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FATIGUE DEGRADATION OF THE RAM-AIR PARACHUTE CANOPY STRUCTURE

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ABSTRACT

In this work, the authors continue researching issues related to fatigue of aircraft structures made of fabrics. Parachute systems are widely used in military, sport and recreational aviation. Braking parachutes as well as skydiving and troop parachutes are characterized by the repeated use of parachute canopies, which are exposed to wear and fatigue. Until now, parachutes were difficult to design aviation systems due to their complex and unsteady opening characteristics, large changes in the geometry of canopies, suspension lines and tape risers as well as exposure to stochastic atmospheric turbulence. The fatigue of the canopy fabric, suspension lines and tape risers is a problem that must be addressed by textile designers and designers of reusable parachute systems. The authors of this work demonstrate the complexity of operating a parachute in hard multiple use conditions and propose ways to extend the parachute's service life without compromising safety.

Keywords: parachute systems, aerodynamic decelerator, ram-air canopy, fatigue degradation, aviation safety.

INTRODUCTION

Modern parachute systems must ensure maximum safety of use because human life depends on their proper operation. This is especially true of reusable parachutes. In many applications, single-shell parachutes give way to spatial constructions of the flying wing type, among which the most popular are parafoils, also called ram-air parachutes.

Parachute systems with ram-air canopies are in widespread use in aviation, ranging from sport parachutes (skydiving, free flying, wing suit flying, base jumps, tandem flying etc.) to military HALO and HAHO jumps of special forces operators to cargo deliveries by utilising GPS/Galileo directed autonomous control systems. Ram-air canopies offer high gliding ratio descending characteristics as well as very good steering and soft landing with full braking. Such performances are achievable without compromising safety during descending and landing.

A typical modern ram-air personnel parachute system consists of two canopies: the main one and the reserve one. The main canopy is used in every jump and can be used over a thousand times. The reserve canopy is only used in emergency situations when any malfunction of the main canopy occurs. Consequently, the main canopy is packed to jump many times while the reserve canopy is packed only occasionally, typically every half a year or even once a year.

During its service life, the main canopy is exposed to sunlight radiation, especially ultraviolet (UV) rays, which can degrade the fabric strength properties and with the UV exposition time cumulating jump after jump. Given such a great number of repacks, jumps and the UV radiation exposition time it is very important to evaluate fatigue damage cumulated that can possibly occur during the exploitation of the ram-air main canopy. Harmful effects of UV on the coatings of fabrics are partly described in [2, 7].

Cargo parachutes represent a separate category of parachutes used for rescue and safe dropping of loads from low altitudes. These are generally used once and in most cases destroyed after use. Publications [11, 13] describe ways of increasing the safety of system use taking into account long-term storage periods.

RAM-AIR CANOPY STRUCTURE

Construction of the ram-air parachute canopy

The parafoil was the first ram-air parachute canopy to be successfully introduced into exploitation in the mid 1970’s. The ram-air canopy is made from upper surface panels, lower surface panels and ribs between them. The ribs have aerodynamic profile shape so such design reflects airplane wing. The shape of the ram-air canopy can be maintained by air overpressure inside the canopy caused by dynamic pressure of air from forward speed of parachute. Air comes inside the parachute by front inlets. Ribs have special holes to maintain the pressure distribution inside canopy even (Fig. 1, 2).

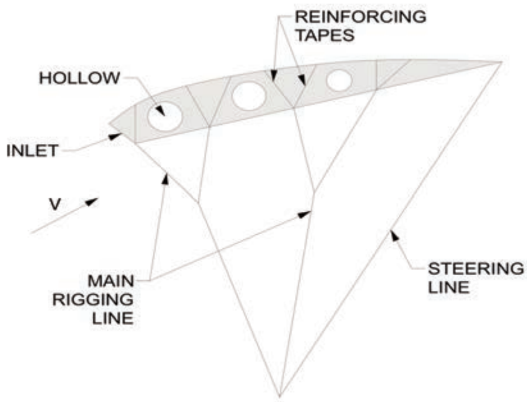

Figure 1. Cross section of ram-air canopy with hollow loaded rib and rigging (suspension) lines attachments to ends of reinforcing tapes of the rib [3].

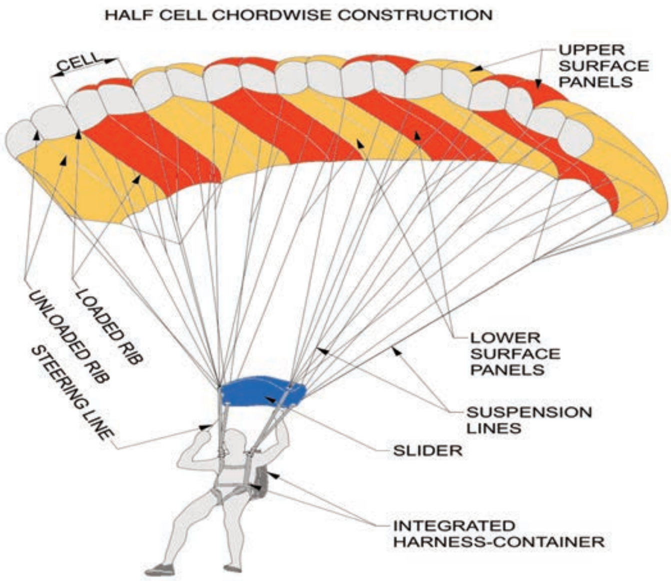

Figure 2. Ram-air canopy with half cell chord wise construction [3].

The parachute canopy is constructed from a system of adjacent cells which are sewed to upper and lower surface panels (Fig. 3). In modern ram-air canopies, the cells are divided by unloaded rib to allow a greater aspect ratio (span to chord ratio) and by this way to achieve a greater gliding ratio.

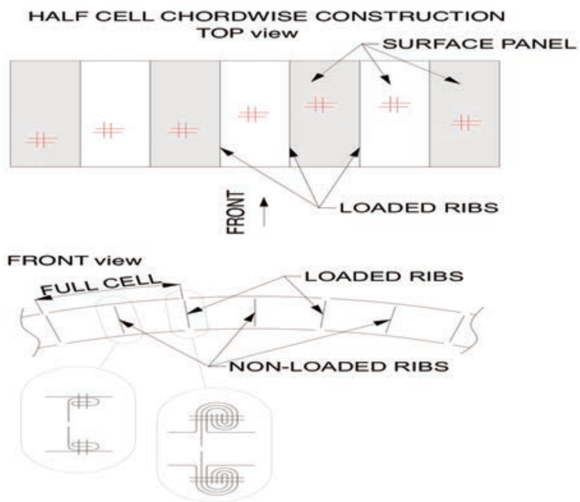

Figure 3. Ram-air canopy half cell chord wise construction - top and front views of the canopy with schemes of sewing surface panels to loaded and non-loaded ribs [3].

To lower the edges of the loaded ribs, the suspension lines are fastened. Suspension lines are connected to the ends of the suspension tapes of the harness. In modern ram-air parachutes, the harness is integrated with the container to achieve a sleeker and more compact design (parachutes are often manufactured with the harness tapes in many sizes in contrast to older parachutes with non-integrated harness which must have a wide range of harness's tapes length). Ram-air canopies are also typically manufactured with a slider device on suspension lines, which slow down the opening process (in older parachutes reefing lines connected to the pilot chute are used).

Textile fabric for the ram-air parachute canopy

The porosity of the fabrics is very important parameter affecting the inflation process and the performance of the parachute canopy after opening during descend like forward speed, descent speed ea. gliding ratio (Lift/Drag) and stability during descending.

The rip stop weave has thicker reinforcement threads interwoven at regular intervals (typically 5 to 8 mm) in a crosshatch pattern. Such a weave makes the fabric more resistant to tearing and ripping, and small tears cannot spread easily (Fig. 4).

Figure 4. F-111 nylon fabric with a distinctive ripstop weave usually used in parachute canopies (HORNET).

Table 1. Technical data of F-111 fabric referred to MIL-C-44378 military specification [8].

Parameter	US units	SI units
Material	nylon 66 yarn with continuous multifilament	nylon 66 yarn with continuous multifilament
Weave	rip stop	rip stop
Area weight max	1.12 oz/sq yd	40 g/m^2
Air permeability	0-3 ft^3/min/ft^2 (CFM)	0 - 0,015 m^3/s/m^2
Thickness max	0.003 inches	0,076 mm
Breaking strength min Warp Filling	 45 pounds 45 pounds	 200 N 200 N
Elongation min Warp Filling	 20% 20%	 20% 20%
Tearing strength min Warp Filling	 5 pounds 5 pounds	 22,25 N 22,25 N

With Parafoil, the first ram-air parachute being introduced to exploitation, a need arose to design a new parachute fabric dedicated to ram-air canopies. Such a fabric, named F-111, was developed and standardised by the Department of Defence in the shape of MIL-C-44378 military specification (Table 1).

The F-111 fabric is now in wide use in other types of parachutes, personnel emergency parachutes, troop parachutes, recovery parachutes (Fig. 5), etc.

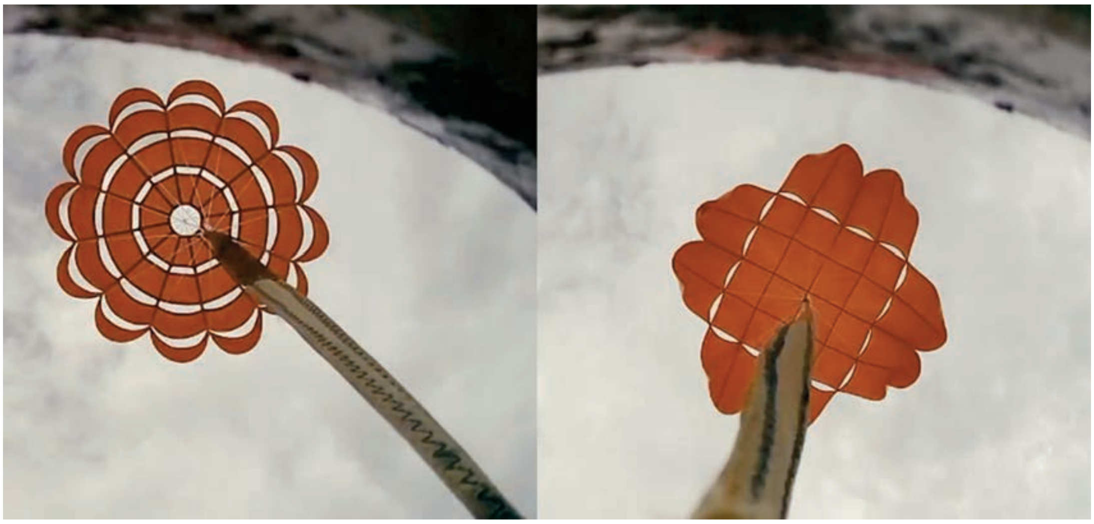

Figure 5. F-111 fabric used by HORNET in structure of stabilising ringslot canopy (left) and main cross canopy (right) of the ILR-33 Amber research rocket designed by the Institute of Aviation [10].

The fabric with non-zero air permeability generates lower opening loads compared to zero air permeability (ZP). Lower loads mean lower stresses exerted on the jumpers' body, especially on their spine, and they can lengthen the service life of the canopy because its strength structure can work with smaller loads. Such a fabric is also less expensive to manufacture compared to the ZP fabric. On the other hand, a 0-3 CFM fabric allows maintaining good overpressure inside the ram-air canopy because only a very small portion of air can escape through the fabric's layer. Too low overpressure can degrade the canopy's stability and steering characteristics during descending a full open parachute.

In the newest sport canopies and military canopies with a greater aspect ratio, upper surface panels are made from the ZP fabric to improve overpressure inside those canopies.

FATIGUE IN PARACHUTE CANOPIES

Repacking

Repacking has a major impact on the canopy's fabric's condition, especially in main canopies, which can be repacked up to 1000 jumps or more. During repacking the fabric of the parachute canopy is bended at many places which in every repack lie in the same part of canopy. So, these special bended parts are especially very prone to damage coating of fabric. The less coating in these parts of the canopy, the more porosity, and the canopy loses part of its overpressure which can affect the stability and steering characteristics during descending. Moreover, the less coating, the more fabric yarns are exposed to the degrading influence of UV rays, which lessens strength of polyamide yarns [4, 5].

Jumps

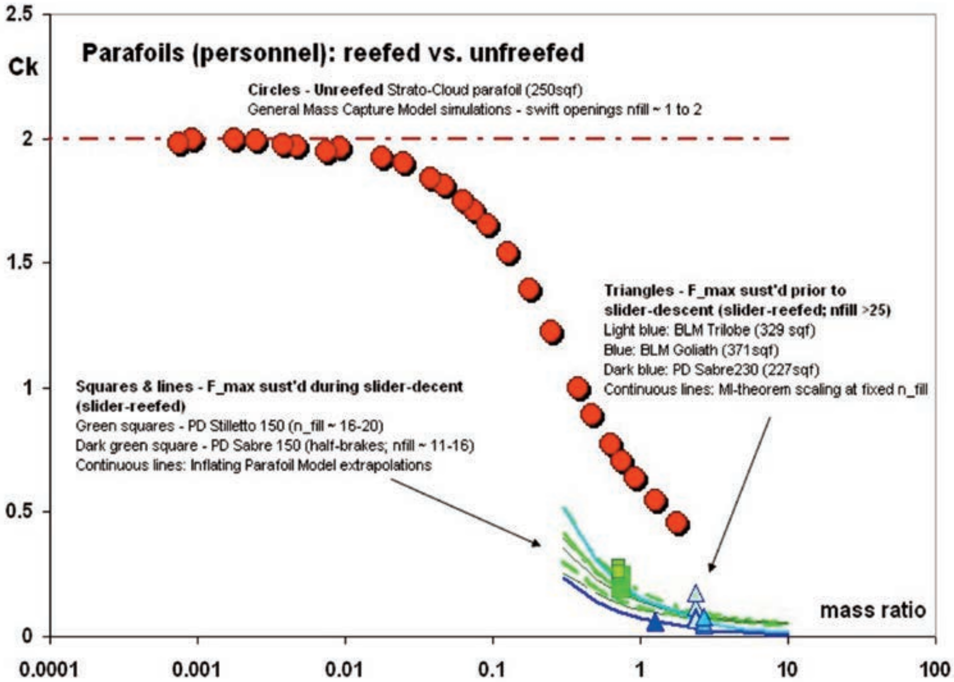

Figure 6. Opening shock factor versus mass ratio for ram-air canopies for unreefed and reefed opening systems [1, 12].

During jump the most danger moment occurs when the canopy is under inflation process. Loads on strength canopy structure are the biggest. During inflation some parts of the canopy can flexibly deform with elongation up to 30% in hard opening (typically no more than 15% at moderate speeds). The fabric of the canopy is working in the same way, so the fabric's coating must elongate flexibly too. But, jump after jump, the coating flexibility degrades and the coating is starting to fragment its surface. Small fragments of the coating diminish, which causes the fabric's porosity to increase. Consequently, after a few hundred jumps, it is likely to see worse descending characteristics with worse stability and steering characteristics in greater scale compared to repacking fatigue.

Maximum opening force during inflation of the ram-air parachute can be written as follows [12]:

$$F_{\max} = C_k \left(\frac{1}{2} \rho V_i^2 \right) (SC_D)_{sd}$$

where:
F_{max} – maximum drag force sustained during inflation
C_k – opening shock factor
ρ – air density at deployment altitude
V_i – parachute-payload speed at the beginning of inflation
$(SC_D)_{sd}$ – drag area during steady descent

So, the opening force directly depends on speed at the beginning of inflation V_i and the opening shock factor C_k. Both factors directly affect stress in the fabric and its elongation during the opening process, consequently they affecting the condition of the fabric's coating and its service life. The speed at the beginning of opening can be lowered by maintaining a proper flat position before inflation. The shock opening factor is immanently joined with the parachute's construction and the opening systems used with reefing or unreefing, as is discussed in paragraph 4.

Sun's ultraviolet rays (UV)

The Sun's rays, especially the ultraviolet spectrum, have a devastating influence on the strength of the polyamide textile yarn (Fig. 6). During a typical jump, the skydiver opens the parachute at an altitude of about 1500 meters above the terrain level. The descending speed is typically about 5 meters per second so the parachutist glides for about 5 minutes with the open canopy exposed to UV rays. Referring to Fig. 6, Nylon 66 yarn loses ca. 35% of its breaking strength after 7 hours of exposure to UV rays. So, it is only about 85 jumps. In real life conditions, the canopy's fabric can withstand 10-15 times more jumps thanks to a special coating attached to the fabric surface. To avoid UV influence as much as possible, after landing parachute canopy is inserted to backpack or repacked to the next jump in shady area.

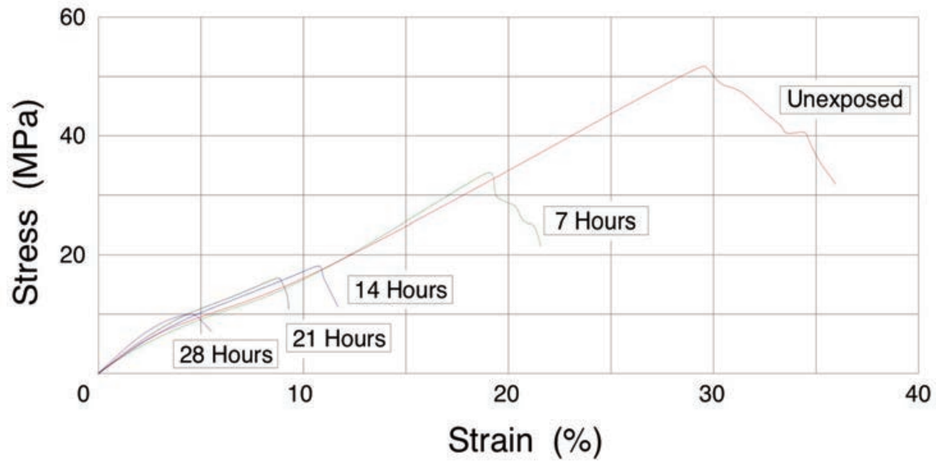

Figure 7. Effect of UV rays time of exposure on for strength of Nylon 66 yarn [7].

Lighter colour fabrics show better resistance to UV rays degradation because such lighter colours absorb less energy than darker ones.

The number of jumps and time of exposure to the Sun’s rays have significantly affect the strength and durability of the suspending lines [2, 3].

REDUCTION OF FATIGUE INFLUENCE

There are limited possibilities of reducing fatigue related to repacking if the number of repacking is high. Each canopy has its own geometry and every time should be packed in the same manner. The main canopy is a work horse in skydiving and when it is loosing its descending characteristics it is simply time to replace it with a new one. As for the reserve canopy, which is used rarely and only in emergency situations, its service life can be extended by making periods between repacking longer. Typically, the time between repacking is 6 months but some reserve canopies allow for 12 months or even longer. Less frequent repacking alleviates the risk of fatigue damage.

Jump-induced fatigue damage especially of the main canopy can be reduced by taking the following means:

1. using the manufacturer’s original parts for the opening system and canopy cover to prevent any additional damage caused by friction between the canopy’s fabric and the canopy’s cover;
2. repacking the parachute’s main canopy by a well trained rigger and repacking the reserve canopy by a certified rigger;
3. using opening systems with soft opening characteristics – it’s the designer’s job to select the right size of the pilot chute;
4. slow down inflation system – the slider is a proved and reliable solution but designer can also changing the geometric porosity of the slider and in this way changing braking characteristics of the slow down system;
5. performing jumps with delayed opening (as is typical in skydiving), which slows down descending up to 200 kph (55 meters per second) in a “flat position” of the parachutist so the inflation is performed at moderate opening speeds generating moderate opening loads and a moderate elongation of the fabric, allowing the coating to withstand more openings.

Figure 8. Two instructors teach a newbie jumper between them to maintain a proper flat position needed for the safe opening of the parachute [9].

The reserve canopy is destined for emergency purposes so only a few jumps are likely to be made during its service life. None of the above recommendations can be implemented when during jumping a safety problem appears. In an emergency the main and only goal is to rescue parachutist's life and health, without worry about the condition of the canopy which can be even scraped after the emergency jump.

UV radiation - induced fatigue can be diminished, for main canopies, by shortening the time of exposure to UV rays. So, after landing canopy should be without any delay packed to the backpack or moved to shady area to wait for the next repacking. Lighter colours of the fabric can also be used in the canopy structure but this possibility is restricted to cost savy jumpers only. In skydiving is a manner of each person style to have as colourful canopy as possible to stand out in the landing zone.

The principles of long-term storage of military equipment and the algorithms used to maximize the reliability and safety of use are shown in [11], with some of them being applicable to parachute systems used irregularly, in which the problems of materials fatigue are transformed by ageing.

CONCLUSIONS

Fatigue is a problem for reusable long living parachute systems. For parachutes with singular use is not the case. Parachutes used for hundreds of jumps have a special design and devices for lowering loads during opening and extending theirs service life. Additionally, the jumper can lower opening loads by using slow opening devices such a slider and by learning to maintain the flat position during diving before inflation to reduce the opening speed. Repacking of the parachute's canopy by a well-trained or even a certified rigger can lengthen the service life and enhance the safety of jumps.

Advances in textile materials combined with a better understanding of parachute inflation, the methods of computational simulation and actual tests results can give foundation for the development of parachute systems that offer higher performances and are less fatigue prone. Long-term storage of military equipment and its irregular exploitation can also have negative influence to the fatigue of parachute's canopies. To maximize the reliability and safety of use, special algorithms can be used based on the actual technical conditions of parachutes besides their remaining service life.

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