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and Space Administration

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DIVERSITY TECHNIQUES FOR OMNIDIRECTIONAL TELEMETRY COVERAGE OF THE HiMAT RESEARCH VEHICLE

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INTRODUCTION

Under the joint auspices of the National Aeronautics and Space Administration and the U. S. Air Force, two highly maneuverable aircraft technology (HiMAT) remotely piloted research vehicles (RPRV's) were constructed to investigate technological advances in aerodynamics, advanced composite and metallic structures, digital fly-by-wire controls, and digitally implemented integrated propulsion control systems (IPCS). The HiMAT RPRV (figs. 1 and 2) is a 0.44-scale version of an envisioned full-scale fighter aircraft with 8g sustained turn capability at a Mach number of 0.9 and an altitude of 7600 meters (25,000 feet). The HiMAT RPRV was built under contract and delivered to the NASA Dryden Flight Research Center for flight testing.

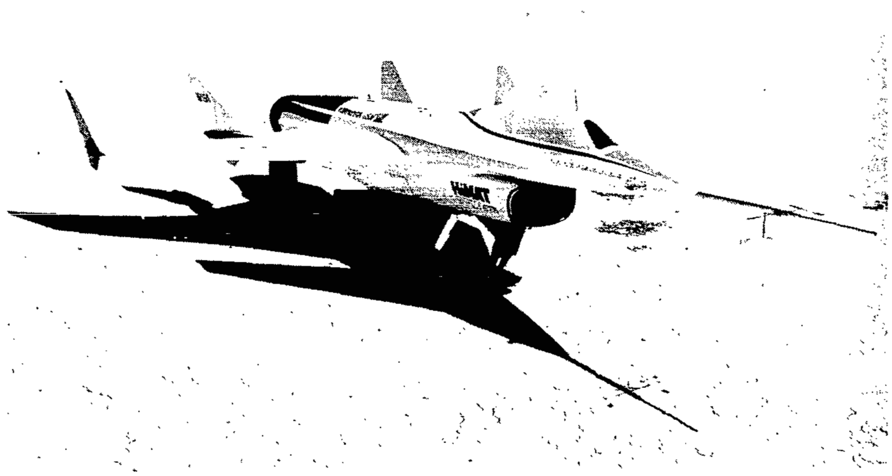


Figure 1. HiMAT RPRV on Edwards dry lakebed.

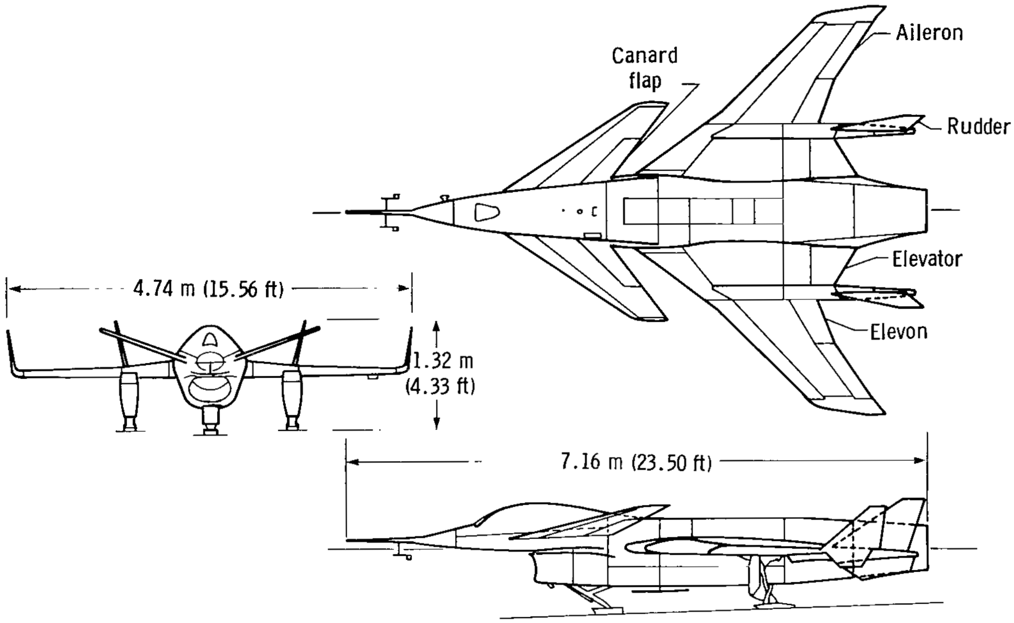


Figure 2. HiMAT control surfaces and vehicle dimensions.

The operational concept for the HiMAT vehicle is similar to that for previous RPRV's flown at Dryden (fig. 3). The vehicle is flown under the control of a test pilot who sits in a ground-based cockpit. The vehicle is equipped with landing skids for horizontal recovery.

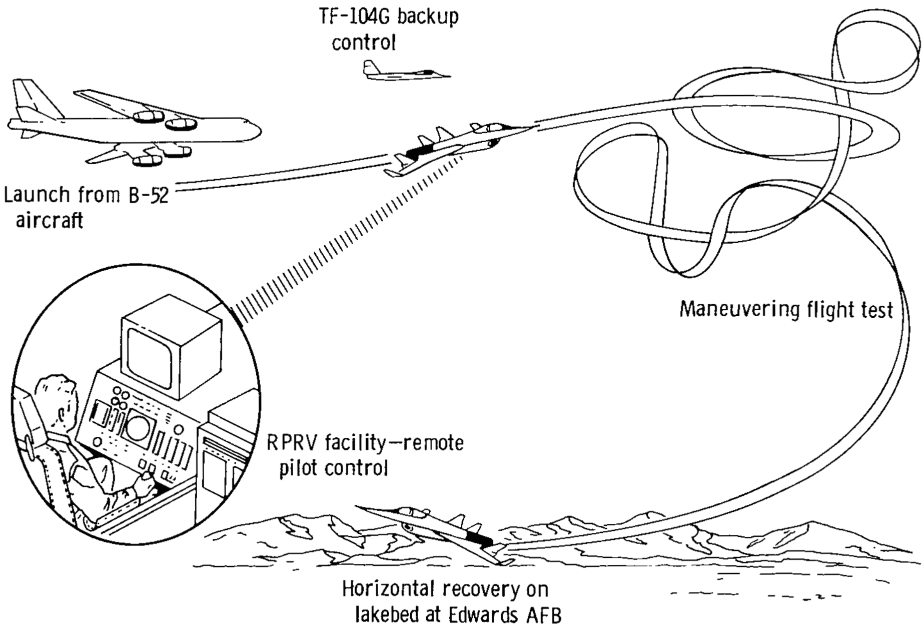


Figure 3. Operational concept.

The HiMAT RPRV operates in two control system modes, primary and backup. A simplified version of the HiMAT control system is shown in figure 4; a complete description is given in reference 1. In the primary mode of operation, data from aircraft sensors are transmitted to the ground by means of a pulse code modulation (PCM) telemetry downlink. The downlinked information is used to operate the ground cockpit instruments and to make inputs to the ground-based control law computer.

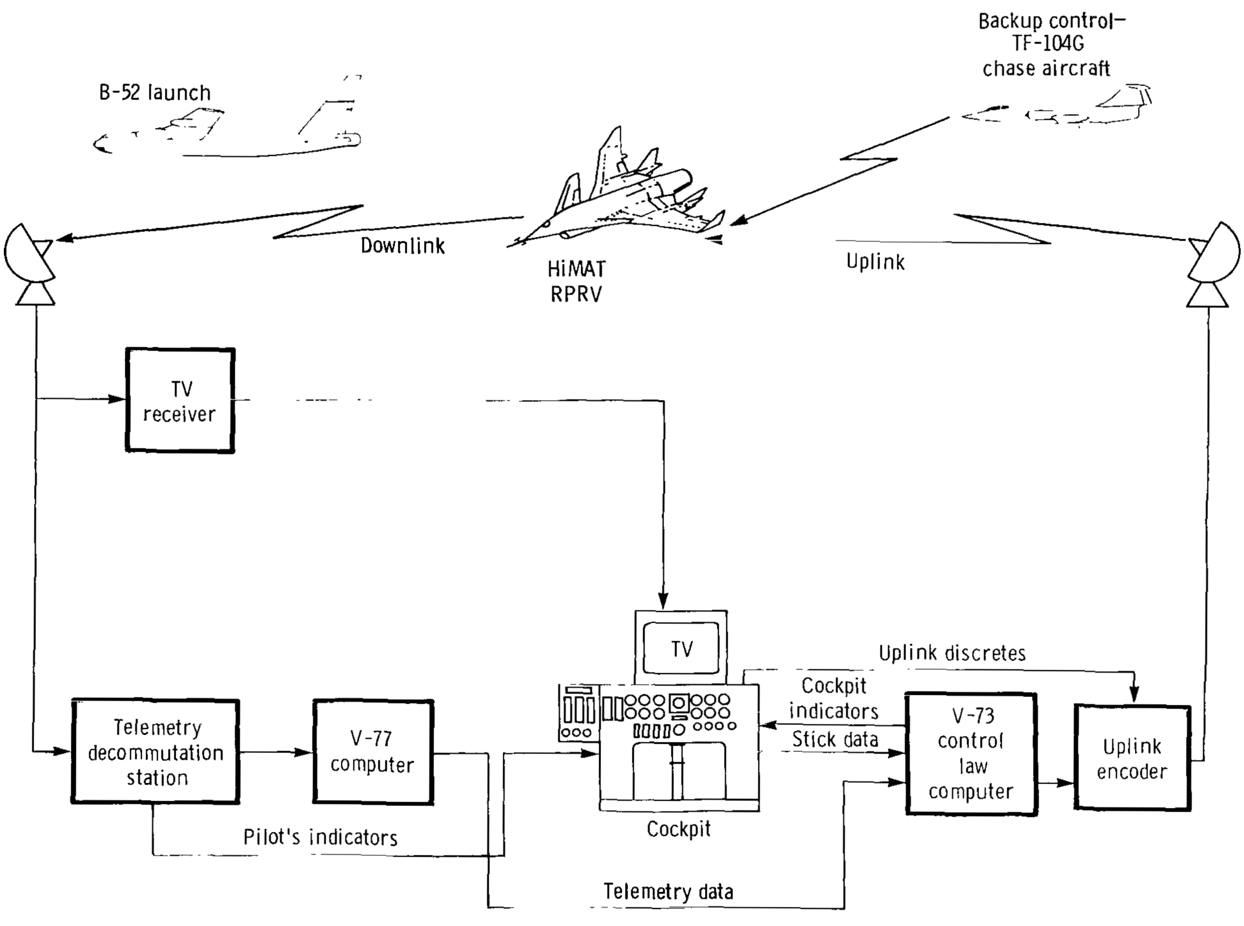


Figure 4. Control system.

The ground cockpit (fig. 5) contains a standard three-axis pilot input control system consisting of a stick, rudder pedals, and a throttle. The control law computer combines the pilot input commands with the aircraft sensor data in the execution of the HiMAT control laws and generates servoactuator commands for the HiMAT vehicle control surfaces. These surface commands are multiplexed by the uplink encoder system and transmitted to the aircraft, where they are processed by two command decoders. The vehicle responses are then fed back to the ground-based RPRV system.

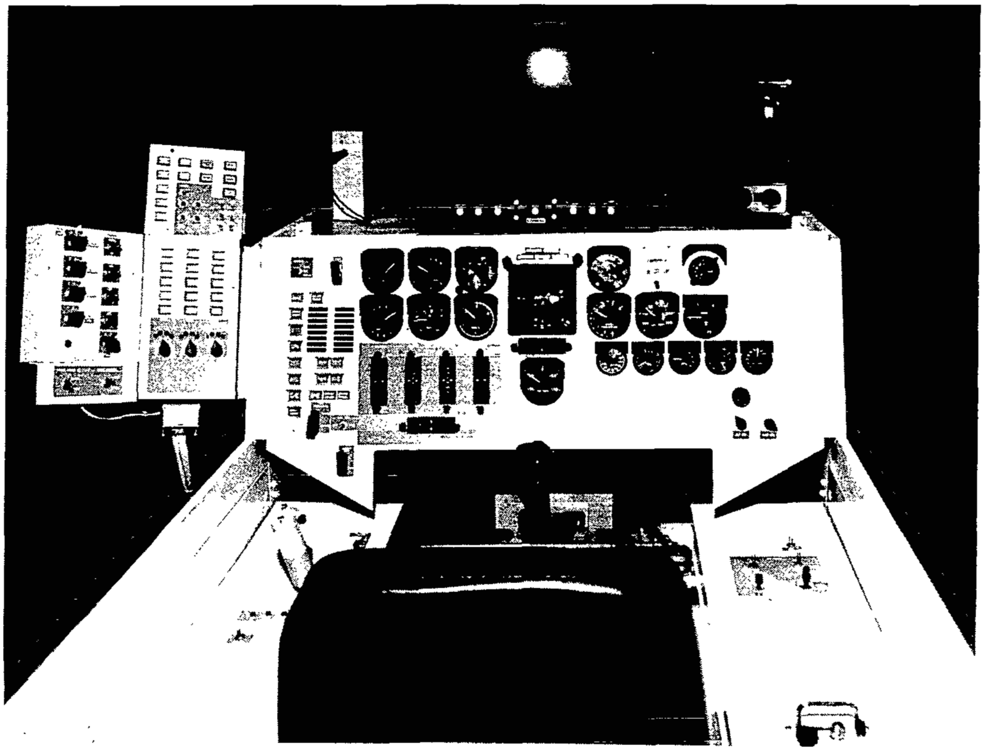


Figure 5. Ground cockpit.

Because control augmentation is critical to flight safety, a backup control system (BCS) is provided by an onboard computer to fly the aircraft in the event the ground-based RPRV system is lost. The BCS, which can take control of the vehicle either automatically or by way of ground pilot command, is designed to recover the vehicle from any unusual attitude after a malfunction in the primary control system. Using a BCS control panel, a controller can issue discrete commands to the HiMAT vehicle from either the ground cockpit or from the back seat of the TF-104G chase aircraft. Using these commands, the controller can fly the HiMAT aircraft back to the lakebed used for landing (for this test series, Edwards dry lakebed).

In either control mode it is vital to have uplink and downlink communication at all times and at all aircraft attitudes during flight. This paper discusses the approach and testing used to fulfill this requirement.

HiMAT TELEMETRY SYSTEMS

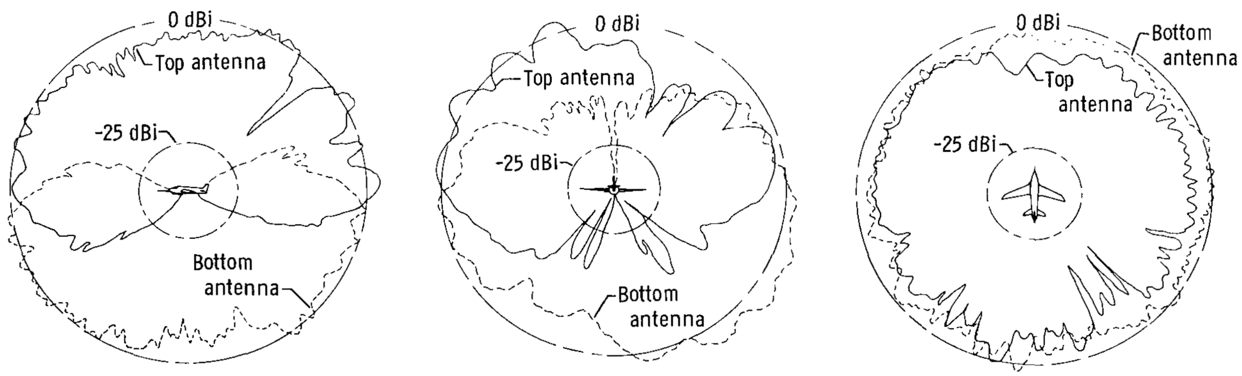
The HiMAT telemetry antennas are quarter wave stubs that are sloped 45° to radiate frequencies that are polarized horizontally and vertically. In the original vehicle design there was a single lower antenna for downlink transmission (at 1441.5 MHz) and there were two antennas, upper and lower, for uplink reception (at 1804.5 MHz). Each uplink antenna fed one receiver; the receiver with the most signal strength was selected by the onboard computer to feed two command decoders. The onboard computer selected the receiver on the basis of carrier loss signals from each receiver and then issued a command to a relay, which switched the receiver output as required. Before flight testing began, an analysis was made of the radio frequency power budgets (table 1) and antenna patterns associated with these antenna

TABLE 1.—RADIO FREQUENCY POWER BUDGETS
[Uplink frequency is 1804.5 MHz; downlink frequencies are 1441.5 and 1452.5 MHz]

	Uplink	Downlink
Power losses—		
Path loss at range of 112 km (70 miles), dB	-137	-139
System losses (estimated), dB	-6	-6
Total losses, dB	-143	-145
Power gains—		
Transmitter power[1], dBm	50	36
Transmitting antenna gain, dB	38	0
Receiving antenna gain, dB	0	31
Gain of preamplifier at receiving antenna, dB	---	25
Total gains, dBm	88	92
Signal level at receiver (gains minus losses), dBm	-55	-53
Receiver threshold, dBm	-93	-105
Margin (signal level at receiver minus receiver threshold), dB	38	52

[1]At 100 watts for uplink, 4 watts for downlink.

locations and telemetry frequencies. Representative antenna patterns are shown in figure 6. Since the uplink and the downlink patterns are similar, only one set is shown. For uplink reception visualization the upper and lower patterns would be used. For downlink transmission visualization only the lower patterns would be used.



(a) Pitch plane. *(b) Roll plane.* *(c) Yaw plane.*

Figure 6. Antenna patterns typical of uplink and downlink transmission.

With regard to the single bottom antenna for downlink transmission, the analysis suggested that any extensive maneuvering would at some time cause the attenuated radiation area or null at the top of the aircraft to be directed toward the telemetry-receiving antenna. Even with a 52 decibel margin, it seemed probable that there would be periods of signal loss, and it was decided that this problem would ultimately have to be resolved. The uplink antenna-switching scheme was considered practicable from the standpoint of signal strength, since presumably one signal or the other would be strong enough, but marginal from the standpoint of mechanical implementation, since it was not known how much time would be necessary to resynchronize the airborne command decoders with the ground station decommutator should a switch occur. However, the original uplink system was left unaltered for the vehicle's first three flights, since these flights did not exercise the full maneuvering capabilities of the aircraft.

IMPLEMENTATION OF DIVERSITY CONCEPT FOR DOWNLINK SIGNAL

Because of the reservations described above about the original downlink design, several other ways to obtain full downlink telemetry coverage were considered. While it is possible to obtain reasonable omnidirectional coverage with one antenna by using a wraparound microstrip array (ref. 2), it was not feasible to modify the HiMAT vehicle to the extent necessary to install one. Installing an additional upper antenna and splitting the transmitter output to both antennas was ruled out because of the so-called interferometer effect: nulls or gaps in telemetry coverage caused by the reinforcement and cancellation of radiation that occurs when two antennas are radiating in the same direction and at the same frequency.

Another solution, the one eventually adopted, was to take advantage of the frequency polarization feature of the ground telemetry autotrack antenna (fig. 7). Normally two receivers are used for each telemetry frequency, one for either horizontal or right circular polarization and the other for vertical or left circular polarization. The outputs of both receivers are then combined in proportion to the relative signal strengths of each receiver to present one PCM bit stream or video output to the decommutation station. In order to take advantage of these characteristics to achieve complete radiation coverage, an additional upper antenna was installed in the HiMAT vehicle and the PCM bit stream was transmitted on two different frequencies (to escape the interferometer effect), one from each antenna. By tuning one receiver to each frequency and using the combining feature of the system, complete radiation coverage was obtained (fig. 8). Each receiver had a different antenna polarization feed, but no problem was anticipated because of the close ranges involved and the cross-polarization of the transmission from the aircraft.

Before this concept was implemented for the HiMAT vehicle it was flight tested on a T-37 utility aircraft, with excellent results. Wing rocking maneuvers and minimum radius turns were performed at ranges of 112, 80, and 40 kilometers (70, 50, and 25 miles), all at an altitude of 7600 meters (25,000 feet).

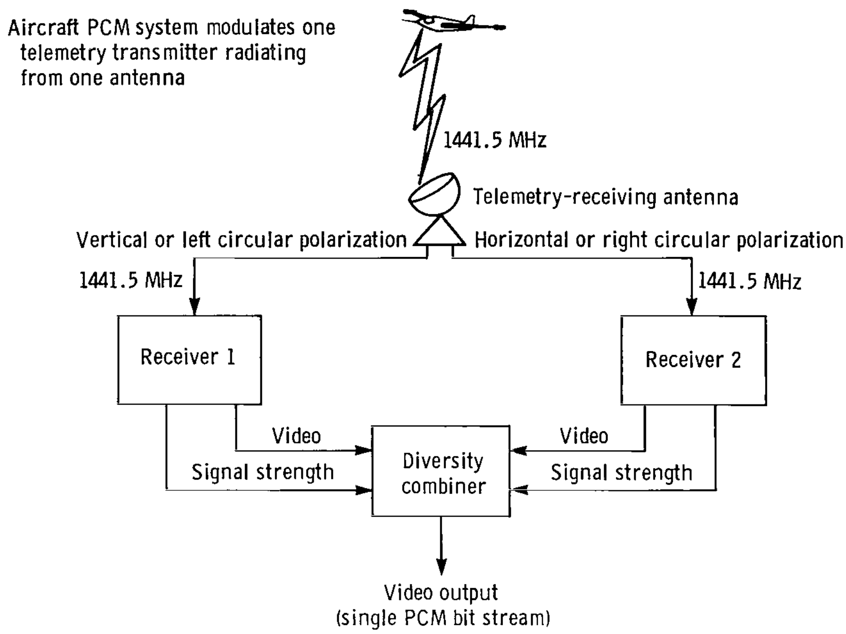


Figure 7. Standard frequency polarization system.

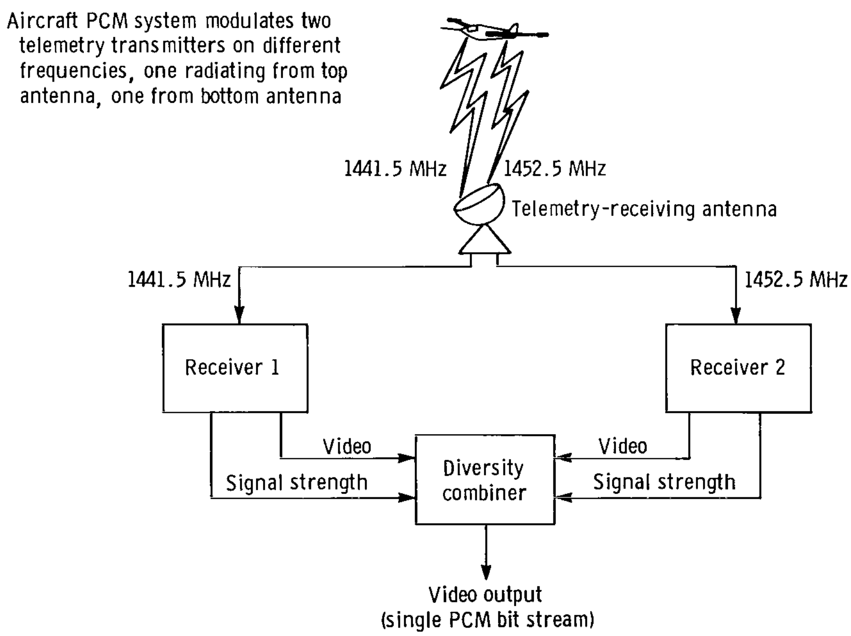
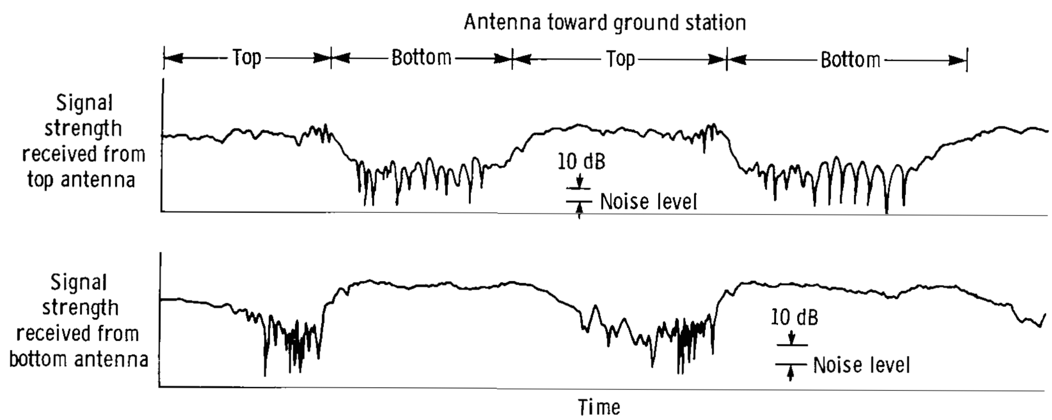


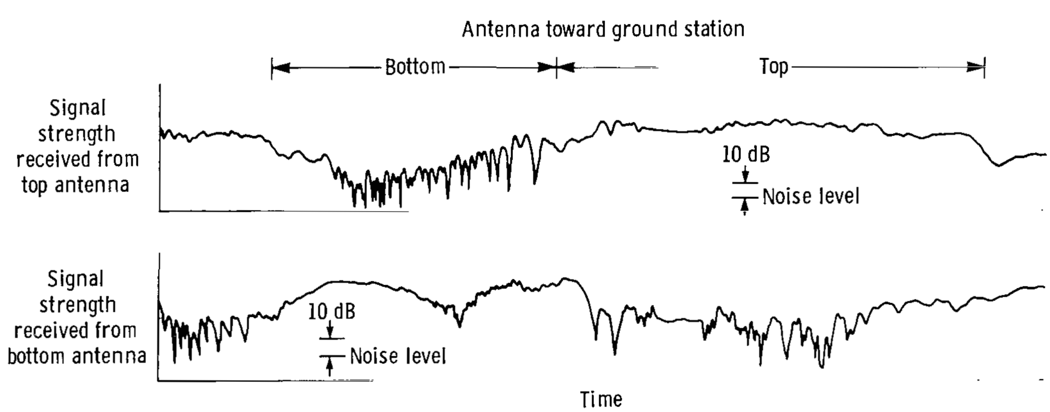
Figure 8. Diverse frequency system as implemented for HiMAT downlink transmission.

Figures 9(a) and 9(b) are strip chart recordings of the relative signal strengths of the top and bottom antennas during a typical maneuver. A signal strength of 10 decibels above noise level was experimentally determined to be the approximate point at which the PCM decommutator began to exhibit synchronization loss. As the figures show, the signal strength from one antenna or the other dropped well below this point during the tests. Decommutator synchronization status was monitored at those times, and the combined PCM signal showed absolutely no loss of synchronization, demonstrating 100 percent radiation coverage.

During these tests, the telemetry receiver antenna was operated in the autotrack mode using right and left circular polarization feeds to provide better balance in the signal strengths. The signal strength filter time constants were decreased in the



(a) Flightpath perpendicular to line of sight from tracking antenna, wings rocked to expose top and bottom of aircraft.



(b) Minimum radius turn at bank angle of ≈80°.

Figure 9. Signal strength of top and bottom antennas during T-37 maneuvers 112 km (70 miles) from receiver antenna. Altitude = 7600 m (25,000 ft); signal strength at receiver is 1480.5 MHz for top antenna, 1441.5 MHz for bottom antenna.

receivers that operated the combiner used for data to achieve faster response if one receiver suddenly lost signal. Two other receivers that had the original time constants and were tuned to the same frequency were used to operate the antenna autotrack feature.

Because of the success of these tests a top antenna radiating at 1452.5 megahertz was installed on the HiMAT vehicle (fig. 10). The total continuous radiation pattern was then similar to the combination of the upper and lower antenna patterns in figure 6. This system was implemented during the first three flights of the HiMAT vehicle, and no interruptions in downlink telemetry occurred.

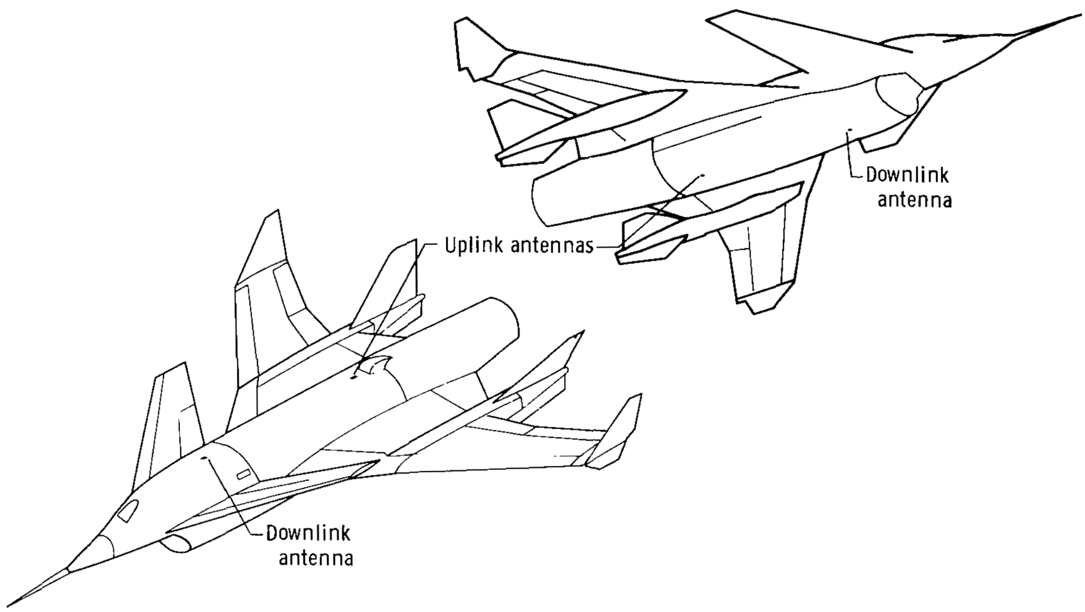


Figure 10. HiMAT antenna locations.

IMPLEMENTATION OF DIVERSITY CONCEPT FOR UPLINK SIGNAL

During the windup turn and banking maneuvers that were made during the vehicle's first 3 flights, there were 15 transfers from the primary to the backup control mode because either or both command decoders in the vehicle received inadequate uplink signals. To improve uplink reception in the aircraft, it was decided to adapt the downlink diversity concept to this application.

To implement the concept, the two existing uplink antennas were used, and instead of switching control from one to the other, their signals were combined continuously. An inspection of the diversity combiner used with the tracking antenna receivers (fig. 11) revealed that the actual combination of the receiver outputs was done on a single printed circuit card. Furthermore, the slopes of the signal strengths from the receivers on board the HiMAT vehicle were compatible with the operation of the card.

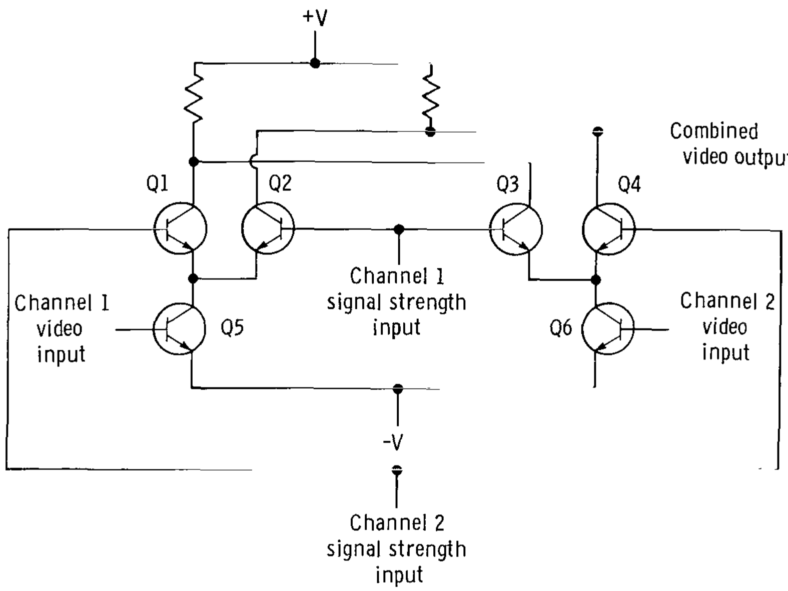


Figure 11. Schematic of diversity combiner.

As shown, the video inputs are applied to the bases of the current sources Q5 and Q6, and the signal strength voltages are applied to the bases of the differential stages Q1 through Q4. Under ideal conditions the signal strength inputs are at equal levels, signifying equal signal levels in both receivers, and each video input contributes 50 percent to the combined video output signal. If one of the signal strength inputs increases, indicating that that channel is receiving a stronger signal, the proportion of the contribution of the corresponding video channel to the combined video output also increases. For example, if the signal strength of channel 1 increases, transistors Q2 and Q3 draw more current and Q1 and Q4 draw less current. Under these conditions, the channel 1 video input, which is applied to current source Q5, contributes a larger proportion to the combined video output. When the differential between the signal strength inputs reaches approximately 20 dBm, the channel with the higher signal strength voltage contributes 100 percent of the output signal.

As stated above, the HiMAT uplink diversity system used two receivers, one each for the upper and lower aircraft antennas. Unlike the downlink implementation, a single transmitter on the ground sent a single frequency to both aircraft antennas. The receiver video outputs were then combined in proportion to their signal strengths on the combiner card. This card was like the one used for the downlink telemetry system except that it was made more rugged to enable it to withstand the airborne environment. In principle, the output of the combiner, which is always present as long as one antenna is receiving a signal, is then fed to the command decoder. In practice, two combiners (one for each decoder) and buffer circuits were utilized to satisfy HiMAT redundancy requirements (fig. 12). The complete unit was environmentally tested for operation at altitudes up to 24,400 meters (80,000 feet), temperatures from -50° C to 10° C (-60° F to 160° F), and vibration of ±8g's in all axes.

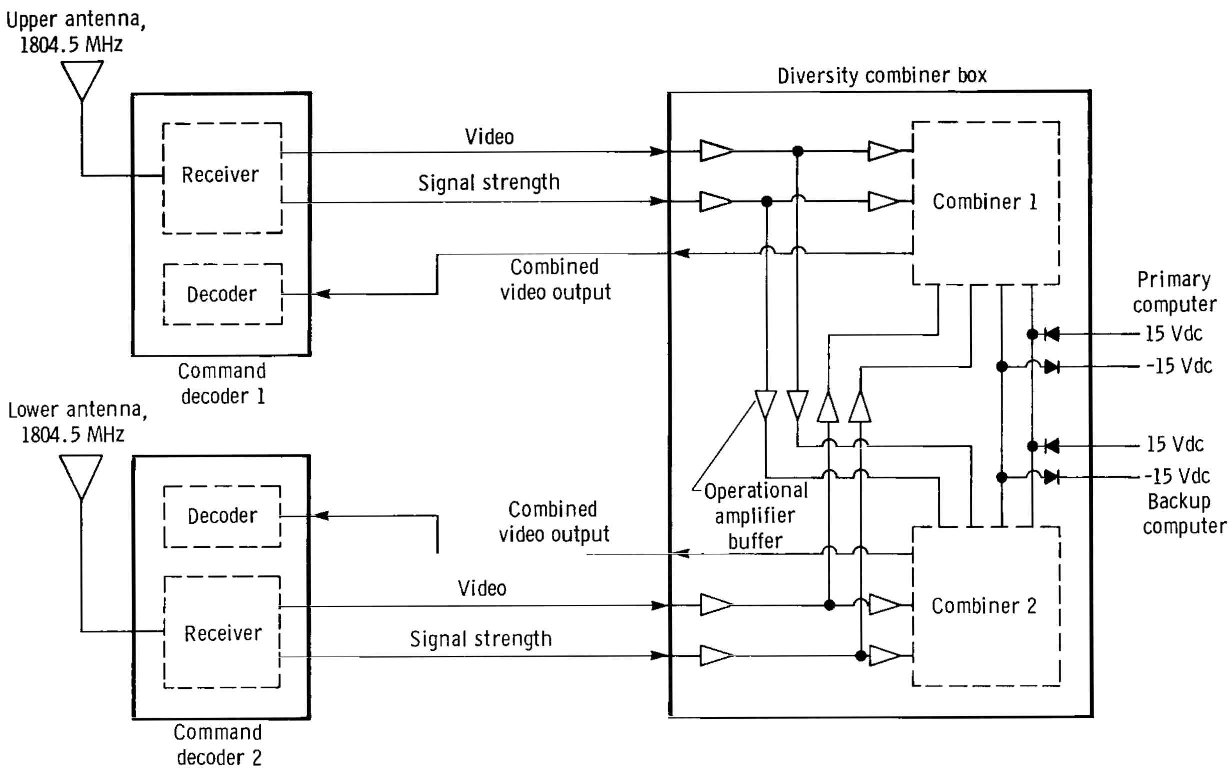


Figure 12. HiMAT diversity system.

To flight test this concept, a partial mechanization of the HiMAT uplink diversity system was installed in a PA-30 utility aircraft. A missing pulse detector was used to monitor for the presence of decoder address gate pulses (fig. 13). The presence of address gate pulses at 18.75 millisecond intervals insures that the decoder recognizes control words with proper parity, synchronization, and address. The output of the pulse detector was sampled as a discrete bit by the PCM system every 5 milliseconds. By calibration, it was determined that each receiver permitted the loss of decoder address gate pulses at a signal strength of approximately -93 dBm. The threshold of the pulse detector was set at this level.

Flight testing consisted of wing rocking maneuvers to expose the upper and lower aircraft antennas separately to the ground antenna. Decoder status was

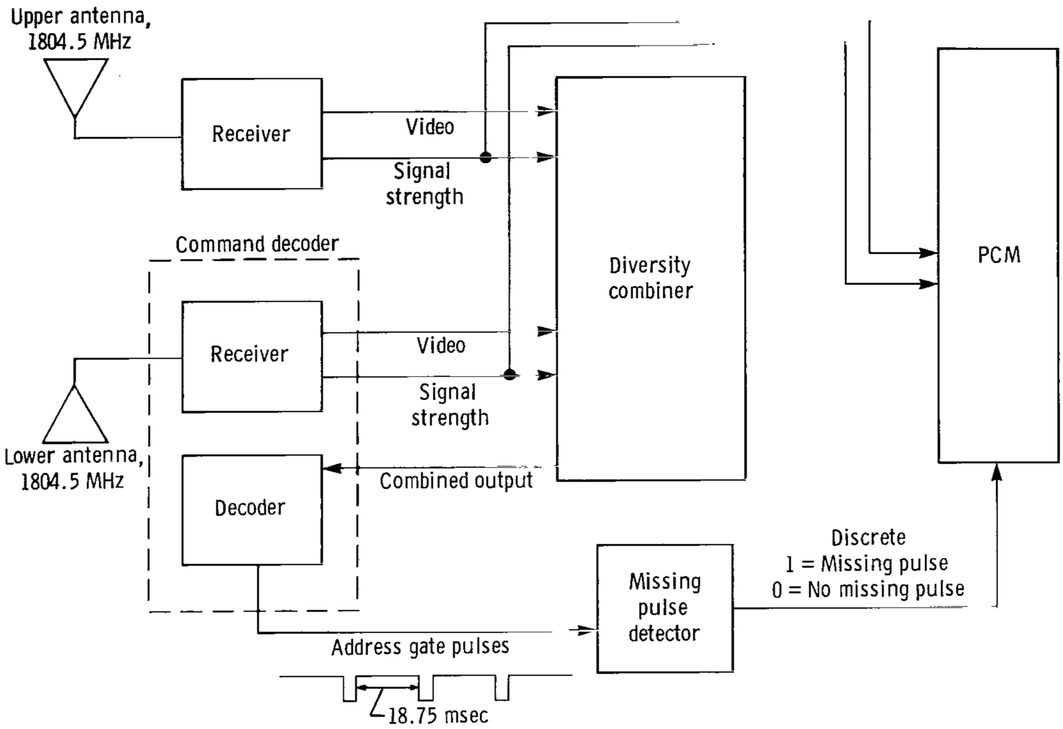


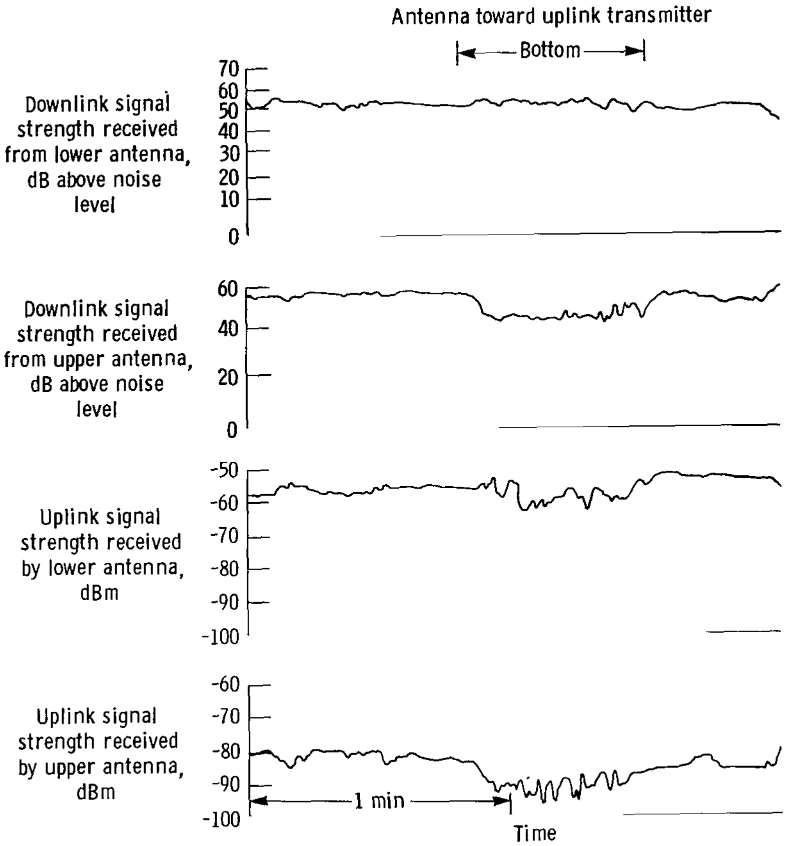
Figure 13. PA-30 flight test of diversity system.

monitored continuously during the wing rocking to verify that either receiver output would keep the decoder operational without interruption. The wing rocking maneuvers were made during descents from altitudes of 3000 and 2400 meters (10,000 and 8000 feet) at ranges of 112, 80, and 40 kilometers (70, 50, and 25 miles). Analysis of the data showed that the decoder was functional at all times during these tests. Decoder address gate pulses were lost only when both receiver signal strengths dropped below -93 dBm.

HiMAT FLIGHT TEST RESULTS

With these results, uninterrupted uplink reception was expected at the HiMAT vehicle at ranges up to 112 kilometers (70 miles) and at altitudes of 3000 meters (10,000 feet) or greater. The climbout data from the PA-30 flight testing indicated that reception from ground level to an altitude of 3000 meters (10,000 feet) would be uninterrupted at ranges less than 32 kilometers (20 miles).

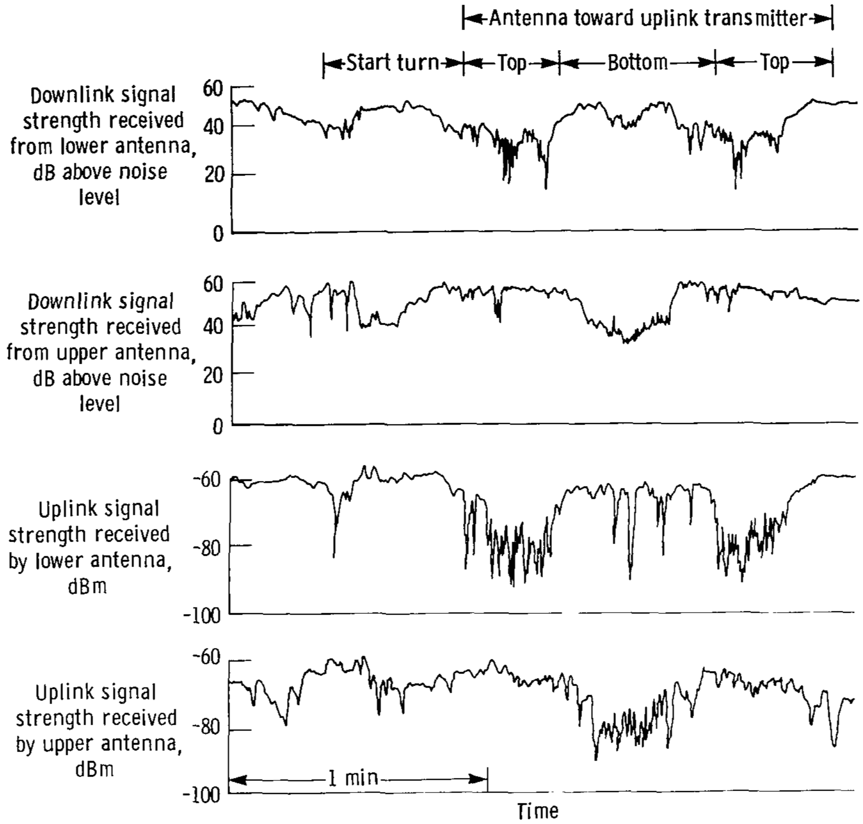
Three flights were made with the HiMAT vehicle with the uplink diversity system operating. The system proved to be quite successful. During one of these flights (fig. 14(a)), a sharp left turn was made away from the ground telemetry antenna at a range of 40 kilometers (30 miles) and an altitude of 7600 meters (25,000 feet).



(a) Sharp left turn.

Figure 14. Uplink and downlink signal strengths during sharp left turn and 360° turn. Lower antenna transmission frequency = 1441.5 MHz; upper antenna transmission frequency = 1452.5 MHz.

As the figure shows, the strength of the top uplink antenna signal dropped to -95 dBm, below the decoder threshold. The aircraft remained in the primary control mode, although this type of maneuver had caused control to be transferred to the backup mode during the first three HiMAT flights. During another flight, a 4g, high bank angle, 360° turn was made (fig. 14(b)). The top and bottom uplink and downlink signal strengths increase and decrease as those parts of the aircraft are alternately exposed to the ground telemetry antenna. This maneuver was made at a range of 64 kilometers (40 miles) and an altitude of 7600 meters (25,000 feet). Again, there was no switch to backup control, even though both top and bottom uplink reception did decrease to the -93 dBm decoder threshold. There were no downlink telemetry signal losses during these maneuvers. During the third flight, two high g, high bank angle turns and a 360° aileron roll were made with no uplink or downlink signal losses.



(b) 360° turn.

Figure 14. Concluded.

CONCLUDING REMARKS

The highly maneuverable aircraft technology (HiMAT) remotely piloted research vehicle (RPRV) requires continuous uplink and downlink telemetry coverage to implement aircraft primary and backup control laws. Omnidirectional radiation coverage for downlink telemetry was obtained by using two radio frequencies to radiate one PCM bit stream, one frequency from a top antenna and one from a bottom antenna. The uninterrupted telemetry coverage was obtained by using the diversity concept (continuously combining the two signals received in proportion to their signal strength). Omnidirectional uplink reception was mechanized similarly except that a single frequency was radiated from the ground to the top and bottom receiver antennas on the aircraft. Diversity combining was done on board, with either or both antenna/receiver combinations able to operate two command decoders.

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15. Supplementary Notes

16. Abstract

The highly maneuverable aircraft technology (HiMAT) remotely piloted research vehicle (RPRV) is being flight tested to demonstrate a number of technological advances applicable to future fighter aircraft. Because the aircraft control system uses airborne and ground-based computers that communicate via uplink and downlink telemetry, it is imperative for this communication to be uninterrupted. Since antenna radiation patterns are normally much less than ideal for continuous reception or transmission for all aircraft attitudes, this anticipated problem was investigated. After flight qualification and testing on other aircraft, a frequency diversity concept and an antenna diversity concept were implemented on the HiMAT vehicle to obtain omnidirectional telemetry coverage.

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