Space Shuttle Orbiter Drag Chute Summary

Charles H. Lowry, Consultant: Garden Grove, CA, 92844

Abstract--This paper summarizes the development history and technical highlights of the Space Shuttle Orbiter Drag Chute Program. Data and references are given on the design, development, and testing of the system, plus several interesting operational issues and solutions.

The last Shuttle flight was completed in 2011 and all the Orbiters have now become museum pieces. Before all the data from system development and the 86 Orbiter Drag Chute (ODC) operational landings is lost or forgotten, it may be useful to summarize it here and to identify data sources for future reference. Much has been written about various aspects of the program, and this summary has attempted to cite many such references to make available more detailed information.

The ODC program was a high-visibility NASA program that afforded the opportunity to thoroughly engineer and test the chute system, far beyond so many of today's tight-budget programs. So the ODC program was extremely informative--it provided a wide scope of information including protective door jettison issues and solutions, wind tunnel data and analyses on chute stability and drag behind a huge and rather blunt forebody, component and system reuse, and chute cleaning methods. Technology and data created have aided several current and past parachute programs, and will continue to do so in the future.

The original Orbiter preliminary design included a drag parachute-- it was deleted early to save weight. But after the 1987 Challenger accident and during the program redefinition phase that followed, Astronaut John Young presented a strong case for enhancing landing safety by adding nosegear steering, brake improvements, and reviving the drag chute. He widely published the statement

"The United States is betting the Space Shuttle Program on the crew's ability to perform with an Orbiter roll-out system that is, at best, intolerant of routine aircraft operating problems such as single tire leaks, nosegear steering malfunctions, or unexpected crosswinds".

Fig. 1- Discovery Landing With ODC

His argument won out and the ODC was adopted. John J. Kennedy of JSC was appointed Subsystem Manager and held that position throughout the program. Requirements were defined in Rockwell International Procurement Specification MC621-0076. Irvin Aerospace (now Airborne Systems, a division of HDT Global) was awarded the development contract in 1988. The system was designed and developed, then introduced on the May 16, 1992 maiden flight of Endeavour (STS-49), 47 launches into the program. The other Orbiters were soon retrofitted to include the system as well (Fig 1).

The best choice for the Orbiter drag parachute was determined to be a single conventional ribbon canopy similar to the SR-71 (40 ft diameter), but with extensive use of Kevlar (in place of Nylon) in the structure of the chute to save weight and volume (Ref 1and 2). Also certain shaping modifications were incorporated to improve the efficiency of the drag-producing surface (Ref 3 and 4).

A pyrotechnic mortar was designed to fire and deploy the 9 ft. diameter pilot chute into clean air far behind the Orbiter, so it could pull the main canopy aft of the severe wake region for positive inflation and good drag. The Orbiter fuselage was considered equivalent to a 25 ft. diameter forebody.

Wind tunnel tests were conducted to determine how far aft need the main parachute canopy be to produce respectable drag, and a riser length of 87 ft was shown to be satisfactory (Ref 5). With a maximum deployment velocity of 230 knots, a main chute design limit load of 100200 lb with dispersions was established.

The Vertical Motion Simulator (VMS) at NASA's Ames Research Center produced some of the most revealing and valuable information on usage of the ODC. This is the 6 degree-of-freedom facility where much of the astronaut training for landing was conducted. It has a high-fidelity cockpit with flying qualities like the Orbiter. The VMS was the perfect tool to evaluate the drag chute and to develop landing procedures. It could simulate wind conditions and failure conditions such as control system problems and blown tires (Ref 5).

The Orbiter normally touches down and rolls a long way with its nose high. It was desired to deploy the drag chute as early after touchdown as possible to make it most effective. But since the riser is attached to the Orbiter so high on the tail, the sudden application of a high parachute drag force at that high attach point tends to pull the nose even further up, increasing the angle of attack and causing the landing Orbiter to skip off and go airborne again. Not good.

So reefing was incorporated into the parachute design to allow early deployment while limiting the force fed into that high point on the tail structure. Reefing allowed the canopy to inflate only to a limited drag value, then after a preset time delay (and further slowdown) allowed full inflation. This configuration and the technique of initiating chute deployment after main gear touchdown and just as the nose starts to drop (derotation) got the chute out sufficiently early with minimum crew workload. After initial reefed inflation, the Orbiter decelerated for 3.7 sec. and then the chute disreefed and was allowed to fully inflate. In this manner, the maximum load applied to the Orbiter was controlled and limited. The VMS was used to develop and validate this configuration. The chute was kept attached until the Orbiter slowed to 40-80 knots, when it was jettisoned.

Fig 2-ODC Installation

The parachute stowage compartment is located in the tail section just below the vertical of the Orbiter, where the airstream passes on either side of the compartment and aids in the deployment of the door and pilot chute. The pilot chute mortar faces aftward as shown in Figure 2. When it fires, it shears the rivets that hold the metallic cover on and the pilot chute then proceeds to full stretch and inflates in about 1.0 sec. The force produced by the inflated pilot chute (about 4200 lb) applies tension to the 2 cut-knives, that sever the Kevlar cords holding the 130lb main chute pack in the compartment. The main chute pack is then accelerated aftward at 30 to 40 gees, so clearance with the main engine bells is assured.

Before all that happens, the compartment door must be removed. The door has a unique jettison feature whereby it swings open on breakaway hinges by force from firing the mortar. The door is just a lightweight aluminum machining with TPS on it, with a total weight of about 12lb. Strangely, the machining ended up looking very much like the door on the Design Group repro machine (Fig 3).

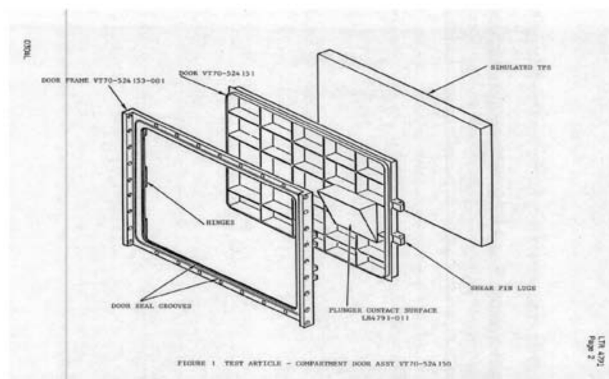


Fig 3-Compartment Door

The door swings open under the force of the pilot chute pack emerging from the mortar to approximately 45 degrees at which point the hinges disengage and the door becomes a free-flying projectile. The hinge breakaway point is carefully defined to ensure the door trajectory carries it aftward (relative to the Orbiter) between the starboard OMS engine pod and the main engine bells, ensuring no contact. The door then trails the Orbiter and frisbees along behind it until it hits the runway and slides to a stop. It has been surprising to note how the flying door often defies gravity and flies formation with the Orbiter for much longer than predicted.

Initially the door was to be opened by a reusable actuator, but the weight of such a system was prohibitive. And when the concept of using the action of the pilot chute mortar was considered, it became apparent that the door would be pushed open so fast that arresting its angular velocity would be difficult. Thus the breakaway hinge and expendable door. The problem then became how to control the door's point of breakaway so it would be jettisoned along a narrow corridor to avoid contacting the Orbiter OMS engines, main engine bells, and vehicle structure. Analyses to determine the hinge dimensions to optimize the breakaway point were not adequate because of complex deflections in the hardware. So static tests were repeatedly run using a pneumatic mortar, and hinge dimensions were varied to reach an acceptable configuration. These tests (Ref 6) produced a highly predictable and repeatable near-field door trajectory until clear of the Orbiter, but after that, the door flew where it wanted to. It was jettisoned to the starboard side, but sometimes ended up trailing the Orbiter on the port side. And once, it contacted the inflated pilot chute, but caused no damage.

Fig 4-B-52 Test

The parachute system, including the compartment and door, was flight-certified by 8 deployments behind a landing B-52 at Dryden (Fig 4)(Ref 7). Obviously we could not duplicate the Orbiter's blunt forebody, high attach point, or even the maximum landing velocity, however deployment, inflation, reefing, and door behavior were verified by those successful tests prior to installation on the Orbiter.

But the B-52 tests revealed that we were far off in our reefed canopy loads. The first 2 B-52 tests showed we were producing first stage loads that would be expected for 27% reefing, whereas we had sized the reefing line to expect 40%. This was a surprise to all involved including Sandia and Knacke, himself. Also the time from disreef to full inflation was much shorter than predicted by conventional methods. So the final reefing line length was resized and verified by continued testing.

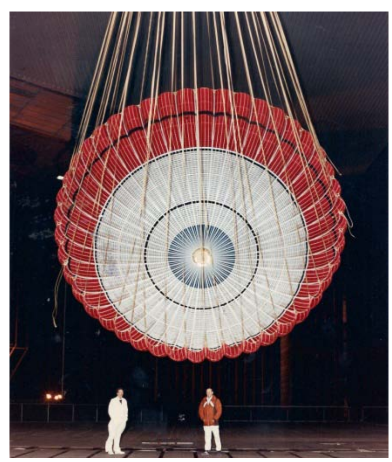
Another notable occurrence was tearing damage on the leading edge of the Kevlar vent band of the main canopy in 3 tests. The design was changed to go back to Nylon to accommodate the concentration of load on the leading edge during inflation. This damage was showing up at approximately 65% of design limit load. Other more minor changes/improvements were incorporated during this test series, including rigging, abrasion protection, and local beefups.

Although the Orbiter wake, max deployment velocity, and attach height above the runway could not be duplicated by using the B-52, it was an extremely valuable test series. To complete ODC verification, 10 operational Orbiter landings, under varying conditions (primarily deployment timing and speedbrake schedule) fully certified the ODC, starting with STS-49.

An interesting problem in parachute technology came up after a few flights. Our inability to initially test the drag chute system in a wake environment simulating the Orbiter led to a problem with parachute stability. The parachute canopy was originally designed with a low porosity to ensure positive inflation in the extreme wake field trailing the landing Orbiter. This was consciously decided at the time of Knacke's famous statement in 1989

"The worst thing that can happen to a parachute engineer is for his parachute to not open while the world is watching."

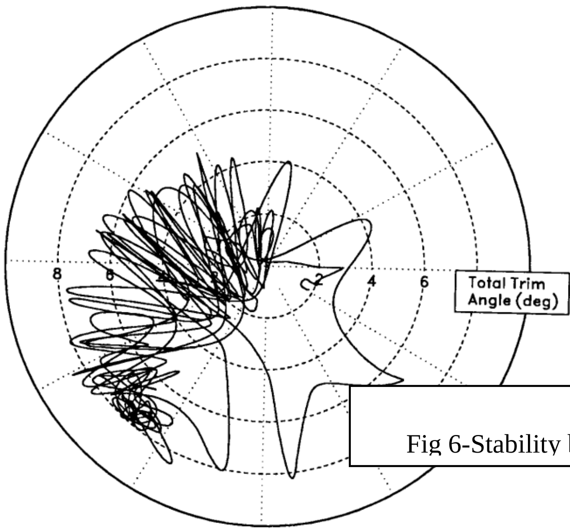
Low porosity encourages inflation in a strong wake field so we leaned that way. But, of course, low porosity also causes a parachute to want to fly at an angle displaced from the direction of airflow and that seemed to be the instability we were experiencing. On the early Orbiter flights the drag chute was found to seek out a stable position of about 7 degrees to one side or the other, causing extra pilot workload. Since observed inflation seemed to be very positive, it was judged that the canopy porosity could be safely increased to make the chute more stable.



With advice and invaluable help from Sandia, we took some

Fig 5-ODC IN Wind Tunnel

parachutes to the very large 80 by 120 ft wind tunnel at Ames and experimented with various schemes to increase the stability of the canopy (Fig 5). The most effective means was found to be increasing canopy porosity by simply incrementally cutting ribbons out of the canopy at key locations and measuring canopy oscillation. A small, lightweight sensor



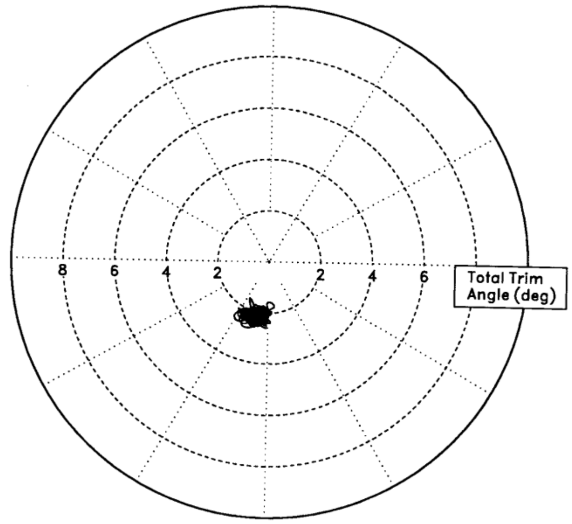


Fig 6-Stability before and after mod

was placed in the center vent area to indicate by means of tracking photography the canopy excursions (angular oscillations) at the various porosities tested. The result was that by removing 5 of the 97 concentric ribbons, increasing the total porosity from 16% to approximately 20%, stability was excellent (Fig 6) in the tunnel and loss of drag was an acceptable 7-8%. This change was incorporated and all subsequent Orbiter landings have been free of the stability issue.

An alternate approach was also tested whereby the canopy was permanently reefed. This worked equally well with the increased porosity option, but resulted in much more drag loss—perhaps as much as 20%. The 95% permanently reefed version actually flew on one Orbiter flight.

Interesting data on measured reefing line tension and canopy pull-down forces was also produced in these wind tunnel tests. This wind tunnel activity is covered by Ref 8.

Another interesting finding during the 86 landing career of the ODC was that on 3 occasions, up to 4 horizontal ribbons were ripped out in the crown area of the main canopy. After entering service in 1992, these happened 1999, 2001, and 2009 after 47, 59, and 77 otherwise damage-free landings. This caused no performance degradation, but in accord with manned spacecraft imperative, extensive failure analysis was carried out each time. The initial and continuing common observation was that the vent tended to snap back following canopy stretch, no doubt contacting crown ribbons and causing the damage. A hint of this possibility was noted during the B-52 testing, when it was noted that as inflation begins, the skirt takes in a gulp of air and expands first. This has a tendency to causes the upper canopy to be blanketed and to be drawn forward into the wake of the skirt. Then as the canopy is stretched and the break tie between the vent and deployment bag separates, a snapback can occur, resulting in the rather massive vent construction to damage the more fragile ribbons.

Fig 7-Riser Deflection

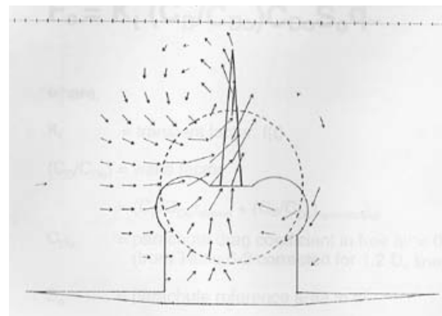


Fig 8-Wake Field

Parachute engineers are accustomed to “random” acts of parachute mischief under usually varying conditions, but here is an application where 86 deployments occurred at practically identical deployment conditions and all with excellent photo coverage. All chutes were alike. All packing/rigging was alike. Why did it happen on these 3 flights? Why didn’t it happen on every flight? As Knacke often said---

“If you don’t like the fickleness (or some such word) of parachutes, why don’t you go into the stock market?”

It’s true that mysterious incidents of damage are sprinkled throughout many test and operational parachute programs. We parachute people know this and we are inclined to throw up our hands in resignation and say “Hey, it happens”. But this rarely satisfies the reliability crowd or the customer.

The wake field behind the landing Orbiter has a very positive up-swirl (Fig 7 & 8)(Ref 9) that results from the high-alpha wings pressing the air down against the runway, and as the wing passes over it, the air expands and causes a very measurable up component. This doesn’t adversely affect the pilot or main canopies, but the largely unkeepered main chute riser was being swept up and into the wake of the speedbrake. It was feared that the riser could damage or interfere with the function of the speedbrakes, so a riser sleeve was added to contain the 44 plies of webbing that comprised the riser into a smaller diameter bundle that is less affected by the local airflow. This was very effective and the concern was eliminated.

The only other notable issue was on John Glenn’s STS-95 flight in 1998, when the parachute compartment door inadvertently jettisoned at launch. As the main engines were coming up to full thrust, the door was seen to come off and get caught up in the main engine plume which carried it down the flame bucket. So we had an Orbiter in flight without a door. This became an extremely uneasy situation because no one knew the condition of the now-exposed main pack retaining ties, or the temperature of the mortar pyro cartridge, and it suggested the chute might deploy at any time during the flight. It did not deploy however, but remained in its compartment through orbital insertion and the entire mission.

But, again, in true manned spacecraft fashion, many groundlings spent the next several days (and nights) thinking up all the horrible things that could happen if the chute inadvertently deployed —and of course, what to do about it. Like what if it deployed in space, flailed around, and became wrapped around the vertical tail so that the rudder and speedbrakes couldn’t function. In such a case, would the chute burn away during entry, or hang around and cause approach and landing problems? Or how about this one—what if it deployed just as the Orbiter was about 40 ft altitude during landing approach causing the Orbiter to touch down short of the runway, or at least endangering an already-difficult landing sequence? Fortunately none of these things happened and landing was normal, but the chute was intentionally not deployed to avoid introducing uncertainties. Post flight inspection showed signs of enough heat to melt some non-structural Nylon on the face of the pack, but otherwise the chute and compartment were in good shape. A specific cause for the anomaly was never duplicated in test, but tolerances and controls on rigging the door were tightened up and no further problems occurred.

People ask if we reused the chutes. Yes—up to 15 uses of the textile parts and 10 uses of the metal parts, such as the mortar. We started out with a reusable main chute but it was heavy with all the extra beef designed into it. So we made it a single use chute and knocked 40 lbs. out of the design. Later we saw that the chutes still looked new after a single use and the cost of replacement chutes had gone up significantly. So we ran a series of laboratory tests (Ref 10 and 11) on materials which confirmed, with adequate controls, we could safely reuse the hardware. A most useful bit of data came from cycling the Kevlar suspension lines from a previously flown main chute at various usage levels to 50 cycles. These tests showed an initial increase in strength after a number of cycles, and an extremely minor loss of strength after the full 50 cycles. In addition, a tired, old operational F-117 drag chute, with similar construction to the ODC was cut up and tested, showing the effects of abrasion and dirt on strength of its 63 usages to increase our knowledge base.

Interesting thing is, we added back less than 1 lb—this to cover areas of possible abrasion. And this slight-of-hand saved us about 39 lb! By the end of the program, we had used main chutes up to 9 times and saved a ton of money. Actually, the canopies showed so little signs of wear, the usage life could probably have been increased much farther.

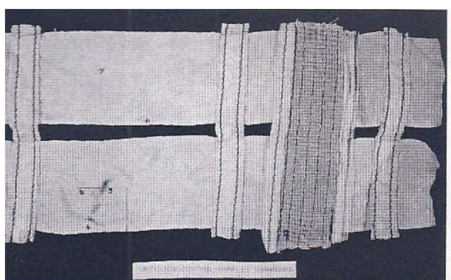


Photo 1 Control Sample

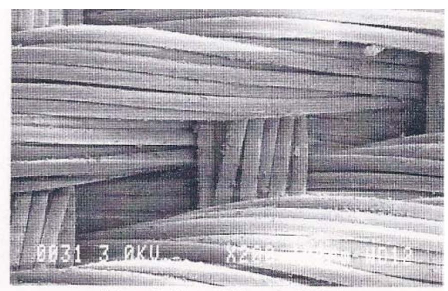


Photo 3 Control Sample (200x)

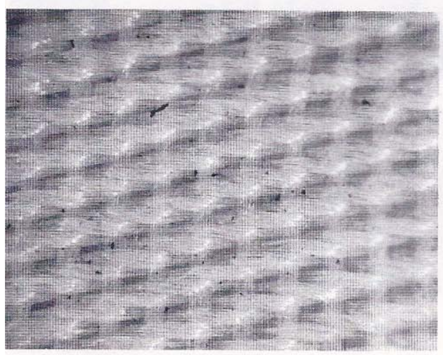


Photo 2 Control Sample (40x)

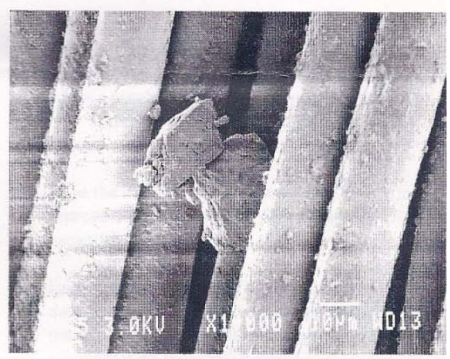


Photo 4 Control Sample (1000x)

Aside from just trying to make the system work, an extensive program was conducted to develop a method of parachute canopy cleaning. Since landing on the EAFB dry lakebed was a useful program option, our chutes would become loaded with dirt and grit on such occasions. From many past tests at Natick and other organizations, data was found that characterized strength degradation in canopies due to various concentrations of dirt from widespread sources such as Yuma, WSMR, etc. This was good background data and it encouraged us to carry this work further.

It was desired to have a proven cleaning method that would reclaim and allow continued use of the ODC. USBI conducted tests on materials and joints from flown and dirty chutes to establish the level of degradation present, the best cleaning method, and the resulting end effects on the chutes, such as residual strength loss and shrinkage. Spectacular photos of dirty and clean textile specimens up to 2000x gave great insight as to effectiveness of various cleaning methods (Fig 9)(Ref 12). This effort should be useful to any program that worries about chute reuse after heavy dirt exposure.

We started with the 40ft, 44 gore all-nylon SR-71 drag chute. The ODC used Kevlar in primary structure and increased the suspension line/radial webbings from 4000lb to 6000lb. The SR-71 used 460lb Nylon horizontal ribbons throughout, whereas the ODC used 300, 200 and 100lb. The ODC gores were changed to make it a conical canopy. Overall, if one multiplies canopy drag by its strength, and divides by weight, the ODC was superior by a factor of 3.7. This, of course, ignores other factors, such as design temperatures. Thanks anyway to new materials and methods.

The ODC was used 86 times with satisfactory results. The astronauts loved it because it gave an added margin of safety in the difficult process of landing that solid brick. It has also, of course, saved untold dollars on brake and tire wear.

We've never had a landing emergency where the ODC was called upon to save the day, but that big red, white, and blue canopy added color, drama, and action to the scene every time the beautiful bird came home. And, of course, we kept on banking the dollars saved on those brakes and tires. So here's to John Young. Too bad he never got to fly it.

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