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Flight Test *Safety* Fact

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FTSW Hotwash

Tom Huff

Summer greetings from the FTSC! We have another great newsletter and encourage the broadest possible distribution to reach all segments of flight test. Don't be shy about providing feedback or authoring a submission. The podcasts and briefing materials have been uploaded here: http://flighttestsafety.org/2019-charleston-sc. If you didn't attend, please check them out. If you did attend, please consider incorporating some of this content into one of your safety standdowns or other training opportunities. The Committee has reviewed the feedback from the 2019 FTSW in Charleston. Attendees gave high praise for the Emergency Response Program content. Post-workshop, tutorial facilitator Fireside Partners was kind enough to offer an ERP Drill Checklist which can be found on the website in the resources section: http://www.flighttestsafety.org/images/Fireside_ERP_DRILLIT_Template.pdf. This is a great resource that can aid in structuring an effective drill to boost preparedness and readiness for a crisis event. The workshop theme of safety assurance was arguably the most challenging as we anchor on the components of Safety Management System (SMS) across the workshops. Flight test organizations appear to have mixed results with establishing and maturing an effective SMS. As I've mentioned at the workshops, without strong safety leadership at the top, culture will suffer and the desired safety performance results will not be achieved. Safety culture surveys have proven to be very effective in organizations that pursue higher excellence. This is an area the FTSC is exploring—if a survey should precede an audit. We have two different auditing checklists tailored for flight test available under the Recommended Practices section of flighttestsafety.org. I'm aware of only a couple of organizations that have used these protocols to conduct an audit. We really need greater use and feedback on these protocols. The 2019 FTSW had the second highest attendance on record! This is a great trend and we are already well into planning for the 2020 Workshops in Denver and London respectively. Our goal is to make the FTSW the "go-to" flight test safety event year-over-year. Your participation and feedback are critical to continuous improvement and ultimately making flight test safer. Thank you for your safety-minded leadership and industry engagement.

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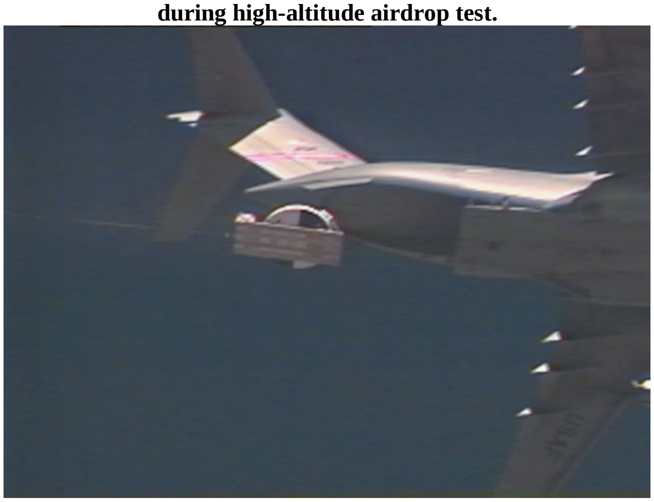
Communicating Uncertainty in Flight Test

Mark Jones Jr.

Just this week, Boeing completed tests of the parachute recovery system of its Starliner space capsule (https://boeing.mediaroom.com/2019-06-25-Starliner-Space-Capsule-Completes-Parachute-Testing). Video from earlier in the test program shows details of the balloon launch and drop test here: https://watchusfly.com/up-up-and-away-boeings-starliner-completes-first-parachute-test/. I found this out just days after selecting the topic for this column.

In July 2008, NASA and the Air Force Flight Test Center began airdrop flight testing of the Orion and Ares test articles in order to prove the design of the parachute recovery systems of both of these space vehicles. The test team used the C-17A to airdrop these test vehicles. For the C-17A, the culmination of these tests was a high-altitude airdrop of a 90,000-pound jumbo drop test vehicle (JDTV), representing an envelope expansion of 50 percent greater than the current operational airdrop envelope, solely for flight test purposes. The following material is a brief summary of this testing. Additionally, the outcome of one of these test points represents a starting point for a more comprehensive discussion about communicating uncertainty (and complexity) in flight test outcomes.

Figure 1 – Drogue extraction of Orion CPAS from the C-17A during high-altitude airdrop test.



(image credit: NASA)

Orion Airdrop Test. NASA developed the Orion crew entry vehicle parachute assembly system (CPAS) and mated the test article with a standard airdrop platform for drogue extraction from the C-17A. In this method of aerial delivery, a small drogue parachute stabilized behind the C-17A and was used to deploy an extraction parachute.

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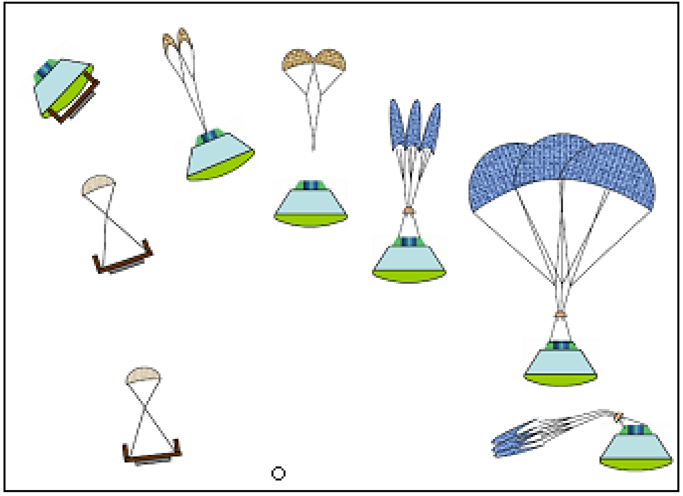
The extraction parachute generated approximately 30,000 pounds of drag at 145 KCAS. This force pulled the airdrop platforms over rollers on the cargo floor and out the back of the aircraft (figure 1). Following extraction, the CPAS would separate from the platform, which would be recovered under a separate parachute system. The CPAS would enter freefall before it began the recovery parachute test. Once the platform exited the aircraft and the Orion separated from the platform, the extraction chutes deployed the recovery parachutes, under which the platforms floated slowly and gently to earth.

Figure 2 illustrates the Orion CPAS test sequence after extraction from the aircraft. The test articles separates from the platform and begins free fall. A sequence of drogue chutes stabilize the test article and initiate the recovery parachute deployment.

Figure 2 – Orion CPAS airdrop test sequence



(image credit: NASA)

NASA documented the first Orion CPAS airdrop test at http://www.nasa.gov/mission_pages/constellation/orion/pa_chute_test.html. (Note: This link does not always function, but the reader may search the internet for "NASA Orion Parachute Test" and find links suitable for viewing the video in its entirety, similar to this one: https://www.youtube.com/watch?v=TVl6lCr1vCo.

Unfortunately, the first Orion airdrop test did not go as planned, as seen in figure 3. It was somewhat surprising that in an age of supercomputers, high-fidelity models, and computational fluid dynamics, we could have such a result, but as we will see, humans have a difficult time interpreting "predictions" along with the outcomes of models and simulations. The program has since completed its testing successfully.

Figure 4 shows the Ares jumbo drop test vehicle (JDTV). The Ares is very similar to the solid rocket booster already in use to boost the space shuttle into orbit. The JDTV was rigged with the recovery parachutes, the system under test, and then the JDTV was ballasted to the weight specified for the test point. NASA and the AFFTC accomplished several build-up Ares flight tests, as shown in table 1. These tests included parachute tow tests demonstrating the design of the Vectran extraction line package; 40,000- and 60,000-pound airdrops of the JDTV; and finally, the parachute design load limit demonstration, a72,000-pound airdrop. For airdrop, the flight manual maximum allowable single platform weight was 60,000 pounds. This restriction was the result of several factors but primarily because of the types of parachutes and types of rigging procedures and materials.

Table 1

Test Point	Objective	Results
Extraction Line Cut Test	Demonstrate Cutting Procedure	Successful
Parachute Tow Test No. 1	Demonstrate Vectran Extraction Line Loads	Successful
Airdrop No. 1, 40,000-Pound JDTV	Build-Up for Parachute	Successful
Airdrop No. 2, 60,000-Pound JDTV	Build-Up for Parachute and Aircraft (Instrumented Ramp)	Extraction Anomaly
Test Tub, 40,000 Pounds	Demonstrate Three-Parachute Cluster Design Deployment	Successful
Parachute Tow Test No. 2	Demonstrate Modified Rigging Procedure (Anomaly Corrected)	Successful
Airdrop No. 3, 72,000-Pound JDTV	Parachute Design Load Limit (DLL)	DLL Validated FQ, Loads Data for Build-Up
Airdrop No. 4, 78,000-Pound JDTV	Build-Up for Aircraft	Not addressed in this paper
Airdrop No. 5, 85,000 Pounds	Build-Up for Aircraft	
Airdrop No. 6, 90,000 Pounds	Demonstrate Load Safety Margin	

Figure 3 – Orion CPAS airdrop test sequence

(image credit: NASA)

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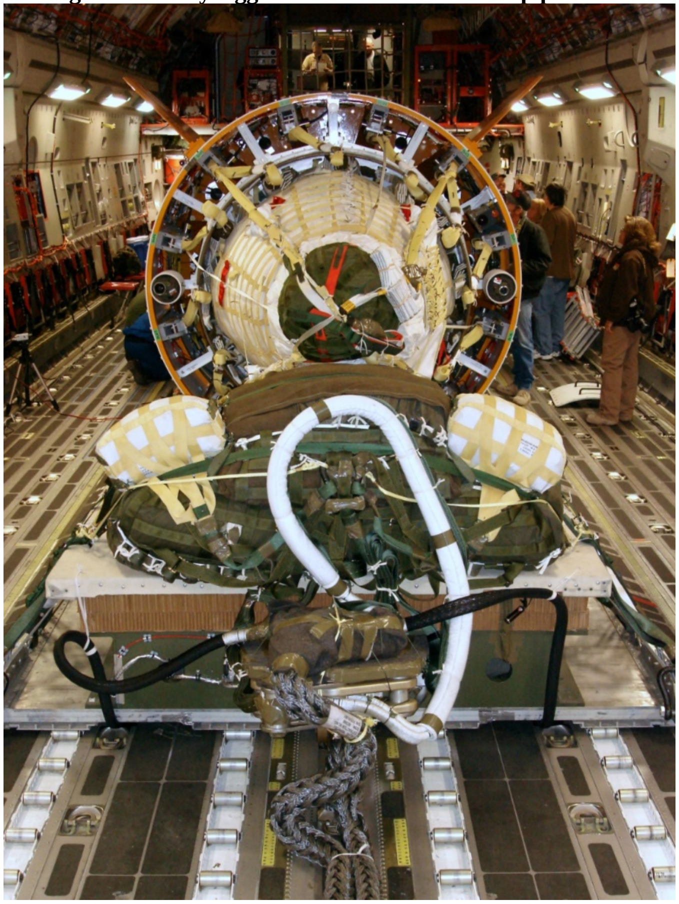
Figure 4 – Ares JDTV being loaded

(image credit: author)

Yuma Proving Ground was the location for all airdrop tests of the CPAS and JDTV.

Figure 5 – Fully rigged Ares JDTV and airdrop platform



(image credit: author)

The Vectran line appears in the bottom of figure 5 and again in figure 6. The test team developed the line to bear a higher load during extraction, as a result of the proposed envelope expansion. This new extraction line necessitated several build-up test points such as a ground test to demonstrate loadmaster cutting procedure and a parachute tow test to demonstrate extraction line loads. Edwards AFB (PIRA) was the location for the build-up tests using the Vectran line.

Figure 6 – Modified extraction line (Vectran)

(image credit: author)

During the tests of the JDTV, the extraction parachute generated drag equal to the weight of the platform at 145 KCAS. This force allowed a 1G extraction of the airdrop platforms. Following extraction, the JDTV would separate from the platform, which would be recovered under a separate parachute system. Then the JDTV would enter freefall before it began the recovery parachute test, similar to the Orion CPAS.

During the 60,000-pound airdrop, one of the two extraction chutes failed to inflate, resulting in a slower extraction rate than desired. Improvements to the extraction rigging, based on analysis of chase high-speed video, resulted in a successful parachute tow test of the modified extraction package. The 72,000-pound drop was highly successful for both the JDTV and the aircraft, with nominal release, extraction, and aircraft dynamics, a stepping stone to build-up efforts and ultimate test at 90,000-pounds. I originally wrote this paper before airdrops tests 4-6, and I want to focus on the malfunction during the 60,000 pound test.

Modeling and Simulation for Test Planning and Test Safety Hazard Mitigation

M&S were used extensively in the expansion of the airdrop operating envelope in several areas, including loads and flying qualities, but the focus of this analysis is on the aircraft dynamics and contingency actions in the event of malfunctions or unusual test events. As you can imagine, when a platform that weighs more than 70,000 pounds rolls from the front to the back of the cargo compartment, the result is a significant change in the aircraft cg and a dynamic aircraft response. Accurate predictions about the attitude changes should enable the pilot to anticipate or diagnose developing contingencies and predict recovery actions. From the moment the airdrop load is released at “green light” to the point at which level, un-accelerated flight conditions are regained after extraction, there are two possible scenarios (nominal or contingency) in each of three phases: release, extraction, and recovery.

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In the nominal case, both simulation and flight test data confirm that each of these phases requires only minor modifications from operationally representative procedures by any test aircrew member.

Release Phase: In the release phase, the primary test hazard is a platform that fails to release, whether as a result of parachute failure or any other malfunctions. If the extraction chutes do not deploy correctly or open in a reasonable amount of time, the loadmaster would declare a malfunction and immediately lock the platform to prevent it from moving.

One of the worst possible scenarios could occur if, after the platform was locked in place, parachutes that had only partially opened suddenly inflated. In this situation, the parachutes being towed by the aircraft could generate drag force equal to the weight of the platform, a situation that would considerably alter both the performance and handling qualities of the aircraft. It is unlikely that full chute deployment would not extract the platform. What is more likely is that the chutes would not develop fully and thus would not generate sufficient force to extract the platform. This scenario would cause far less drag.
This situation could be further exacerbated by the need to cut the extraction line in a timely manner. Two possibilities exist: 1) recovering straight ahead and thus exiting the test range into a very crowded airway and cutting away parachutes where they might cause a significant in-flight hazard to other aircraft, or 2) maneuvering (180-degree turn) an aircraft with degraded performance to remain within the test range and to allow the loadmaster to cut away the chutes in sanitized airspace.

Extraction Phase: During the extraction phase, the platform is exiting the aircraft. Possible contingencies for this phase include various failures of the extraction chutes, which would result in a gravity drop of the platform, known as a “slow roller.” This hazard would result in unexpected pitch change caused by a slower than nominal extraction. In fact, the corrective action calls for allowing the deck angle to increase to effect the gravity extraction of the platform. This could result in a rapid decrease in airspeed if this deck angle were maintained, especially when we consider that the aircraft already would be at a high thrust setting in level flight.

Recovery Phase: This brings us to the final phase, in which the aircraft is returned to level, unaccelerated flight from the high deck angle and potentially high pitch rate that would have occurred during the extraction phase.

The test team rehearsed each of these phases in high-fidelity C-17A simulators, which brings us to the problem at hand: How do we model non-standard extraction parachutes, non-standard airdrop platform weights, and non-standard rates of extraction? What about the countless permutations of partial failure states where, for example, only one parachute fails or several parachutes only partially inflate? Additionally, how we do simulate the increased drag caused by towed parachutes? Finally, what is the best method of recovery from an unknown flight attitude?

The extraction parachutes and airdrop platform size/weight used for the test were not operationally representative and were not included in the simulator model. This could result in extraction rates that do not represent test conditions, yet the rate of extraction is a major factor in pitch attitude and rate change.

What level of statistical confidence, if any, do we have in the results from the simulator? I leave this rhetorical question unanswered for your rumination, but the key insight in the planning process was this: It is almost certain that aircraft dynamic response, in almost every case, would not exceed the case of a gravity extraction at 90,000 pounds. Mathematically speaking, we would assign to this event a probability almost equal to one, and we call this valid, statistical parameter the maximum. Use of these kinds of parameters, outside of what we usually encounter (mean, standard deviation, etc.) is both mathematically rigorous and less complex in many cases, but it is something we don’t usually consider. During the safety planning, average response, standard deviation of deck angle change, median extraction times, etc., simply were not considered. The sample size required to achieve any reasonable confidence, in the purely classical statistical sense, would be insurmountable, given the modeling constraints. But the levels of certainty in our prediction on the maximum are much greater. The simulator model also gives a benchmark for nominal aircraft response. We are practically certain that nominal extractions will be “better” (as quantified, for example, by faster extraction rates) than simulator predictions. In both of these cases, we have bounded the expected response. In the former, we have demonstrated capability to safely execute the test in this worst-case scenario and subsequently developed and rehearsed techniques to recover from these unexpected aircraft attitudes. On the other side of the spectrum, any deviations from simulated nominal extractions immediately signal impending contingency to the pilot, even faster than the loadmaster or copilot can verbally announce, allowing the pilot to prepare for what follows. In essence, instead of a best-fit regression line, the aircraft response has been bounded above and below by worst cases.

Conclusion: Broadening our understanding of concepts like these, which we don’t usually encounter formally, is critical for flight test professionals. Armed with this knowledge we can develop heuristics for communicating uncertainty, ambiguity, and even complexity. We need something more formal than gut instinct and yet flexible and broad enough for widespread adoption. Furthermore, we must be able to communicate our conclusions made using these heuristics to senior leaders, who, understandably, are moving farther from the increasingly technical details of our increasingly complex systems under test. Unfortunately, the length of this article means that a formal introduction to these heuristic rules must wait until the next issue. (In anticipation of the next issue, I recommend the following introduction of these heuristics to the reader: https://thestrategybridge.org/the-bridge/2017/3/30/communicating-uncertainty-in-wargaming-outcomes.

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