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# Packet Radio Data Link Applications in the NASA Langley Research Center Transport Systems Research Vehicle

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# SUMMARY

An amateur packet radio system has been used to support bidirectional air/ground data link requirements for a number of Transport Systems Research Vehicle (TSRV) flight test programs at the National Aeronautics and Space Administration (NASA) Langley Research Center. Data transfer between ground-based and airborne packet radio stations was accomplished via audio modulation of a Radio Frequency (RF) carrier. For TSRV use, the baseline configuration of each station consisted of a Very High Frequency (VHF) transceiver, a packet Terminal Node Controller (TNC), an antenna, and a computer terminal for monitoring and control. User system interfaces for both ground and airborne baseline stations were configured to meet the specific requirements of each test conducted.

Within each station, audio and RS-232 digital data connections are present for the packet TNC. The audio connection is to the VHF transceiver which serves as the air/ground data transfer medium. For transmission, the TNC passes audio signals to the transceiver for VHF carrier modulation. For reception, the TNC receives, via the audio interface, signals representing digital data transmitted by another station. The received and transmitted audio signals are converted respectively to and from RS-232 data by the TNC. The RS-232 data stream is the interface medium for two-way communication between the TNC and a user system.

Descriptions of the varied packet link configurations employed to support the TSRV efforts are contained in this document.

## LIST OF FIGURES

## CREDITS

Borland C++ compiler package version 3.1, S/N DA973A10058087 was used to support the tasks described in this document. This is a copyrighted product of Borland International, Inc., Scotts Valley, California.

MS-DOS and Microsoft C were also used in support of the tasks described herein. They are copyrighted products of Microsoft Corporation, Redmond, Washington.

The ground map illustrated in figure 6 was written by Richard W. Dickson of Computer Sciences Corporation. All airborne display software was written by Chris Slominski and Valerie Plyler of Computer Sciences Corporation.

The packet Radio Terminal Node Controllers (TNC's) described in this document are products of MFJ Enterprises, Starkville, Mississippi. Personnel from MFJ Enterprises also have provided technical support.

The radios used with the MFJ packet TNC's are products of Motorola Corporation.

All other tasks described in this document were performed by the authors.

## 1.0 INTRODUCTION

The Transport Systems Research Vehicle (TSRV) is a research flight system operated by the Terminial Area Productivity Program Office (TAPPO) at the NASA Langley Research Center. Three TSRV flight test programs conducted beginning in 1990 have required a real-time, ground/air data link. These programs are:

1. Data link experiments involving air traffic control and weather information.

2. Differential Global Positioning System (DGPS) flight tests.

3. Terminal Doppler Weather Radar (TDWR) data link as part of the NASA Langley Windshear Flight Test Program.

The data link requirements for these test programs were met with an amateur packet radio system consisting of both airborne and ground stations. Each packet station consisted of a Very High Frequency (VHF) transceiver, a packet modem known as a Terminal Node Controller (TNC), an antenna, and a computer terminal. User system connections to ground data bases and airborne computers were built around this basic station configuration.

The VHF transceivers, via a Radio Frequency (RF) link, provide the air/ground transmission medium with digital data transfer being accomplished by audio modulation of the VHF carrier. At these VHF frequencies, link range is limited to line-of-sight distance between the air and ground stations.

The packet TNC has two interfaces, an audio connection to the transceiver and an RS-232 digital data connection for user system interfacing. Conversion of digital data between audio and RS-232 signals for use by these respective interfaces is done by the TNC. RS-232 data originating from the user system is converted to audio signals for VHF carrier modulation and radio transmission. Conversely, audio signals resulting from demodulation of received VHF carrier energy are converted to RS-232 for input to the user system.

A number of hardware and software configurations involving the TNC interfaces and functions were developed to support the varying requirements of the different experiments conducted. Also system monitoring and control functions to enhance operation were developed. Descriptions of all the techniques used in implementation and operation of this packet radio data link are contained in this document. Only summary descriptions of the actual experiments are included, however, since references containing more detailed treatment of those are provided.

## 2.0 LIST OF ABBREVIATIONS

| | |
|---|---|
| A/C | Aircraft |
| Alt | Altitude |
| APT | Airport |
| ARINC | Aeronautical Radio Incorporated |
| ARINC-429 | An ARINC Serial Data Bus Standard |
| ASCII | American Standard Code for Information Exchange |
| AWAS LLWS | Advanced Warning System Low-Level Wind Shear |
| Bit | Binary Digit |
| BYTE | Eight-Bit Data Unit |
| CDU | Control Display Unit |
| COM | Personal Computer (PC) RS-232 Communication Port |
| CONV | Packet Terminal Node Controller (TNC) operational mode |
| CRC | Cyclic Redundancy Check |
| CRT | Cathode Ray Tube |
| DGPS | Differential Global Positioning System |
| DMA | Direct Memory Access |
| GPS | Global Positioning System |
| Hex | Hexadecimal Number |
| I/O | Input/Output |
| Lat | Latitude |
| LIDAR | Light Detection and Ranging (Windshear sensor) |
| Lon | Longitude |
| MSB | Most Significant Bit |
| MS-DOS | Microsoft Disk Operating System |
| NASA | National Aeronautics and Space Administration |

| | |
|---|---|
| PC | Personal Computer |
| PGS | Packet Ground Station |
| Pos | Position |
| RAM | Random Access Memory |
| RF | Radio Frequency |
| RFD | Research Flight Deck |
| RS-232 | Serial Communication Standard |
| RX | Receive function of an RS-232 port |
| SW | Switch |
| TAPPO | Terminal Area Productivity Program Office |
| TDWR | Terminal Doppler Weather Radar |
| TNC | Terminal Node Controller |
| TRANS | Packet Terminal Node Controller (TNC) operational mode |
| TSRV | Transport Systems Research Vehicle |
| TX | Transmit function of an RS-232 port |
| UHF | Ultra High Frequency |

## 3.0 BASELINE PACKET LINK CONFIGURATION

The major components of the ground and airborne packet data link stations used for TSRV support are listed in section 1.0. Descriptions of their operating configurations are contained in this section.

### 3.1 Baseline Packet Ground Station

Figure 1 contains a functional diagram of the baseline packet ground station used to support all TSRV data link experiments conducted to date. Individual component descriptions follow.

#### 3.1.1 Terminal Node Controller (TNC)

The TNC is a data conversion modem and is the heart of the packet data link system. As seen from figure 1, it has an RS-232 port for user interfacing via a computer or terminal, and an audio port for radio transceiver connection. Two-way data communication is accomplished by audio frequency modulation and demodulation of the VHF carrier. Digital data from the host computer enters the TNC through the RS-232 port and is converted into audio signals for VHF carrier modulation. For data passage in the opposite direction, audio signals retrieved via demodulation of the VHF carrier are converted into RS-232 digital data for output to the host computer. The basic data unit used in packet link transmission is the byte, or eight bit data unit.

Three principal operational modes exist for the TNC. These are the "COMMAND", "CONVERSE", and "TRANSPARENT" modes. In the "COMMAND" mode, the TNC is under control of the host terminal via its RS-232 port, and all input data are intercepted for internal use. This mode is used for link startup and to set TNC configuration parameters, a function typically accomplished by uploading an ASCII configuration disk file from the host terminal. Also in this mode a TNC resident configuration file can be downloaded into a PC disk file and saved for later use. When "CONVERSE" and "TRANSPARENT" modes are active, TNC input is not intercepted but passed through for normal data link operation. The "CONVERSE" mode can be used for applications whose data transmission can be limited to printable American Standard Code for Information Interchange (ASCII) bytes. Here the Most Significant Bit (MSB) of the data byte is not used. "CONVERSE" mode entry from the "COMMAND" mode is accomplished by sending the character string "CONV" to the TNC. The "COMMAND" mode can be reentered at any time by sending the TNC a 03 Hex (Control C) byte. The "TRANSPARENT" mode is required for binary transmission in which all eight bits of the data byte are significant. This mode is entered from the "COMMAND" mode by sending the string "TRANS" to the TNC. Once in this mode, however, returning to

"COMMAND" mode is more complex since now all bytes count as data and the TNC intercepts nothing. Methods consisting of sending the TNC certain control bytes in rapid succession are used for "COMMAND" mode reentry here.

Packet operation in the "CONVERSE" mode has proven most desirable for the TSRV applications. The monitor and control functions described later as well as operator intervention for problem diagnosis and correction are easier in this mode.

Numerous TNC configurations are possible through parameter settings from the "COMMAND" mode. Once in TNC memory, battery backup Random Access Memory (RAM) ensures non-volatility of the configuration information. Typically a configuration file specific to each desired application is stored on the PC hard disk for uploading to the TNC. The details of all possible configurations are too numerous for inclusion in this document. They are, however, contained in TNC documentation supplied by the manufacturer.

Communication transfer protocol resident in firmware in each packet TNC is used to maintain integrity of transferred data. Integrity checks made for each packet (block) of data bytes transferred include a Cyclic Redundancy Check (CRC) with retransmissions being made for a data packet whose CRC check fails. A closed-loop connected link state between two stations, in which each station is locked to the call sign of the other, is needed to ensure effective protocol functions. With a properly functioning RF link between the transceivers, packet connected operation can be initiated from "COMMAND" mode by sending to the TNC the string "CONNECT" followed by the call sign of the station to which connection is desired. For example, to connect the TSRV ground station to the airborne station, the string "CONNECT N515NA" is sent to the ground TNC by the host ground terminal.

### 3.1.2 Ground VHF Transceiver

The VHF transceiver illustrated in the upper right of figure 1 is a standard Motorola commercial unit. It is designed for voice communication and as such has a relatively narrow data communication bandwidth. However the unit has proven very adequate for a 2400 baud packet data rate, the maximum rate used in the TSRV applications.

### 3.1.3 Packet Ground Station Monitor and Control

All control and configuration functions described in subsection 3.1.1 are performed using the Personal Computer (PC) hosted dual port terminal program and associated hardware switching arrangement illustrated in figure 1.

The PC-based terminal software was locally developed and has been tailored to the TSRV packet application. It is described in detail in reference 1. Its principal functions are: (1) simultaneous real-time monitoring of two RS-232 ports, (2) display in both ASCII and binary of input bytes from each monitored port in separate windows, (3) selectable transmission of disk files or keyboard entries to either or both RS-232 ports, (4) capture of screen contents to disk file, and (5) recording of data from each port in separate PC disk files. Versions of the terminal software have been developed for both normal PC RS-232 communication ports and a special Grid laptop bus expansion port used in the airborne packet station described later.

Both SW 1 and SW 2 shown in figure 1 are three position ganged switches which are used to select ground system monitor and control functions. Their configuration shown in figure 1 illustrates the monitor functions associated with normal packet operation. RS-232 two-way communication exists through SW 1 between the ground data source at the upper left and the TNC at the upper right. Also, through SW 2, the receive lines of COM 1 and COM 2 of the PC monitor unit (lower right) are connected in parallel with the transmit lines of both the ground data source and the TNC. Thus, all data passing in both directions are captured for real-time display and recording on the PC.

For data link startup or operator intervention to correct a problem, PC transmission to the ground data source or the TNC is needed. This is accomplished by changing the SW 1 and SW 2 settings shown in figure 1. When SW 1 is changed from Pos 1 to Pos 2, the ground data source is disconnected from the TNC. Then with SW 2 remaining in Pos 1, the transmit line of PC COM 1 is connected to the receive line of the TNC. Also, the PC COM 1 receive line is connected to the TNC transmit line. Two-way RS-232 communication between the PC and TNC will then exist, and activation of COM 1 transmission on the PC will allow sending keyboard or disk file commands for link startup, TNC problem diagnosis, or uploading a TNC configuration file. When transmission is active on the PC, all keyboard and disk file entries transmitted are also displayed in the LOCAL screen window. (See figure 1, lower right.)

Alternately, when both SW 1 and SW 2 are in Pos 2 and transmission is active for PC COM 1, two-way RS-232 communication between the PC terminal and the ground data source will exist. All command and control functions described in the last paragraph can then be accomplished for the ground data source.

### 3.2 Baseline Packet Airborne Station

Figure 2 contains a functional diagram of the baseline TSRV airborne packet station. The TNC and VHF transceiver units are identical to and perform the same functions as the corresponding units in the ground station described in section 3.1. However, the hardware switching and PC terminal configurations differ and are described below.

### 3.2.1 Interface Switching

The principal computers contained in the TSRV flight system are two Microvax units, one for Flight Management computations and the other for display-related computations. Airborne packet system use has involved both of these. As can be seen from figure 2, SW 1 is a ganged three-position switch which allows establishment of two-way RS-232 communication between the TNC and either Microvax or between the TNC and the airborne terminal and control unit. The specific SW 1 setting shown represents a TNC connection to the Display Microvax. Changing SW 1 so that Pos 2 is active for each switch will result in a TNC RS-232 connection to the Flight Management Microvax. Also, setting SW 1 to Pos 3 will connect the TNC to the PC-based terminal. Operations with this SW 1 setting for PC terminal connection involve SW 2, a two position ganged switch whose functions are described in the following subsection.

### 3.2.2 Packet Airborne Station Monitor and Control

Since a number of Grid laptop computers are resident in the TSRV baseline system as Microvax terminals, it was advantageous to adapt one of them for the packet terminal and control unit. These Grid units are MS-DOS clones but, as delivered, they contained only one externally usable RS-232 port, COM 2. This configuration would not support the dual port monitor function required for the TSRV packet link system. Fortunately, a second RS-232 port could be adapted through software developed specifically for a standard Grid internal bus expansion hardware module. This development, which is described in reference 2, permitted dual-port terminal airborne packet monitor and control functions identical to those in the ground station. The configuration used is illustrated at the right of figure 2. In this case, the terminal screen's top window is labeled "GRID WINDOW" rather than "COM 1 WINDOW" to distinguish it from the more standard PC RS-232 configuration shown in figure 1.

Configured as shown in figure 2, the system will produce normal operation with data transfer occurring between the TNC and the Display Microvax. Real-time, dual-port monitoring is active on the terminal. TNC input data (Microvax output) will appear in the terminal's "GRID WINDOW" and TNC output (Microvax input) will appear in its "COM 2 WINDOW." Thus, a display of both TNC input and output is available for log file recording and real-time operator inspection. Changing the switch configuration such that SW 1 is set to Pos 3 and SW 2 is set to Pos 1 disconnects both Microvaxes and establishes two-way RS-232 communication between the TNC and the terminal. Then, activation of transmission for PC COM 2 will allow sending keyboard and disk file commands to the TNC for link startup, TNC problem diagnosis, or TNC configuration file uploading.

## 4.0 FLIGHT RESEARCH PROGRAMS USING THE PACKET DATA LINK

Three TSRV experimental flight research programs which used the packet radio data link were listed in section 1.0. The specific packet air and ground configurations used for each application are described in this section.

### 4.1 Air Traffic Control and Weather Data Link Experiments

The first TSRV packet use was for flight tests conducted in mid-1990 involving two-way, data-link communication with an experimental ground-based air traffic control station and a weather data base system. Figure 3 illustrates the ground and air packet configurations used for these tests, and reference 3 describes the research program in greater detail.

#### 4.1.1 Ground Packet Configuration

A PC served as the ground-based data source for air traffic control messages, and uplink was a major aspect of the experiment. The PC software contained menu selections which allowed a ground controller to configure and send messages appropriate to the traffic situation being simulated. (See reference 3.) The telephone modem shown in figure 3 was connected to a weather data base and served as the source of weather information for uplinking to the TSRV. For this experimental flight program, the closed-loop, connected packet-link state described in subsection 3.1.1 was used with a data rate of 1200-baud. Also, the TNC "CONVERSE" mode was used since all messages were composed of printable ASCII characters.

#### 4.1.2 Airborne Packet Configuration

The airborne packet station configuration used for air traffic control testing is illustrated in figure 3. Uplinked messages were routed from the airborne TNC to the data link host computer. After various processing by this host computer (see reference 3), the uplinked data were routed to one or more of three destinations: (1) a Cathode Ray Tube (CRT) display in the TSRV Research Flight Deck (RFD), (2) a PC containing a voice adapter allowing the messages to be spoken through the TSRV intercom system, and (3) a PC for log file recording of each message. Except for the CRT display, all these interfaces were RS-232.

Possible pilot actions in response to uplinked messages included acknowledgment, rejection, or direct entry into the flight navigation system. Most actions resulted in downlink messages transmitted to the ground station via the packet link. In addition to acknowledgment and rejection responses to uplinked messages, requests for weather information could be downlinked by pilot action. Also, custom messages requesting information from the ground control station could be configured for downlinking using the airborne Control Display Unit (CDU).

Pilot actions were facilitated by a touch panel mounted on the RFD data link CRT display. A menu of predefined standard messages with selection icons could be displayed on the CRT screen under the touch panel. Touching the icon corresponding to a message would select it for downlink or other action.

### 4.1.3 Remarks and Conclusions

Packet radio data link performance was satisfactory in supporting this series of flight tests. Equally important, experience gained during this first application proved valuable for increased efficiency and reliability in later packet implementations. For example, it was demonstrated that the PC monitor and control function (see figures 1 and 2), originally intended as a convenience, was indeed a requirement for efficient operation. A major reason involved the sensitivity exhibited by the TNC in "CONVERSE" mode to random non-printable data bytes entering its RS-232 port. Such bytes occasionally resulted when the connected user system produced randomly scrambled data due to such things as hardware or software malfunctions and power glitches. If the random data stream contained a 03 Hex byte (Control C), the TNC would enter the "COMMAND" mode and intercept all subsequent input bytes for internal configuration control. Unpredictable TNC configurations and link failure would often result from TNC interpretation of character combinations occurring in such data streams. Tools provided by the monitor and control system, notably real-time operator observation and the ability to establish terminal-to-TNC communication, allowed detection and rapid correction of this type of problem.

Flight paths used in these experiments resulted in distances exceeding 100 miles between air and ground packet stations. However, altitudes flown were high enough to prevent significant data loss due to interruption of line-of-sight RF coverage.

Additional information on the results of this TSRV data link flight research program can be found in reference 3.

### 4.2 Differential Global Positioning System Flight Tests

The second TSRV use of the packet radio data link was in support of a Differential Global Positioning System (DGPS) flight test program conducted in late 1990. This was a joint effort involving NASA Langley Research Center and the Honeywell Corporation. Figure 4 illustrates both the ground and air packet configurations used.

#### 4.2.1 DGPS Ground Packet Configuration

The DGPS ground packet configuration is illustrated in the left side of figure 4. The ground data source was a PC which received input from a ground-based Global Positioning System (GPS) receiver via an ARINC-429 bus. Satellite position information from the GPS receiver was processed by software in the PC and sent out its RS-232 port to the packet TNC for uplinking to the TSRV. Flight computers then applied the uplinked information as differential corrections to position information derived from an airborne GPS receiver. Evaluation of increased guidance accuracy from the differential corrections was the goal of this experiment.

Again, for these tests, the closed-loop connected packet link state was used with a data transfer rate of 1200-baud. Also, uplinked position correction data was configured by the ground PC into printable ASCII messages, thus allowing use of the packet "CONVERSE" mode.

#### 4.2.2 DGPS Airborne Packet Configuration

The DGPS airborne packet configuration is illustrated in the right side of figure 4. While the packet link itself operated in the same manner as that described in section 4.1, the nature of the DGPS tests required a significantly different total flight system. No downlink functions were required. Uplinked data consisted of real-time control and navigation information and, as such, were used only by the Flight Management Microvax. Effects of the data on aircraft position were reflected in the RFD navigation display.

#### 4.2.3 Remarks and Conclusions

Performance of the packet link system in support of the DGPS testing was satisfactory. However, the need for an increased data transmission rate was clearly identified, as the 1200-baud rate used was barely adequate.

Data link maintenance in the final approach flight phase was critical for these tests. Potential existed for link interruption due to loss of line-of-sight RF coverage and antenna shielding during the low altitude maneuvers associated with this flight phase. However, due to close proximity of the air and ground stations, link loss problems were minor and could likely be rendered almost nonexistent by increased optimization of the aircraft antenna location.

Additional discussion concerning results of the TSRV DGPS research efforts can be found in reference 6.

### 4.3 Windshear Applications of the Packet Data Link

Extensive use was made of the packet data link system in supporting the TSRV Windshear Flight Test Program during 1991 and 1992. Figure 5 illustrates the ground and airborne packet configurations used for these tests.

#### 4.3.1 Windshear Ground Packet Station Configuration

For windshear applications, the packet ground data source was a Terminal Doppler Weather Radar (TDWR) system. Data defining location (relative to the TDWR ground site), size, and intensity of storm cells were converted to an RS-232 format for uplink to the TSRV. The packet ground station in this application was remotely located from the ground data source (TDWR site). A ground telephone modem link was used for data transfer between these sites, and in the packet ground station (see figure 5), an RS-232 connection between this modem and ground TNC was required. Beyond this interface, packet link data transfer was identical to that for the previously described applications.

Hardware and software functions contained in the packet baseline ground configuration (see figure 1) were indispensable for operation of this ground station. The two modems (telephone and packet TNC) required independent startup and connection operations followed by connection to each other for normal data communication. This was readily accomplished by connecting each modem in turn to the dual port PC terminal and establishing their respective operating configurations using terminal output commands. Then, returning to the switch configuration shown in figure 1 allowed normal communication between the modems plus terminal dual port monitoring and recording of data moving in both directions.

#### 4.3.2 Ground Computations and Display

The principal real-time use of TDWR data was creation, for CRT moving map display, of oval-shaped icons representing weather cells. Such maps in both the ground and airborne stations were produced.

A PC was used to generate the ground station map. As illustrated at the left of figure 5, two PC RS-232 receive lines were connected respectively to the TDWR output (uplink data) and the ground TNC transmit line which contained downlinked data. Among the downlinked aircraft parameters were Latitude, Longitude, Altitude, and Track. These data, combined with position, size, and intensity information in the TDWR weather cell data, permitted generation of the moving map. Thus, a graphical display of weather cell positions relative to the aircraft position was constantly available for use by ground-based personnel. PC graphics and communication software used to accomplish this was written using the Borland C++ 3.1 compiler package with the Borland Graphics Interface (BGI).

An illustration of the ground map is shown at the left of figure 6. The oval objects represent weather cells shaded according to intensity. In the actual display, color coding was used for this intensity identification. Also, various downlinked parameters are shown in text form in windows at the right side of the display. The lower two windows contained parameter values used to generate the map. The top window displayed windshear alerts generated by the listed airborne sensors.

A downlinked packed discrete data byte contained the alert information. This byte was configured by the airborne sensors, each of which produced a discrete warning upon detection of potentially hazardous windshear conditions close ahead in the current flight path. The alerting sensor would then cause the flight computers to set its corresponding bit in the downlink alert byte. Highlighted display on the ground PC of the name of each sensor exhibiting alert status was then accomplished by decoding this byte. Also an aural warning was produced by the PC upon receipt of any alert.

### 4.3.3 Windshear Airborne Packet Station Configuration

In the TSRV, TDWR uplinked data was used to produce a real-time map on one of the RFD color CRT units. This airborne map also displayed oval weather cell icons relative to aircraft position with color coding used for weather cell intensity identification. An example scenario map in the "TRACK UP" mode is illustrated at the right of figure 6. The "TDWR ALERT" message appears indicating that the aircraft is approaching a potentially hazardous weather cell. The triangular symbols above and to the right of the aircraft represent obstacles, such as towers, with obstacle height in feet displayed.

### 4.3.4 Remarks and Conclusions

Packet data link performance in support of the TSRV Windshear Flight Test Program was very satisfactory. This performance was significantly enhanced by an increase in link data rate to 2400 baud. Since most flying was done at altitudes below 1500 feet, line-of-sight RF range limitations existed. However, no significant problems occurred in the required operating range of approximately 35 miles from the TDWR site.

Position, size, and intensity parameters derived from the uplinked weather data and presented on the airborne map were used in conjunction with voice communication with the TDWR site, for aircraft guidance during all TSRV windshear flights. Testing of all the airborne sensors involved real-time selection of flight paths based on these information sources. Thus, operational reliability of the packet link was highly important to the entire Windshear Flight Test Program, not just TDWR testing. Effective conduction of this test program would have been very difficult if uplink information had been limited to voice communication with the TDWR site.

Production of the ground station map by parallel connection to the packet link was very beneficial. Through graphical information contained in it, ground-based personnel were able to effectively track aircraft status and progress with minimum use of a voice link. Also, postflight reproduction of the map for data analysis was possible using the PC map software with ground station recordings of packet data moving in both directions.

Additional information on the results of the NASA Langley Windshear Flight Test Program can be found in references 4 and 5.

## 5.0 DATA PACKET CONFIGURATION

Data bytes entering a packet TNC are placed in a RAM buffer. Normally they are transmitted as a packet when a user-selected maximum buffer count, nominally 256 bytes, is reached. When data transfer is limited to printable ASCII; however, the TNC "CONVERSE" mode (see section 3.1.1) is available, and the user system can force packet transmission at any time by sending a non-printable control byte to the TNC. Normally this control byte is a carriage return (0D Hex), but it is user selectable.

The TNC "CONVERSE" mode with a carriage return for forced transmission has been used for all TSRV packet applications to date. Packet message configurations specific to the data requirements of each application were designed and implemented. As an example, packet configurations for downlinked data during windshear testing are shown in figure 7. Byte fields representing data parameters in each packet are identified. Three data message types are shown, alert data, aircraft location data, and aircraft status data. Each individual message was sent as a packet by appending to it a carriage return (0D Hex byte) in the airborne computer. The checksum shown in the aircraft location packet in figure 7 allowed transfer integrity checking for this individual packet. However, use of individual packet checksums such as this does not replace the CRC integrity checking inherent in the packet transfer protocol. (See section 3.1.1.)

Techniques to condense packet byte contents were used when possible to reduce the transmitted data load. For example, as can be seen from figure 7, colon character separators in the time, latitude, and longitude byte fields are omitted. Proper reinsertion of this type of character into a string can be readily accomplished by ground software after decoding of the packets.

The alert discrete byte shown at the top of figure 7 is an example of messages requiring special attention for TNC "CONVERSE" mode operation. Its packed, discrete nature frequently yielded a non-printable byte, certain values of which can change the TNC mode from "CONVERSE" to "COMMAND." (See section 3.1.1.) Fortunately, all control bytes that cause this TNC mode alteration are in the lower ASCII range, and their MSB is zero (MSB reset). Thus, permanently setting the MSB of the downlinked alert discrete byte ensured that no critical TNC control character would be transmitted. This disabled use of the MSB of the byte for an alert discrete, but the lower seven bits were adequate for the application.

Other techniques can be implemented to transfer data bytes needing all eight bits using the TNC "CONVERSE" mode. One common method is sending a binary byte as two printable Hex characters. This requires splitting the byte in the origin system and recombining the two characters into one byte at the destination. However, such techniques which involve transmission of more than one character per binary byte results in decreased effective data transfer rates.

## 6.0 CONCLUDING REMARKS

Successful conduction of the three TSRV flight research programs listed in section 1.0 required a reliable and economical air/ground data link. These requirements were satisfactorily provided by adaptation of the amateur packet radio system described in this document.

Implementation of the system involved flight hardening of low-cost commercial packet TNC and radio units. Due in large part to small physical size and inherent hardware reliability of these units, no significant difficulty in this area was encountered. Enhanced operational efficiency resulted from development of the monitor and control functions illustrated in figures 1 and 2.

A maximum data transfer rate of 2400 baud was available for the packet system used in the TSRV applications. Upgrade to a higher capacity system is possible using more sophisticated modulation techniques and increased transceiver bandwidth. Investigations conducted to date indicate that this may require operation in the Ultra High Frequency (UHF) band, a situation which could adversely affect the packet operating range due to increased RF interference and reflection.

An integrated and tested packet data link subsystem in the TSRV has resulted from the applications described in this document. Within its inherent bandwidth and RF line-of-sight range constraints, this packet system can be expected to provide reliable support for future TSRV data link requirements.

## REFERENCES


1. Easley, Wesley C.: A PC-Based Bus Monitor Program for Use With the Transport Systems Research Vehicle RS-232 Communication Interfaces, NASA Technical Memorandum 104175, 1991.

2. Easley, Wesley C.: Expanded Serial Communication Capability NASA Technical Memorandum 104176, 1991.

3. Knox, C. E.; and Scanlon, C. H.: Flight Tests Using Data Link for Air Traffic Control and Weather Information Exchange. 1990 SAE Transactions, Volume 99, Sect. 1, No. Pt. 2, September 1991, p. 1683.

4. Hinton, D. A.: Air/Ground Wind Shear Information Integration; Flight Test Results. Presented at Fourth Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting, April 14-16, 1992, Williamsburg, Virginia.

5. Hinton, D. A.: Forward-Look Wind-Shear Detection for Microburst Recovery, Journal of Aircraft, Volume 29, No. 1, January-February 1992, pp. 63-66.

6. Hueschen, R. M.; Spitzer, C. R;, and Person, L. H.: Analysis of GPS and MLS Final Approach Navigation Errors and Control Performance Data. Presented at National Technical Meeting of the Institute of Navigation, January 27-29, 1992, San Diego, California.

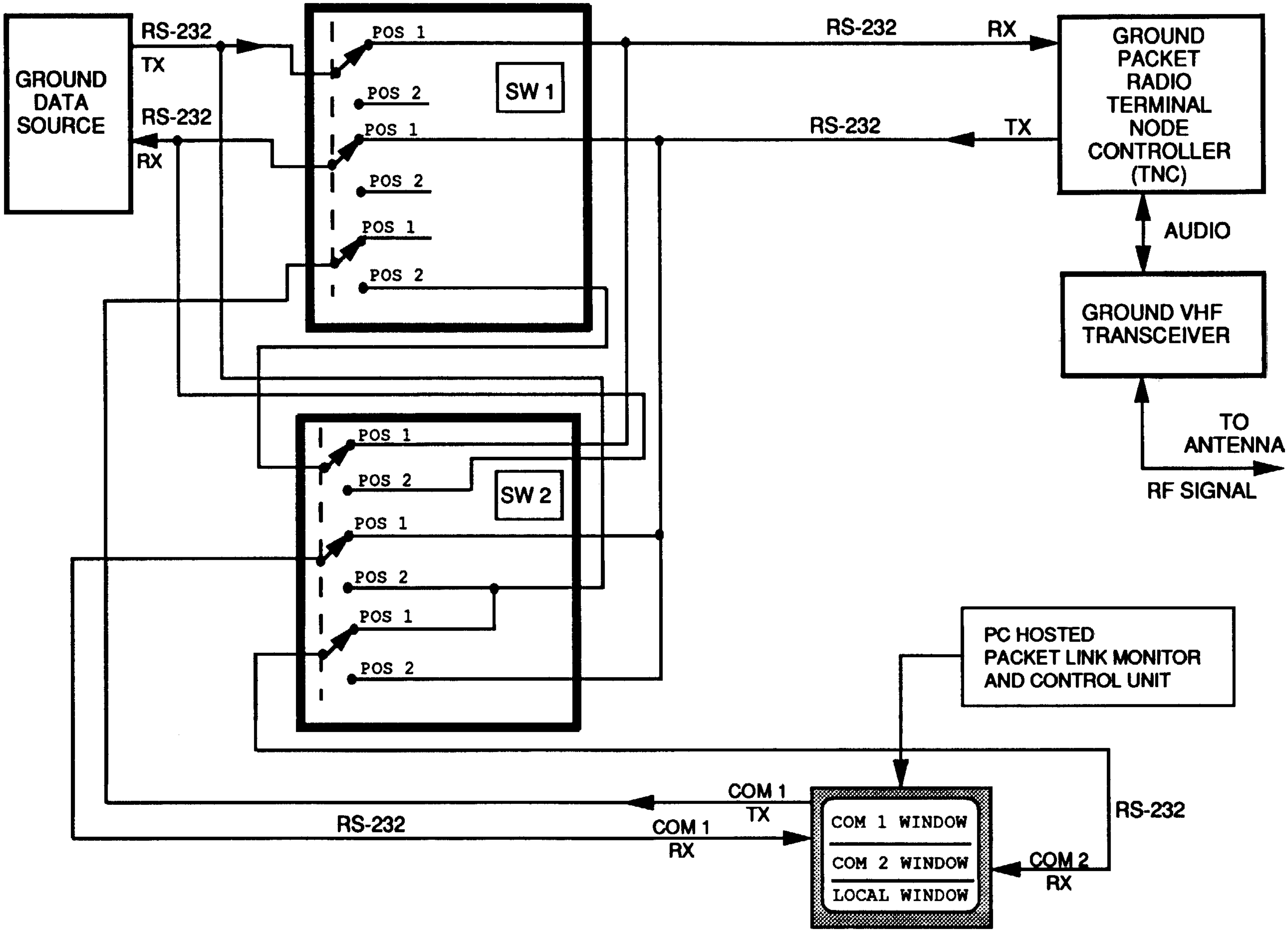



FIGURE 1. CONFIGURATION OF TSRV BASELINE GROUND PACKET DATA LINK STATION.

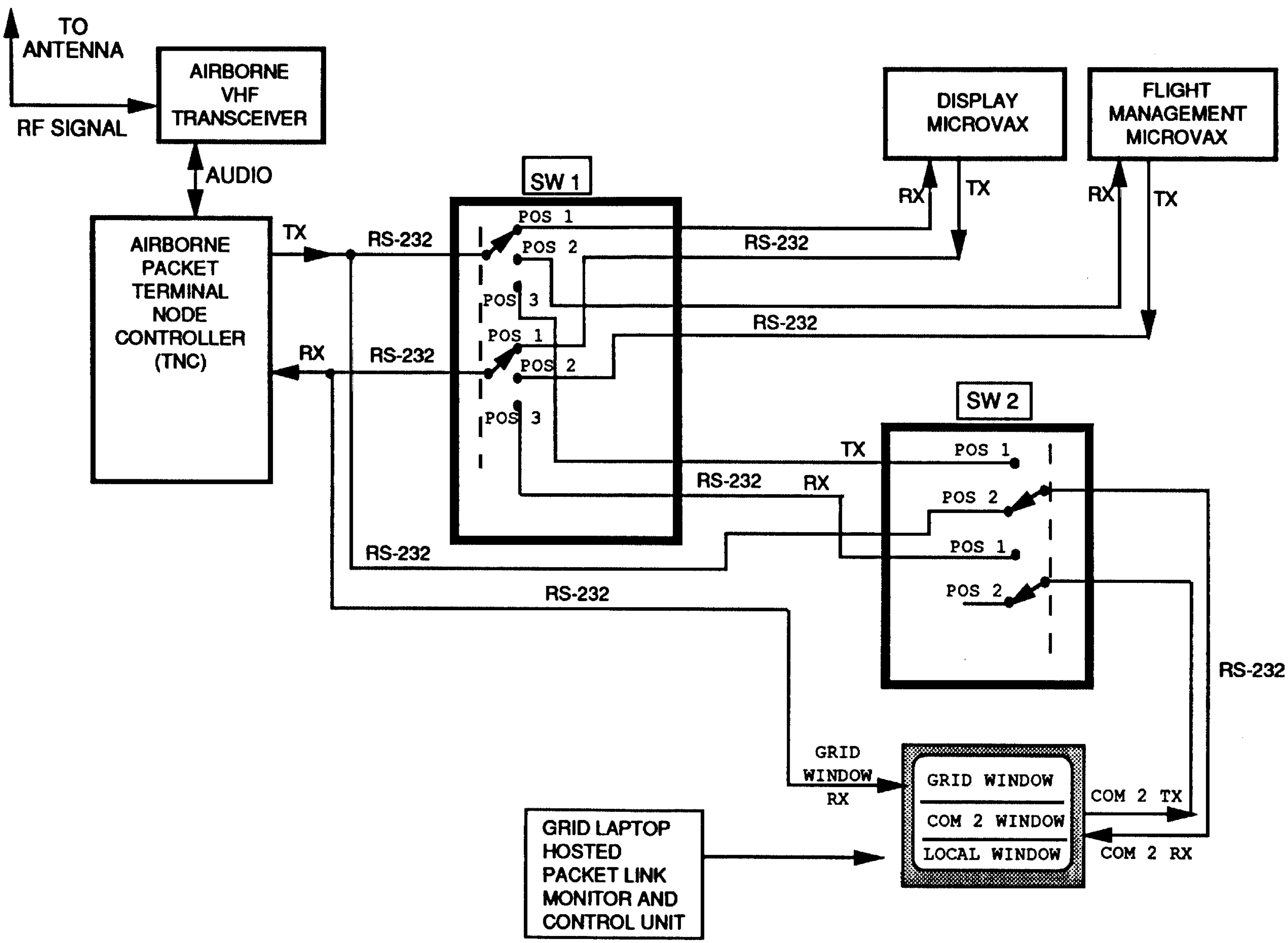



FIGURE 2. CONFIGURATION OF TSRV BASELINE AIRBORNE PACKET DATA LINK STATION.

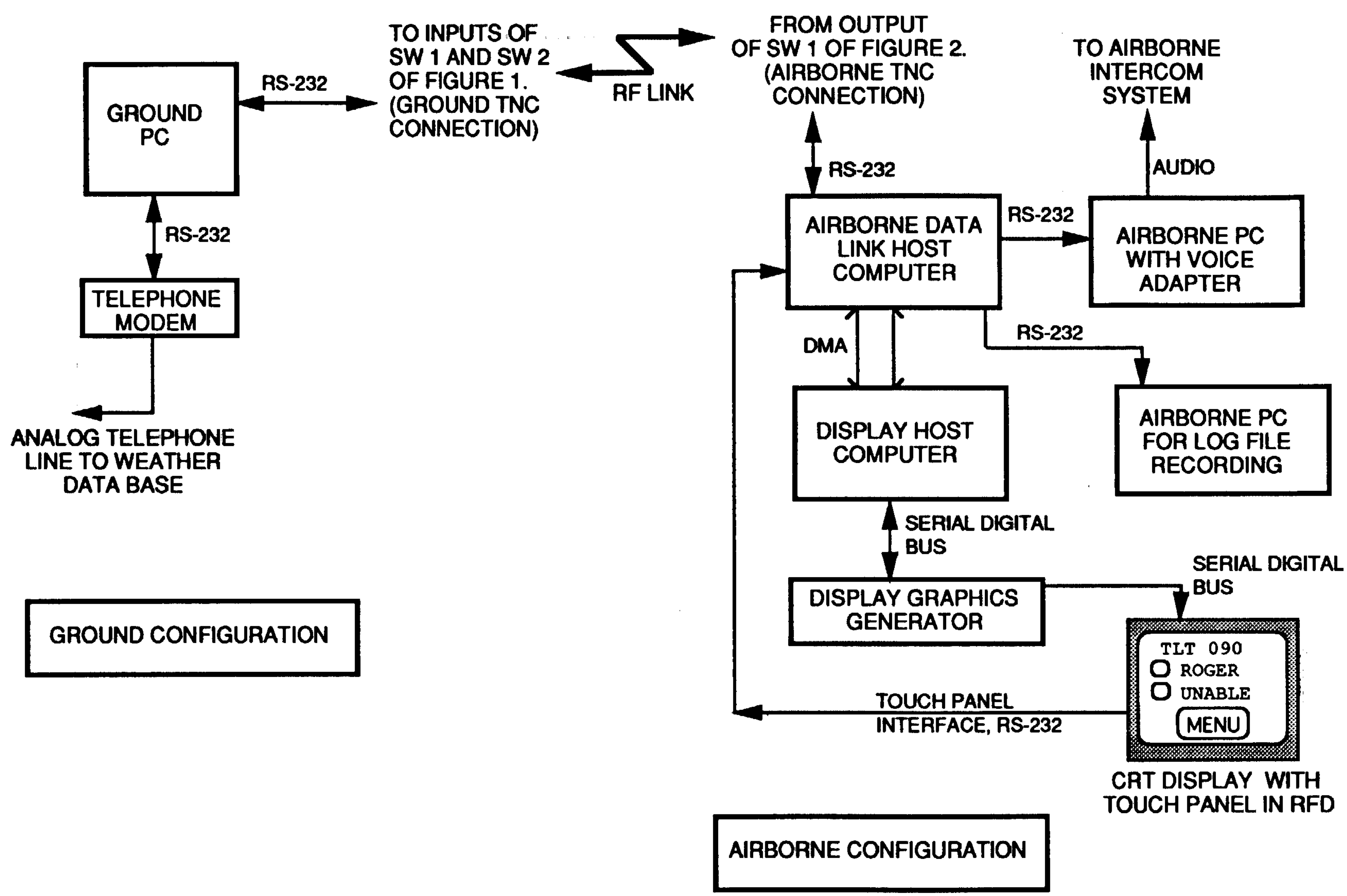



FIGURE 3. GROUND AND AIRBORNE CONFIGURATIONS FOR AIR TRAFFIC CONTROL AND WEATHER INFORMATION DATA LINK EXPERIMENTS.

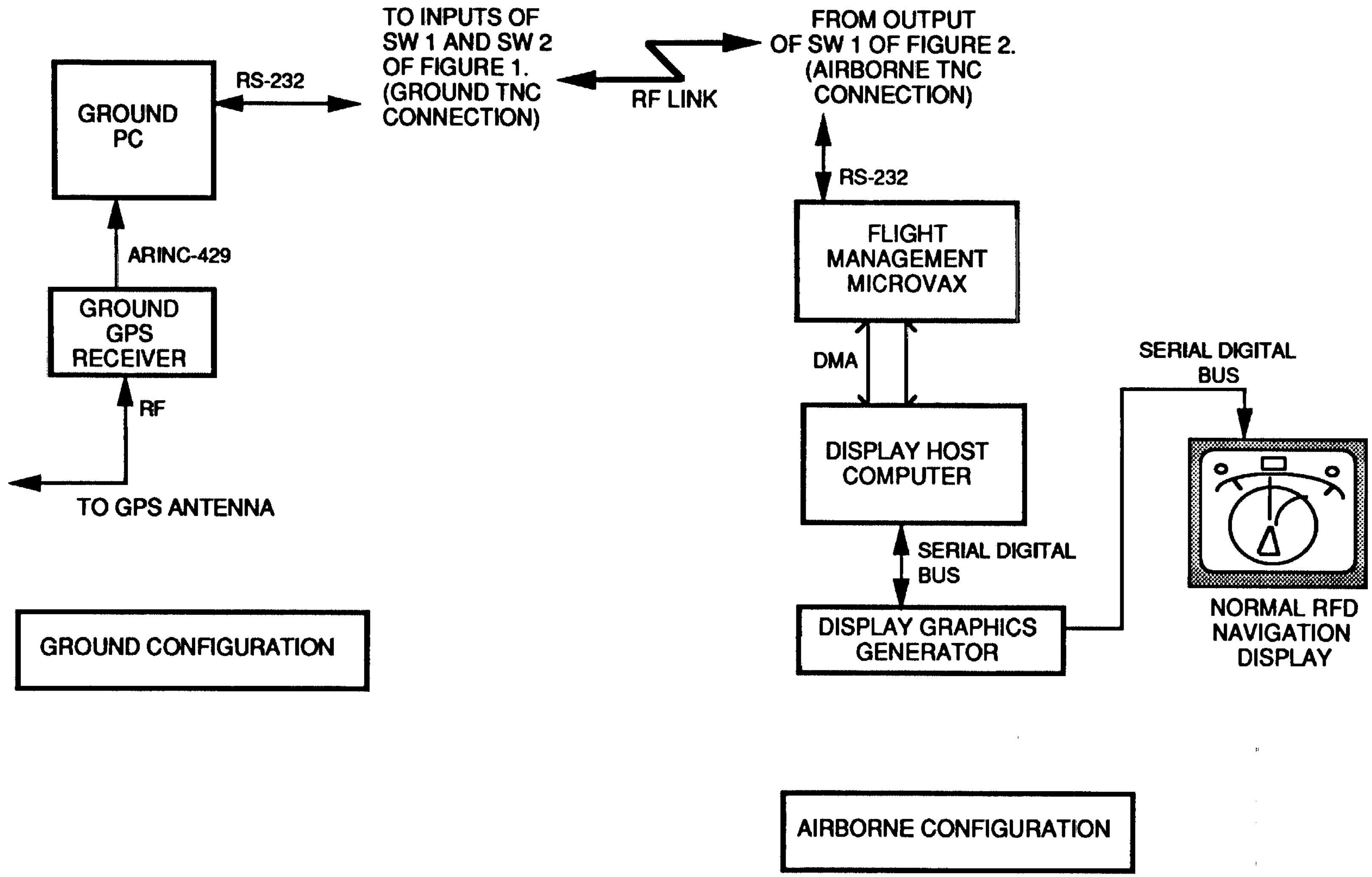



FIGURE 4. GROUND AND AIRBORNE CONFIGURATIONS FOR DIFFERENTIAL GPS DATA LINK APPLICATION.

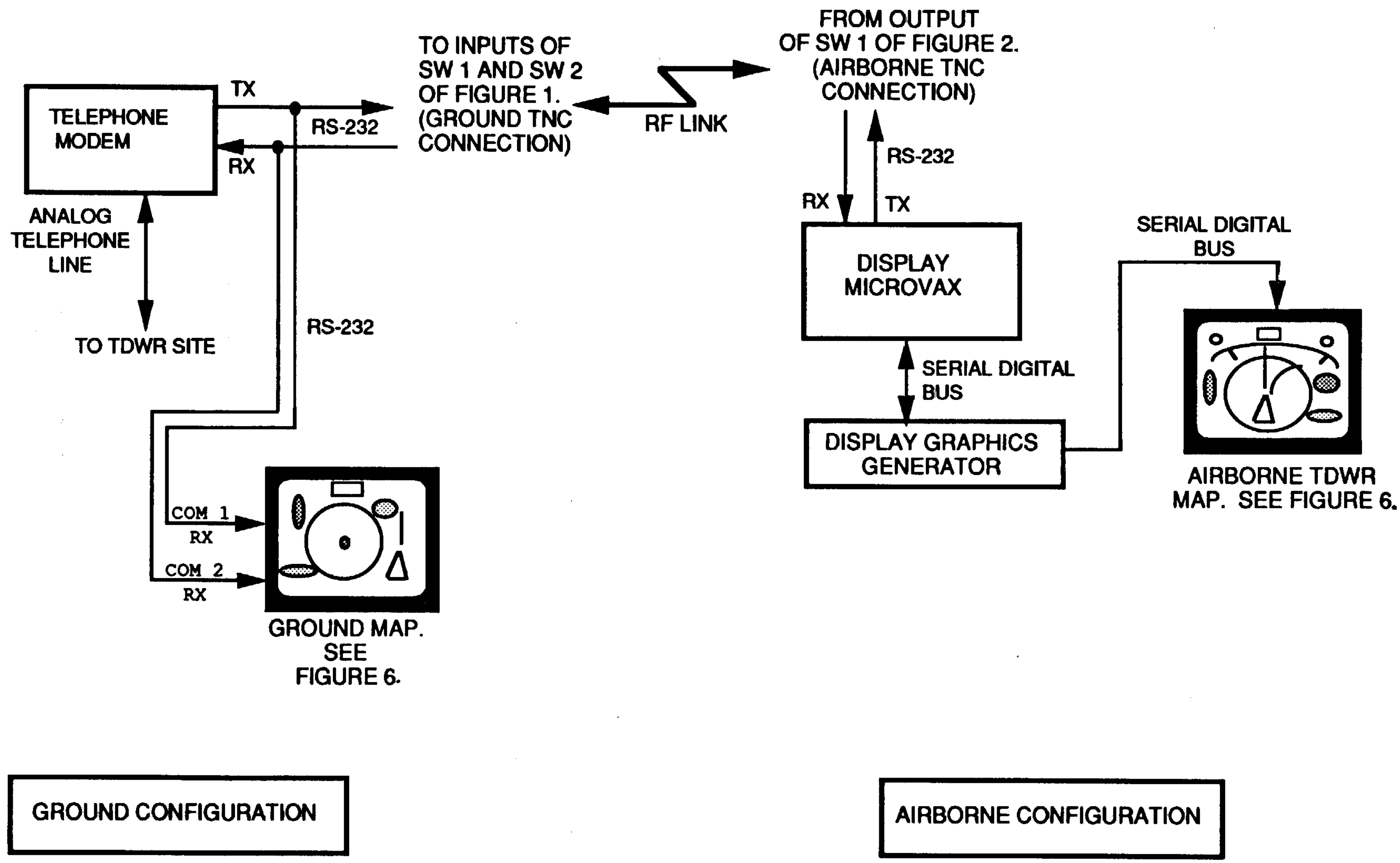
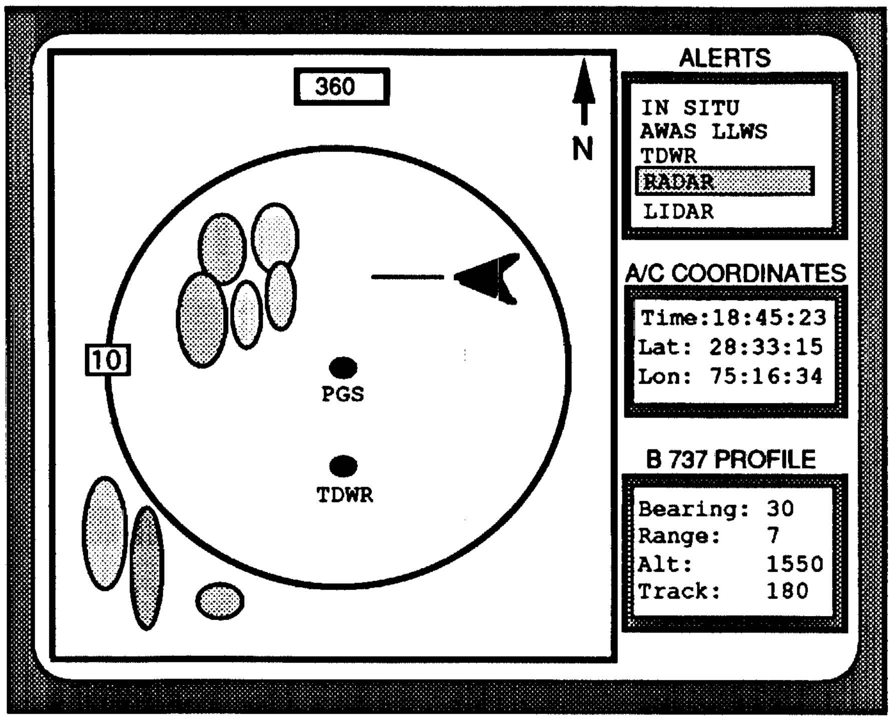
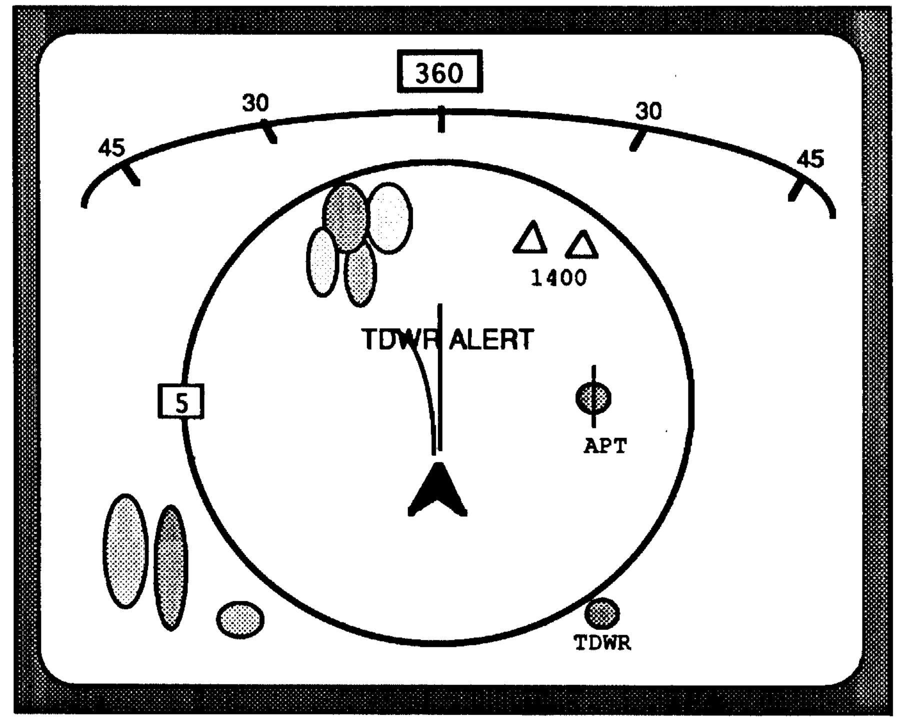



FIGURE 5. GROUND AND AIRBORNE CONFIGURATIONS FOR DATA LINK SUPPORT OF WINDSHEAR FLIGHT TESTS.




TDWR GROUND MAP ILLUSTRATION




TDWR AIRBORNE MAP ILLUSTRATION

FIGURE 6. ILLUSTRATIONS OF GROUND AND AIRBORNE MAP DISPLAYS FOR TDWR PACKET LINK DATA.

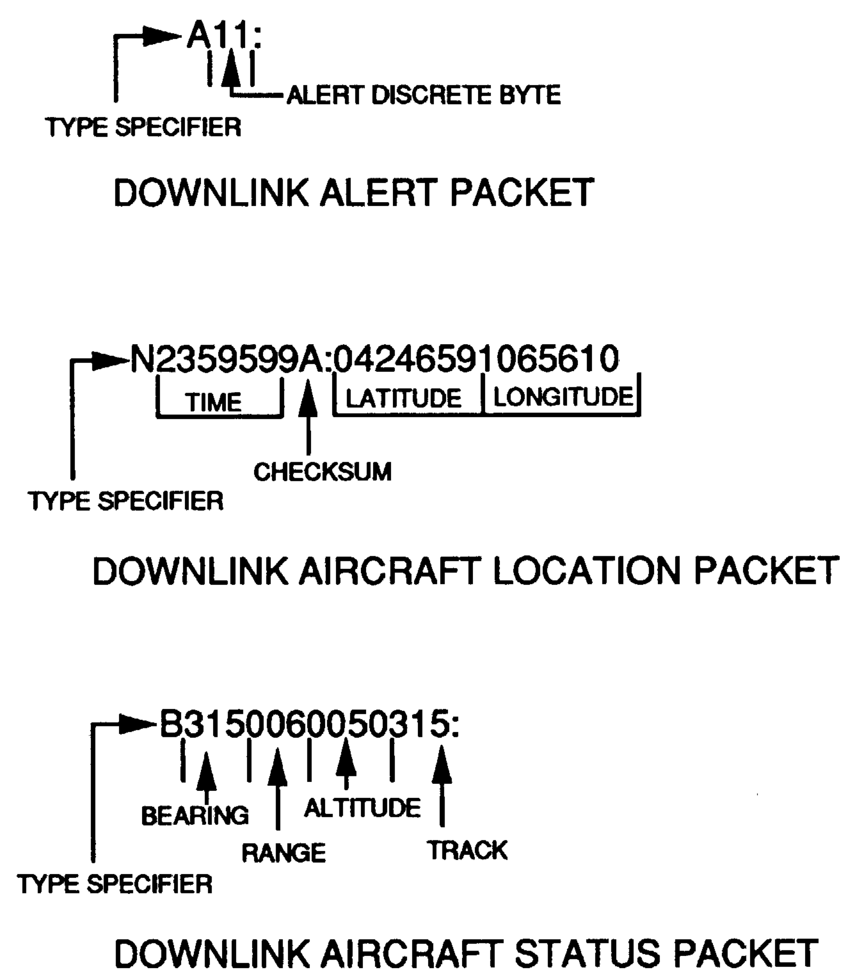



FIGURE 7. WINDSHEAR DOWNLINK MESSAGES ILLUSTRATING DATA PACKET CONFIGURATION.

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An amateur packet radio system operating in the Very High Frequency (VHF) range has been implemented in the Transport Systems Research Vehicle at the NASA Langley Research Center to provide an economical bidirectional real-time, ground-to-air data link. The packet system has been used to support flight research involving Air Traffic Control (ATC), Differential Global Positioning Systems (DGPS), and windshear Terminal Doppler Weather Radar (TDWR). A data maximum rate of 2400-baud was used.

Operational reliability of the packet system has been very good. Also, its versatility permits numerous specific configurations. These features, plus its low cost, have rendered it very satisfactory for support of data link flight experiments that do not require high data transfer rates.

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