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SYNOPTIC MONITORING OF ORBITAL DEBRIS (SYNMOD): A PROGRESS REPORT ON CURRENT AND FUTURE APPLICATIONS

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ABSTRACT

The definition of, justification for and present status of SYNMOD, the small-particle monitoring system chosen as "strawman" payload element for Eureca reflight is described. A preliminary engineering definition study is underway, and hypervelocity impact calibration testing is in preparation for the near future. SYNMOD is also candidate for several other possible applications.

1. THE NEED FOR SPATIO-TEMPORAL MONITORING OF SPACE DEBRIS

The orbital debris environment is a determining factor in the temporal efficiency profiles and the useful lifetimes of both spacecraft systems and observing devices. That environment is currently too poorly-known and understood. Most current debris predictions are based on spatially-isotropic circular-orbit models with slow temporal growth rates. The LDEF Interplanetary Dust Experiment (IDE) provided the first-ever mapping of the angular distribution of small particulates in near-Earth space over an extended time interval and at high time-resolution (ref. 1). Contrary to most predictions, that environment was shown for the first time to be extremely non-isotropic and time-variant (*e.g.* ref. 2). Most of the debris is contained in clouds of megameter extent, in which the particle number density can exceed the long-term background mean by nearly four orders of magnitude (*e.g.* refs. 2, 3). At least some of those clouds are in eccentric orbits, even <u>very</u> eccentric orbits. Knowledge of such an environment can only be had by continual global monitoring.

The LDEF results are now beginning to be factored into predictive models (*e.g.* refs. 4, 5), but it must be borne in mind that LDEF was at a single LEO altitude, only at low latitudes, and the IDE timed data cover only just less than one year nearly a decade ago. At other altitudes and other times, the observational situation is frankly disastrous. There are few groundbased data and essentially no on-orbit data. All models beyond LEO are based largely on extrapolations and hypotheses, not observation. More data are needed at all altitudes and over long time spans before the models can really become satisfactory. Improved predictive models of the small-scale debris environment in both space and time will permit more rational design of spacecraft components. Real-time spatio-temporal monitoring of that 4-dimensional environment will also eventually permit the incorporation of active hazard mitigation systems that can significantly prolong spacecraft useful lifetimes, and can therefore reduce the long term costs of space operations, be they scientific, Earth resources, commercial or military. Both goals, model improvement and near-real-time hazard mitigation, can be accomplished with the multi-spacecraft mission concept designated **Synoptic Monitoring of Orbital Debris (SYNMOD).**

2. DEFINITION OF THE SYNMOD CONCEPT

Most space measurements of the particulate environment in Earth orbit have been conceived for studying dust of cosmic origin, not manmade contaminants. Little directional or temporal data exist. A detailed, long-term evolutionary model for orbital debris will require a database that combines:

1) high counting rates, for better statistics. This implies the need for a significant minimum high-sensitivity detector area;
2) longer time periods, to measure seasonal variations and to assure the separation of debris clouds from meteor streams. This implies the need for long-lived detectors and also that monitors on "dead" spacecraft be supplanted by subsequent carriers;
3) different orbital altitudes and inclinations, plus one or two highly-elliptic orbits, to map the radial and global distribution of debris; and -- perhaps most important,
4) simultaneous measurements from several satellites, allowing one to follow the dispersion and decay of debris clouds.

High time-resolution is necessary due to the extreme clumpiness of the debris environment, shown by LDEF/IDE data. Acquiring this database is not just another "scientific" experiment, but an urgent matter of surveillance, monitoring, and modelling of an environmental problem that poses considerable economic impact and physical hazard. The SYNMOD concept, if fully implemented, will provide such a database using a network of non-dedicated Earth-orbiting satellites covering a wide range of altitude and inclination, carrying a low-resource observation system based on the LDEF-IDE detector concept (refs. 6, 7).

The idea that triggered the author to develop the SYNMOD concept is that one place where many satellites have large amounts of available space is the

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* Representing a multi-national SYNMOD Team with numerous members; see Section 6: Acknowledgements. As a point of information, ISST-Europe is a non-profit French scientific Association (loi 1901) unrelated to the Institute for Space Sciences and Technology, Gainesville USA.

backsides of their solar panels. That location has the signal additional advantage of known directionality. Such accommodation would not provide the complete six-directional coverage as on LDEF, but the facts that the directions will be precisely known at all times and that other spacecraft may well be carrying the same equipment at complementary altitudes and orbital inclinations would still provide a spatio-temporal database presently unmatched by any other technique. This can be accomplished without compromising the basic function of the solar panels. Of course, some satellites do not have solar wings (LDEF, for example), and in any case, it is very desirable to have detectors looking in more than one direction. Few satellites have LDEF-type gravity-gradient and rotationally-damped stabilization; some are spin-stabilized (*e.g.* HITEN), some are stabilized to a fixed target whose direction changes with time (*e.g.* EuReCa). Consequently, the optimal (or minimal) distribution of SYNMOD instrument locations will be both spacecraft- and mission-dependent. Nonetheless, we propose that SYNMOD detector units be considered system elements to be included on as many satellites as practicable, launched for whatever purpose.

We note in this context that the Eureca SYNMOD proposal specified placement on the wings. In accommodation discussions at MBB-ERNO, it was quickly agreed that a) we couldn't have those locations, because the solar generator structures had already been space-qualified for Eureca-1, and b) some of the body sites proposed by ERNO would have been desirable even if we had gotten accommodation on the wings.

3. CURRENT STATUS OF DETECTOR DESIGN AND CALIBRATION

3.1. The basic SYNMOD detector

SYNMOD is an observation concept, an environmental monitoring strategy. Nonetheless, one needs a detection instrument with which to accomplish the strategy. The heart of the original SYNMOD instrument design is a relatively simple device developed by Prof. J. J. Wortman of the North Carolina State University and covered by NASA (public domain) patents, consisting of a parallel-plate capacitor with one plate exposed to the environment of space. The inner plate is voltage-biased through a high resistance. The general name of such a device is *metal-oxide-silicon (MOS) capacitor.* When a hypervelocity particle impacts the detector, an electrical discharge signal is obtained from the plate, and this triggers the data collection system. The basic device is space-proven on both Explorer-46 Meteoroid Technology Satellite (MTS) and the LDEF Interplanetary Dust Experiment (IDE), and it is sufficiently well-described in the literature that we omit a technical description here (refs. 1, 7, 8). It suffices here to note that the observable particle diameter range at nominal 10 km/s impact speed is roughly 0.1μm to several hundred μm.

The MTS and IDE detectors were circular MOS wafers of approximately 50 mm diameter. Wortman originally suggested that the units for Eureca SYNMOD be disks of about 100 mm, but electrically separated into four or more separate detectors per wafer. A nominally "basic" detection unit might be eight such units grouped together with a single multiplexer, although the concept is so flexible that they can be put together in almost any number and configuration, depending on the available space. This is what we have proposed for specific flight applications until now, and several such units will soon undergo hypervelocity impact calibration testing (see below), which will test both the impact sensitivities of the several dielectric thicknesses and the electrical interaction behavior of several detectors on a single support. Already two years ago, there were discussions about the packaging advantages of using square detectors cut from the wafers, but there were also fears of leakage problems at the corners. Wortman now believes this to be no problem, and he suggests cutting four 35-mm squares from each 100-mm silicon disk. Current spacecraft applications concepts will likely be redesigned to incorporate this change, resulting in either larger detection area or smaller (and lighter!) instrument packages.

As mentioned above, new hypervelocity impact calibration tests beyond the qualification tests run for MTS and LDEF in 1973 are planned as part of the SYNMOD program and should be underway within days under the direction of Jean-Claude Mandeville. The participating facilities are ONERA-CERT (Toulouse), the Max-Planck Institut für Kernphysik (Heidelberg), and the University of Kent at Canterbury. Perhaps others will be added later. Wortman has provided us with six 8-segment MOS wafers with dielectric thicknesses of approximately 2, 4, 7 and 14kÅ; the dielectric thickness controls the sensitivity of the device to impact energy. The test program objectives, developed in collaboration with the Eureca SYNMOD Team, the IDE Analysis Team and other collaborators, are

a) To determine the minimum kinetic energy required to trigger the sensors, with a preference for higher velocity particles as opposed to higher mass.
b) To determine, when possible, the distribution of impactor debris and contamination using Secondary Ion Mass Spectrometry.
c) To determine the minimum successive impact separation time of a non-flight sensor.
d) To explore the possible dependence of discharge level on impact energy.

and perhaps

e) To explore the process of plama production, separating the plasma produced by the impact from that produced by the capacitor discharge.

3.2. Supplementary detectors

MOS detectors are not the only possible devices for a SYNMOD-type monitoring system. Last summer, A. J. Tuzzolino approached us with the suggestion that we collaborate on applications for a combined MOS-PVDF instrument. The PVDF (polyvinylidene fluoride) device was developed by Tuzzolino and Prof. J. A. Simpson (ref. 9), and would bring the advantage of extending the range of observable particles up into the millimetric range, the lower end of the range of bistatic radar observations of debris in LEO (ref. 10). For the upper end of its range, PVDF provides both mass and velocity information. This very attractive idea has been presented informally by us to at least two programs, but no actual work is yet underway.

4. CURRENT STATUS OF DETECTION SYSTEM DESIGN

The MOS device by itself is only a capacitor, not a spacecraft instrument. To constitute a complete detection system, the capacitors must be wedded to an electronic data collection system, which is accomplished by attaching the electrodes to a simple electronic chip that itself connects to a multiplexer system integrated on the substrate to which the MOS wafer is mounted. Such an approach constitutes a clear advantage over the 1970-era technology used on LDEF. The detector is the fundamental element of the instrument, but it is unreasonable to consider it as a viable unit in and of itself. The viable operational module is a multi-element array of detectors, to assure a large enough detection surface area to have a particle flux sufficiently large to provide good statistics, and to assure that any given catastrophic impact will not compromise the overall effectiveness of the system. These arrays can, in principle, be distributed in a totally arbitrary fashion. Any geometric arrangement is possible, and each application will be considered separately, in concert with the spacecraft designers.

The data system envisioned for Eureca and some other applications is very simple and has already flown on the NASA MTS (Explorer 46) and LDEF in a more primitive form. The communication channel and protocol is a single multidrop network, with a single controlling node for any number of detector groups. The connection between the individual detectors and the spacecraft data handling system (DHS) is accomplished by four elements: Each detector connects through a protective chip to a multiplexer circuit that services several detectors. Each group feeds to its own line driver, or local group controller, which latches the events registered on its associated detectors and clocks them serially onto the common data bus lines when polled by the central logic-control-interface module, where the synchronization data are added. This buffer is accessed by the computer interface. Only a portion of the SYNMOD Logic Interface Package (SLIP) is spacecraft-specific. When any given detector issues an impact signal, it is communicated to the memory buffer, which stores the tick count from the instrument clock (resolution $\leq$ 1 sec) and the detector identification. Periodically, the spacecraft clock stores the clock synchronization data to the buffer and triggers a detector interrogation sequence that determines the status of each detector and, if and only if that status has changed since the last interrogation, transmits the detector identification and the tick count to the memory buffer. After the interrogation sequence, the buffer is dumped to the DHS for later downlink transmission.

One such MOS-based system is the subject of a study, funded since only late 1992 by USAF Operational Test and Evaluation Center (Albuquerque) through USAF Phillips Laboratory (Albuquerque), tasked to complete a Technical Specification by late Spring 1993. The work is well advanced. This is a necessary stage preliminary to prototype design and fabrication. Obviously, some of the details given above are subject to change as flight hardware development progresses. Any eventual implementation of additional detector types, such as PVDF, into the SYNMOD program will necessarily require their integration into the data collection system now being designed. The facts that PVDF devices have already been flown with downlink data handling systems (*e.g.* Vega-1 & -2) and that new software development is scheduled for an ARGOS satellite application, suggests that this will not be a difficult problem.

5. PROSPECTS FOR SYNMOD FLIGHT OPPORTUNITIES

The germ of the SYNMOD concept was planted in mid-1990, and the first attempts at developing it had only just begun when the Eureca-2 flight opportunity was announced later that year. A major effort was undertaken to use the Eureca-2 mission as a forcing function to define the outlines. That effort was successful to the extent that SYNMOD is adopted as part of the "strawman" payload for both engineering accommodation and costing studies for Eureca-2 and Eureca-3. As of this writing, just before the retrieval of Eureca-1, the formal payload decisions for Eureca-2 are not yet made and a period of "hibernation" has been announced, but every indication is that SYNMOD has a very good chance of being selected if Eureca is relaunched. This would be a very important step from at least four standpoints: 1) It will be a major new body of high time-resolution data on orbital debris impacts in LEO, the (or one of the) first since mid-1985; 2) The Eureca orbit is very similar to that of LDEF, so it will provide both a validation and an update of the LDEF observations; 3) The retrieval of Eureca, as with LDEF, will provide an important opportunity for post-flight engineering evaluation of system component design and fabrication, preliminary to a full-scale network deployment; and 4) a significant part of the preliminary engineering applicable to all future flights will have been done, thus reducing the unit cost for follow-on missions. Indeed, the "leverage" to be gained from the Eureca application is one of the major justifications for the present funding from USAF Phillips Laboratory for the preliminary engineering study.

SYNMOD is being considered for the TOPAZ missions, whose tentative mission profiles each cover an extremely broad range of radial distance and would thus be very important to debris model development. In addition, discussions are underway with respect to other potential carriers, civil (including commercial) and military. A variant oriented towards natural micrometeoroidal particles has been proposed for the NASA *Discovery* planetary program, which may be echoed in the ESA M3 program. On the orbital debris side, we welcome contacts from any and all with future plans for satellites large or small that might be interested in participating in an eventual SYNMOD environmental monitoring network, either as a member of the prime network, or simply with a local self-protection mitigation system.

6. ACKNOWLEDGEMENTS

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