Lightweight Materials Development for Parachutes

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Parachutes for the Orion Multi-Purpose Crew Vehicle must meet requirements for volume and mobility in the parachute compartment in addition to meeting constraints on launch weight. Parachute pack density must be kept low; therefore, decreasing parachute volume by increasing parachute pack density is not a solution. It is imperative that pack density be low enough to allow for complete, rapid, and damage-free deployment of the parachutes. High pack density was cited as the most difficult challenge to the main parachutes on Apollo, and must therefore be avoided for the Multi-Purpose Crew Vehicle. Development of lightweight parachute materials will help meet requirements on volume, mobility, and weight.

One material identified for development is lightweight Nylon broadcloth for the skirt-to-shoulder region of the main parachute canopies (figure 1). This technology development addresses the risk of insufficient volume for the Capsule Parachute Assembly System (CPAS) main chute pack and harness and riser routing, offering a significant reduction in parachute material volume in an already constrained parachute compartment volume. While weight savings is of secondary concern to decreased pack density, successful development of the lighter-weight fabric results in a weight savings of approximately 25 to 50 lbs. to the vehicle as well.

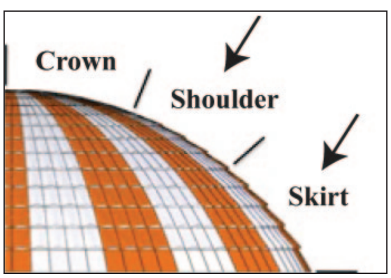

Fig. 1. *Skirt-to-shoulder region of the parachute canopy.*

The development is conducted in a phased approach, with Phase I completed in 2010. The first phase was a feasibility assessment of the fabric. Phase II will assess performance of the fabric in a parachute. A parachute using one of the newly developed lightweight Nylon broadcloths is currently in production and will be flight tested to assess performance.

Phase I was comprised of fabric builds and laboratory testing of the resultant fabrics to verify that these fabrics meet requirements, with areal density being one of the most critical requirements to this work. The baseline CPAS design uses Nylon broadcloth of 1.10 ounces per square yard (oz/yd^2) in the region identified for use of the new fabric. A goal of 0.70-0.90 oz/yd^2 was required for the areal density of the new lightweight Nylon broadcloth. Additional requirements included a permeability of 100 ± 20 cubic feet per minute (cfm) to meet the baseline CPAS design, and an elongation in both warp and fill directions of 20% minimum. Because it is expected that a reduction in areal density will come with some penalty to strength, both a goal strength to meet the baseline CPAS design and a minimum strength to meet expected loads were identified for break and tear strengths. A goal of 42 lbs. with a minimum of 38 ± 10% lbs was identified for break strength in both warp and fill directions, and a goal of 5 lbs with a minimum of 4 lbs. was identified for tear strength in both warp and fill directions. Warp and fill are defined in figure 2.

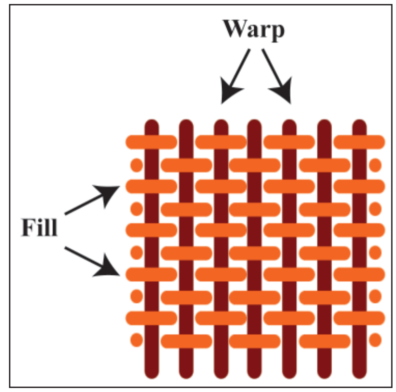

Fig. 2. *Warp and fill.*

A lighter-weight fabric presents challenges in seaming and joining. Stitches are less likely to hold the more delicate fabric in place. Thus, seam and joint design, builds, and laboratory testing of these seams and joints were also critical to Phase I. Seam and joint efficiencies are defined as the strength of the pristine material to the strength of the material over a seam or joint. While an efficiency of 80% or greater was identified as a highly desirable accomplishment, the goal of this project was not to increase seam and joint efficiency, but to match that of the baseline CPAS joints in the same region. NASA selected one standard seam—a single reinforced French fell seam, as described in American National Standards Institute/American Institute of Aeronautics and Astronautics S-017A-2000, "Aerodynamic Decelerator and Parachute

A B C D E

Fig. 3. *Heat set and pack: A. Packing fixture; B, C. Seam and joint samples and extra packing material for filling required volume at required pressure are packed into the packing fixture using a hydraulic press; D. Packed samples and fabric are held in the heat set fixture; E. Packed samples following 8-hour heat set. Photos courtesy of Pioneer Aerospace Corporation.*

Drawings"—for evaluation and comparison across all fabrics (figure 3). The agency also evaluated alternative standard seams, as well as some original seam designs.

Performance of the seams and joints after exposure to a heat set and pack, as well as to salt fog, was also of interest. To achieve and maintain the parachute pack density, parachutes are typically packed into their deployment bags using a hydraulic press, held under pressure, and heated to set. It is vital that the parachute deploy properly and without damage after this treatment. Any effect of this process on the baseline 1.1 oz/yd^2 fabric is known to be of no consequence, but a lighter-weight fabric could be more susceptible to any unwanted adhesion between surfaces, leading to possible damage on deployment. Additionally, the heat set and pack treatment could cause deterioration of fibers and seams in the lightweight fabrics. Therefore, it was required that a heat set and pack demonstration be executed on a total of 1 lb. of fabric at a temperature of 82°C (180°F), with a pack density of 45 lbs. per cubic foot and a pack pressure minimum of 450 lbs. per square inch (figure 3). Seam and joint samples were included in this demonstration, as well as additional yardage to make up the remainder of the required 1 lb.

Parachutes are expected to encounter a salt fog environment. While it is known that the baseline 1.1 oz/yd^2 fabric can tolerate this exposure, the effect of exposure and possible formation of salt crystals within the smaller denier fibers of the lighter-weight Nylon was unknown. Thus, NASA also performed salt fog testing, with exposure in accordance with military standard MIL-STD-810G, Method 509.5. The efficiency of the seams and joints was demonstrated and documented before and after heat set and pack demonstrations, and before and after exposure to salt fog. Some seam samples were also subjected to both heat set and pack and salt fog exposure so that a predicted worst-case condition could be evaluated.

Two different parachute vendors participated in this development. The products of the Phase I work are four viable fabrics—two from each vendor. The permeability, elongation, break strength, and tear strength of each, along with the corresponding minimum requirements, are listed in Table 1. It may be easily observed that all requirements are met, with the one exception of the permeability of Fabric 4. Recall that the required permeability was 100 ± 20 cfm, or a minimum of 80 cfm. Because it is the upper bound of this requirement that is most significant to parachute performance, it was determined that the 4% deviation below the lower bound would be acceptable, allowing for inclusion of the lightest-weight fabric in the options to select from for Phase II of the work.

All seam and joint testing of seams constructed in all four fabrics resulted in efficiencies above the desired 80% efficiency. Heat set and pack did not induce any degradation in performance below this desired efficiency, while salt fog exposure did show a very small negative effect on Fabrics 2 and 4, while improved performance was observed in the case of Fabric 3. This result should be further investigated in a larger sample set for improved statistics.

Table 1. Fabric Properties

	Minimum Requirement	Fabric 1	Fabric 2	Fabric 3	Fabric 4
Areal weight (oz/yd^2)	0.70	0.83	0.89	0.87	0.76
Permeability (cfm)	80.0	119	86.5	93.5	77.0
Elongation (%)					
Warp	20.0	33.9	31.4	37.7	36.4
Fill	20.0	26.5	27.8	37.5	37.5
Break strength (lbs.)					
Warp	34.0	45.2	42.8	41.9	41.1
Fill	34.0	37.5	43.5	43.2	41.7
Tear strength (lbs.)					
Warp	4.0	8.1	8.1	10	5.5
Fill	4.0	4.5	7.1	9.5	5.8

A single main parachute will be built and flight-tested during Phase II. A successful flight test will demonstrate mass and pack density reduction, with the parachute remaining packable and deployable without damage. Flight performance needs to be similar to the reference CPAS parachute in inflation loads, parachute stability, and parachute drag area. Timing of flight testing is intended to take advantage of existing planned CPAS tests with the agreement of all circumstances and parties.

Future development of a second lightweight fabric—an M5 fiber-based fabric for use in the structural grids of all parachutes in the system—is being pursued. M5 is a novel fiber with a tenacity, or strength-to-weight ratio, approximately twice that of Kevlar®. Development of M5 fiber-based fabrics in the form of cords, straps, and tapes could result in a weight savings to the vehicle estimated at 104 lbs. in addition to the decrease in pack density, which is so important for complete and rapid damage-free deployment of the parachutes.