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AEROMECHANICS PREDICTION AND ANALYSIS TECHNIQUES

UNIVERSITY OF FLORIDA

TECHNICAL REPORT AFATL-TR-74-157

SEPTEMBER 1974

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

Aeromechanics Prediction And Analysis Techniques

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FOREWORD

This report was prepared by the University of Florida, Gainesville, Florida under Contract No. F08635-74-C-0039 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Dr. George B. Findley (DLMA) monitored this program for the Armament Laboratory. This test began on November 1, 1973 and was completed on June 30, 1974.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JOHN W. JOHNSON
Deputy Chief, Guided Weapons Division

ABSTRACT

Final results on the development of a precision and automated capability for determining dynamic data for modular aerodynamic configurations (MAC) in free-flight are presented. The system developed includes a modified single engine aircraft with bomb release and various electronic capabilities, a digital telemetry system, a telemetry receiving van with associated receiving and recording elements, and the MAC's with instrumentation devices, soft recovery parachute systems and flight safety equipment. Descriptions are given of drop test of MAC's from the aircraft and of MAC wind tunnel tests.

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INTRODUCTION

The system developed under this contract is a missile air drop test system with precision and automated capabilities for determining missile free-flight dynamic data. The system has the capability to investigate the subsonic regime of scaled models of air-launched vehicles and other aerodynamic shapes. Aerodynamic free-stream missile velocities up to about 550 feet/second and missile weights up to 150 pounds are possible. A soft recovery system for the missile with its precision instrumentation has been developed and tested. All air drops were conducted at Camp Blanding with excellent cooperation from the Army National Guard at that facility.

The research aircraft modifications and capabilities are presented in Section II. The Contractor telemetry receiving vehicle and its operation with the free-flight missile's telemetry system is described in Section III. Section IV contains a description of the missile instrumentation for precision measurement of aerodynamic effects. Important parts of the missile's digital data system are the encoder and decoder. Section V details the design of the efficient precision encoder and decoder subsystems. The test missiles with their safety mechanisms and soft recovery systems are described in Section VI with results of missile tests in a wind tunnel and in free-flight.

SECTION II

RESEARCH AIRCRAFT

1. Aircraft Modifications

A standard Cessna 172 aircraft owned by the contractor has been modified (similar to Figure 1) by the installation of the following:

a. A wing pylon of the type shown in Figure 2 has been mounted on the lower surface of each wing utilizing strong points of the wing structure which were specified by the aircraft manufacturer.

b. A standard shackle assembly of the type USAF MA-4A has been mounted in each wing pylon.

c. A mechanical coaxial cable has been installed in each wing to operate the mechanically activated release lever of the shackle on that wing. The cockpit end of a mechanical release cable terminates in a T-handle located in the upper front corner of the cabin on the same side as the shackle it operates and well within reach of the pilot. (See Figure 3.)

d. An electrical system to control the shackle which is described below and diagrammed in Figure 4.

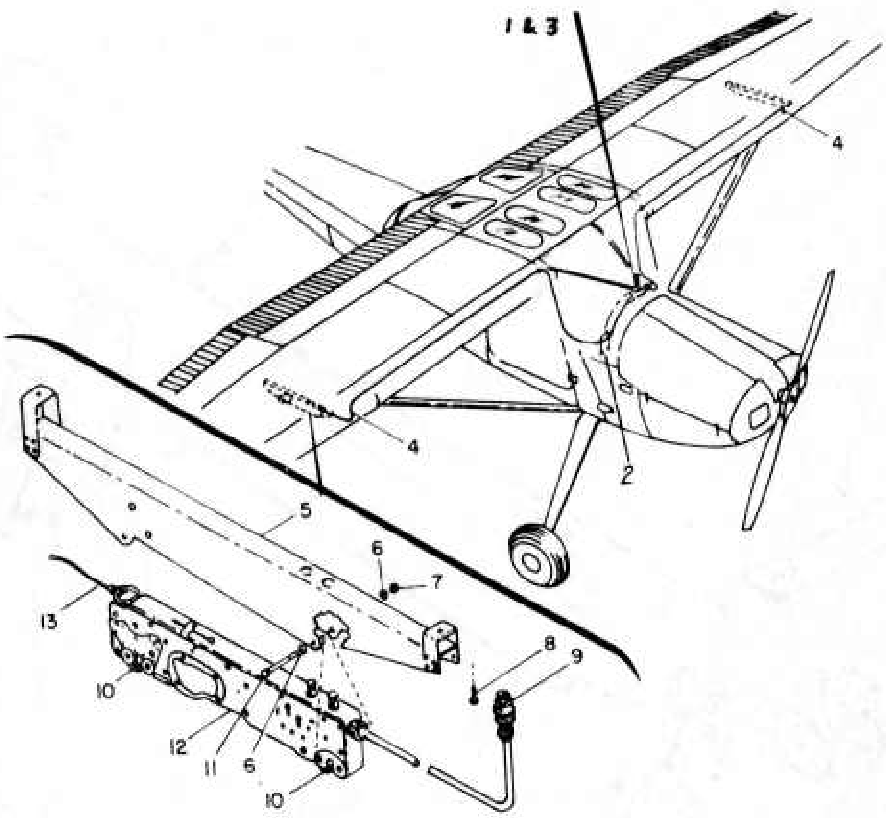
(1) It is completely independent of the original aircraft electrical system.

(2) This two-shackle system is composed of two exactly symmetrical halves: (1) The left wing shackle and its control circuitry and (2) the right wing shackle and its control circuitry. The battery supply, master release switch, and pilot light are common to both halves.

(3) Location of electrical system components

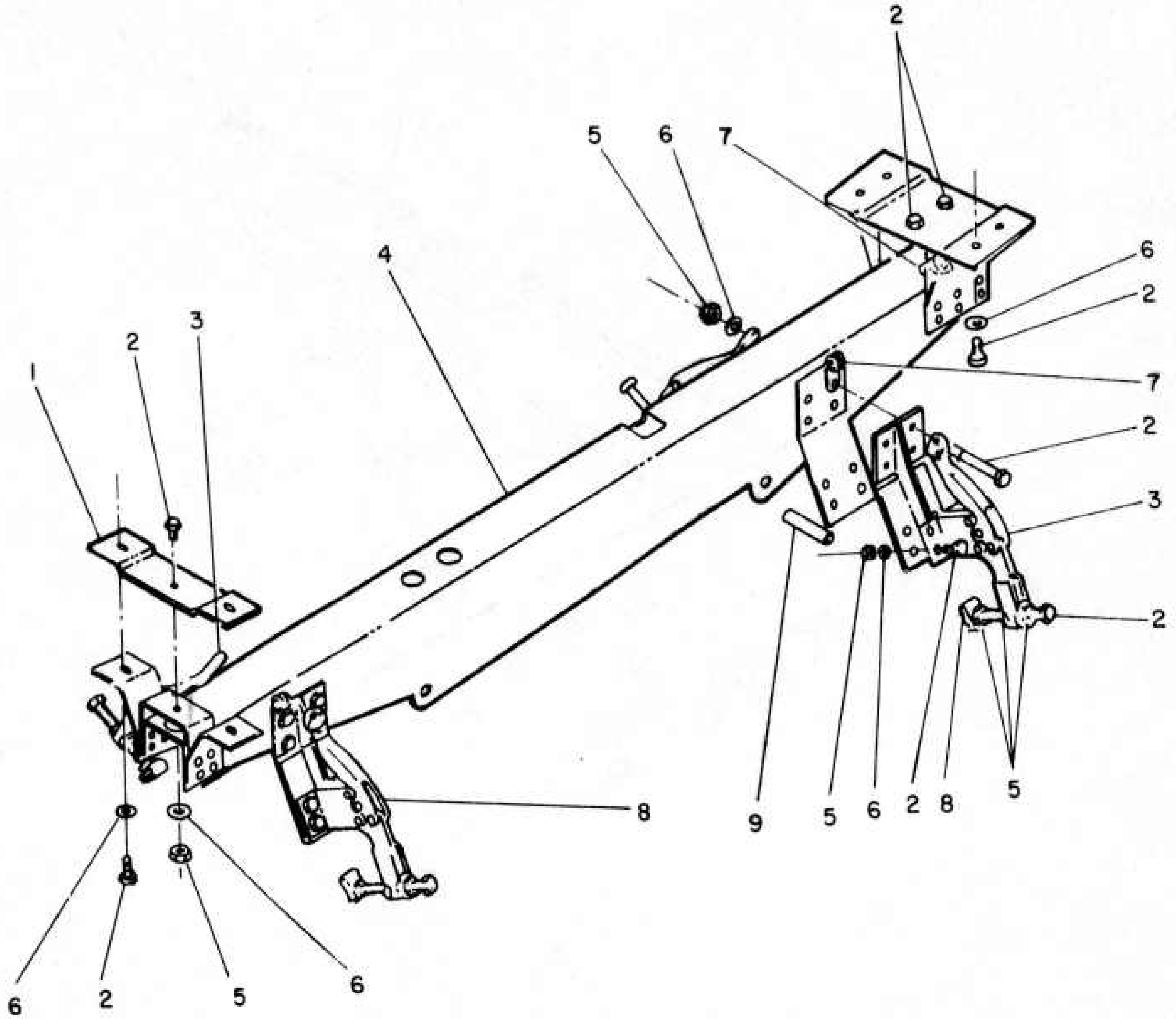
(a) Shackles -- One shackle is mounted on the lower surface of each wing just distal to the point where the strut meets the wing. (See Figures 1 and 5.)

(b) Cable connectors -- One connector (Amphenol type MS3102R-18-1SX) is mounted on the lower surface of each wing just forward of the shackle.



1.	Shackle Switches	8.	Bolt
2.	Terminal Board	9.	Shackle Plug
3.	Master Shackle Switch	10.	Load-Carrying Hooks
4.	Electrical Receptacle	11.	Bolt
5.	Shackle Adapter	12.	Drop-Load Shackle
6.	Washer	13.	Lanyard
7.	Nut		

Figure 1. Two-Shackle Drop-Load System



1. Base Plate
2. Bolt
3. Clamp - Anti-Sway
4. Adapter Assembly
5. Nut
6. Washer
7. Clamp
8. Adapter
9. Spacer

Figure 2. Wing Pylon

Figure 3. Mechanical Shackle Release Handle

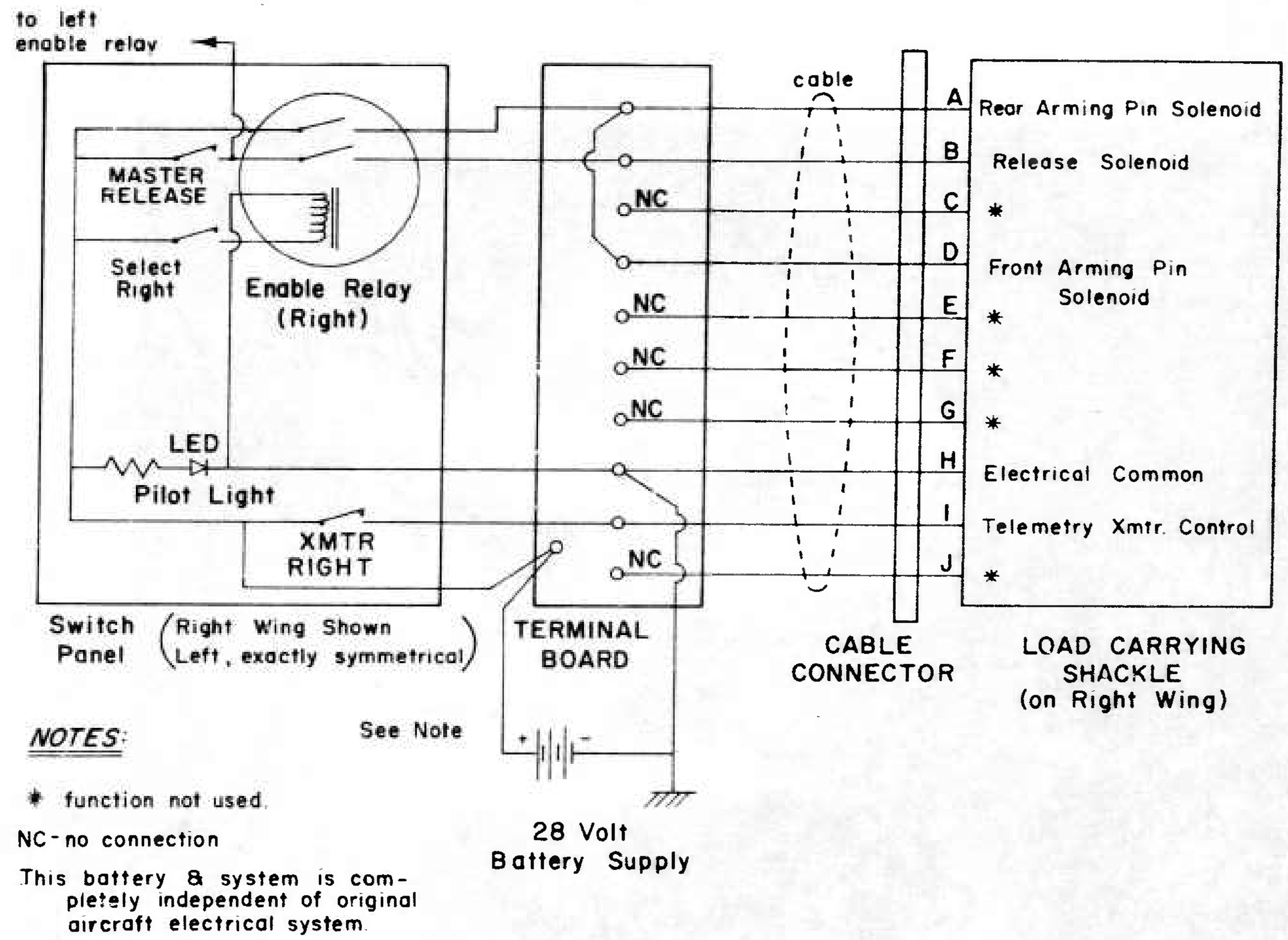


Figure 4. Electrical System for Shackle Control

(c) Cable -- In each wing the cable is routed from the connector through the existing wire way inside the leading edge of the wing and into the cabin, down the door post with existing wires, in the cabin wall below the window (still with existing wires) to the rear surface of the instrument panel where it follows a main wire bundle until it terminates on the terminal board.

(d) Terminal Board -- The terminal board is mounted in the instrument panel on the copilot's side above the map box. It is not visible from the cabin when the plastic instrument panel cover is in place. (See Figure 6.)

(e) Switch Panel -- This panel is clearly visible in the center of the instrument panel below the radio and transponder. (See Figures 4 and 7.)

(f) 28-Volt Battery Supply -- This unit is contained in a metal case 8.5 x 11.5 x 5 inches which will be strapped down in the luggage compartment of the plane just behind the rear seat. (See Figure 8.)

e. A mechanical cable to pull the aircraft door hinge pins and permit the pilot to bail out if an extreme emergency should occur. This cable terminates at a D-ring on the front door post. (See Figure 11.)

2. <u>Operating Procedure for the Load Carrying Shackle System</u>

a. Load the shackle -- The shackle can only be cocked mechanically. Position a projectile or pod under the shackle with its lugs ready for the shackle's hooks. Pull the cocking linkage handle at the rear of the shackle and the hooks will close. (See Figures 9 and 10.)

b. Connect the 28-Volt battery supply -- Strap the battery supply case down in the luggage compartment and plug in the polarized 3-prong connector of the white cable (which is clamped to the leg of the rear seat) to the only socket on the battery supply box. The red pilot light on the switch panel should now glow. Check that all switch panel switches are off.

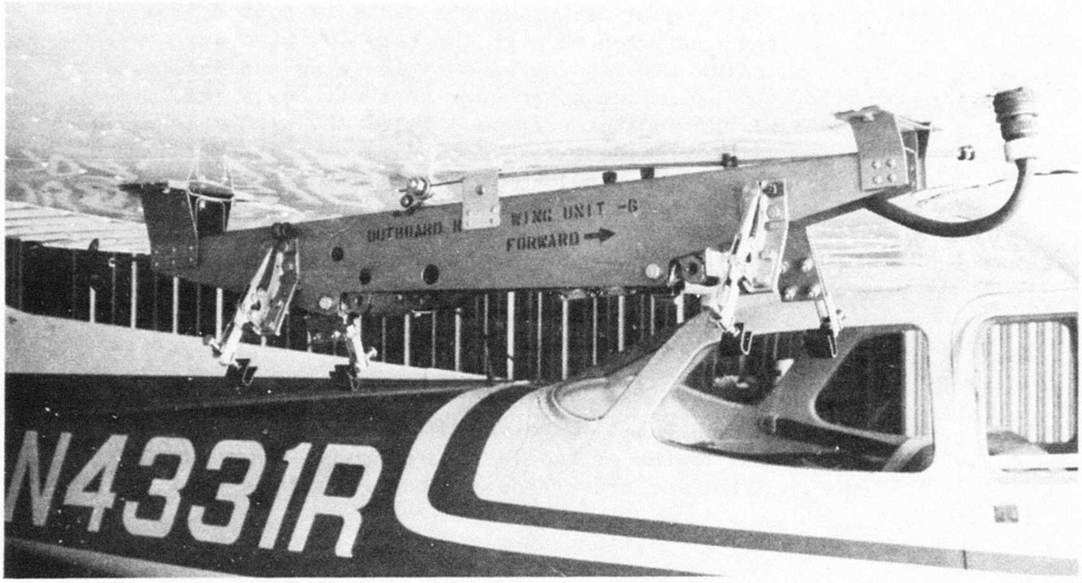


Figure 5. One of Two Installed Wing Pylons with Shackles

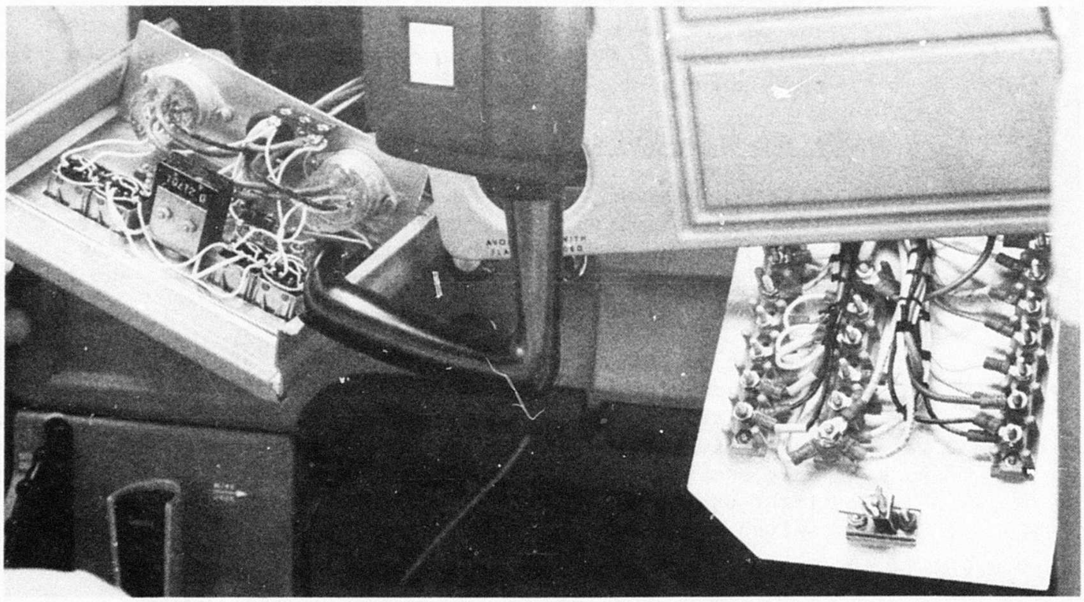


Figure 6. Switch Panel and Terminal Board Opened from Aircraft Instrument Panel

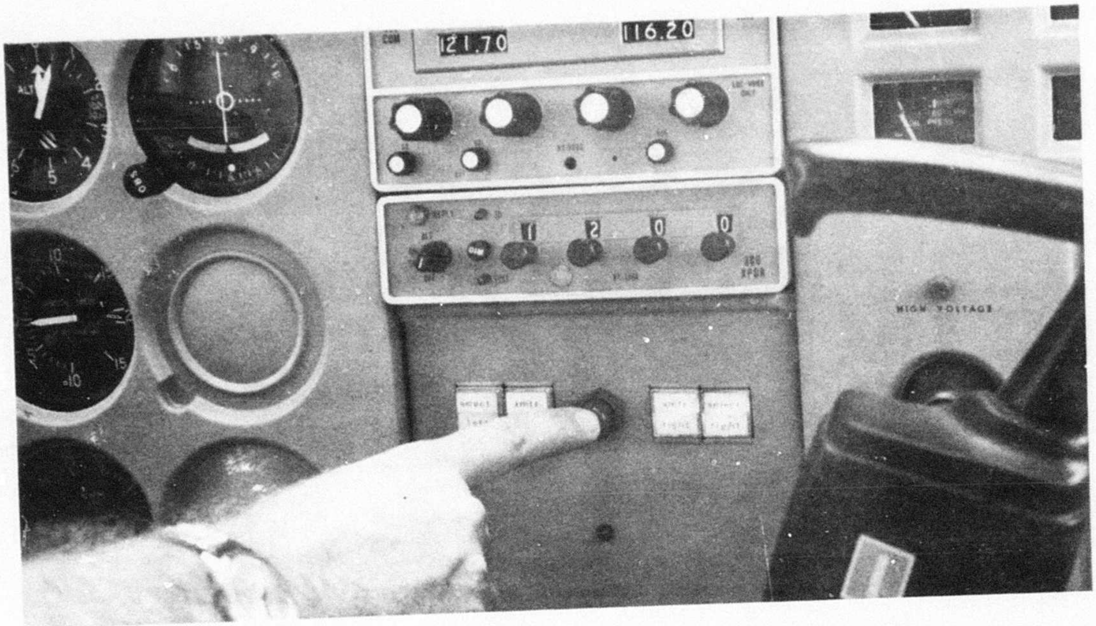


Figure 7. Switch Panel Front View

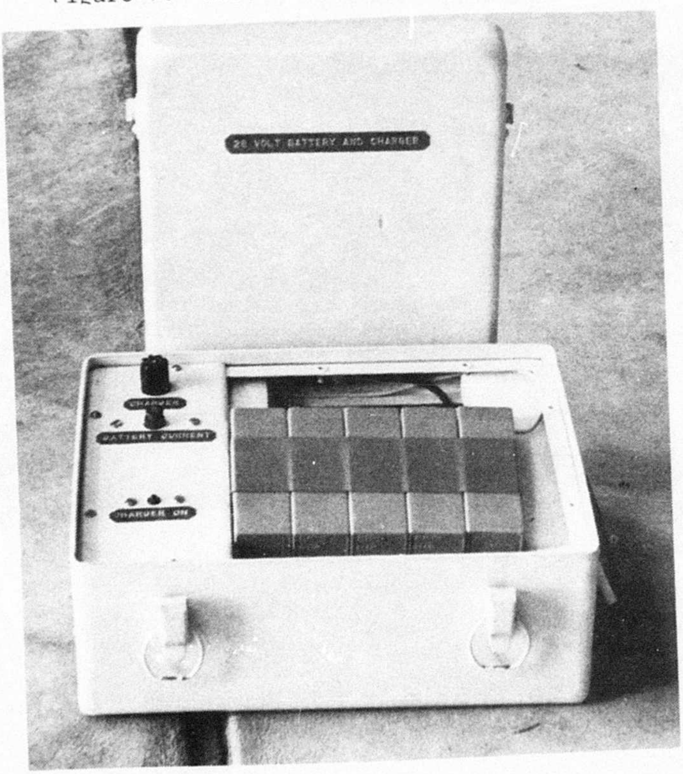


Figure 8. The 28-Volt Battery Package

Figure 9. Shackle Cocking Procedure

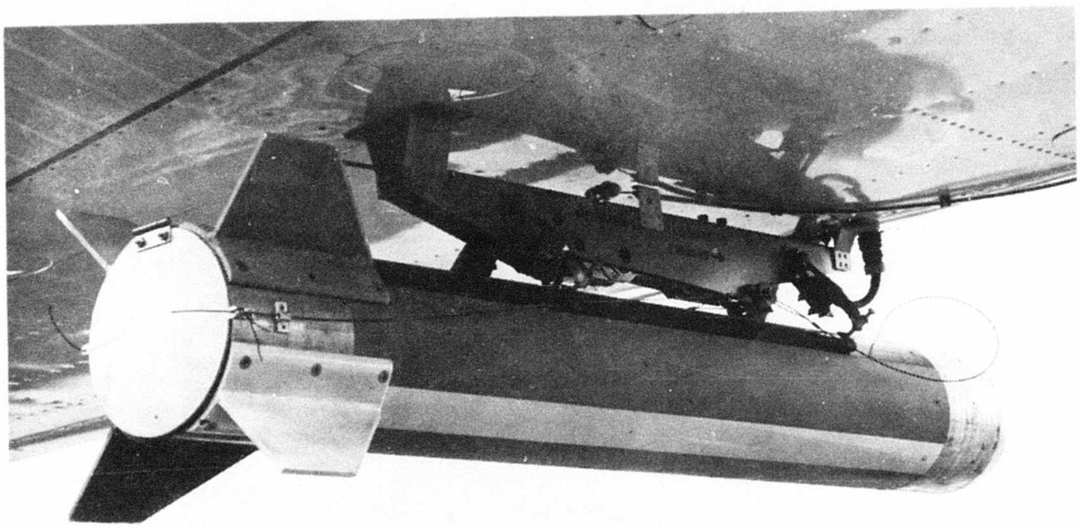


Figure 10. MAC Projectile Mounted On The Aircraft

c. Fly the airplane to the desired drop zone.

d. Activate telemetry transmitter -- To activate the instrumentation and telemetry system in a projectile, press the appropriate push button switch -- either XMTR LEFT or XMTR RIGHT. (Refer to Figure 7.)

e. Enable release -- While on the approach to the desired release point, press the appropriate select switch -- either SELECT LEFT or SELECT RIGHT.

f. Release -- At the desired release point press the MASTER RELEASE switch.

g. Clear the switch panel -- After release, turn off the XMTR and SELECT switches.

3. Emergency Procedure

If, while flying, it is necessary to release a projectile and the electrical system fails, a purely mechanical release system can be operated by pulling the chrome T-handle found in the upper front corner of the cabin where the leading edge of the wing meets the canopy (Figure 3). The left shackle is linked to the T-handle on the left side of the cabin, and the right shackle is linked to the right handle.

In case of an extreme emergency, the emergency door release is accomplished by (1) opening the door latch and then (2) pulling the D-ring on the front door post. (See Figure 11.) This makes it possible for the pilot to bail out. Each cabin door is equipped in this manner.

4. Capabilities of Research Aircraft

a. Loading

1. Any load to be carried using the wing shackles must be sufficiently aerodynamically shaped that it does not create excessive or unnecessary drag and must be designed to be stabilized by the pylon.

2. A weight limit of 150 pounds per shackle load is maintained to assure that weight and balance recommendations for the aircraft are not exceeded.

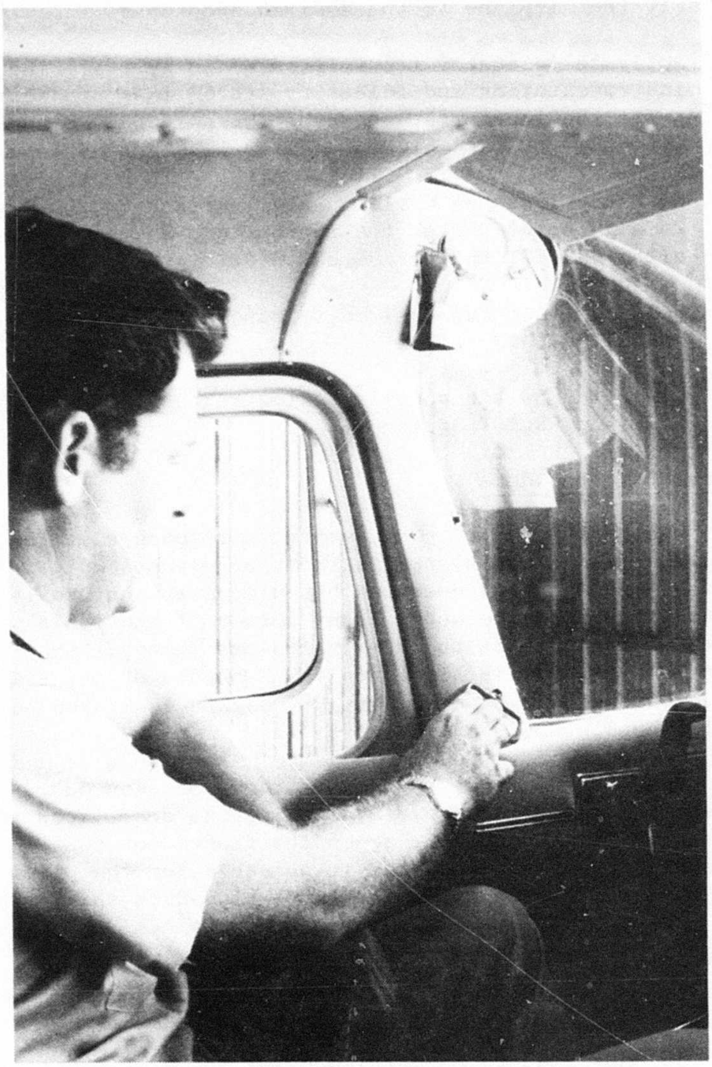


Figure 11. Emergency Door Release D-Handle

b. Flexibility of the electrical system -- The 10 lead electrical cables which terminate in a connector just forward from the pylon and shackle assembly on each wing are, at the other ends, brought to a terminal board in the aircraft cabin. Since mechanical systems to latch and release the shackles are functional in this installation, all 10 leads of each cable can be utilized to transmit power, control signals, and data signals to and from packages being carried by the shackles. Thus, this aircraft is equipped for collecting in-flight data from instrument packages carried under the wings and for flight testing of new or modified instruments.

c. This aircraft installation has been inspected and accepted by the Federal Aviation Agency (FAA).

SECTION III

TELEMETRY RECEIVING AND TRANSPORT TRUCK

1. Introduction - Structural Description of the Vehicle

A 1968 Ford truck shown in Figure 12 has been converted into a mobile telemetry receiving unit (MTRU). The box of this truck is aluminum and measures 12 feet long by 7 feet high. It has been fitted with two windows for ventilation, insulation, wall paneling, ceiling paneling, and a vinyl floor covering. Illustrated in the drawings of Figure 13, the telemetry receiving instruments are individually shock-mounted in a two-rack assembly at the front end of the box. The rear half of the box is reserved for transporting the MAC projectiles in their carrying racks, the receiving antenna and its tripod, and the portable electric power generator.

2. Operation of the Mobile Telemetry Receiving Unit (MTRU)

To execute an experimental drop of MAC projectiles, the projectiles are transported in the MTRU truck from the University of Florida in Gainesville, Florida, to the airport at Keystone Heights, Florida, where they are loaded onto the load-carrying shackles of the research aircraft. The MTRU is then driven to the edge of the drop zone inside Camp Blanding (east of Starke, Florida) and readied for operation by setting up the portable power generator on the ground to the right side of the truck and the receiving antenna with its tripod on the ground to the left of the truck. Next the generator is turned on, and basic operation of the instrumentation is checked. When the research aircraft appears over the drop zone at approximately 10,000 feet altitude, (1) the pilot turns on the telemetry transmitting system in one of the MACs, (2) one of the ground personnel begins manually tracking the aircraft with the receiving antenna, and (3) another of the ground personnel fine tunes the receiver and verifies the copy. At this point, the ground crew signals the pilot to drop one MAC on his next pass over the drop zone. (Two-way VHF air-ground communication is useful here but is not yet available.) As the aircraft approaches the drop zone, the digital tape recorder is activated and records data from the flight of the MAC. As soon as the MAC is down, the recorder is deactivated. The drop of the second MAC is similar to that of the first from the point of view of the MTRU. When both MACs are down, they are recovered from the drop zone using a suitable off-road vehicle and driver from Camp Blanding and loaded into the MTRU truck for the return trip to the University of Florida in Gainesville.

3. Free-Flight Missile Telemetry System

A telemetry system has been developed to transmit data from

Figure 12. MTRU Truck Beside the Research Aircraft

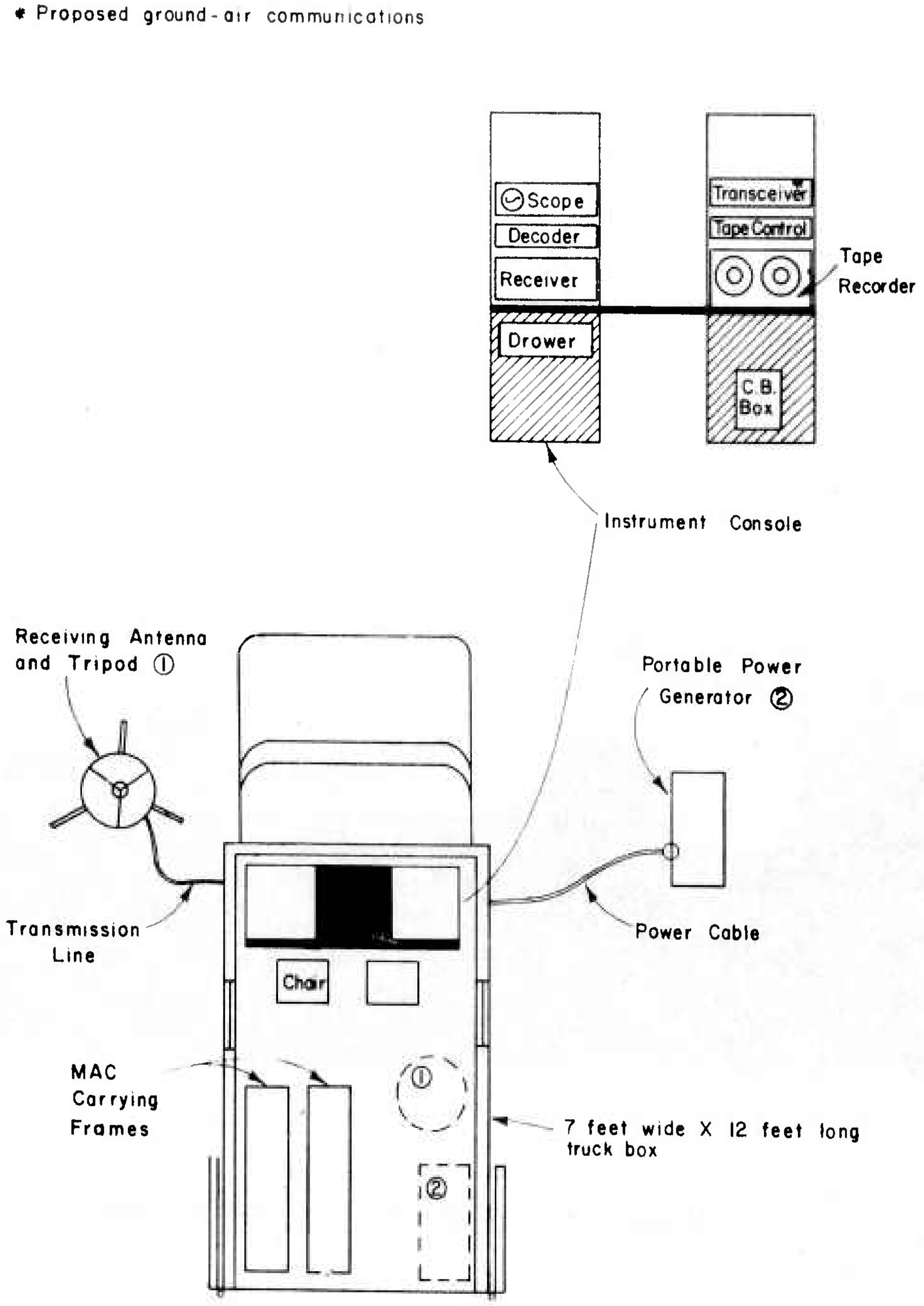


Figure 13. Mobile Telemetry Receiving Unit Layout

physical sensors inside the MAC projectile to a mobile telemetry receiving unit on the ground while the MAC is in free flight. This system uses PCM-FM on a carrier of 1448.5 MHz and is designed to transmit up to ten 8-bit data words and one 8-bit frame synchronization word per frame at word rates up to 4,440 words/second (approximately 40,000 bits/second). The details of encoding and decoding data within the system are given in the next section of this report. Figure 14 presents a block diagram of the complete system.

The transmitting portion of the system consists of (1) physical sensors, (2) an encoder unit, (3) an FM telemetry transmitter, (4) a pair of transmitting antennas, and (5) the power supply.

The physical sensors which can be used include accelerometers, velocimeters, pressure transducers, an electrostatic field sensor, and attitude measurement systems. At present, a ±50 G 3-axis accelerometer, a Miniature Inertial Digital Attitude System (MIDAS), six ±12 G accelerometers, and three 200 radians/second^2 angular accelerometers are available.

Functions performed by the encoder include providing the digital system clock, multiplexing of sensor outputs, Analog/Digital conversion where necessary, word and frame control, synchronization pulse writing, frame synchronization word writing, and premodulation filtering. The encoder output is a modulating signal which can be applied directly to the modulation input of the FM telemetry transmitter.

The transmitters used are standard 2- and 5-watt units packaged in rugged 10- to 30-cubic-inch housings and approved by the Joint Frequency Panel. For this project a fixed carrier frequency of 1448.5 MHz is used, and the signal bandwidth is well within a 1-MHz-wide channel. In addition, IRIG Telemetry Standards applicable to transmissions in this channel are observed.

The transmitting antennas are a pair of flush-mounted L-band antennas which are shaped to fit the 8-inch diameter of the MAC body and are located 180 degrees apart on the MAC body to provide a good radiation pattern for the transmitted signal. A power divider unit is used to properly distribute the RF energy to the antennas.

Power is supplied to this system by a 28-volt rechargeable, spill-proof battery package. This 28-volts is used directly, and also converter and voltage regulator circuits produce +5, -15, and +15 volt d.c. from this basic source. To avoid unnecessary RF transmission and power drain from the battery package, power in the MAC is switched on and off by an electrical signal from a switch on the pilot's control panel. This signal is applied to the MAC through a contact on the case which mates with a contact on a modified pylon stabilizer foot. Upon release of the MAC from the shackle, this contact pair opens without exerting any significant force on the MAC and the power is latched on.

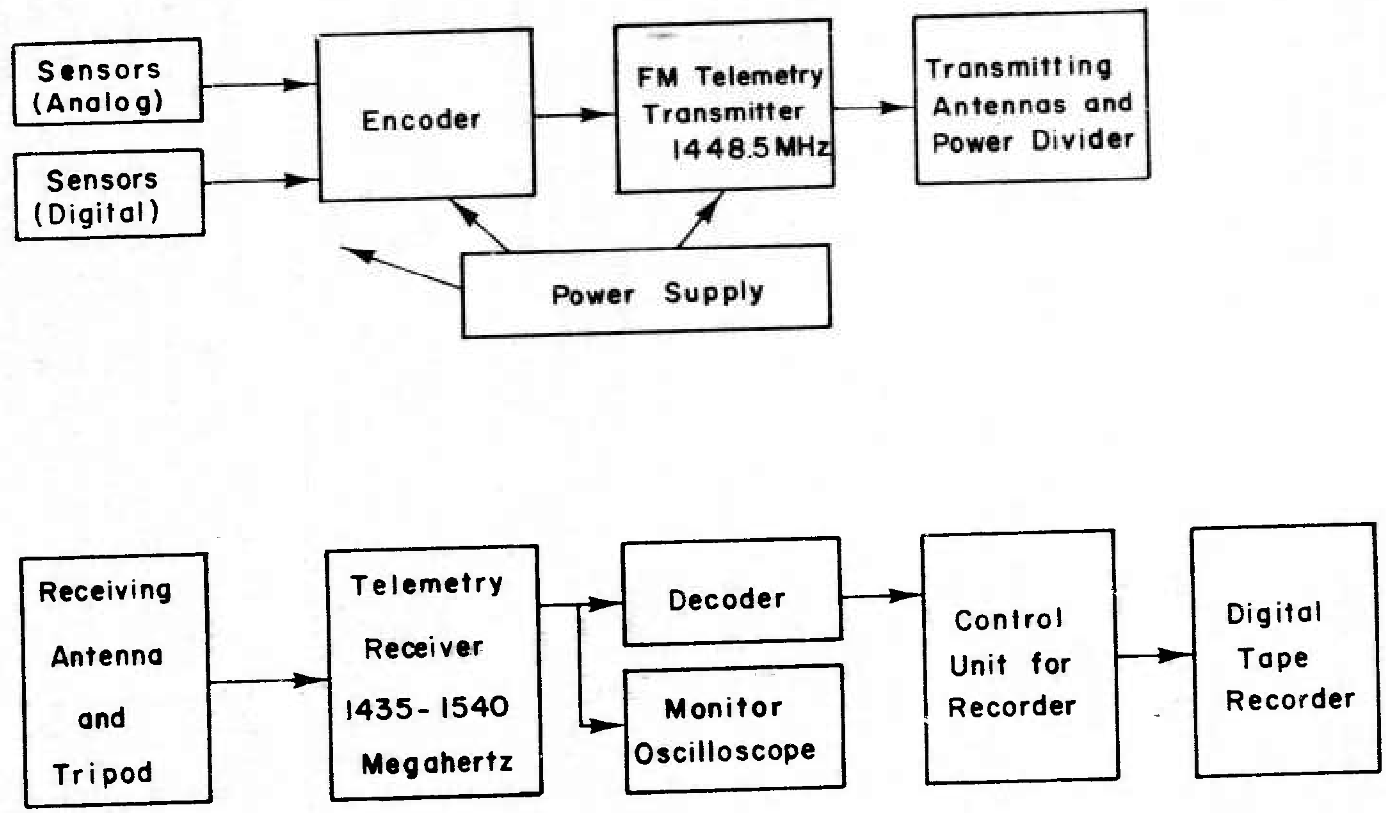


Figure 14. Diagram of Telemetry System for MAC Flight Data

4. Missile Data Receiving System

The receiving portion of the system consists of (1) a parabolic dish antenna which feeds RF signal through a short length of low loss transmission line to (2) an L-band telemetry receiver from which the video output signal feeds both (3) a monitor oscilloscope and (4) the decoder unit which provides parallel binary 8-digit words by way of (5) the format and control unit to (6) the digital tape recorder.

The receiving antenna is a 2-foot-diameter parabolic dish with dual linear polarization. It has a maximum beam width (-3 db) of 25 degrees and a minimum gain of 15 db. It is mounted on a tripod and used with a low power optical sighting scope to manually track the MAC projectile during its flight.

The L-band telemetry receiving unit tunes the range 1435 to 1540 MHz. It has a 1-MHz 2nd IF bandwidth and an FM discriminator which is linear for signals up to 1-MHz bandwidth. It is of modern design and contains automatic frequency control search and lock capability.

The monitor oscilloscope is a portable, solid-state, single channel scope which is used to view the video output of the receiver and determine that the amplitude, d.c. level, and wave shape are acceptable for decoding.

The functions accomplished in the decoding unit include recognition of synchronization bits, synchronization of the decoder clock with the encoder clock, recognition of frame synchronization words, and serial-to-parallel conversion of the 8-bit data words. The decoder is capable of recovering synchronization very quickly if it is lost.

The format and control unit for the digital tape recorder produces the necessary write select, write data strobe, end of record command, and end of file command signals to coordinate the flow of data words from the decoder to the magnetic tape. It also provides the means by which the above signals are inhibited when one of the several control signals from the tape recorder indicates that it is not ready to receive data.

The digital tape recorder is a 9-track, 800 bits/inch, 15 ips machine. It contains buffer memory to enable recording of high speed data up to 250,000 8-bit words/second and the necessary electronics for parity generation, check character generation, and gap length control are within this recorder. The tapes produced are IBM compatible.

SECTION IV

INSTRUMENTATION FOR PRECISION MEASUREMENTS

1. Inertial Devices and Carco Test

The array of precision inertial instruments selected for use in various combinations in missile free-flight test is:

a. Three Systron-Donner angular accelerometers (Model No. 4591) with ranges of ± 200 rad/sec^2, natural frequency of at least 180 Hz and nonlinearity with hysteresis of less than 0.05 percent of full range (twice full scale).

b. Six Honeywell miniature linear accelerometers (Model No. GG326G1) with a range of ± 12G's, natural frequency in excess of 100 Hz and nonlinearity of less than 0.25% of full scale.

c. One Bell and Howell, 3-axis linear accelerometer system with a range of ± 50G's and nonlinearity with hysteresis of less than 0.08% of full range.

d. A Miniature Inertial Digital Attitude System (MIDAS) built by Space Vector Corporation with drift rate of less than 0.4 degree/minute, maximum roll rate of 15 revolutions/second, 360 degrees of angular freedom in Roll and Pitch and 85 degrees of freedom in yaw.

The Systron-Donner angular accelerometers were tested on a variable angular rate, rate table at the Guidance and Control Laboratory of the U. S. Army Missile Systems Research and Development Engineering Laboratory in Huntsville, Alabama. These devices were found to exceed the performance specifications given above.

The three-gimbal, three-axis simulator (Figure 15) called a Carco table has been installed in the contractor's Engineering Dynamics and Vibration Laboratory and used for testing full-up inertial instrument packages. These tests are made just prior to installation in the missiles to be used in free-flight test. Figure 16 is a photograph of the Carco table with the three angular accelerometers mounted on the inner gimbal. A strip chart recorder is used for recording

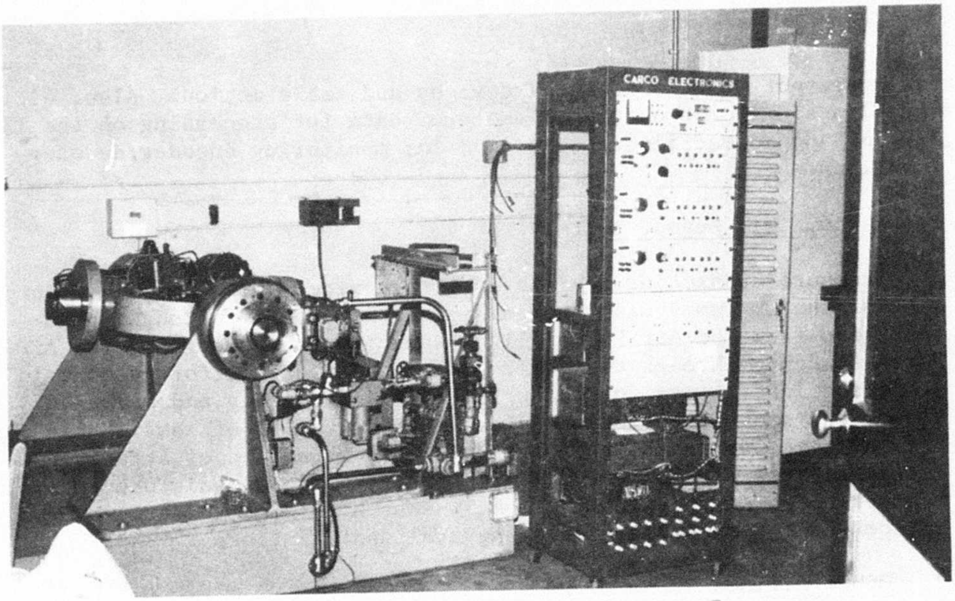


Figure 15. Carco 3-Axis Simulator System

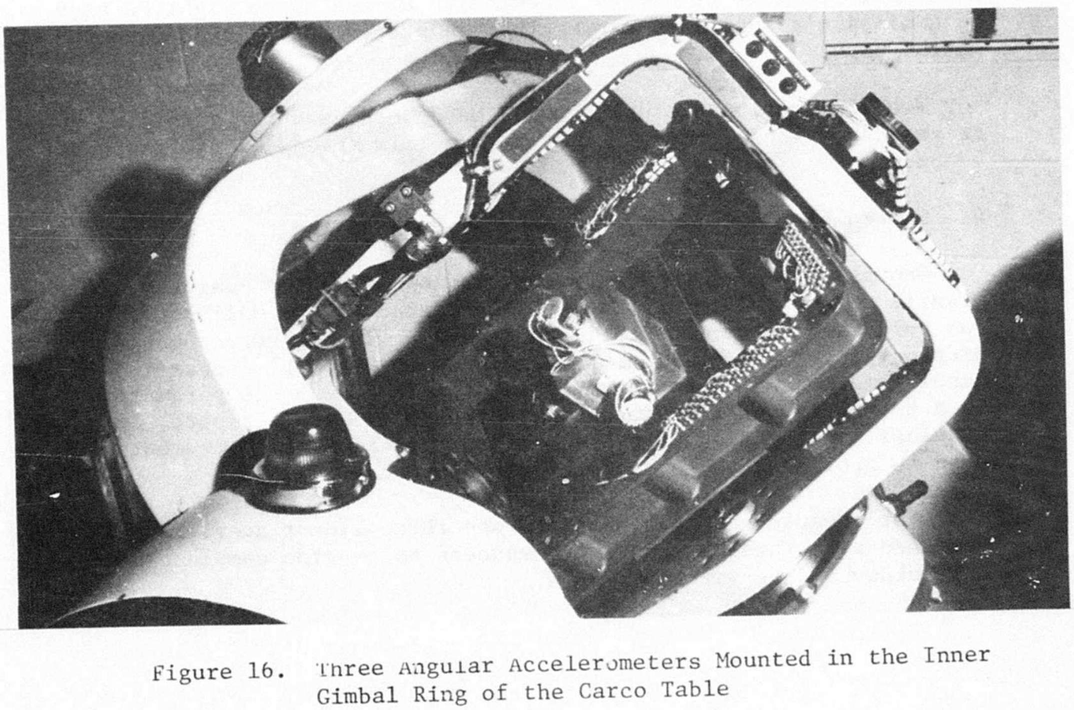


Figure 16. Three Angular Accelerometers Mounted in the Inner Gimbal Ring of the Carco Table

analog outputs of the inertial devices and table motion. Also, digital recordings are made of the telemetered data for processing on the IBM 370/165 and an oscilloscope is used for monitoring encoder/decoder functions.

2. Aerodynamic Measurements

Pressure transducer devices interface nicely with the other components of the system. Close coordination has been effected with researchers from the Air Force Flight Dynamics Laboratory and the Air Force Academy, through the AFATL program monitor's effort to obtain precision instruments for measuring missile velocity and angles of attack and sideslip. These devices must be small, of low inertia for precision measurements, and work well at high angles of attack. Existing devices are not adequate for precise aeromechanic prediction measurements, so that considerable research efforts to develop new devices have been proceeding at several installations.

3. Other Devices

A dual probe electrostatic field sensor with its differential amplifier signal processor has been developed. This probe, when mounted correctly on the missile, can give roll or pitch information and rate information. This is a very inexpensive device which might be used in a missile's autopilot rather than in precision attitude measurements.

Two 16mm motion picture cameras have been used for recording qualitative data. These cameras have maximum film speeds of 64 frames per second.

4. Instrument Groups for Aeromechanic Predictions

Groups of the above instrumentation are used for measurements of missile motion and environment. These data must be well structured (as well as precise) for optimal processing in the aeromechanic prediction programs. Previous reports such as Bullock[1] describe processing methods for accurately predicting aeromechanic parameters. In a University of Florida master's thesis and AFATL report, Solomon[2] develops a methodology for the optimal selection of instrument groups used to provide data to the prediction processor.

For example, a midas platform and three linear accelerometers are used with three pressure transducers to provide complete motion and aerodynamic environment data.

SECTION V.

ENCODER/DECODER

1. General Description and Purpose

The complete Data Link System is to be used to transmit, by means of a radio signal, data from a number of sensors on board a free-falling projectile to a ground receiving station where the data will be signal processed and recorded on a digital tape recorder for later computer analysis.

The signal or data sources are various sensors (such as roll rate, acceleration, position, etc.) on the projectile. Upon release of the projectile from the carrying aircraft, data from these sensors will be transmitted continuously as the projectile falls.

In keeping with the current state of the art and to eliminate interference and drift-induced loss of data signals, the sensor analog outputs are converted to binary coded digital information and transmitted serially from the on-board transmitter system of the projectile.

At the fixed ground receiving station, the signals are received by a commercial telemetry receiver and then reconstructed to produce digital data for recording on a standard IBM compatible tape for later use in the computer analysis.

2. Block Diagram System Description

Refer to the block diagrams in Figures 17 and 19 (Encoder and Decoder) as well as Figure 19 (the waveshapes drawing). In the description that follows, numbers in parenthesis, for example (23, refer to circuit lines in the block diagrams, and references to the waveforms are indicated as W-1, etc.)

A. Transmitter

As many as 16 analog output sensors may be used with this system, although it was initially set up to use only 10 inputs or channels of sensor data. These analog signals are fed into the Data Acquisition Module (DAM). In the DAM, the 10 used inputs are sequentially scanned at a rate of just under

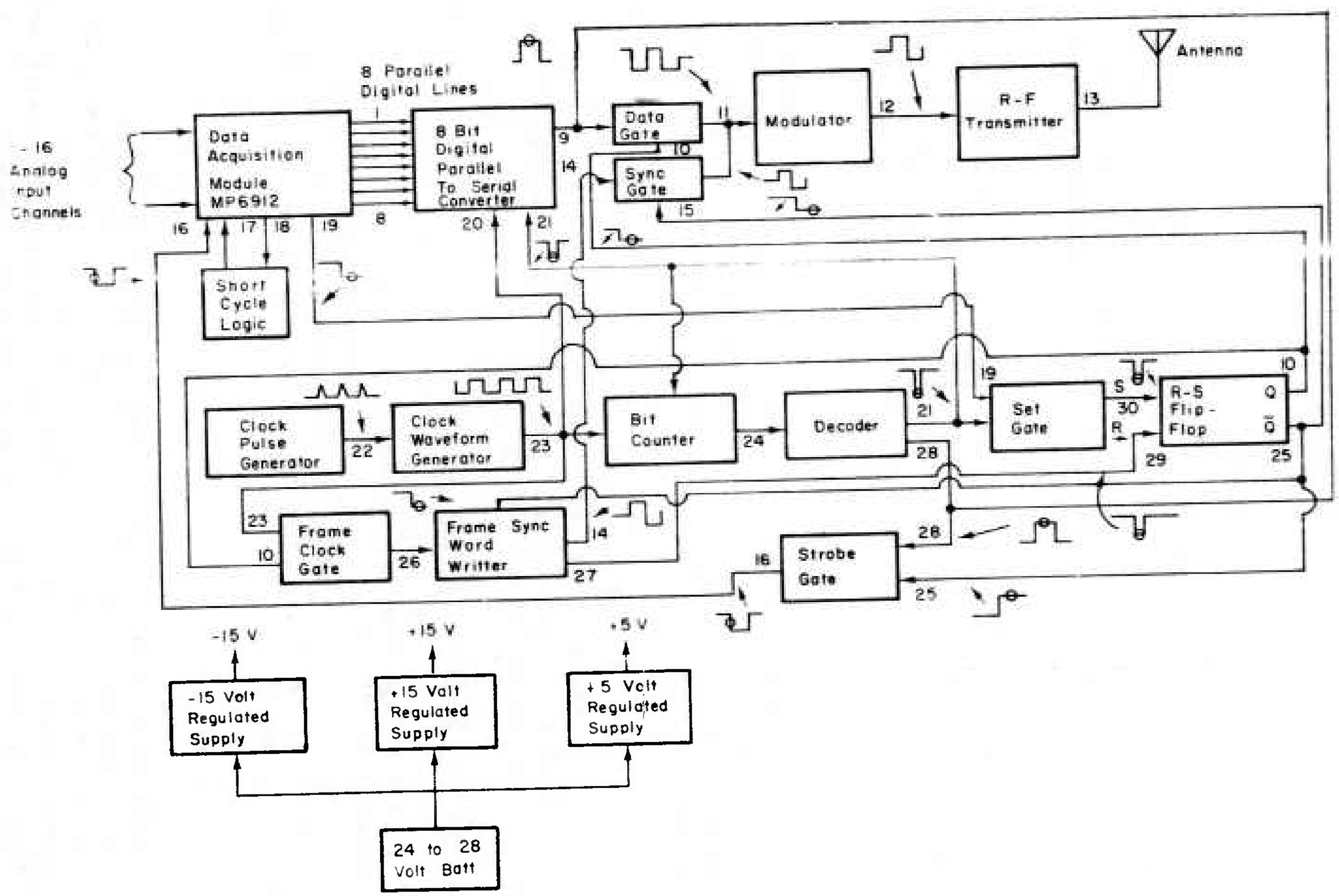


Figure 17. Encoder Block Diagram

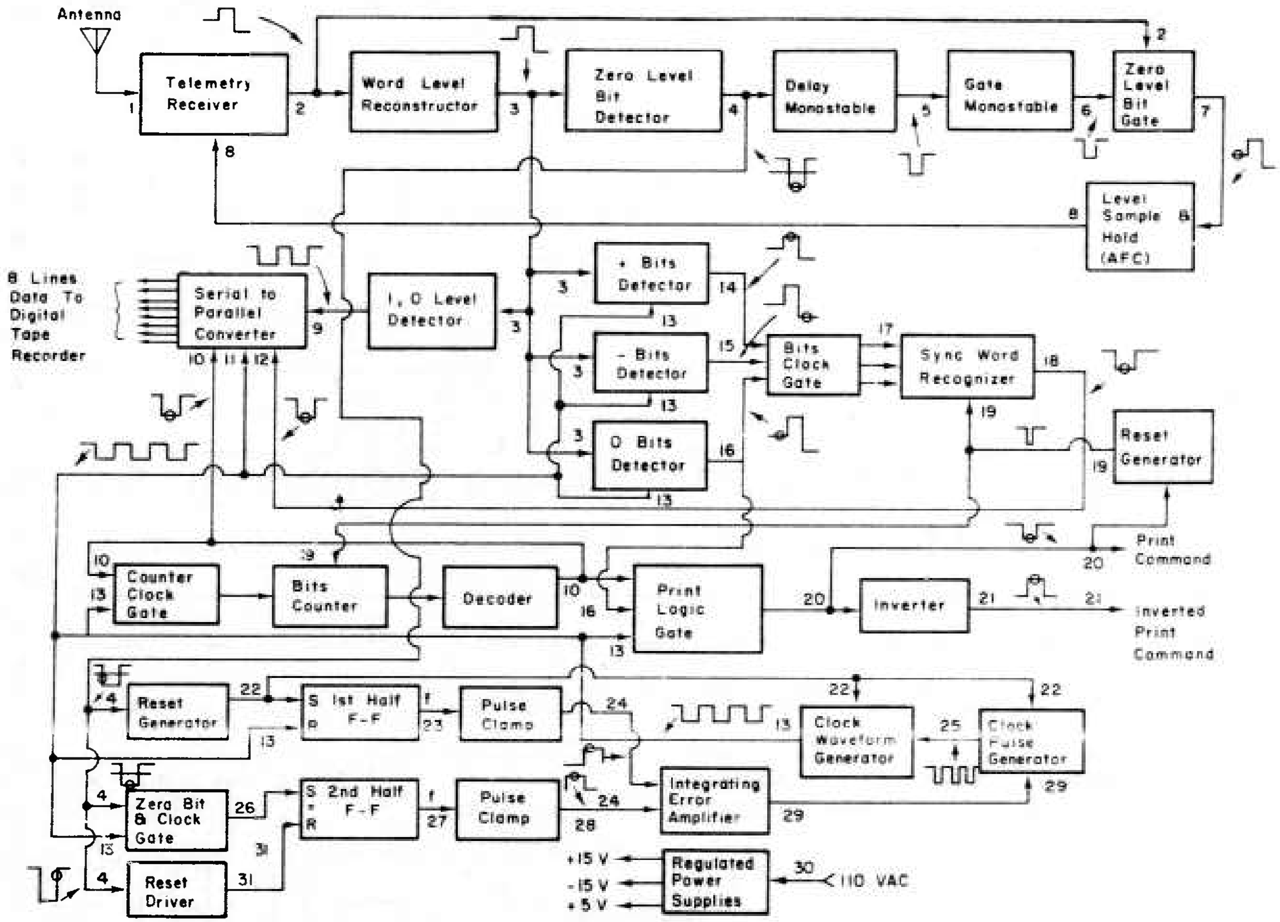


Figure 18. Decoder Block Diagram

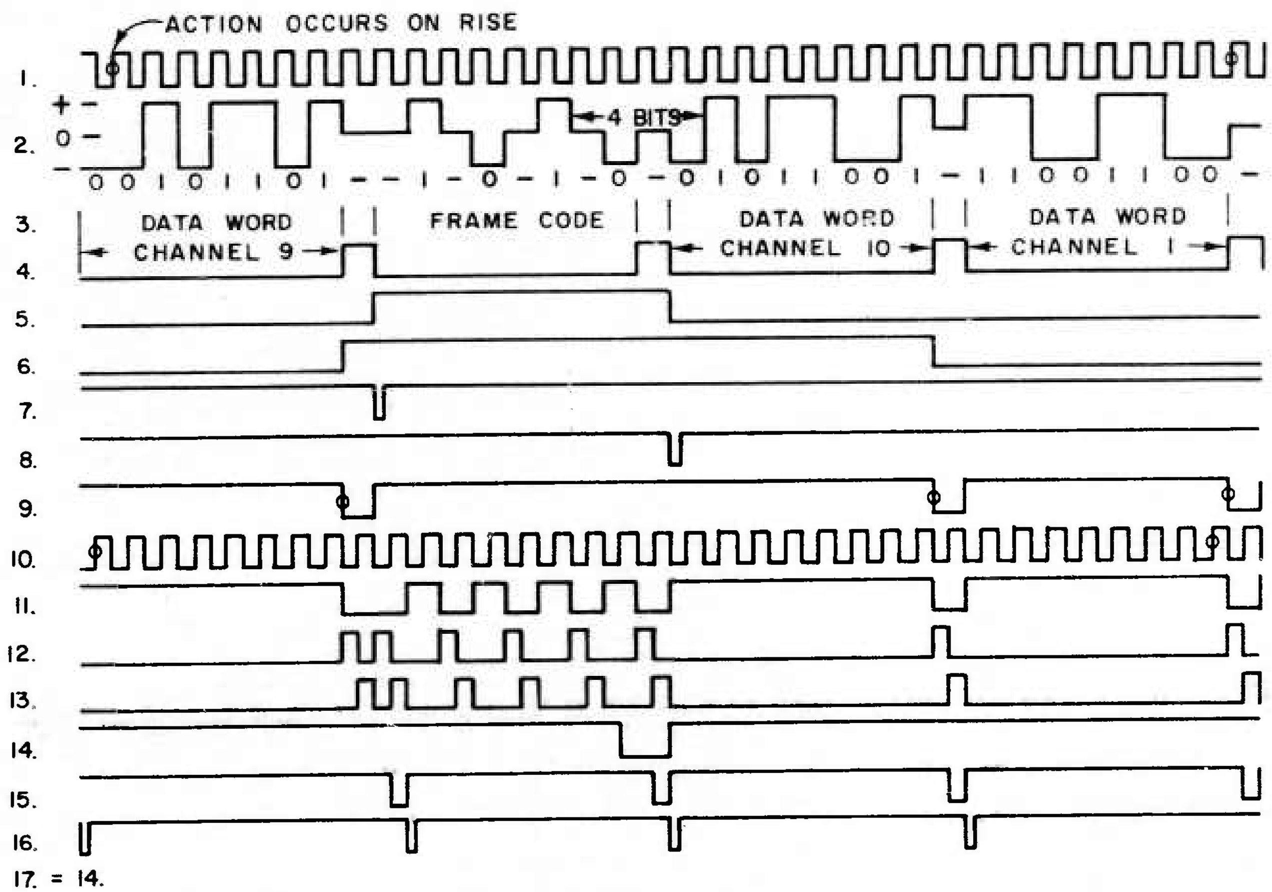


Figure 19. Waveshapes. (1) Encoder Clock, (2) Serial Bits at Modulator, (3) Channel Addressed, (4) Bit Counter, (5) Q of Transfer Flip Flop, (6) Channel 10 Addressed, (7) Flid Flop Set, (8) Flip Flop Reset, (9) Data Strobe, (10) Decoder Clock, (11) Zero Level Bit Detector, (12) 1st Half Flip Flop, (14) Synchronization Word Recognized, (15) Print Command, (16) Reset, (17) Clear

5,000 samples per second; thus, each channel receives just under 500 samples per second, permitting a frequency response for each channel of about 50 Hz, considering a minimum of 10 samples per cycle being required to determine a sine wave type of input signal.

As each channel is addressed (electronically connected or sampled in the DAM), it is converted by the DAM to a digital code consisting of eight parallel lines of data using the 2's complement digital code. This provides a digital resolution of one part in 256 or better than 1/2 percent. The amount of time required by the DAM to perform this conversion is very small (about 5 microseconds), and the 8 lines of digital data (1-8) output from the DAM remain present until it receives a command to advance to and convert the next channel of analog input data.

Each complete scan through the 10 used input channels constitutes a frame of data. Each frame consists of 10 words or data samples, and each word contains eight lines or bits of digital information (plus a word synchronization bit to be described later).

The DAM is externally controlled by the short cycle logic which senses the current channel being processed (18) and when channel 10 has been reached, causes the DAM to advance next to channel 1 (17).

The next process is to convert the eight parallel lines of digital data into a form that can be transmitted over a single radio frequency channel. Instead of using eight parallel radio signals (which cannot be practically done due to bandwidth limitations), the lines are transmitted one at a time in a serial fashion. This is accomplished in the 8-bit digital-to-parallel converter which receives the digital information from the DAM converter, which receives digital information from the DAM (1-8) and remembers it until the data gate is operated to channel the information to the modulator (11) for transmission by the radio frequency transmitter.

The heart of the control of the system is the transmitter clock, which provides a stable timing frequency (about 40,000 cycles per second) to control all the functions of the transmitter. In the transmitter, all operations occur on the positive transition of the clock signal (W-1). Each clock period (one high and one low state) corresponds to the serial transmission of one bit of data (W-2).

Since it is important at the final analysis point to be able to identify which channel each word of data corresponds to, at each cycle of the DAM (frame), a special frame synchronization word is transmitted as would normally be a data word. This frame synchronization word allows the computer to identify the start of the next ten channels. Should this frame synchronization word be lost, only a single frame of data will be lost before the system relocates itself.

A unique feature and simplification of this system, however, is the method of writing the frame synchronization word. Using ordinary two state binary coding (ones and zeros), it, requires a 32-bit word (far in excess of a simple systems capability) to identify a frame word. This system, however, while writing the frame synchronization word <u>only,</u> uses the normal 1 and 0 levels (actually corresponding to + and - frequency deviation in the FM transmitter) and also a halfway or 1/2 level bit, corresponding to a zero frequency modulation of the transmitter (W-2). Thus, with three states present, definite detection of a frame word is possible at the receiver with the use of fewer word bits.

Referring again to the transmitter block diagram, the original clock frequency is generated as short pulses by the clock pulse generator (22), and in the clock waveform generator it is converted into a rectangular clock wave train (23) (W-1). This clock signal is used by the serial-to-parallel converter (20) to transmit each data bit in serial sequence (9), it is used by the frame clock gate (23), and it is counted by the bit counter to determine when a full word has been created by decoding its output (24).

Each transmitted word actually consists of 9 bits, 8 for data and the 9th bit is a zero level (or 1/2 bit as perviously described) which identifies the end of a word and permits time for the DAM to advance to and convert the next channel while the parallel-to-serial converter is cleared and all circuits are made ready for the next word.

Thus, during normal data word transmission (information from the DAM being transmitted), the bit counter decoder provides an output (21) at the beginning of each 9th bit which strobes the DAM (advances it to the next input channel and causes an analog-to-digital conversion), unless inhibited by the strobe gate.

At this time, the 9th bit also causes the parallel-to-serial converter to load (21) the data from the DAM for transmission during the writing of the next word.

In this manner, all ten used channels are transmitted in sequence. However, when channel 10 is addressed (W-6) but the data not yet serially transmitted, the 9th bit indication (21), plus the channel 10 address (19), is used by the set gate to change (W-7) the state of the R - S flip flop - which determines if a data word or a frame synchronization word is being written. When the R - S flip flop changes state, it closes the data gate (10), opens the synchronization gate (15) to the modulator, and permits the clock signal (23) to pass through the frame clock gate and drive (26) the frame synchronization word writer. The output (14) from the frame synchronization word writer consists of both 1, 0, and 1/2 level signals (whereas the data word contains only 1 and 0 levels except for the 9th bit which is a 1/2 level), and thus it writes the frame synchronization word (W-2) which contains; a 1/2 level (from this point on, 1/2 amplitude levels will be called zero levels, 0 digital bits will be minus bits, and 1 digital bits will be + bits), followed by a + bit, a 0 bit, a - bit, a 0 bit, a + bit, a 0 bit, a minus bit, and finally the word synchronization 0 bit. Thus, the frame synchronization word contains two + bits, two - bits, and five 0 bits (including the word synchronization bit) which are transmitted in a particular sequence (W-2).

At the end of the 9th bit from the frame synchronization word writer, an output (27) returns the R - S flip flop to its original state, (W-8) causing the writing of data words. During the frame word write state of the R - S flip flow (W-5), the DAM was not receiving a strobe signal (16) due to the inhibiting action of the strobe gate as determined from the state of the R - S flip flop (25). The data for channel 10 was already converted and loaded into the parallel-to-serial converter, however, and it is now transmitted. Thus, the frame synchronization word is actually written between the data from channel 9 and 10.

Power for the transmitter is derived from a battery pack, whose output is, in turn, regulated to provide $\pm$ 15 volts D.C. and +5 volts D.C. All the circuits used are solid state, and the logic employs transistor-transistor logic (TTL).

B. Receiver

The same notations in parenthesis used for the transmitter description apply.

The receiver also employs a clock, which must be accurately synchronized in frequency and phase with that in the transmitter. This is one of the more difficult tasks in the receiver. First, note that the receiver clock (W-10) is 180 degrees out of phase (inverted) to that of the transmitter clock (W-1), and that all receiver action also occurs on the rising part of the clock pulse (as circled). (In some circuits used in the transmitter encoder and receiver decoder, inverter circuits are not shown on the simplified block diagrams.)

The incoming signal is FM received by a commercial telemetry receiver. It should be noted that this type of FM is one employing only three degrees of frequency deviation: (1) no frequency deviation (corresponding to a 0 level or 1/2 bit), (2) full deviation in frequency in one direction (+ bit), and (3) a full deviation in the other direction (- bit). This differentiates the system from an analog FM system wherein the frequency deviation is directly proportional to the analog signal amplitude and subject to drift.

By using the zero, ± full deviation digital system, small drifts do not induce error into the system.

The video (data) output of the receiver (2) may contain some electrical noise level; thus, it is passed through the word level reconstructor, which detects any signal level near zero and a definite zero, and + bits as a full + bit, and any - bits as a full - bit. Thus, its output (3) resembles that of the modulator in the transmitter.

The zero level bit detector detects the zero (1/2 level) bits for the word synchronization bits (bit number 9) and the zero bits in the composite frame synchronization word. Its output (4) (W-11) is used to operate or trigger the delay monostable, which provides an output (5) that ends after a short time into each zero level bit. The ending pulse, in turn, triggers the gate monostable, which generates a pulse (6) that occurs in the middle of each zero bit. By being shorter than and occurring in the middle of each zero bit, this pulse excludes a possible roll-off or distortion at the start and end of each zero bit. The pulse is then used to operate the zero level bit gate so that it may sample the true D.C. level (2) of the receiver output during the zero bits and apply this information to the level sample and hold. If the actual level is off in a plus or minus direction, output (8) occurs from the circuit which is fed to the receiver automatic frequency control (8) and corrects the receiver tuning to center the receiver about the desired frequency.

When receiving data words, the 1, 0 level detector (+ and - bits) feeds the correct bits from the word level reconstructor (3) to the serial-to-parallel converter (9), where they are serially loaded into a register which produces a parallel 8-line output corresponding to each eight serial data bits received.

Once an 8-bit data word has been entered into the serial-to-parallel converter, it is ready for acceptance by the digital tape recorder 8-line input. The print logic gate operates when the 9th bit has occurred (during which time data should be processed), as detected by the 0 bits detector (16) (W-11), and the bit counter decodes (10), and the clock signal is on the leading edge (13). At this point, a print command is generated (W-15) (20, inverted 21) for operating the digital tape recorder and causing it to accept and write as an 8-bit word the eight parallel outputs of the serial-to-parallel converter. The digital recorder is a standard IBM-compatible 1/2-inch-wide, 15 ips, 800 bpi, 9-track NRZ1 type of unit. At the end of the print command, a reset pulse is generated (19) by the reset generator to clear the bits counter and the synchronization word recognizer. Thus, the data word detection and print cycle continues unless a frame synchronization word is recognized.

Note that by having the receiver clock 180 degrees out of phase with the transmitter clock, time is allowed for all data bits to settle and become noise free so that they are actually sampled or detected in the middle of the bit to eliminate distortion and noise which may occur on the leading and trailing edges of the bits.

The frame synchronization word is recognized by counting the + bits (14), the - bits (15) and the 0 bits (16) and when all have occurred within nine transmitted bits of information, at the next clock pulse the bits clock gate passes this information to the synchronization word recognizer which clears any information which might be in the serial-to-parallel converter (12), leaving it empty. This occurs in the middle of the 8th bit of the frame synchronization word (W-17); thus, no data (only a blank) is written when the frame synchronization word occurs. The analyzing computer program is written to recognize this as indicating that the next word is a data word from channel 10.

Thus, the data and frame synchronization words are processed by the receiver portion of the data link system.

The clock for the receiver is again generated by a pulse generator but one which operates at twice the normal clock frequency. It is divided by two (13) by the clock waveform generator and controls all circuit operation.

To phase and frequency synchronization the clock to the transmitter clock, the zero bit level (4) is detected by the reset generator and causes the 1st half flip flop (22) to change to the high output state (W-12). This same reset generator also resets the clock pulse generator and the clock waveform generator so that they are just starting a new clock period at that time. When the clock signal then drops halfway through its period, the 1st half flip flop is returned to its low state. However, this same clock transistion plus the zero bit condition operates the zero bit and clock gate (26) to cause the 2nd half flip flop to go to the high output state (27) (W-13). At the end of the zero bit (4), the reset driver output (31) returns the 2nd half flip flop output to the low state. Thus, the two flip flop outputs (23, 27) occur during each transmitted zero bit, and if the receiver clock changes state right in the middle of the bit (indicating it is of the correct frequency and phase), the two outputs (23, 27) (W-12, -13) will be of the same time duration. If the clock frequency is too high, the first pulse will be shorter than the second, and if the frequency is to low, the second pulse will be shorter.

These pulses are kept at a constant amplitude by the pulse clamps and are integrated (after one is polarity inverted) (24, 28) by the integrating error amplifier. The output of the amplifier (29) is proportional to the differences in the widths of the two pulses, and thus is proportional to the frequency error and direction of error. This correction voltage (29) is applied to the voltage sensitive clock pulse generator to bring it back to the correct frequency.

Thus, the critical phase and frequency of the receiver clock is maintained, and the data link telemetry system is completed.

Future additions would include a system for manually selecting (but electronically controlling) any given channel of transmitted data and having it immediately converted back to an analog signal for real time or on-line observation on an oscilloscope or chart recorder to check the operation of the entire system, including the sensors on board the projectile.

Some modifications and improvements have been made in the system since its original design and laboratory operation. However, the system is basically the same as described herein. Detailed schematics, parts identification, layouts, and photographed oscilloscope waveforms have been made and maintained for the entire system.

Due to changes in the sensor types that may be used (in particular, the use of a more current Midas platform than was originally indicated), some major changes may be required in the transmitter (the Midas generates its own digital instead of analog output, and it has a different clock rate and bit count than the remainder of the system). However, the original relatively simple design and the feature of a three-bit level system can still be maintained with these changes.

Considerable attention was given in the system design to prevent any race problems - conditions wherein tow events happen from a common signal source, but one must be completed before the second event starts for proper system operation. In the one circuit where this could possibly occur, a delay (capacitative) was used to insure that the second event followed the first.

Most of the circuit design was a matter of proper logic and timing design. The receiver clock synchronization circuit was perhaps the most difficult, and some re-design has been done to improve these circuits. The normal amount of coupling between circuits and frequency response problems to be expected did occur. There was considerable wiring on the circuit boards; therefore, layout to minimize cross talk, etc., was employed.

SECTION VI.

MISSILE SYSTEM TESTS

1. Description of Test Missiles

The scaled model modular aerodynamic configurations (MAC's) used in the missile drop tests were designed and provided by the Air Force Armament Laboratory. These MAC's were used as provided except for minor modifications which included a new hinge arrangement on the parachute release door and lug bolt attachments.

As shown in Figure 10, the missile is basically a 5-foot-long, circular, aluminum cylinder with:

a. Bulkheads to divide compartments and provide attachment points for instruments and soft recovery mechanisms.

b. A solid aluminum nose cone to provide realistic inertia properties and to provide strength to the structure to withstand a relatively soft impact with the earth.

c. Tail fins to provide aerodynamic stabilization as a model of a typical modular missile.

Within the three bulkhead compartments are from fore to aft:

a. The soft-recovery parachute ripcord mechanism which pulls the parachute release ripcord at a preset time after passing through a preset altitude. (This mechanism is activated on release from the aircraft by a lanyard which pulls free of the mechanism and missile.)

b. The instrumentation, power supply, encoder, and transmitter with associated leads to flush mounted antennas.

c. The two-stage parachute assembly which consists of a 15-foot, ribbon, cargo chute with reefing line, two explosive cutters for cutting the reefing line and drogue chute with deployment spring.

A hinged plate covers the rear end of the missile and retains the parachute assembly until two safety cables and the ripcord are pulled. Two safety cables are attached to the bomb rack and pass through guide wire connections on the body of the missile and then through small holes in the hinged plate. Retainer clips are slipped over the cables and pressed snuggly against the hinged retainer plate to keep it from opening while this missile is on the aircraft wing. When the missile drops away from the aircraft's wings, the safety cables are pulled through the retainer clips and cables are pulled away from the missile. This leaves only the ripcord cable with its retainer clip holding the plate which keeps the parachute from springing out. The metal cable ripcord from release mechanism to hinged plate is inside of a small aluminum tube which is mounted on the inside of the missile cylinder.

The lug bolts used for mounting the missiles on the bomb racks were designed, tested, and installed at the contractor's facility. Several configurations with small cross sections for minimum aerodynamic effects were designed and tested on a materials testing machine before selecting the final design. Lug bolts which would retract out of the airstream leaving a cleaner missile were designed but were not used.

Figure 10 shows a missile attached to the bomb rack on the wing of the aircraft. The safety cables can be seen in this photograph. The colors (black, green, orange, yellow and white) are in a broad band of the visual spectrum so that missile attitude is easily observed even in black and white photographs. The four fins are green, yellow, black and white and the missile is orange with alternating two-inch-black-and white strips at 90 degrees apart.

2. Wind Tunnel Tests

The MAC was tested in a 5-foot x 7-foot wind tunnel test to determine the security of the recovery parachute storage and for any inadvertent deployment tendency. Every effort was made to duplicate the actual conditions the package might encounter while mounted on the wing of our delivery aircraft in flight.

The MAC was suspended from the ceiling of the test section, utilizing the same Cessna 0723-617-7/8 adapter and FED 1095-874-9581 bomb rack assemblies as were later used on the Cessna 172 delivery aircraft. (See the experimental setup in Figure 20.) The speed range during the investigation was varied from zero to 130 mph. The upper speed limit was sustained for a period of 5 minutes.

Next, the hinged trap door to the parachute storage compartment at the rear end of the MAC was intentionally opened to between 1/8 inch to 3/16 inch during several test runs. This was done to determine if the air load might be capable of forcing a complete opening of the door by aerodynamic forces overcoming the clip retainer mechanism, and, thus, to allow an unscheduled deployment of the recovery parachute in flight. In our experiment, such an untimely event did not occur.

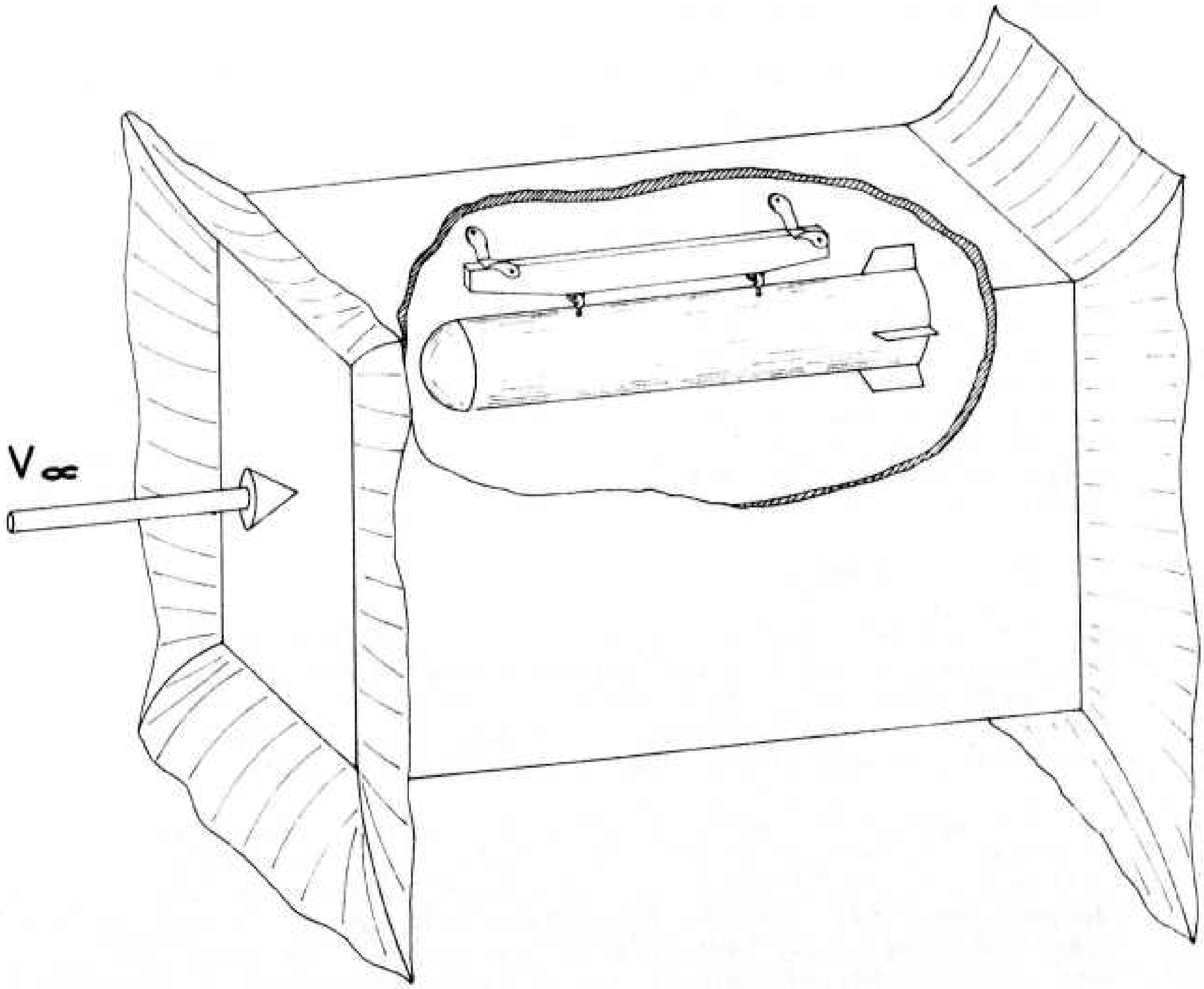


Figure 20. Wind Tunnel of MAC Aerodynamics

It was noticed during the wind tunnel test that an oscillation of the MAC in the yaw mode ensued. This was attributed to cross-flow conditions in the test section.

The conclusion from the results of this particular phase of the testing is that the three-WIRE/CLIP method of securing the recovery parachute compartment is satisfactory and may be utilized throughout the remainder of these tests. However, new clips should be used for each missile flight since they have a tendency to weaken in their ability to hold the safety cables and release cable.

3. Safety Tests of MAC Release and Parachute Retention Mechanisms

Two series of tests were made on the bomb release mechanism, as installed on the wing of the delivery aircraft. The purpose of the first set of tests was to determine if the release latch system could sustain various conditions of support for the MAC without failing to operate properly. For example, it was desired to ascertain if the latch mechanism would still function while supporting all of the weight on the front latch. Likewise, the function of the rear latch was checked with all of the weight supported by the rear latch point. In all, twenty drops were conducted in all possible configurations of possible inadvertent support conditions for the MAC. In addition, at this time both the manual release and electrical release systems were thoroughly checked. It was found that, if the battery voltage is low due to a condition of low charge, the electrical release system will fail to work. Approximately 30 electrical releases are possible with a fully charged battery. All repetition on both wing stations were conducted without difficulty.

The intent of the second test series was to evaluate the parachute deployment timer mechanism after the MAC had been released from the wing of the aircraft. Consequently, a couch was placed directly under the bomb rack on the aircraft. This allowed a fall sufficient for the arming wires to pay out and thus trigger the timer mechanism after it had fallen from the aircraft onto the couch. The fall was of approximately 5 feet. Fifteen consecutive releases were made successfully. As the MAC fell free from the rack and as the arming wires were paying out, a slight tendency to hinge forward on these wires was noticed. On the fourteenth attempt, it was noticed that the timer was taking up a little more ripcord wire each time than could be retrieved in the re-cocking procedure. Finally during the sixteenth attempt, the length of ripcord wire retrieved was insufficient for proper cocking of the mechanism, and further drops were temporarily suspended.

The check procedure was resumed two days later with a different MAC package. These drops were not immediately as successful as the preceding ones had been. On that particular test a 40% failure rate of the parachute's automatic ripcord pull mechanisms occurred. The length of the release wire was shortened and 20 consecutive successful drops were performed. This shortening of the wire was necessary because the pull mechanism was not operating properly. It appears that these mechanisms have a short life-span (about 20 operations) due to fraying of the cable or wear within the mechanism.

4. Free-Flight Tests of MACs

A Cessna 172 was used to make an aerial delivery of two MACs to a designated impact area. Delivery altitude was 8500 feet while the airspeed at release was 85 mph, straight and level.

The aircraft handling characteristics were somewhat different than in the clean configuration, but this was as expected. However, no adverse characteristics were noted throughout the flight regime. No adverse yawing tendencies were noted on take-off roll, and the stick forces on rotation were about normal, with just a very slight nose heavy tendency noted. Roll rates are somewhat more sluggish than in the clean configuration. In the loaded configuration more pronounced changes of indicated airspeed accompany incremental changes in pitch attitude than are otherwise experienced. A rate of climb varying from 800 to 500 fpm was maintained throughout the climb from take-off to level-off at 8500 feet pattern altitude. The excellent rate of climb observed presages a delivery ceiling of about 12,000 feet. The pilot used offset bombing techniques to approximate the proper release point. Although it is felt that this approach will generally produce satisfactory results, it is highly recommended that some type of bomb sight be incorporated to provide the pilot with sufficient real-time inputs to more consistently deliver the MAC to an intended impact area with accuracy.

The first MAC fell away from the rack in an uneventful manner. A chase plane with photographer recorded its trajectory from the air, while a ground crew recorded the drop from the ground. By ground observers' account, the parachute deployed at approximately 4,000 feet. However, the canopy did not fully open, although the cutter bars fired and cut the reefing lines during the free-fall to earth. It is recommended that subsequent drops use a high visibility multicolored cargo chute instead of the olive drab model to facilitate assistance from the air in recovering the MAC after delivery.

On the second drop as the MAC fell away from the rack the safety pin for timer did not pull out freely, which caused the package to hang up on the arming wire and to quite appreciably hinge forward before it finally wrenched free. The chute on this second attempt also deployed but likewise did not fully inflate. Its trajectory was followed visually and on film to the ground.

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13. ABSTRACT

Final results on the development of a precision and automated capability for determining dynamic data for modular aerodynamic configurations (MAC) in free-flight are presented. The system developed includes a modified single engine aircraft with bomb release and various electronic capabilities, a digital telemetry system, a telemetry receiving van with associated receiving and recording elements, and the MAC's with instrumentation devices, soft recovery parachute systems and flight safety equipment. Descriptions are given of drop test of MAC's from the aircraft and of MAC wind tunnel tests.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Modular Dynamic Configurations						
Missile Air Drop Test System						
Missile Free-Flight Dynamic Data						
Two-Shackle Drop-Load System						
Aeromechanics Prediction and Analysis Techniques						