AEROFLIGHT COMMUNICATIONS AND RF NAVAIDS

DOUGLAS S. LILLY
Lyndon B. Johnson Space Center
Houston, Texas

Summary. The Space Shuttle Program concept of a low cost, reliable and reusable orbital vehicle has proven to be a driving function in systems design and integration. Extensive use of existing designs to satisfy these requirements has been effectively employed in the aeroflight systems. Appropriate planning and a careful appraisal of maturity, cost, performance, vehicle burdens, and operational flexibility were completed prior to a system choice. The aerial navigation and landing systems selected for the orbital vehicle are described and their interfaces with the control and navigation system discussed.

Introduction. The Space Shuttle Orbiter vehicle atmospheric flight maneuvers are among the most critical performed during a nominal mission. The re-entering unpowered orbiter has a decreasing landing footprint and a rapidly increasing state vector error. Consequently, reliable and accurate position updates to correct the state vector for trajectory determination are of prime importance. To this end and with system costs in mind, a complement of aeroflight communication and RF navaids were selected from off-the-shelf (existing) hardware. A mixture of redundant systems and software is used to insure that the data eventually presented to the guidance system is reliable. In general, triple redundant systems that can be computer controlled are used in time critical maneuvers. The only navaid exception is the radar altimeter since a third functional (and independent) path is available by computation from the range and angle data of the landing system.

This paper first describes the operational use requirements and then describes the individual systems through the use of the system block diagram and functional interfaces. Redundancy management is not treated in depth but the following paragraph will serve as an introduction to that vital function.

Redundancy Management. The redundancy management is primarily a software routine to determine which sensor (or sensors) have correct data to within an allowed error budget. For triple redundant systems, this may be as simple as a vote (2-1). However, since failures must be expected additional criteria must be used. Accordingly, the following type of information and data are obtained, stored, and reviewed at each update by the redundancy management software routine:

1. Status at last self test
2. Reasonableness of data compared to last update and the stored state vector?
3. Previous determination of status?
4. Is system configuration correct?
5. Is other data from the system valid (agc, loop track valid, etc.)

Operational Requirements. The principal requirements and the selected systems are graphically presented in figure 1. The TAGAN (TACtical Aerial Navigation) R/T (receiver/transmitter) unit,RA (radar altimeter), MSBLS (microwave scanning beam landing system),and UHF transceiver constitute the operational hardware. A C-band beacon is used to provide the beacon track capability for the ALT (approach and landing tests) portion of the ground test program. The URF transceiver also functions as the receiver/ transmitter for a duplex EVA (extra vehicular activity) communication link.

TACAN is used immediately after re-entry blackout to interrogate ground stations for position information. This occurs around 150,000 feet altitude and a range to the landing field of about 280 nautical miles.

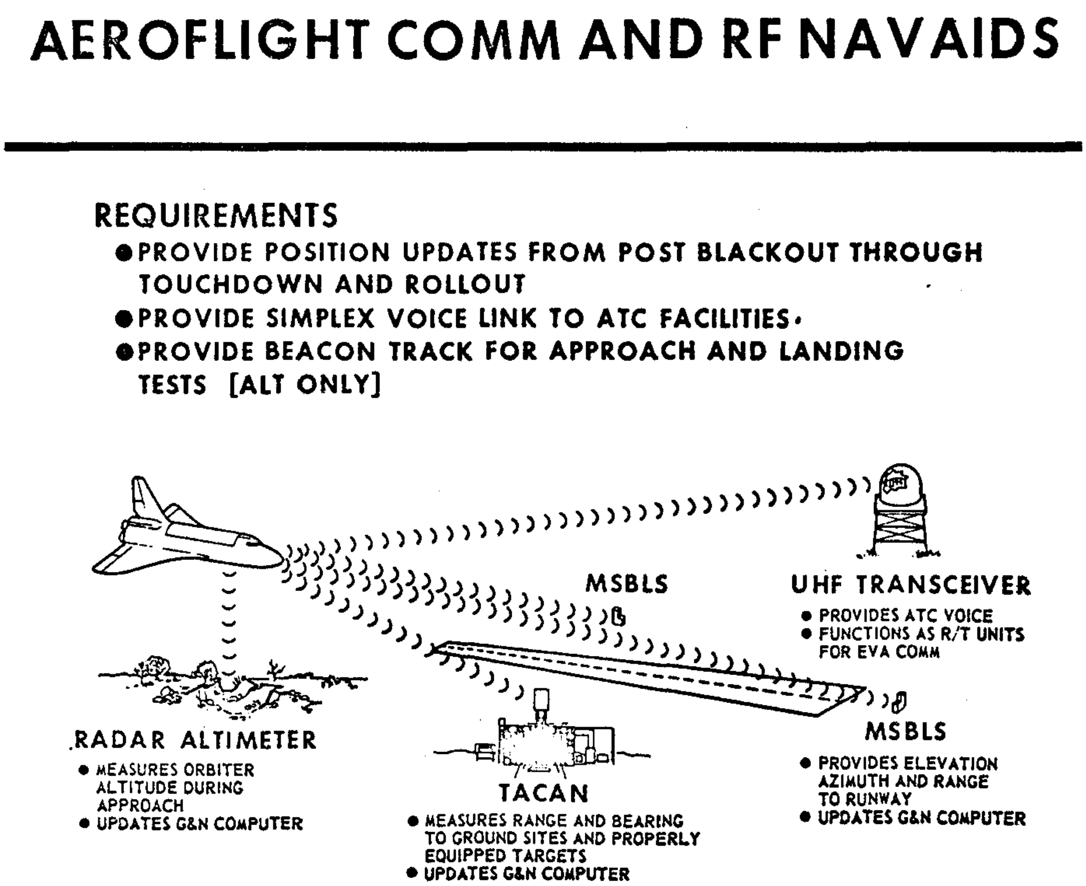


FIGURE 1 - OPERATIONAL REQUIREMENTS/SYSTEMS

Successive updates are used to further reduce the state vector error and provide guidance until the terminal area landing phase is initiated.

The MSBLS intercept occurs at around 12,000 feet and 8 nautical miles to touchdown. The MSBLS guidance signal is used to guide the Orbiter to the touchdown point and through rollout with the RA refining altitude information for flare maneuvers from about 2500 feet altitude to touchdown.

The UHF transceiver is in use throughout the atmospheric flight regime after blackout.

Systems Description. The block diagram (see figure 2) indicates the redundancy level and major interfaces. Note that parallel redundancy is maintained from antenna to data system interface. The MDM (multiplexer-demultiplexer) is an interface device between all data sources and the data bus (a party line type). The data bus interconnects the MDM's and the G&N (guidance and navigation) computer. The MDM designations--FF1, FF2, FF3 -identifies a particular unit

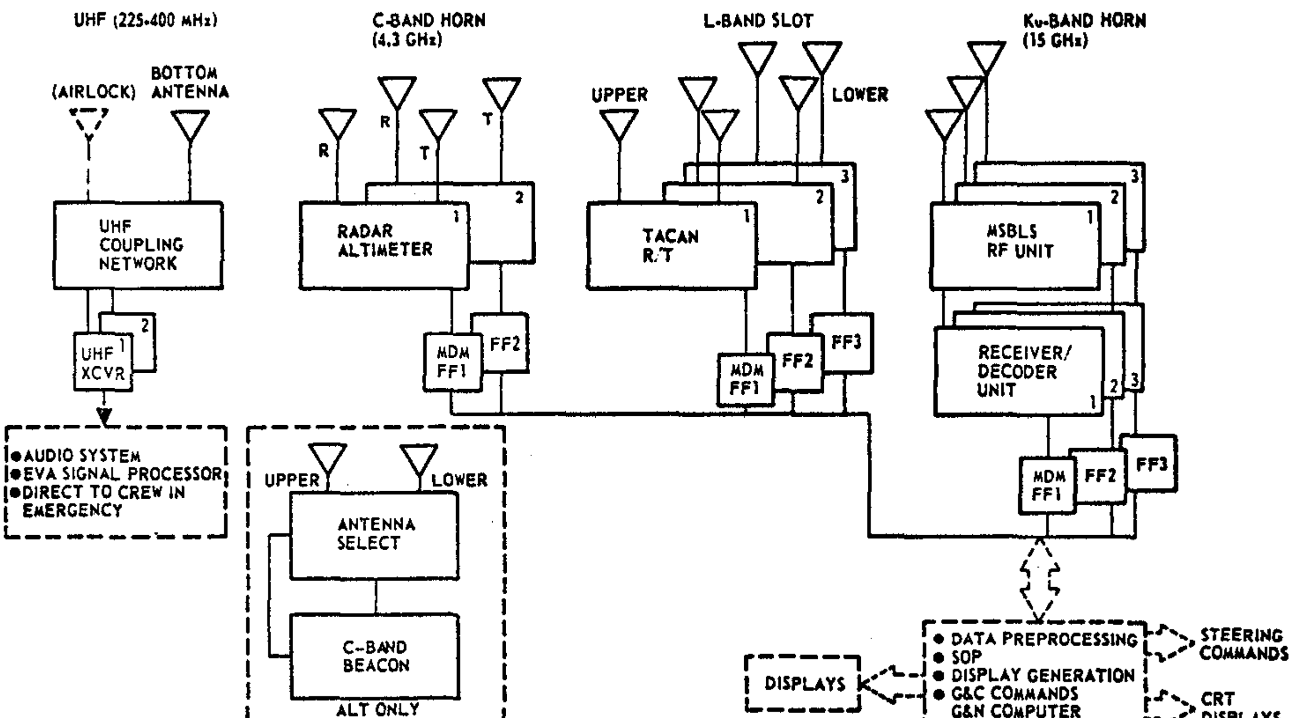


FIGURE 2 - BLOCK DIAGRAM

The G&N computer provides timing, sequencing, data preprocessing as required, SOP (subsystem operating program) execution for data manipulation failure detection, and isolation, as well as generating displays and the steering commands. There is no sensor data displayed directly to the cockpit indicators.

The UHF transceiver interfaces directly to the audio center but in an emergency or failure of the audio center can be directly switched to the crew. The transceivers can be connected to either antenna in a simplex mode for ATC voice or a duplex mode for the EVA communication link. In the duplex mode separate frequencies are used for transmit and receive and each transceiver can be either a transmitter or a receiver. Broadband noise generated by the transceiver acting as the transmitter is kept out of the complementary receiver by port-to-port isolation in the coupling network.

Figure 3 depicts the cockpit control console for the systems and figure 4 shows the displays. Separate controls are used for each redundant system but the IVISBLS and the TACAN display are time shared on the HSI (horizontal situation indicator). For the TACAN both range (DME) and bearing are displayed. The MSBLS angle data is converted to deviation from a selected glidepath for convenience to the crew in monitoring the autoland system or in manual landing mode. The MSBLS range data is dis1 ed in the same manner and lace as the TACAN range data.

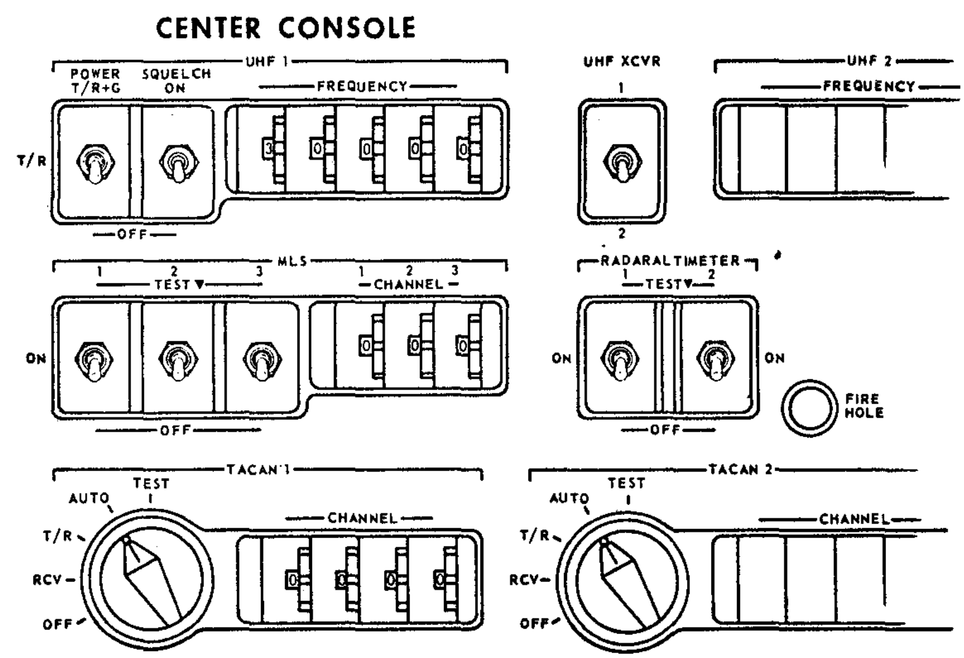


FIGURE 3 - CONTROLS

The RA data is displayed on the AVVI (Altitude Velocity Vertical Indicator) along with altitude rate and barometric altitude.

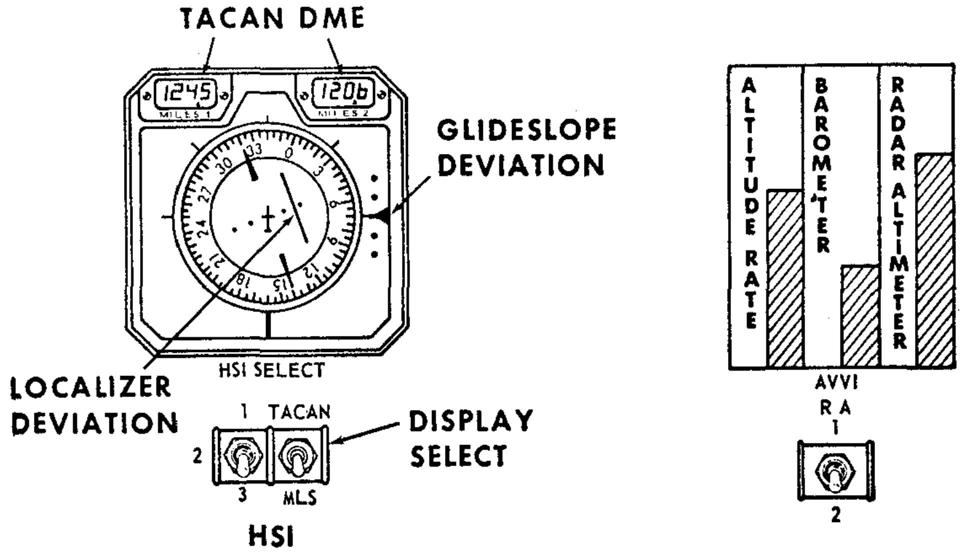


FIGURE 4 - DISPLAYS

UHF Transceiver. The UHF transceiver is a 7000 channel AM communications device similar to the ARC-150 used by the military. Modification extent has been limited to a reduction of transmit power in the EVA mode. Nominal power output is 10 watts but reduced to 0.5 watts for the EVA mode. Channel spacing is 25 kilohertz and the frequency, volume, squelch level, squelch on/off, guard receiver and power are all adjustable.

Radar Altimeter. The RA is a leading edge pulse type altimeter similar to the military APN-194. Only two level redundancy is used since altitude computed from the MSBLS is accurate enough to support all the maneuvers and software requirements except final flare (approximately the last 200 feet of altitude). Table 1 gives the RA performance characteristics. Functional interfaces (see figure 5a.) are straightforward. A special I/O (input/output) module sequences BIT (built in test) commands from either the control head or the data systems to the altimeter, converts the serial digital word to a data system compatible format, and interleaves the reliability signal. The reliability signal indicates proper range loop track. The “OF” MDM, different design from the “FF” MDM, performs a switch scan to determine its on-off status.

MSBLS The MSBLS airborne unit consists of an angle decoder, distance measuring equipment and an RF unit that transmits an interrogate pulse to the ground transmitting system. The design is based on the military ARQ-31. The ground system consists of an elevation angle transmitter on the side of the runway about 5000 feet from threshold (pavement end), an azimuth transmitter located at the end of the runway, and an interrogate reply unit located with the azimuth transmitter. The azimuth and elevation transmitters sequentially scan the required coverage volume with planar beams and transmit a pulse code modulated signal that uniquely defines its instantaneous pointing angle. As the planar beam scans by the airborne receiver it is detected and the pulse code translated into an angle. The scan occurs five times each second and covers 20° to either side of the runway and from 0 to 30° in elevation. The range measurement is a straightforward interrogate-reply process allotted a set time to occur during each total ground system scan. Table I gives the expected total system performance including both airborne and ground systems errors.

The MSBLS functional interfaces are shown in figure 5b. Power on and channel select (10 channels are available) are direct wired from the control head to the receiver/decoder unit. As with the RA, the BIT is routed through the MDM so that it can be accomplished by the data system as well as by the control head. Angle data, range data, and status is contained in 3 data words (16 bits each) which are sequenced by the MDM to the data system.

TACAN The TACAN unit is an airborne L-band receiver/transmitter with demodulating, decoding, and data computation capabilities for air navigation functions. It is based on the military ARN-84V. The airborne unit transmits to and receives from a ground navigation beacon a combination of pulsed signals conforming to MIL-STD-291, from which it derives and processes the information necessary to do the following:

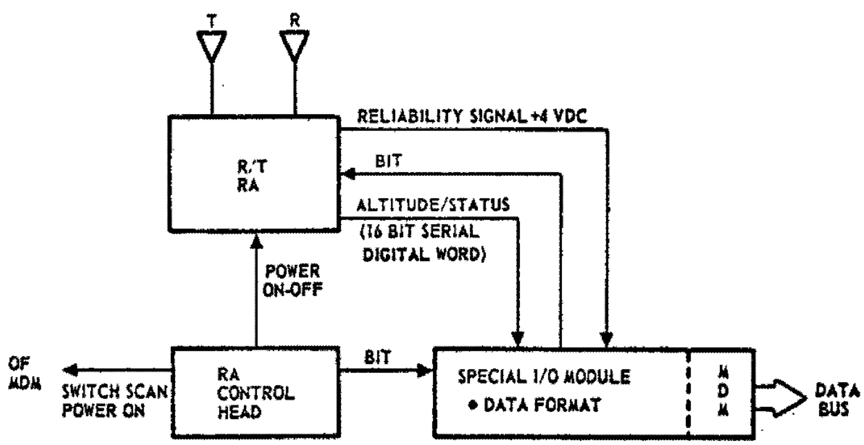
a. Provide bearing to the ground beacon
b. Provide slant range to the ground beacon in the T/R and AUTO modes (see figure 3)
c. Automatically select, for satisfactory performance, one of the two associated antennas in the RCV, or T/R mode (see figure 3)
d. Give an aural identification to the crew of the beacon to which the equipment is channeled.

There is also a capability to provide range data between two or more similarly equipped vehicles (air-to-air mode) but this is not presently implemented in the control loop. Table 1 gives the TACAN performance.

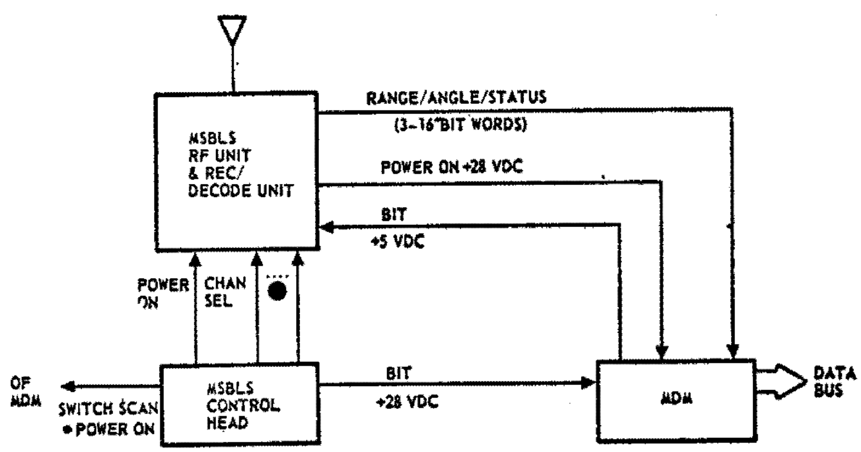
The TACAN functional interfaces are shown in figure 5c. Parallel inputs from the control head channel select, X-Y, AUTO, mode, and BIT are converted to a 16 bit serial control word by the special I/O module in the MDM. This module also converts the 32 bit ternary data word coming from the TACAN unit into the Manchester biphase format used in the data system. Suppression pulses are interconnected to all three TACAN units to keep multiple interrogations from occurring simultaneously.

TABLE 1 - RF NAVAIDS PERFORMANCE

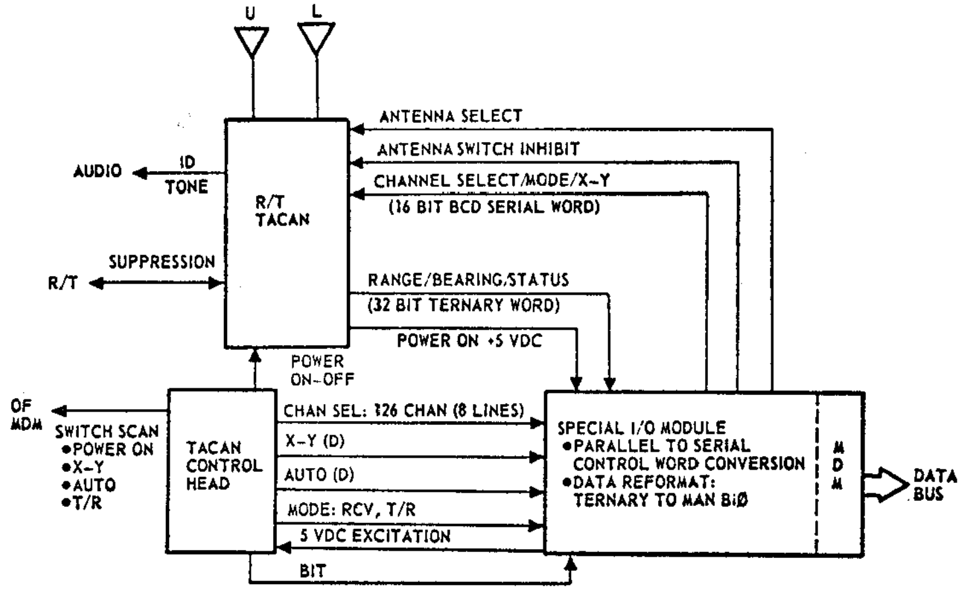
	RANGE	ACCURACY (1σ)
TACAN	300 N. MI (MIN)	50 to 300 N.Mi-0.1 N. MI <50 N. Mi. - 0.05 N.Mi.
MSBLS	10 N. Mi. (MIN) In 10 mm/HOUR Rain	<100 Ft. in Range <0.03° in Elevation <0.05° in Azimuth
RA	2500 Ft. (MIN)	3 Percent or 1.5 Feet (Whichever is Greater)



5a - RADAR ALTIMETER



5b - MSBLS



5c - TAGAN

FIGURE 5 - FUNCTIONAL INTERFACES

Conclusions. The Space Shuttle Orbiter atmospheric flight systems represent an adaptation of existing designs to a new application. Fortunately, design improvements have been held to a minimum with no new concepts or extensive modifications required that might compromise previous system experience or qualification status. Performance also mapped quite well into anticipated requirements.

Where possible, the newest concepts have been utilized - digital designs, serial digital control, etc. - and integration of software and hardware has been accomplished to control and manage time critical processes such as BIT and redundancy management.