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Summary Report--Full- Scale Transport Controlled Impact Demonstration Program

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Final Report

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16. Abstract The Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) conducted a full-scale air-to-surface impact-survivable "impact demonstration" with a remotely piloted transport aircraft on December 1, 1984, at Edwards Air Force Base, California. The test article consisted of experiments, special equipments, and supporting systems, such as antimisting kerosene (AMK), crashworthiness structural/restraint, analytical modeling, cabin fire safety, flight data recorders, post-impact investigation, instrumentation/data acquisition systems, remotely piloted vehicle/flight control systems, range and flight safety provisions, etc. This report describes the aircraft, experiments, systems, activities, and events which lead up to the Controlled Impact Demonstration (CID). An overview of the final "unmanned" remote control flight and sequence of impact events are delineated. Preliminary post CID observations are presented.			
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EXECUTIVE SUMMARY

Planning for the Full-Scale Transport Controlled Impact Demonstration (CID) began in July 1980. The aircraft experiments and systems integration began in December 1983. The first full dress rehearsal took place February 29, 1984, and the CID aircraft first flew on March 7, 1984.

In all there were 14 manned test flights prior to CID. On December 1, 1984, the remotely piloted CID aircraft took off on its final flight and impact demonstration at Edwards AFB, California -- within 120 days of the target date commitment made to Congress in 1980.

This was the first time that a four-engine jet aircraft (Boeing 720) had been flown successfully by remote control. It was also the first time that an aircraft was flown solely and successfully on antimisting kerosene fuel (AMK). In previous flight tests, AMK was used to fuel one engine, while the other engines had operated on conventional Jet A.

The complex CID did not perform as planned, however, the results provided much valuable data on the antimisting fuel and crashworthiness experiments. The cabin fire safety experiments in CID provided little data due to extensive fire damage. The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) concluded that the CID was a survivable accident. On April 2, 1985, the two agencies reported on their preliminary findings of the joint CID undertaking to the Transportation, Aviation, and Materials Subcommittee of the House Committee on Science and Technology.

Overall observation and impression of the CID operation was that it was at the highest professional level by the entire CID team. The ground team, remote control vehicle lab/cockpit team, aeronautical test range, control room (support operations), and Air Force support (i.e., ground, tower, CFR, etc.) performed flawlessly. The NASA, FAA, DOD, industry, etc., team must be complimented for their performance in this effort.

INTRODUCTION

The Full-Scale Transport Controlled Impact Demonstration (CID) Program was a joint Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) research effort conducted on December 1, 1984, at the NASA-Ames/Dryden Flight Research Facility (NASA-A/DFRF), Edwards Air Force Base, California.

This Summary Report is a deliverable product supporting the program Management Plan. It delineates a summary of the total CID experiments, instrumentation/data acquisition, telemetry, remotely piloted vehicle/flight control system (RPV/FCS), systems integration, flight operations, impact demonstration, post-impact investigation, and "quick-look"/preliminary data results. Detailed technical reports are scheduled to be prepared by the FAA and NASA.

BACKGROUND.

In 1980, the FAA planned to conduct a controlled impact of a typical modern day jet transport aircraft to demonstrate the effectiveness of the antimisting kerosene (AMK) fuel concept. While planning the AMK experiment, it became obvious that a test of this magnitude could support various other research experiments which would be the basis for regulatory actions or long-term research initiatives. It appeared logical that crashworthiness/structural/restraint and cabin fire safety research efforts could benefit from such a impact demonstration.

Therefore, the FAA invited NASA to participate in and support the crashworthiness experimentation and flight operations of this test. The NASA-Langley Research Center (NASA-LaRC) provided the structural crashworthiness instrumentation and CID program data acquisition systems (DAS). The NASA-A/DFRF supported the test by AMK, crashworthiness, and cabin fire safety experiment integration, instrumentation, and data acquisition integration; remotely piloted vehicle/flight control system (RPV/FCS) design and development; ground and flight test operations; the subsequent impact demonstration; and data reduction and analysis.

The Full-Scale Transport CID Program was developed and primarily based on a culmination of FAA and NASA exhaustive laboratory, simulation, and development tests conducted for AMK, crashworthy design features, and cabin fire safety. The consummation of this demonstration and the other test efforts is to provide the evidence, specifications, and criteria for consideration of rulemaking action.

The aircraft (figure 1) was a typical 4-engine jet (Boeing 720) intermediate range design which entered airline service in the mid-1960's, but its physical design features and construction practices are common to U.S. and foreign airframe manufacturers (i.e., B-707, DC-8, B-757, A-300 etc.).

The CID aircraft contained the necessary systems, components, instrumentation, and data acquisition systems to support the AMK, crashworthiness, and fire safety experiments. Current and new generation flight data and cockpit voice recorders were installed. Passive and benign hazardous materials packages were located under the galley area for this test. The RPV/FCS (ground and airborne) were integrated in the B720 to provide remote controlled air-to-surface impact.

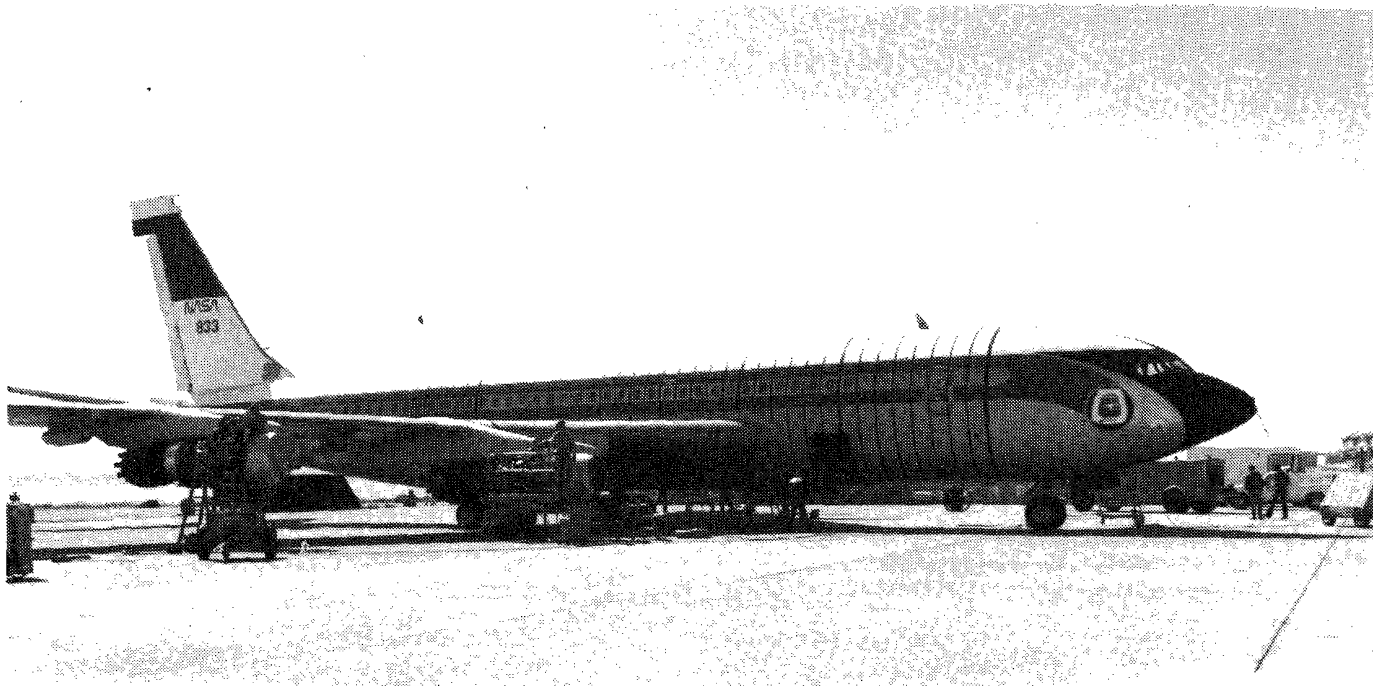


FIGURE 1. CID/BOEING 720

Engineering high-speed motion picture, video, and still cameras (airborne and ground) provided the necessary internal and external data documentation. A flight safety termination system was provided in case of loss of remote control. Basically, the B-720 was unchanged from its original configuration other than that necessary to integrate the systems and equipments of the experiments and the RPV system.

The FAA's aircraft safety program, as proposed to Congress in mid-1980, identified a need for a large transport crash test which would demonstrate and validate technology that can improve transport aircraft crash survivability through: (1) reduced post-crash fire hazard; and (2) improved crash impact protection.

PROGRAM EXPERIMENTS/OBJECTIVES

TECHNICAL.

Recent advances in impact technologies and their applications for post-crash safety provide for:

- o Antimisting Kerosene Fuel (AMK)--verify that AMK can preclude ignition of an airborne fuel release and/or suppress the ignited fireball growth characteristic upon impact and demonstrate AMK in an operational fuel/propulsion system.

- o Structure (fuselage, wing, floor)--examine structural failure mechanisms and correlate analytical predictions; provide baseline etal crash data to support FAA and NASA composite crash dynamics research; and define dynamic floor pulse for seat/restraint system studies.
- o Seat/Restraint System--assess regulatory criteria; evaluate performance of existing, improved, and new lightweight seat concepts; and evaluate performance of new seat attachment fittings.
- o Stowage Compartments/Galleys--evaluate effectiveness of existing/improved retention means.
- o Analytical Modeling--validation of FAA "KRASH" and NASA "DYCAST" models to transport aircraft and verify predicted crash test impact loads.
- o Cabin Fire Safety--observe seat blocking layers, burn-through resistant windows, and low-level emergency lights performance.
- o Flight Data and Cockpit Voice Recorders (FDR/CVR)--demonstrate/evaluate performance of new FDR/CVR systems, and demonstrate usefulness for accident investigation analysis.
- o Flight Incident Recorder/Electronic Locator Transmitter (FIR/ELT)--demonstrate/evaluate performance of the ejectable U.S. Navy/Naval Air Test Center (NATC) system.
- o Hazardous Materials Package--demonstrate performance of packages in an impact environment.
- o Post-Impact (Accident) Investigation Analysis--assess adequacy of current National Transportation Safety Board (NTSB) forms and investigation procedures.
- o Remotely Piloted Vehicle/Flight Control System (RPV/FCS)--guide the "unmanned" aircraft through the flight profile, activate the onboard experiments/systems, and control the aircraft to a precise impact target area.

MANAGEMENT.

The following were the primary management tasks:

- o Provide program development, coordination, and implementation.
- o Provide program and technical support.

PROGRAM MANAGEMENT

A Test Management Council (TMC) was established to overview CID and to assure implementation of the participating FAA and NASA organizations commitments and responsibilities. Council representatives were from the FAA Technical Center, NASA-Langley Research Center, and NASA-Ames/Dryden Flight Research Facility management. The TMC was the Program Manager's route to each participating agency's top management for problem solving and general project/program reporting.

The Program Manager provided overall program development, coordination, and implementation coordination with all participating organizations.

PARTICIPANTS.

Participants included numerous government and industry organizations with various program functions and responsibilities. Appendix A provides a general listing of those organizations and individuals who contributed heavily to the success of the CID program.

PROGRAM IMPLEMENTATION

The Management Plan (reference 1), by its January 1984 release, represented the experiments and systems plans as implemented. The experiment/systems deliveries and installations were well underway by the issue and distribution date. CID was functioning under the NASA-A/DFRF "Basic Operations Plan" (reference 2) as augmented by the "CID Project Operations Plan" (reference 3). A "Configuration Management Plan" (reference 4) was implemented as early as an initial wrench applied to the B-720, experiments/systems installation and integration, checkout, maintenance, repair/replace, etc. The "Ground Operations Plan" (reference 5) provided the final organization and operations of the ground activities. Other supporting documents will be identified in the appropriate subject sections. CID documents Index (appendix B) is a listing of the working documents.

The NASA-LaRC was given the overall CID program schedule tracking responsibility whose reporting was provided in a management information (reference 6) format on a monthly basis. This document contained comprehensive integrated/flow-charted (logic flow networks) schedule for all aircraft, systems, experiments, tests (ground/flight), etc., segments of the CID program activities.

Initial experiment deliveries to NASA-A/DFRF by mid-December 1983 with installation/integration were started in late December 1983 and were basically completed by the end of February 1984. RPV/FCS ground checkout started in mid-February 1984. A successful ground Combined Systems Test (CST) was conducted on February 29, 1984, and first manned flight was conducted on March 7, 1984. Subsequent flights were planned for April, May, and June 1984, with the final three flights, including the impact demonstration, occurring in late July 1984. A flight test buildup plan was initiated which was a systematic development to assure manned flight safety and CID mission success. This systematic development minimized risks, established system reliability and performance, and "confidence" that the CID was ready for the final unmanned mission. This meant

not only confidence must be built up on the basic aircraft but also the AMK degrader/engine systems, instrumentation/data acquisition/camera systems, FDR/CVR, and the RPV/FCS concept.

The test aircraft, experiments/systems installation, integration/checkout, ground, and flight operations are generally discussed in the following sections.

TEST AIRCRAFT.

The test aircraft was a typical four-engine jet (Boeing 720) intermediate range design which entered airline service in the mid-1960's. This aircraft was purchased new by the FAA in 1960 for \$4.2 million for use in training the agency's jet operations inspectors. During its FAA career, it logged more than 20,000 hours and made over 54,000 takeoffs and landings. Basically, it had come to the end of its useful career, and was judged to be the best candidate aircraft for CID.

The physical design features and construction were common to U.S. and foreign airframe manufacturers (i.e., Boeing 707, McDonnell Douglas DC-8, Boeing 757, Airbus A-300, etc.). Airframe structure, cabin interiors, flight deck, seat/restraint systems, fuel and propulsion systems, flight control and avionics systems were representative of the aircraft industry cross-section.

The general specifications for the Boeing 720 are:

Length	136.7 Feet
Wing Span	130.9 Feet
Empty Weight	106,000 Pounds
Maximum Landing Weight	175,000 Pounds
Gross Takeoff Weight	203,000 Pounds
Fuel Capacity	12,189 Gallons
Flight Crew	(3)
Passengers	(124) Normal (113) CID Configuration

The aircraft was turned over and delivered to NASA-Ames/Dryden Flight Research Facility in June 1981 to prepare for the CID program. During the summer of 1983, initial interior materials, floor, and side panel removals began in order to access areas for accelerometers, strain gages, an instrumentation/power cabling installation. In some areas, selected side panels and materials were not replaced; i.e., cargo compartment, fuselage ceiling, etc. Seat/restraint systems were replaced with the planned experiment standard/modified seat-restraint systems. The flight deck, flight control and avionics systems were modified for Edwards Air Force Base operations, remote piloted vehicle, and instrumentation.

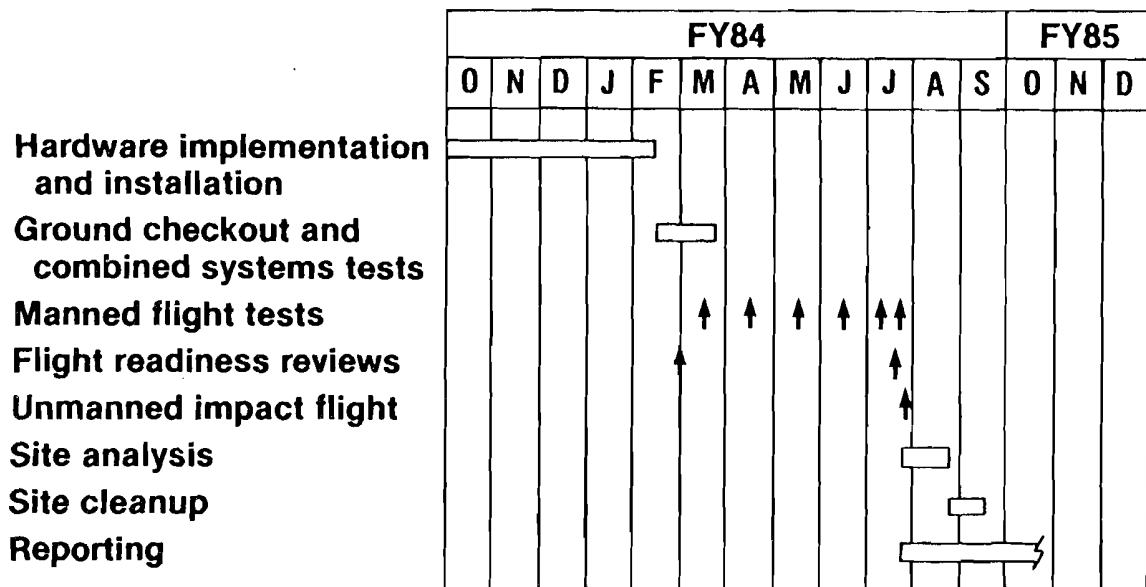
The fuel and propulsion system were modified to support the AMK degrader system, instrumentation, and operations. Air-conditioning and pressurization turbocompressors were removed from the engine to allow installation of the AMK degrader system. Thermal anti-icing systems for the wing leading edges were eliminated. An AMK positive ignition source/dual flame generator package was installed in the tail cone.

EXPERIMENTS/SYSTEMS INSTALLATION, INTEGRATION, AND CHECKOUT.

All modifications to the B-720 were under the jurisdiction of NASA-A/DFRF. FAA Technical Center, NASA-Langley Research Center (NASA-LaRC), and/or their contractors could work on the aircraft with the appropriate NASA-A/DFRF assigned crew chief and Chief, Aircraft Maintenance and Support Division approvals. Various FAA, NASA, and industry contractors developed engineering drawings (reference 7) for the installation and integration buildup. Responsible lead individuals and points of contact were identified, and they in turn maintained the required documentation revisions and necessary coordination for configuration control (reference 4).

Installation, integration, and checkout were generally accomplished in accordance with the CID team approved original project planned schedule (table 1) and as detailed in the NASA-LaRC prepared monthly system report (reference 6) and the NASA-A/DFRF "Top Man Schedule." Daily schedule of activities and events was reported/reviewed at the Dryden Project Managers morning meeting. Once each week, a total CID team/crew meeting was conducted to review past weeks progress, problems, solutions, etc., and the new week work item lists.

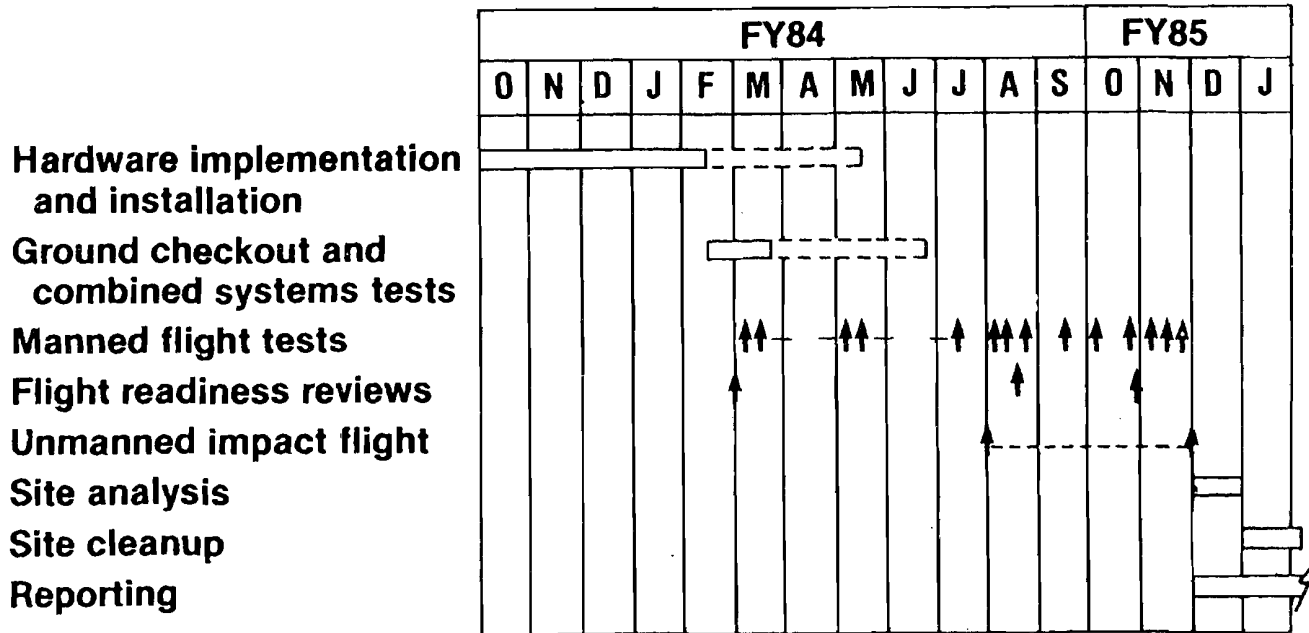
TABLE 1. ORIGINAL PROJECT SCHEDULE -- INSTALLATION AND FLIGHT SCHEDULE



As the schedule indicates, experiments and systems installation/integration began in early December 1983. Basic aircraft compliance with FAA/manufacture aircraft directives (AD) had been initiated in early 1983. Sensor/instrumentation/power cabling was started in October 1983 with initial data acquisition system (DAS) and high-speed motion picture camera systems installation beginning in mid-December 1983. Table 2 provides an actual project history and schedule overview.

Delivery and installation of the four AMK fuel degrader systems were delayed based on bench testing of the first flight degrader. Corrective actions were accomplished by the contractor for all degraders and the on-site installation design and buildup continued. RPV (ground and airborne) systems installation and checkout were in progress and were generally in a state to participate in the combined systems tests (CST).

TABLE 2. PROJECT HISTORY AND SCHEDULE



The initial CST was conducted on February 29, 1984. The DAS performed limited checkouts, and the AMK degrader/pod system was installed but nonoperational. The RPV system performed many of its uplink/downlink control functions. The aircraft/engine systems performed satisfactorily in preparation for first flight on March 7, 1984.

On April 4, 1984, the initial degrader/engine systems operations were attempted. The plan was to step each degrader through a systems checkout prior to integration with an engine and ground run. Once that checkout was completed, then integrate one degrader with a companion engine and conduct normal engine run procedures. After a series of degrader systems only checkout attempts, the operation was shutdown. Numerous anomalies occurred, problems corrected, and the first degrader/engine run was successfully conducted on April 11, 1984. Flight AMK/degrader buildup plan (appendix C) provides a general insight as to degrader/engine system checkout.

GROUND OPERATIONS.

The ground operations (reference 5) activities not only included the impact site development but also the operational control and support (as required) over all ground support elements participating in pre-impact, impact, a post-impact activity within the operational control area for CID operations. Responsibility for the CID impact site operations rested with the Ames/Dryden Project Manager down to within 3 days of impact. Coordination was then transitioned to the CID Ground Operations Manager/Convoy Commander (GOM/CC) finally at CID impact.

Impact Site. The CID test area was located on Rogers Dry Lake immediately adjacent to the Edwards Air Force Base Precision Active Impact Range Area (PAIRA). The impact site (figures 2 and 3) was covered with a 4- to 6-inch deep layer of 1-1/2 inch diameter hard rock for a distance of 1,200 feet by 300 feet wide.

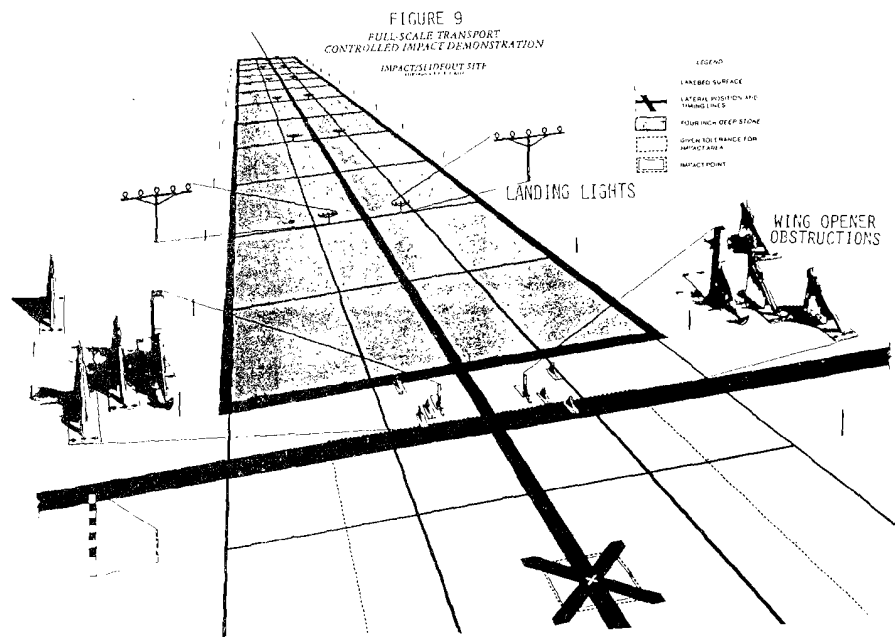


FIGURE 2. IMPACT/SLIDEOUT SITE

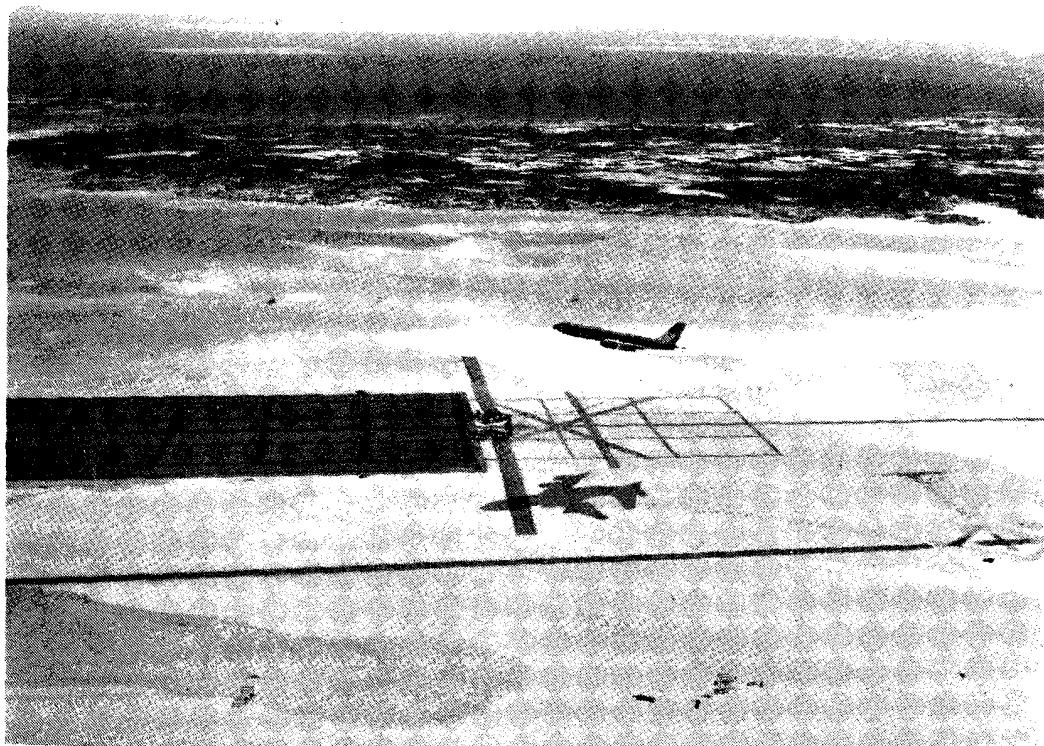


FIGURE 3. ACTUAL IMPACT SITE

Ground photographic/video coverage fixed position and tracker platforms were installed either side of the impact and slideout area. Thirty-four photographic range poles (10 feet high) serving as photographic identification aids were installed at the impact site. They were located at 100-foot intervals on each side beginning about 200 feet before the planned impact point.

Twelve low impact resistance, breakaway landing approach light structures, each 10 feet tall with five lights per pole, were located every 100 feet beginning 300 feet after the impact point, six on each side of the runway, 75 feet across from each other. They are constructed of lightweight fiberglass tubes with breakaway couplings every 42 inches. These light towers and their 60 300-watt approach lamps serve to provide a realistic fuel ignition source.

Eight wing openers (figure 4) were located between 50 and 100 feet past the planned impact point. Contact by the leading edge of the wing will cause the lower half of the wing opener to rotate upwards and cut into the lower portion of the wing, rupturing the fuel tanks. Each wing opener weighs approximately 400 pounds and is 8 feet by 7 feet long (blade part) by 2 feet wide. For RPV pilot visual target alignment and aiming, a black fence (figure 5) with an international orange center was installed in front of the wing openers.

Operational Control. The GOM/CC was responsible for the control of all operations, personnel, and equipment during the final 3 days prior to impact, at impact, and up through approximately T+15 days in the CID operational control area. The Air Force Flight Test Center (AFFTC) On-Scene Commander was responsible for all the AFFTC/Department of Defense (DOD) resources which were either a part of the CID operations or that which may be called into the vicinity of the CID/720 during an emergency operation.

The Impact Site Operational Control Area was under NASA/USAF security control 24 hours per day beginning 1 week prior to impact up through approximately T+15 days. USAF Security Police were posted, sealed off access, and helicopter searched the lakebed/sterile termination envelope area prior to engine start through impact and a safe "all clear" signal. Entry into the control area was by radio communications and special badging.

Aircraft, experiments, and systems operations teams supported the lakebed operations pre- and post-impact. Engineering photographic/video coverage teams required access to service, load, and set up the equipment prior to impact and after impact to recover the film and video tape.

Official technical observers, VIP's, guests, and media personnel were assigned designated observer areas off the lakebed and outside the termination envelope area.

Crash fire rescue personnel and firefighting apparatus were prepositioned at designated locations on the lakebed outside the termination envelope area. Standard USAF water and foam firefighting vehicles were provided with a normal crew complement. An FAA accident investigation specialist was transported with the firefighting teams in order to check the aircraft for toxic or unsafe gases prior to allowing the aircraft/systems safing team onboard after fire extinguishment.

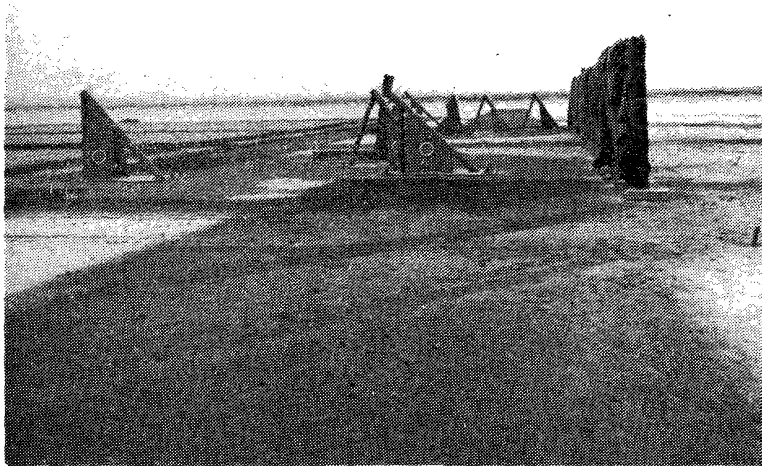


FIGURE 4. WING OPENERS



FIGURE 5. VISUAL TARGET ALIGNMENT FENCE

The aircraft/experiment safing team; tape, film, and experiments recovery team; TV/photographic documentation team; documentation research team; and the post-impact investigation team were among the additional personnel requiring pre- and post-impact access to the operational area.

FLIGHT OPERATIONS.

All flight operations were conducted in accordance with the Dryden Basic Operations Plan (reference 2) and the CID Project Operations Plan (reference 3). All ground (aircraft/systems) and airborne operations were supported by the NASA One Main Control Room and Spectrum Analysis Facility (figures 6 and 7).

Appendices C and D provide typical flight test buildup plans that were developed and implemented for a systematic checkout of the aircraft, experiments/systems, and the RPV/FCS. The initial Flight 001 (March 7, 1984) was basically a test of the aircraft/systems and an opportunity for the flight crew to assess the flying qualities and systems of the aircraft, as the aircraft had not been flown since its 1981 delivery to Dryden. Initial follow-on flights were:

Flight 002	March 15, 1984
Flight 003	May 3, 1984
Flight 004	May 9, 1984

After a number of attempts on May 17-19, 1984, to complete the degrader system (only) ground and flight checks for Flight Numbers 005 and 006, a number of installation induced technical deficiencies were observed; therefore, the CID Program Manager and Dryden Project Manager shut down the operation. After a series of CID team reviews, a work item list of approximately 13 items for the degrader and engine systems was developed, and it was estimated that approximately 5 weeks of work would be required to accomplish the task. On May 23, 1984, the decision was made to remove the aircraft from flight status and to begin the work on the engine/degrader systems as well as other work identified for instrumentation, data acquisition systems, remote control, etc. It was then obvious that Flights 005 and 006 would be delayed and therefore impact the planned CID date of July 28, 1984. FAA and NASA management participated in status reviews, and a new schedule was developed. On July 10, 1984, a successful combined systems test (CST) was run with minimum anomalies. Flight 005 was conducted on July 13, 1984, and a number of anomalies occurred. Problems did occur with experiments, systems, and the old Boeing 720 aircraft.

After Flight 005, generally the flights were as follows:

Flight 006	August 7, 1984	
Flight 007	August 17, 1984	
Flight 008	August 28, 1984	
Flight 009	September 18, 1984	
Flight 010	October 1, 1984	
Flight 011	October 25, 1984	Dress Rehearsal
Flight 012	November 5, 1984	
Flight 013	November 15, 1984	
Flight 014	November 26, 1984	Final Flight Preparations (Manned)
Flight 015	December 1, 1984	CID (Unmanned)



FIGURE 6. MAIN CONTROL ROOM

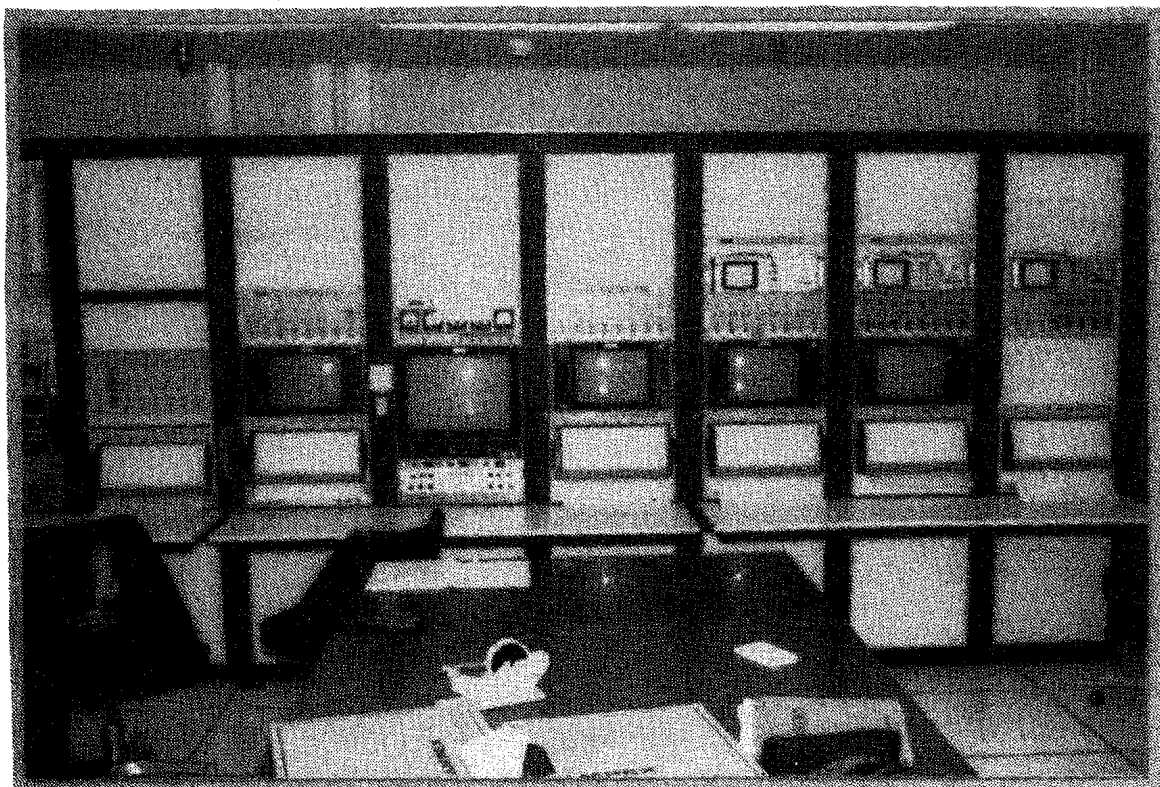


FIGURE 7. SPECTRUM ANALYSIS FACILITY

To summarize the CID flights, there were 14 "manned" flights flown:

- Total flight time: 31.4 hours
- Total RPV time was 52.2 percent of total
- 9 RPV takeoffs and 13 RPV landings
- 69 CID profiles/approaches to altitudes between 150 and 200 feet

One "unmanned" flight was flown:

- Total RPV time was 8 minutes: 54 seconds.

The final CID unmanned flight (015) will be discussed in more detail in the impact scenario (actual) and RPV/FCS summaries. Flight 015 Mission Rules (reference 8), Operating Rules (reference 9), and Flight Cards (reference 10) were used for Day of Flight (DOF) operations.

IMPACT SCENARIO

In the 1980-1981 time frame, the FAA B-720 (N-23) transport was made available for testing purposes to the FAA Technical Center. As originally conceived, the aircraft was to be primarily used for:

- o Demonstrating the effectiveness of AMK in a typical impact survivable postcrash fire environment. The decision was made to piggyback the AMK experiment with additional crashworthiness experiments which included an instrumented structure (to validate analytical model predictions) and a series of instrumented cabin and seat/restraint systems installations.

However, recognizing that experimental incompatibility may exist, priorities were established by the FAA Office for Aviation Standards and CID team members.

- o AMK
- o Structural (Fuselage, Wing Measurements)
- o Validation of Analytical Model (KRASH)
- o Seats/Restraint Systems
- o Seat Blocking Layers/Burn-Through Resistant Windows
- o FDR/CVR's

As a part of the effort to define an acceptable impact scenario to all experimenters, a joint effort between the FAA Technical Center, NASA-LaRC, and the major transport aircraft manufacturers was contracted to do an indepth investigation of transport aircraft accidents. The purpose of this study was to define failure mechanisms affecting occupant survivability in a crash environment, and to define a range of survivable crash conditions or crash scenarios that may form a basis for developing improved crashworthiness design technology.

The accident data base consisted of a review of 933 worldwide transport accidents which occurred during the years of 1959-1979. The sources of the data were the files of the FAA, Civil Aeronautics Board (CAB), NTSB, transport aircraft manufacturers, etc. The data focused on survivable accidents only which, after applying established criteria to the total data base, was reduced from 933 accidents to 175 survivable transport accidents (domestic: 99; foreign: 76) delineated by operational phase, failure modes, and occupant statistics.

The following criteria was established for statistics to be considered in this data base: (a) Airframe survivable volume was maintained during impact and prior to severe fire; (b) at least one occupant did not die from trauma; (c) potential for egress was present; and (d) accident demonstrated structural or system performance.

The scenario was derived from a detailed review of the survivable accidents data, analytical model predictions, and full-scale fuselage section drop testing, plus stated experimenter requirements.

Antimisting Kerosene (AMK)

- o Compatible AMK fuel and engine systems
- o CID performance of fuel; i.e.,
- o Air-to-surface impact demonstration
 - Maximum 155 knots at wing tank rupture obstructions
 - 20-100 gallons per second fuel release per each single point tank rupture
 - 4-5 second exposure after tank rupture above 100 knots
 - Decelerate to 100 knots
- o Verifiable positive ignition sources; i.e., engine separation, slide-out gravel, frangible landing lights, etc.
- o Under consideration: Simulated ignition sources; i.e., aircraft mounted and/or impact site

Crashworthiness

- o Representative of an impact survivable accident
- o Emulates a final approach/landing, missed approach, and/or aborted takeoff
- o Maintain fuselage integrity
- o Sink rate at impact = 17 feet per second (f/s)
- o Vertical impact pulse prior to impact obstructions

Seat/Restraint System

- o Evaluate performance of existing, improved, and new lightweight seat/fitting concepts
- o Vertical sink rate at impact = 17 f/s
- o Longitudinal acceleration (9-10 g's) accept 4-6 g's, or what we could get at impact (at floor)

Structural/Bending Bridge

- o Calibration of fuselage/wing structures for comparison to analytical models

IMPACT SCENARIO (PLANNED).

The final "unmanned" CID was to fly the flight profile (figure 8) after a series of engine/systems/experiments ground checks. The final flight time was to last less than 9 minutes. The aircraft will takeoff from the lakebed, climb to 2,300 feet, and circle the dry lakebed to intercept a simulated instrument landing system beam. At the intercept, the remote pilot on the ground sets up an approach speed, altitude and sink rate, and begins the descent.

FIGURE 8. CID IMPACT FLIGHT PROFILES

The aircraft will descend along a glide slope at a controlled sink rate. It will strike the prepared impact area in a nose-up attitude with the wheels retracted and wing flaps set at 30 degrees. Almost immediately after impact, the wings will strike a series of wing openers for the purpose of rupturing the fuel tanks allowing fuel to be released into the airstream and creating potential fire situation.

The aircraft then will continue along a prepared gravel surface striking six sets of frangible approach light towers similar to those installed at commercial airports. The aircraft is expected to come to rest 1,000 to 1,200 feet from the initial impact area.

In November 1984, after numerous flights, the Flight Readiness Review (FRR) Committee recommended a relaxation of impact requirements and accuracies in order to improve the probability of enhancing the RPV pilot's impact success. The CID team reviewed the mission requirements in light of flight safety and mission success, and implemented the following scenario:

<u>Impact Scenario (At Impact)</u>			
	<u>Current Requirements</u>	<u>Implementation</u>	<u>Comments</u>
Sink Rate	17+0 f/s -2	17+3 f/s -2	Difficult with ground effects
	+5	+5	
Longitudinal Velocity	150-0 kts	150-5 kts	Can control
Pitch	+1°+0	+1°+1°	Difficult with ground effects
Longitudinal Accuracy	+75 feet	+75 ft (long) -125 ft (short)	Difficult with ground effects but improves probability
Lateral Accuracy	+15 feet	+15 feet	No problem
Roll	0+1°	0+1°	No problem
Heading	+1°	+1°	No problem

The above reduces the accuracy pressures from the RPV pilot, allows him additional mental and physical flexibility, and should not compromise CID mission objectives and goals.

IMPACT SCENARIO (ACTUAL).

The remote takeoff and climbout from the lakebed appeared to have proceeded in a relatively typical manner as compared to previous remote takeoffs. Climb-out to racetrack intercept was normal, and final approach intercept occurred 5 minutes: 25 seconds following takeoff rotation. (Impact occurred 2 minutes:24 seconds following pushover.) Total flight time from brake release to impact was 8 minutes: 54 seconds.

The initial final descent appeared to be acceptable with typical high pilot workload. At about 500 feet above ground level (AGL), the aircraft began drifting across the impact centerline from left to right. At the 260-foot AGL point, the aircraft was moving rapidly across the centerline from left to right. At this point, the pilot workload increased dramatically as he attempted to align the aircraft with the runway centerline. The resulting series of turns, similar to a lateral offset maneuver, resulted in roll oscillations which were continuing at impact. Peak-to-peak amplitude of the bank angle excursions were approximately 15 degrees. At impact, the vehicle was approximately aligned with the runway, however, offset to the right.

First contact (figure 9) with the ground was by the left outboard or Number 1 engine with about a 2.0° nose-up attitude yawed about 13° left about 410 feet short of the planned impact (X). Impact velocity was 149 knots (TAS) with a sink rate of 18.5 feet per second. Following left outboard engine contact, the inboard left engine impacted followed by the bottom forward antenna and then the fuselage forward of the wing root. The aircraft was about 50 feet to the right of centerline.

The aircraft continued its slide-out yawing about 40° to the left. First contact (≈ 120-122 knots) with the wing opening obstructions was made by the right inboard or Number 3 engine. This cutter entered the right hand side of the nacelle continuing into the engine at the seventh stage of the low pressure compressor. Postcrash analysis of the engine showed rotation was stopped in approximately one-third of a revolution. One-tenth of a second later, ignition occurred on the inboard or left side of the engine. The cutter also severed the fuel and oil supply lines as well as the accessory gear case releasing lubricating oil, hydraulic fluid, and degraded AMK. The impact also caused the front of the engine to torque itself counterclockwise severing the fuel inlet and discharge lines of the degrader (which is mounted in the strut doghouse area on the CID aircraft engine installations). The cutter then broke loose and rotated upward into the Number 3 main fuel tank. Simultaneous to the destruction of the Number 3 engine, two additional wing opening devices entered the wing inboard of the Number 3 engine. The innermost opener tore through the leading edge of the wing at the approximate center of the inactive right hand "hip" or "cheek" tank, and proceeded through the fuselage to the main landing gear wheel well tearing out the aircraft keel beam and the two forward main gear tires on the left hand set.

The innermost cutter entered the wing leading edge passing through and slashing diagonally through the lower skin and the Number 3 main fuel tank inboard end rib. Part of this cutter was found in the aft lower cargo compartment.

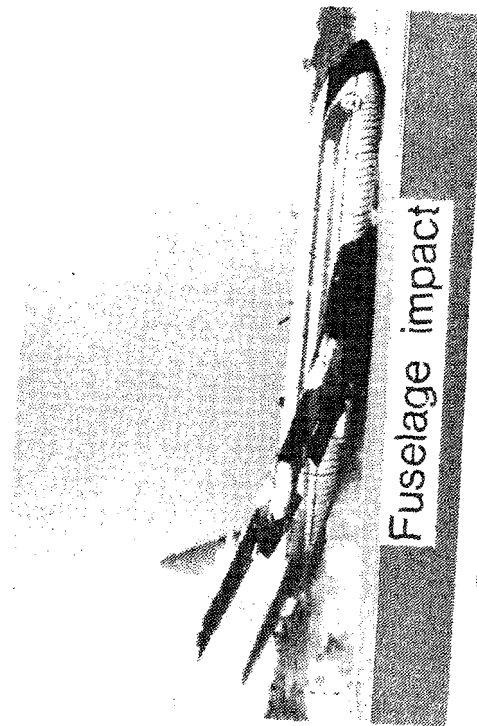
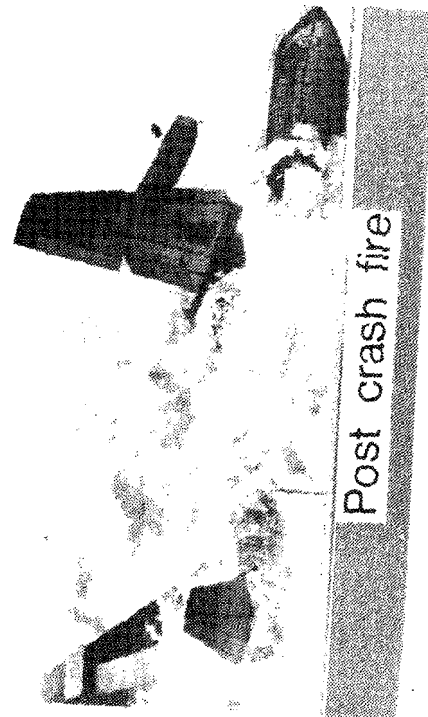


FIGURE 9. CJD IMPACT SEQUENCE

The flame which initiated at Number 3 engine continued to burn with the fire flowing over the fuselage as the aircraft continued its slide-out with the yaw angle constantly increasing until the aircraft came to rest. The initial fire was the result of ignited degraded fuel lubricating oil, and hydraulic fluid. This, added to the heat released from the destructing engine, was fed fuel through the ruptured fuel inlet line to the degrader (for as long as the wing was unseparated). Once the wing did separate, the fuel to the fire was still fed through the cross-feed fuel line in the wing from the override boost pump in the left "cheek" tank. All engines on the aircraft were operating off this tank and boost pump during the CID.

The total time from initial contact of the Number 1 engine until the aircraft came to rest was 11 seconds. The fire, as the aircraft came to rest, diminished greatly. The total time of the fire at its fuselage-involving state was 9 seconds. At the time the fire diminished, the fuselage exterior was not visually damaged to any degree by the flame. All paint instrumentation lines and aircraft markings were plainly visible.

The following summary is presented for comparison of the "planned" specified impact parameters versus the actual measurements:

Impact Scenario (At Impact)

	<u>Pre-CID Requirements</u>	<u>Actual CID Measurements</u>	
		RPV Downlink	AFFTC
Sink Rate	17+3 fps -2	18.45 f/s	17.3 f/s*
Longitudinal Velocity	150+5 kts	149 kts (TAS)	151.5 kts (TAS)*
Pitch	+1 ⁰ +7 ⁰	+2.0 ⁰ ***	-----
Longitudinal Accuracy	+75 feet long -125 short	-----	#1 engine impact left wing 410' short from fuselage 281' short (X)
Lateral Accuracy	+15 feet	-----	+34 ft right wreckage (fuselage) distribu- tion figure
Roll	0+1 ⁰	13 ⁰	-----
Heading	+1 ⁰	13 ⁰ left***	-4+1.

* Phototneodolite

* FPS-16 Radar

** Ground Measurement

*** High-speed photography

EXPERIMENT(S)/SYSTEMS PERFORMANCE

Results of the experiments are described in the following sections. In most areas, these are preliminary findings/results as detailed data reduction and analysis is continuing. Key areas will prepare detailed technical reports and/or notes on those completed analyses and findings.

ANTIMISTING KEROSENE (AMK).

The CID AMK experiment had two primary objectives: (1) demonstrate the effectiveness of the antimisting kerosene fuel concept in preventing large post-crash fireballs, (2) verify the operational compatibility of AMK in an aircraft fuel/propulsion system.

In November 27, 1984, the final AMK blending (figure 10) and fueling procedure was briefed to the FRR and subsequently to the Technical Briefing with NASA-A/DFRF senior management. The aircraft wing tank flushing was accomplished on November 28, 1984. Early on November 29, 1984, the AMK blending/fueling of the aircraft was initiated. Approximately 11,325 gallons were loaded into the aircraft fuel tanks. As the blending/fueling process was in progress down through fueling completion, samples of the Jet-A/AMK were being taken and those samples analyzed/characterized in the fuel laboratory. Samples were taken on a prescribed schedule up to and including early in the morning of December 1, 1984. Fuel analysis results showed that the AMK in all the aircraft fuel tanks met or exceeded the FAA AMK specification requirements.

As described in the previous section, "Impact Scenario--Actual," instead of hitting the impact site symmetrical, the aircraft was yawed to the left when it struck the ground. This yaw resulted in one of the steel wing openers at the impact site hitting and destroying the right inboard engine prior to cutting and severing the right wing. A large fire occurred as a result of severing pressurized degraded AMK fuel, oil, and hydraulic lines in the engine and strut compartments. Simultaneously, the wing failed, pouring fuel onto the ruptured combustor area. Other wing openers penetrated the lower right fuselage enabling burning fuel to enter the aircraft.

The preliminary conclusion is that the yawed impact of the aircraft created a situation in which a large ignition source (the destroyed Number 3 engine) was placed right at the major fuel release point. As a result, the fuel was immediately vaporized and burned before any significant antimisting action could develop. Moreover, the left yaw angle at impact caused the Number 3 engine and pylon to form a shield against the onrushing air, creating a stagnation region at the fuel release/ignition point allowing the fuel a longer residence time than expected at the ignition source.

The impact demonstrated that there are conditions in which the jet fuel antimisting additive used in this test is not sufficient to prevent a postcrash fire. One example of such conditions, as illustrated by the CID, is the destruction of an engine and the rupture of fuel lines on the engine pylon which produced an intense ignition source near the point of fuel release. While the antimisting characteristic of the fuel would have prevented forward propagation of the fire had the ignition source been further aft, nevertheless it provided limited, although still significant, protection in the Edwards scenario.

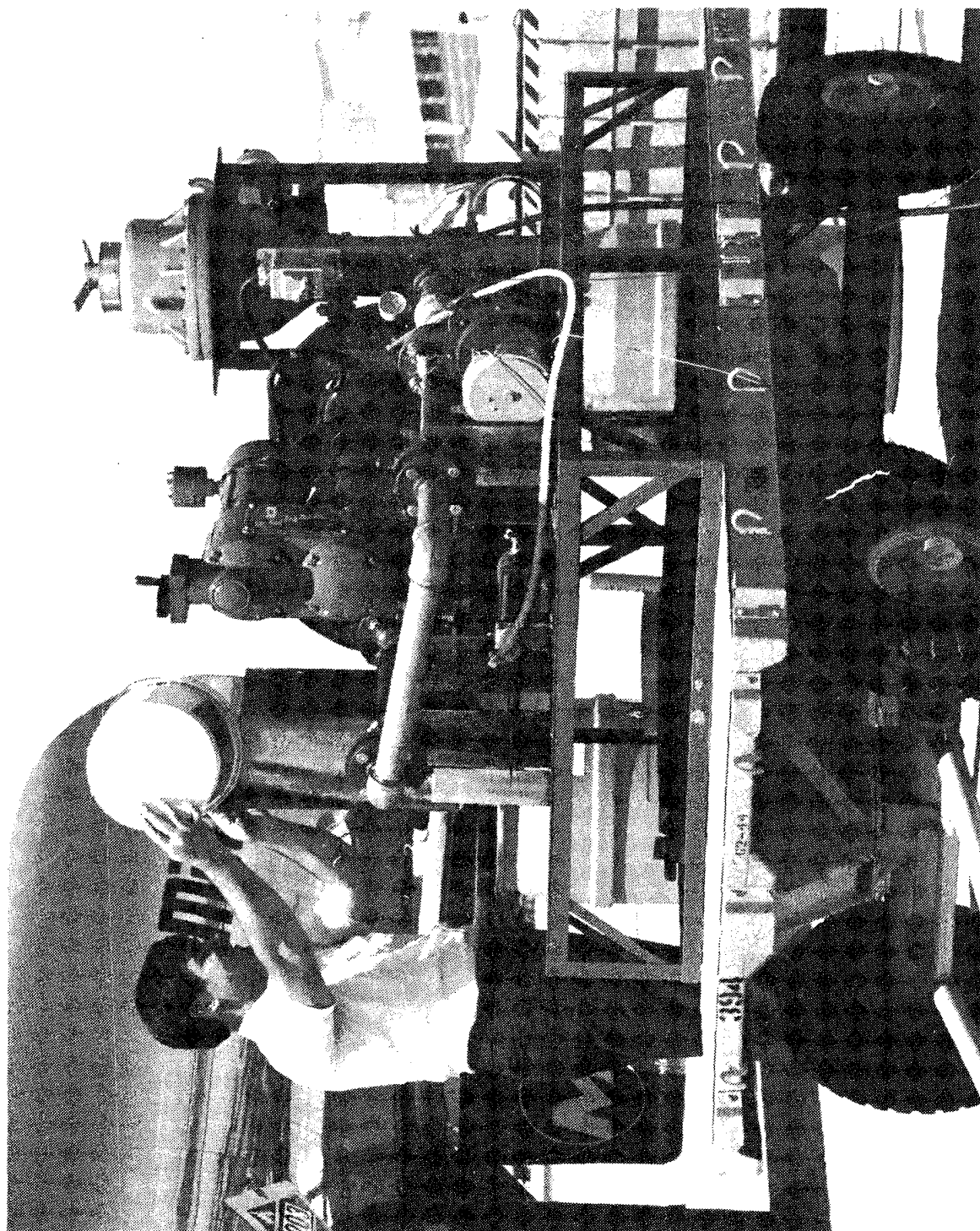


FIGURE 10. AMK BLENDING

Exterior and internal film documentation indicates that the resulting fire diminished within 9 seconds. Examination of the film footage and the fuselage shows that the fuselage sustained relatively little damage during the duration of the fire. The reduced intensity of the fire is attributed to the antimisting characteristic of the fuel. The fire which later damaged the interior of the aircraft resulted from the burning of fuel which entered the fuselage during the aircraft slideout. This fuel appeared to have entered through a forward cargo door and/or openings made by passage of wing cutters through the fuselage structure. Researchers discovered that the fire which later damaged the aircraft did not result from a failure of AMK. Burning fuel inside the fuselage ruptured by wing cutters was responsible for the long-term fire which entered the cabin by burning through the floor.

The FAA is to investigate this conclusion by duplicating the CID impact conditions in controlled laboratory and field tests. It is also attempting to determine statistically, through review of past accident reports, the percentage of "impact survivable" accidents that correspond to CID as it actually happened.

Engine/degrader system (figure 11) operation was as planned with no anomalies. Up to the DOF, the degrader (figures 12 and 13) operational experience was as follows:

Jet-A Ground Run/Tests	14.3 hours
Jet-A Flight Tests	<u>12.7 hours</u>
	27.0 hours
AMK Ground Run/Tests	7.1 hours
AMK Flight Tests	<u>4.0 hours</u>
	11.1 hours
DOF Run Times	
AMK Ground Run	≈ 0.7 hours (40 minutes)
CID Flight	<u>≈ 0.2 hours (8 minutes:54 seconds)</u>
	0.9 hours

The degraders were each started first and then the companion engine brought up to idle. Degrader operation was a nominal 21K RPM and engine(s) idle at ≈ 66 to 67 percent N₂. At impact, degrader speed was ≈ 21K RPM and engine speed at 74 to 77 percent N₂. All degrader/engine systems performed flawlessly. Total fuel consumed estimated at 1,191 gallons.

CRASHWORTHINESS/STRUCTURAL/RESTRAINT.

Crashworthiness refers to the ability of the aircraft fuselage, floor structure, and seat/restraint systems to protect the passengers and crew in a typical landing or takeoff accident. A review of past accidents has shown that occupants have received serious or fatal injuries in accidents that have been termed survivable. A "survivable" accident is defined as one in which the airframe, seat/restraint system, and cabin environment remain reasonably intact, and the impact forces experienced by the occupants are within the limits of human tolerance.

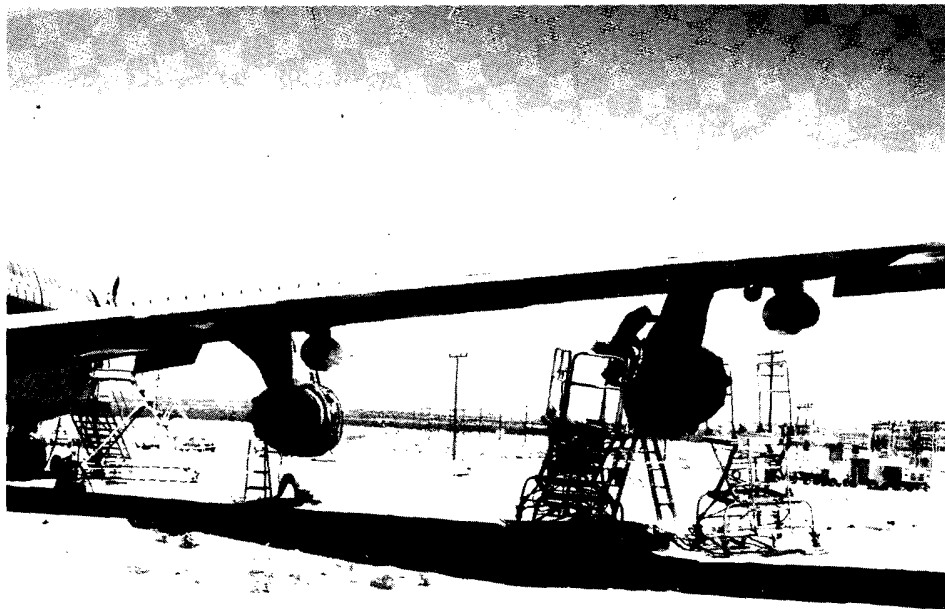


FIGURE 11. ENGINE/DEGRADER SYSTEM INSTALLATION

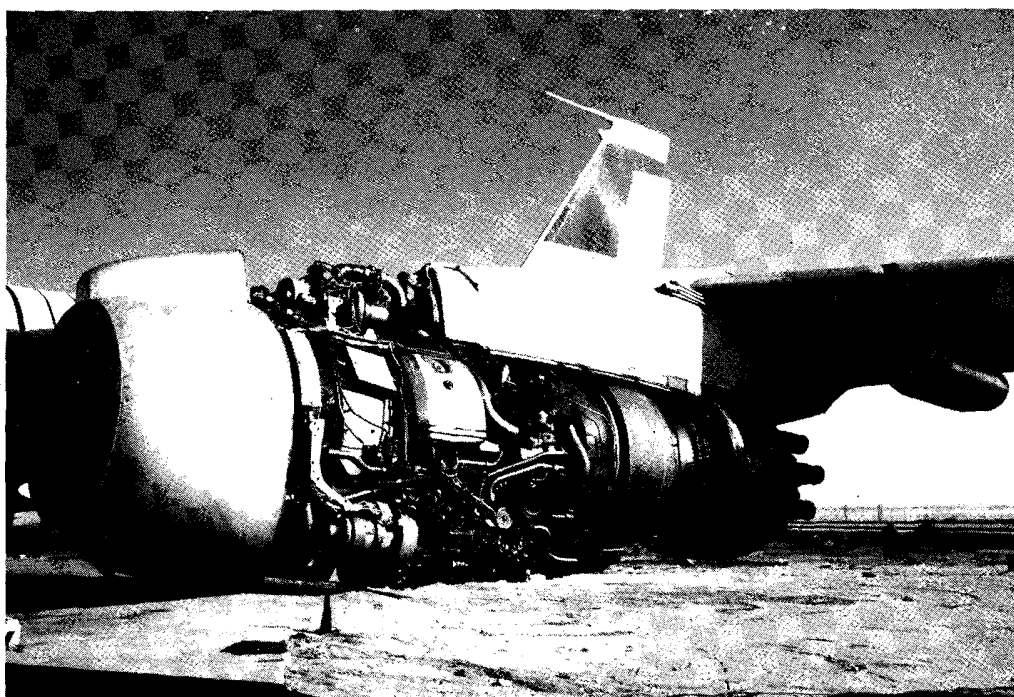


FIGURE 12. ENGINE/DEDRADER

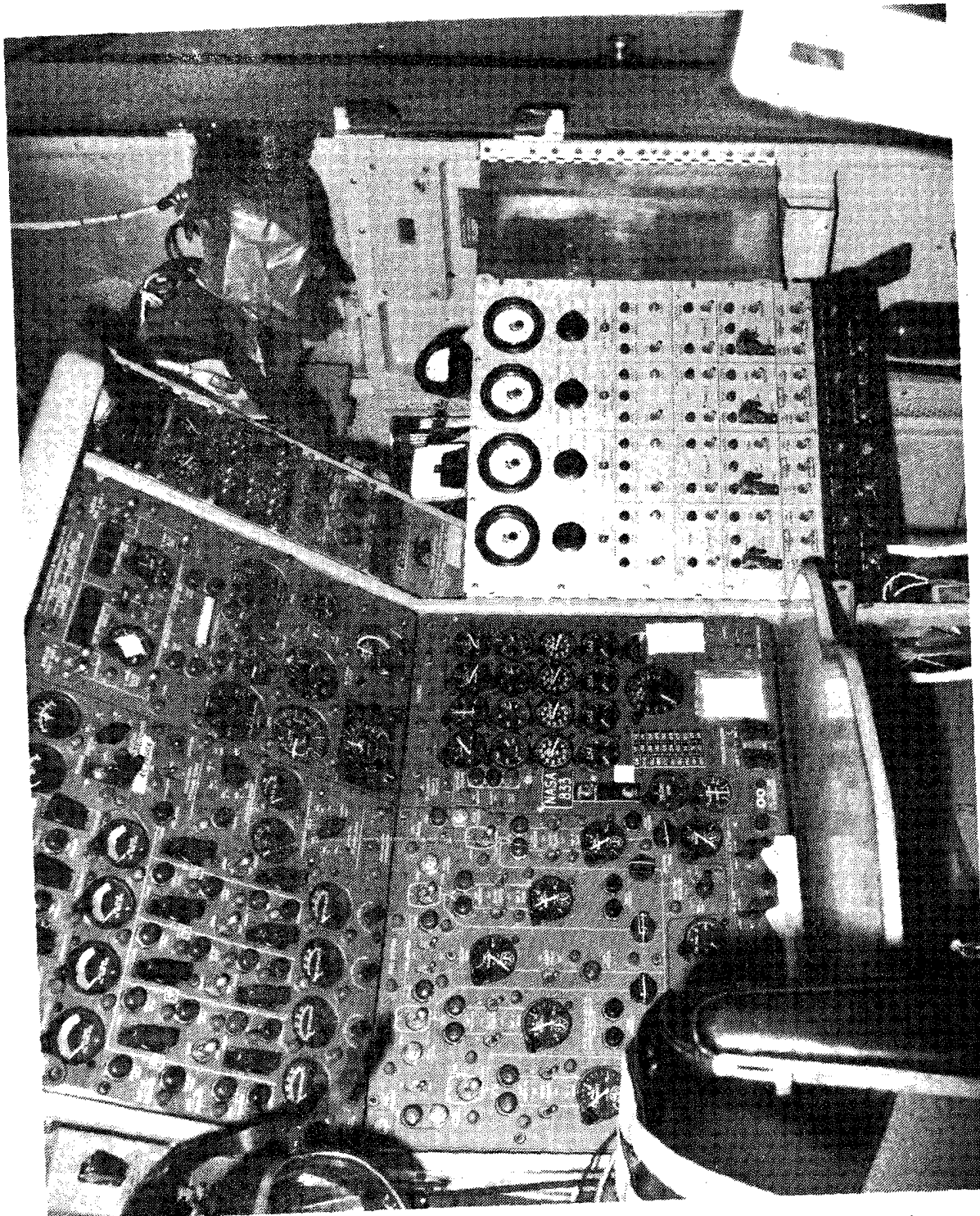


FIGURE 13. DEGRADER CONTROL PANEL

The CID was expected to yield data that will help researchers obtain a better understanding of aircraft structure response to various crash loads. Accelerometers and strain gages were installed at 175 points in the aircraft wing, fuselage, floor, and galley/stowage compartment areas with an equal number of sensors in the seat/restraint systems and the dummies that occupied those seats. These sensors would be used to obtain accelerations and transmitted loads during impact and slideout. Information from those sensors were taped by onboard recording equipment and also transmitted directly to the ground control center for recording at that location. Additional data was collected by 11 high-speed cameras strategically located in the aircraft cabin and cockpit.

The interior of the aircraft was configured (figure 14) much like a typical passenger jet except for the instrumentation and other special test equipment. there were a total of 75 seats, almost all of which were occupied by human-like dummies (figure 15). There were 13 instrumented anthropomorphic adult dummies which represented 11 passengers, 1 pilot, and 1 flight attendant. Instrumentation did include accelerometers installed in the head, thorax, and pelvic locations. The remainder were noninstrumented adult dummies with one noninstrumented child dummy. Many of the seats and adjoining floor structure also contained multiple accelerometer installation.

- o Structural (Fuselage, Wing, Floor)

The structural experiment consisted of matching the analytical predictions of the fuselage deformation/failures, etc., with the post-impact structural damage and subsequently establishing criteria which addresses the variable impact of metal structures. The criteria will be established on the basis of a validated model and will be obtained from the application of this model to a matrix of aircraft configurations and crash conditions in which floor pulses and optimum seat/restraint system designs can be identified.

As described in the "Analytical Modeling" section, an unsymmetrical yaw/roll condition was introduced which will necessitate remodeling (change to symmetrical model) of the CID impact. Most important, however, is the loss of posttest evidence due to the unexpected wing opener damage and fire which destroyed the ability to correlate actual ground impact deformation/damage with predicted results.

With results obtained from the revised unsymmetrical model and available postcrash structural information (also supporting drop test data), a correlation of information will be developed. FAA and NASA future reports will provide the detailed technical analysis and results.

- o Seat/Restraint System Experiments

The seat/restraint system experiments did include improved seat-track attachment devices and energy-absorbing devices installed as part of the seat leg structure and seatbelt/seat-pan structure. In almost all cases, the modified seats were located next to a standard seat of the same basic design so researchers could assess the benefits of the modifications. Other experiments included an evaluation of rear facing seats and a newly-designed child restraint system.

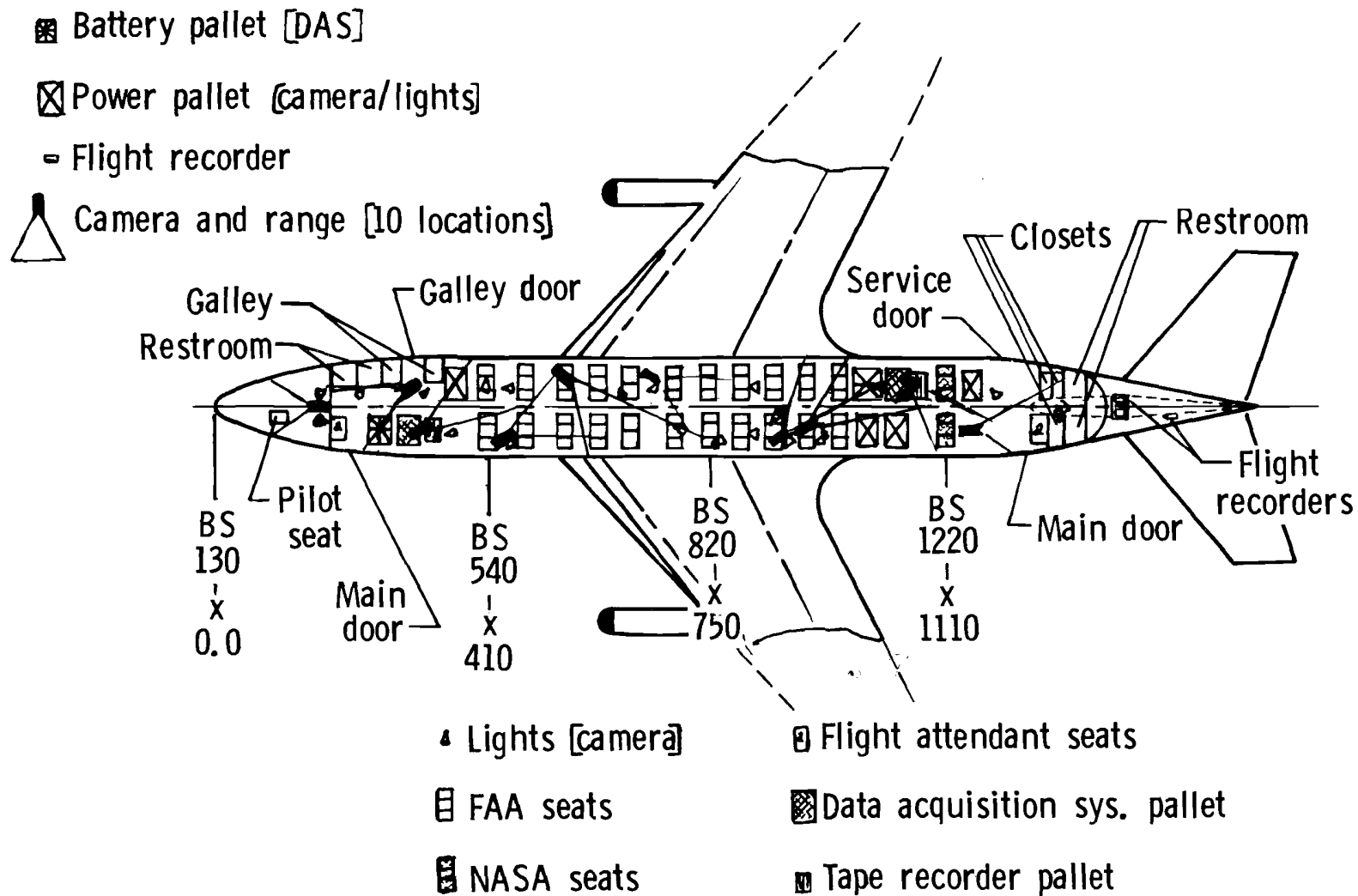


FIGURE 14. INTERIOR CONFIGURATION

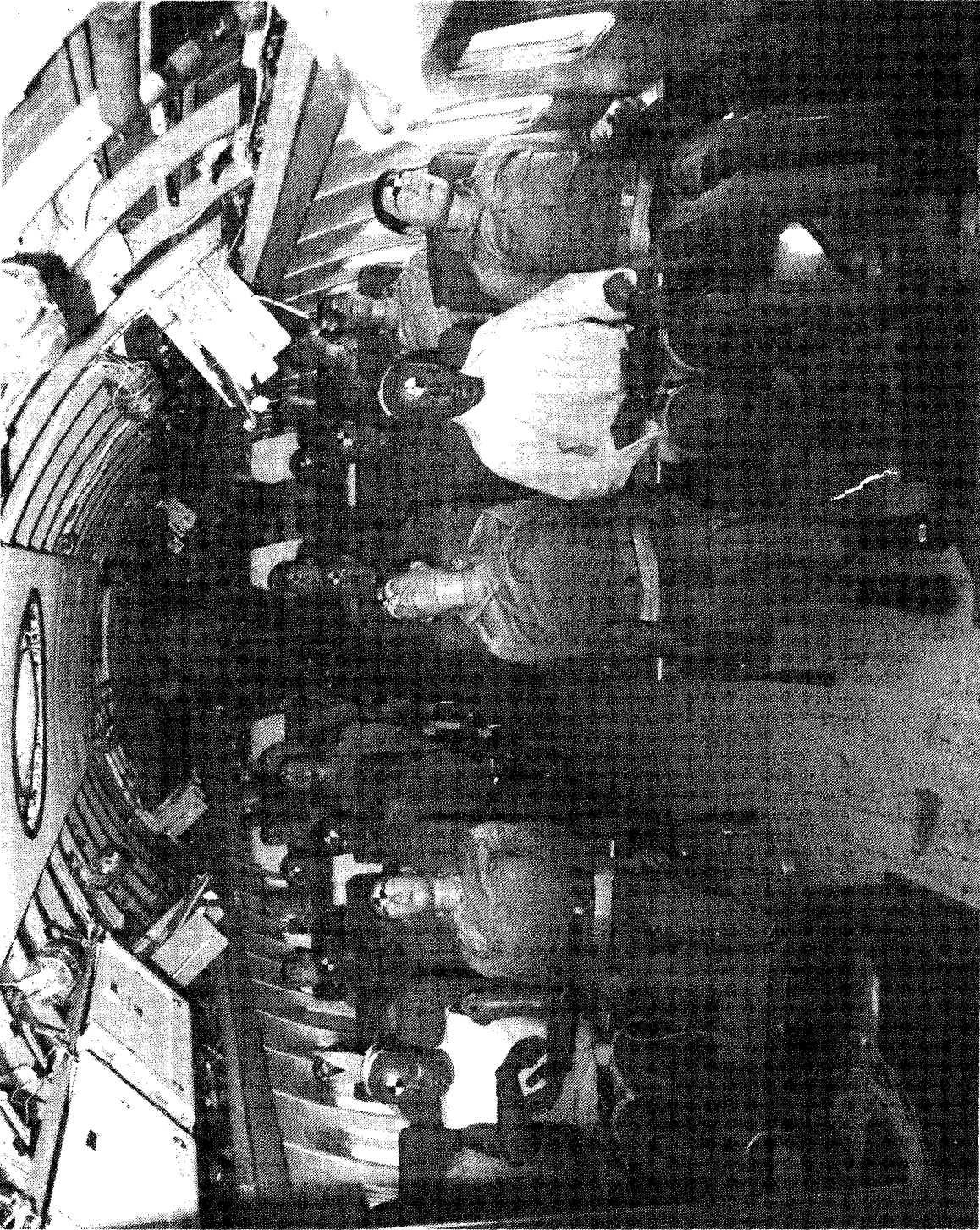


FIGURE 15. DUMMY INSTALLATION

The CID multiple type restraint system experiments consisted of 13 standard and 14 modified crew/passenger seat designs (FAA/NASA/French) containing 13 instrumented and 60 noninstrumented dummies. The instrumentation (seat and dummies) included 168 accelerometer/load cell data channels. The CID performance of the occupied standard seats (meeting minimum static loads of 9g forward, 1.5g side, 4.5g down, and 2g up) would be compared to the performance of the modified seats. The FAA seat modifications (featuring energy-absorbing stroking devices and improved seat-track fittings) were designed and tested to meet peak dynamic loads of 18g forward, 10g side, 10g down, and 6g up in the 35/50 feet per second velocity change range.

Post-impact examination revealed that 15 standard/modified seats show no structural deformation while two standard seats had minor deformation being directly involved in the fuselage cutter damage. The remaining 10 seats, including two NASA designs and one French design, were destroyed by the fire.

Based upon observed test film and except for the two seats directly involved in the fuselage wing opener damage, the CID impact loads appeared to be less than either the standard/modified seat design strengths. Instrumented seat/dummy data is currently being analyzed to complete this performance assessment.

Preliminary data (figure 16) revealed the following impact pulses--g forces as a function of time. (Data is currently being analyzed for completeness and accuracy.)

The floor values:

In the "cockpit" were:

Vertical	14 for 0.8 seconds
Longitudinal	2.6 for 0.14 seconds
Lateral	4.9 for 0.14 seconds

In the forward cabin:

Vertical	6.0 for 0.14 seconds
Longitudinal	1.6 for 0.20 seconds
Lateral	2.4 for 0.18 seconds

Over the wing box:

Vertical	5.5 for 0.14 seconds
Longitudinal	3.5 for 0.14 seconds
Lateral	2.0 for 0.11 seconds

In the back part of the cabin:

Vertical	3.0 for 0.10 seconds
Longitudinal	5.0 for 0.14 seconds
Lateral	2.0 for 0.09 seconds

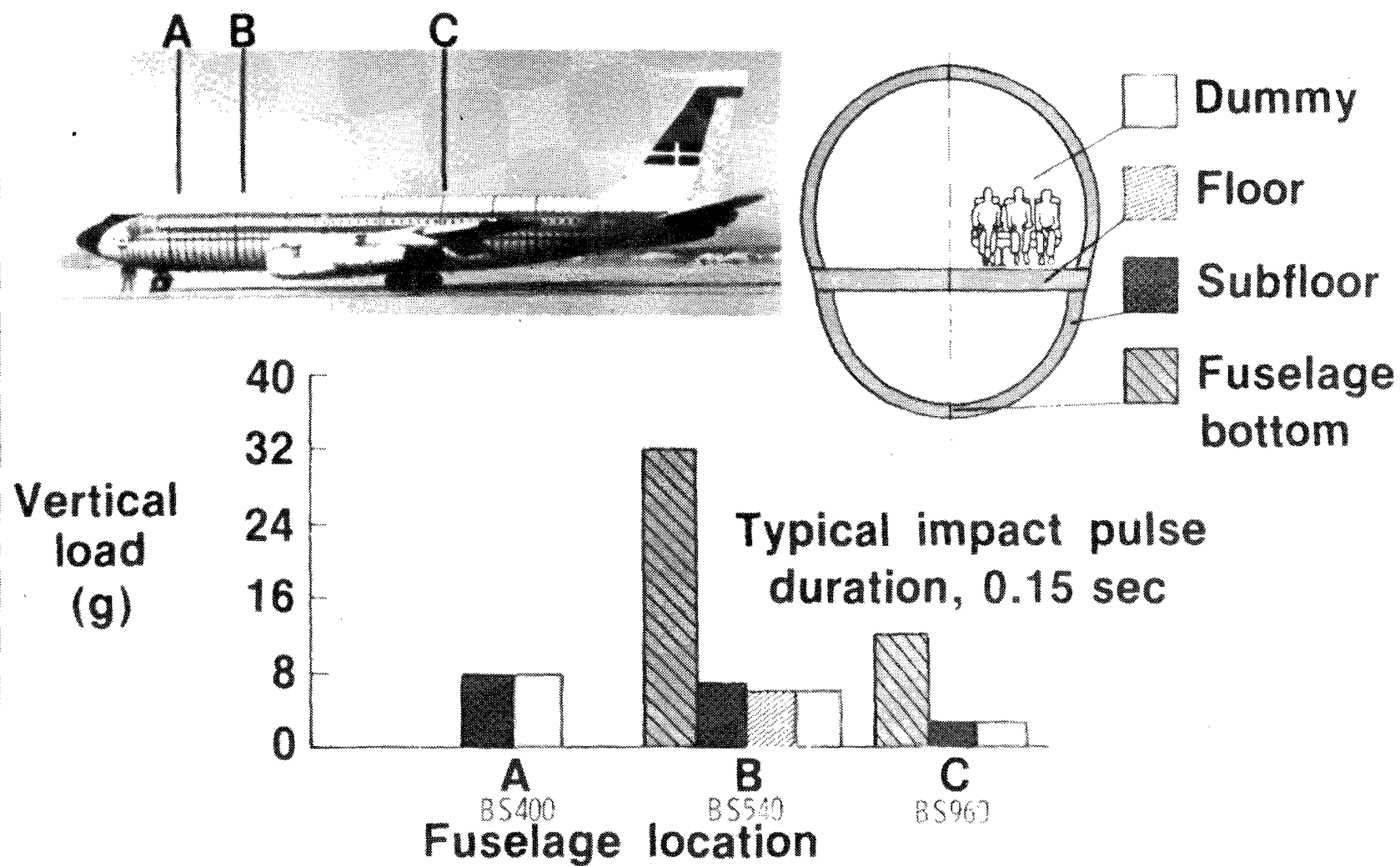


FIGURE 16. AIRCRAFT STRUCTURAL RESPONSE

o Stowage/Galleys Compartments

Researchers planned to evaluate the affect of crash loads on galleys and stowage areas because investigation of past accidents has shown that passengers have been injured or have had difficulty evacuating an aircraft due to improperly or inadequately restrained galley equipment and/or passenger carry-on items. Standard restraint systems were tested in both the galleys (figures 17 and 18) and overhead compartments (figure 19), and the results will be applied as necessary in the development of new design criteria.

The CID stowage and galley compartment experiments consisted of two galley modules (filled to volume capacity) located in the forward starboard side of the aircraft and two overhead stowage compartments (filled to capacity weight) mounted aft the galley modules. While the galleys were not instrumented, accelerometers were installed at nearby structural support areas. The overhead occupant compartment supports were instrumented with three load cells and a traix accelerometer installed on one of two 75-pound test weights.

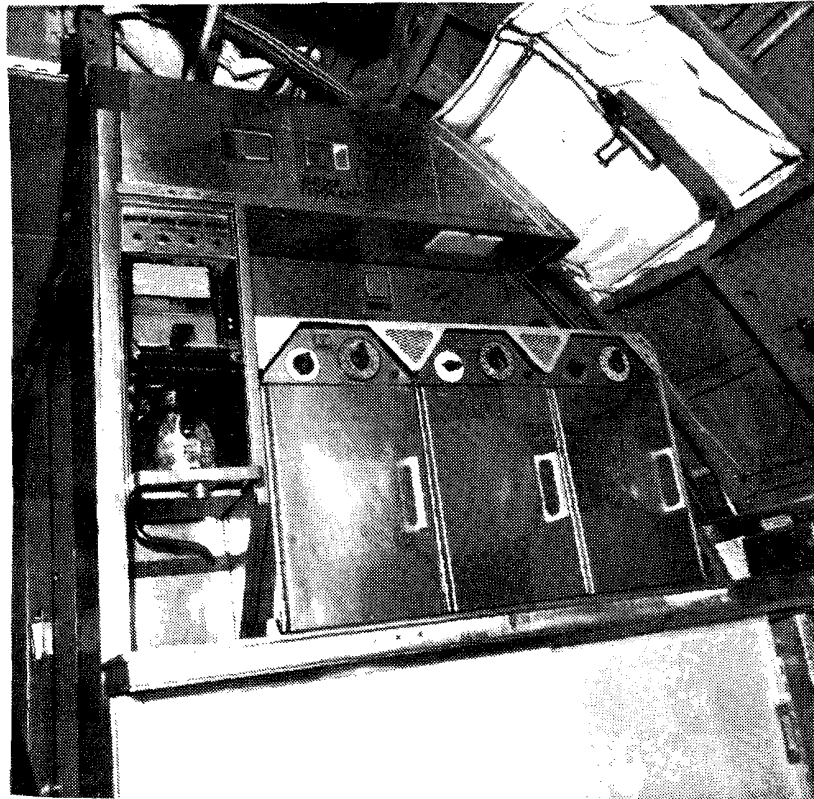


FIGURE 17. FORWARD GALLEY INSTALLATION

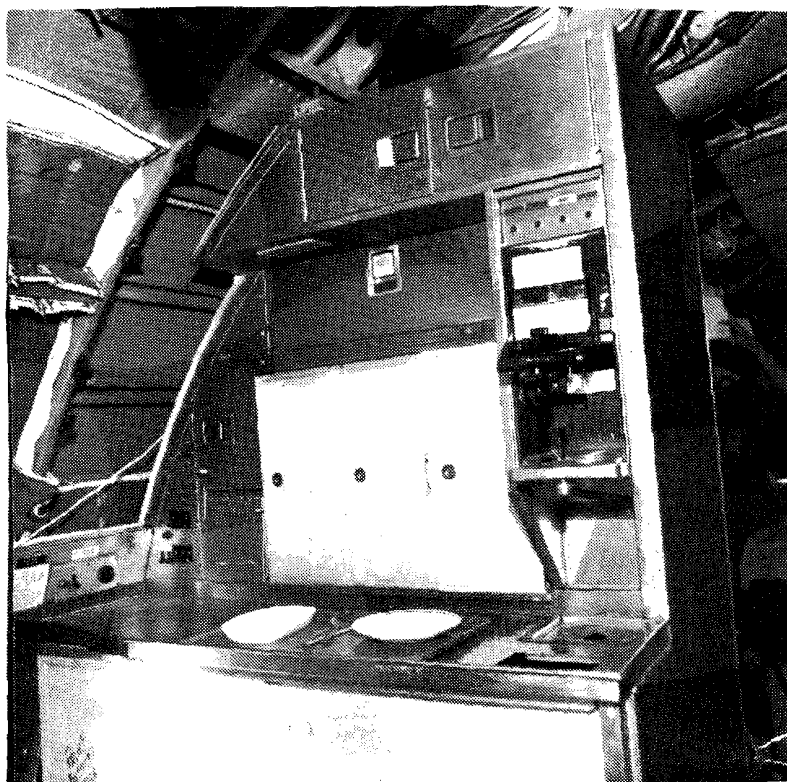


FIGURE 18. AFT GALLEY INSTALLATION

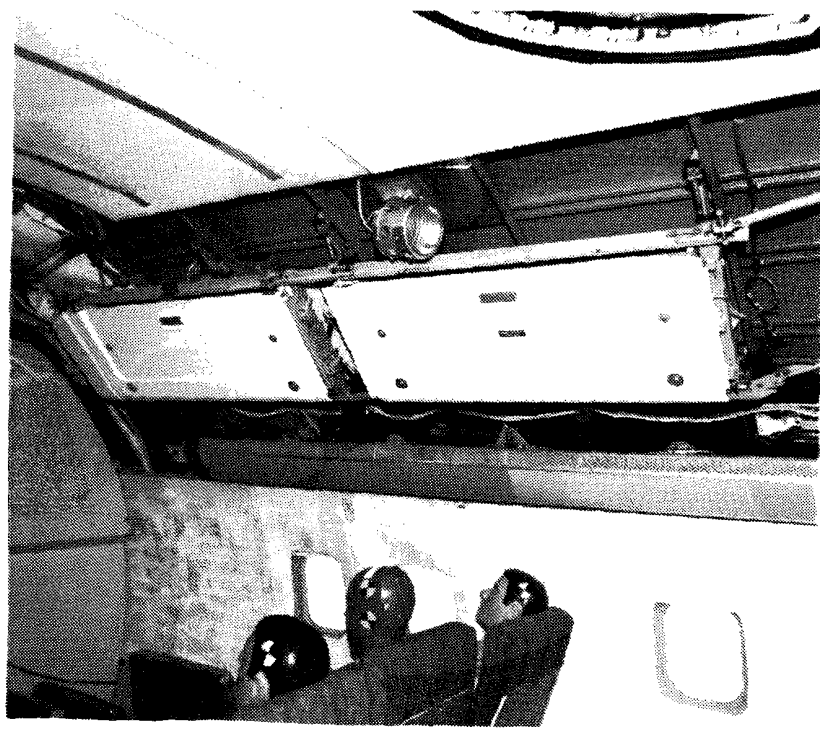


FIGURE 19. OVERHEAD COMPARTMENTS

As observed on film, during the initial ground impact, one overhead compartment door opened while both the galley modules stayed intact, including their internal contents. Post-impact examination showed that fire had destroyed one overhead compartment and partially destroyed the other. The forward galley showed partial fire damage while the aft galley, including contents, showed minor damage (mainly soot).

Based upon the observed film and posttest examination, the CID impact loads appeared to be less than the design strengths of both the galleys and overhead compartment restraint means. The inadvertent opening of the overhead compartment doors must be further assessed.

o Analytical Modeling

Data collected during the demonstration will be used to validate computer modeling programs called "KRASH" and "DYCAST." KRASH, for example, has been used extensively in evaluating the design characteristics of small aircraft and helicopter structures to determine their crashworthiness capabilities. Researchers used KRASH and DYCAST to simulate the controlled impact demonstration. These simulations then will be compared with the actual results of the demonstration, providing a data base from which a generic model will be developed for possible application to future transport aircraft designs.

Both the lump mass FAA KRASH and finite element NASA DYCAST models were used to predict the structural behavior of CID aircraft during condition of a severe/survivable impact. At the prescribed air-to-ground impact conditions of 17 feet per second (f/s) descent, 3-1/2-to 4-degree pitch, 150 knots ground speed, and with zero roll/yaw angles, the models predicted vertical loads in the 18g peak range and horizontal loads in the 6 to 9g range, with minor fuselage rupture and floor deformation.

The actual impact involved the additional yaw/roll conditions which resulted in a change to the predicted values obtained from the analytical models. Both models were developed on the basis of a symmetrical impact without lateral loads induced by the unexpected high yaw and roll angles.)

It is believed that the additional lateral loads may not have significantly affected the peak vertical and longitudinal responses predicted by the analytical models. However, to support this position, an unsymmetrical model (KRASH) will be developed which considers the actual CID impact condition with the additional lateral loads.

Instrumented CID data is being analyzed. These data will be evaluated against the results of an unsymmetrical KRASH model to satisfy above objectives.

CABIN FIRE SAFETY EXPERIMENTS.

The use of AMK in the demonstration was expected to preclude or minimize the fireball that might otherwise engulf the test aircraft, penetrate the fuselage, and ignite interior materials like seats and wall panelings. However, researchers did incorporate several experiments aimed at preventing or retarding the spread of flames into and within the cabin, should fire occur.

o Seat Blocking Layers

Fire-blocking layers (figure 20) were selectively installed on approximately 50 percent of the passenger seats. Extensive laboratory experiments already have shown that these fire-blocking layers are effective in retarding the spread of flames, and FAA is taking regulatory action to require them on all airlines.

Seat cushion fire-blocking layers are fire-resistaut fabrics which encase the urethane foam cushions. Basically, the blocking-layer material inhibits or prevents the urethane foam from burning. Extensive full-scale (C-133) testing and evaluation have proven the value of seat cushion fire-bolocking layers in delaying the onset of flashover during post-crash cabin fires, and preventing inflight and ramp fires when a seat is the initial target of the ignition source. One type of effective blocking layer is Norfab[®], an aluminized blended fabric. Norfab was used on 32 (11 rows) of a total of 68 (23 rows) individual seats on the CID test aircraft. The fire-blocked seats (rows) were positioned alternately with standard seats (rows) so that a visual comparison of fire damage could be performed in the event of a cabin fire. No instrumentation other than high-speed movie cameras was employed because the probability of a fire was considered to be minimal.

The intense cabin fire gutted most of the passenger seats. However, the cabin area from the center wing station to the trailing edge of the wing was in a burned condition that permitted visual and physical comparisons of fire damage.

It was noted that on the standard seats, fire had burned away the outer fabric, melted the foam completely from the headrest area, and in most cases, melted the outer fabric and foam from the back-rest areas--extending downward to seat level. In all cases, the fire-blocked seats were in superior condition. Although the finished outer fabric was burned away, the Norfab aluminized blocking material was in place and unburned. In some cases, the aluminized surface appeared in new condition. When the headrest areas were hand squeezed, it was noted that the underlying foam was firm and resilient. Greater fire damage was also observed on the walls and ceiling areas of the cabin both above and adjacent to the nonblocked seats as compared to those areas adjacent to fire-blocked seats.

The fire-blocked seats performed in a manner consistent with the results obtained in component and large-scale testing by providing resistance to fire growth.

A new flammability standard for seat cushions was enacted by the FAA on November 26, 1984, which requires the installation of fire-blocking layers over a 3-year period from this effective date.



FIGURE 20. SEATS WITH FIRE BLOCKING LAYERS

o Burn-Through Resistant Inner Window Panes

The second experiment was the selective use of burn-through resistant epoxy windows (figures 21 and 22).

The advanced window contains an improved inner pane which was developed by NASA and is referred to as EX 112; the improved window resistance to fires of this type provides additional burn-through that would normally be experienced with post-crash external fires. Full-scale testing at the FAA Technical Center, using a C-133 airframe section permitted the comparison of the conventionally stretched acrylic window and the EX 112 advanced window in side-by-side exposure to external fuel fires. The advanced window provided approximately 60 seconds of additional time before burnthrough compared to the conventional window.

A total of 26 burn-through resistant improved inner pane (EX 112) windows were installed on the aircraft. They were alternately installed with standard inner pane windows, 13 on each side of the aircraft starting at the rear most window and progressing in the forward direction. This positioned the forward-most panels at approximately mid-wing. The alternate installation was selected for visual comparative purposes in the event that a post-crash external fuel fire occurred.

The damage sustained by the aircraft resulted in a fuel fire under the aircraft and inside the cargo compartments. Evidence suggests that fire penetration was through the floor, except possibly for an area forward of the wing where all the windows were of the conventional type.

In the window string on the right side of the aircraft, three of the improved inner panes and two of the standard inner panes were intact. The window string on the left side contained a similar count. All of these windows were in series just aft of the trailing edge of each wing.

Due to the intensity and duration of the fire, all of the other windows in each series were melted out or distorted. No judgment could be made by visually comparing the remaining inner panes.

The characteristics of the uncontrolled fire, and particularly the fact that the fire penetrated the cabin primarily by burning up through the floor, and the damage to the test article did not result in any evidence of differences in burn-through resistance between conventional and advanced windows.

o Low-Level Emergency Lighting

Low-level emergency lighting devices (tritium) were selectively installed on a number of seats which were located on the seat arms next to the aisle. These were to be observed for performance during impact.

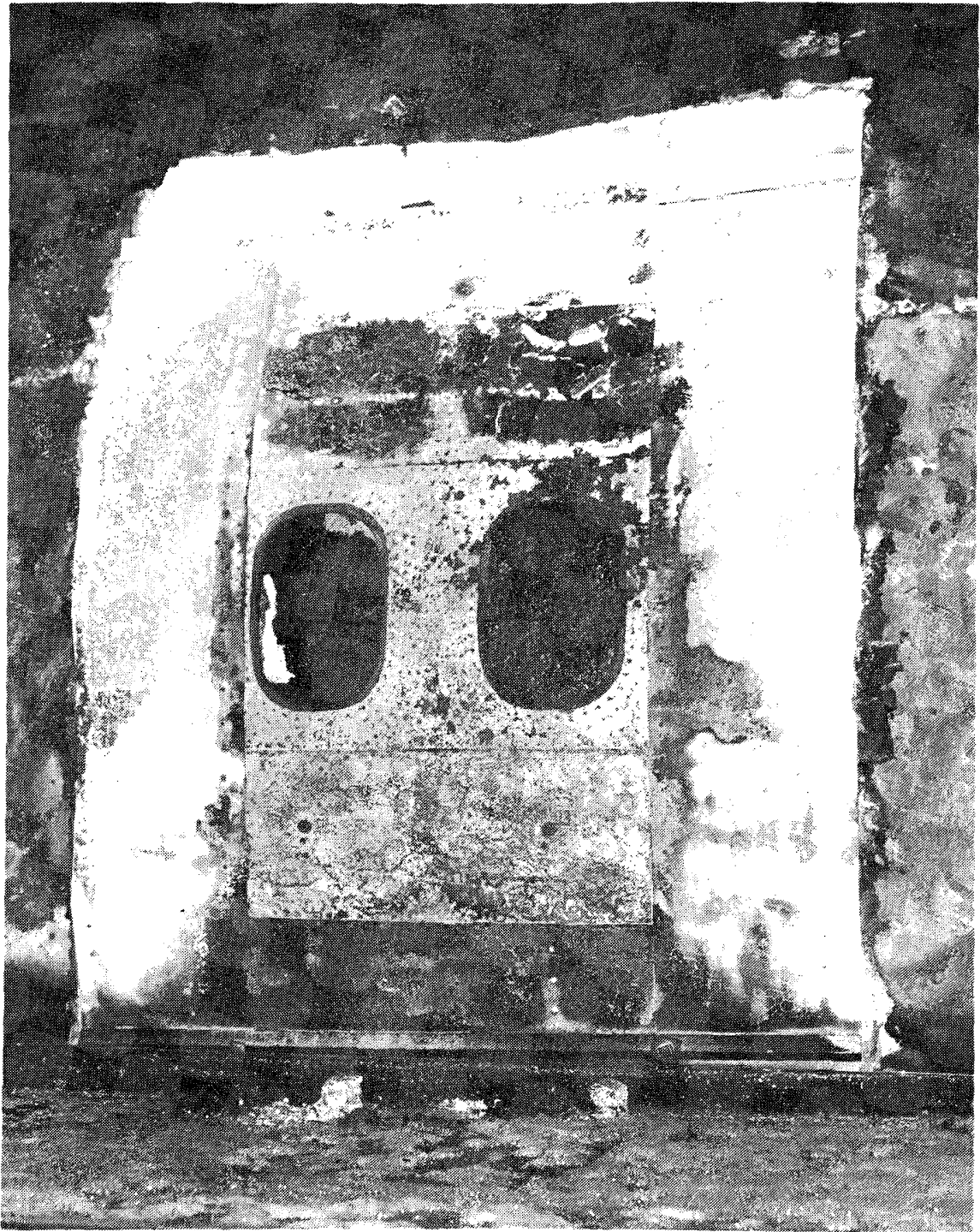


FIGURE 21. BURN-THROUGH RESISTANT EOPXY WINDOWS (WITH FRAME)

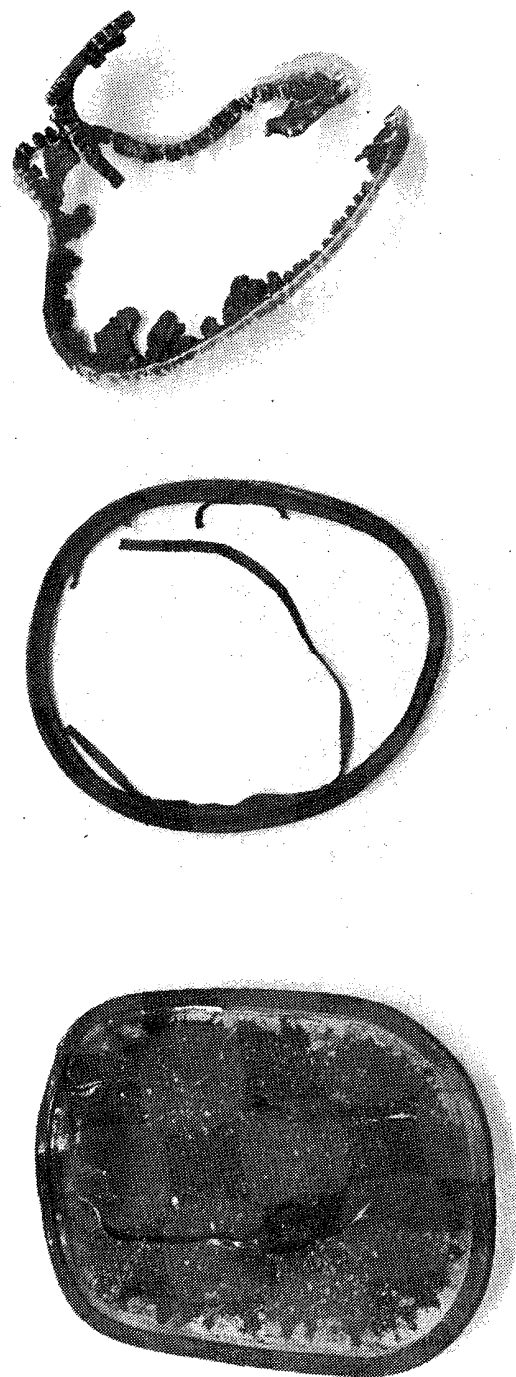


FIGURE 22. BURN-THROUGH RESISTANT EPOXY WINDOWS (INDIVIDUAL)

Floor proximity lighting can provide escape-route guidance to passengers and crew members in a smoke-filled cabin environment that would obscure ceiling-mounted lighting. FAA extensive fire testing and evacuation studies with human subjects in a theatrical environment have proven the effectiveness of floor proximity lighting.

Twenty-five Tritium lights (figure 23) were installed on the aircraft. A total of 8 aisle seats were selected throughout the cabin, and a light was installed on the top of the armrest, the side, and the rear. An additional light was installed on a ninth armrest. Two different types of two-part adhesives were used in mounting the lights to the armrests.

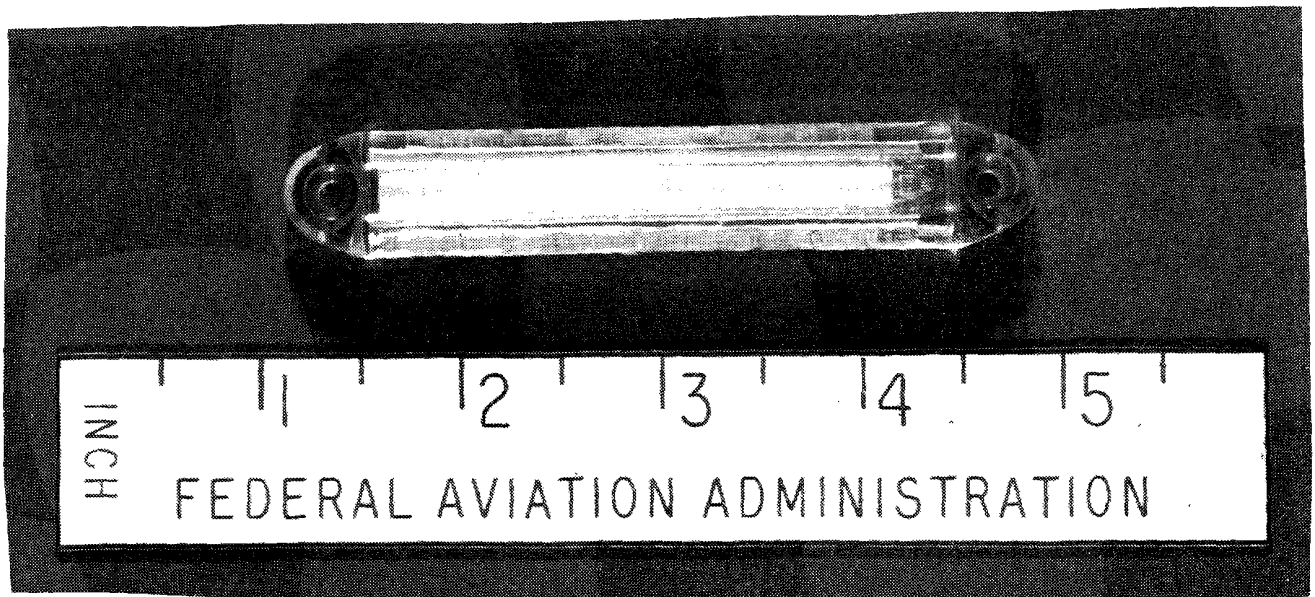


FIGURE 23. TRITIUM LIGHT DEVICE

Only three tritium lights remained bonded to two seats (two on one seat and one on another). No additional lights were found on the floor or in the floor debris. Fire consumed the missing lights in an environment beyond the point of occupant survivability.

All lights should be mechanically fastened to maximize their time of usefulness. A standard for floor proximity lighting was enacted by the FAA on November 26, 1984, which requires compliance by the U.S. fleet within 2 years from this effective date.

FLIGHT DATA AND COCKPIT VOICE RECORDERS.

The CID also provided a unique opportunity to evaluate the usefulness of current and advanced technology flight data recorders (FDR's), cockpit voice recorders (CVR's), and special sensors since the information obtained from these systems could then be compared with the data acquired from the various other onboard

experiments and flight data recording systems. The results could then increase our understanding of the adequacy and usefulness of FDR's and CVR's in postcrash aircraft accident investigations, particularly with regard to occupant impact survivability determination and aircraft performance analysis on impact.

Presently, FAA requires both types of recorders on all air carrier aircraft as an accident investigation tool. The newer FDR's record a variety of data such as heading, pressure altitude, airspeed, normal acceleration, pitch and roll attitude, and longitudinal and lateral acceleration--all on a time base that permits investigators to reconstruct the flight path and impact conditions. The CVR's record crew conversations and other cockpit and external sounds on a continuous 30-minute tape.

Flight data recorders to be used in the CID demonstration included the aircraft's original analog signal unit (Sunstrand), which records limited information on a foil roll, and advanced digital systems supplied by various manufacturers.

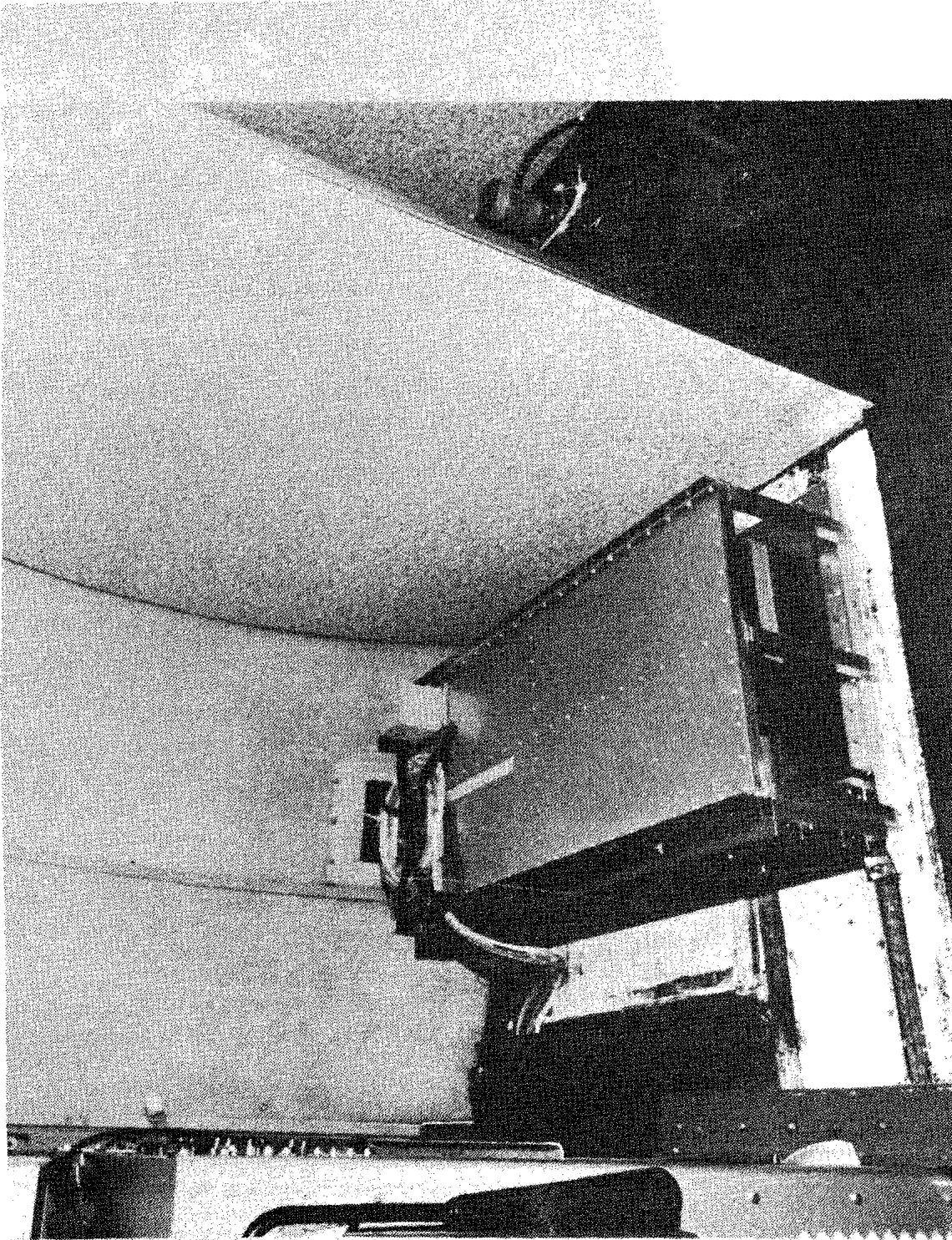
Three state-of-the-art digital flight data recorders (DFDR's) (Fairchild, Lockheed, Sundstrand), one Lear Siegler (LSI) solid-state memory FDR, and one CVR (Fairchild) were installed (figure 24) in the aft cabin area along with a special Flight Data Acquisition Unit (FDAU), signal conditioning unit (Teledyne), and special sensors to provide unique signals on aircraft performance to the DFDR's. The LSI FDR was not to record data, having a prerecorded data set stored, but was being demonstrated primarily for survivability. The existing B-720 foil recorder was refurbished by Sundstrand and a new foil recording medium was installed, and the FDR was reinstalled in the aircraft.

All FDR systems and sensors were installed and operated as planned. The three DFDR's, the foil recorder, and the CVR, although subjected to extreme fire generated heat and molten aluminum impingement, did have their respective recording mediums survive, and the tapes were subsequently processed and analyzed by both NTSB and the respective manufactures. The LSI FDR was subsequently checked by LSI to determine extent of unit to internal fire damage, if any, and was found to have the prerecorded data set intact and useable.

Overall, the experiment was a success. Sampling rates for certain signals were found to be definitely too low, particularly for the pitch, roll, and acceleration signals, although the programmed rates were in accordance with applicable Federal Aviation Regulations (FAR's) which obviously must be revised. Impact and post-impact data is difficult to obtain with present DFDR's because of their design, which permits data loss during recording under relatively high, but humanly survivable, deceleration load factors. This happened in this case to all three DFDR's during impact.

FLIGHT INCIDENT RECORDER/ELECTRONIC LOCATOR TRANSMITTER.

Also tested was a uniquely deployable Flight Incident Recorder (FIR)/Electronic Locator Transmitter (ELT) provided by the Naval Air Test Center (NATC). It was mounted (figures 25 and 26) in the vertical stabilizer and fired in the air on impact. It was to land away from the aircraft wreckage, thus assuring its survivability.



F.A.A. TECHNICAL CENTER
ATLANTIC CITY, NEW JERSEY

65-1960

FIGURE 24. DIGITAL FLIGHT DATA RECORDER PACKAGE

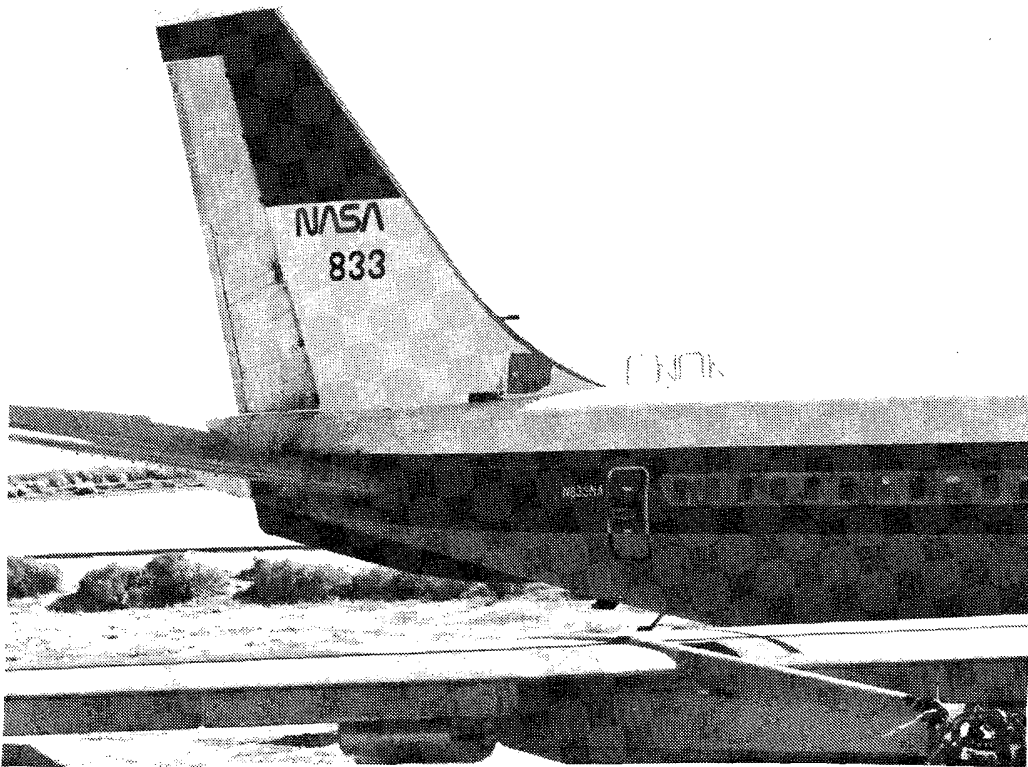


FIGURE 25. U.S. NAVY FLIGHT INCIDENT RECORDER/ELECTRONIC LOCATOR TRANSMITTER

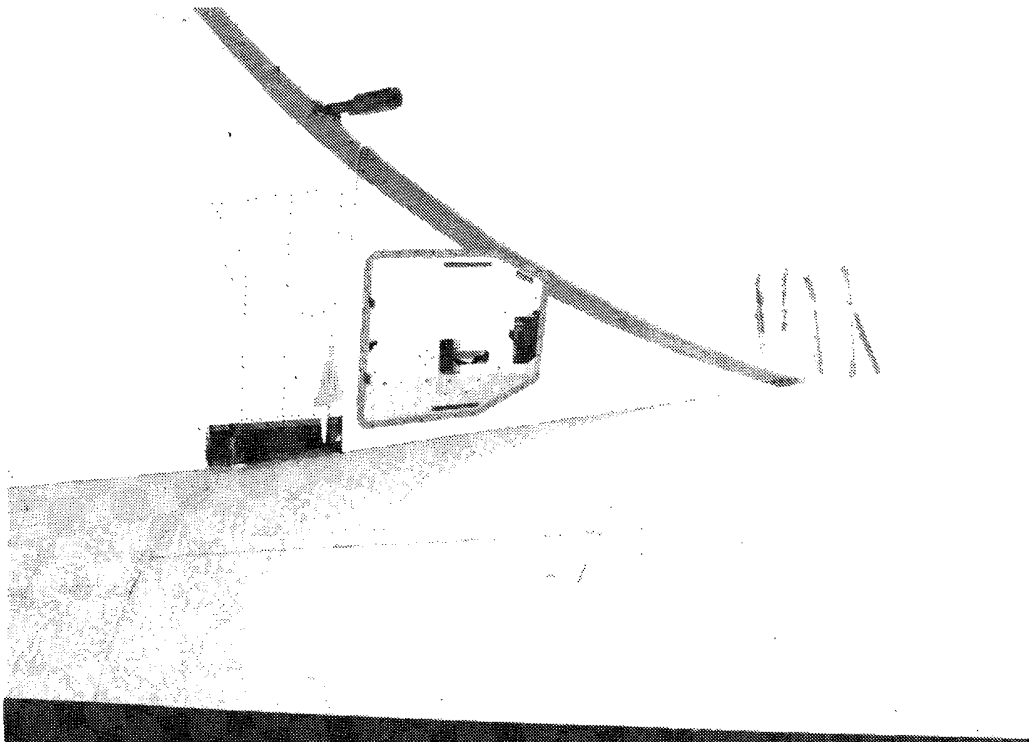


FIGURE 26. CLOSE-UP OF INCIDENT RECORDER/ELECTRONIC LOCATOR TRANSMITTER

The Nave/Canadian Forces joint experiment contained a prototype solid-state FIR/ELT that was installed to test the ejection/separation characteristics in a crash environment. The FIR contained preprogrammed data and was not actively interconnected with aircraft sensors. ELT (radio beacon) and visual marker strobe (VMS) operation and survivability were to be investigated.

The FIR/ELT ejected when the B-720 decelerated to a stop. The unit was found approximately 15 feet from the vertical stabilizer dorsal fin. The unit did not eject earlier (at impact) due to the nose frangible switch (one of two) which did not break (under fuselage switch triggered ejection). The aircraft's left yaw during slideout and AMK flame pressure on the right side of the vertical stabilizer tended to hold the FIR/ELT airfoil in the dorsal fin mounting tray until the aircraft came to rest.

FIR data did survive (no bit drop-out) and was in an operable condition. the ELT radio beacon (both 121.5 MHz and 243.0 MHz) transmitted for less than 10 seconds after ejection. The unit failed due to impact fluids (fuel, CFR foam, etc.) shorting out a circuit board. The VMS operated for some period of time after ejection. The plastic covers were blackened by the ensuing fire.

HAZARDOUS MATERIAL PACKAGES.

Dow Chemical and Lawrence Packing (figure 27) provided pint and quart packages which had been filled with a scent jelled water material--nonrunning (the jelling material was an inert acrylic copolymer). These packages were located in the forward lower cargo galley near floor positioned accelerometers in order to acquire load data. No special instrumentation was provided.



FIGURE 27. SIMULATED HAZARDOUS CARGO

The experiment represented a series of 15 hazardous material packages (filled with multiple metal containers of nonhazardous jelled water) placed within the lower forward galley compartment.

During the period in which the firemen entered the aircraft galley area, smoke was coming from the lower galley compartment due to the lower cargo compartment fire. The fire men axed into the compartment, retrieved the burning packages, and threw them outside of the forward right-hand exit.

During the posttest examination, none of the packages that were intact and not affected by the firemen's axe and/or from being dropped outside the aircraft appeared to have been damaged during the aircraft ground impact. the transmitted impact loads appeared low.

Upon completion of the analysis of the instrumentation data obtained from the galley area, the actual dynamic loads transmitted to the hazardous material packages will be identified.

DATA ACQUISITION/PHOTOGRAPHIC SYSTEM.

The floor plan of the CID aircraft is as presented in figure 14. Instrumentation hardware consisted of DAS pallets (two sets located for and aft) per figure 28, recorded subsystem (figure 29), four power pallets (cameras/lights), checkout system (figure 30), 10 cameras and associated lights (figure 31).

NASA-LaRC developed the complete instrumentation/data acquisition system for the CID crashworthiness/crash behavior experiments. The DAS, as developed, included two independent systems, each capable of collecting and processing data from 180 sensors. The DAS signal conditioning units had 30 channels per unit. There were six of these systems in each DAS for a total of 180 channels of which 176 were used for data and the balance for system monitoring. The data from each DAS was transferred directly to two onboard 14-channel tape recorders, then simultaneously transmitted air-to-surface via four telemetry systems and recorded at the ground receiver control station.

The overall performance of the DAS and onboard photographic systems was excellent. At impact, 97 percent of the transducers/sensors were active, and all 10 cameras functioned properly. The DAS/photographic systems were enclosed in thermal insulation which prevented fire damage to all onboard recorded information. The onboard film provided unique insight into the reaction of the seat/dummy systems, and propagation of fire and smoke in the aircraft interior.

REMOTELY PILOTED VEHICLE/FLIGHT CONTROL SYSTEM.

The remote flight control and guidance system was developed for CID in order to conduct a remote aircraft air-to-surface impact (representing a near real-world crash situation) with the designated experiments and supporting systems. The NASA-A/DFRF was selected for its role in the CID program because of its experience in flying remotely piloted research vehicles (RPRV) and its associated physical facilities.

The RPRV technique was developed by NASA-A/DFRF in the early 1970's as a means of flight testing experimental aircraft and advanced technologies in a far less hazardous manner. This technique allows a pilot sitting in a ground cockpit

DAS MAIN PALLET

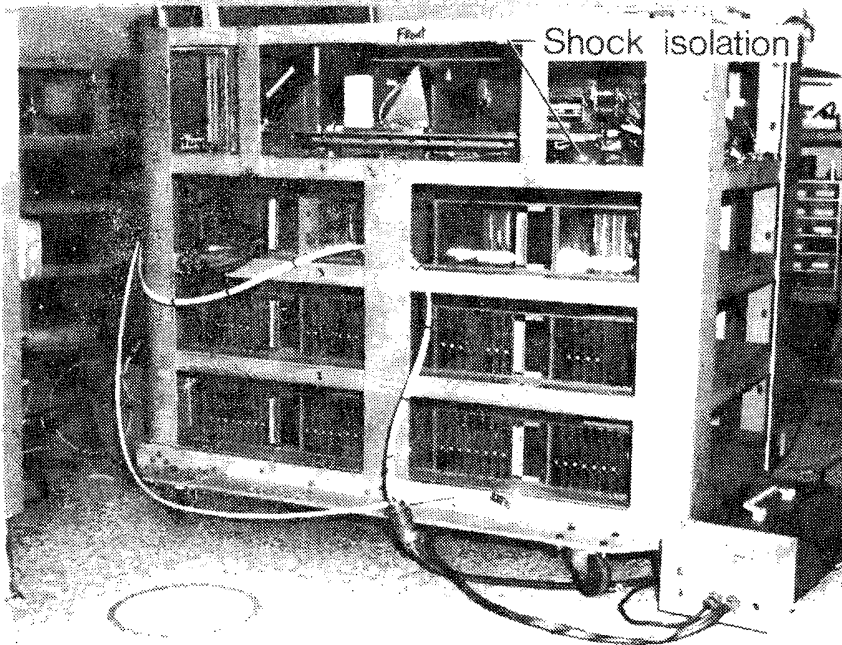


FIGURE 28. DAS MAIN PALLET

RECORDER SUBSYSTEM

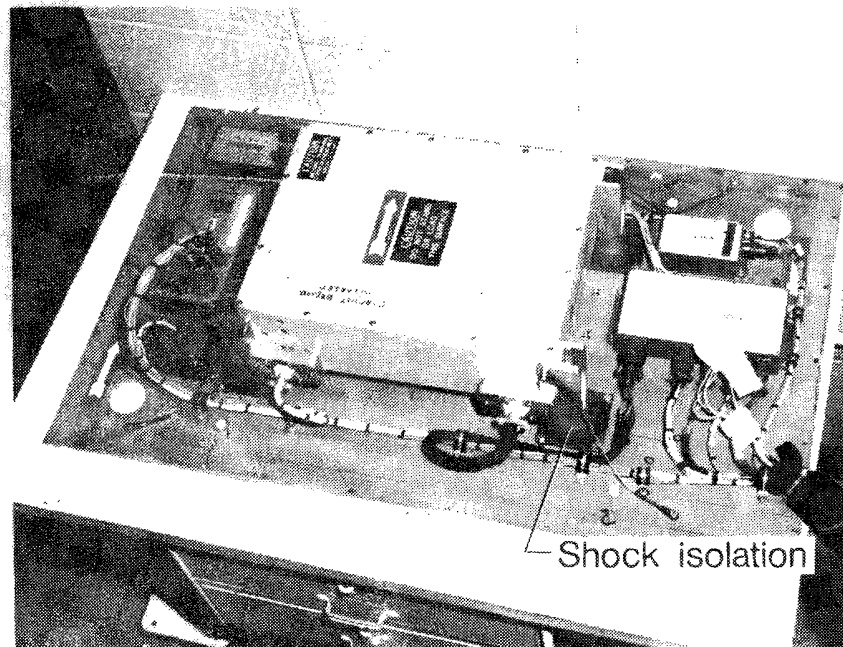


FIGURE 29. RECORDER SUBSYSTEM

CHECKOUT SUBSYSTEM

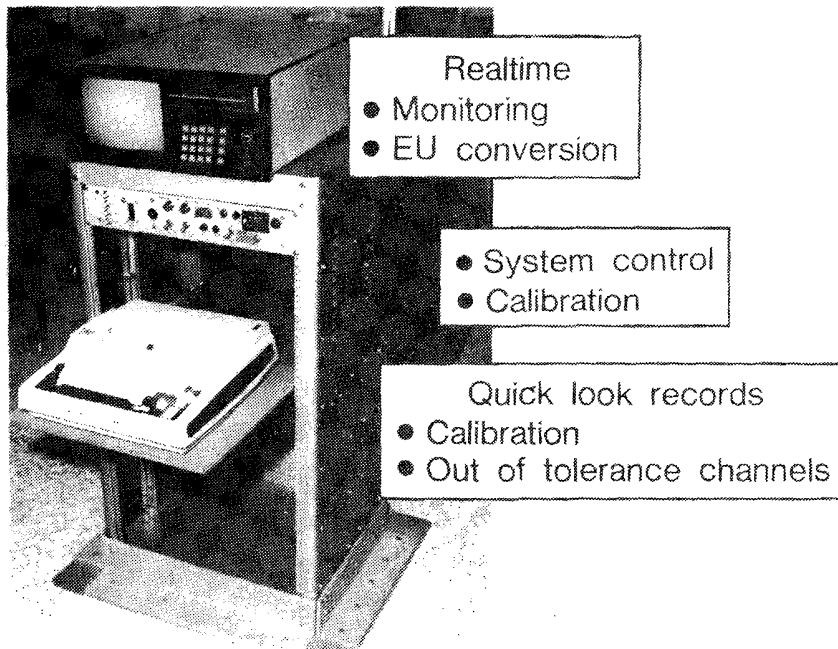


FIGURE 30. CHECKOUT SUBSYSTEM

NASA
L-84-1222

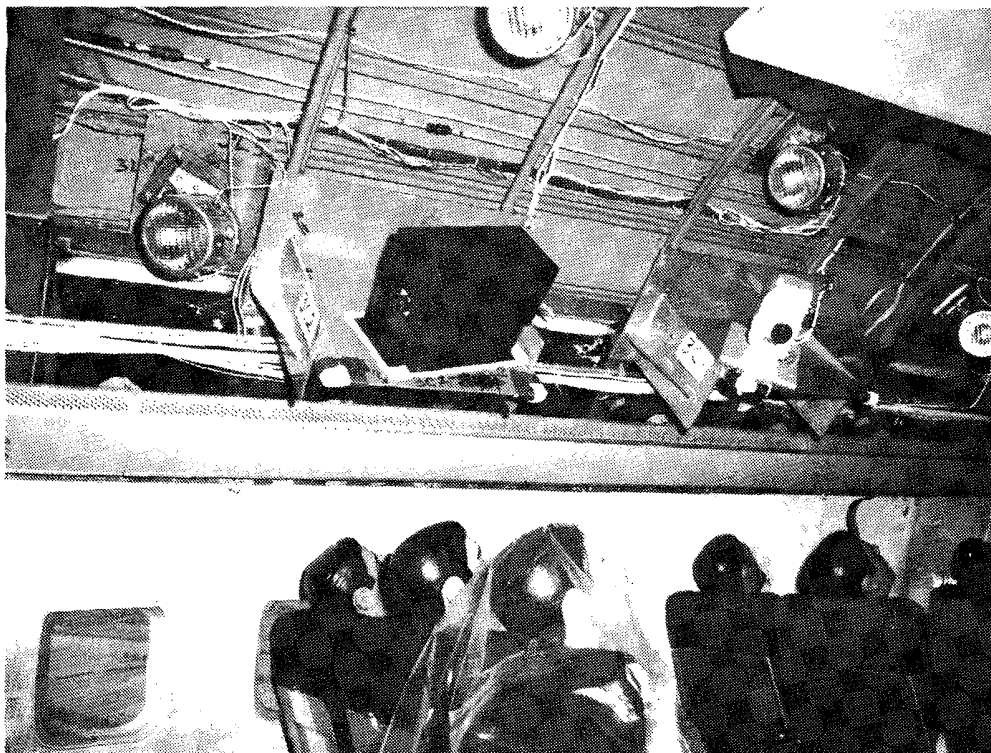


FIGURE 31. CAMERA/PHOTO FLOODLIGHT INSTALLATION

(figure 32) to fly an airplane using telemetry and radar. Flight control commands are sent electronically from the ground cockpit to the aircraft (figure 33), and flight information is returned in the same manner.

The RVP technique differs from conventional remotely piloted aircraft because it permits the pilot to fly precise test maneuvers instead of merely guiding the aircraft from point to point.

The B-720 was the largest remotely piloted research vehicle ever flown. Flight commands for such functions as engine throttles, elevators, ailerons, flaps, rudder, landing gear, brakes, nose wheel steering, and others were sent from the ground cockpit to the aircraft via an uplink system. Commands for the elevators, ailerons, and rudders which provide direct flight path control are fed through the onboard autopilot system. The other functions are fed directly to the appropriate system.

Flight information such as engine pressure ratio, exhaust gas temperature, RPM, fuel flow, and flight navigational information such as heading, attitude, altitude, and airspeed was returned to the ground cockpit using a downlink system.

A series of operating rules for the final "unmanned" CID approach to impact were implemented as follows:

1. From brake release down to 400 feet on final approach, any experimenter or systems support lead can call a "go-around" and RPV pilot initiates the go-around per normal procedures. During go-around, program/project management reviews problem and determines (based on problem) if another impact attempt is in order or abort to land. This decision directed to RPV pilot (appendix E).
2. Between 400 feet down to 150 feet on final approach, only RPV pilot can call a go-around based on his impact accuracy assessment.
3. From 150 feet to impact, turn on photo batteries, DAS recorders and cameras, and the JPL lakebed camera system. RPV pilot must continue to impact.

FLIGHT SAFETY/FLIGHT TERMINATION SYSTEM.

In the event that the ground-based RPV cockpit had lost the ability to control the aircraft, or in the event of an onboard flight control system failure, the flight termination system was to be activated to return the aircraft to an uncontrolled ground impact within the designated CID sterile lakebed area. The CID profile/sterile area was void of humans and was basically a barren lakebed within the designated CID boundaries. The program plan was to fly the unmanned aircraft at a specified speed and rate of descent into the prepared impact area under the control of an RPV pilot located in the ground cockpit at NASA-A/DFRF.

In the event of an onboard failure or that the ground-based pilot lost the ability to control the aircraft, a separate and independent ground command radio link was to be used to terminate the flight. The aircraft's throttles were to be automatically retarded to idle and the aircraft turned into a steep right-hand spiraling descent to the ground. Engines 1, 3, and 4 were to be shutdown

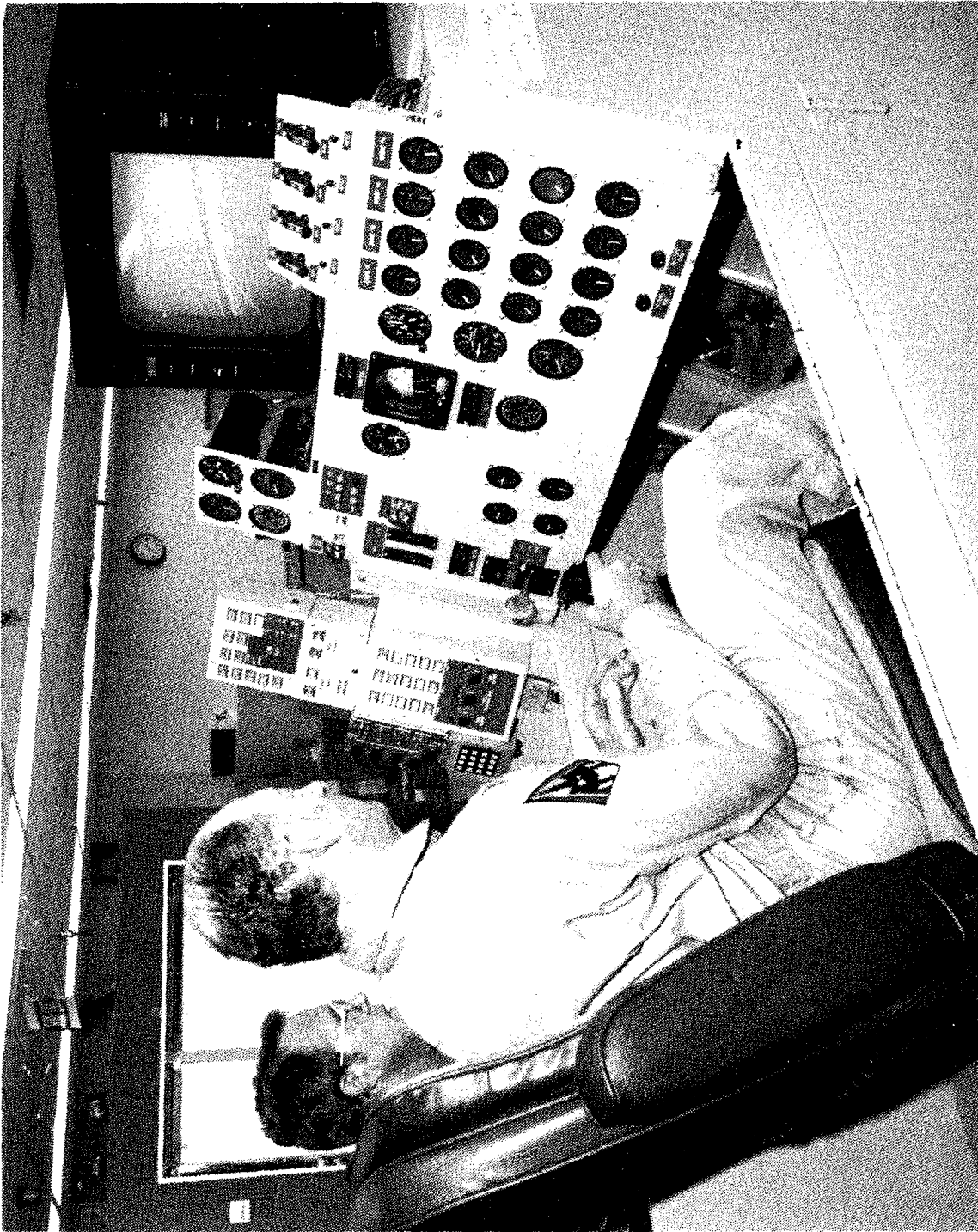


FIGURE 32. RPV GROUND COCKPIT

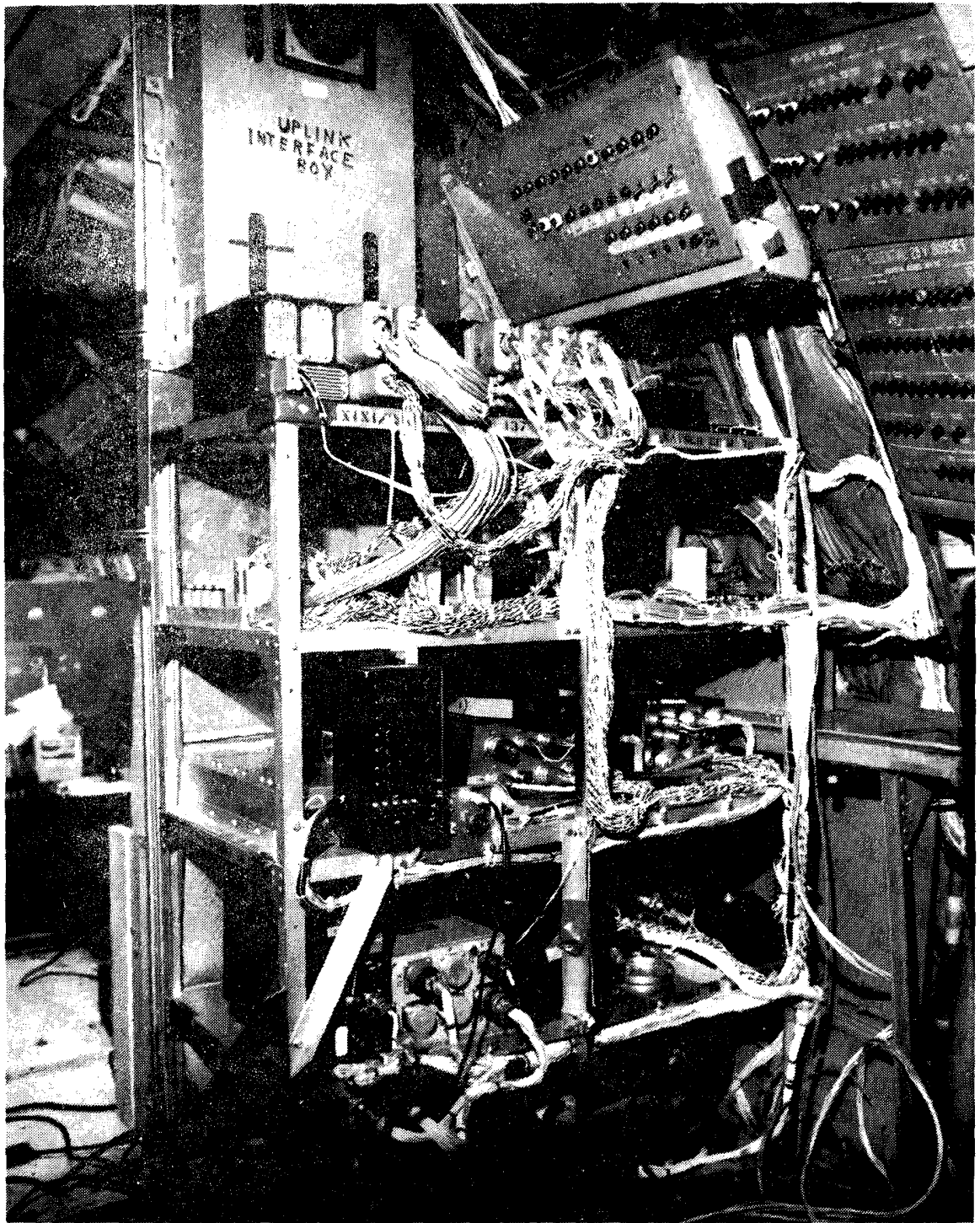


FIGURE 33. FLIGHT CONTROL UPLINK/DOWNLINK RACK INSTALLATION

immediately with engine 2 shutting down 25 seconds later. Landing gear was to be lowered and the stabilizer commanded to go to leading edge up. (There was no destruct system onboard the aircraft.) The flight termination system was not activated as the RPV system and aircraft performed as planned.

ENGINEERING PHOTOGRAPHIC/VIDEO COVERAGE

The CID program developed a total motion/still film and video documentation of the aircraft experiments, installation/integration, flight operations, and controlled impact demonstration. Ground cameras documented all of the appropriate portions of the total flight profile and impact scenario through slideout deceleration to a stop. Airborne cameras documented all of the appropriate portions of the total flight profile and impact scenario through slideout deceleration to a stop.

o Airborne Photographic and Video Coverage

The airborne black and white and color video nose cameras were primarily assigned to the RPV pilot guidance and control in the ground cockpit. A total of 11 high-speed engineering film cameras were strategically located in the passenger bin and crew cockpit to acquire dummy impact response. A high-speed film camera was mounted in the nose of the aircraft as was one mounted in the top of the vertical stabilizer, also in the cockpit overlooking the pilot in his view of the wind screen by the Jet Propulsion Laboratory (JPL). Two helicopters (Army and NASA) provided airborne film and still coverage prior to impact through slideout to eventual aircraft rest. A Navy P-3 "CAST-A-GLANCE" aircraft (figure 34) positioned itself above the CID aircraft and two helicopters (figures 35 and 36) to acquire total CID profile film and video coverage.



FIGURE 34. U.S. NAVY P.3 "CAST-A-GLANCE" AIRCRAFT



FIGURE 35. NASA PHOTOGRAPHIC HELICOPTER



FIGURE 36. U.S. ARMY PHOTOGRAPHIC HELICOPTER

- o Ground Photographic and Video Coverage

A ground photographic/video coverage system (figures 37 and 38) was set up around the impact site perimeter by JPL. Comprehensive remote file, video, infrared, specialty, and documentary camera (≈ 100) systems were in place and operated prior to impact through deceleration to rest. These systems were time correlated with airborne and ground instrumentation/photographic and video systems.

CRASH FIRE RESCUE

The principal objective of the crash fire rescue (CFR) service is to save lives in an aircraft accident by establishing a fire-free evacuation route for occupants. The most important factors bearing on effective rescue are the training received, the effectiveness of the equipment, and the response time.

The equipment responding to the CID site comprised a mix of P-2, P-4, P-10, P-13 USAF vehicles, and an F-6 foamer. The B-720 aircraft is served by Index C airports requiring a minimum of 2,100 gallons of water for foam production (AFFF), two foam trucks, and one rapid intervention vehicle (RIV). The practical critical fire area for Index C airports is 10,539 square feet. Employing proper firefighting techniques, 10,539 square feet of fire surface can be controlled (90 percent covered by foam) in 60 seconds and extinguished in 90 seconds.

Description of Events. The response time of the CFR to CID impact was approximately 90 seconds. Response time is the total elapsed time from the notification of the CFR to move out (alarm) to the first effective fire intervention (agent discharge) at the accident site. A response time of 2 minutes is the recommended objective of both the ICAO and NFPA.

The major pool fire (figure 39) on the left side of the fuselage was estimated to be 6,500 square feet. This fire was controlled with foam in 45 seconds after the initial discharge. A narrow but intense fire burning along and under the right side of the fuselage was attacked by two foam trucks from the front of the aircraft. The rapid control of the fire on the left side of the fuselage protected the left wing, which contained its original load of AMK, from fire involvement.

After obtaining control of the fire on the left side of the fuselage, the rescue crews entered the two main cabin doors with portable hose lines equipped with variable pattern spray nozzles. At this time, the temperature and smoke in the cabin were considered nonsurvivable to occupants. These environmental conditions were sustained by a pool of AMK which had entered the baggage compartment through a rupture in the fuselage during slideout. Since this fire was below the cabin floor, it was not readily accessible to the firefighters in the cabin nor from outside the fuselage.

Accident experience and full-scale fire tests conducted at the FAA Technical Center have shown that well established interior fuselage fires have been virtually unextinguishable by the rescue and firefighting services. Consequently, very large quantities of extinguishing agents were consumed in an effort to extinguish interior fires, control small external fires, and "cool" the fuselage. The USAF A/S32P-13 vehicle containing 507 pounds of Halon 1211 was equipped with the aircraft skin penetrator nozzle and employed to extinguish some of the "hidden" interior fires.

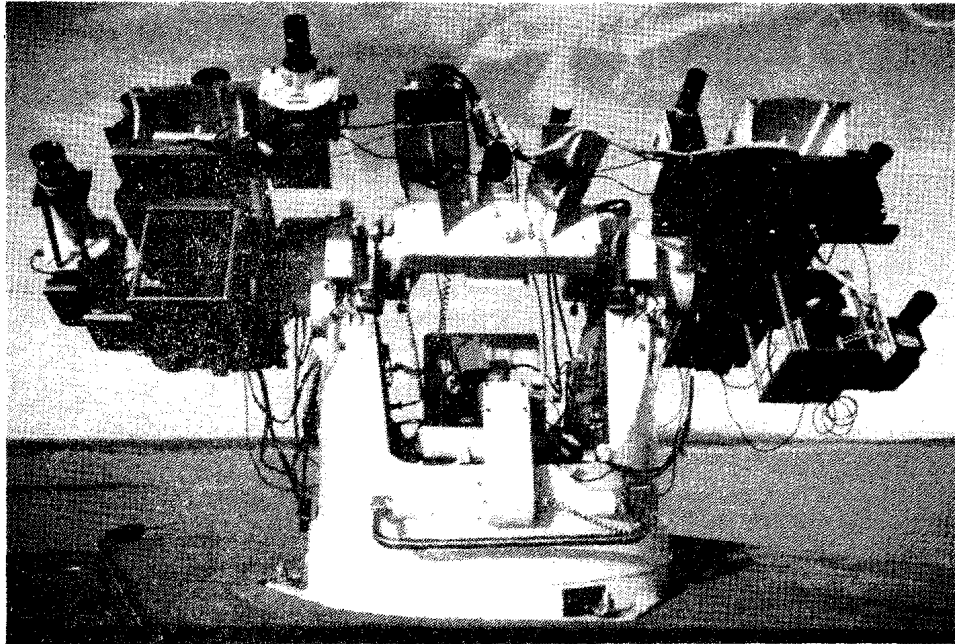


FIGURE 37. REMOTE CINE-SEXTANT TRACKER SETUP

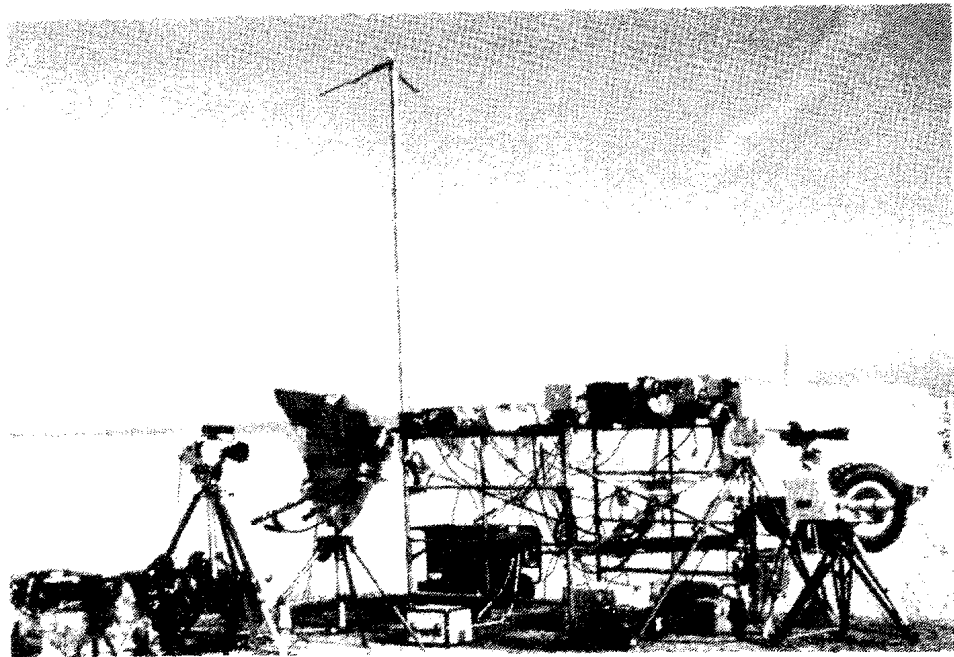


FIGURE 38. CAMERA STATION

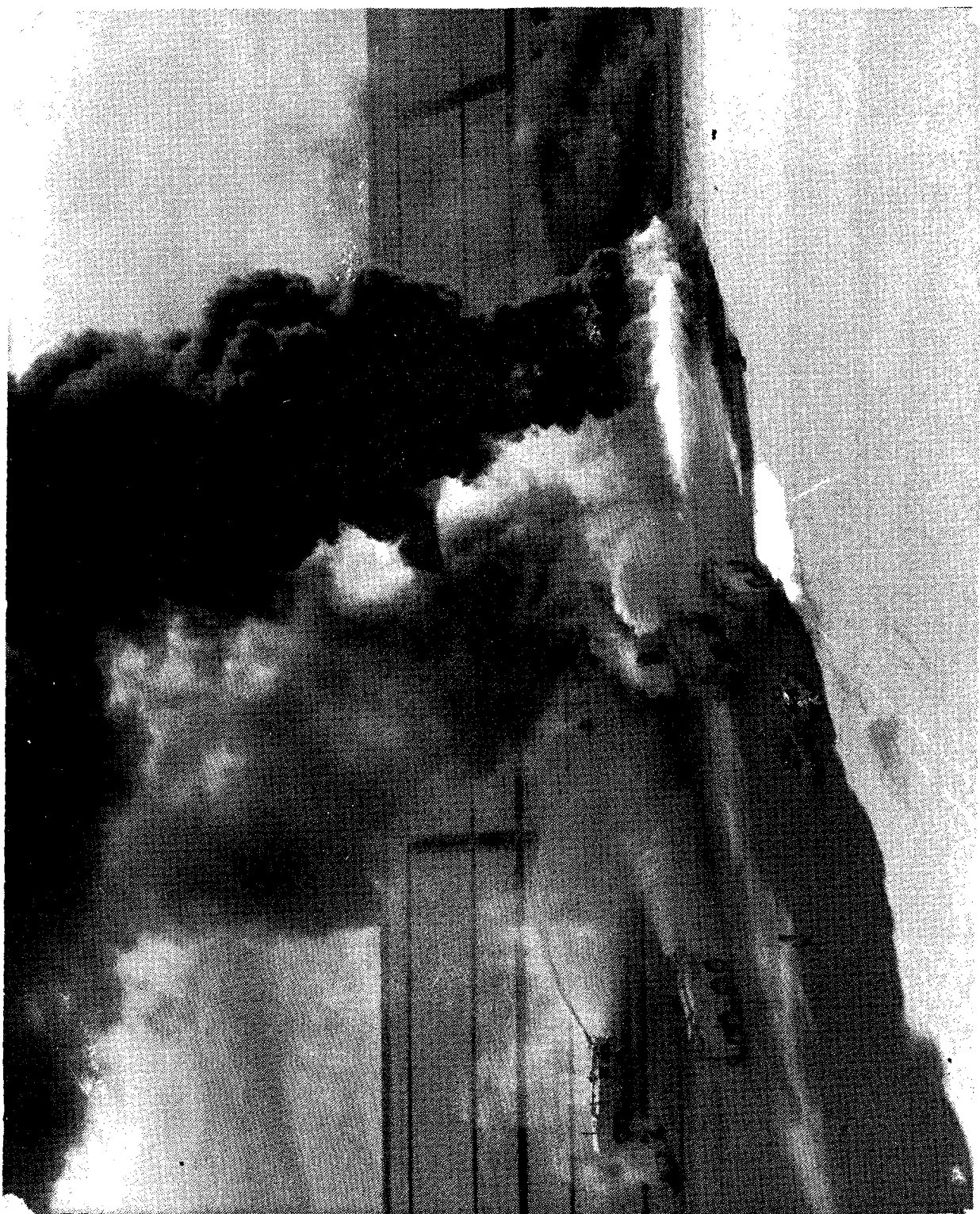


FIGURE 39. CFR

The quantities of firefighting agents dispensed comprised 34,000 gallons of water; 1,300 gallons of AFFF; and 2,000 pounds of Halon 1211. This enormous quantity of agents required multiple resupply efforts during the course of fire extinguishment.

Conclusions

1. The response time of CFR (90 seconds) was below that recommended by the ICAO and NFPA (2 minutes).
2. Control of the major pool fire (6,500 square feet) required 45 seconds which was below that recommended by FAA, ICAO, and NFPA.
3. The firefighting vehicles with agents responding to the CJD were in large excess over that required in FAR Part 134.49 for Index C airports.
4. The burning AMK which entered in the cargo hold was the principal cause of the burnout of the cabin interior.
5. The single skin penetrator nozzle was not adequate to dispense effectively the agents required to extinguish the large AMK fire in the cargo hold.
6. CFR crew report stated that the hidden source of the fire was not diagnosed soon enough.
7. Based upon photographic coverage, it was evident that better coordination between the firefighting crews and command personnel would have improved the effectiveness of the CFR mission.

POST-IMPACT (ACCIDENT) INVESTIGATION/ANALYSIS

At the conclusion of the CID, FAA conducted a "formal" full-scale accident investigation and analysis. An accident investigation team composed of specialist in the areas of aircraft performance, structures, propulsion, human factors, operations, and crash fire rescue handled this effort. The team (figure 40) was formed with members from FAA, NASA, DOD, and private industry. Investigative groups were to be formed as required by NTSB directives and report each day to the FAA Investigator-In-Charge (IIC) on the progress in their respective groups.

The purpose of this experiment was to assess the adequacy of the current accident reporting forms, investigative procedures, documentation, analyses, and reporting requirements. The analyses will also include a readout of the flight data and cockpit voice recorders, and comparison of this information with that obtained from various onboard flight data monitoring systems. The results will be made available for use in refining accident investigation techniques and procedures.

The CID documentation research and the investigative team met 2 days after the B-720 CID, and plans and procedures formulated. The on-site investigation was, for all practical purposes, completed within 5 days after initiation and group factual reports were being prepared by group chairmen.

The experiment, initially proposed and pursued by the FAA personnel, was a success in that it was enthusiastically received and was conducted by professional personnel with recognized expertise in required disciplines for this type effort. Because of the unforeseen catastrophic fire damage (figure 41) and wing openers damage to the aircraft, the investigation proved to be more of a challenge to and which was met by the investigators.

A detailed integrated report of the group factual reports is to be available.

EMERGENCY EVACUATION DATA

Investigation has revealed that the internal fire originated from fuel fires in the lower areas of the fuselage; that is, the cargo compartments below the cabin floor. A review of onboard film coverage by 11 cameras during the slideout of the aircraft revealed rapid buildup of smoke. The average for cameras forward of the circumferential structure crack was approximately 5 seconds from slideout complete until complete smoke obscuration, and approximately 20 seconds for the aft section of the aircraft. It has been determined that sidewall cargo liners were not in place for the forward and aft cargo areas, and this was the likely reason for such fast smoke obscuration.

At this time, the best estimate is that 23 to 25 percent of a full complement of 113 people may have escaped from the CID aircraft. The total includes a limited quantity of evacuees from the cabin area forward of the circumferential break and a greater number of evacuees from the area aft of the break.

Evacuation from the cabin is based on the following major considerations:

- The only usable exit was the left forward door (front right galley door and overwing exits blocked by external fire).
- Approximately 5 seconds of time from slideout to complete smoke obscuration (based on onboard cameras).
- In spite of dense smoke, crew members would instinctively locate forward door, and passengers would move toward door used for aircraft entry.
- Assuming each evacuee requires slightly more than 1 second to go through exit, to the total time to evacuate (15 seconds) was 200 percent greater than the 5 seconds to smoke obscuration (assume 5 seconds required to open door/deploy slide).

Evacuation from the aft cabin is based on the following major considerations:

- The only usable exit was the right rear door (left rear door blocked by external fire).
- Approximately 20 seconds of the time from slideout to complete smoke obscuration (based on onboard cameras).
- Assuming each evacuee requires slightly more than 1 second to go through an exit, the total time to evacuate (33 seconds) was 65 percent greater than the 20 seconds to smoke obscuration (assume 8 seconds required for flight attendant to reach/open door and deploy slide).

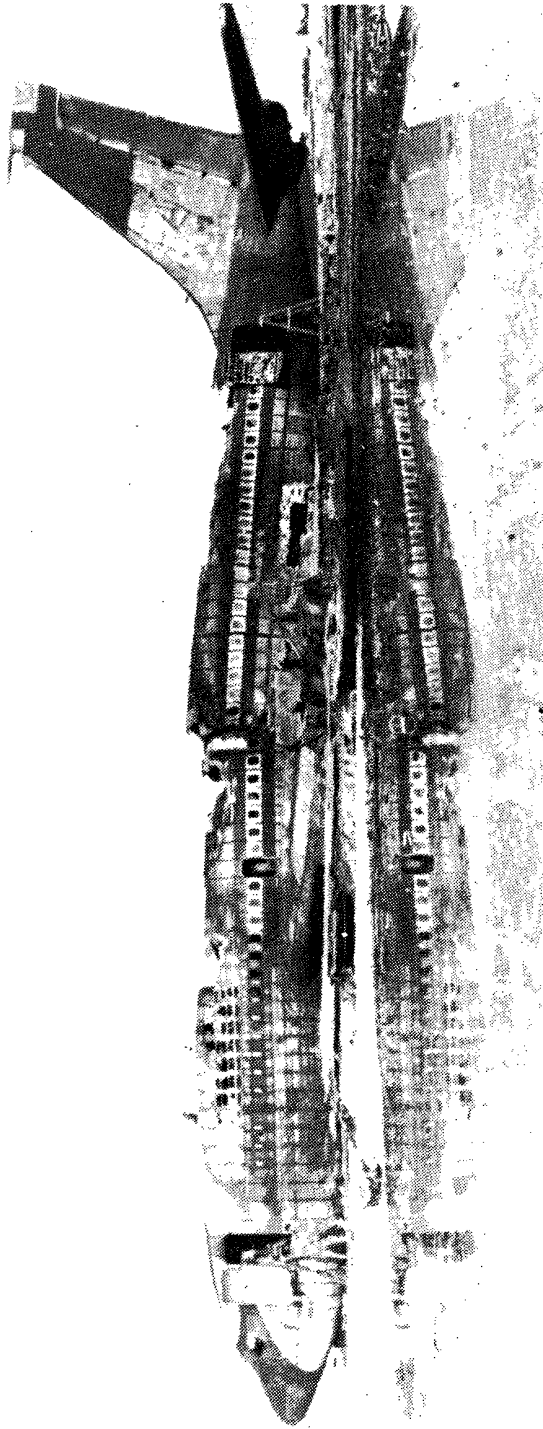


FIGURE 41. CID FIRE DAMAGE

How many additional people could have survived and escaped through dense smoke is highly speculative. Unfortunately, no instrumentation was installed on the aircraft to measure temperature, smoke density, or toxic gas concentration. Therefore, no estimate can be made as to when the cabin fire environment became untenable.

OBSERVATIONS

Flight Plan G--Flight 014 (pilot proficiency) was successfully conducted on November 26, 1984. Flight 015 technical briefing was conducted on November 27, 1984. On November 28, 1984, the NASA-A/DFRF FRR committee presented to the NASA-A/DFRF senior management their findings and recommendations on the Flight 014 anomaly. Based on senior management's review, the decision was rendered to "go with CID" as scheduled.

The AMK flushing and fueling operation, aircraft preflights, reconfiguration, etc., were initiated. The crew briefing and photo briefing were conducted on November 30, 1984, and the aircraft/systems operations were moved to lakebed runway 17. Day of Flight (DOF) Flight Plan H--Flight 015 started at 3:30 a.m. with the ground crew and proceeded to a call-to-stations at 7:25 a.m. Winds were reported at less than 3 knots north with a temperature of 42°F at takeoff (approximately 9:14 a.m.). The takeoff, CID profile, and down to impact (9:22:11) appeared to be normal and as planned.

As previously indicated, the documentation research/post-impact (accident) investigation teams began their investigation/analysis on CID plus 2 days. Their investigation was completed within 5 days of work. As their work was completed, the security of the impact site was minimized, and the carcass salvage contractor moved on-site.

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5. Ground Operations Plan, CID 84-23, dated October 29, 1984.
6. Management Information Control System Report, NASA-Langley Research Center, prepared monthly (initial report: December 13, 1983).
7. CID Drawing Number Reference Document, CID 84-36, dated October 30, 1984.

8. CID Mission Rules, CID 84-28, dated November 1984.
9. CID Operating Rules, CID 84-33, dated November 1984.
10. CID Flight Cards, CID 84-35, dated November 29, 1984.

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3. Crashworthiness Experiment Summary Full-Scale Transport Controlled Impact Demonstration Program, Final Report DOT/FAA/CT-85-20, dated June 1986.
4. Galley and Overhead Compartment Experiment Results--Full-Scale Transport Controlled Impact Demonstration, Report DOT/FAA/CT-85-33, dated December 1985.
5. Full-Scale Transport Controlled Impact Demonstration, NASA Conference Publication 2395, dated April 1985.
6. Impact Data from a Transport Aircraft During a Controlled Impact Demonstration, NASA Technical Paper 2589, dated September 1986.
7. Full-Scale Transport Controlled Impact Demonstration Program: Jet Propulsion Laboratory Final Report, DOT/FAA/CT-85-35, dated April 1986.
8. Full-Scale Transport Controlled Impact Demonstration-Aircraft Accident Investigation Experiment and Report of Investigation, Final Report DOT/FAA/ASF-86-001, dated July 1986.

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APPENDIX A

PARTICIPANTS

The FAA Technical Center (Atlantic City Airport, New Jersey) was responsible for the overall conduct of the CID and was serving as the CID Program Manager. It also was responsible for many of the experiments; i.e., antimisting kerosene, crashworthiness, cabin fire safety, etc., onboard the test aircraft.

NASA's Langley Research Center (Hampton, Virginia) had crashworthiness/structural/restraint experiments on the aircraft. Its major contribution was the development of the instrumentation/data acquisition systems (DAS) for the entire CID.

NASA's Ames/Dryden Flight Research Facility (Edwards, California) had the responsibility for the design and implementation of the remotely piloted vehicle's flight control and guidance system. It also handled the integration of all the experiments and system hardware that flew on the airplane. Additionally, it did conduct all ground and flight operations.

FAA-Ames Research Center (Moffett Field, California) was a test team member having the responsibility for the AMK degrader system integration, checkout, ground, and flight tests.

FAA headquarters (Washington, D.C.) test team members represented headquarters management and participated in a Flight Readiness Review (FRR) team in the CID activities, and conducted the post-impact (accident) investigation experiment.

NASA headquarters (Washington, D.C.) test team members represented headquarters management and the FRR team in the CID activities.

NASA-Ames Research Center (Moffett Field, California) participated as FRR team member and supporting flight following aircraft support.

Each Government agency utilized industry support to the greatest extent practical through the competitive contracting process. Formal interagency agreements and memorandums of agreement were in force between the FAA, NASA, Department of Defense (DOD), and international governments. The CID team included Government and industry participants as follows:

U.S. Military Services

o U.S. Air Force

- Air Force Flight Test Center (Edwards Air Force Base, California)-- Range, tracking, communications, crash fire rescue, air traffic control (ATC), security, etc.
- United States Air Force 1369th Audio Visual Squadron (DOI) (Vandenberg Air Force Base, California)--Ground photographic/video coverage: Manned and remote tracking

- o U.S. Army
 - Air Force Flight Test Center (Edwards Air Force Base, California)--
Photographic/video coverage helicopters
- o U.S. Navy
 - Naval Air Test Center (Patuxent River, Maryland)--Flight Incident Recorder/Electronic Locator Transmitter (FIR/ELT) experiment.
Industry support provided by:
 - Leigh Instruments LTD (Canada)--FIR/ELT developer, test, and support
 - USN/Naval Surface Weapons Center (Dalgren, VA)--Remote tracking/
radio controlled camera tracker system
 - USN/P-3 Orion Squadron (Pt. Mugu Test Center, California)--
P-3 Orion "Cast-A-Glance" airborne photographic/video coverage
- o National Transportation Safety Board (Washington, D.C.)--Flight data and cockpit voice recorders (FDR/CVR) tape readout and analysis, and post-impact investigation team member
- o Department of Transportation (DOT)/FAA
 - Civil AeroMedical Institute ([CAMI] Oklahoma City, Oklahoma)--
Seat/restraint systems tests and analysis

Foreign Governments

- o United Kingdom
 - Royal Aircraft Establishment--Antimisting kerosene experiment support and analysis
- o France
 - Airbus Industrie (Toulouse)/French Embassy (Washington, D.C.)--
Seat/restraint system, anthropomorphic dummy, data acquisition system experiment, and structural analysis. Industry support provided by:
 - Dynamic Science, Incorporated (Phoenix, Arizona)--
Seat/restraint system, dummy, instrumentation, and data acquisition system development, integration, and tests/support

Industry/Additional Support

- o Imperial Chemical Industries of America (Wilmington, Delaware)--AMK additive (AVGARD®) developer/supplier, sampling and characterization, tests and analysis support

- o General Electric (Evandale, Ohio)--AMK degrader program manager, design, developer, installation, and test support
 - Garrett Pneumatic Systems Division (Phoenix, Arizona)--Degrader system manufacturer, integration, and test/support
- o General Electric (Edwards, California)--Engine/AMK fuel degrader instrumentation, integration, checkout, fuel analysis laboratory, and general aircraft maintenance support
- o Jet Propulsion Laboratory (Pasadena, California)--AMK simulation, tests, sampling, characterization, and analysis support
 - JPL Photographic Section, Ground/Airborne (Pasadena, California)--Responsible for ground/airborne photographic/video system design, development, integration, test, and support.
- o Lockheed Aircraft (Burbank, California)--"KRASH" model development and analysis
- o Boeing Commercial Airplane Company (Seattle, Washington)--"DYCAST" model development and analysis; Boeing 720 technical support
- o Boeing Technical Services (Seattle, Washington)--Boeing 720 technical support
- o Republic Management Systems (Trevose, Pennsylvania)--Management of seat/restraint system development and tests experiment (FAA) -- SIMULA, Incorporated (Tempe, Arizona)--Seat/restraint system development, supplier, tests, and support; SOMTA seat model analysis
- o Kentron (Hampton, Virginia)--Instrumentation/data acquisition system support
- o System Development Corporation (Hampton, Virginia)--Impact dynamics computer analysis program/support
- o Lockheed Aircraft Services (Ontario, California)--Flight data and cockpit voice recorder(s) systems design, integration, checkout, and test support; and supplier of an FDR, data reduction and analysis
 - Teledyne Controls (West Los Angeles, California)--Manufacturer/supplier for flight data acquisition unit
 - Fairchild Aviation Recorders/Fairchild Weston Systems, Incorporated ()--Supplier (On load to CID) state-of-the-art FDR and CVR; data readout and analysis
 - Sunstrand Data Control (Redmond, Washington)--Supplier (on loan to CID) state-of-the-art FDR; data readout and analysis
 - Lear Siegler, Incorporated ()--Supplier (on load to CID) state-of-the-art solid state memory device

- o Dow Chemical Company (Midland, Michigan)--Supplier and integrator for hazardous materials packaging experiment(s)
 - Lawrence Packaging (Newark, New Jersey)--Supplier of experiments
- o Pratt and Whitney Aircraft (E. Hartford, Connecticut)--B-720 propulsion system technical support
- o Bendix (Long Beach, California)--Autopilot/flight control system technical support
- o Jim Matthiesen (Redwood City, California)--Boeing 720 consultant, pilot, flight engineer, ground school and simulator instructor, Bon vi-vant, etc.
- o Frank Sanders Aircraft (Chino, California)--Tailcone frame generators design, development and installation
- o Cal Yandell Industries (Fontana, California)--Aircraft salvage contractor

APPENDIX B

CID DOCUMENTS INDEX

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- 03 CID SYSTEM DESIGN APPROACH AND RISK ASSESSMENT
- 04 CID REMOTE FLIGHT CONTROL SYSTEM FINAL DESIGN AND STATUS REVIEW
- 05 AIRBORNE CONTROL SYSTEM DESCRIPTION: UPLINK
- 06 AIRBORNE CONTROL SYSTEM DESCRIPTION: POWER DISTRIBUTION
- 07 AIRBORNE CONTROL SYSTEM DESCRIPTION: LANDING GEAR
- 08 AIRBORNE CONTROL SYSTEM DESCRIPTION: THROTTLES
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CID-84

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- 04 CID B-720/CID FLIGHT CONTROL AND GUIDANCE SYSTEM
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APPENDIX C

DEGRADER SYSTEM JET-A/AMK BUILD-UP PLAN (PRELIMINARY)

The first test buildup plan assures that the following sequence of degrader runs is followed. This will lead to a fully qualified degrader to perform the CID mission.

In order:

1. Start and run in level flight on Jet-A
2. Run through speed accels and decels on Jet-A
3. LAND WITH DEGRADER RUNNING ON JET-A
4. Takeoff with degrader running on Jet-A
5. Repeat 1 through 4 on AMK

Furthermore, the following guidelines will be met at all times:

During qualification testing, the number of degraders running during the landings and takeoffs will be sequentially increased from 1 to 4.

During qualification test (1 through 5 above), only one engine will be running on AMK during all landings and takeoffs.

To implement this qualification, the following flight plan is established:

<u>FLIGHT</u> <u>Plan</u>	<u>ENGINE NUMBER</u>			
	1	2	3	4
C	TE/JET-A	TE/JET-A L/JET-A	TO/JET-A	TE/JET-A
D	L/JET-A	TO/JET-A L/AMK	TO/AMK @	L/JET-A
E	TO/JET-A L/AMK	TO/AMK L/JET-A	@ L/JET-A	TO/JET-A L/JET-A
F	TO/AMK L/JET-A	TO/JET-A L/JET-A	TO/JET-A L/JET-A	TO/JET-A L/AMK
G*	TO/AMK	TO/AMK	TO/AMK	TO/AMK

TE = TEST

L = LAND

TO = TAKEOFF

@ = NO DEGRADER OPERATION TO SATISFY REQUIREMENT B ABOVE

G* = ENGINES QUALIFIED FOR CID ON THIS FLIGHT

NOTE: Once AMK added to a tank, AMK will always stay in that tank

Manned flights - AMK tank to engine - but can cross-feed Jet-A to engine

APPENDIX D

TYPICAL FLIGHT PLANS AND SCHEDULES

For each flight plan, there are a series of events which are required prior to flight. Flight Plans C and D below are typical for the Jet-A only flight and the first AMK flight. Additions were identified such as Flight Readiness Review (FRR) Committees (Ad Hoc NASA-Ames and FRR board NASA-A/DFRF) Review/Meetings, FAA/NASA flight go-ahead, etc.

Briefly described below are typical preflight plan activities and major test times of that flight.

o FLIGHT PLAN C--FLIGHTS 005 AND 006

June 28-30, 1984	-	Degrader Systems Checks (only)
July 2-3, 1984	-	Degrader Systems/Engine Runs
TBD	-	Technical Briefing (NASA-A/DFRF management--overview of Flight Plan C; i.e., major flight tasks, mission rules, go/no-go criteria, etc.
	-	Procedures review for Combined Systems Test (CST)
July 4, 1984	-	HOLIDAY
TER	-	Pre-CST meeting
July 6, 1984	-	CST--ALL systems up; i.e., ground remote control cockpit, control room, and aircraft/ experiments -- step-by-step dress rehearsal of Flight Plan C
July 7, 1984	-	Pre-flight Engines
July 9, 1984	-	Pre-flight Aircraft (including fuel)
TBD	-	Crew brief-final procedures and flight plan review
July 10 & 12, 1984	-	Flights 005 and 006

Major Test Items

1. Takeoff-degrader on Jet-A, Engine Number 3
2. Fuel degrader tests Jet-A, Engines 1, 2, and 4
3. Ground effects tests
4. Airspeed calibrations

5. Langley experiments checks (DAS/camera system)
 6. CID profiles - remote piloted vehicle (RPV) control
 7. Land - degrader on - Jet-A engine number 2
 8. Flight termination shutdown
 - o FLIGHT PLAN D - FLIGHT 007
 - Post-flight Plan C
 - Systems/experiment anomaly maintenance/repair-- aircraft, systems, or experiment squawks, failures, discrepancies, etc.
 - AMK blender set-up and checkout
 - Blend AMK fuel, sample, characterize
 - Flight Readiness Review (prior to first AMK flight) Technical Briefing
 - AMK/degrader systems checks
 - Flight configuration degrader/engine ground runs
 - CST
 - Pre-flight engines
 - Pre-flight aircraft (including fuel)
 - Crew Brief
- August 3, 1984 - Flight 007

Major Test Items

1. Takeoff degrader on - AMK Engine Number 3; Jet-A Engine Number 2
2. Fuel degraders tests - AMK Engines 2 and 3; Jet-A Engines 1 and 4
3. CID profiles - RPV control
4. Approach to Runway 25
5. Land Runway 22 - Airborne Control - Degraders on - AMK Engine Number 2; Jet-A Engines 1 and 4
6. Takeoff Runway 22 - RPV control - degraders off
7. Land Runway 22 - RPV control - degraders off
8. Remote Pilot (RP) ground operations; i.e., nose wheel steering and brakes

9. Remote engine shutdown

o FLIGHT PLAN E

- Post-flight Plan D
- Systems/experiment anomaly maintenance/repair
- Blend AMK fuel, sample, characterize
- Technical brief
- AMK/degrader systems checks
- Flight configuration degrader/engine ground runs
- CST
- Pre-flight engines
- Pre-flight aircraft (including fuel)
- Crew brief

August 13, 1984 - Flight

Major Test Items

1. Takeoff - remote pilot - degrader off - Runway 22
2. Land - remote pilot - degraders off - Runway 22
3. Takeoff - airborne control - degraders on - AMK Engine Number 2; Jet-A Engines 1, 3, and 4
4. Fuel degrader tests - AMK Engines 1 and 2; Jet-A Engine 4
5. CID profiles RP control
6. Approach to Runway 25
7. Land Runway 25 - degraders off - RPV control
8. Configure for RP operation on lakebed
9. Takeoff - remote pilot
10. CID profile RP control
11. Land - degraders on - AMK Engine Number 1; Jet-A Engines 2, 3, and 4

o FLIGHT PLAN F

- Post-flight Plan E
- Systems/experiment anomaly maintenance/repair
- Blend AMK fuel, sample, characterize
- Technical brief
- AMK/degrader systems checks
- Flight configuration degrader/engine ground runs
- CST
- Pre-flight engines
- Pre-flight aircraft (including fuel)
- Crew brief

August 27, 1984 - Flight

Major Test Items

1. Takeoff - remote pilot - degraders off - Runway 22
2. Land - remote pilot - degraders off - Runway 22
3. Take off - airborne control - degraders on - AMK Engine Number 1;
Jet-A Engines 2, 3, and 4
4. Fuel degrader tests - AMK Engines 1 and 4; Jet-A Engines 2 and 3
5. CID profiles RP control
6. Approach to Runway 25
7. Land Runway 25 - degraders off - RPV control
8. Configure for RP operation on lakebed
9. Takeoff - remote pilot - degraders off - Runway 16
10. CID profile RP control
11. Land airborne control - degraders on - AMK Engine Number 4;
Jet-A Engines 1, 2, and 3

o FLIGHT PLAN G - FINAL "MANNED" FLIGHT

- Post-flight Plan F
- Systems/experiment anomaly maintenance/repair aircraft, systems, or experiment squawks, failures, discrepancies, etc.
- AMK blender set-up and checkout
- Blend AMK fuel, sample, characterize
- Flight Readiness Review (prior to final AMK flight)
- Technical briefing
- AMK/degrader system checks
- FLight configuration degrader/engine ground runs
- CST
- Pre-flight engines
- Pre-flight aircraft (including fuel)
- Crew brief

This sequence of events will follow the Flight Plan D sequence of events. The FRR Committees (Ad Hoc Ames and A/DFRF Board) will meet, deliberate, and provide their findings and recommendations to the CID program, A/DFRF Site Manager (Marty Knutson), and subsequently his recommendations to Dr. Bill Ballhaus, Director, NASA-Ames. At sometime prior to Flight Plan G, Dr. Ballhaus would apprise NASA and FAA management of the state of readiness for Flight Plans G and H, and generally solicit their concurrence.

September 1, 1984 - FLIGHT G - WINDOW OPENS

Major Flight Items - manned

1. Takeoff - remote pilot - degraders off Runway 17
2. CID profile - RP control
3. Land - remote pilot - degraders off - Runway 22
4. Configure for CID mission

o FLIGHT PLAN H - CID

The original Flight Plans G and H objectives were to accomplish a complete manned dress rehearsal of the CID mission (FLight Plan G0; if successful with minimum anomalies, remove the crew, reconfigure for "unmanned" flight/CID mission.

As each flight plan currently progresses, the magnitude of the logistics of an hour or two turn-around from G to H with an all-up status of all ground facilities, and aircraft, systems, and experiment, being required, it is not clearly obvious that this objective can be satisfied. A comprehensive review of all the final pieces of the CID is in progress, and may not be in place until Flight Plan F.

FLIGHT H

CID Mission - Unmanned

1. Takeoff - remote pilot - AMK/degraders on - Runway 17
2. Perform CID

APPENDIX E

CID PILOT/CREW REPORT

The following report is provided by the CID RPV pilot, flight test engineer, and the remote control vehicle laboratory supervisor:

Introduction. This was the fifteenth flight of the CID Test Program but was the first and only flight to be flown without a safety crew onboard. The flight objectives were to remotely fly the B-720 aircraft from lakebed runway 17 and climb to approximately 2,300 feet above the ground while positioning the airplane on the racetrack pattern inside the designated sterile area. It was then to be flown around the racetrack and onto the final approach where a northerly descent would be started to allow the airplane to impact the ground just prior to the gravel slideout area. It was then expected to slide into cutters which would rupture the wings and create a fuel spillage. The flight was completed in the manner described.

Preflight, Engine Start, and Final Checks. The cockpit setup and engine starts were done by the onboard crew of Tom McMurtry (pilot), Vic Horton (flight engineer), and Buzz Sawyer (technician). The checks and engine starts appeared to go efficiently and without any significant problems. The onboard crewmembers started to evacuate the airplane at 5 minutes prior to the planned takeoff. There was a minor delay in getting clearance for takeoff since the security personnel had to assure that everyone was out of the sterile area. The two photo helicopters, the King Air safety chase, and the Navy P-3 photo airplane were airborne and ready to support the mission, and then NASA One Control Room gave the clearance for takeoff.

Takeoff and Initial Climb. Following a countdown, the brakes were released and the throttles gradually increased to takeoff power of approximately 2.66 EPR. The throttles were bolted together for this flight and that caused a minor variation between engine power settings. The elevator trim started to move slightly nose down from the 2.5 degree setting as the airplane accelerated, but a small aft movement of the stick slowed the trim movement, and therefore, it caused no problem.

The acceleration appeared to be normal and the airplane was steered down Lakebed Runway 17 using the rudder pedal steering system. The steering was quite sensitive and some minor directional deviations resulted during the first part of the roll. The color TV installed in the nose of the airplane had less contrast than on some previous flights but provided an adequate picture.

At speed of 80 knots, the nose when steering was disengaged, and thereafter, aerodynamic rudder control was used to provide directional control. It was quite effective and completely satisfactory. The calculated V_1 , V_2 speeds were set about 10 knots fast to allow more speed margin during the rotation and takeoff. At V_R , the stick was moved gently aft between V_R and V_2 , but the rate was noticeably slower. Liftoff was very close to the V_2 speed of 151 knots, and the airplane climbed away nicely.

Using the attitude gyro and the TV picture, the pitch attitude for climb could be held relatively constant. After assuring that a positive rate of climb was continuing and that the hydraulic pressure was normal, the landing gear was selected up. The flaps stayed at 30 degrees throughout the flight.

Upon reaching 200 feet above ground level (AGL), a left turn to 120 degrees heading was started and the engine power reduced to approximately 2.35 EPR. The airplane climbed to 4,600 mean sea level (MSL) (2,300 feet AGL). A small right aileron trim bias had to be set in to maintain a constant heading. This resulted in about one or two degrees of indicated right bank angle. The error was thought to be a result of gyro precession during the takeoff. This bank angle error, even though small, was distracting as it had been on previous flights.

Racetrack Pattern. Using the raw data and steering bar needles, the airplane was established southbound on the desired downwind leg at approximately 4,600 feet MSL. The guidance system allowed the track and altitude to be closely held. While flying straight away on the downwind, the aileron trim bias had to be adjusted again to hold a constant heading.

Base Leg. As the base leg was approached, the vertical steering bar moved right to command a right turn. However, once the airplane had been rolled into the turn, the airplane would drift outside the track if the steering bar was held centered. In order to hold the desired track while turning the bank, angle had to be increased until the vertical steering bar was approximately 1/2 inch left of center. This was similar to conditions experienced on previous flights and caused no real problems.

Final Approach. Turning onto the final approach, the target area and the lead-in line on the ground could be seen on the TV screen, but the contrast was low and the picture was not as clear as on some flights. When the "terminal guidance" became active, the airplane was nose down to intercept the desired glideslope. As the glideslope was intercepted, the pitch attitude was adjusted to place the TV boresight X on the orange panel of the target area fence. Instead of holding the glideslope, the airplane drifted low and had to be flown back up to the glideslope. It was also determined that the raw glideslope indicator and the pitch steering bar had minor indication errors. Several oscillations up and down through the glideslope allowed an approximate calibration to be made. The autothrottle held the speed very close to 146 knots while coming down the final.

While making the glideslope and pitch adjustments, the airplane drifted slightly right of the center line, and a correction to the left was made. When passing 200 feet altitude, the airplane was still slightly right of center and a go-around was considered, but there seemed to be enough altitude to correct back. The concern expressed many times by senior engineering personnel and Flight Readiness Review (FRR) Board members about the lack of redundancy in the overall control system was certainly a factor in the decision to continue and make the touchdown on the first attempt. The ground rules required a continuation after reaching 150 feet, and the flight test engineer activated the remotely controlled instrumentation at that altitude.

APPENDIX F
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