

ANTENNA MEASUREMENTS: TEST & ANALYSIS OF THE RADIATED EMISSIONS/IMMUNITY OF THE NASA/ORION SPACECRAFT DART PARACHUTE SIMULATOR & PROTOTYPE CAPSULE ~ THE CREW EXPLORATION VEHICLE

John Norgard, PhD, PE
NASA/JSC
Houston, TX 77058
USA

ABSTRACT

For future NASA Manned Space Exploration of the Moon and Mars, a blunt body capsule, called the Orion Crew Exploration Vehicle (CEV), composed of a Crew Module (CM) and a Service Module (SM), with a parachute decent assembly is planned for reentry back to Earth. A Capsule Parachute Assembly System (CPAS) is being developed for preliminary prototype parachute drop tests at the Yuma Proving Ground (YPG) to simulate high-speed reentry to Earth from beyond Low-Earth-Orbit (LEO) and to provide measurements of position, velocity, acceleration, attitude, temperature, pressure, humidity, and parachute loads. The primary and secondary (backup) avionics systems on CPAS also provide mission critical firing events to deploy, reef, and release the parachutes in three stages (extraction, drogues, mains) using mortars and pressure cartridge assemblies.

In addition, a Mid-Air Delivery System (MDS) is used to separate the capsule from the sled that is used to eject the capsule from the back of the drop plane. Also, high-speed and high-definition cameras in a Video Camera System (VCS) are used to film the drop plane extraction and parachute landing events.

Intentional and unintentional radiation emitted from and received by antennas and electronic devices on/in the CEV capsule, the MDS sled, and the VCS system are being tested for radiated emissions/immunity (susceptibility) ~ (RE/RS).

To verify Electromagnetic Compatibility (EMC) of the Orion capsule, Electromagnetic Interference (EMI) measurements are being made inside a semi-anechoic chamber at NASA/JSC on the components of the CPAS system. Measurements are made at 1m from the components-under-test (CUT). In addition, EMI measurements of the integrated CEV system are being made inside a hanger at YPG. These measurements are made in a complete circle, at 30° angles or less, around the Orion Capsule, the spacecraft system under-test (SUT). Near-field B-Dot probe measurements on the surface of the Orion capsule are being extrapolated outward to the 1m standard

distance for comparison to the MIL-STD radiated emissions limit, and far-field hybrid antenna measurements at 3m are being extrapolated inward to the 1m distance for similar comparisons.

Keywords: NASA, Orion, CEV, CM, SM, CPAS, EMC, EMI, MIL-STD RE, RS

1.0 Introduction

This paper describes EMI/EMC antenna measurements of the new NASA/Orion prototype capsule assembly. NASA's new direction/mission is to maintain the International Space Station (ISS) and to learn to live in space and to return to the Moon and establish a Lunar Habitat on the Moon and learn to live outside the Earth's environment. Later, NASA plans to robotically mine the moon's minerals, to build a Plasma Driven Spaceship on the Moon, and to fly astronauts to Mars.

As shown in Figure 1, the Orion Spacecraft, which will replace the decommissioned Space Shuttle, consists of a Crew Exploration Vehicle (CEV), composed of a Crew Module (CM) and a Service Module (SM), a Launch Abort System (LAS), and a rocket attachment assembly to ride on the top of a heavy-lift launch vehicle into its parking orbit, which will be well beyond low-earth-orbit (LEO).

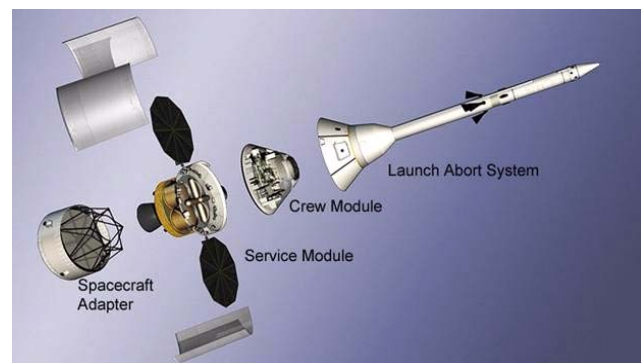


Figure 1 – Orion Spaceship: CEV, CM&SM, LAS, Adapter

The CM of the Orion CEV is a blunt body reentry vehicle that will be slowed on reentry by the Earth's atmospheric drag and will use parachutes for a soft landing in the last stage of decent.

2.0 CPAS (Parachute Drop Tests)

Among other tests conducted at JSC, viz. Thermal/Vac, Vibration, Acoustics, EMI, etc., the parachute landing system on the Orion CM is being tested for reliability, functionality, and safety in a series of parachute drop tests at the Yuma Proving Ground (YPG).

A Capsule Parachute Assembly System (CPAS) is used during the parachute drop tests to provide measurements of position, velocity, acceleration, attitude, temperature, pressure, humidity, and parachute loads. The avionics system in CPAS also provides mission critical firing events to deploy, reef, and release parachutes in three (3) stages (extraction, drogues, mains) using mortars and pressure cartridge assemblies (PCAs), initiated with NASA Standard Initiators (NSIs).

3.0 Orion Testing

The LAS is being tested at the White Sands Missile Range (WSMR) during a series of live firings. The external phased array antennas on the CEV CM/SM capsules are being tested in the Anechoic Chamber at JSC for antenna placements for space-to-space and space-to-Earth communications. In addition, MIL-STD EMI tests of the unshielded internal CPAS components are being performed in the Semi-Anechoic Chamber at JSC. All parachute drop tests are being conducted at YPG.

Individually shielded CPAS components mounted on a test sled, called the DART (which will fit inside a C130), and the integrated CPAS system mounted inside a mock-up CEV capsule (which will fit inside a C17) are being tested to simulate the advanced behavior of the CM on an actual reentry.

To assure Safety-of-Flight (SoF) for the parachute drop planes, preliminary EMI tests are also being performed at YPG before the parachute drop tests are actually conducted.

4.0 CEV Tests

The CEV tests performed at JSC (external antenna placement tests in the anechoic chamber and internal unshielded CPAS component tests in the semi-anechoic chamber) and the shielded DART CPAS component test and the integrated CEV Capsule test conducted at YPG are described below.

4.1 NASA/JSC Tests

4.1.1 Anechoic Chamber Tests (Phased Array Antenna ~ External Placement Test)

The CEV CM/SM combination is being tested for proper antenna array placement. Figure 2a shows the Orion CEV Capsule in orbit. Figure 2b shows the combined CM/SM prototype on its test stand. Figure 2c shows the CM being tested on the pedestal tower. This prototype is a full-scale AL mockup of the external details/characteristics of the CM/SM capsules.

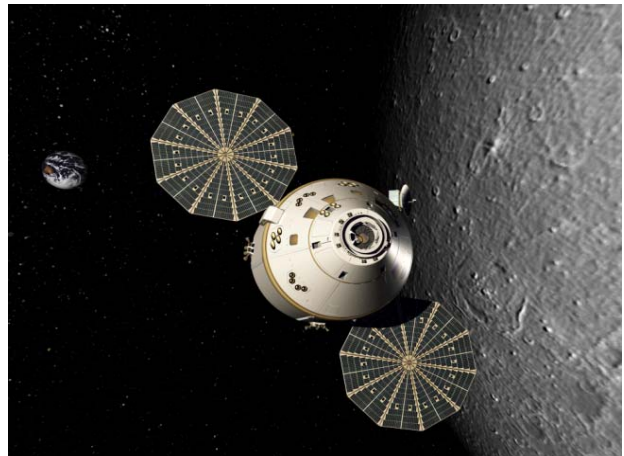


Figure 2a – Orion CEV Capsule (on Orbit)



Figure 2b - CM/SM Prototype (on Test Stand)

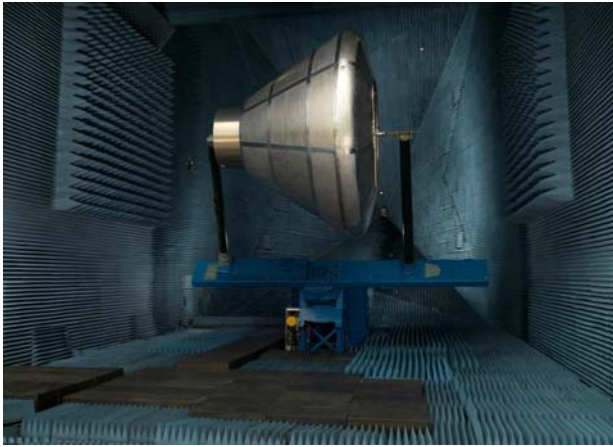


Figure 2c – CM Prototype (on Test Tower)

4.1.2 Semi-Anechoic Chamber Tests (MIL-STD Tests ~ Unshielded Internal Components)

The test setup for CPAS is shown in Figure 3.

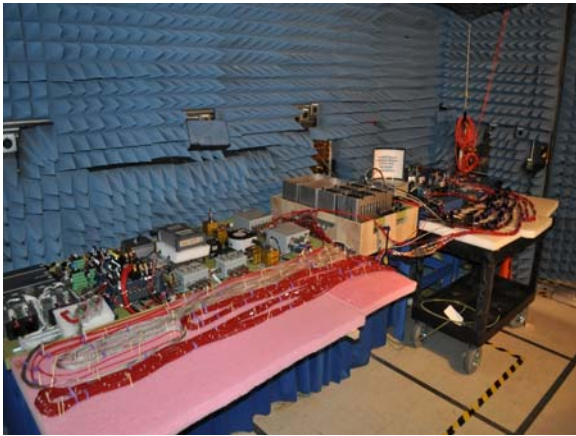


Figure 3 – CPAS Extended Test Layout/Setup

The test procedures, test setups (frequencies, bandwidths, polarizations), equipment, limits, etc. are from MIL-STDs 461 and 462.

CPAS was tested from (in Horizontal/Vertical Polarizations) : [See Figures 4(a-d)]

- 2-30 MHz (VP)
- 30-200 MHz (HP/VP)
- 200-1000 MHz (HP/VP)
- 1-10 GHz, 11.5-15.5 GHz (HP/VP)

CPAS failed the initial MIL-STD radiated emissions test in the 200 MHz – 1 GHz frequency range. The non-compliances in this frequency range are shown in Figure 5.



Figure 4a – CPAS Test Setup (2-30 MHz) Unshielded (VP)

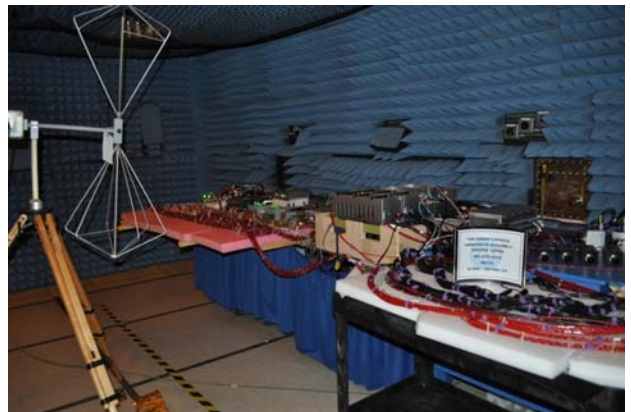
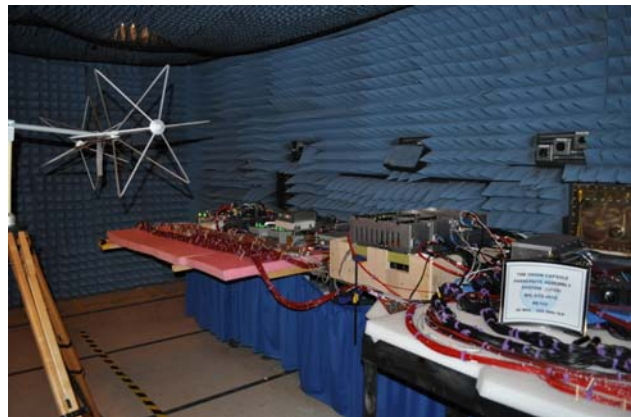


Figure 4b – CPAS Test Setup (30-200 MHz) Unshielded (HP/VP)



Figure 4c – CPAS Test Setup (30-1000 MHz) Unshielded (HP/VP)

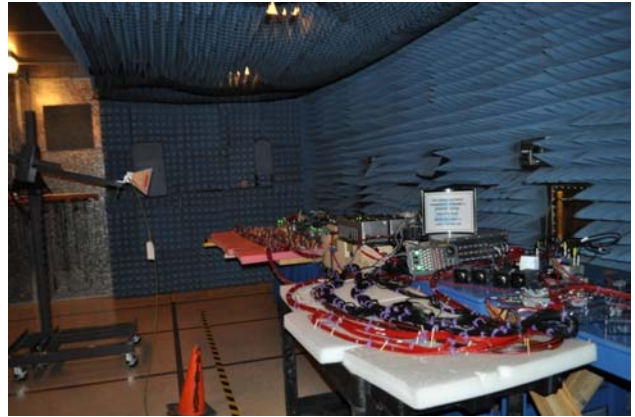


Figure 4d – CPAS Test Setup (1-15.5 GHz) Unshielded (HP/VP)

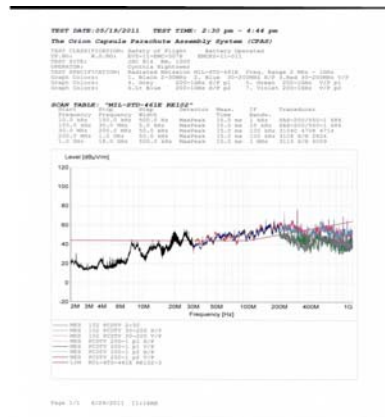
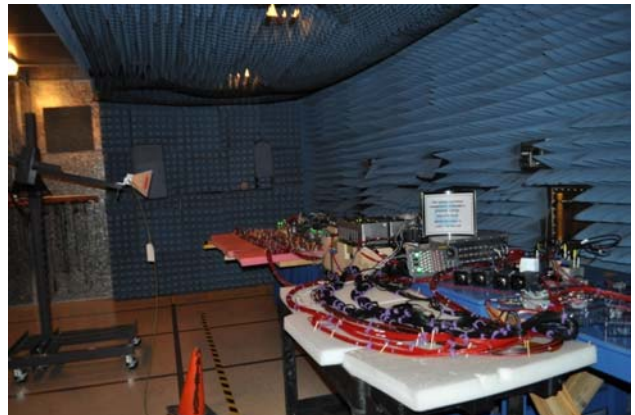
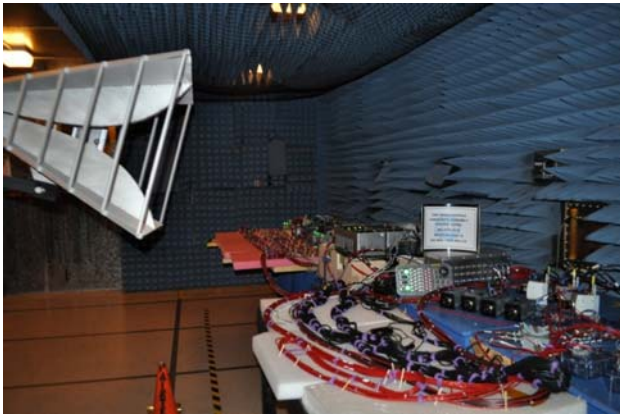


Figure 5 – CPAS Non-Compliances (Unshielded Component Trays)

The shielding of the cables and components of CPAS greatly reduced the EMI non-compliances to a few low-intensity, narrow-band spikes across the 20 MHz - 1 GHz frequency range.

Therefore, a more permanent shielded enclosure (Faraday cage) for the CPAS tray was constructed, as shown in Figure 9, for the future hanger and drop tests at YPG.



Figure 9 – Primary&Secondary Avionics Trays (Metal Sides, Conductive Cloth Cover, Mesh Window)

4.2 YPG CPAS Drop Tests

The CPAS drop test system consists of a DART Simulator and an Orion Prototype Capsule Simulator.

The DART Simulator and the Prototype Capsule Simulator were tested in a hanger at YPG.

4.2.1 CPAS/DART Simulator

The DART simulator, pictured in Figures 10(a-d), consists of a Parachute Capsule Delivery Test Vehicle (PCDTV), a Mid Air Delivery System (MDS), and a Video Camera System (VCS: multiple high-definition and high-speed cameras).

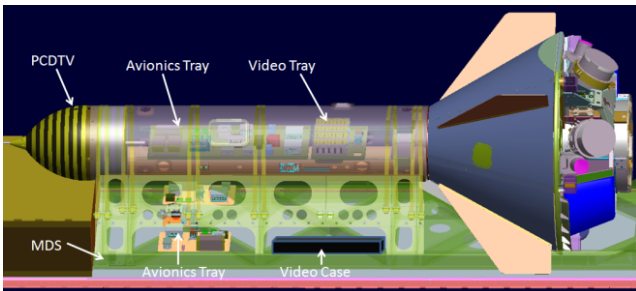


Figure 10a – DART Drop Test Simulator Schematic



Figure 10b – DART Drop Test Simulator (Before MDS and Parachute Loading)



Figure 10c – DART Drop Test Simulator (After MDS and Parachute Loading)



Figure 10d – DART Drop Test Simulator (Parachute Compartment)

The PCDTV houses the Primary&Secondary(Backup) Avionics Trays, in the shape of shielded rectangular bays as shown in Figure 9, that fit inside the framework of the PCDTV. The layout of the electronic devices on the Primary&Secondary Avionics Trays is pictured in Figure 11. The PCDTV has identical Primary and Secondary Avionic trays. Identical systems are on the MDS.

The CPAS cameras were used during the parachute drop tests to provide close-up views of parachute deployments, platform motion, vehicle motion, and steady-state parachute dynamics.

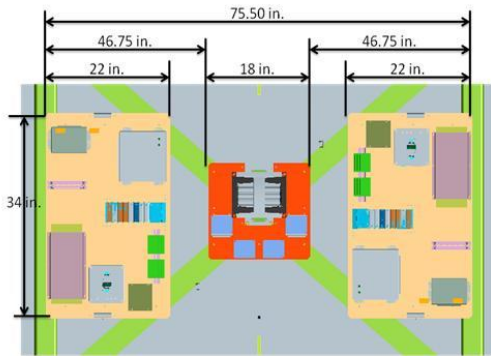


Figure 11 – PCDTV Primary&Secondary Avionics Trays

4.1.2.1 YPG DART Hanger Tests

The test procedures, test setups, equipment, limits, etc., are from MIL-STDs 461 and 462.

To measure the radiated emissions from the PCDTV, MDS, and VCA trays, a B-Dot probe was scanned over the various aperture locations around the DART.

4.1.2.2 YPG B-Dot Probe Field Tests

After the B-Dot probe was setup at each location, the received power was measured with a S/A, as shown in Figure 12. The probe was connected to a Spectrum Analyzer (S/A) through a 20’ section of coaxial cable.

Two channels on the S/A were used to measure the radiated emissions and background noise inside the hanger (Channels A&B). Channel A was used to record the “A”ntenna field (radiated emissions); channel B was used to record the “B”ackground ambient field (noise level). The S/A was scanned from 10 kHz -1 GHz.

For each test location, the probe was placed on the SUT to sample the local electric/magnetic-field levels near the aperture. The SUT was switched off. The S/A was “Zeroed”. Then, channels A & B were put on “Max Hold”. When channel B had captured all the background

reference signals in the hanger (along with channel A), it was placed on “View” to capture the background level. Then, the SUT was switched on. The S/A was switched to channel A and the probe measured the radiated emissions from the SUT for 60 s. Then, channel A was also put on “View” to capture the radiated emissions from the SUT.

The S/A was put in the “Peak Search” mode for channel A. Wherever a peak in channel A was observed above the background reference level in channel B, the peak level was recorded (in dBmW). There were, typically, 20 to 30 such peaks for each SUT. If an aperture peak occurred over a background peak, the peak level was not recorded, as it was a pre-existing noise level peak.

Note that, in these uncontrolled field tests (“outdoor” EMI tests in the hanger), if a background signal were to unexpectedly appear in channel A after channel B was captured, it would be mistakenly counted as a radiated emission from the PCDTV tray. Therefore, the SUT was scanned as quickly as possible and the channel A signal “Viewed” immediately after completion of the scan to lessen the chances of new background signals appearing in the radiated emissions measurements. When a new signal was noticed, Channel A was zeroed, put back in Max Hold, and the scan was started again. The tests were conducted during the night.

The B-Dot probe was scanned over the surfaces of the unshielded and shielded components, as the system was built-up. Assuming that the probe was electrically small, which is a good approximation at the lower frequencies, the power in the probe was measured and converted analytically into an equivalent magnetic field intensity in the near, intermediate, and far fields of the probe. The near field (aperture plane) was extrapolated outward to the 1m transverse plane, the distance at which the MIL-STD radiated emissions limit apply.

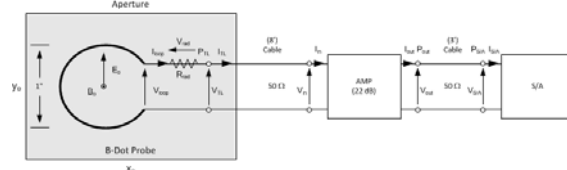


Figure 12 – B-Dot Probe Calibration

4.1.2.3 YPG DART Radiated Emissions Test

Radiated Emissions (RE) measurements were made around the PCDTV and MDS trays.

As a single, but typical, example of the radiated emissions from the equipment on the Avionics Tray, the radiated emissions from the unshielded cRIO component are

shown in Figure 13a; the radiated emissions from the shielded cRIO component are shown in Figure 13b. All the frequency components were non-compliant for the unshielded case; only one frequency component was non-compliant for the shielded case.

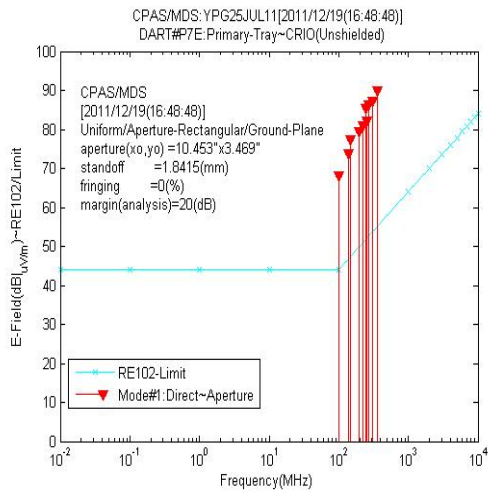


Figure 13a – DART/cRIO (Unshielded) Avionics Tray

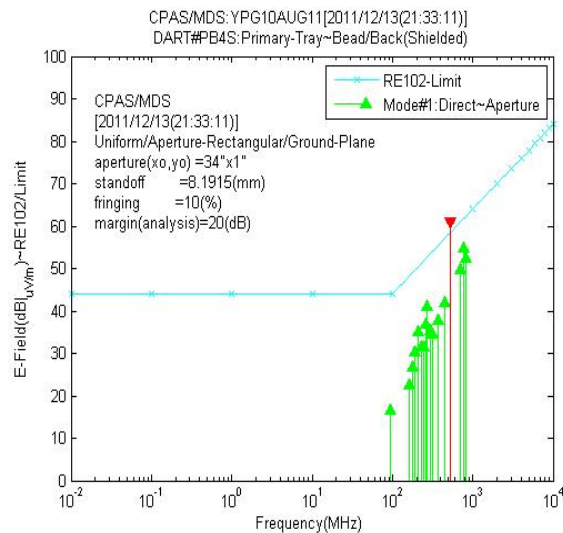


Figure 13b – DART/cRIO (Shielded) Avionics Tray

4.1.2.4. CPAS/DART Simulator Drop Tests

After the SoF verification, the DART Simulator was loaded into a C130 drop plane, as shown in Figure 14a. Figure 14b shows the release/extraction of the DART Simulator. Figure 14c shows the drop test with only two (2) of the three (3) chutes opening to simulate a 1 chute firing failure and resulting high-impact G-forces on landing. Figure 14d shows the DART Simulator after a relatively smooth landing.



Figure 14a – DART C130 Loading



Figure 14b – DART C130 Release/Extraction



Figure 14c – DART Drop (2 Chutes out of 3 Simulating a 1 Chute Firing Failure)



Figure 14d – DART Landing: Recovery/Repair/Refurbish/Reuse

4.2.2 CPAS Prototype Capsule Simulator

The Orion spacecraft simulator consists of a Parachute Test Vehicle (PTV), a Cradle Platform Separation Sled (CPSS), and a Video Camera System (VCS). The PTV is pictured in Figure 15.



Figure 15 – PTV ~ Orion Capsule Prototype Simulator (During Component Integration)

The PTV houses the Primary&Secondary Avionics Trays, in the shape of triangular bays that fit inside the framework of the PTV Capsule, as shown schematically in Figure 16.

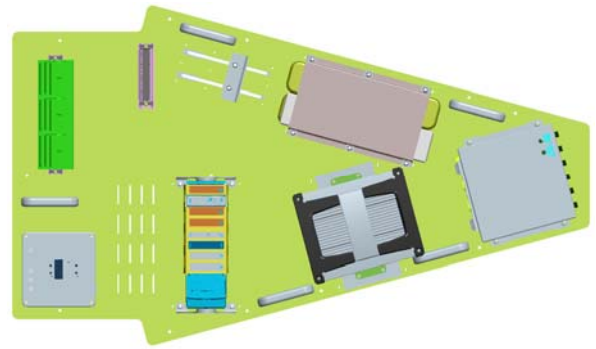


Figure 16 – Primary&Secondary PTV Avionics Trays

The PTV has identical Primary and Secondary Avionic trays.

4.2.2.1 YPG Orion Capsule Simulator Hanger Tests

The test procedures, test setups, equipment, limits, etc. are from MIL-STD 464.

To measure the radiated emissions from the CPSS sled and the PTV capsule, a monopole antenna and a hybrid biconical-log antenna were positioned at the various locations around the sled and the capsule.

4.2.2.2 YPG Hybrid Antenna Field Tests

After the antennas were setup at each location around the PTV, the received power was measured with a S/A using a procedure similar to the DART test, with the B-Dot probe replaced by a broadband hybrid antenna.

The S/A was scanned from 2-1000 MHz in two (2) bands: 2-30 MHz and 30-1000 MHz, using the active Monopole antenna from 2-30 MHz and the hybrid Biconical-Log antenna from 30-1000 MHz.

The measured S/A power was transferred to the end of the 20' cable using the cable insertion loss data. Then, the power levels were converted to equivalent voltage levels in the 50 Ω coax cable. After that, the antenna factor for the Monopole or the Biconical-Log antenna was used to convert the voltage levels to incident electric field intensities at the measured 3m mark. The magnitude of the measured data was directly a function of both antenna position and ambient noise contribution. Raw data was collected in terms of radiated power. This was done to simulate the measurements being collected inside the aircraft.

The Primary&Secondary CPSS Avionics trays and the Instrumentation tray were inserted into the forward end of the CPSS sled. A Faraday Cage was built around the trays to partially shield and attenuate the radiated

emissions from the electronic components on the trays. The radiated emissions from the CPSS trays couple through multiple apertures in the shield of the Faraday Cage for wire penetrations, power, and control cables.

The HD cameras were mainly positioned around the aft end of the CPSS sled. The HD cameras were placed inside five (5) sided metal enclosures, but, for proper viewing, could not be completely shielded. Therefore, the HS cameras produced higher radiated emissions than the Primary, Secondary, and Instrumentation trays.

If the measurements had been made inside the aircraft, the aircraft fuselage would have attenuated the ambient observed in the hangar, and the entire data set would have been reduced accordingly, since the contribution of the ambient would have been far less. Once the data set was reduced, the radiated emissions of the SUT were extracted from the ambient using a root-sum-square algorithm. No emissions were reported below the noise floor, as it would have been impossible to measure such emissions. The result of this process shows the ambient is slightly less than the MIL-STD standard radiated emissions limit line, and is believed to accurately exhibit the radiated emissions of the SUT.

4.2.2.3 YPG Orion Capsule CPSS Hanger Tests

The Orion Capsule CPSS sled was tested in a hanger at YPG. Radiated emissions measurements were made around the CPSS sled, which is shown in Figure 16 before mounting the PTV on the sled.

The parachute compartment and Avionics tray were tested on the CPSS sled.



Figure 17 – CPAS/Orion CPSS Separation Sled

4.2.2.4 YPG Orion Capsule PTV Hanger Tests

The PTV capsule was tested before it was coupled to the CPSS sled.

The Primary&Secondary Avionics trays and the Instrumentation tray were inserted into the four (4)

forward bays of the PTV vehicle, from the gusset at 360° down to the gusset at 270°. Each compartment is 30° in width. The outside frames of the 360° gusset and the 270° gusset are shielded with AL panels and AL tape. A Faraday Cage was built around the trays inside the gussets to partially shield and attenuate the radiated emissions from the electronic components on the trays. The radiated emissions from the PTV trays couple through multiple apertures in the shield of the Faraday Cage for wire penetrations, power, and control cables.

The HD and HS cameras were positioned around the PTV vehicle.

An active Monopole antenna was used to measure the radiated emissions in the frequency range from 2-30 MHz. A hybrid Biconical-Log antenna was used to measure the radiated emissions in the frequency range from 30-1000 MHz. Ambient background measurements were also made.

The Monopole antenna was vertically polarized. The Biconical-Log antenna was polarized vertically (VP) and horizontally (HP).

All antenna measurement positions were 3m from the System-Under-Test (SUT).

Measurements were made before (open) and after (closed) the panels were installed.

4.2.2.4.1 YPG Orion Capsule PTV Hanger Tests (Open Panels)

The Avionics tray was tested on the PTV capsule, as shown in Figure 18.



Figure 18 – CPAS/Orion Capsule (Open Panels)

The CPAS PTV was first tested with the panels over the Avionics tray open. The results are shown in Figures 19(a-f).

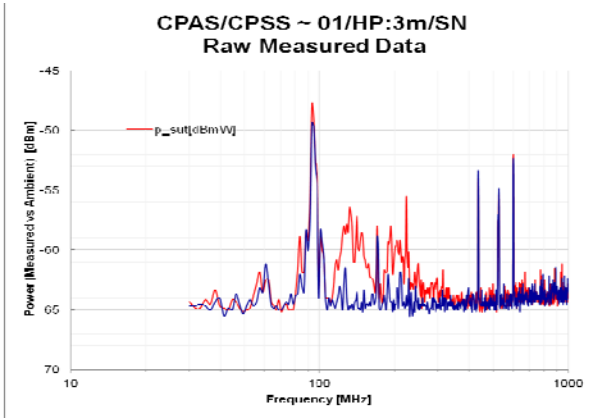


Figure 19a – CPAS/Orion Capsule Radiated Emissions (Measured Data ~ Radiation/Ambient)

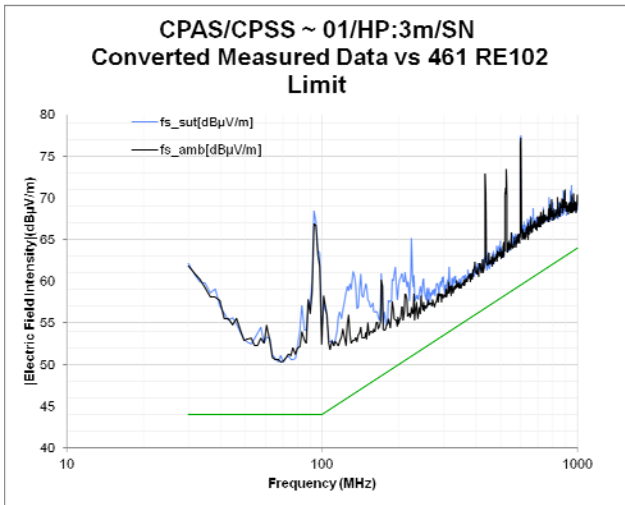


Figure 19b – CPAS/Orion Capsule (PTV) (Measured Data ~ AF Converted)

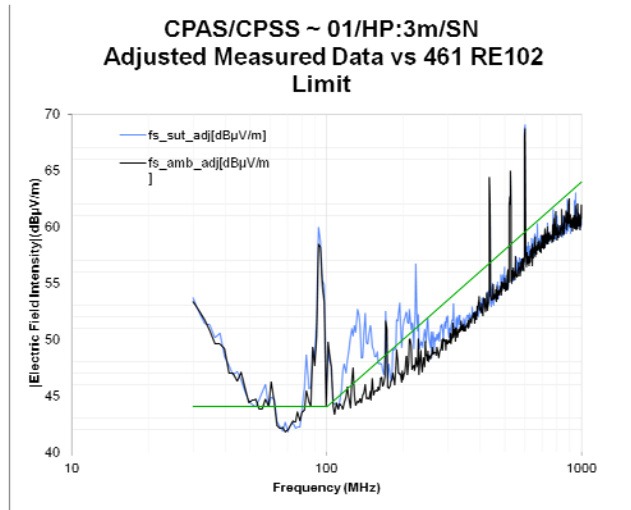


Figure 19c – CPAS/Orion Capsule (PTV) (Measured Data ~ Adjusted to 1m Shielded)

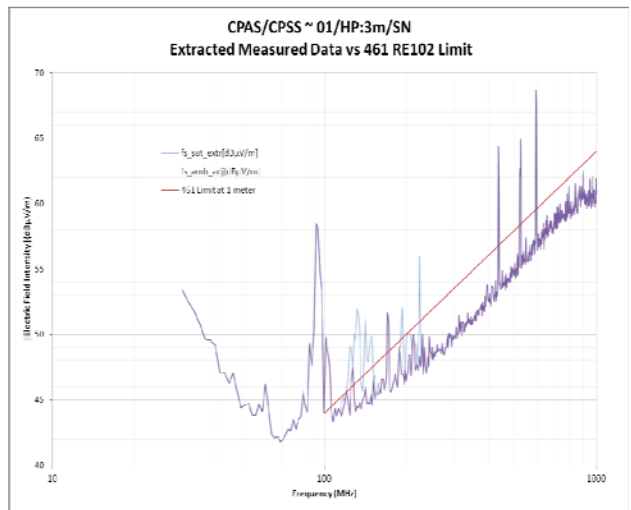


Figure 19d – CPAS/Orion Capsule (PTV) (Measured Data ~ Extracted = Radiation - Ambient)

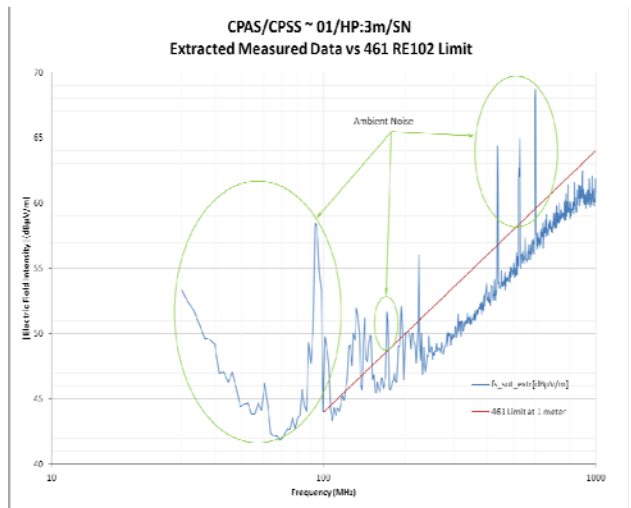


Figure 19e – CPAS/Orion Capsule (PTV) (Measured Data)

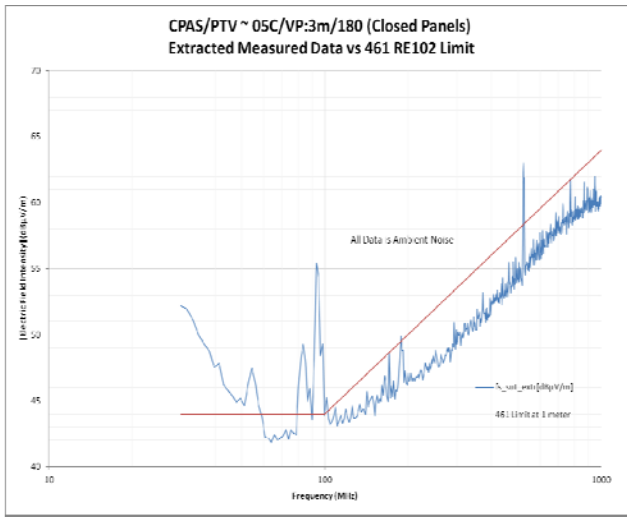


Figure 19f – CPAS/Orion Capsule (PTV) (Measured Data)

4.2.2.4.2 YPG Orion Capsule CPSS Hanger Tests (Closed Panels)

The CPAS PTV was also tested with the panels over the Avionics tray closed, as shown in Figure 20. The result is shown in Figure 21.



Figure 20 – CPAS/Orion Capsule (Closed Panels)

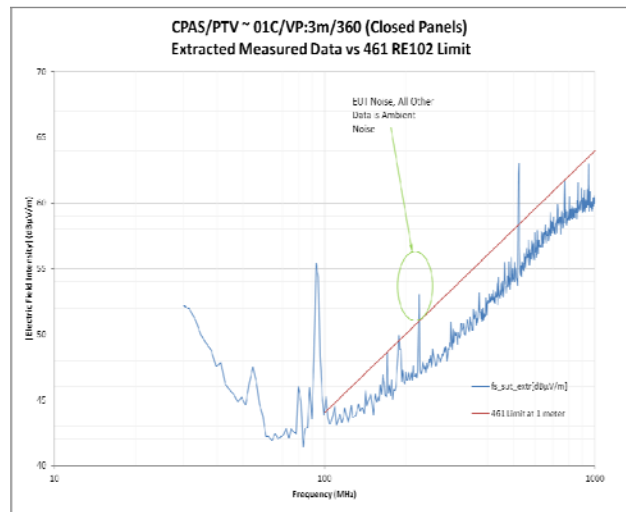


Figure 21 – CPAS/Orion Capsule (PTV) (Measured Data ~ Adjusted to 1m Shielded)

4.2.2.6. Final Test Configuration

The final flight configuration is shown in Figure 22, just before loading into the C17.



Figure 22 – CPAS/Orion Capsule (Final Assembly)

4.2.2.6. YPG Capsule Drop Test

Figure 23a shows a sequence of pictures of the CPAS Capsule being loaded into a C17 drop plane, the release/extraction, and several pictures of the decent. Figure 23b shows a composite of two positions in the drop. Figure 23c shows the drop test with an unstable tilted capsule. Figure 23d shows the CPAS Capsule after a rough landing.



Figure 23a – CPAS/Orion Capsule (Drop Test)



Figure 23b – CPAS/Orion Capsule (Drop Test)



Figure 23c – CPAS/Orion Capsule (Drop Test)



Figure 23d – CPAS/Orion Capsule (Landing)



Figure 23e – CPAS/Orion Capsule (Recover/Repair/Reuse)

5. Summary

The test data measured with a B-Dot probe or a hybrid broadband antenna and S/A at YPG have been converted from power to voltages to electric field intensities. Then the data were extrapolated to 1m. The capsule data were further shielded by the C17 fuselage. The data was then compared to the MIL-STD radiated emissions limit.

For the measured PCDTV/MDS and CPSS/PTV trays, it appears that the results validate the initial impressions from the measured CCDTV data that the new cloth shielding material is forming a good flexible shield over the trays and is attenuating the radiated emissions from the components on the trays, as required. There has been a tremendous improvement in lowering the overall radiated emissions from the CPAS trays. Most of the lower frequency (~200-400 MHz) radiated emissions are attenuated close to the MIL-STD radiated emissions limit. However, as also noted earlier, the HD cameras, which are not completely shielded, produce radiated emissions higher than the limit.

6. Conclusions

EMI testing has been on-going on CPAS hardware (PCDTV/MDS and CPSS sled and the PTV capsule).

The permanent shield of the PCDTV components worked well and the radiated emissions, with few exceptions, passed the SoF tests.

The CPSS electronics were checked. The measured results indicate that the avionics and instrumentation electronics are performing well, but the HD cameras, as expected, are exhibiting non-compliant behavior in the VHF/UHF range (~ 200 MHz through 400 MHz). This is of interest, because this behavior resides in the same frequency range as the USAF C17 communications equipment. The behavior below 200 MHz, and above 400 MHz, is typically in the noise floor (the local Yuma radio frequency environment) of our ability to measure here. However, this should not be an issue, because the C17 aircraft must be able to operate in the environment independent of the CPAS hardware. If the CPAS hardware is no worse than the environment, there should be no issues for operations.

The PTV (simulated capsule) was also checked, and its performance looks much better than the CPSS Sled, showing behavior just above the noise floor from 2 MHz to 1 GHz. We were able to collect data for the PTV capsule both without and with the external closeout panels installed; and, thus, we hope to be able to estimate the vehicle shielding effectiveness, an important characteristic for future equipment integration activity.

The CPSS does show non-compliant data in the VHF/UHF comm bands, but it is not as broadbanded, nor as large in magnitude as we had first thought. The PTV Capsule performance with the exterior panels in place exhibits excellent compliance, with only one or two frequency peaks appearing above the noise floor, and those being very directional with respect to the interior electronics locations.

Based on the data in this paper, a standard foreshortened SoF measurement process has been approved by USAF to clear the CPAS PCDTV/MDS and CPSS/PTV hardware for upcoming drop tests.

7. References

- [1] MIL-STD 461
- [2] MIL-STD 462
- [3] MIL-STD 464

8. Acknowledgement

The author wishes to thank the YPG Army Base Commander for allowing NASA to test the DART Simulator and the CPAS Capsule Simulator at the YPG Drop Test Range.