NASA Technical Memorandum 4035

Description of MSFC Engineering Photographic Analysis

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INTRODUCTION

MSFC's Engineering Photographic Analysis Group provides a wide range of data reduction and analysis capabilities for the various engineering and design disciplines at MSFC. Working from a background that dates from the earliest stages of the space program, the MSFC Photo Analysis Group has developed and expanded the resources necessary to effectively cover and analyze both photographic and video coverage of each flight and ground test. Development of these objectives as well as the methods used is always evolving as photo analysis needs change and new analysis techniques are developed and improved. Utilizing a mix of the best established techniques and new methods, the MSFC Photo Analysis Group can effectively fulfill its objectives and satisfy center-wide photo analysis needs.

BACKGROUND

MSFC has been heavily involved in photographic evaluation since the early Apollo-Saturn Program. During this program, MSFC personnel were instrumental in development of the photographic coverage requirements including establishment of camera site locations, appropriate fields of view, required camera run speeds, various camera exposure criteria, and camera orientation of the more than one-hundred cameras used in the photographic coverage system. Implementation of this coverage based on these criteria provided the data necessary to adequately cover photo analysis needs. A progression of earlier photographic requirements was carried forward into the Shuttle program with MSFC being the lead center in supplying requirements through the Program Requirements Document (PRD) for both KSC and LVS launch facilities. Photographic systems requirements for the engine test stands at NSTL and MSFC were also established by MSFC photographic evaluation personnel. In addition, personnel are experienced in the development of photographic requirements for on-board camera systems used to view experiments as well as functions and performance of the various structural and mechanical elements.

MSFC has a wide range of photographic evaluation experience ranging from anomaly detection, and related causal studies, event determination and timing, position and attitude determination to the more recent methods of imagery analysis concepts using various enhancement techniques and CAD/CAM overlay processes to aid in performance analysis of a mission or a test. After establishment of the requirements for the photographic analysis coverage of the Shuttle program, MSFC phased down the photo evaluation effort through the first four Shuttle missions. During this time MSFC management recognized the need for a stronger photo evaluation organization and re-instituted the photo evaluation effort within S&E, by J. R. Thompson's memo [EE01 (150-82)] of December 17, 1982. Continuing emphasis has been placed on this effort with developmental work being done on enhancing existing techniques as well as creation of new techniques thus increasing the capabilities to the present levels which are discussed more completely below.

ORGANIZATION

MSFC's basic photographic evaluation group is administratively based within the Propulsion Laboratory as a service organization. These services are available to all projects and disciplines at MSFC. The overall effort receives basic technical direction from the project, element, system or subsystem conducting the tests or evaluation with techniques and analysis of the subject test or launch determined jointly by the photo analysis group and the group involved with the actual test or launch.

In addition to the resources available within the Propulsion Laboratory as described later, the photographic evaluation effort, through well established communication lines receives support from the Photographic and Structures and Dynamics Laboratories as well as the MSFC Communications center. The Photographic Laboratory supports the photographic evaluation group with film processing, copying, enlargements and by providing photographers, cameras and equipment when required for specific application. The Structures and Dynamics Laboratory assists photographic evaluation with image enhancements, digitizing and computer evaluations of selected film frames, and images that require more extensive analysis capabilities than exist within the Propulsion Laboratory. The MSFC Communications Center provides similar support as the Photographic Laboratory with respect to video records and equipment.

In the event of a major anomaly or accident, Photographic Evaluation Personnel are assigned to the MSFC contingency team leader and respond directly to this team. During such an event, all priorities and technical direction will be directed through the contingency team leader or his designated representative.

FUNCTIONS AND RESPONSIBILITIES

For purposes of this report, functions and responsibilities will be described as they relate primarily to the evaluation associated with launches and flight missions. The function of Photo Analysis can be divided into four basic categories: (1) Preliminary Assessment, (2) Anomaly Investigation and Resolution, (3) Detailed Evaluation, and (4) Quality Assessment.

1. *Preliminary Assessment:* Preliminary assessment of all film and video records is accomplished primarily by photographic evaluation personnel only and consists of a complete review of each item (films, video tapes, etc.) to identify the occurrence of any anomaly or unusual condition that could adversely affect mission safety during orbit or re-entry of the vehicle. This activity must be completed while the vehicle is in orbit and prior to start of re-entry. Anomalies or unusual conditions that may require unscheduled maintenance are also identified. Appendix I lists each film item normally received for each launch. Included here are prime and alternate functions for each item as well as listings of events timed and measurements that are routinely made from these items.

Times of selected events that must be correlated with other instrumentation and telemetry systems, as well as times of suspected anomalies or equipment failures must be determined and reported to the Flight Evaluation Group (FEG) during this assessment phase. The FEG will make comparisons and

review other data sources at this time to confirm certain events or use these comparative data to explain these occurrences and, if necessary, request additional investigation or provide direction as to how to proceed with the analysis process.

The launch facility and GSE hardware are viewed during launch procedures to check for proper operations and event time determination. Special attention is directed toward any interference or damage occurring to the vehicle because of abnormal operation.

The effects of pad, facility and perimeter debris are assessed to assure that no damage to the vehicle occurred that could have a detrimental effect on mission objectives and/or vehicle re-entry.

2. *Anomaly Investigation and Resolution:* When a suspected anomaly or area of concern is detected during the preliminary assessment, the film or video records are more closely scrutinized and reviewed. CAD/CAM overlays are projected onto the images, and cursory measurements made in order to determine the nature of the irregularity and locate the anomaly and its source. The appropriate project office and/or design organization with the responsibility for the specific system or hardware is notified. A viewing, with representatives of these offices, is held with as much data and information as possible presented for their review and analysis. Resolution of the problem is made or direction for further evaluation given.

Detailed analysis of an anomaly or problem area is tailored to the occurrences under investigation and may range from simply timing of sequential events to digitizing and computer evaluating and/or enhancement of the images. Graphic representations and animations of sequential occurrences, motion analysis and derivative calculations are examples of the analyses typically used in this investigation (Figs. 1 through 5). The equipment and software capabilities are discussed in a later section of this report.

3. *Detailed Evaluation:* A detailed photographic evaluation is performed for each mission. This evaluation is divided into two categories: (a) motion analysis, and (b) a chronology of event times:

(a) Motion Analysis: MSFC has the capability to perform various types of motion analysis from either film or video records. Vehicle displacement, rates and angular measurements are made for each mission either as a standard procedure or upon special request.

A few examples of measurements and computations that have been performed are presented below to illustrate the types of motion analysis that are available. In general, any angular or linear measurement can be made if the proper conditions, such as proper camera orientation and exposure, exist. Each task must be examined individually to determine if the accuracy of the measurements will satisfy the user requirements.

Vehicle first vertical motion and lift off characteristics are measured and converted to inches or feet of vertical or horizontal movement (Fig. 1). These values can be plotted versus time or cross-plotted to show vertical versus horizontal motion. Drift rates and/or velocities can be calculated and printed or plotted as required.

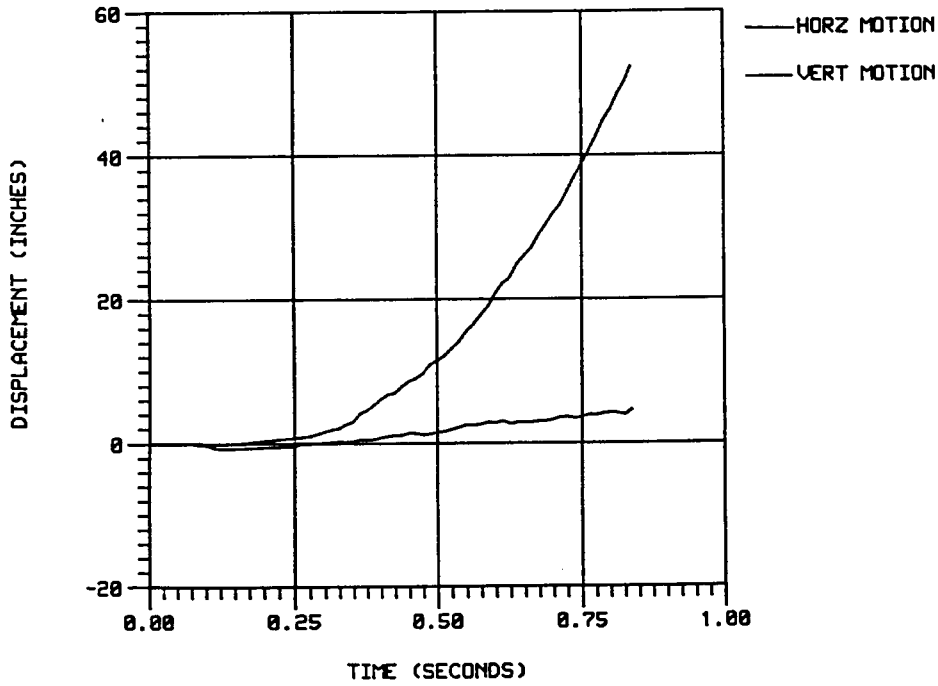

Figure 1. Vehicle first motion.

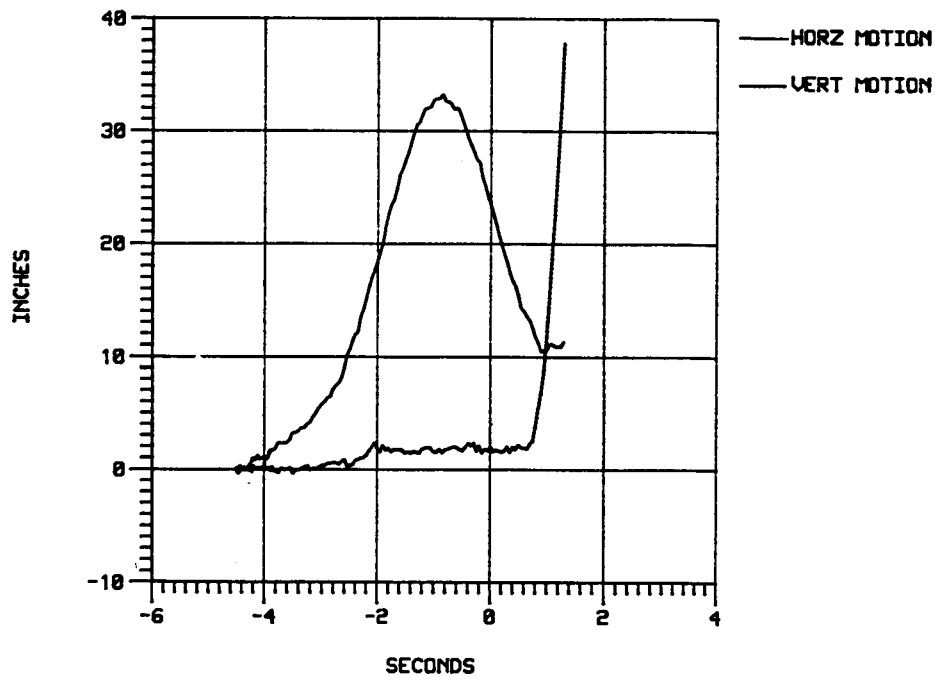

Figure 2. ET tip deflection.

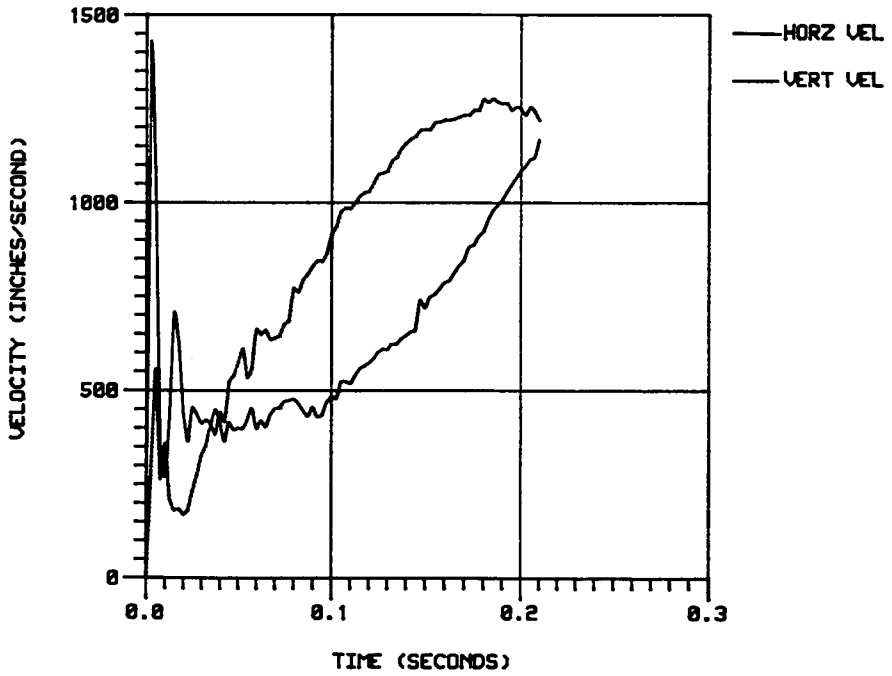

Figure 3. Example of a velocity plot.

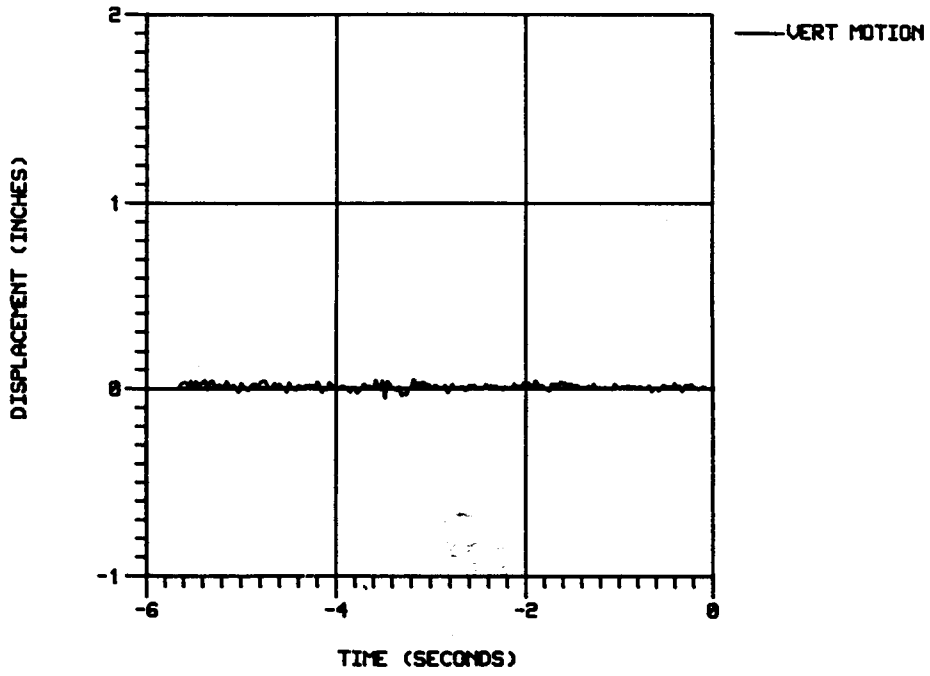

Figure 4. Holddown post displacement.

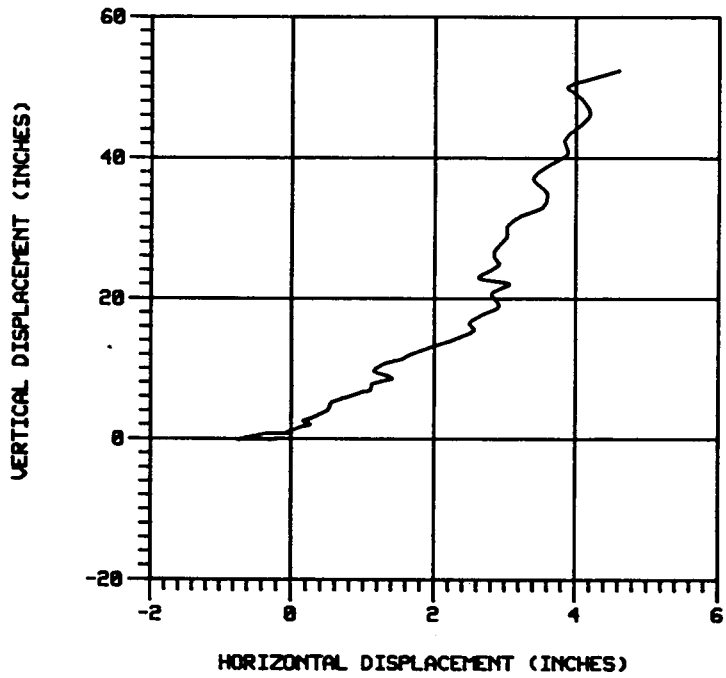

Figure 5. Example of general motion analysis.

ET Tip Deflection ("TWANG") is determined by measuring the movement of the lighting rod on the tip of the external tank against a static background target (Fig. 2). The findings of these measurements can be translated to the SRB to calculate lateral loads on the hold down post at the time of lift off.

Graphic or pictorial representation of the vehicle, GSE, or facility is made to show an area of concern or to depict the location of an anomaly.

Timing of retraction and fall away rates of the umbilical carrier plates or arms can be measured and rates determined (Fig. 3).

Relative vehicle attitude within the film plane can be determined by taking measurements of known points on the vehicle and calculating the angles with respect to known coordinate systems. Likewise, attitude of GSE or facility components can be measured.

Various output capabilities exist to allow the user to obtain the data in printed or plotted formats. These data are also made available over most of MSFC computer networks for input to user analysis programs or to intercenter computer networks for rapid access by other NASA centers.

3-D CAD/CAM overlays (Fig. 6) can be projected over the projected film images, then visual locations or areas of concern can be marked (Fig. 7) and the subject 3-D image rotated to determine more precise location of anomalies relative to vehicle coordinates. The image may be enlarged or zoomed (Fig. 8) in the exact area of concern to assist in determination of the source of probable cause of the problem encountered. Cursory distance measurements can also be obtained with this system.

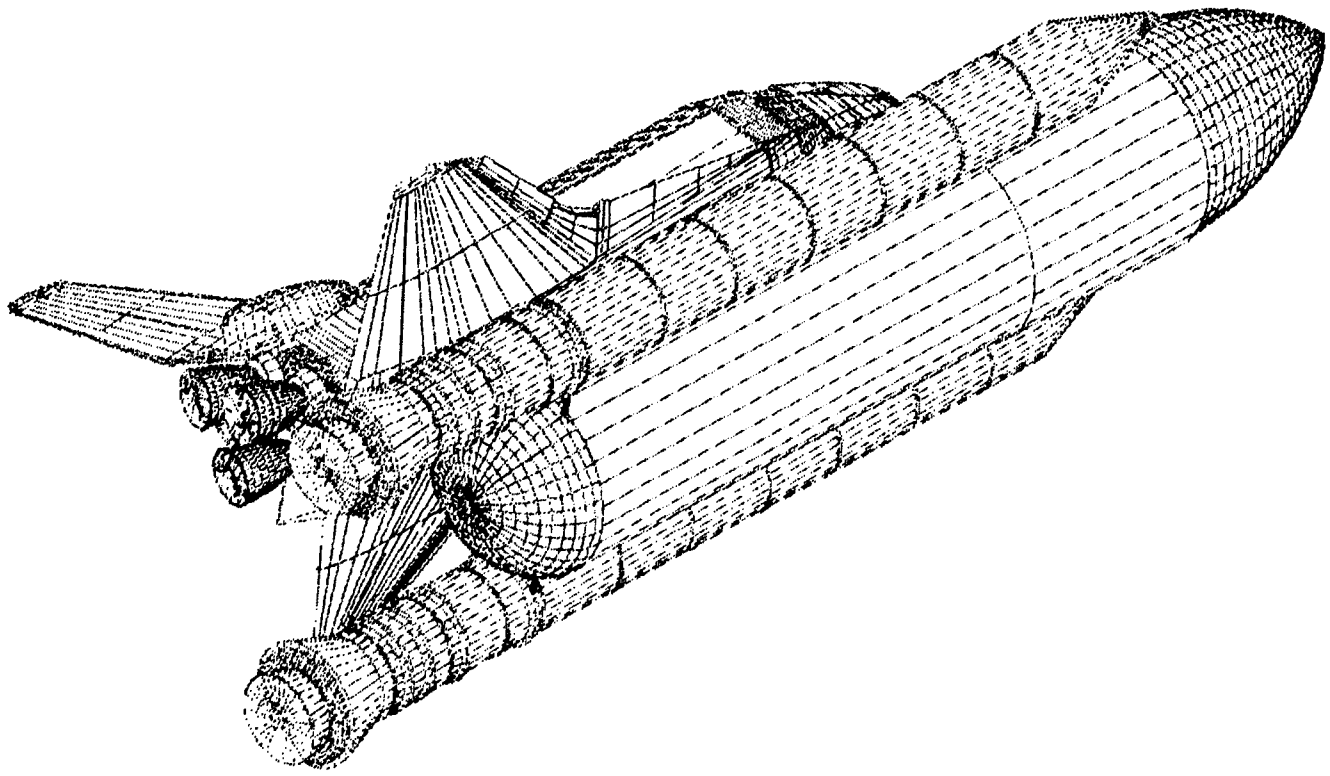

Figure 6. Three-dimensional CAD/CAM overlay model.

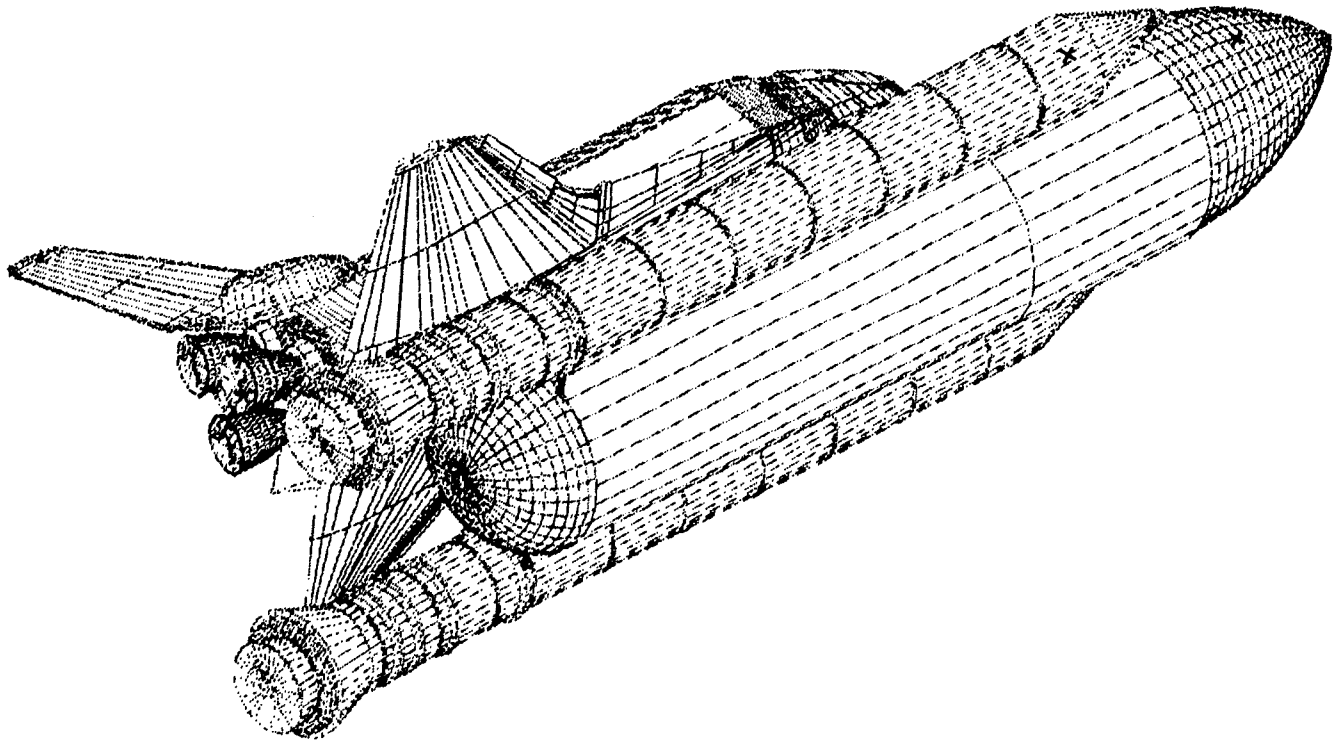

Figure 7. CAD/CAM overlay model with positions marked.

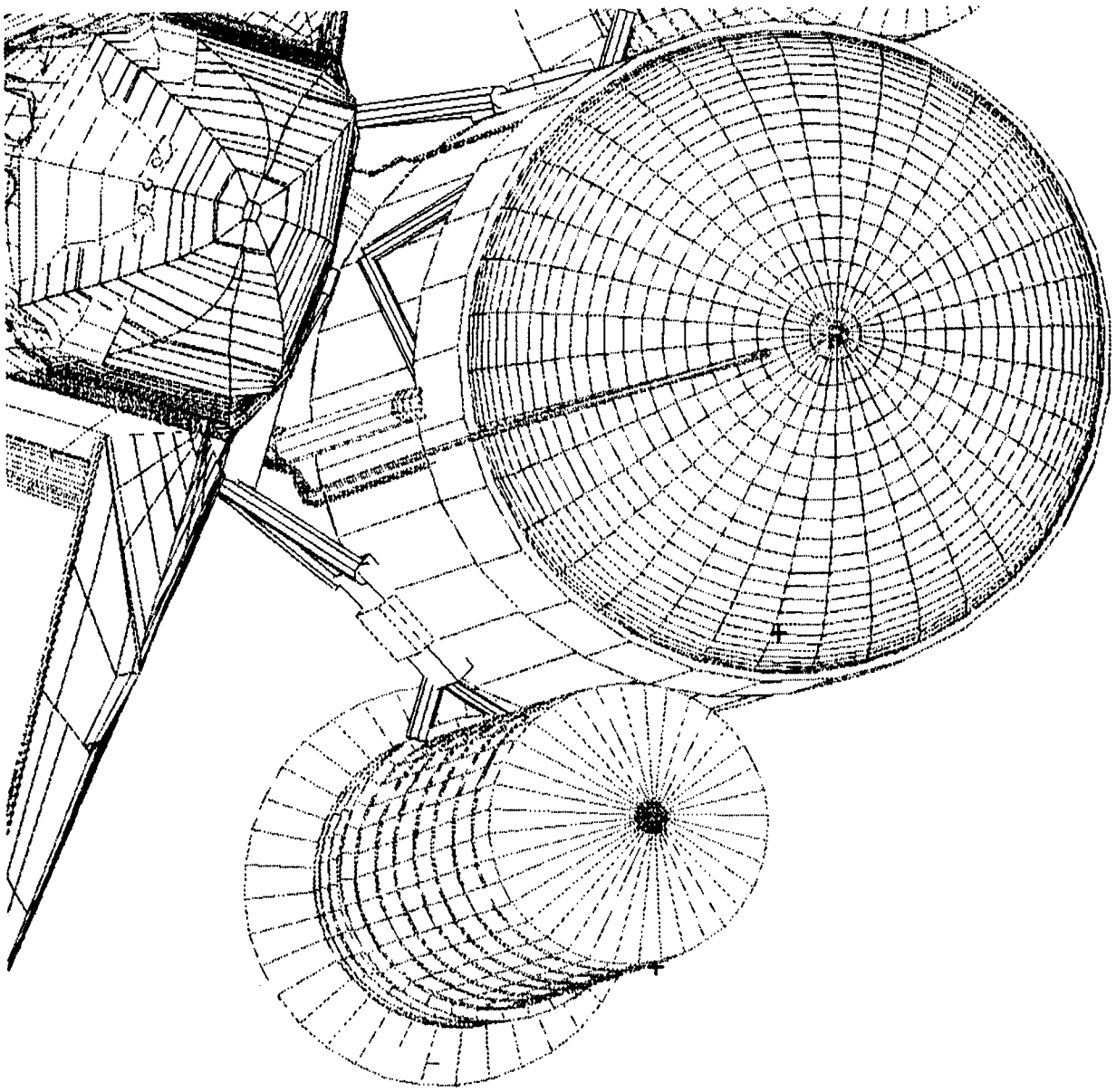

Figure 8. Zoomed and rotated CAD/CAM model.

Engine tests can also be analyzed for various measurements as well as studied for source or cause of anomalous operation. A three dimensional CAD/CAM model of the SSME also exists (Fig. 9) to be used in the projected film image overlay process described above. Models of other components and devices are being developed as well and will further contribute to the capabilities involved with the CAD/CAM overlay analytical process. An example of a typical measurement made during engine hot firings is the motion analysis plot of nozzle undulation (Fig. 10).

(b) Chronology of Event Times: The following is a typical chronology (time history) of events that are determined for each mission.

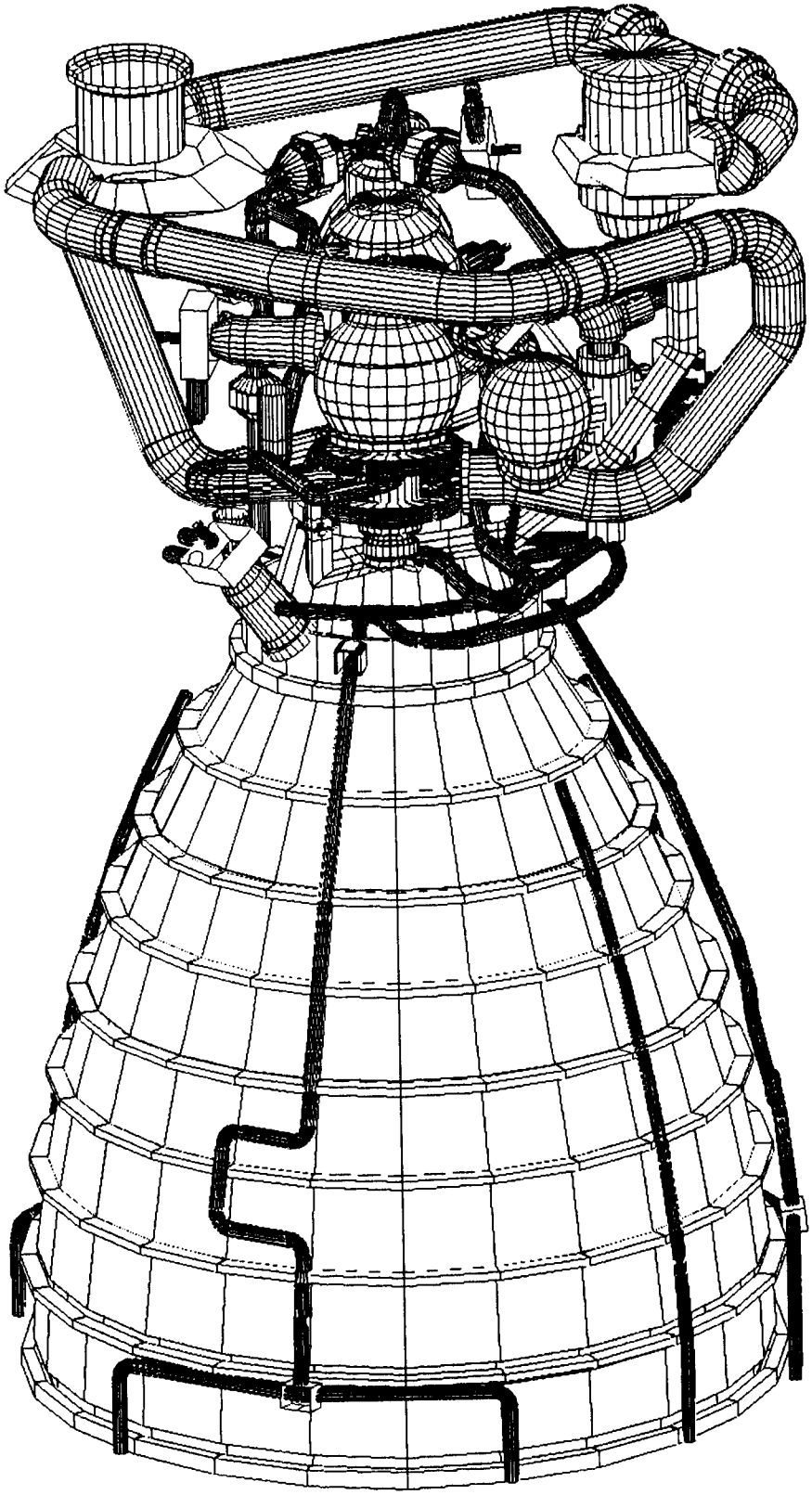

Figure 9. Three-dimensional CAD/CAM SSME model.

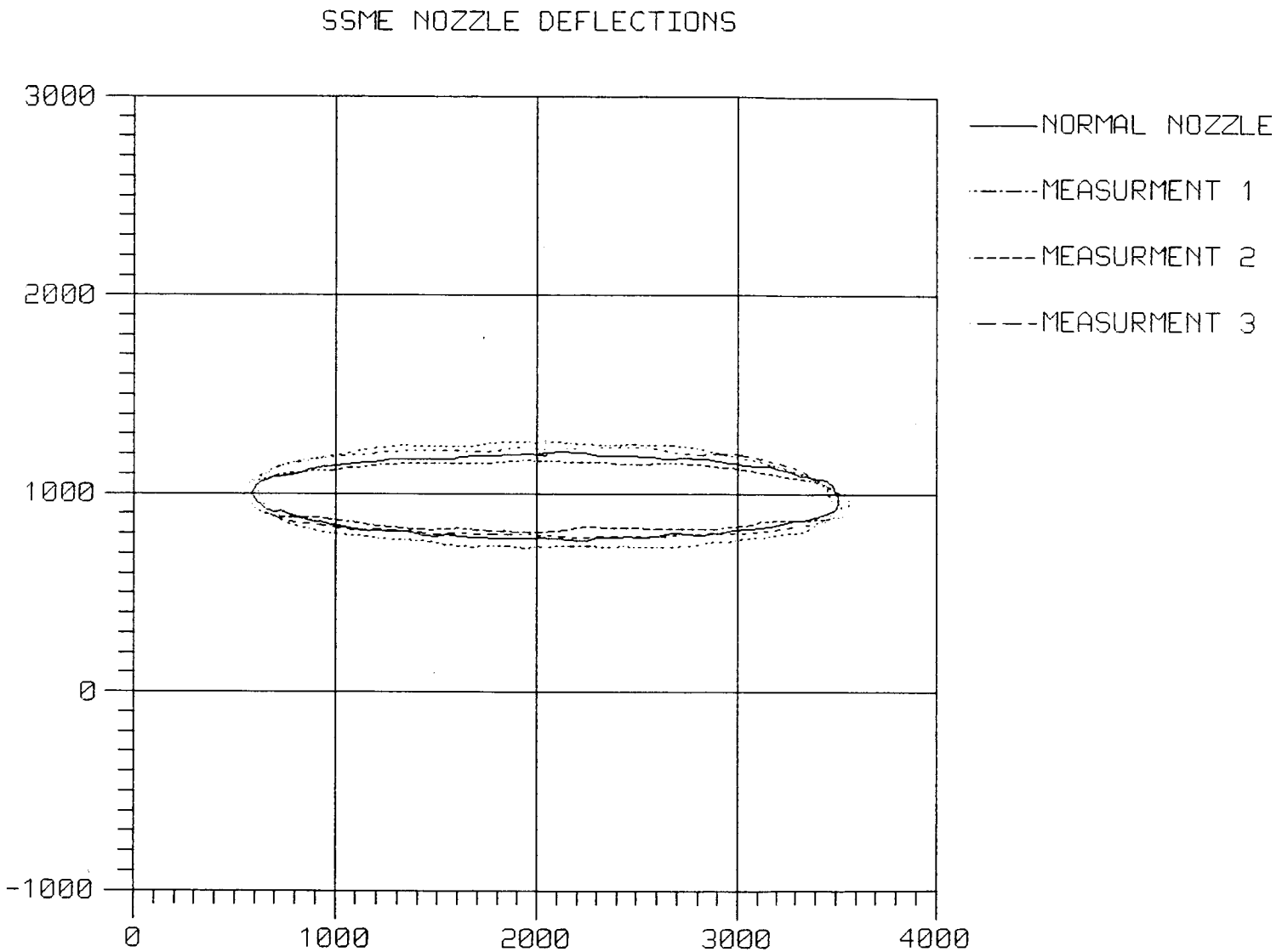

Figure 10. Example of motion analysis of SSME test film.

Free Hydrogen Burn Off System			
	Ignition	XX:XX:XX:XXX	GMT
	Cut Off	XX:XX:XX:XXX	GMT
	Delta	XX:XX:XX:XXX	GMT
SSME			
	First Indication of Fuel Lead	XX:XX:XX:XXX	GMT
	First Visible Fire in Nozzle	XX:XX:XX:XXX	GMT
	Main Stage	XX:XX:XX:XXX	GMT
SRB			
	First Motion	XX:XX:XX:XXX	GMT
	SRB Separation	XX:XX:XX:XXX	GMT
	Nose Cap Separation	XX:XX:XX:XXX	GMT
	Pilot Chute Deployment	XX:XX:XX:XXX	GMT
	Drogue Chute Deployment	XX:XX:XX:XXX	GMT
	Drogue Chute 1st Disreef	XX:XX:XX:XXX	GMT
	Drogue Chute 2nd Disreef	XX:XX:XX:XXX	GMT
	Frustum Ordinance Fire	XX:XX:XX:XXX	GMT
	Main Chute Out of Frustum	XX:XX:XX:XXX	GMT
	Main Chute 1st Disreef	XX:XX:XX:XXX	GMT
	Main Chute 2nd Disreef	XX:XX:XX:XXX	GMT
	Nozzle Extension Jetison	XX:XX:XX:XXX	GMT
	Splash Down	XX:XX:XX:XXX	GMT
GSE or Facility			
	TSM LO_2 Umbilical Disconnect	XX:XX:XX:XXX	GMT
	TSM LH_2 Umbilical Disconnect	XX:XX:XX:XXX	GMT
	GN_2 Vent Line Umbilical Disconnect	XX:XX:XX:XXX	GMT
	GN_2 Vent Line Capture	XX:XX:XX:XXX	GMT
	GN_2 Vent Line Latch	XX:XX:XX:XXX	GMT

4. *Quality Assessment:* Each film or video item is reviewed and an assessment made (Appendix I) of the quality of recording, processing, the field-of-view and orientation of the cameras. The film exposure, quality of processing and/or copying as well as the recorded time are assessed and recommendations for improvement or corrective actions are coordinated with the appropriate organizations. Timing for each record is also reviewed and cameras verified for proper operation and utility.

Upon completion of this assessment and review process, the pertinent information and data are compiled into a report and given wide distribution throughout MSFC as well as other NASA centers.

GENERAL CAPABILITIES AND RESOURCES

For purposes of this report, only the Propulsion Laboratory's (EP55) capabilities will be discussed. The Photographic Analysis System (PAST) consists of various hardware and software components. The system is divided into three main parts: (1) Film Analysis System (FAST), (2) Video Analysis System (VAST), and (3) CAD Analysis System (CAST). The film and video analysis systems allow the user to view and digitize the displayed image and related movements. From these data, calculations of items such as position, velocities, motion, attitude, etc. can be made and data files generated

which then allow production of data plots. The chief value of this means of data extration is its inherent relative accuracy and its value as a comparative tool relative to other means of data acquisition. Further measurements and analysis as described above rely on this basic data extraction process. The CAD analysis system allows the user to overlay a wireframe drawing or model onto either a projected film or video image allowing various data to be determined or extracted. Markers can be placed on the wireframe model which can be zoomed, panned, and rotated to more precisely determine relative vehicle coordinates or sources of anomalous conditions. Relative distances and angles can be calculated to allow preliminary analysis to be made and later other more precise calculations can be made using this CAD/CAM overlay process.

1. *Hardware:* The hardware configuration is depicted in Figure 11 and is outlined below:

a) NAC 16mm/35mm/70mm Film Analyzers

b) NAC Video Analyzer

c) 16mm/35mm/70mm Film Projectors

d) Electrohome Video Projector (not procured at this time)

e) Electrohome CAD/CAM projector

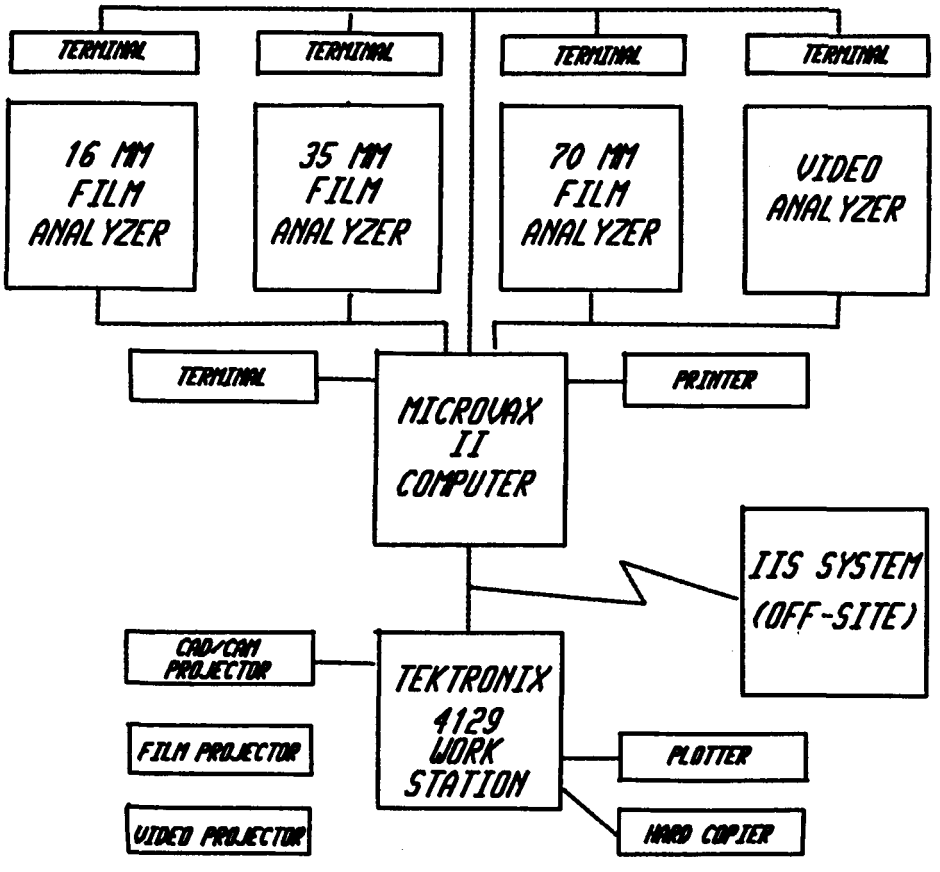

Figure 11. Photo evaluation hardware setup.

f) Digital Micro-Vax II Computer

g) Tektronix 4129 Workstation

h) Tektronix 4692 color copier

i) Tektronix 4663 digital plotter

j) DEC Letter printer

k) International Imaging Systems Image Enhancement Station.

The Micro-Vax II computer system serves as the backbone of the FAST and VAST. File transfer to the Tektronix Workstation is by direct means for display or plotting of data. The Tektronix Workstation serves as the core of the CAST. The three-dimensional models used in the CAST are currently created on either an Intergraph or Computervison Workstations and then translated to the correct format so that it can be transferred to the Tektronix Workstation.

2. *Software:*

a) FAST/VAST: Software for these systems consists of data acquisition programs which acquire x, y, and time data from the analyzers. The data can be read as raw data points or can be calibrated relative data. Also these data points can be used to calculate distances, velocities, line lengths, areas, and angles. A quick plot of these data can be displayed on the CRT to ensure good data before actual production. Those data files are then transferred to the Tektronix workstation where data plots can be created or projected for review. These data plotting routines also have the capability to perform animation using the data curves.

b. CAST: Software for the CAST consists of two-dimensional or 3-dimensional display and analysis techniques. The images or models are displayed on the viewing screen in the correct orientation. For film/video overlays of the Shuttle stack, the software provides quick positioning of the three-dimensional wireframe model over the Shuttle image based on locating certain items of the film image. From the overlays in relation to the film image, markers can be placed on the model surface, then measurements of angles and distances can be made. Once the marker is placed on the model surface, the model can be zoomed, panned, and rotated for a better perspective and more precise determination of relative locations. Vectors and text can be placed on the models to create presentation quality materials.

In the two-dimensional software, drawings of the film image can be created and metric measurements and calculations can be made. These data are saved for plotting or analysis in much the same way as the three-dimensional overlay process.

Other software capabilities for the PAST consist of a historical database for each mission that contains data such as camera types, film quality, anomalies, comments, etc.

Display software exists for the images from the enhancement system on the Tektronix workstation so the images can be recorded by the copier or displayed over the CAD/CAM projector.

Most or almost all software has been developed entirely by MSFC Photographic Analysis Personnel. Documentation of this software is being updated as the software is expanded and improved. As new analysis needs are recognized, the existing software may be enhanced as necessary to meet any new analysis objectives.

SUMMARY

Utilizing a background that includes development of basic launch and test photographic coverage and analysis procedures, the MSFC Photographic Evaluation Group has built a field of experience that enables it to effectively satisfy MSFC's engineering photographic analysis needs. Combining the basic soundness of reliable, proven techniques of the past with the newer technical advances of computers and computer-related devices, the MSFC Photo Evaluation Group is in a position to continue to provide photo and video analysis service center-wide and NASA-wide to provide an improving photo analysis product to meet the photo evaluation needs of the future; and to provide new standards in the state-of-the-art of photo analysis of dynamic events.

APPENDIX A

ENGINEERING ANALYSIS CAMERA ITEMS

ITEM NO.	VIEW	PRIME FUNCTION	ALTERNATE FUNCTION	EVENTS TIMED	MEASUREMENTS
E-1,2,3,4	Launch Deck and Lower 1/4 of Vehicle	1) Structural and Thermal Insulation Evaluation 2) Launch and Lift Off Characteristics	1) Falling Debris/Particle Identification	1) Anomaly Investigation	1) Anomaly Investigation
E-5,6,31	ET - Orbiter Fluid/ Electrical Umbilical Body Flap and Surrounding Area	1) Detect Leakage, Ice Formations 2) Insulation or Structural Failures	1) Over Pressure Effects On Elevons and Body Flap 2) Debris/Particle Identification and Orbiter Stricks Evaluation	1) Anomaly Investigation	1) Cursory Elevon Motion
E-7 thru 14	SRB Restraining Devices (Hold Down Post)	1) Monitor Operation of Each Hold Down Post 2) Operation of Hold Down Post Protective Covers (When Installed)	1) Ignition effects on Thermal Curtain, Rain Curtain, Nozzle Insulation 2) Pad Debris/Particle Identification	1) Lift Off Time Determination 2) First Motion 3) Anomaly Investigation	1) Lift Off Rates 2) Vehicle Drift
E-15,16	SRM Nozzle to show motion, hold down post clearance, and thermal curtain integrity	1) Ignition effects on Thermal Curtain, Rain Curtain, Nozzle Insulation and performance of SRB Nozzle	1) Pad Debris/Particle Identification	1) Back-up for E7-14 For Lift Off Time and First Motion	1) Back-up for E7-14 Lift Off Rates 2) Vehicle Drift
E-17,18	TSM Umbilical	1) Monitor Disconnect and Withdrawal	1) Debris/Particle Identification	1) Disconnect Times	1) Withdrawal Rates

ITEM NO.	VIEW	PRIME FUNCTION	ALTERNATE FUNCTION	EVENTS TIMED	MEASUREMENTS
E19,20,77,76	Engines, Engine Compartment, and AFT Bulkhead Heat Shield	1) Engine Analysis 2) Leakage Detection 3) Ice Frost Formation 4) Tile and/or Space Surveillance 5) Plume Analysis	1) Debris/Particle Identification 2) Over Pressure Effects on AFT Compartment OMS Nozzles-Back for E23,24 3) Free Hyd Burn Off System Performance	1) First Visual Indication of Fuel Lead 2) First Indication of Flame in Nozzle 3) Main Stage 4) Free Hyd Burn Off System Ignition and Cut Off	1) Nozzle Motion during Start and Shut Down
E23,24	OMS Engine Nozzle	1) Effects of Ignition on OMS Nozzles	1) Tile and/or Spacer Surveillance 2) Debris/Particle Identification	1) Anomaly Investigation	1) Anomaly Investigation
E25,26	Area Between Orbiter SRB/ET	1) Debris/Particle Identification and Orbiter Stricks Evaluation	1) Back-up to E5-6 of Over Pressure Effects	1) Anomaly Investigation	1) Anomaly Investigation
E30	SRB Secondary Holes on MLP	1) Monitor Ignition Effects on Over Pressure Suppression System	1) Debris/Particle Identification	1) Anomaly Investigation	1) Anomaly Investigation

ITEM NO.	VIEW	PRIME FUNCTION	ALTERNATE FUNCTION	EVENTS TIMED	MEASUREMENTS
E32	Area Between TSM and Orbiter Wing	1) Lateral Displacement Between Orbiter Wing and TSM	1) Debris/Particle Identification 2) SSME Water Spray System Performance	1) Anomaly Investigation	1) Distance Between Wing and TSM
E33,39,41, 42,50	GH2 Umbilical Vent Line	1) Umbilical carrier plate separation, fall away, capture and latching performance	1) Debris/Particle Identification 2) Ice Frost Build Up (Pad 39A)	1) Release Time 2) Capture and Latching (Approx)	1) Fall Away Rates
E34,35,36,40	Surfaces Between Orbiter and SRB/ET	1) Orbiter Tile Surveillance	1) Debris/Particle Strikes of Orbiter Tiled Surfaces	1) Anomaly Investigation	1) Anomaly Investigation 2) ET Tip Deflection Back up to E79 (E40)
E52,53,54	Close in Tracking Coverage of entire Vehicle	1) General Assessment of Over All Vehicle Performance during Lift Off thru first 1200 ft of flight	1) Falling Particle Identification 2) Roll Manuever Performance 3) General Assessment of SSME and SRM Performance	1) Anomaly Investigation	1) Anomaly Investigation 2) CAD/CAM Overlays applied to assist in Performance Analysis
E57,58,59,62	Vertically staged to cover entire vehicle thru tower clearance	1) General Assessment of Over All Vehicle Performance during Lift Off thru Tower Clearance	1) Falling Particle Identification 2) General Assessment of SSME and SRM Performance	1) Anomaly Investigation	1) Anomaly Investigation

ITEM NO.	VIEW	PRIME FUNCTION	ALTERNATE FUNCTION	EVENTS TIMED	MEASUREMENTS
E60,61,63	Entire Vehicle, FSS and MLP	1) General Assessment of Over All Vehicle Performance During Lift Off	1) Anomaly Detection of FSS or MLP 2) General Assessment	1) Anomaly Investigation	1) Anomaly Investigation 2) CAD/CAM Overlays Applied to Assist in Performanced Analysis
E68,69,70, 71,72,73, 74,75	Long Range View of Vehicle, FSS MLP and Surrounding Area	1) Catastrophic failure while on Pad	1) Failure During Tanking and Pressurization	1) None	1) None
E79	Tip of External Tank	1) TWANG Analysis	1) SRB/ET Structural Assessment During Lift Off	1) Anomaly Investigation	1) ET Tip Deflection
E201,202, 203,NC,214, 215,216,217	Coverage of Entire Vehicle from Lift Off until LOV	1) General Assessment of Over All Vehicle Performance During Early Powered Flight	1) Engine Plume Analysis 2) Roll Manuever Evaluation 3) Lift Off Characteristics	1) Anomaly Investigation	1) Anomaly Investigation 2) CAD/CAM Over Lays Applied to Assist in Performance Analysis
E204,205, 206,207	Coverage of Entire Vehicle from Acquisition until LOV	1) General Assessment of Over All Vehicle Performance	1) General Assessment of SRB Separation and Fall Away	1) SRB Separation 2) Anomaly Investigation	1) Anomaly Investigation 2) CAD/CAM Over Lays Applied to Assist in Performance Analysis 3) Cursory measurements and Angular Computations of SRB's at Sep.

ITEM NO.	VIEW	PRIME FUNCTION	ALTERNATE FUNCTION	EVENTS TIMED	MEASUREMENTS
E230,231, 232 (Cast Glance)	Coverage of SRB Re-entry (Approx 100K FT) to Splash Down	1) General Assessment of SRB Re-entry 2) Parachute Performance Analysis	1) SRB Nozzle Area Structural Evaluation 2) Splash Down Effects and Flotation Characteristics	1) Nose Cap SEP 2) Pilot Chute Deploy 3) Drogue Deploy 4) Drogue Disreefing 5) Frustom Ordinance 6) Main Chute Deploy 7) Main Chute Disreefing 8) Nozzle Extension Jetison 9) Splash Down 10) Anomaly Investigation	1) Anomaly Investigation 2) CAD/CAM Over Lays Applied to Assist in Analysis
E301,302 SRB ON BOARD	Coverage of Parachutes	1) General Assessment of Parachute Performance	1) Debris/Particle Identification and Effects on Parachute Performance	1) No timing on film, Rough Back up to Cast Glance Event Times	1) Anomaly Investigation

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16. ABSTRACT

Utilizing a background that includes development of basic launch and test photographic coverage and analysis procedures, the MSFC Photographic Evaluation Group has built a field of experience that enables it to effectively satisfy MSFC's engineering photographic analysis needs. Combining the basic soundness of reliable, proven techniques of the past with the newer technical advances of computers and computer-related devices, the MSFC Photo Evaluation Group is in a position to continue to provide photo and video analysis service center-wide and NASA-wide to provide an improving photo analysis product to meet the photo evaluation needs of the future; and to provide new standards in the state-of-the-art of photo analysis of dynamic events.

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