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CHAPTER II

ENVIRONMENTAL MEASUREMENTS SESSION SUMMARIES

INTRODUCTION

The Shuttle Environment Workshop was organized to present data collected during flights STS-1 through STS-4 relating to the definition of the environment associated with Shuttle flight. Although the "environment" is generally considered to include all aspects, i.e., vibroacoustics, loads, thermal, electromagnetic and contamination in the form of light emissions, particles and gases, only a limited number of these aspects could be covered in detail at this conference. Prime emphasis was placed in presenting data from payloads flown on the subject flights including results from the Induced Environment Contamination monitor (IECM). Brief summaries of the vibroacoustics, loads, electromagnetic and thermal aspects of the environment, as derived from Shuttle system measurements, were presented primarily to indicate where the environment was different than observed and, therefore, where specification changes may be forthcoming. In addition, brief summaries of two somewhat unexpected effects, the "vehicle glow" and interaction between the low earth environment and Shuttle payload bay materials were presented as an aid in interpreting other environmental data.

Papers for each payload/experiment involved in Shuttle flights were presented essentially in flight-related chronological order. A significant portion of time was allocated for presentation of IECM data since this payload was flown on STS-2, STS-3, and STS-4 and, therefore, represents the largest data base relative to the contamination environment. Comparison of data gathered using the IECM on these three flights in question could be made. Summaries of papers presented follow and copies of the presentation material used by each speaker are included in Appendix A.

In general summary form the following comments regarding the data presentation portion of the workshop are appropriate. Information collected from the first four Shuttle flights represent a significant base which can be used for assessment of the Shuttle environment not only in the area of contamination but also for the electromagnetic aspects as measured by portions of the OSS-1 payload. This conclusion can be drawn in spite of the preliminary nature of the measurements presented. Although not covered in detail at this workshop, a large number of measurements relating to the vibroacoustics, load and thermal environments also have been made.

The contamination measurements made to date, however, present only a limited view of the Shuttle operational environment, since mission planning for the subject flights was driven by system performance assessment considerations and was not optimized for contamination assessment. For example, it has been recognized for years that contamination sensitive measure-

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since they were expected to perturb the environment significantly. There were periods that did represent operational conditions typical of that which can be expected by sensitive payloads. Under such conditions and taking into account the development nature of the flights, the operational limitations as previously discussed and the unexpected low earth environmental interaction with the vehicle, the Shuttle environment does seem to be in compliance with the contamination requirements as originally defined. This assessment is limited by the extent of the data gathered to date. For example, background light emission measurements have not been made in the far ultraviolet and infrared portions of the spectrum so that detailed assessment of the environment in these spectral regions will have to await data from future payloads. Information of this nature will define detail operational characteristics of the Shuttle and allow proper planning of future missions.

EMI/EMC AND VIBROACOUSTICS

Payloads to be flown on the Orbiter must be able to withstand the induced environment that will be present in the payload (P/L) bay during main engine ignition, SRB ignition/lift-off, transonic/max Q, and entry/ landing. A comprehensive study was conducted during the orbital flight test (OFT) program to affirm the predicted induced environment that would be present in the P/L bay. The induced environments of major concern are loads from structual responses, random vibration generated by the acoustic environment at lift-off, the aeronoise environment during ascent, and the mechanically-induced vibration. Data for study were obtained from microphones located in the P/L bay and from accelerometers located on structural members of the bay. Additional data were obtained from transducers located on the payloads that were flown on the OFT flights. The measured flight data were compared with the analytical predictions and were found to be equal to or less than the predictions.

The electromagnetic environments to be considered in the design and development of STS cargo are currently defined in the Core ICD. Environmental data are based on vehicle level testing (OV-101), test data from the Shuttle Avionics Integration Lab and component level test data. No in-flight electromagnetic environmental data have been taken, and there are no plans to do so. STS performance results to date indicate that the design environments are adequate.

THERMAL MEASUREMENTS

The Orbiter payload bay on-orbit thermal data in general have been warmer than predicted. The hottest and coldest thermal environment for the payload bay occurred during STS-3. In the STS tail-to-sun and nose-to-sun attitudes, temperatures dropped to a minimum of -140°F as compared to preflight prediction of -180°F. The measured temperature on the payload bay insulation near the centerline reached 260°F as compared to preflight predicted temperature of approximately 200°F in the top-to-sun attitude.

The payload retention fitting minimum temperature ranged from -62°F on the DFI pallet longeron trunnion to -45°F on the DFI pallet keel trunnion. The flight measurements for STS-3 were 10 to 15°F warmer than predicted in the tail-to-sun or nose-to-sun attitudes and up to 30°F warmer during the top-to-sun attitude. Review of the data also shows that for a given location, the latch, rail, and trunnion temperatures were generally within 10°F of each other.

KSC SHUTTLE GROUND TURNAROUND EVALUATION

Prior to launching, STS Orbiters and their cargoes are integrated at the launch site. An overview of the various payload processing flows, facility interfaces, operational considerations, facility internal environments and the ambient KSC environment was presented to acquaint the experimenter with the conditions to which the payloads will be exposed at the launch site. Generic classes of experiments most frequently requiring stringent environmental control was discussed as well as methods of supplemental payload protection. The post-landing servicing environment was described. The early and complete identification by STS users of experiment environmental and cleanliness requirements in the requirements documents for the mission was presented as the essential first step in adequate protection of payloads. These requirement statements form the basis for KSC development of the Launch Site Support Plans (LSSP), KSC development of orbiter payload bay cleaning instructions and indentification of other actions suggested for payload element protection.

EVALUATION OF THE GROUND CONTAMINATION ENVIRONMENT FOR STS PAYLOADS

The Space Transportation System must accommodate the requirements of a wide variety of spacecraft systems and experiments. The contamination environment during ground processing operations was recognized as an area of concern early in the program.

NASA established the Particles and Gases Contamination Panel (PGCP) and Contamination Requirements Definition Group (CRDG) to provide advice and define requirements. In order to define the cleanliness performance requirements for ground facilities it was necessary to review payload requirements as well as to evaluate the technology of clean facilities.

The presentation reviewed the requirements, defined terms, and discussed the results of measurements performed during checkout of facilities and ground operations through the first four STS missions. Trends and expectations in the ground contamination environment of the STS were discussed based on current data.

LOW EARTH ENVIRONMENT INTERACTION WITH VEHICLE SURFACES – MATERIAL EFFECTS

Significant surface characteristic changes have been noticed on materials that were exposed in the payload bay of the Space Shuttle Orbiter on the first four flights. The most notable change was mass loss of Kapton film used as a component of thermal blankets. This film exhibited 35% mass loss on STS-3 and loss of material was noticed on all flights. Other changes consist of rapid aging of paints, oxidation of silver and other minor effects.

A mechanism has been proposed for the effects described and involve the interaction of these organic materials with atomic oxygen available at low earth orbital altitudes. Acceleration of this oxidation reaction is probably caused by solar heating. Evidence supporting the mechanism as derived from measurements made on Shuttle materials was presented.

OBSERVATIONS OF OPTICAL EMISSIONS FROM STS-3

Photographic and television observations made during the flight of STS-3 in March, 1982 reveal the presence of three separate optical emissions which may have direct impact upon planned scientific uses of the space shuttle. The first is a bright, orangish glow which appears as a thin halo surrounding all vehicle surfaces exposed to the ram direction. Observations show that this emission competes in intensity with bright stars seen within the photographic field of view and estimates based on the airglow background give photon fluxes larger that 100,000 R. The processes giving rise to the vehicle glow phenomenon are unknown at the present time, but it has been conjectured that excited states of the hydroxyl radical (0H) as well as certain states of molecular oxygen and nitric oxide may be responsible. Based on the present results, it appears likely that the peak radiant intensity of the vehicle glow may occur in the near infrared, beyond the viewing capability of the optical instruments used on STS-3. A second major source of optical emission seen during STS-3 was luminosity produced through the firings of the Vernier and Primary Reaction Control System jets. Large, bright clouds of gas having lifetimes on the order of 0.5 to 1.0 seconds were seen frequently during the TV observation periods. The intensity of these light bursts was substantially greater than that due to vehicle glow. Based on the color film results, it appears that the principal emissions of these clouds lies in the infrared. The third source of light observed at nighttime during the flight arose from Earth's airglow emissions. When positioned correctly, the STS-3 cameras and TV systems observed a single bright emission layer at about 100 km altitude. Between this layer and the surface of Earth, a more general, diffuse emission could be readily detected. Based on other observing programs, the two principal emissions are that of atomic oxygen at 5577Å and the combination of 0H and molecular oxygen emissions at wavelengths longer than 7600Å.

OBSERVATIONS OF OPTICAL EMISSIONS ON STS-4

Following the discovery of the intense vehicle glow of the space shuttle on the STS-3 mission a new experiment was devised rapidly and flown on the shuttle STS-4 mission. The experiment consisted of a conventional camera which was equipped with an objective transmission grating. Exposures were taken of the shuttle tail from the aft flight deck window. Shuttle glow was observed on a long (400 second) exposure and the spectrum was interpreted. It appears that the shuttle glow has a diffuse spectral component in the spectral region 6300 to 8000Å. The flight deck window limits the observations in the range from 4000 to 8000Å. By interpreting the shadow of the aft tail stabilizer section as it was superimposed on a bright background caused by the firing of an orbiter thruster we have found that this light is confined to a narrower spectral band in the 7200 to 8000Å region.

INDUCED ENVIRONMENT CONTAMINATION MONITOR ASCENT/ENTRY, OPTICAL AND DEPOSITION MEASUREMENTS

A summary of ascent/entry, optical, and deposition results was presented from the measurements obtained from the Induced Environment Contamination Monitor (IECM) on STS-2, 3 and 4 flights.

Ascent and Entry results from the Dew Point Hygrometer Humidity Monitor, Air Sampler, Cascade Impactor, and Temperature-Controlled Quartz Crystal Microbalances were presented.

Optical measurement results were presented from the Optical Effects Module, Passive Sample Array and the Camera/Photometer instruments.

Molecular deposition measured by the Temperature-Controlled Quartz Crystal Microbalances located on five sides of the IECM and the Cryogenic Quartz Crystal Microbalance were discussed.

The on-orbit optical and deposition measurements were presented for transient events (water dumps, payload bay door openings and closings, reaction control system operation) and for quiescent periods.

INDUCED ENVIRONMENT CONTAMINATION MONITOR MASS SPECTROMETER RESULTS

A neutral gas mass spectrometer has been flown successfully on STS-2, STS-3, and STS-4 as part of the Induced Environment Contamination Monitor. The collimated field of view of 10^o half angle is normally oriented to view along the shuttle -Z axis so that the measured contaminants are the consequence of scattering, mostly from the ambient atmosphere.

Gaseous atoms and molecules with a mass to charge ratio of 1-150 amu are sampled with each integral mass number sampled for 2.0 seconds or during special events for 0.2 seconds. A full spectrum is thus obtained in either 300 or 30 seconds respectively. Particular emphasis is placed on the measurement of the H_2O contamination, so it is sampled on a continuous basis between scans of the entire spectrum.

H_2O is the major gaseous contaminant; the return flux of H_2O has been seen to vary from less than 1×10^{12} cm^{-2} sr^{-1} s^{-1} to perhaps 200 times that value. STS-3 showed the lowest values – frequently below the limit of detectability.

Large fluxes of methane were observed correlated with thruster firings, however, these have been due to an instrument artifact. H_2O fluxes also increase significantly during these methane events and NH_3 and C_2H_6 have also been identified.

The contaminant environment above mass 50 was remarkably clean. A few hydrocarbons were seen and on STS-4, Freon 21 was a significant contaminant. For the most part, the fluxes of heavy molecules were less than 10^9 cm^{-2} sr^{-1} s^{-1}.

Noble gases in the atmosphere are well measured by the mass spectrometer and the results for helium and argon are in good agreement with model values for these constituents. The important aspect of this result is the confidence that it brings to the contaminant flux measurements.

MODELING CORRELATION WITH FLIGHT DATA

In space, the Space Shuttle Orbiter, like any spacecraft, induces its own particulate and molecular environment. This may be harmful to certain measurement and operational mission activities. In recognition of this fact, specific requirements establishing goals for maximum allowable levels of contamination were defined during the early days of the Orbiter development.

In order to provide the capability to predict the Orbiter on-orbit molecular environment as a function of specific configurations and operating modes for comparison with these requirements, a molecular flow math model called Shuttle/payload contamination evaluation program (SPACE) has been developed. So far, the model has supported the Orbiter development as well as the STS test series mission planning. Since an induced environment contamination monitor (IECM) flew on mission STS-2/3/4 to provide measured environmental data, the model also was used to predict values from certain parameters measured by IECM instruments on-orbit. Therefore, a comparison of predicted and measured data was made to verify model performance.

A brief summary of the model was given along with the results of this comparison. Processes such as (a) the direct flux from molecular sources resulting in deposition on the TQCMs, (b) return flux to the mass spectrometer (MS) from the molecular environment, and (c) direct flux from molecular sources to the MS during the environment survey of STS-4 with the unberthed IECM on the RMS were discussed. Gas sources analyzed were outgassing (early absorption), cabin leakage, flash evaporator, and a special H_2O^{18}/Ne gas source. Since column densities were not specifically measured, the model is used to derive approximate values from the measured return flux data. The comparison performed so far indicate an overall satisfactory agreement.

EFFECTS OF SHUTTLE ENVIRONMENT ON INSTRUMENT PERFORMANCE

OSTA-1 carried four earth-viewing optical instruments. These were the Ocean Color Experiment (OCE), Measurement of Air Pollution from Satellites (MAPS), Feature Identification and Location Experiment (FILE) and the Shuttle Multispectral Infared Radiometer (SMIRR). The instruments were in orbit slightly more than two days. Pre-flight and post-flight calibrations of these instruments showed no change in performance within experimental error. Any effects of the Shuttle environment were too small to be detected.

OSS-1/CONTAMINATION MONITOR

The Contamination Monitor Package (CMP) was one of the nine OSS-1 experiments flown on STS-3. It contained four temperature controlled quartz crystal microbalances (TQCM) which were commanded real-time to temperatures simulating contamination sensitive surfaces. Molecular mass build-up and loses on these surfaces were measured almost continuously from pre-launch to post-landing.

Results have provided an insight to accretion rates (Angstroms/hr.) for surface temperatures of -50 to +60°C showing a very strong dependence on the Shuttle bay temperature or attitude. The data has been corrected for TQCM residual temperature sensitively; solar induced shifts were removed. Selected events occuring during the eight day mission were indicated on the time line in an effort to show dependence or lack of same.

Three high temperature (60°C) clean-up phases were conducted during the on-orbit period which provides reference levels useful in assessing cleanability of the various surfaces after exposure to the attitude dependent environments. Significant amounts of material (50-90Å) remained after the bay to sun exposure and subsequent clean up phase. This information scopes the molecular contamination hazard for solar viewing attached instruments.

The bay door-closed on-orbit phase provides preliminary data for a near-empty bay condition useful in the contamination control assessment for both attached and free-flyer payloads.

TEST FOR CONTAMINATION OF MgF_2 COATED MIRRORS

Results of reflectivity tests made on MgF_2 mirror samples during pre-flight, the actual STS-3 flight, and post-flight were presented for both covered and exposed conditions. Both the control mirror and flight mirror samples were contained in the OSS-1 Contamination Monitor. The comparison of results for these mirrors was presented for each sample before and after flight. The results showed (1) No change $> 1.8\,\sigma$ observed, except for fingerprint, (2) Weak evidence ($\leq 1.8\,\sigma$) for degradation at 1216Å and 1600Å found in several samples, (3) No significant difference between flight mirrors and control mirrors, (4) Covered samples suffered more than samples exposed to sun, but differences barely significant, and (5) Exposed side of flight mirrors found to be somewhat dusty.

The conclusions indicate that there was no evidence for permanent solar induced deterioration. Further, there was no evidence of deterioration on surfaces exposed during coating to oil-pumped (vs oil-free) vacuum conditions.

VEHICLE CHARGING AND POTENTIAL ON THE STS-3 MISSION

The Vehicle Clearing and Potential (VCAP) experiment flown on STS-3 was designed to study the electrical interaction of the shuttle orbiter with the low earth orbit environment. Measurements were made in the payload bay of the ion energy and density, electron density and temperature, ion and electron currents to metallic surfaces and charging of dielectric surfaces. These measurements were made under a wide range of conditions. Parameters included sun angle, magnetic field direction and the vehicle attitude with respect to the velocity vector. An electron gun which emitted a 100 mA beam of 1 keV electrons was used to perturb the vehicle potential and the environment in a series of active experiments. Measurements from the VCAP experiment vary greatly depending on the conditions. Large effects in plasma density were observed which depended on wake effects and exposure to sunlight. Dielectric charging was observed and in some cases the discharge times approached minutes in duration. Operationally, it was found that EMI was not a problem; on-orbit data are the quietest data obtained during the testing, integration and mission activities. Photographs and videotape of the electron beam were obtained which indicate approximately ambient pressure levels near the orbiter. A surface glow was discovered as a result of the VCAP Photo/TV sequences. The glow was produced by impact of the ambient atmosphere on surfaces oriented generally in the ram direction. Light emission from the electron beam and the surface glow was completely dominated for short periods of time by firing of the attitude control thrusters.

STS-3/OSS-1 PLASMA DIAGNOSTICS PACKAGE (PDP) MEASUREMENTS OF THE TEMPERATURE, PRESSURE, AND PLASMA

Operating at its pallet location and maneuvered by the RMS, the PDP made measurements of temperature, pressure, plasma, potentials and fields in and just above the payload bay.

While on the pallet without a coldplate, the PDP was designed to be held above -25°C by heaters and below 50°C by thermal blankets and radiators; on-orbit the measured extremes were -25°C and +52°C. Pressure was measured between 10^{-7} torr (ambient at 240 km altitude) and 10^{-3} torr (corona regime); it took 24 hours for the Orbiter to outgass to ambient levels; the pressure was modulated between 10^{-7} and 10^{-5} torr with Orbiter attitude – the peak occurring with the bay in the ram direction; at a primary thruster burn, the pressure increased to 3×10^{-4} torr; and during the top-to-sun attitude, the pressure reached 2×10^{-5} torr.

Ambient O^+, N_2^+ and O_2^+ ions were observed with the addition of Orbiter-produced H_2O^+. The ion density varied over 5 magnitudes with Orbiter attitude, day/night and charge state. Directed ion beams with 10 eV energies were detected associated with the Orbiter wake; at times energized ions up to 30 eV and electrons up to 100 eV are observed in the vicinity of the payload bay.

STS-3/OSS-1 PLASMA DIAGNOSTICS PACKAGE (PDP) MEASUREMENTS OF ORBITER TRANSMITTER AND SUBSYSTEM ELECTROMAGNETIC INTERFERENCE

The PDP included a complement of receivers covering the frequency range of 30 Hz to 800 MHz and S-band at 2200 ± 200 MHz to assess the intentional (transmitter) and unintentional (subsystem) electromagnetic interference (EMI) levels. The measured S-band data downlink transmitter field strength was 90/Range in meters Volts/meter whereas the predicted value was 50/R V/m. At the pallet location, the UHF voice downlink transmitter field strength did not exceed 0.1 V/m; on the RMS the PDP measured less then 0.5 V/m. Above 300 kHz Orbiter subsystem noise was not detected at the receiver noise levels (80 dB μV/m/MHz ± 20 dB) which was well below the ICD spec limits. Below 300 kHz, the magnetic field noise was nearly constant at 30 dBpT ± 20 dB due probably to power converters and clocklines. Also, below 300 kHz, the electric field noise was broadband and variable over at least 60 dB depending on thruster firings and Orbiter attitude. This noise may be generated by the Orbiter interaction with the ambient plasma. Emissions stimulated by the electron beam were ~20 dB above Orbiter associated levels at all frequencies $\lesssim$60 MHz.

OSS-1/STS-3 SHUTTLE INDUCED ATMOSPHERE EXPERIMENT

Preliminary results from the OSS-1/STS-3 Shuttle Induced Atmosphere experiment identified difficulties associated with making pointable, low light level observations during Orbiter day - due to both stray light in the bay and to sky brightness (induced atmosphere) arising from sunlight scattered by particulates originating from the Orbiter and its payload. On-board television in a split screen "stereoscopic" format was used to provide information on individual contaminant particulates. Astronomical data were obtained from measurements over large regions of the Milky Way and zodiacal light. Coordinated and sometimes simultaneous observations were successfully made from Mt. Haleakala, Hawaii and from STS-3 to provide unique information on atmospheric sources and sinks of radiation.

SOLAR ULTRAVIOLET SPECTRAL IRRADIANCE MONITOR EXPERIMENT ON OSS-1

The need to improve the accuracy of measurement of the absolute solar flux within the wavelength range of 120-400 nm requires an extensive effort in contamination control and in tracking the instruments stability. The techniques used in the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) flown by the Naval Research Laboratory on OSS-1 resulted in very high calibration stability as proven by pre-flight and post-flight calibration. In-flight calibration and the pointing accuracy provided by the shuttle attitude control system was described.

RESULTS OF THERMAL ENVIRONMENT MEASUREMENTS ON THE THERMAL CANNISTER EXPERIMENT AND GET AWAY SPECIAL ENCLOSURE

Thermal sensors located on the radiators of the thermal cannister experiment and several locations on the GAS (Get Away Special) enclosure measured the total thermal flux (UV + IR) through the use of thermopile sensors and the IR only using selective (silver Teflon) coatings. Flight data compared to preflight predictions shows significant differences occurred during tail and nose to sun conditions with fairly good agreement in the bay to sun attitude.

STS-3 "SNOWFLAKE" STUDY

During the STS-3 mission, a significant number of particles was observed being released from the orbiter. Video tape recordings were made on days 3 and 7 with the forward bay television camera. Studies of the data were made to determine sources and sizes. The determinant particles ranged in size from 0.11 cm to 0.72 cm. Indeterminant particle sizes ranged from 0.85 cm to 2.6 cm. The tapes indicated that a significant number of 1 mm to 1 cm diameter particles in the vicinity of the STS-3 were observed. Their origin may be near the aft end of the orbiter, but for the examined trajectories (33) over half were definitely forward of the aft end of the bay. It was also determined that there may be larger particles near the aft end of the orbiter.

SPACE SHUTTLE: A VIEW OF WHAT WE HAVE DONE SO FAR

Accomplishment of the Shuttle is reviewed at the transition point of the Workshop, where the agenda shifts from presentations of the environmental measurements to Panel deliberations on the role of the Shuttle environment in future programs. Questions directed to the presenters and to the IR, UV and Plasma Panel sessions sharpen the discussion of what changes are expected, or need to be made, on the Shuttle for the maximum compatibility of vehicle and payloads.

Unlike the common viewpoint of problems getting in the way of a desired result, the philosophy of "context" is adopted. Context is illustrated using the Apollo program as an example; that program was an idea large enough to include many problems, difficulties and alternatives that could have been said to oppose the program.

The context put forth for the Shuttle is that its success marks the era of the accomplished "spaceship" – a vehicle that can carry large payloads into space, perform complicated functions there including observation, construction and satellite launches, and return to Earth. This context for the Shuttle was created, and the successful Shuttle vehicle is the result.

The creation of context is a conscious process that shapes the future. As the Shuttle program continues and opens up further possibilities for man's exploration of space, the Workshop participants can be expected to establish new contexts for their work. This process will inspire, create and direct the further development and use of the Shuttle as a spaceship.