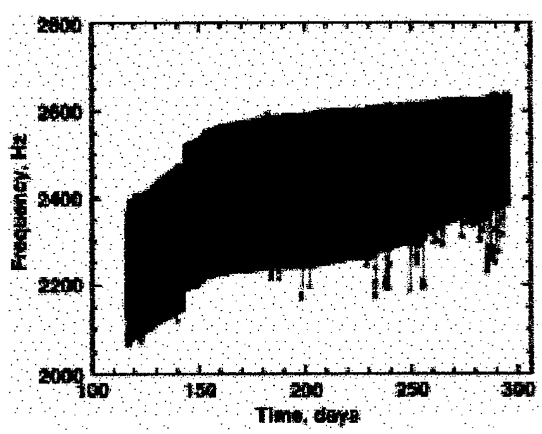

Figure 15. TQCM #4 plot showing increase in frequency due to accreted mass at (+X) location.

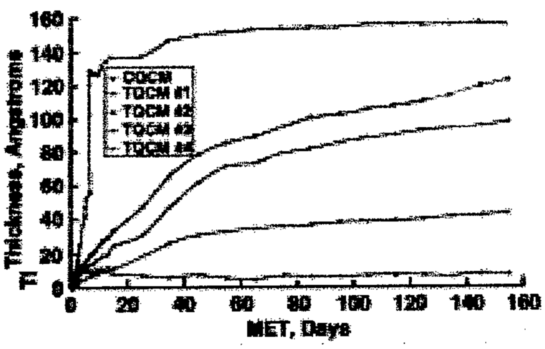

Figure 16. Accreted contaminant film thickness versus mission elapsed time for CQCM and 4 TQCMs.

versus mission elapsed time (MET) in days. The total film thickness deposited for TQCMs 1-4 and the CQCM are shown in Table 2:

Table 2: Film thickness deposition on each of the QCMs as of 10/21/96

QCM	Thickness, Å	Location
TQCM #1	97	+Y, +Z
TQCM #2	121	+Z
TQCM #3	6	+Y, -Z
TQCM #4	42	+X, +Z
CQCM	154	SPIRIT 3 Telescope

TQCMs 1 and 2 have the largest deposition rates of the four TQCMs, as seen in Fig.16. They both have view factors of the solar panels which apparently are the major sources of contaminants on MSX. The rate of deposition has slowed but the deposition rate on these two TQCMs is still appreciable - on the order of 0.2 Å/day. TQCM 3, as expected, has shown the least amount of deposition. TQCM 4, looking in the same general direction as the science instruments, +X, has indicated a total deposition of 42 Å as of October 21, 1996. It, too, is still picking up mass, but at a much reduced rate.

Summary and Conclusions

The Midcourse Space Experiment (MSX) satellite QCMs have proven to be quite useful for monitoring the on-orbit contaminant mass buildup on the SPIRIT 3 cryogenic telescope primary mirror and on the satellite external surfaces. After 168 days in orbit (as of Oct. 21, 1996) the CQCM (and primary mirror) have accumulated 154 Å of condensate on the 20 K surfaces. Most of this condensate was due to the argon condensed during the SPIRIT 3 cover release. Essentially, all of the condensate has been argon, oxygen, and nitrogen with less than 1 percent being water and carbon dioxide as determined by the thermogravimetric analyses before and after the cover release. Ground tests on the optical effects of condensed films on cryogenic mirrors at 20 K indicate that this 154 Å film has negligible effects on the mirror scatter and reflectance.

The four TQCMs mounted on satellite external surfaces have been operated at temperatures of ~ -50° C and have shown accumulations between 6 and 121 Å, depending on the TQCM location on the spacecraft. The TQCMs having the solar panels in their field of view have shown the largest deposition rates. The solar radiation incident on the crystals has shown two separate effects: (1) a quick response negative shift in output frequency between 300 and 400 Hz when solar radiation is incident normal to the crystal and (2) the solar UV component solarizes the contaminant such that during TGAs only a small portion of the condensed mass is evaporated. The TQCMs are continuing to accumulate mass, and the long-term trends established for MSX will be extremely valuable for future BMDO satellites.

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13. ABSTRACT *(Maximum 200 words)*
The Midcourse Space Experiment (MSX) is a Ballistic Missile Defense Organization (BMDO) demonstration and validation satellite program that has both defense and civilian applications. MSX was launched April 24, 1996, and has UV, visible, and infrared instruments including the SPIRIT 3 (Space Infrared Imaging Telescope) cryogenic telescope. It also has several contamination mea-suring instruments for measuring pressure, gas species, water and particulate concentrations and condensable gas species. A cryogenic quartz crystal microbalance (CQCM) and four temperature-controlled microbalances (TQCMs) are part of this suite of contamination measuring instruments on board the satellite. This paper describes some of the flight QCM data obtained and analyzed to date. The CQCM is located internal to the SPIRIT 3 cryogenic telescope and is mounted adjacent to the primary mirror. Monitoring of contaminant mass deposition on the primary mirror is being provided by the CQCM, which is cooled to the same temperature as the mirror -- ~20 K. The four TQCMs are mounted on the outside of the spacecraft and monitor contaminant deposition on the external surfaces. The TQCMs operate at ~ -50 C and are positioned strategically to monitor the silicone and organic contaminant flux arriving at specific locations, such as near to the UV instruments, or coming from specific contaminant sources such as the solar panels. Time histories of contaminant thickness deposition for each of the QCMs are presented. During the first week of flight operation, all QCMs recorded deposition in the 10-20 ng/cm 2 -day (1-2 ang./day) range. These TQCM deposition rates have continuously decreased, and after 100 days into the mission the measured rates have fallen to values between 0 and 0.2 ang./day depending on TQCM

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