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REMOTE CONTROL OF AN IMPACT DEMONSTRATION VEHICLE

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ABSTRACT

Uplink and downlink telemetry systems were installed in a Boeing 720 aircraft that was remotely flown from Rogers Dry Lake at Edwards Air Force Base and impacted into a designated crash site on the lake bed. The controlled impact demonstration (CID) program was a joint venture by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) to test passenger survivability using anti-misting kerosene (AMK) to inhibit postcrash fires, improve passenger seats and restraints, and improve fire-retardant materials.

The uplink telemetry system was used to remotely control the aircraft and activate onboard systems from takeoff until after impact. Aircraft systems for remote control, aircraft structural response, passenger seat and restraint systems, and anthropomorphic dummy responses were recorded and displayed by the downlink systems. The instrumentation uplink and downlink systems are described.

Key words: Telemetry data, remotely piloted aircraft, radio control, command and control.

INTRODUCTION

The full-scale transport, controlled impact demonstration (CID) was a result of the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) aircraft safety programs. Occupant survivability in a transport-aircraft postcrash environment may be significantly enhanced by minimizing fuel fires and improving seat and restraint design features. Postcrash fireballs resulting from the ignition of spilled fuel during crash deceleration, wing breakup, and fuel tank rupture result in a high percentage of transport crash fatalities.

Impact from an otherwise survivable crash may result in serious injuries or fatalities when the occupant is subject to impact forces that compromise the structural integrity of the fuselage and cause failure of the floor, seat, and other installed cabin equipment. The purpose of this flight test program was to validate technology that could improve aircraft occupant crash survivability through reduced postcrash fire hazard and improve crash impact protection.

The test consisted of a full-scale air-to-surface survivable impact demonstration using a remotely piloted transport aircraft on Rogers Dry Lake near NASA Ames Research Center's Dryden Flight Research Facility (Ames-Dryden) at Edwards AFB, California. The aircraft was a typical four-engine turbojet, intermediate-range transport (a Boeing 720 airplane) which entered airline service in the mid-1960's (Figure 1).

The crash scenario was representative of an air-to-surface impact survivable accident, such as a missed approach or an aborted takeoff (Figure 2). For the controlled impact, the landing gear was retracted and the flaps extended. The airspeed and vertical velocity were selected to maintain fuselage integrity while acquiring vertical and longitudinal acceleration data. Obstacles that would open the aircraft fuel cells were installed at the crash site to ensure dispersal of the fire-retardant antimisting kerosene (AMK) fuel being tested.

The onboard data acquisition system was designed to collect aircraft and experimental performance data from the takeoff of the aircraft through surface impact and deceleration. Aircraft and experimental data were recorded on board the aircraft and simultaneously transmitted by a telemetry link to ground recorders.

REMOTE CONTROL CONCEPT

The general remote operation concept (Figure 3) consists of commands telemetered (or uplinked) to the 720 aircraft and responses from the aircraft telemetered (or downlinked) to the ground receiving station.

Uplink commands generated in the ground cockpit were transmitted to the aircraft from either a primary or backup ground-based antenna. Commands were received in the aircraft by means of antenna diversity; that is, antennas were located on the top and bottom of the aircraft for omnidirectional telemetry coverage (Figure 4). Each antenna feeds a separate receiver; the output of each receiver is combined in proportion to its signal strength. The combined output then becomes the single input to one decoder. The decoder processes the uplink data and generates the analog and discrete commands listed in Table 3.

Commands generated by the remote control pilot in the RPV lab are conditioned in redundant control law computers before being encoded and transmitted to the aircraft. Redundant uplink transmission antennas could be selected by the flight engineer at the remote pilot station.

The downlink PCM system used for control system data contained aircraft instrumentation signals that were used not only for display to the remote pilot but also for evaluation of the aircraft flying characteristics. There were two other PCM systems containing research data, which are described later. All PCM systems used transmitters of different frequencies for top and bottom antennas. Diversity combiners at the ground receiving station blended the downlink reception from the top and bottom antennas for omnidirectional telemetry reception. Frequency pairs and power budgets for the telemetry systems are shown in Table 1. Uplink and downlink system characteristics are shown in Table 2.

The diversity techniques for the uplink and downlink telemetry system using top and bottom antennas for omnidirectional radiation coverage are described in Reference 1.

FLIGHT TERMINATION SYSTEM

The profile for the final remotely controlled crash flight (Figure 5) was carefully considered to minimize danger to ground population should the aircraft primary system fail and control of the aircraft be lost. The flight termination system was an independent aircraft radio uplink at 421 MHz to command an intentional crash of the CID aircraft should this occur. The termination system contained several safety features to prevent inadvertent activation such as an interlocking arming sequence and dual-coded command tones. The termination command would have energized appropriate relays to complete sequences such as shutting the engine fuel off, retarding throttles, lowering landing gear, and commanding a pitch-down right turn to the control system.

AIRCRAFT NOSE TELEVISION

Two forward-looking television cameras (a primary color system and a backup black-and-white system) were installed in the nose of the 720 aircraft. These and certain other cockpit displays were presented to the pilot to aid in flying the aircraft and in final guidance to the crash site.

The forward-looking television system featured redundant links to monitors displayed in the ground cockpit. The primary camera had its own transmitter and upper-fuselage-mounted antenna. The color television signal was received at the primary telemetry receiving site and relayed by land line to the remote cockpit. The black-and-white backup camera transmitted on a different frequency from a separate antenna mounted on the lower fuselage. This signal was received on a different telemetry antenna located on the same building that houses the remote cockpit. The resulting television images were presented simultaneously to the pilot in the remote control cockpit. Either television display provided enough out-the-front view to allow the pilot to land the aircraft on a dedicated lakebed runway if the impact mission had to be aborted.

DOWNLINK TELEMETRY SIGNALS

Downlink instrumentation consisted of three PCM systems. Two were dedicated to experimental data and one, referred to under REMOTE CONTROL CONCEPT, was dedicated to control system and aircraft data (Figure 6). Antenna locations for the various radio frequency functions are shown in Figure 7.

Control System Downlink

Data on the control system downlink generally contained information about aircraft systems and flying qualities. Some data were displayed in the remote cockpit for pilot information and partially duplicated indicators in the 720 cockpit (Figure 8). For instance, along with the previously mentioned forward-looking television, the pilot had standard airspeed, altitude, heading, and engine instruments to aid in flying the aircraft. In addition to data displayed for pilot information, other telemetry parameters were used to monitor aircraft system health in the mission control center, which is described later. There, system engineers monitored such things as autopilot inputs and outputs, stability and control behavior, and engine operation.

The fire-retardant antimisting kerosene (AMK) fuel required special in-line degrader units that converted the AMK back into a burnable form that could be used by the aircraft engines. There was a significant amount of instrumentation to monitor the operation and status of the four AMK degraders.

Crashworthiness Data Downlink

Data on the two high-bit-rate PCM systems consisted of several hundred high-frequency accelerometer measurements on the aircraft framework to validate structural deformation models and to analyze new seat restraint designs. Several versions of advanced crashworthy seat designs were instrumented with accelerometers as were anthropomorphic dummies placed in the seats (Figure 9). The interior of the aircraft was photographed by ten high-speed cameras mounted at various viewing angles to provide complete photographic coverage of seat and occupant activity during aircraft impact.

The cameras, as well as the data system recording components, were encased in fire- and penetration-protected containers.

CONDUCT OF THE MISSION

Initial flight testing was accomplished with the 720 aircraft manned not only to verify aircraft modification integrity but also to practice the remote control aspects of the mission. Of particular importance was qualification of the fuel degrader units that restored the AMK to usable fuel for engine operation. In addition, designs for such functions as remotely flying the aircraft through autopilot inputs, or remotely raising and lowering landing gear and flaps, were refined during the flight program. Large parts of the manned flight series were used by the remote pilot to practice the actual mission crash profile (Figure 5). Using the visual television cues and ILS-type guidance displays, approaches were flown over the designated site to verify that the impact scenario was not only feasible, but also within the desired forward speed, vertical velocity, and aircraft attitude limits. Fourteen rehearsal flights were flown, during which, in addition to the above, radio frequency signal strengths for telemetry links and termination functions were verified to be adequate over the mission profile.

The CID flights were area controlled in close coordination with the remote pilot and monitored from one of the mission control centers at Ames-Dryden. Here the test conductor communicated with the test aircraft, the chase aircraft, the remote pilot, and the various disciplinary engineers monitoring data. Radar space-position data were also displayed on geographical plot boards to track the CID aircraft in flight. Data from the aircraft were displayed in various formats in both the main control center (Figure 10) and an additional support room, the Spectral Analysis Facility. Eighteen strip charts were available in these rooms, displaying accelerometer data, system status, engine data, degrader data, and aircraft performance.

Additional engineering-unit information was displayed on one of several cathode ray tube (CRT) formats for real-time monitoring and was listed in postflight data runs for troubleshooting or analysis. Another CRT format to allow real-time monitoring of the CID flight features alphanumeric go or no-go information in color. This display is used principally for discrete alarm or attention-getting information that must be readily noted by personnel observing system status. For CID, the real-time displays showed temperature or overpressure warnings for the fuel degraders, and the battery voltage status of the downlink data system.

CONCLUDING REMARKS

The controlled impact demonstration of a Boeing 720 airplane was successfully completed on December 1, 1984, using a combination of proven and innovative techniques for telemetry and remotely controlled vehicles. The requirements to guide the pilotless test aircraft to the precise impact point and maintain exact flight conditions were met using a telemetry command uplink and telemetry feedback downlink.

The uplink commands to control aircraft attitude, speed, and systems, and to activate the experimental onboard cameras and tape recorders were successful.

The downlink data displayed in the remote cockpit for pilot indications and displayed in the mission control center for system status monitoring worked perfectly. The two forward-looking television cameras in the nose of the aircraft, which assisted the pilot in remotely controlling the aircraft, worked perfectly throughout the flight. The color camera with the upper antenna became unusable only after the impact of the 720 aircraft broke the lens in front of the television camera, distorting the view. The black-and-white camera with the bottom antenna became unusable on initial impact.

Approximately 97 percent of the research data telemetry from the aircraft to the mission control center for real-time monitoring and recording for later evaluation worked throughout the flight and postcrash slide-out. Ten high-speed cameras to record interior movement of dummies, equipment, and panels were turned on by uplink commands, and usable film was recovered from eight cameras. Two cameras jammed shortly after being turned on.

REFERENCE

(1) Harney, Paul F., "Diversity Techniques for Omnidirectional Telemetry Coverage of the HiMAT Research Vehicle," NASA TP-1830, 1981.

NOMENCLATURE

AFFTC	Air Force Flight Test Center
AMK	antimisting kerosene
ATR	Aeronautical Test Range
CID	controlled impact demonstration
FAA	Federal Aviation Administration
IRIG A	InterRange Instrumentation Group time code "A"
ILS	instrument landing system
NASA	National Aeronautics and Space Administration
NRZ	non-return to zero
PCM	pulse code modulation
RIDS	radar information display system
RPV	remotely piloted vehicle
TM	telemetry
TV	television
VHF	very high frequency
XMTR	transmitter

Table 1. Radio Frequency Power Budgets.

Uplink frequency is 1804.5 MHz; L-band downlink frequencies are 1462.5 MHz and 1480.5 MHz; S-band downlink frequencies are 2278.5 MHz, 2242.5 MHz, 2228.5 MHz, and 2207.5 MHz; TV frequencies are 1727 MHz and 4860 MHz.

	Uplink	Downlink		TV	
		L-band	S-band	1727 MHz, secondary	4860 MHz, primary
Power losses —					
Path loss at range of 112 km (70 mi), dB	-139	-137	-140	-137	-147
System losses (estimated), dB	-6	-6	-12	-12	-12
Total losses, dB	-145	-143	-152	-149	-159
Power gains —					
Transmitter power[1], dBm	50	36	36	37	37
Transmitting antenna gain, dB	38	0	0	0	0
Receiving antenna gain, dB	0	31	30	30	42
Gain of preamplifier at receiving antenna, dB	---	25	25	30	50
Total gains, dBm	+88	+92	+91	+97	+129
Signal level at receiver (gains minus losses), dBm	-57	-51	-61	-52	-35
Receiver threshold, dBm	-88	-105	-105	-72	-83
Margin (signal level at receiver minus receiver threshold), dB	+31	+54	+44	+20	+48

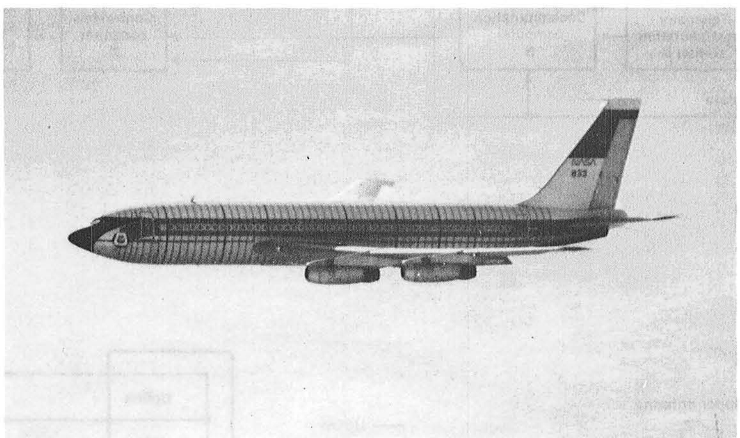
[1]At 100 watts for uplink, 4 watts for L- and S-band downlink, 5 watts for TV.

Table 2. System Characteristics.

Parameter	Uplink	Downlink	
		Control system PCM	Crash data PCM (2 systems)
Bit rate	Fixed 96.768 kbit/sec	160 kbit/sec	1Mbit/sec
Word length	16 bits (10 bits analog, 6 bits discrete)	10 bits	8 bits
Words/frame	Variable 1 to 16	80	129
Frame rate	Variable depending on words/frame	200 per sec	969 per sec
Frames/data cycle	----------------------	10	10
Output	Manchester PCM	NRZ PCM	NRZ PCM
Transmitter frequency	1804.5 MHz	1462.5 MHz 1480.5 MHz	2278.5 MHz 2242.5 MHz 2228.5 MHz 2207.5 MHz
Transmitter deviation	±120 kHz	±80 kHz	±500 kHz
Number of channels	----------------------	160	352 (2 systems)

Table 3. Uplink Commands.

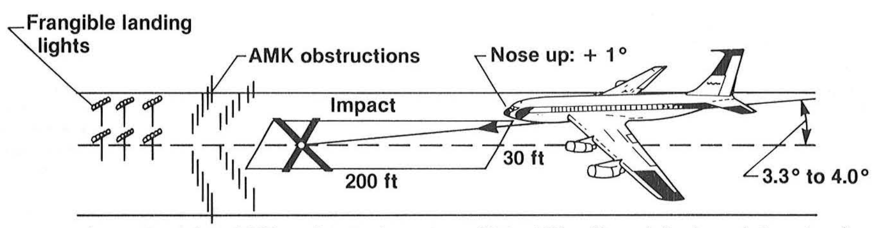
Analog	Discrete
Elevator (1)	Landing gear up/down (3)
Aileron (1)	Engine kill (4)
Rudder (1)	Engine fire extinguish (4)
Throttles (2)	Flaps (3)
Brakes (2)	Throttle select (1)
	Emergency brake (1)
	Nosewheel steering (3)
	Experiment camera/ recorder activation (14)



ECN 31591

Figure 1. Boeing 720 aircraft.

- Representative of a survivable accident
- Crash: air-to-surface; final approach/landing, missed approach, and/or takeoff abort
- Aircraft configuration: landing gear retracted, flaps, spoilers (as required), symmetrical/stabilized
- Sink rate: ~17 FPS
- Logitudinal velocity: ~150 knots
- Glidepath: 3.3° to 4.0°
- Gross weight: ~180,000 lb



Impact goals: AMK – wing tank rupture, 20 to 100 gal/sec (single-point rupture), 4- to 5-sec exposure with positive AMK ignition, slide-out to 100 knots

Crashworthiness – survivable impact, maintain fuselage integrity, vertical impact pulse (1 sec), longitudinal acceleration data

Figure 2. Impact scenario.

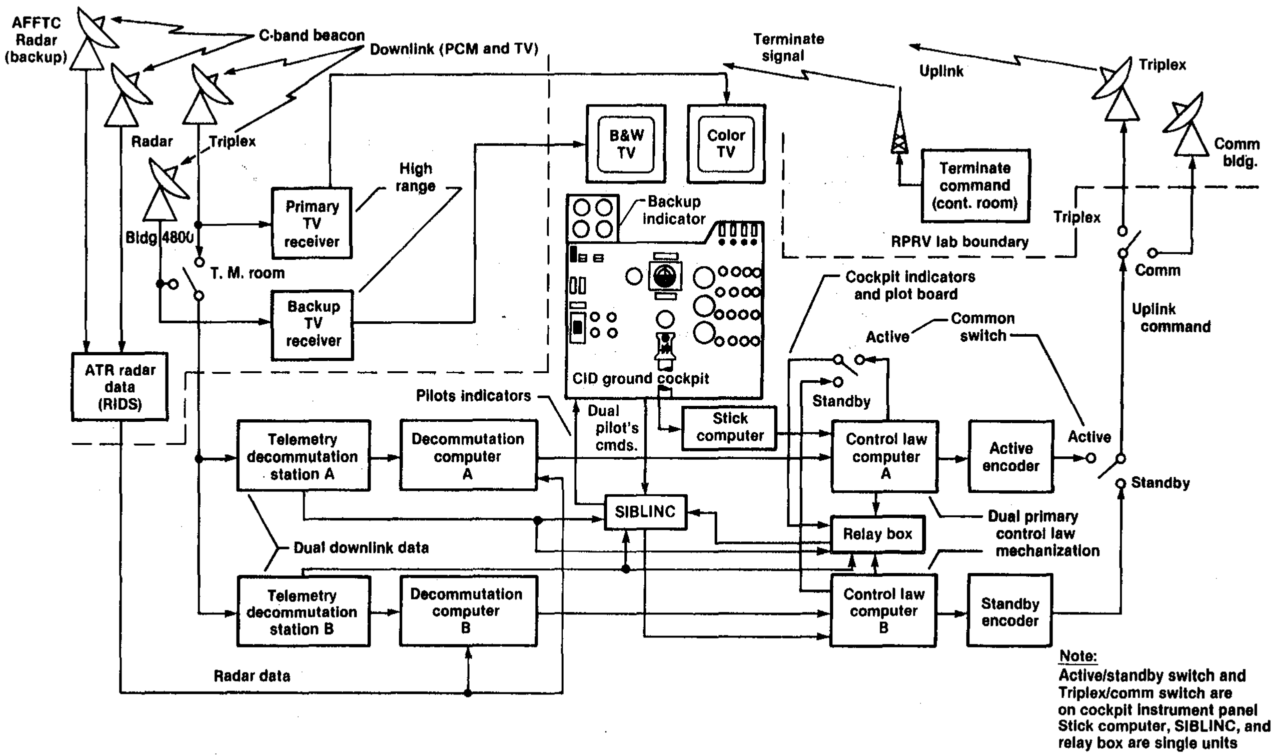


Figure 3. CID ground RPV control system.

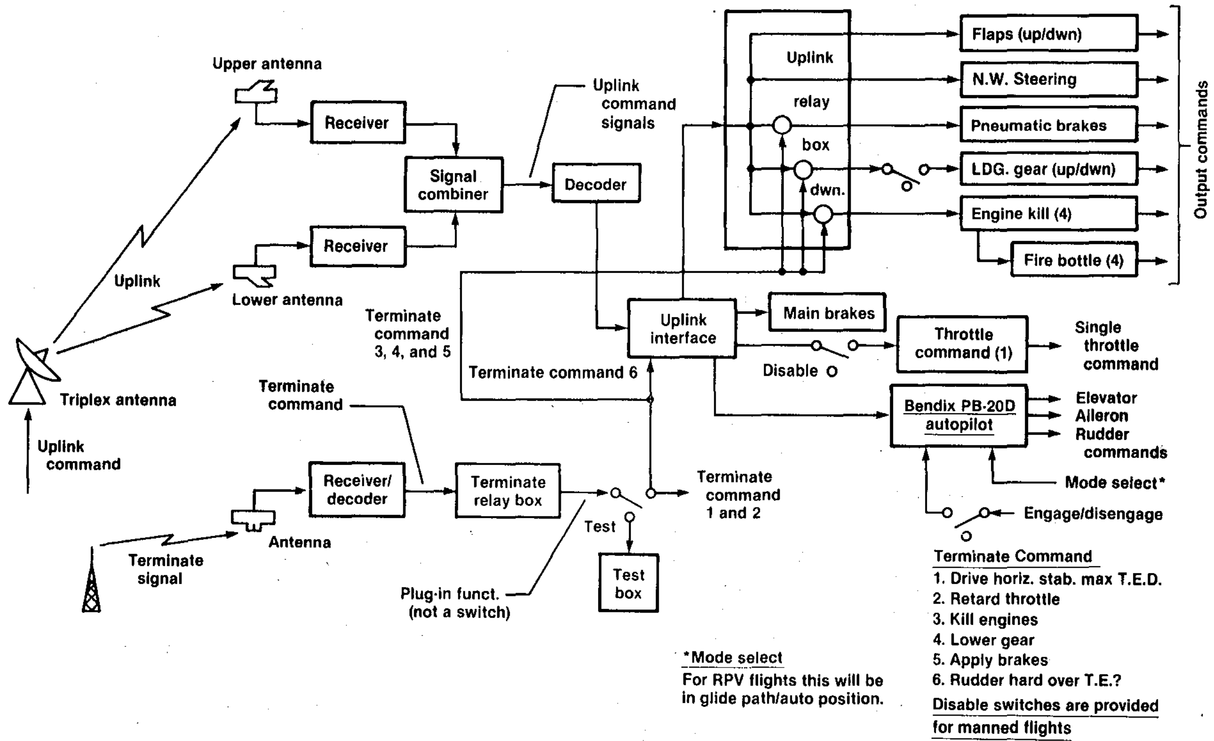


Figure 4. CID airborne RPV control system.

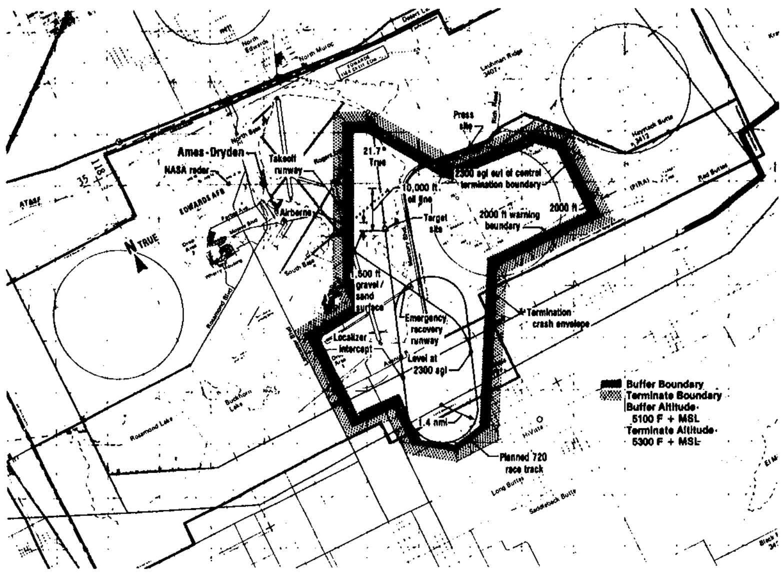


Figure 5. CID impact flight profile.

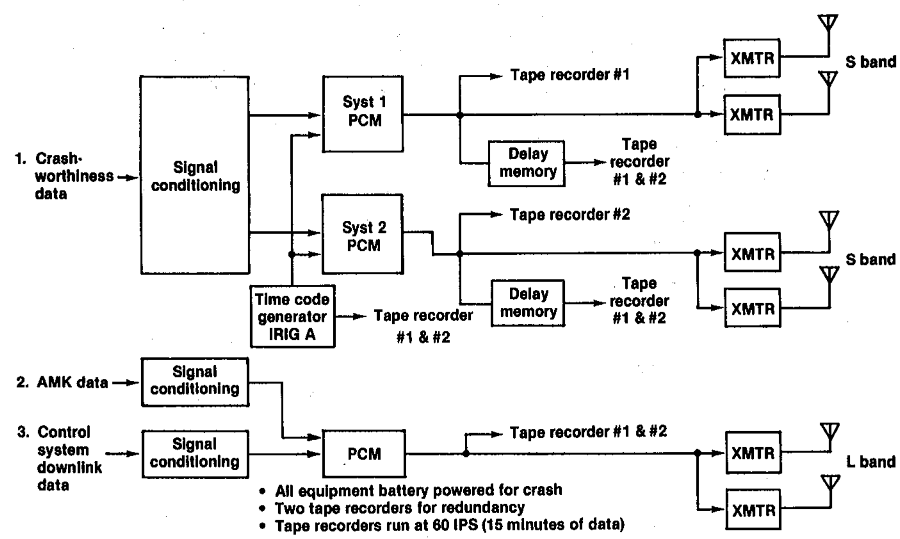


Figure 6. Onboard instrumentation.

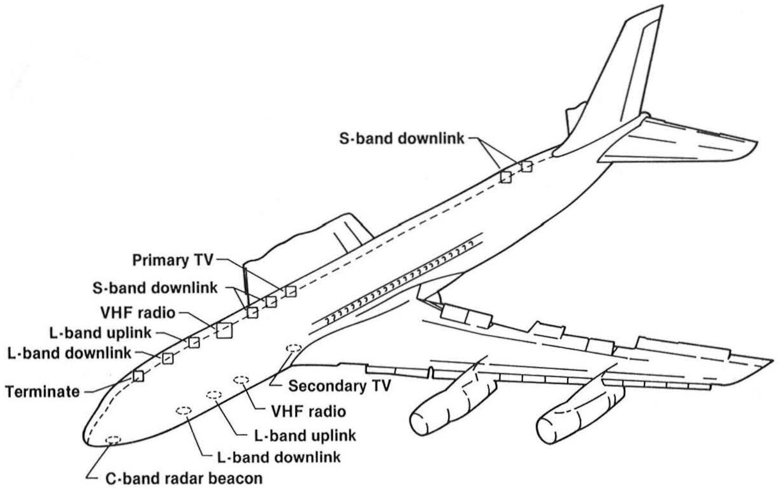
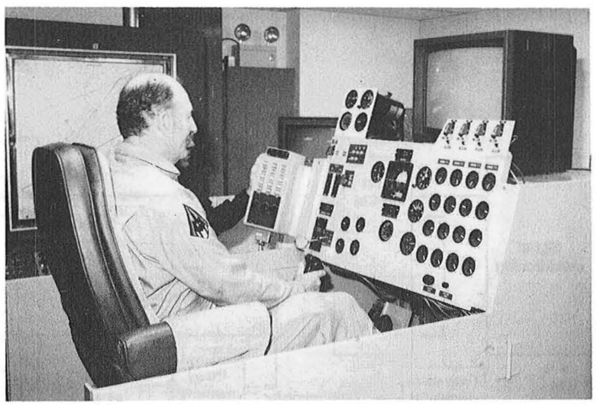


Figure 7. Antenna locations.



ECN 28021

Figure 8. Remote control cockpit.

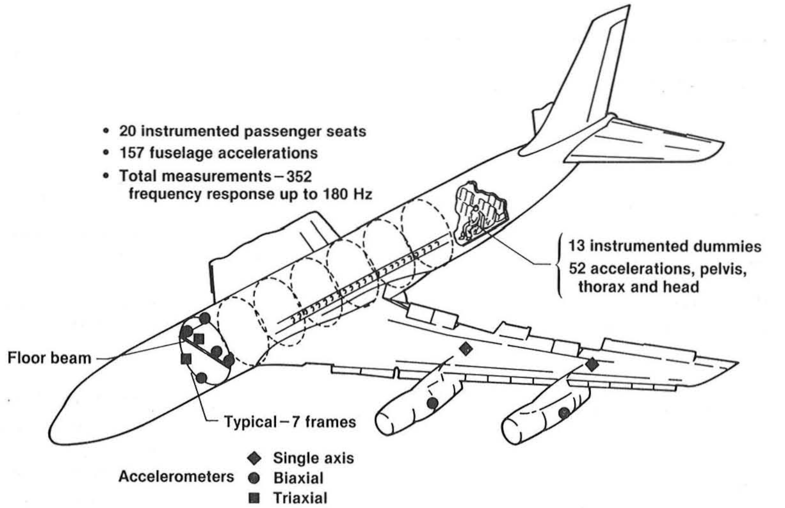


Figure 9. Accelerometer locations.

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Figure 10. Mission control center, blue room.

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15. Supplementary Notes

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16. Abstract

Uplink and downlink telemetry systems were installed in a Boeing 720 aircraft that was remotely flown from Rogers Dry Lake at Edwards Air Force Base and impacted into a designated crash site on the lake bed. The controlled impact demonstration (CID) program was a joint venture by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) to test passenger survivability using antimisting kerosene (AMK) to inhibit postcrash fires, improve passenger seats and restraints, and improve fire-retardant materials.

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