# Visualization of Wall-Bounded Turbulent Flow Dynamics

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## Creating Energy Efficient Aircraft

- The aviation industry is working towards reductions in the fuel consumption of aircraft to save both money and energy. This can be achieved by:
  - Building aircraft out of lighter materials
    - Reducing its mass and decreasing the force necessary to move the craft
  - Creating more fuel-efficient engines
    - Yielding more thrust for less input energy
  - Making the surfaces of the aircraft sleek and/or “intelligent”
    - Decreasing the energy lost in overcoming friction between the aircraft and surrounding airflow
- This final point is the specific area our lab is researching.
- Studying the properties of airflow can help us to predict its behavior in complicated situations and to create surfaces that work *with* the wind instead of *against* it.

## Investigating Turbulence

- The focus of our research this summer was the design, construction, and implementation of a device that can make airflow visible.
  - This device will be able to show the transition from laminar (ordered) to turbulent (disordered) flow as well as the development of boundary layer separation over a dynamic surface that changes shape.
  - It will also serve as a valuable source of qualitative data.

## Methods of Flow Visualization

- There are many different processes of seeing the complex motions of fluids
  - Direct application of colored oil or tufts of string to investigate how air moves over a surface
  - Showing changes in air density due to heat or sound waves by using shadowgraphs or Schlieren photography
  - Illuminating microparticles (such as in smoke) with a laser or other strong light source
    - This is an exceedingly common method.
- We employed this endmost technique for our wind tunnel design, albeit with some variations.

## Designing the Smoke Rake

- Our final wind tunnel setup consists of:
  - A commercial fog machine to produce the smoke
  - A premade flow diffuser (the “rake”), which ejects the smoke in smooth lines through thin valves
  - Thick rubber tubing, which transports the smoke and prevents condensation
  - An LED bar light to illuminate smoke flow
    - This goes below the testing section of the tunnel, so it is out of sight and unlabeled for Figures 1 & 2.
  - Sheet metal that curves to varying degrees when a hydraulic piston is activated at regular intervals
- To optimize the visibility and clarity of the smoke lines, several variables were tested
  - Type and length of tubing
    - Thin, plastic tubing would melt due to the heat of the fog machine, and a long tube would allow the smoke to condense, resulting in extremely faint lines
  - Number and spacing of open valves on the rake
    - If too many valves were open, the lines would be faint, and if the open valves were too close, the smoke lines would become a smoke sheet

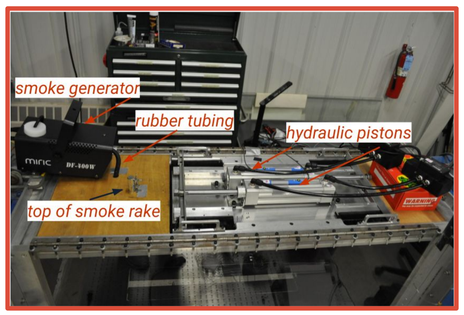


*Fig. 1. The complete wind tunnel setup from above.*

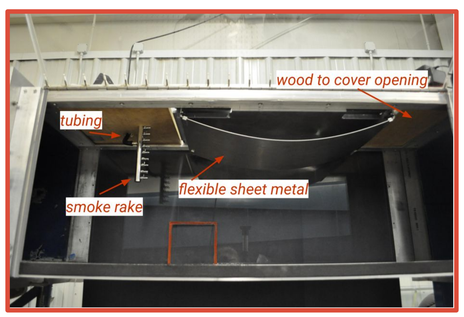


*Fig. 2. The complete wind tunnel setup from the side.*

## Results & Future Experiments

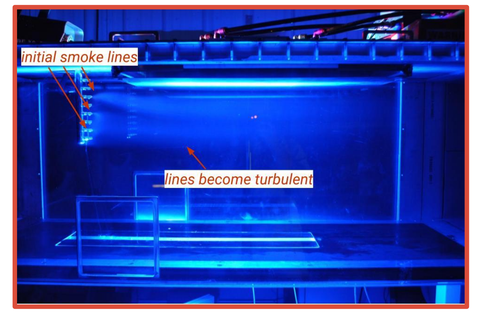


*Fig. 3. Smoke trails developing under a flat metal plate.*

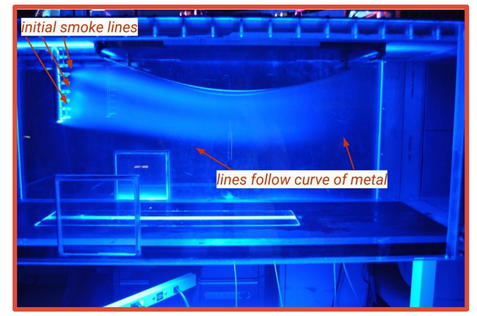


*Fig. 4. Smoke trails developing under the same sheet metal, now curved.*

- After copious testing, we concluded that:
  - A short, thick-walled tube was best to transport the smoke
  - Opening three alternating valves yielded the clearest smoke lines
- Even after perfecting the setup, unexpected results still occurred. We had hypothesized that the flow would separate and move away from the sheet metal after hitting the bottom of the curve, but it kept following the curve, as evidenced in Figures 3 & 4.
  - This abnormal phenomenon would require further testing to fully understand.
- The smoke rake proved to be cost-effective and easy to implement, although the lines are not as laminar as desired.
  - This could be improved by:
    - Utilizing a smaller diameter valve to increase the pressure and subsequent flow velocity
    - Using a denser smoke (e.g. a mixture of $TiCl_4$ + $CCl_4$) instead of a water-based fluid

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