# **Dynamics of Thread Movement in Turbulent Flow Field**

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## Abstract:

The main goal of this work is to understand the instability mechanism in melt blowing. To model this problem, experiments are done with a thread attached to a high pressure tank. The movement of the thread is followed spatially and materially (Eulerian and Lagrangian). The results have yet to be matched with the theoretical formula, which is also being processed.


## Introduction:

Melt blowing serves as one of the most often used ways to mass produce non-woven nanofibers on the order of 5-50 microns even to few hundred nanometers. Molten polymer is delivered from a small hole (or series of small holes) and hot air is blown from each side at an angle toward a collecting plate at a very high pressure. Other groups have researched and modeled some behavioral elements of the thread during melt blowing, but because they have not combined the Eulerian and Lagrangian perspectives into one model, the instability mechanism is not properly understood. Once this mechanism is understood, melt blowing will become more efficient in that a desired fiber diameter can be made by altering the air speed and the distance from the exit plate to the collector plate.

## Experiment, results, and discussions:

$N_2$, (ultra-high purity) purchased from Airgas, was used as a high pressure reservoir. Sewing thread was used as the model melt blown fiber. For taking pictures, a high speed camera (Redlake MotionPro) was used. Images were taken at 500 fps at a shutter speed of 1/9000-1/10000 seconds. To track the material movement, beads of PEO (4.5 wt% in 40/60 water/ethanol solution) were put on the thread at regular intervals (figure 2a). The images were analyzed using MATLAB. A polyester sewing thread was used to model the behavior of melt blowing (fig. 1a-b). The polyester does not fray, so it does not interfere with the air flow. Air passed through the nozzle at 40 bar.

From the analyzed data from figure 2a the amplitudes of oscillation are found and then from there the velocity in x and y direction is determined as shown in Fig. 3 a-b. This information is going to be used to find the harmonics of oscillation, which are very important for theoretical modeling.

Using the Eulerian perspective, we see how the string moves in space in order to determine flow field. For this the general idea is same as described before but the only difference is that this time there was no bead on the thread (fig 2-b). With our new rendition of the string, we tracked the position of the pixel in each column and we found a position vs. time graph of each column in the frame (fig 4).

Using the displacement information from these graphs and a fast Fourier transform, the harmonics that defined the motion of the string were found. As it can be seen from the figure 5 a-b there is no single discrete peak. Rather there is a continuous distribution of frequencies, which strongly hint that the flow is turbulent. To fortify this autocorrelation function was determined using IMSL library functions. As it can be seen from figure 6 the autocorrelation function dies out as we go up in time steps.

Because the correlation function goes down to 0, rather than show a number of discrete lines, the motion of the string is chaotic.

The last test used to examine the behavior of the string was to measure the length of the snapping point of the string. The snapping point is where the motion of the thread becomes elliptic from hyperbolic. At first, the snapping point was measured using a high-speed camera. The snapping point can be seen when the string goes vertically up or down whereas the rest of the string remains relatively horizontal. Unfortunately, the results of the snapping length did not match the theoretical model. The snapping length tended to increase with the length of the string even thought the two should have been independent of each other. It was possible that the theoretical model was wrong and the experiments displayed a new mechanism of behavior; however, the major inconsistency in the snapping lengths when the string length and velocity remained constant indicated that the setup had some drastic error. It was decided that gravity had a more substantial role than what was originally considered. In order to make the gravity ineffective to the string, the setup was turned vertical that way the weight of the string couldn't create an artificial snapping point.

In order to consistently find the snapping point, rather than use the naked eye to determine the snapping point, a specific measureable criterion needed to be used. The criterion used was a width that was a multiple of the width of the nozzle. This also turned out to show that the snapping length depended on the string length. The error with the criterion was that as the string became longer, the conical expansion of the flow field caused a larger envelope for the thread to travel through. This increased envelope size achieved the criterion earlier on in the string to make it seem like the snapping length is increasing with string length.

It can be shown that the submerged axisymmetric jet structure can be approximated with a triangle. At snapping point because of the sudden change of movement of the thread the thread should not be within the triangle. This was taken as our guiding parameter. For this images were taken with NIKON D-70S with a shutter speed of 4 so as to catch the envelope movement (fig 9-a) and at point where the thread went out of the triangle and at a certain time kept on moving in the same direction was considered to be the snapping point. It can be seen from figure 9-b as we go up in pressure, the snapping length kept on increasing.

**Conclusion:** Using the Lagrangian and Eulerian perspectives, an FFT, a correlation function, and different snapping length measurements, an accurate model of the movement of the thread can be obtained. The next step is to drip a polymer solution in front of the same jet and track its movement to see if it obeys the same model as the solid thread. If it does obey the same model, then the model found in this project can be considered an accurate representation of the instability mechanism in melt blowing.

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**Figure 1:** (a)Schematic of the experimental setup; (b)Envelope of string movement
**Figure 2:** (a) String used for Lagrangian perspective; (b) String used for Eulerian perspective
**Figure 3:** (a) Velocity in Y direction for bead 4 in fig. 2a; (b) Velocity in X direction for bead 4 in fig. 2a
**Figure 4:** Amplitude for one point on the string from fig 2b
**Figure 5**: (a) FFT representation string movement; (b) Amplitude contribution from each frequency; (c) Correlation function showing string movement is chaotic
**Figure 6:** Vertically hanging thread setup
**Figure 7:** Snap length increases linearly with string length when it should be independent of string length
**Figure 8:** (a) Envelope of string movement; (b) ln(snap length) vs. ln(velocity) with a linear slope of 2.61