Simulation of Temperature Variation in Parachute Inflation

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Simulation of Temperature Variation in Parachute During Inflation

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In this paper the variation of temperature during parachute inflation is simulated by system dynamics methodology. In this methodology, causal loops for the system have been identified and flow diagram is drawn. Flow diagram consists of flow rate variables, level variables and auxiliary variables. In causal mechanism, principal feed back loops are identified. It also simplifies illustration due to various influencing factors such as pressure, rate of pressure, mass of parachute, textile characteristics, motion of folded parachute to compression under pressure and interaction between parachute and its container/bag.

Keywords: Parachute Packing; System Dynamics Technique; Parachute Inflation; Simulation Model.

NOTATION

A : absorptivity of the canopy material
C : Stefan-Boltzmann constant, BTU / s °R 4 ft²
C1 : specific heat of canopy material, BTU / lb °R
E : emissivity of canopy material
E1 : energy stored in canopy
FS : radiation shape factor
H : convective heat transfer coefficient, BTU / s °R 2 ft²
J : J th time instant
JK : time interval between J th and K th time instant
K : K th time instant
KL : time interval between K th and L th time interval
L : solar radiation intensity, BTU / h / ft²
M : mass of canopy, lb
REI : rate of change of energy stored in canopy
RT : rate of temperature rise
S1 : surface area of body exposed to aerodynamic heating for hemisphere (πD²/2) ft²
S2 : projected area of body in a plane normal to the sun rays (πD²/4 - for hemisphere) ft²
S3 : area of body radiating to space, (πD²/2) ft²
S4 : area of body radiating to earth, (πD²/2) ft²
T : temperature at wall, °R
TA : room temperature, °R
TAW : adiabatic wall temp °R
TS : temperature of space, °R,

INTRODUCTION

Major part of all modern weapons comprises of electronic gadgets and propulsion system. In some of the weapons, parachutes are also required to impart high deceleration for reorientation of weapon's altitude and reduction of velocity. As such the parachute is also required to be housed in the same weapon. Since parachutes are made of textile materials, attempts of system designers are always to allocate bare minimum volume for housing the packed parachute system. Many major failures have been attributed to wrong handling of parachute during packing. There have been cases of bursting of parachute during opening due to wrong packing. The preferred packing densities of textile material fall in the categories as given in Table 1. Generally attempts are made to achieve an average packing density of 40 lb / ft³ for weapon's parachutes. This range of density can only be attained by using a powered press. The schematic diagram of a press, is shown in Fig 1. This comprises of a small hydraulic device having a long stroke pivoted cylinder with extendable arm that can be positioned over the opening of the parachute container having parachute packing bag. A pressure foot of suitable shape and size is fitted with extendable arm to the piston of the cylinder to provide the pressing surface against the material being compressed. For rigidity, this pressure foot is constructed of thick hardwood, or metal with a smooth surface and edges as required. The press is positioned at the end of the parachute packing table as illustrated in Fig 1, where the stretched out parachute is fed progressively into the container in a series of 'S' folds between successive application of the pressure. After putting the complete parachute in the parachute bag (housed in container), required pressure is applied slowly in order to achieve : (i) slow release of air trapped between the layers

<table>
<thead>
<tr>
<th>Method</th>
<th>Applied Pressure</th>
<th>Maximum Volume Reduction, %</th>
<th>Average Packing Density, lb/ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Pack</td>
<td>1 – 2.5</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Mechanical</td>
<td>0 – 300</td>
<td>50</td>
<td>41</td>
</tr>
<tr>
<td>Hydraulic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum</td>
<td>0 – 15</td>
<td>25 – 30</td>
<td>30</td>
</tr>
<tr>
<td>Lace</td>
<td>0 – 40</td>
<td>30 – 40</td>
<td>34</td>
</tr>
</tbody>
</table>

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of parachute, and (ii) low generation of heat/temperature due to friction between the layers of parachute mass as well as between parachute mass and surface of parachute bag (in which it is packed). Parachutes for weapons are made of nylon and kevlar materials. Nylon is more susceptible to temperature rise beyond a certain level of compression, compared to kevlar and it loses its strength once significant rise in temperature occurs.

After packing to the desired shape in the parachute bag, these are integrated to the parent weapon/payload. Parachute is later deployed in flight as per the sequence (reverse to packing) as shown in Fig. 2. In this reverse phase heat is generated during: (i) extraction of parachute out of bag and (ii) deployment of parachute (opening of parachute) in the air. The temperature raised during these phases are much higher compared to the values during packing.

System dynamics technique invokes an innovative approach for modelling these temperature histories in such a system. In this technique, at first the cause-effect relationships between the pair of variables (known as causal links) are developed and combine them into loops. After getting the principal feedback loop, the flow diagrams are prepared, which simulates the model. Using the flow diagram, one can write the DYNAMO equations. For developing the model a few important assumptions were made, namely,

(i) parachute is considered as a solid mass,

(ii) the specific heat of nylon material is considered to vary linearly with temperature, and

(iii) heat is generated uniformly on the entire surface of the parachute.

HEAT GENERATION

Parachute Packing

During parachute packing, the heat is generated due to friction, (i) between the layers of material subjected to the pressure applied from the top and, (ii) between the inner surface of bag and parachute. While packing, the parachute is pressed very slowly in the bag which usually has a cotton lining. It has been found that the heat generated between the nylon and cotton is less compared to nylon lining and nylon parachute material. The specific heat and frictional coefficient between various combinations of nylon and cotton materials are given in Table 2.

As may be extracted from the data in Table 2, temperature attained by the nylon-cotton combination of material works out to be very low compared to other combinations due to the low coefficient of friction. The coefficient of friction for nylon-cotton combination changes with the parachute compression rate which varies from about 3.6 cm/min to 200 cm/min.

Parachute Extraction

The parachute is extracted from its bag relatively at very high speed compared to the rate at which the parachute is packed. The large extraction rate generates frictional heat. If the parachute is not extracted smoothly for any reason such as due to uneven inner surface, then there are possibilities of localized heat generation due to excessive friction. This tends to weaken the parachute cloth. If the weakened area is large, then the parachute has tendency to propagate the tearing or bursting during the parachute inflation leading to partial collapse of parachute or total separation of parachute from payload. These are modelled and discussed in this paper.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>THE SPECIFIC HEAT AND FRICTIONAL COEFFICIENT BETWEEN VARIOUS COMBINATIONS OF NYLON AND COTTON MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre (Dry)</td>
<td>Specific Heat, J/g/k</td>
</tr>
<tr>
<td>Nylon on Nylon</td>
<td>1.51</td>
</tr>
<tr>
<td>Cotton on Cotton</td>
<td>1.21</td>
</tr>
<tr>
<td>Nylon – Cotton</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>
Parachute Inflation

When a parachute moves through the air at supersonic speed, its surface becomes heated to a temperature above that of the surrounding undisturbed air due to aerodynamic heating.

The model of heat generation is obtained by applying the principle of conservation of energy, by equating the difference between the rate of energy entering and leaving a body to the rate at which energy is stored within the body.

As the canopy moves through the atmosphere at high speed, there will be a flow of energy into the canopy by aerodynamic heating, part of this energy goes to raise the temperature of the canopy and part of it is radiated back to the space. These are taken into account in the simulation model described below.

MOdELLING OF HEAT GENERATION IN PARACHUTE

Using System Dynamics Technique

As mentioned earlier, a large amount of heat is generated, during power packing and deployment of the parachute. Canopies constructed of fabrics are poor conductors of heat and in maximum cases are of irregular shape. Large temperature gradients can develop in the material both normal and parallel to the canopy surface. This may cause a major failure in the parachute. Therefore, it is quite essential to model these effects. Since the parachute material is of very low thickness, it is assumed that uniform heat generates on the parachute canopy surface. The model equations are framed accordingly. Parachute design engineers can choose the proper material in proper shape using this model, so the heat generated is limited avoiding the failures in the parachute.

Modelling of Heat Generation during Deployment

The temperature profile of aerodynamic devices (specifically parachute canopy) is worked out by applying system dynamics technique. In the development of the model, the sun is assumed to be located vertically, above the descending canopy. Here, two negative causal loops are identified as shown in Fig 3 of causal loop diagram. From this diagram, the flow diagram is drawn as shown in Fig 4. After drawing the flow diagram, DYNAMO equations are written. This dynamo model was simulated directly on the computer in DYNER package without any change in the model. This is an advantage of the model, when developed by this technique. This model is developed basically for the deployment of the parachute and similarly another model can also be developed for the packing of parachute. But the heat generated in packing will be very small if the rate of packing is low, hence the model for this is not developed here.

Dynamo Equations for Heat Generation

The causal loop and flow diagrams lead to develop dynamo equations that suffices for representing information feedback systems. The equations tell how to generate the system conditions for a next point in time, given the condition known from the previous point in time. The dynamo equations of the model are evaluated repeatedly to generate a sequence of steps equally spaced in time. Level equations and rate equations represented by putting L and R in the starting columns of the DYNAMO model, which generates the level and rates for the system. In addition auxiliary, supplementary and initial value equations are used, to facilitate the calculations for level and rate variables of the given system. The auxiliary equations, add convenience and clarity to complex system equation but these are not fundamental for the model structure. The interval of the time between solutions must be relatively short, determined by the dynamic characteristics of real system that has been modelled.

\[ L.T.K = T.J + DT \times RT.JK \]

This equation is used for the calculation of the present value of level variable, i.e., temperature \((T.K)\) from the previous value of it \((T.J)\).

\[ N.T = 5.73 \]

This represents the initial condition of level variable \((T)\) in degree \(R\).

\[ RRT.KL = (CCC.K + L.A.S2 - BBB.K - AAA.K) / (M.C1) \]
This is a rate equation, which indicates rate of change of temperature ($RT$) and this is constant for interval between time instants $K$ and $L$.

$$A\ A A A\ .\ K = C * F S * E * S 4 * (T .\ K ** 4 - T A ** 4)$$

$$A\ B B B\ .\ K = C * S 3 * E * (T .\ K ** 4 - T S ** 4)$$

$$A\ C C C\ .\ K = H * S 1 * (T A W .\ K - T .\ K)$$

These are auxiliary variable equations used for calculating the auxiliary variables $AAA$, $BBB$, and $CCC$. These variables are substituted in the rate equation $RT$.

$$C\ H = 5.64e - 4$$

$$C\ S 1 = 25.145$$

$$C\ S 2 = 12.745$$

$$C\ S 3 = 25.145$$

$$C\ S 4 = 25.145$$

$$C\ L = 425$$

$$C\ A = 0.82$$

$$C\ C = 172.8e - 11$$

$$C\ E = 0.85$$

$$C\ F S = 0.6$$

These equations are used for representing the values of different constants, required in the rate equations or auxiliary equations as mentioned above.

$$A\ T A W .\ K = T A B L E (T A T , T .\ K , 500, 1100, 100)$$

This is also an auxiliary equation for getting the value of adiabatic wall temperature in degree $K$ from the Table $T A T$ as given below:

$$T\ T A T = 700, 550, 400, 250, 100, 100$$

$$C\ T A = 573$$

$$C\ M = 30$$

$$C\ C 1 = 0.47$$

$$C\ T S = 490$$


$$N\ E 1 = 10$$

These equations indicate the level equation for energy stored in the canopy and the initial value equation for the initial value of energy stored in canopy, respectively.

This is a rate equation used for calculating the rate of change of the energy stored in the canopy.

$$S A V E\ T , R T , E 1 , R E 1$$

This statement is used for saving the different level and rate variables, which are calculated in the model developed.

$$S P E C\ L E N G T H = 4 , D T = 0.001 , S A V P E R = 0.001$$

This represents the specifications for a particular simulation run. For example, length of simulation in this case is 4s, time duration between two time instants $K$ and $L$ is 0.001s, and save the level and rate variables after 0.001s.

**RESULTS**

The main objective was to develop the model for simulation. The input data was fed into the model as given earlier under 'Dynamo Equations for Heat Generation'. The results have shown in Fig 5 - Fig 7 indicate trends in variations of temperature and energy during inflation and deceleration phases. The maximum wall temperature for four feet diameter parachute before deployment was taken 597.9°F. The maximum temperature of the parachute when deployed at Mach 2 was attained 729.2°F. The maximum temperature attained and variation trend is comparable with the results obtained from empirical relations of aerodynamic heating.

**CONCLUSION**

Parachutes are used for deceleration of payload. These are densely packed due to volume limitations using mechanical/hydraulic press. A lot of heat is generated in this type of packing. It can be controlled by rate of applying pressure. Again significant heat is generated in the deployment phase due to frictional heat of extraction and aerodynamic heating. A simulation model has been developed for the heat generation during deployment. The model developed by the system
dynamics methodology offers a convenient way for incorporating the different variables which effect heat generation. The model can be used effectively for estimating parachute surface heating at transonic and supersonic speeds.

REFERENCES