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Performance Investigation of Nylon-Kevlar Ringslot Parachute

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ABSTRACT

Kevlar material is being used in parachute systems require high strength-to-weight ratios or becoming resistance to sustain high temperatures. However, Nylon-Kevlar parachutes are popular these days and are first preference of the parachute designers specially for recovery system of reentry vehicles. Tests of using Kevlar suspension lines, radials, vent and skirt re-enforcements, risers demonstrated that the Kevlar material can be used successfully in Ringslot parachute. The opening shock experienced by the parachute does not differ from all-Nylon parachutes. The parachute is much lighter and capable of withstanding higher load and therefore can be used for extraction or deceleration in recovery system of reentry vehicles. The design and performance of a hybrid Ringslot was investigated experimentally in sled test. The experimental method and performance data are described in this paper.

Keywords: Ringslot, Kevlar, Nylon, opening shock, wind tunnel, taschengurt

NOMENCLATURE

S	Parachute area
C_D	Drag coefficient
D	Parachute nominal diameter
F	Drag force
m	Total sled mass
n_f	Filling time index
t	Time
t_f	Canopy filling time
V	Velocity
V_s	Velocity on line stretch
T	Air temperature
ρ	Air density
P	Air pressure
R	Universal gas constant
x	Distance

Subscripts

o	Nominal
p	Parachute

1. INTRODUCTION

Parachutes are always designed for a specific purpose. Many parachutes are designed with adequate strength to accommodate the inflation load without exceeding the weight and volume restriction. Specially, the parachutes used in space application have limitations on weight and volume. Consequently, parachute designers are always looking for the material of high strength-to-weight ratio for use in all structural elements of a parachute system.

Ringslot parachute[1] was developed in 1951 at Wright Field as a low-cost supplement to the ribbon parachute and has similar aerodynamic characteristics but 10 to 14 % higher drag. The basic design of Ringslot parachute is same as Ribbon parachutes. The horizontal ribbons are replaced with rings made up of fabric. Ringslot parachutes have been used in many applications viz. aircraft landing brake, load extraction, tandem engagement, and spin recovery of aircraft. It was also used in Apollo parachute system to support the apex cover removal and prevent re-contact with command module and further the similar parachute was used for deployment of large main parachutes.

Peterson[2], *et. al.* explained that the parachute can be made of All-Nylon, All-Kevlar and Nylon-Kevlar materials. There are other materials equivalent to Kevlar can also be used in place of Kevlar. All Kevlar canopies are practically a necessity for parachutes that operate at supersonic speeds and elevated temperatures for extended period of time[2]. All-Nylon parachute is the first choice of any designer if the weight and volume restrictions are not predominant. Hybrid parachutes are best suited for subsonic application in which Kevlar skirt bands, circumference bands, radials, pocket band, suspension lines and vent lines can be used. On hybrid and All-nylon canopies, Nylon vent reinforcement is preferred over Kevlar. Hybrid parachutes have additional advantage of weight and volume saving and specifically used in space applications. Kevlar lines, tapes and webbings are preferred but not the Kevlar fabric because the stitching efficiency of Kevlar fabric seams is lower than that of the equivalent Nylon seams.

The Kevlar suspension lines and radials can cause high snatch load experienced by the parachute. It could be higher than the peak inflation load also due to low elongation of Kevlar materials. However, the snatch load does not depend upon the suspension line material as much as upon the deployment system and canopy geometry. Snatch loads can be accommodated by Kevlar suspension lines if an orderly,

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line first deployment of the parachute system is inherent in the deployment system design.

2. DESIGN OF RINGSLOT NYLON-KEVLAR HYBRID CANOPY

Canopy has been designed based on the conventional method of Ringslot parachute design given by Wolf[3]. For analysis of load, a small parachute of 16 gores, nominal diameter 2.5 m is considered for design which has geometric porosity of about 17 %. The porosity provided at vent i.e., vent area is about 0.65 % of the nominal area of the parachute based on the experience gained by many other systems. The total geometric porosity is inclusive of vent area and distributed symmetrically all around the canopy.

The suspension line length to diameter ratio is established from wind tunnel tests which is 1.2 to achieve higher drag coefficient of the parachute. The canopy also incorporates Taschengurts located in every gore at skirt to improve its inflation characteristics.

A long riser length was taken to minimize the wake effect at high subsonic speed and to verify the ejection from mortar. The 44 mm webbing Kevlar riser was folded and stitched to make 22 mm width to look better for such a small parachute.

The parachute was designed to withstand a load of 22 KN so that requirement of Kevlar material can be justified. The slots in the canopy are provided symmetrically to achieve symmetric load distribution. Accordingly the Kevlar textile materials are selected at all places except the fabric and verticals. The canopy gore fabric is tailored with high strength Nylon fabric. Vent & skirt were reinforced with tape Kevlar. Nylon tapes are used in verticals and tape Kevlar as radials in two layers. Suspension lines and vent lines are selected as cord Kevlar.

Usually in Nylon-Kevlar hybrid canopies, the vent bands are recommended in Nylon material. However, in this design the Kevlar tape was chosen to verify its performance in the test. The canopy gore was made up of 6 rings, 5 slots and three verticals (Fig. 1).

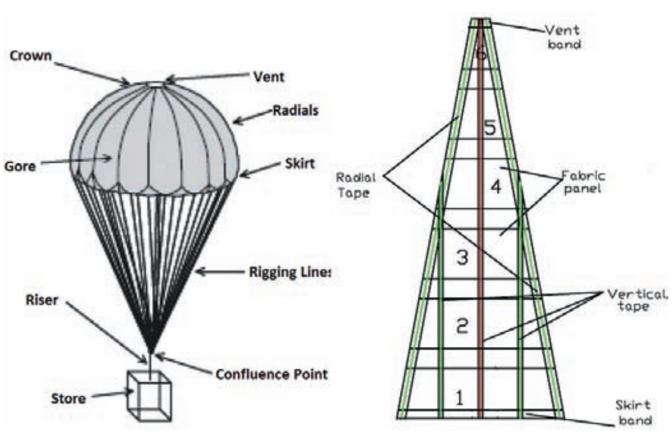


Figure 1. Parts of a typical parachute system and gore profile of ringslot parachute.

The material shrinkage due to stitching of nylon and Kevlar is practically identified to maintain the dimensional stability. Two gores are fabricated and joined first to confirm the allowance. The edges of all fabric-panels are folded to avoid tearing during inflation.

Mortar is used as a deployment mechanism for the Ringslot parachute which requires pressure packing of the parachute inside the pack cover. Pack cover is made up of Nylon fabric and tapes in cylindrical shape and size to meet the inner space of mortar. The sabot of mortar is integrated with the pack cover. The parachute is packed with packing density of 480 kg/m^3.

3. MODEL TEST IN WIND TUNNEL

Two parachutes models of different sizes were considered to be tested in wind tunnel to verify the design in terms of drag coefficient and stability of the parachute. This experimental study was carried out at National Wind Tunnel Facility, Indian Institute of Technology, Kanpur[4] at various speeds. This study involved quantitative measurement of drag force during and after deployment. Load cell has been used for the drag force measurement. Also, the parachute oscillations (stability) were seen from video data.

In wind tunnel tests, parachute performance is determined using scaled models. The drag coefficient of the parachute obtained as 0.6-0.65 against the literature value of 0.56-0.65. The recommended value of the drag coefficient should also be within the range.

3.1 Test Results

The models of 17 % geometric porosity were tested at speeds ranging from 40 m/s to 65 m/s. Deployment phenomenon was recorded by video camera and the drag force was measured using a 3150 N load cell. The test results were summarized by Poddar[7] and given in Table 1.

Table 1. Summary of WT test results

Model	Speed (m/s)	Ref.[1] C_D	Test C_D	Ref. Area
Model-1	40	0.56-0.65	0.63	1.495 sqm
	65		0.63	
Model-2	40	0.56-0.65	0.60	0.346 sqm
	65		0.62	

The models were observed to be stable (less oscillations). The recommended value of the drag coefficient for the present design is 0.6.

4. PROTOTYPE TESTING IN RAIL TRACK ROCKET SLED

The prototypes were tested in cluster configuration at load conditions higher than the flight opening shock (22 KN). The cluster configuration of two parachutes was chosen to generate the data of two parachutes at a single attempt in place of repeating the trial. This was planned to qualify the parachutes at higher load condition but below the safety margin (22 x 1.6 KN) where the safety margin is 1.6 for the parachute design. The load of the parachute was simulated to calculate the sled speed for parachute deployment. The parachutes were deployed at sled speed of 133± 3% m/s. It was expected that this speed of the sled should achieve on full stretch of the parachutes.

To avoid parachutes from falling down on track during stretching and inflation, the parachute was planned to be deployed at angle. A deployment angle of 8^0 was raised from the horizontal.

4.1 Data Acquisition

During performance evaluation trials of the prototype parachutes at rail track rocket sled (RTRS), following parameters were measured using onboard instrumentation.

- **Load Profile**

Load profile is useful for deriving peak load on the parachute. Generaly these loads are measured using load cell of higher sensitivity. Author may mention the types of the load cell used.

- **Velocity profile of the sled**

Sled velocity is measured using the magnetic coils mounted every 10 m on the rail track. When sled moves over these magnetic coils, an electric pulse is generated that is recorded by Online Data Acquisition system. Based upon the time taken by the sled to move from one coil to another, velocity profile is computed.

- **Acceleration profile of the sled**

Sled acceleration profile is important for deriving velocity profile and to ascertain various events during the test. It also provides verification of the peak load measured by the load cell. Acceleration profile is measured using an accelerometer. The accelerometer is mounted with its sensing axis pointing towards the movement of the sled. Output of the accelerometer is also conditioned and fed to the Data Logging unit.

- **Pyro-current**

Pyro-current is measured to determine the amount of current flowing through the squib of the mortar based parachute deployment System. A Hall- Effect sensing is used to sense the pyro-current. Variation in the current flowing through the squib causes change in magnetic field which in turn causes change in the hall voltage of the Hall sensing element.

- **Air temperature, humidity and pressure measurement**

To record the atmospheric data during the trial, BL2120 Single Board Computer (SBC) based Temperature and Pressure Monitoring unit is developed. It uses HS-2000V Sensor for measurement of the temperature and humidity and precision digital- Output pressure sensor is used for measuring Atmospheric pressure. Temperature and humidity sensor was interfaced with the ADC module while Pressure sensor was interfaced with the digital ports of the BL2120 SBC. A LCD module is provided for display of sensor data.

Data logging unit consists of cRIO-9014 real time embedded controller, 4-slot chassis and NI 9205 general purpose analog module. All the signal conditioner outputs are fed to the analog input module. Real Time (RT) controller reads these inputs via field progammable gate array (FPGA) and logs the time- stamped data onto the disk. The Data logger unit was mounted on the sled.

4.2 System Integration

The integration of the system starts with pressure packing of the parachute inside the pack cover. The packed parachute is then inserted into the mortar casing.

1 m riser of the parachute was kept out of the mortar through a slot provided at the mouth of the mortar for its attachment with load cell.

The mortar was mounted over the sled with a bracket which is welded on the sled to provide the desired angle of parachute deployment. Riser is attached to the load cell and load cell is attached to the sled through an intermediate strap.

Two data acquisition systems were mounted over the sled (Fig. 2). Along with ground based camera, onboard cameras were also mounted to capture the close view of the parachute inflation.

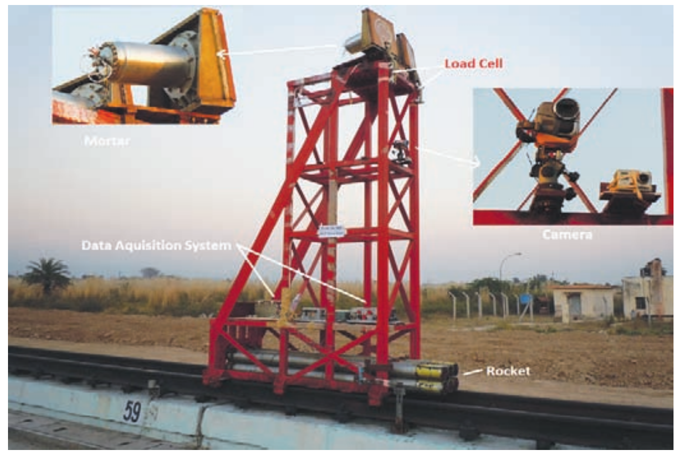


Figure 2. Test set up.

The rockets mounted on the sled are fired which propels the sled to the desired speed. Once the rockets are burned completely, the sled starts decelerating. During this deceleration phase, the parachutes were deployed at required speed.

The deployment begins, governed by fire current of mortar which ejects the parachute at ejection speed 40 m/s into the free stream. The parachute then starts inflating to full open.

4.3 Results

A. Atmosphere Data

The measured atmospheric data of the trial site at trial time is

Air pressure : 99200 Pa

Air temperature : 20.6 °C

The air density can be calculated as

$\rho = P / RT$

$= 99200/(287 \times 293.6)$

$= 1.177$ kg/m^3

B. Opening Shock of Parachute

The load cell data (Fig. 3) shows the peak values of both the parachute as

Parachute 1, F = 28.7 KN

Parachute 2, F = 26.01 KN

The data also indicates the parachutes were not inflated simultaneously. There was a delay in inflation of one parachute (no. 2).

C. Delay in Parachute Deployment

The delay was calculated from the load cell data from Fig. 3 as difference in two peaks as

Delay = 0.272 - 0.226 = 0.046 s.

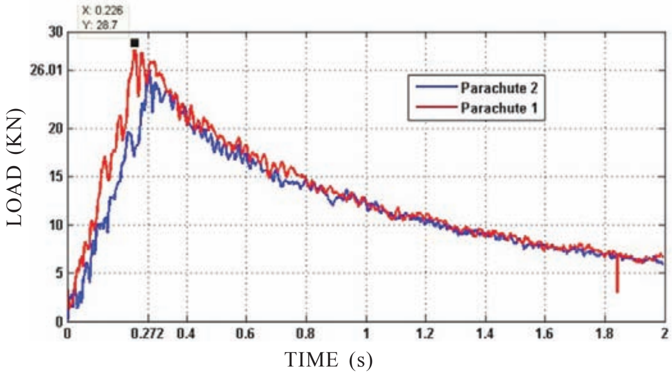


Figure 3. Measured load profile of the parachutes.

D. Drag Coefficient of Parachute

From the wind tunnel test data

$C_d = 0.6$

E. Canopy Filling Time

Canopy1 = 0.226 s

Canopy2 = 0.272 s

F. Speed at Complete Stretch of the Parachute

The sled speed profile is mathematically simulated from the accelerometer data (Fig. 4).

Measured speed = 137.4 m/s

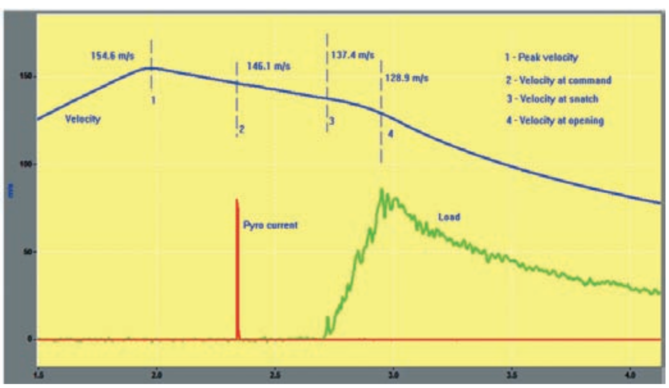


Figure 4. Velocity profile of the sled.

4.4 Result Analysis

4.4.1 Canopy Filling Time

Canopy filling time, $t_f = n_f D_o / V_s$

where $n_f = 14$ for Ringslot parachute[3]

$t_f = 14 \times 2.5/137.4 = 0.254$ s

Ideally, the canopy filling time of parachute 1 should be 0.254 s however it will be lesser because of sled speed reduction during inflation of parachute no. 2. Hence the canopy filling time of 0.226 s for parachute no. 1 achieved from test data is justified. In parachute no. 2, it will be higher due to delay.

4.4.2 Opening Shock of Parachute

The opening shock force is calculated by simplifying the equation given by Libii[8]. The equation of motion can be written for horizontal deployment of the parachute can be written as

$$\frac{dV}{dt} = -\frac{F_P}{m} \qquad \frac{dx}{dt} = V$$

The drag force generated by the parachute is proportional to the squared of the velocity

$$F_p = \frac{1}{2}\rho V^2(t) C_D S(t),$$

where drag area variation is linear. Being a highly porous canopy, the effect of apparent mass is neglected. The opening shock mathematically is simulated based on above equations (Fig. 5).

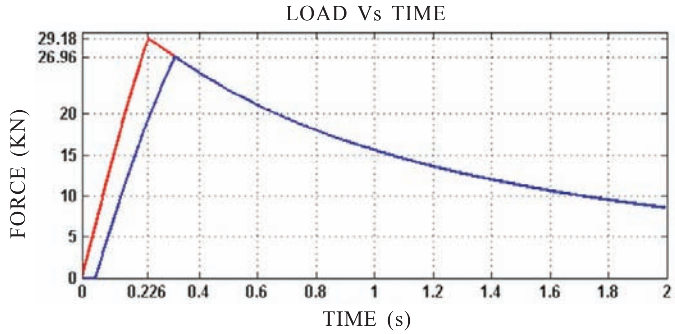


Figure 5. Mathematically simulated load profile.

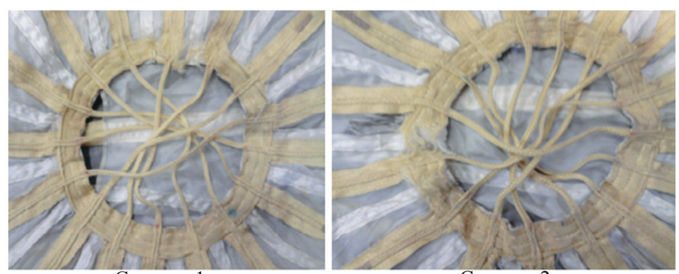
5. OBSERVATIONS

i. Parachutes ejected as expected and deployed beautifully (Fig. 7). Parachutes have stretched completely by mortars.

ii. No damages are seen in the canopy, suspension lines and risers except the vent area.

iii. Vent bands are broken in both the parachutes (Fig. 6).

iv. Mortar Sabots with the deployment bag are also recovered and no damages are seen the deployment bag.



Canopy 1 Canopy 2

Figure 6. Broken vent band after test.

Figure 7. Parachute in deployed condition in RTRS test.

6. CONCLUSION

In Sled test, a proper deployment of the Nylon-Kevlar parachute was observed. The functioning of deployment mechanisms, i.e., mortars, was perfect. A non-simultaneous deployment of the parachutes was seen. The delay of 0.046 sec in parachute deployment was observed from load cell data. This delay will vary for each trial and cannot be eliminated.

The canopy filling time and opening shock measured are in good agreement with the calculated values. This shows, there is no significant effect of the using Kevlar material on the filling time and opening shock.

The vent bands materials were selected based on designed values and Kevlar tape was chosen to verify its structural integrity. The failure of vent bands shows that it should be chosen from Nylon rather than Kevlar material.

The application of Kevlar material in the Nylon Ringslot parachute played a good role in weight reduction. The strength of the parachute structure is increased without compromising the performance of the parachute.

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