CU Boulder

Team Second Report

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Introduction

This short video visual shows how a curved surface alters a nearby smoke plume to reveal fundamental flow features around an airfoil. A household spoon was oriented with the convex side down and held stationary while smoke from an extinguished match was introduced beneath it. The intent was to visualize streamline curvature, potential attachment of the flow to a curved surface (Coandă-like behavior), and any subsequent separation or vortex formation along the trailing region. The video was conducted as an individual effort.

Context and Purpose

The flow apparatus consisted of a standard metal teaspoon approximately 4 cm wide and 5–6 cm long. The spoon was oriented with the convex side facing downward, and the smoke from an extinguished wooden match was positioned several centimeters below the leading edge so that the buoyant plume could rise and interact with the surface. As the smoke encountered the spoon, the streamlines deflected upward and curved along the surface contour before thickening and separating near the trailing region. This motion reflects local pressure gradients around the body, where the flow accelerates over the curved section and decelerates downstream, resulting in detachment and small-scale eddies. NASA Glenn Research Center notes that smoke flow visualization effectively highlights these pressure-driven behaviors and separation regions in low-speed flow experiments [1].

Taking air ($\nu \approx 1.5 \times 10^{-5}\ \mathrm{m}^2/s$), a characteristic length $D = 0.04\ \mathrm{m}$(spoon width), and a representative local plume speed near the spoon Uin the range $0.10 - 0.30\ \mathrm{m}/s$(typical of small buoyant plumes near the source), the Reynolds number is:

$$\mathrm{Re} = \frac{UD}{\nu} = \frac{(0.10 - 0.30) \times 0.04}{1.5 \times 10^{-5}} \approx 2.7 \times 10^2 \text{ to } 8.0 \times 10^2.$$

This range corresponds to laminar or weakly transitional flow, consistent with the smooth streamlines observed near the leading region and the onset of instability farther downstream. Similar transitional behavior has been documented in smoke-plume studies, where entrainment and diffusion gradually introduce unsteadiness as the plume rises [2]. The apparent attachment of smoke to the curved spoon surface can be interpreted as a Coandă-like effect, in which a jet or plume follows a nearby surface due to pressure coupling between the flow and boundary curvature [3]. While this configuration differs from a forced jet, it demonstrates qualitatively how curved geometries can redirect surrounding flow and influence local velocity and pressure fields.

A still image taken from the original video is shown in Figure 1 below, however, the video is not included due to the file format of this submission

Figure 1. Flow Visualization Set-Up

Visualization Technique

The visualization relied on smoke produced by blowing out a wooden match, which generated fine soot particles that made the flow path visible. The experiment was performed indoors with minimal air movement to maintain stability in the plume. The smoke source was carefully positioned and held steady beneath the spoon to ensure repeatable results. Illumination was provided by standard ambient indoor lighting with an additional ring side light, which created sufficient contrast between the light-gray smoke and the darker background. This simple, low-cost technique provided a clear and controllable visualization of the local flow field, effectively revealing the trajectory and deformation of the rising plume around the curved surface.

Photographic Technique

The flow was captured on video using a smartphone camera positioned approximately 20–40 cm from the setup. The captured file, submitted separately, has a resolution of 1080 × 964 pixels, a frame rate of approximately 30 frames per second, and a total duration of about four seconds in the final cropped length. Automatic exposure and focus settings were used to accommodate indoor lighting. The field of view included the spoon and roughly 10–15 cm of the smoke plume height. No post-processing was performed other than in-camera video compression and shortening of video length, and playback occurs at the capture rate of 30 fps. This setup provided a sharp, high-contrast recording that allowed the smoke motion and separation region to be clearly identified.

Conclusion

The resulting visualization successfully captured the deflection and partial attachment of the smoke to the spoon's curved underside, followed by its eventual separation into small vortices. This pattern demonstrates how a curved surface can redirect nearby flow and induce localized pressure variations similar to those around an airfoil at low Reynolds number. The smoke visualization effectively revealed laminar motion near the surface transitioning to unstable, oscillatory motion downstream. A limitation of the experiment was the sensitivity to small drafts and variations in smoke intensity. In future iterations, using a controlled jet or mini air pump instead of a buoyant plume could produce a steadier flow. Overall, the experiment fulfilled its intent by illustrating how simple at-home apparatuses can qualitatively demonstrate aerodynamic behavior around curved geometries.

References

References
[1] NASA Glenn Research Center, *Smoke and Tuft Flow Visualization*, NASA, 2024.
[2] Meehan, R., and Kieffer, S., "Richardson and Reynolds Number Effects on the Near Field of Buoyant Plumes," *Journal of Fluid Visualization and Dynamics*, 2022.
[3] *Coandă Effect*, NASA Glenn Research Center, 2024.