METEOROID & DEBRIS SPECIAL INVESTIGATION GROUP

DATA ACQUISITION PROCEDURES

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SUMMARY

The entire LDEF spacecraft was examined by members of the M&D SIG for impact (*i.e.*, craters ^{3}0.5 mm and penetrations ^{3}0.3 mm in diameter) and related features (*e.g.*, debris, secondaries). During the various detailed surveys conducted at KSC, approximately 5,000 impact-related features were photodocumented, and their locations measured and recorded; an additional approximately 30,000 smaller features were counted. The equipment and techniques utilized by the M&D SIG permitted the determination and recording of the locations and diameters of the 5,000 imaged features. A variety of experimental and LDEF-structural hardware was acquired by the M&D SIG and is presently being examined and curated at JSC.

INTRODUCTION

The Long Duration Exposure Facility (LDEF) exposed several dedicated experiments designed to study the hypervelocity particle environment in low-Earth orbit (LEO). While most of these experiments were intended to investigate natural micrometeoroids, a substantial concern regarding the contributions of man-made orbital debris emerged since the conception of these experiments. These developments made it paramount that LDEF's cumulative impact history be quantified to the greatest extent possible. Because of the stochastic nature of the bombardment process, this quantification required that efforts be made to obtain the best statistical information possible from LDEF.

It was realized prior to the retrieval of LDEF that the dedicated meteoroid experiments would not suffice to accomplish these objectives, and that systematic scanning of the entire LDEF spacecraft would be necessary to obtain information complementary to, or in addition to, that expected from the dedicated instruments. Issues that would benefit from this additional information include (1) addressing theoretically predicted variations in the absolute magnitude of particle fluxes as a function of instrument orientation relative to the velocity vector of a non-spinning spacecraft in LEO, (2) obtaining statistically reliable data for large impactors, which demands analysis of the largest area-time products, and (3) target-of-opportunity investigations on the dynamic behavior of any number of materials that may be incorporated in future spacecraft. All of these issues figure prominently in the understanding of collisional hazards in LEO, and in the characterization of the dynamic properties of both natural and man-made impactors, the latter ultimately yielding a better understanding of their origins and sources.

To this end, the LDEF Micrometeoroid and Debris Special Investigation Group (M&D SIG) was organized. Previous experience with the impact record on planetary surfaces and retrieved spacecraft components (*e.g.*, Solar Max) revealed the somewhat subjective nature of simple crater counts. Thus, it was decided that a limited number of experienced individuals would be best suited to perform the global LDEF survey in a systematic and internally consistent fashion. This group (*e.g.*, the M&D SIG "A-TEAM") resided at the Kennedy Space Center (KSC) during the entire LDEF deintegration (*i.e.*, February through April, 1990). The A-Team optically scanned and photodocumented all exposed LDEF surfaces (*i.e.*, measured and photographed approximately 5,000 individual impact events) for impact-related features (*i.e.*, craters ^{3}0.5 mm and penetrations ^{3}0.3 mm in diameter, as well as other related features [debris, secondaries]), and identified and secured surfaces of special interest. The long-term curation of these materials and all documentation was subsequently transferred to the

Johnson Space Center (JSC), which is responsible for open and continued access to these materials by qualified investigators, and for maintaining an up-to-date database of LDEF impact data.

This report is a brief synopsis of the A-Team activities at KSC. It summarizes a detailed report published earlier (1), and discusses post-deintegration activities of the M&D SIG at JSC. A companion paper (2) presents some first-order observational results extracted from the extensive database generated during the KSC documentation efforts. It is hoped that this synopsis provides some background and context to ongoing LDEF studies and that it introduces the uninitiated reader to the significance and unparalleled opportunities afforded by LDEF to improve our understanding of cosmic dust and orbital debris.

IMPACT FEATURE CHARACTERISTICS

Diameter Measurements

The two primary reasons for making diameter measurements of craters/penetrations at KSC were to (1) determine if the minimum feature-size criterion had been met and (2) develop a first-order database for feature sizes and locations. Ultimately, it is the goal of the M&D SIG to report diameter information which reflects the feature's diameter at the original target surface (D_c). At KSC, diameter measurements were made directly from video monitors because no reliable and practical technique was available to measure the diameters in real time at the target surface. By using this video technique, attempting to measure the diameter at the level of the original surface would have been a very subjective process. KSC measurements, therefore, were made from rim-crest-to-rim-crest (D_r) on opposing sides of the feature because (1) such locations were easy to determine and (2) subjective error was minimized. The difference in these diameters is illustrated in Figure 1.

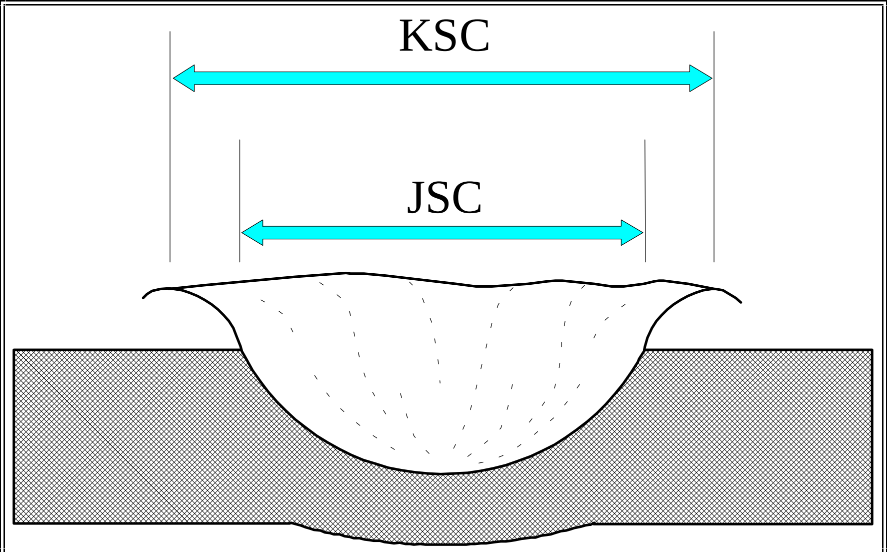

Figure 1. Diagram illustrating the relationship between the *estimated* diameter (D_r) and the actual diameter (D_c).

To ensure that all operators measured approximately the same diameters, measurements were made of a stage micrometer at the four predefined (*i.e.*, click-stop) magnifications in order to generate a set of correlation graphs which permitted diameters measured on the video screens to be converted to the *estimated* feature diameters. Feature diameters were estimated to the nearest 0.01 mm using these conversion graphs. However, because there were several possible sources of error in the measurement techniques employed, the reported diameters are given only to the nearest 0.1 mm. This represents the level of accuracy that could realistically be expected from the measurement techniques and the large number of system operators contributing to the M&D SIG database.

The majority of impact features on LDEF were located in metallic surfaces, were symmetrical and possessed raised rims. For these features the measured diameters were the rim-crest-to-rim-crest diameter mentioned above (Figures 2a-2c). For craters and penetrations not possessing a raised rim, measured diameters reflect the edge-to-edge distance between opposing sides of the feature (Figure 2d). For most penetrations in the A0178 thermal blankets, the measured diameters equal the center-of-lip-to-center-of-lip distance between opposing sides of the raised Teflon lips (Figure 2e). Lastly, for rimless craters in glass or brittle materials, the measured diameters equal the distance from opposing sides of the residual crater or central pit of the structure (Figure 2f).

Elliptical features that had major- and minor axes that varied by $^{3}10\%$ (Figure 2g), and highly-oblique (*i.e.*, extended tear-drop shaped; Figure 2h) features were measured along both axes. Accurate measurement of oblique features was often complicated by the poorly defined, diffuse boundaries of the impact-affected area. Their dimensions were measured between the furthest points of altered surface material discernible under optical magnification.

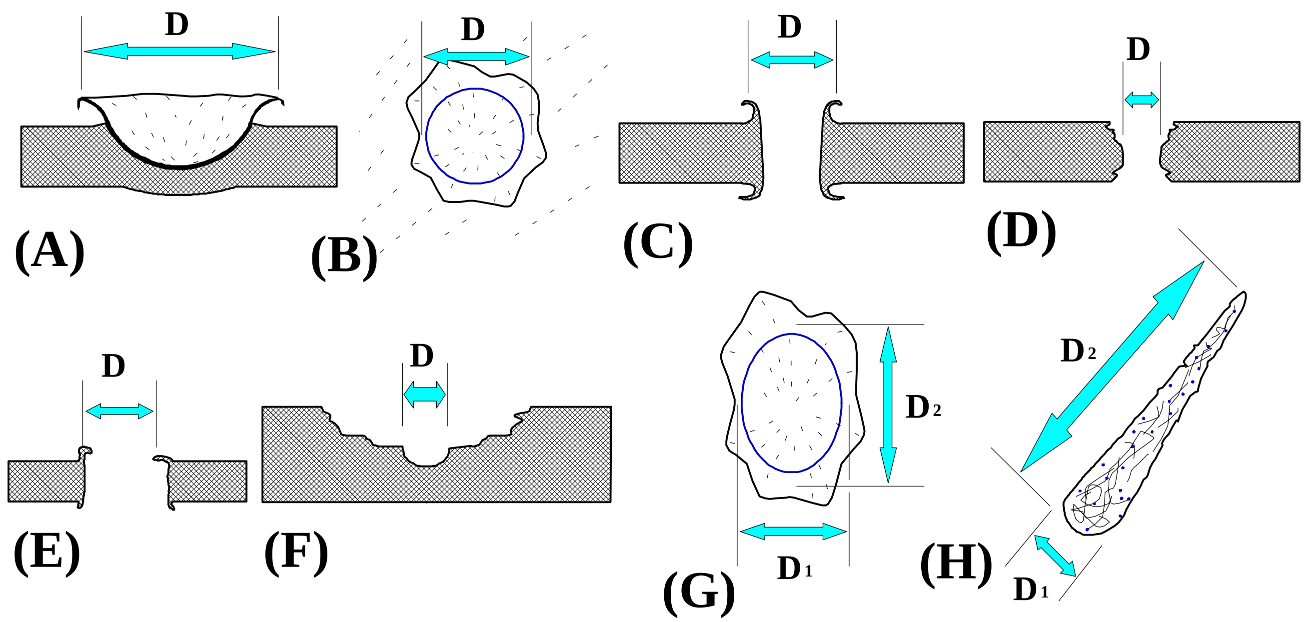

Figure 2. Typical impact feature structures and associated diameter measurements. (A) Cross-section of a typical crater with symmetrical rim and overturned lips, (B) Top view of [A], (C) Cross-section of a penetration with symmetrical rim and overturned lips, (D) Cross-section of a penetration without rims, (E) Cross-section of a penetration -- with collapsed rims -- through a single-layer thermal blanket, (F) Cross-section of residual crater (*i.e.*, central pit) in glass or brittle material, (G) Top view of elliptical crater, and (H) Top view of highly elliptical, extended tear-drop shaped feature.

Morphology

Metals

Approximately 75% of the exposed surface area on LDEF consisted of coated or uncoated aluminum alloys. All experiment-tray flanges (*i.e.*, tray lips), tray clamps (except for a few), and the structural members of the LDEF frame were constructed from chromic-anodized 6061-T6 aluminum. The same aluminum was used in the fabrication of the space-end thermal panels, space- and Earth-end dummy plates, grapple-fixture trays, experiment environment control cannisters (EECC), a variety of experiment-frame structures, and the experimental surfaces of the 25 whole or partial S0001 experiment trays. The Earth-end thermal panels were anodized by a slightly different process which resulted in their black color. Structural members which were held together with 303 stainless steel bolts. In addition, a variety of small uncoated metal samples were exposed as part of several experimental packages.

Most craters in uncoated metal surfaces were symmetrical in shape and possessed raised rims (Figure 2a and b), while only a small percentage exhibited asymmetric rim shapes or were elliptical (Figure 2g). Several dozen highly elliptical features (Figure 2h) were found on the black Earth-end thermal panels. These latter, extended tear-drop shaped features possessed semi-minor axes of <0.5 mm, while the semi-major axes were commonly >1.0 mm. A few similar features were found in various locations around the spacecraft. Several multi-cratering events were found on metal surfaces. These unusual and rare impact features consisted of tens to hundreds of smaller craters lining the bottom and walls of the host crater formed by the overall event.

Penetrations through metallic surfaces, such as the foils of the A0023 experiments, and a few large penetrations through 1.6 mm thick aluminum exhibited the general symmetrical hole and rim shapes depicted in Figure 2c. Thinner foils possessed correspondingly narrower rims that were not always evident when viewed under the microscope system. However, hole-diameter measurements were easily made for these features regardless of the rim width.

Coatings on some metal surfaces ranged from several microns to approximately 75 to 100 µm layered (*e.g.*, Teflon/silver/adhesive) coverings on several experimental surfaces (*e.g.*, S1005 and S0069). Between these extremes were many painted aluminum surfaces which had a variety of primer and top coats totaling approximately 25 to 50 µm in thickness.

Impacts in aluminum coated with silvered-Teflon were evaluated differently than features found in other coated- and uncoated metal surfaces. Since the coating was relatively thick (75 to 100 µm) the impacts were treated as if they had occurred in Teflon foils. Impacts in these surfaces produced a penetration/melt hole and a shock delamination zone in the Teflon that commonly extended tens of hole diameters around the penetration, as well as areas of black discoloration partially around some features. In most cases there was a small crater in the underlying aluminum.

Larger craters (*e.g.*, >0.5 mm) in painted metal surfaces were often surrounded by spall zones extending outward for several crater diameters. Multilayered spall zones extending radially for tens of crater diameters were frequently encountered on aluminum coated with several layers of paint.

Glasses and Brittle Materials

Several square meters of surface area on LDEF were occupied by glass that included solar-cell covers, metal-oxide-silicon (MOS) capacitor-type detectors, and hundreds of small glass and crystalline samples. In addition, there were several experimental surfaces which utilized glass or crystalline materials as covers or windows. The morphologies of impacts into such materials depended on the physical properties of the individual material. In general, these materials behaved brittlely and exhibited several, if not all, of the following characteristics: rims, spall zones, fracture zones, and/or extended fracture zones (Figure 2f).

The extent of the spall and fracture zones, and the presence or absence of a rim around the crater or penetration were the major differences among impacts in these materials. When rims were present, or when there was a penetration hole without a rim, feature diameters were measured as discussed earlier. Rimless craters were common in these materials; for such features the residual-crater (*i.e.*, central-pit) diameter (Figure 2f) was measured and reported.

Solar-cell cover glasses exhibited more complex, local fracture zones and fewer extended fractures zones, while smaller spall zones were found around impact sites in crystalline substrates. Occasionally, the fracture zones extended tens of crater diameters to the edges of the glass or crystalline substrate. In general, spall zones were relatively large, which may account for the absence of rims. In cases were the central pit was indiscernible (due to dislodged materials), the spall-zone diameter was recorded.

Polymers

Impacts into relatively thick polymers that were not subjected to extensive atomic oxygen erosion possessed the same general morphology as impacts into uncoated ductile metal surfaces. Diameter measurements were made using the criteria described above. The few impacts in thick polymeric surfaces which were subjected to significant atomic-oxygen erosion (*e.g.*, G21 and G23 leading-edge reflectors) appeared worn and ill-defined. The diameters of these features were determined from the residual rims or craters.

Seventeen peripheral trays were covered with Scheldahl G411500 thermal blankets (STB) consisting of an outer layer of FEP Teflon (~125 µm thick) backed by a layer of silver/inconel (200 to 300 Å thick), which in turn was backed by DC1200 primer and Chemglaze Z306 black conductive paint (80 to 100 µm thick). The major difference between impacts in the STBs was the presence of a collapsed or an uncollapsed rim around the site. Most impacts produced variable delamination zones, some of which extended radially up to tens of penetration-hole diameters. Penetrations were generally surrounded by one or more (whole or partial) rings that varied in size and color. In general, rings were more pronounced around events on the leading-edge, as opposed to their trailing-edge counterparts.

Impacts into laminated polymeric films (*e.g.*, Kapton specimens on A0138) produced craters and penetration holes with the general structure described above, but also exhibited delamination zones, each of which appeared as a bubble between layers. Fiber-reinforced layered plastics exhibited less extensive delamination zones, and frayed fibers were often noted overlapping the penetration holes.

Composite Structures

Several experiments exposed composite materials consisting of layers of carbon, glass, and/or Kevlar woven fibers laminated with resin binders. Impacts in such materials generally resulted in rimless features, while impact-induced damage commonly took the form of broken fibers and missing binder from the affected volume. Remnant fibers were often found extending over the area of excavated binder material which complicated feature location and diameter measurements. In some cases the diameter of the affected volume increased with depth. This effect appeared to be a function of the composite's density, layering style, layer spacing and fiber type. Spall zones, which generally extended only a few crater diameters, were common around impacts in layered composites and were defined by areas where the binder had been disrupted and/or ejected. Delamination-type zones were present around many large impacts that extended a few crater diameters beyond the spall zone. Images were extremely difficult to record on composite surfaces due to the overlap of broken fibers and the generally low albedo of such materials.

Multilayer Thermal Blankets and Structures

Several square meters on LDEF were covered with multilayer thermal blankets (MTB) or other multilayered surfaces. Most MTBs consisted of approximately 5 µm thick layers of aluminized Mylar separated by approximately 100 µm thick Dacron netting. One MTB in Bay B10 (S1005) consisted of 8 to 10 layers of approximately 5 µm thick aluminized Mylar separated by Dacron netting and encased with an outer covering of Teflon-coated fiberglass (beta cloth). Additional multilayer structures covered experiments in Bays B04 and D10 (A0054) and consisted of an outer layer of aluminized-Kapton followed by bonded layers of conducting epoxy, aluminum, non-conducting epoxy and Kevlar.

Large impacts in MTBs produced "normal" penetrations through the exterior layer (Figure 2c and 2d), followed by successively larger holes in subsequent layers caused by expanding debris clouds. However, the bottoms of such features were rarely visible in the assembled MTB if the overall event effected more than two or three blanket layers. In all cases the catalogued hole diameter refers to the outer foil.

Impacts in the materials similar to beta-cloth were, in many respects, like penetrations in the fibrous-composite materials. The dominant observable impact-induced damage was the rupture of the fibers that commonly overlapped the penetration. It was not possible to see beneath the beta-cloth layer of this MTB type. In addition, as a result of the strand diameter (~200 µm) and weave spacing, it was difficult to detect very small impacts into such surfaces. All impact events detected in beta-cloth surfaces were photodocumented, and their diameters measured from the apparent edges of the disrupted fibers on opposite sides of the site.

Impacts in the A0054 multilayer structures resulted in events which affected differing numbers of layers of the laminated substrate. Feature diameters were measured from the center points on opposite sides of the crater rims, as shown in Figure 2c. A variety of delamination and spall zones, and areas of rolled back foil were present around several of the large impact sites.

LDEF SURVEYS

Following *Columbia's* rendezvous with LDEF on January 12, 1990, the M&D SIG performed various inspections and surveys of the spacecraft. Cursory inspections were conducted from JSC by monitoring the recovery on closed-circuit television, and by examining photographic negatives of the LDEF on-orbit documentation. The next inspections occurred in the Orbiter Processing Facility (OPF) prior to LDEF's removal from *Columbia's* payload bay at KSC, and during the transfer of LDEF from the payload canister to the LDEF Assembly and Transportation System (LATS) in the Operations & Checkout (O&C) building. All detailed surveys occurred following LDEF's arrival at the Satellite Assembly and Encapsulation Facility 2 (SAEF II), where LDEF was completely deintegrated. Detailed examinations included the (1) Bolts, Clamps, Shims and Experiment Tray Flanges/Lips Inspection and Bolt Orientation Survey, (2) General Experiment Tray Front- and Backside Survey, (3) Detailed Experiment Tray Survey, (4) Thermal Panel Inspection and Bolt Orientation Survey, (5) Detailed LDEF Frame Survey and (6) Detailed Thermal Panel Survey.

On-Orbit Survey

The initial spacecraft survey was conducted by the LDEF Inspection Team, which included an M&D SIG member, monitoring *Columbia's* downlink video and audio signals at JSC during the retrieval operations on January 12, 1990. Significant M&D SIG-related observations made during this survey included (1) the A0187-2 thin-foil samples which were partially detached and rolled up, (2) the A0187-1 clamshells being open, and (3) dark circular features on the A0178 thermal blankets.

The second survey involved viewing the first-generation negatives of the on-orbit LDEF photography taken by the STS-32 crew. The astronauts were present, which provided an opportunity to ask about their personal impressions and observations of the LDEF spacecraft. According to the astronauts, LDEF continued to generate debris throughout the mission following its retrieval, especially during crew exercise periods.

Orbiter Processing Facility Survey

The next opportunity to examine LDEF was after *Columbia* (containing LDEF) had been ferried to KSC and moved into the OPF. On January 31, 1990, the LDEF Inspection Team monitored payload deintegration operations for possible movement-related damage. LDEF was still located in the payload bay at that time so only Rows 1, 2, 10, 11 and 12 were completely visible; portions of Rows 3 and 9 were partially visible. This survey identified the circular features on the A0178 thermal blankets as relatively small penetration holes surrounded by substantial dark-colored rings.

Prior to removing LDEF from the payload bay, LDEF's trunnion pins were surveyed for impact features which would have been damaged during installation of the trunnion-pin caps. No such features were found at that time, nor during later detailed surveys. After LDEF was removed from the shuttle and placed in the payload canister, OPF personnel retrieved various LDEF materials from the payload bay including an approximately 10 x 10 cm solar panel.

Operations & Checkout Survey

After leaving the OPF, LDEF was moved to the O&C building were it was transferred from the payload canister to LATS on February 1, 1990. Again, the LDEF Inspection Team was present to monitor operations. Once it was in LATS, much of the spacecraft could be surveyed at a reasonable distance for the first time. This survey permitted full access to Rows 3 and 9, as well as to Rows 4, 5, 7 and 8. The primary observation made during this survey dealt with the generation of a large number of thin (~0.1 µm thick) aluminum-foil contaminants (primarily from Tray F09). These foil flakes were found floating in the air of the O&C building and, later, became a major source of contamination in SAEF II.

Bolt, Clamp, Shims and Experiment-Tray Flanges/Lips Inspections and Bolt-Orientation Survey

Preceding LDEF deintegration in SAEF II, the M&D SIG conduct an inspection of all bolts, clamps, shims and experiment-tray flanges to identify impact-related features which could be damaged by (1) experiment-tray cover installation,

(2) clamp and experiment tray removal and (3) placing the experiment trays within the experiment-tray rotators. In addition, the M&D SIG had planned to record the orientation of those clamp bolts that possessed impact-related features, but, at the request of the LDEF Project Office, this effort was expanded to include every clamp- and thermal-panel bolt on the entire spacecraft.

On February 5, 1990, an M&D SIG member crawled underneath the spacecraft (Row 6) to inspect the areas where the jacks would be placed to lift the spacecraft into its rotatable configuration. This was the first opportunity to view Row 6 at close range, and no unusual features were observed.

Several pieces of hardware were removed from the spacecraft prior to the first detailed M&D SIG surveys. These pieces included the two Earth-end trunnion-pin scuff plates, the Earth-end walking beam and trunnion pins, and thermal panels G19 and H19. In addition, the layered thermal blankets of M0001 (*i.e.*, Bays H03 and H12) were removed or taped down by the PI so that LDEF could be rotated without causing further damage to these surfaces. However, all of these items were examined prior to or following their removal.

The first systematic survey was conducted one row at a time over the three-day period of February 20-23, 1990, by two teams, each consisting of a person scanning and measuring, while the other recorded the data. The bolt-orientation information and other data were recorded on specially prepared bay maps. After labeling the bay maps, the orientation of all clamp bolts was recorded. Next, the clamps, clamp bolts and tray flanges were examined for impact-related features which could be damaged during tray deintegration, and, if found, their locations were recorded. Lastly, a small section was cut out of each tray-cover gasket in those places that would have come into contact with these particular features; the actual gasket cutting took place in the outer air-lock of SAEF II. Only a small section of the gasket was removed (*i.e.*, inner, central or outer) so that the gasket could still seal against the tray flanges. Once the gasket was trimmed and cleaned, the cover was attached to the appropriate tray by Ground Operations personnel. During tray removal, Ground Operations personnel consulted these bay maps to determine if special tools or handling procedures were required. The original bay maps now reside in the Curatorial Facility at JSC.

General Experiment Tray Front- and Backside Survey

The M&D SIG performed several inspections of all experiment trays. The first was conducted while each experiment tray was suspended from an overhead crane and concentrated on impact-related features that could be damaged by placing the tray in a rotator stand. The front and back of the tray flanges were searched for impact-related features (*e.g.*, craters, bulges, spallation effects); if found, such features were photodocumented before placing the tray in the rotator. In addition, the back surface of the tray was examined for unusual features (*e.g.*, spallation, outgassing stains, discoloration). Survey results were entered in logbooks which now reside in the JSC Curatorial Facility.

Following this survey, the trays (except for the S0001s) were placed in one of the Langley Research Center (LaRC) or JSC rotators for examination, photographic documentation and ultimate instrument deintegration. Trays were held in the rotators either by two pairs of aluminum angles squeezing the side tray flanges (LaRC rotators), or by clasping the flanges between six sets of aluminum plates (JSC rotators).

Detailed Experiment Tray Inspection

The M&D SIG set-up three work stations in SAEF II to conduct their detailed examination and documentation of all LDEF hardware. Each station was equipped with a Coordinate Registration System (CRS), a Stereo-Microscope Imaging System (SMIS) and a complete computer system. Stations/Systems 1 and 2 were used primarily for documentation of entire experiment trays, while Station/System 3 was used mostly to document miscellaneous hardware (*e.g.*, bolts, clamps, reflectors, walking beam, scuff plates).

Suspected impact features that met the minimum size requirements, or smaller features that exhibited some interesting characteristic (*e.g.*, associated debris) were visually identified on the experiment tray or subcomponent surface and their coordinates determined. Impact-feature coordinates were recorded to (1) assure the ability to relocate features and (2) document location information which would permit plotting and analyses.

The Coordinate System

With the exception of a few miscellaneous pieces of hardware (*e.g.*, walking beam, scuff plates), all X-, Y- and Z-coordinates were measured (in millimeters) in a Cartesian coordinate system from a standard (0,0) reference point that was assigned by the M&D SIG. Unusually shaped hardware was assigned unique (0,0) reference points that are fully described by See *et al* (1). For such components a Cartesian grid was partially abandoned in favor of a more appropriate system (*e.g.*, a radial Y- and a linear X-coordinate).

The location of the (0,0) reference point for experiment trays was defined to be the lower-left corner at the intersection of the left and bottom tray flanges. For all but few trays, a physical reference mark was placed on the bottom of the left flange where the flange curved 90^{o} to form the inner-flange wall. For small subcomponents (*e.g.*, clamps, bolts and shims) no physical marks were made on the hardware since their positions relative to (0,0) are readily reconstructible.

The M&D SIG standard orientation for each component is the orientation it possessed at the time of deintegration from the spacecraft. For Bays A01-F12 the "up" direction, or top flange (facing the spacecraft with the Earth-end to the left and the space-end to the right), was the long flange closest to the next lowest row number on LDEF. Similarly, the top flange of each Earth- and space-end tray was defined as the flange that was at the top of the tray as it was positioned for deintegration from LDEF.

*Coordinate Registration System***.** Three electronic coordinate registration systems were fabricated from electronic linear spars (Mitutoyo AT11N) that had been mated to high-precision sliding tracks normally used on drafting tables (Vemco V-track 630), and fitted with adjustable-height spotter scopes. The upper and lower lenses of the scopes were etched with a crosshair and 1.0 mm circle, respectively, which helped to minimize parallax errors by allowing the crosshairs to be reliably positioned in the center of the circle. The signals from the electronic spars were displayed on a digital readout unit (DRO; Mitutoyo ALC-EC). Each CRS was paired with one of the three LaRC rotators. CRS precision was measured to be ±0.2 mm over a 100 cm distance, while the overall accuracy was determined to be within ±0.5 mm.

Manual Coordinate Registration Systems. Experiment trays that arrived in the M&D SIG area on a JSC rotator could not use the CRS due to the rotator's tubular-frame design. In addition, all S0001 trays (except B08) were documented in the horizontal position on either a workbench or rollable table, precluding the use of a CRS. In such cases, and in other instances (*e.g.*, on small subcomponents and on the frame), a metric tape measure or scale was used for determination of feature coordinates. The relative accuracy of manually determined coordinates was approximately ±2 mm for small components. On large and/or complex surfaces (like an irregular thermal blanket), the relative accuracy of manually determined coordinates varied. The overall average is believed to have been ±5 mm. This higher value is due to (1) the reproducibility of measurements using the tape measure or scale, (2) the requirement of no physical contact with LDEF surfaces, and (3) the different personnel who participated in the documentation efforts.

Surveying Procedures

As a tray entered the M&D SIG area, it was moved to the first available station (generally System 1 or 2) and the tray was cover removed by Ground Operation personnel. A CRS was attached to those trays mounted on an LaRC rotator by affixing the X- and Y-scales to the rotator.

Surveying was generally conducted by two-person teams (one surveying and one recording the information in a logbook). First, a (0,0) reference mark was placed on the tray flange (see above) and, if a CRS was used, the spotter scope was moved to the (0,0) reference mark and the X- and Y-LEDs of the DRO zeroed. Next, the coordinates of any fiducial marks on the component surface were recorded. On A0178 thermal blankets, a cross (+) was marked on the top and bottom of each blanket third and their positions recorded. In addition, on these and several other trays, the coordinates of the left, center and right tray-cover bolt holes on the top and bottom tray flanges were determined and recorded.

Actual documentation of impact features occurred in two discrete steps: first, by naked-eye inspection and second, by detailed microscope characterization. The operational goals of the naked-eye inspection were (1) to identify all impacts visually detectable to obtain their cumulative number, (2) to identify candidate features for detailed documentation (*i.e.*, craters ≥0.5 mm and penetrations ≥0.3 mm in diameter) and record their exact locations, and (3) to identify/record any unusual features that would deserve special attention or documentation. Feature diameters were conservatively estimated during the naked-eye inspection to assure that all features meeting the established size criteria were ascertained. Features that did not unquestionably fall into either the "too small" or "to-be-documented" categories were entered in the logbook as "borderline". Further sorting of these latter features was made via the detailed microscope examination.

After surveying the entire tray, the SMIS was brought in for detailed examination and diameter determination of all indexed features. If the feature was determined to be of sufficient size, or exhibited some particularly interesting characteristics, it was documented by acquiring a digitized stereo-image pair of the object. Each image was combined with alphanumeric identifiers and other comments that were entered via a portable computer (*e.g.*, bay location, experiment number, component number, the X,Y-coordinates, magnification, rotator number, optical-disk number, and up to 130 characters of comments) and stored on two separate laser WORM (Write Once, Read Many) drives. This redundancy was undertaken to assure that no data would be lost due to the failure of a storage drive, or as a result of damage to a disk.

Following photodocumentation the tray was released by the M&D SIG and the tray cover replaced by Ground Operations personnel. All sixteen A0178 trays and the Seeds in Space tray (P0004/P0006) were returned later for trisecting, removal and packaging of the thermal blankets (see below). The original survey records and digitized image files are now located in the Curatorial Facility at JSC. The images are currently being analyzed for depth- and more accurate diameter information (see below).

Thermal Panel Inspection and Bolt Orientation Survey

The second on-spacecraft inspection was conducted on March 29, 1990, to identify impact-related features found on thermal panels, reflectors, and thermal-panel bolts that could be damaged by its removal. Similarly, the orientation of all bolts securing this hardware was documented using the procedures described earlier.

Detailed LDEF Frame Survey

The final on-spacecraft inspection was carried out between April 2-11, 1990, following the removal of all of the experiment trays and thermal panels. The purpose of this survey was to identify and photodocument impact-related features on the longerons and intercostals of the LDEF frame. During this particular survey all other activities within SAEF II had to cease, because walking on the cement floor was often sufficient to induce unacceptable vibrations into the SMIS that were located on a flat-bed trailer. Therefore, surveying and photodocumentation of the frame required dedicated operations between 5:00 pm and 3:00 am. A Balimore (*i.e.*, rollable scaffolding) and the Ground Operations deintegration platform had to used to document features on the space- and Earth-end, respectively.

As a result of the difference in length between the 9.1 m LDEF spacecraft and the approximately 6 m flat-bed trailer, the frame survey was conducted in three phases. During phase one Bays A-F were completely scanned (including the interior of frame components) and the coordinates of applicable features recorded. However, only Bays C-F and part of the Bay B longeron could be photodocumented. As a result of the approximately 61 cm vertical motion limits of the SMIS on the trailer, LDEF had to be rotated approximately 15^{o} on LATS in order to completely photodocument an entire bay. Once photodocumentation of all accessible features was completed, the trailer was rolled forward to permit phase two photodocumentation of the remaining features in Bays A and B. Phase three involved scanning and photodocumenting the space- and Earth-ends of LDEF.

Coordinates for documented features were determined with a metric tape measure from the corner located directly behind the experiment-tray (0,0) reference point. Craters <0.5 mm in diameter were not photodocumented unless there was some interesting characteristic associated with the feature (*e.g.*, secondaries, debris), but their cumulative numbers were counted as in the tray operations described above.

Detailed Thermal Panel Survey

The detailed survey and photodocumentation of the thermal panels were carried out on several workbenches. The (0,0) reference point was assigned to the lower leftmost corner or angle of each panel. Coordinates for features identified during the initial survey were determined with a CRS that had been attached to each workbench, while the coordinates of any features added during the detailed microscopic examination were measured with a metric tape measure. A positive Z-value was assigned to features residing on the small row-facing strip of each panel. Horizontally configured microscopes (Systems 1 and 2) were utilized to photodocument the space- and Earth-facing components of each panel, while System 3 (vertically configured) was alternated between stations to document the row-facing strips.

The detailed examination of the thermal panels revealed the apparent bimodal distribution of some highly oblique, extended tear-drop shaped features (Figure 2h); such features were common on the black Earth-end thermal panels, but were apparently absent on their space-facing counterparts. These features were found on both the Earth-facing and row-facing components of about 75% of the Earth-end panels, appearing as little more than scratches in the black panels, but were determined to be impact-related following SMIS examination. No dominant directionality was noted for these features. A re-examination of one space-end thermal panel at the Langley Research Center did not reveal the presence of similar features on that particular panel. However, a detailed microscopic scan of several space-end thermal panels is being conducted at LaRC in search of these highly-oblique features.

IMAGING PROCEDURES

Description of Equipment

Each SMIS consisted of a Wild Leitz M8 stereo-microscope body with four click-stop magnifications (6X, 12X, 25X and 50X) and could be fitted with one of four objective lenses (350 mm, 0.4X, 1.0X and 1.6X). A beam splitter was placed between the M8 body and the binocular eyepieces which directed 50% of the incoming light to the eyepieces and 50% to the CCD (or 35-mm) camera systems. Attached to both sides of the beam splitter were Cine/TV tubes, on each of which was attached a custom camera adapter housing an eyepiece (10X, 20X, or 32X). These adapters were specially designed to interface with either the Nikon F3-HP 35-mm cameras or the Sony XC-711 CCD video cameras.

Illumination was provided by a Volpi Intralux 6000 Fiber Optic, Cold-Light Illuminator and transmitted to the imaging/viewing area by fiber-optic cables. The light source was an Intralux 6000, 20-volt 150-watt tungsten light bulb. Objects were illuminated by one of three fixtures: (1) a pair of Volpi two-branch flexible "gooseneck" light pipes with focusing lenses (for directional and long-distance lighting), (2) a Volpi ringlight (for 360^{o} uniform lighting) or (3) a Volpi "Hydra" light-pipe system (four directional and distance-adjustable lights).

The microscope/camera system was attached to a microscope carrier that was connected to a fully articulated floor-stand. The floor stand consisted of a rolling/lockable base with an approximately 1.2 m tall center post, on top of which was mounted a hydraulic counter-balanced, vertical motion and stability arm (~0.9 m long) which could be rotated 360^{o} in the horizontal plane at both ends. Connected to the counter-balance arm was an approximately 30.5 cm long pin-stopped arm that permitted rotation to six preset positions (15^{o}, 30^{o}, 45^{o}, 90^{o}, 180^{o} and 270^{o}) in the vertical plane. Attached to the pin-stop arm was another 360^{o} rotation joint, followed by another pin-stop arm. This final pin-stop arm was affixed to the microscope carrier which could be rotated about 235^{o} horizontally around the pin-stop arm. The integrated system provided complete mobility and permitted the microscope to be moved to virtually any position at heights ranging from approximately 0.8 to 2.1 m.

CCD output was carried by standard BNC cables to the computer system for digitization and data storage. The computer system consisted of an NEC Portable Powermate 386 SX computer containing Data Translations DT2871 and DT2869 frame grabber/digitizing and encoder/multiplexer board, respectively, and a Storage Dimensions WORM-drive controller board. Images were displayed on two Javelin CVM-13A video monitors and stored on two Storage Dimensions MAXTOR

LS800AT-E External Laser WORM drives using Maxtor 5.25" (13.3 cm) OC-800 optical-disk cartridges (400 megabytes per side) that hold approximately 490 images per side. The left CCD camera was fed directly into the encoder/multiplexer that passed the signal to the digitizing board, from which the digitized image was fed back through the encoder/multiplexer to the left monitor. The right camera signal was split between two lines, with one line interfacing with the encoder/multiplexer and the other feeding directly into the right monitor (*i.e.*, the right monitor always displayed a "live" image). Digitized images (left or right) were always displayed on the left monitor.

Lockheed personnel developed the software used to control the integrated SMIS, and permitted the operator to input various information (*e.g.*, bay location, component type and number) for each feature. This software also interfaced with the digitizer/frame-grabber software (Aurora Library SP0225CN) and WORM drives to provide user-friendly operations through a single, menu-driven package. Based on the bay location and the component type, the software assign a unique feature number (in ascending order) to each image pair. The image side (left or right), component type and number, feature number and bay location were used to create the file names for each image. For example, the right image of an integrated experiment tray's (component E00) third feature (0003) from Bay D08 would be given the file name of "RE000003.D08", while the left image would be assigned "LE000003.D08". All user input, plus the file name was added as a single identification line, along with the WORM disk number and side (A or B), at the bottom of the digitized image. Additionally, two 65-character comment lines were added below the identification line.

Description of Operations

SMIS imaging began on February 4, 1990, and was conducted in one of two modes, horizontal or vertical. The vertical mode (Systems 1 and 2) was used for imaging experiment trays on the rotators and for documenting the LDEF frame, while the horizontal mode (System 3) was utilized during documentation of certain experiment trays, bolts, clamps, shims and other hardware on workbenches. During the frame survey, Systems 2 and 3 were used in the vertical configuration, while System 1 was used in the horizontal mode to image the thermal panels and associated hardware. All operations were performed in such a manner as to ensure that multiple backups were made of all collected data to minimize the possibility of data loss.

Alignment Procedures

Analysis of stereo-images is possible only after the left and right images are merged into a single 3-dimensional view. To ensure that the images could be later processed to yield depth and diameter information, the microscope/cameras were aligned daily in an effort to simplify the process of image registration. Such alignment was necessary to assure (1) the microscope lens was parallel to the imaged surface, (2) the cameras were in the same orientation, and (3) the displayed images had similar horizontal and vertical centering.

Using a sheet of metric graph paper (with a fiducial arrow) the SMIS alignment was checked for parallelism (using a metric scale) and the microscope focused on the arrow at the lowest magnification. The directional alignment was checked with the arrow. Next, the microscope was changed to the highest magnification and refocused; the magnification was then lowered through the other click-stop positions to ensure that the image stayed in focus. Finally, the images on the monitors were compared for horizontal and vertical alignment. If either was off by more than 0.5 mm, the Cine/TV tubes had to be realigned. Once alignment was achieved, the SMIS was considered operational. All three SMIS were checked daily, or every time a SMIS was changed from vertical to horizontal mode and vise versa.

Imaging Procedures

Imaging procedures varied slightly between the different scanning locations (*i.e.*, experiment-tray rotators, workbenches and the LDEF structure). The standard configuration for a SMIS utilized the 1.0X objective lens, 10X eyepieces in the camera paths, 20X eyepieces in the binocular tube and the gooseneck light-pipes. In general, imaging was conducted at the highest magnification that permitted the entire feature to remain within the camera's field of view. Imaging was normally performed by two-person teams with one individual operating the microscope, while the other operated the computer. Besides increasing efficiency, this provided verification of all information and data collected, ensuring that errors were rapidly spotted and corrected.

Experiment-Tray Rotator Operations. As was the case with surveying, imaging was performed in three zones (high, middle and low) for trays mounted in the various rotators. After the initial survey was completed, the features that had been identified were examined by the SMIS. If the feature diameter met the established criteria, or exhibited some interesting or unusual characteristics, a pair of stereo images was acquired. All features in the upper zone would be checked and imaged, if necessary, followed by those in the middle and lower zones, respectively. If a feature was judged to required 35-mm photodocumentation, the feature number was noted in the logbook. After all video imaging was completed the SMIS was reconfigured for 35-mm camera operations by removing the CCDs and installing the 35-mm cameras. Following rotational alignment of the cameras and focusing, pictures were taken by using cable releases (to minimize vibrations) to activate the shutter mechanisms.

Workbench Operations. Procedures for workbench operations were similar to experiment-tray rotator operations, but were performed with the SMIS in the horizontal configuration. When experiment trays had to be imaged on the workbench (primarily the S0001 experiment trays), the binocular eyepieces were rarely used to prevent the operator from having to lean over the tray.

LDEF Structural Frame Operations. Surveying and imaging of the frame began with Row 5. System 2 was used for imaging Bays A-C, while System 3 was utilized for Bays D-F. Generally, all features on the longeron of a particular row were imaged first. Next, the microscope was rotated ($\sim 15^{o}$) so that it was parallel to the upper portion of the intercostals and the indexed features imaged. LDEF was then rotated so the lower portion of the intercostals could be accessed and imaged. LDEF was again rotated to bring the next longeron into position, the microscopes were repositioned to be parallel, and surveying and imaging of the next row began. This process was repeated for all 12 rows of LDEF. The two ends (Bays G and H) were imaged using similar procedures with System 3 documenting the space-end (Bay H), while System 2 was used for documentation of the Earth-facing end.

Shut-down Procedures

At the end of each day's operations, the SMIS were moved into the M&D SIG area, powered-down, all BNC and power cables were unplugged, and the microscope was positioned on the floor-stand for overnight storage. The daily "all.img" and "all.com" files were downloaded to 3-1/2" floppy disks (for post-processing) and the computers were turned off. Finally, if experiment trays were to remain in the M&D SIG area overnight, Ground Operations personnel would install the tray covers to protect the experimental surfaces.

Daily File-Processing Procedures

One of the floppy disks with the downloaded files was removed from SAEF II for processing. The files were copied to a Bernoulli and an internal hard disk for processing and back-up. Each system's "all.img" file was loaded and the highest feature number from each component copied into a "master" file. When completed for all three image files, the master file was copied to a new "all.img" file for uploading during the next morning's start-up operations. This post-processing was necessary to ensure that all three systems started each day with the same feature numbers for all trays, and provided an additional back-up of all data to be kept outside of SAEF II.

KSC THERMAL BLANKET PROCESSING

Background

The 17 Scheldahl thermal blankets provided a large, uniform meteoroid-detector randomly spaced around LDEF; only Rows 3, 9 and 12 did not contain one of these blankets. The blankets provided thermal insulation to the sixteen A0178 trays and one P0004/P0006 experiment. The M&D SIG was also responsible for trisecting, removing and packaging all 17 blankets. The left 1/3 of each A0178 blanket remained in the U.S. and is now archived at JSC, while the remaining 2/3 were returned to the European Space Technology Center (ESTEC) in The Netherlands. The entire P0004/P0006 blanket (Bay F02) resides at JSC.

Thermal Blanket Boxes

Lockheed personnel at JSC designed and constructed about 60 thermal blanket boxes (TBB) to protect and transport the trisected blankets from KSC. Details of the materials used in the construction of these devices is beyond the scope of this report and can be found in See *et al.* (1). However, the main thrusts behind their design were to protect the blankets during transport and to utilize the flight velcro in securing and transporting the blankets. Following assembly, each TBB was cleaned, packaged in a vacuum-sealed polyethylene bag and placed into specially designed wooden crates for shipment to KSC.

Processing Procedures

Thermal Blanket Processing

Processing of the thermal blanket consisted of six steps: (1) TBB preparation, (2) survey and preparation, (3) trisection, (4) removal and placement into the TBB, (5) photography and (6) final sealing, packaging and shipping.

TBB Preparation. The empty TBBs were delivered to KSC inside vacuum-sealed polyethylene bags. The lexan top was removed to prepare the adjustable aluminum angle for blanket attachment. Threaded nylon rods were inserted through the holes in the outer aluminum frame, lexan standoffs and an adjustable aluminum angle inside the TBB, and secured in place with nylon nuts and washers.

Survey and Preparation. First, the 2.5 cm piece of the thermal blanket that was folded between the experiment-tray wall and the experiment canisters was unfolded to expose the entire blanket. The blanket was then inspected to determine the best places to cut the blanket, avoiding penetration features or their associated delamination zones.

Trisection. The outline of the velcro that attached the blanket to the tray-support frames was used as a cutting guide. An incision was made through the middle of the velcro such that velcro was on both sides of the trisected piece of blanket to facilitate its attachment in the TBB. The incision was slowly extended through the blanket until the bottom was reached. If and when an impact feature was found in the path of the incision, it was skirted to preserve the feature and associated delamination zone, if present. The entire blanket remained on the experiment tray while the second cut was made. Throughout trisecting operations, the A-Team observed that the leading-edge blankets tended to be thinner and easier to cut than their trailing-edge counterparts.

Grounding straps from 11 of the A0178 experiments (A02, A04, A10, B05, B07, C05, C08, C11, D05, D11 and F04) were committed to the Materials SIG. The straps were detached by cutting a semicircle approximately 10.2 cm in diameter around the point where the strap attached to the blanket.

Removal and Placement in the TBB. Following trisection, the left third was removed first by slowly separating the velcro on the blanket from the velcro on the support frame. The blanket was then placed in the TBB and held in place by matching the blanket velcro with the new pieces that had been attached to the aluminum angles in the box. After the blanket was secured to both sides of the TBB, tension was applied by adjusting the position of aluminum angle along the nylon rods. After all blanket pieces were removed from the tray, the tray interior was surveyed for craters and/or debris. When encountered, such features were photographed with the SMIS.

From every U.S. portion an approximately 10.2-cm wide strip was removed from one end and given to the Materials SIG. Care was taken to determine which end to cut in order to sacrifice the fewest impact features. Prior to removal, all impact features in the strip were counted and the information recorded in the logbook.

After the Materials SIG specimen was removed, the lexan top was secured into position and Kapton tape was placed over the screws to prevent damage to the polyethylene bags. The bay location, experiment number, blanket orientation and blanket fraction was written on the lower right-hand corner of the lexan top.

Photography. Front- and back-surface photographs of the blankets secured in the TBB were taken (from ~2 m) with a 35-mm Nikon camera. Back-surface photographs used backlighting to illuminate the penetrations (which were counted) through the blanket.

Final Packaging and Shipping. TBBs were placed in pre-cleaned polyethylene bags and heat sealed, leaving only one small opening. A dry-nitrogen flush was performed for approximately two minutes, following which a vacuum was pulled on the bag, and the bag heat-sealed. The bagged TBB was placed into a second polyethylene bag and vacuum sealed. The doubly encapsulated TBBs were then placed vertically into a specially designed (foam-lined) wooden shipping crate (five to a crate).

JSC ACTIVITIES

Stereo Image Processing

During the three month deintegration of LDEF, the M&D SIG generated approximately 5000 pairs of digital, color stereo images of impact-related features from all space exposed surfaces. Currently these images are being processed at JSC to yield more accurate feature information (*e.g.*, the diameter of the crater at the original target surface). In addition, many features possessed structures (*e.g.*, ring diameters associated with A0178 blanket penetrations) that lend themselves to analysis by standard image-processing techniques. In order to retrieve depth, height and diameter measurements of the features, it is necessary to combine the image pairs to produce a three-dimensional representation of the imaged objects. This merging of images is accomplished by determining the pixel locations of various tiepoints (*i.e.*, points in common between the left and right images). Selection of these tiepoints is currently underway in the JSC Video Digital Analysis Systems (VDAS) Laboratory.

The Stereo Images

Parallax is exploited in determining an object's distance with stereo photograhy. Parallax is defined as the apparent change in the position of an object resulting from the change in the direction or position from which it is viewed. Objects closer to the viewer (or camera) display a greater angular displacement than more distant objects as the viewpoint changes, and it is this phenomenon which permits the determination of relative (or absolute) distance. Normal human (and most animal) eyesight is designed to make use of parallax through binocular vision. Having two eyes allows us to obtain images from two sources at once, and our brain permits us to integrate these two images and extract distance information from the inherent parallax. The LDEF imagery has been gathered in much the same way as would be by the human eyes.

Each image gathered by the M&D SIG was quantized into a digital copy of 512 samples by 512 lines, resulting in a total of 262,144 "pixels" (picture elements) per image. Each pixel contains a red, a green and a blue band of information, with each band able to contain any one of 256 intensity levels. Thus, the three bands combined enable a total of 16,777,216 discrete possible colors. Current studies underway to define the impact related geometries do not currently make use of the color information contained in the imagery, but the presence of the data permits the future use of multi-spectral analysis techniques to pursue materials studies. The digital images can be thought of as a grid containing 512 X-positions (horizontal), and 512 Y-positions (vertical), and each pixel position within the image may then be referred to by its own unique pair of coordinates.

The Image Analysis

Figure 3 is a simplified diagram of the geometry involved in calculating the height of a point based on the parallax observed in a pair of binocular images. The parameters ***Wd***, ***Dist***, and ***f*** remain constant for a data collection system and can be determined empirically using calibrated features (*i.e.*, objects of a known height and depth). The height of each point of interest (POI) is then calculated based on the difference in X position between the two views. Note that Figure 3 has the POI projected onto the center of the field of view on the right camera for simplicity.

In practice, matching data points (tiepoints) are selected by an analyst from each of the images for several points on the original target surface so that corrections may be made for differences between the system focal plane and the target surface (*i.e.*, rotations and offsets). Next, tiepoints for impact-related features are selected, and heights for each point are calculated with respect to the original target surface. Work is currently underway for using a minimal number of data points to parametrically define impact-crater morphologies in order to minimize the man-hour intensive task of tiepoint selection. Early attempts to automate the tiepoint selection were unsuccessful, and further attempts have been postponed until a fully functional interactive system has been be completed.

Two-dimensional analysis of non-relief type features (such as the aforementioned ring diameters associated with A0178 blanket penetrations) are also under development. This analysis makes use of conventional image-analysis techniques such as Laplacian edge detectors to accurately define two dimensional impact-related features.

No Figure

Figure 3. Illustration depicting the geometric relationships involved in the extracting of distance (*i.e.*, depth, height and diamter) informaation from stereo photographs.

Data Acquisition and Curation

Spacecraft and experimental surfaces acquired by the M&D SIG during the KSC deintegration activities are presently being scanned for additional craters and penetrations smaller than 0.5 and 0.3 mm, respectively. These data are being incorporated into the Meteoroid & Debris database that is being managed by the JSC Curatorial Facility. Additionally, the Curatorial Facility is handling the distribution of acquired LDEF materials to interested and qualified investigators. Persons desiring to study these surfaces should contact the JSC LDEF Materials Curator (Mike Zolensky) with a formal written request outlining the materials desired and the type of investigations planned.

FOILS Laboratory

Scanning of acquired surfaces is being carried out in the Facility for the Optical Inspection of Large Surfaces (FOILS) Laboratory at JSC, which was originally established to permit scanning of Solar Maximum and Palapa hardware returned from earlier satellite repair and recovery shuttle flights. The laboratory is in a Class 1000 clean room that contains SMIS System 3, which has been mated to a motorized X-Y comparator/scanning table. Software was written to control the scanning-table motors to permit detailed microscopic scanning of the desired surface in a systematic fashion.

A component is first placed on the scanning table and aligned such that the positive X- and Y-directions correspond to the same axes as were assigned during the KSC Detailed Experiment Inspection discussed earlier. Next, the same (0,0) reference point is employed, or the necessary offset to the original (0,0) point is input to the system such that (1) all newly documented features are assigned to locations from the same coordinate system used at KSC and (2) no features documented at KSC are counted a second time at JSC. Once the system is initialized with the necessary information, the operator scans the surface by watching video monitors or by looking down the binocular eyepieces of the microscope. Generally, the latter techniques is employed as the 3-D view aids in the identification of smaller (<100 µm) features. When a feature is found, the operator stops the scanning table and documents the feature by examining it under high magnification, looking for unusual characteristics or possible projectile residues, recording the coordinates, measuring and recording its diameter, recording other information (*e.g.*, material type, feature type), and assigning a feature number. If a feature is encountered that may have been documented previously at KSC, the operator uses the feature's coordinates and diameter to determine if it already has an assigned feature number. If it does, the operator can override the new computer-assigned number and manually input the original feature number should there be a need to redocument the feature for any reason (*e.g.*, verify diameter information, re-photograph). However, in general, stereo-image pairs are acquired only if the operator observes possible projectile residues or some unusual characteristic associated with the feature. Following documentation of a feature, the scanning table automatically returns to the spot where the operator halted scanning operations and resumes the scan from that point. After an entire view width (video or microscope) is scanned along the entire X-axis, the Y-axis is increased by approximately 0.8 of a view width, and the component is scanned in the negative X-direction; the approximately 20% overlap assures that no areas are missed in the scanning process. This process is repeated until the entire component has been microscopically examined.

Database

Once a component has been completely scanned, the file containing all acquired information is transferred to the Curatorial VAX computer and incorporated into the M&D SIG database. Presently, the database contains information on approximately 8,000 individual impact features (*i.e.*, approximately 5,000 documented at KSC and approximately 3,000 added from the JSC FOILS Lab). Investigators obtaining meteoroid and debris information that can be included in the database should send the data (in both ASCII and written formats) to the JSC Curatorial Facility, attention Claire Dardano. Access to the M&D SIG database can be accomplished by either the SPAN Network or modem. In either case, a terminal emulator must be used that is compatible with DEC computers; the preferred emulation mode is VT100.

To access the M&D SIG database

SPAN

1) Log onto your host computer.
2) Type **SET HOST 9300** at the system prompt.
3) Type **PMPUBLIC** at the *Username:* prompt.

NOTE: Your system manager may add node CURATE to the DECNET database on your host computer; the SPAN node number is 9.84. You may then access CURATE by typing **SET HOST CURATE** instead of **SET HOST 9300**.

MODEM

1) Dial (713) 483-2500 or (713) 483-2501.
2) Press **<CR>** three (3) times.
3) Type **SN_VAX** at the *Enter Number:* prompt.
4) Press **<CR>** three (3) times.
5) Type **J31** at the prompt.
6) Type **PUBLIC** at the *Enter Username>* prompt.
7) Type **C CURATE** at the *Xyplex>* prompt.
8) Type **PMPUBLIC** at the *Username:* prompt.

For problems or additional database information contact Claire Dardano at (713) 483-5329 [FTS 525-5329] during normal business hours.

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All of this work, and LDEF itself, would not have become a reality without the continuing, career-long support of LDEF Project Scientist Bill Kinard. Finally, we thank our families whose support, during our long absences, made this work possible.

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