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Science Fair Logbook:
Experimental Optimization of Vortex Generators in Boundary Layer Separation Mitigation on a NACA 2412 Airfoil

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October 2024: Planning and Apparatus Design
Potential Ideas
1. Lift Test: Measure how VGs affect lift forces.
2. Drag Test: Evaluate the impact of VGs on drag forces.
3. Stall Mitigation Test: Determine how VGs delay boundary layer separation and increase the stall angle of attack (AOA).
4. Angle of Attack vs. Lift force
5. Airfoil Shape Optimization:
6. Boundary Layer Visualization:
7. Winglet Design and Effectiveness:
9. High-Lift Devices (flaps and stats):
10. Effect of Aspect Ratio:
11. Flow Control Techniques (suction/blowing):
12. Airfoil Performance at Different Reynolds Numbers:
13. Effects of different kinds of flaps:

3 Final Designs Chosen:
1. Lift Test: Measure how VGs affect lift forces.
2. Drag Test: Evaluate the impact of VGs on drag forces.
3. Stall Mitigation Test: Determine how VGs delay boundary layer separation and increase the stall angle of attack (AOA).

Apparatus Design:
We designed a low-speed flow visualization wind tunnel to simulate flight conditions for a NACA 2412 airfoil. The wind tunnel was constructed using readily available materials, including a suction fan, an airflow filter, and a smoke-generating device for flow visualization. The testing chamber measured 7.50 cm (width) × 34.0 cm (length) × 12.0 cm (height) and operated at a Reynolds number below 2300 (laminar flow) with an airspeed of 0.84 m/s.

The NACA 2412 airfoils were designed using graphing software and 3D printed in PLA. Vortex generators were modeled in TinkerCAD and attached to the airfoils at varying locations and spacings.

November 2024: Data Collection
Experimental Setup:
We tested eight airfoils with different VG configurations:

- Long Gap Spacing: 2 mm, 3 mm, 4 mm, and 5 mm.
- VG Location: 10%, 15%, 20%, and 25% of the chord length.

There was a control airfoil with no VGs as well.

Each airfoil was tested in the wind tunnel by increasing the AOA until boundary layer separation occurred at 30% of the chord length. Smoke visualization helped identify the separation point, and the corresponding AOA was recorded.

Initial plans to measure lift and drag forces were abandoned due to the apparatus not working, and the breaking of prototypes

The only thing tested was the stall mitigation AOA.

December 2024:

Raw Data:

The AOA at which boundary layer separation occurred was recorded for each airfoil configuration.

Using parabolic regression, we determined the optimal VG configuration:
- Optimal Location: 17.2% chord length, achieving an AOA of 11.8°.
- Optimal Spacing: 3.6 mm, achieving an AOA of 7.5°.

This led to us considering optimization.

A full paper report was written at this time.

January 2025: Refinement and Finalization

Optimization:

An optimized airfoil was printed and tested with the methods before.

Limitations:
- Only one factor (stall mitigation) was fully tested due to resource constraints.
- The lack of lift and drag measurements limited our understanding of the trade-offs between stall delay and parasitic drag.

Future Work:
- Incorporate force sensors to measure lift and drag coefficients.
- Explore other VG factors, such as inflow angle and vane shape, for further optimization.

February 2025: Conclusion

Final data was calculated, and put together into a trifold and extended report.