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Aerodynamic Analysis and Design of Banners for Remote-Controlled Aircraft

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***Abstract*—**Banner towing is a major form of advertisement. It consists of a banner showing a logo or a selection of words or letters being towed by an aircraft. Traditionally bush planes have been used to tow banners given their high thrust capabilities, however, with the development of Remote-Controlled (RC) aircraft, they could be a good replacement as RC planes mitigate the risk of human life and can be easier to operate. This paper studies the best banner design to be towed by an RC aircraft. This is done by conducting wind tunnel testing on an array of banners with different materials and designs. A pull gauge is used to record the drag force during testing which is then used to calculate the coefficient of drag, C_d. The testing results show that the best banner design would be a hybrid design with a solid and mesh material. The design with the lowest C_d of 0.082 was a half ripstop nylon half polyester mesh design. On the other hand, the design with highest C_d of 0.305 involved incorporating a tail chute to decrease fluttering.

***Keywords*—**Aerodynamics of banner, banner design, banner towing, drag coefficients of banner, RC aircraft banner.

I. Introduction

AERIAL advertisement is a form of advertisement used to target a large group of people at a certain location. Though advertisements started in the 19th century, mainly in forms of newspaper and posters, aerial advertisement started around the year 1922 with the development of early aircraft. The most common type of aerial advertising is banner towing. This type of advertisement gives advertisers the option to either advertise a drawing (logo) or a collection of letters in the form of a banner, which is towed by a bush plane. Bush planes are primarily used to tow these banners as they have high lift and thrust capabilities allowing the towing of large banners at low travel speeds.

Over the years, banner towing advertisement have proved to be successful; however, it also has proved to be dangerous as there have been many fatal crashes when attempting to connect the aircraft towline to the banner rope after takeoff.

Research has been done to study the aerodynamic characteristics of banners, flags, and streamers not only for advertisement application, but also for other applications like stabilizing ribbons for ground launched rockets [1]. The main areas of focus for banners are overall drag and stability performance. Most of the research performed on banners concludes that the coefficient of drag of a banner decreases as the aspect ratio increases [2]. Additionally, the material of the banner used has a significant impact on the aerodynamic behavior [3].

The most relevant research was performed by Faithorne [4], who tested rectangular banners and triangular flags for advertising applications. The research involved testing rectangular flags with aspect ratios between 0.5 and 4.0 as well as triangular flags with aspect ratio of 0.25 to 1.0. Faithorne's research determined that there is a direct correlation between the density of the flag material and the overall drag.

Given the dangerousness of banner towing in the traditional manner, and with the development and rapid growth of small RC aircraft, using such aircraft rather than a full-sized bush plane is safer. An RC aircraft would eliminate risking human life and would allow the towing of smaller banners as the aircraft can fly at lower altitudes. This would also allow the banner to be stowed on the aircraft and deployed after takeoff, mitigating the risk typical bush planes face during the banner hooking process after takeoff.

This paper will focus on characterizing the drag performance of different banner designs to be towed by an RC aircraft. This research will examine the possibility of different banner design configurations and manufacturing them with the use of new material technologies, such as ripstop nylon (RN) and polyester mesh (PM). These banners will be tested at low air speeds to simulate the speed of the RC aircraft during flight. The banners will be tested in a wind tunnel with the aim of calculating the coefficient of drag for each banner design using the drag force collected during testing. The coefficient of drag will be used to size the largest banner that the RC aircraft can tow for a certain flight time.

II. Materials and Methods

A. Material Selection and Manufacturing

First, banners were primarily designed and manufactured from different configurations as rectangular, trapezoidal and triangular shapes with the same aspect ratio.

The primarily results showed that the rectangular banner shape has a better response and stability. Then, the overall rectangular design was selected for the banner as shown in Fig. 1.

All the banners tested are rectangular shaped and maintain a constant aspect ratio. Additionally, a thin pultruded carbon fiber tube is placed at the start of the banner with a weight at the bottom to help maintain a vertical orientation. Fishing wire was selected to connect the banner to the aircraft, given it is light

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and has good tensile properties. The fishing wire will asymmetrically tie to the carbon fiber tube at the start of the banner to further assist with the stability of the banner and then hooked onto a custom designed ring on the aircraft.

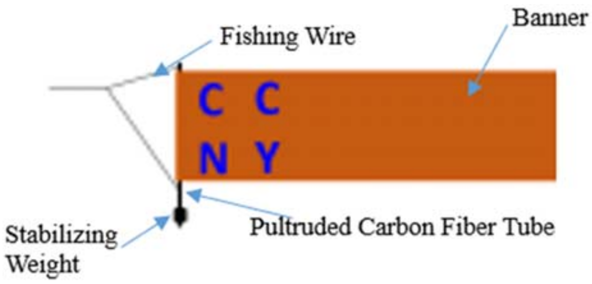


Fig. 1 Overall Banner Design

The material selection for the banner itself involved selecting fabric that has a high denier count to increase durability, a low weight per square area, and an aerodynamic mesh pattern for better flight performance. In addition, the selected fabric had to be foldable to allow for stowing on the aircraft. Three fabrics were selected for testing based on the criteria mentioned above including RN, chiffon, and PM. Given the inaccessibility of the denier count for the most material, the weight per square area was mostly used to select the material. Table I outlines the weight per square area for the candidate materials.

TABLE I
WEIGHT COMPARISON BETWEEN CANDIDATE MATERIALS FOR THE BANNER

	RN	Polyester Chiffon	PM
Weight per square yard (oz)	1.9	1.31	6.75

The main manufacturing method of the banners is sewing using a singer 8280 Prelude machine, with a cotton thread. Initially, the banners are traced out using a grid and rulers to the desired size. A half-inch margin is added to the desired dimensions for hemming purposes, and for assembling the design with the reinforcing rod and stabilizing weights. Once the pattern is cut, the sides are basted to prepare for the machine. After a baste stitch is complete, the hems are sewn using a zig-zag stitch, for breathability while in flight.

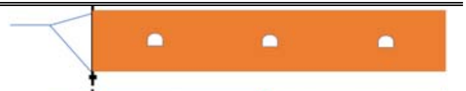
Table II shows all the banner designs that will be tested in the wind tunnel.

B. Experimental Setup

The testing was conducted in an open circuit, honeycomb inlet, laminar flow wind tunnel with a maximum velocity of 36 ft/s. The wind tunnel had a square cross-sectional area with a width of 4 feet. A Push Pull Force Gauge (BAOSHISHAN - max 5lbf) was used to record the drag force of the banner. 3D printed adapters were custom designed and printed to connect the pull gauge to the banner's fishing wire. A wooden stand was fabricated to hold the pull gauge in the wind tunnel as shown in Fig. 2.

A camera was mounted on the side of the wood stand to record a video of the pull gauge force reading during the testing. The video and a stopwatch were simultaneously started, and the stopwatch was used to timestamp important notes during testing such as wind tunnel air speed, and banner stability. The timestamped events were compared with the video after testing to corelate wind speed to force readings and calculate the drag force.

TABLE II
BANNER DESIGNS TO BE TESTED

Half Circle Wind Slit	
Half RN - Half – PM	
RN with Streamer	
Half and Half – RN and Chiffon	
Rectangular Chute without Rod	
Rectangular Chute with Rod	
Cylindrical Tail Chute. All RN	

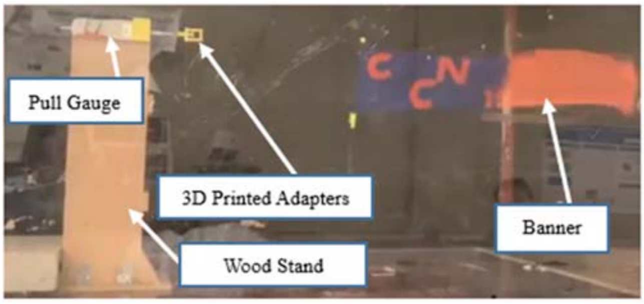


Fig. 2 Wind Tunnel Experimental Setup

C. Drag Analysis

To analyze the data of the wind tunnel test, first the video of the pull gauge reading is isolated to the time the wind tunnel was at maximum speed 36 ft/s (0.33 Mach). This is done by referencing the timestamped notes that were taken during testing. For example, for the first banner test it was noted that the wind tunnel reached maximum speed at 4:32 minutes and the speed ramped down at 6:00 minutes; therefore, the force reading between the two timestamps was the force used for the analysis.

The force value at maximum wind tunnel speed, the surface area, and wind speed for each banner configuration were used to calculate the coefficient of drag for that design using (1):

$$C_d = \frac{2F_d}{\rho V^2 A} \quad (1)$$

In which the cross-sectional area, A, of the banner was taken as the area of the banner parallel to the airflow [5]. The maximum speed obtained in the wind tunnel for all tests was 36 ft/sec.

Using the drag coefficient for each banner design, a MATLAB [6] code was developed to size the largest banner that the designated RC plane could tow without sacrificing any mission of flight. The MATLAB code sums the forces acting on the aircraft during cruise including the banner drag, and ensures that the aircraft has enough lift and thrust to maintain a safe flight. The code iterates different banner lengths and cruise velocities.

Fig. 3 shows the forces acting on the aircraft that were considered for the MATLAB code, while Fig. 4 is a flow chart of the logic the MATLAB code followed.

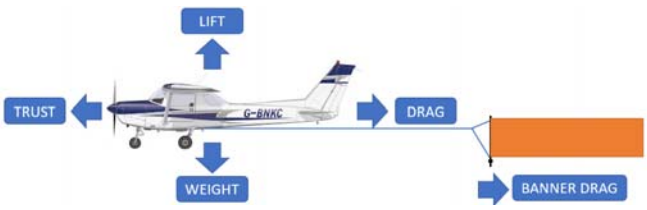


Fig. 3 Overall forces considered acting on the aircraft

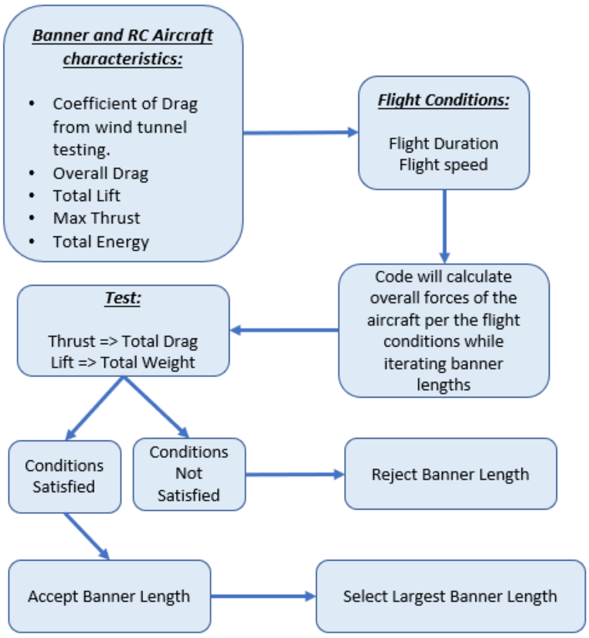


Fig. 4 MATLAB code flow chart

III. Results and Discussion

A total of 10 banners was tested in the wind tunnel. The overall testing results showed that the material and aspect ratio of the banners had an impact on the aerodynamic properties as well as the stability of the banner. When comparing the calculated, C_d , for the half RN - half PM design for different banner lengths, the C_d decreased as the length of the banner increased as shown in Fig. 5. Therefore, it can be concluded that increasing the length of the banner while maintaining the aspect ratio will decrease the coefficient of drag, however, this is at the cost of increasing the overall weight. Furthermore, in the next step, the length of the banner was kept constant, and the wind tunnel tests were conducted for different design configurations as shown in Table II. Fig. 6 shows the calculated C_d for an array of test banner design all with a length of 40 inches. The design with the chute addition had the highest C_d as expected with a C_d of 0.305. The aim of the chute was to decrease the fluttering in the rear of the banner, however, from visual observation the fluttering did not improve.

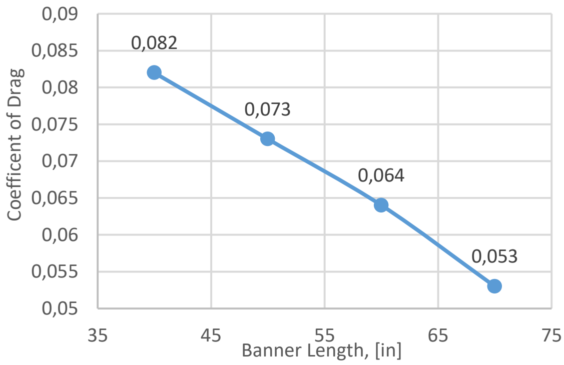


Fig. 5 Coefficient of drag for (RP-PM Half and Half) design with different lengths

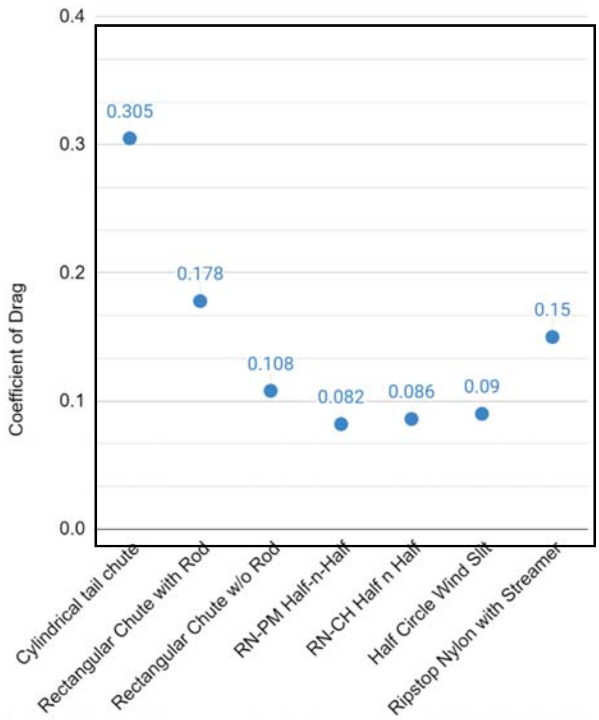


Fig. 6 Coefficient of drag for various banner designs

The best performing banners were the banners with the half and half design with the PM design performing a bit better than the deign with the chiffon. From all the experiments, it was concluded that having a design that allows for air to flow through the banner improves the aerodynamic performance.

VI. Conclusions

In conclusion, the best banner design would be one with a high aspect ratio and a combination of a solid and mesh material with the solid material preferably in the leading edge of the banner. Using a mesh material that is not completely solid will decrease the overall drag of the banner which will allow for either towing a larger banner or increasing the flight time. However, it is still necessary to retain some solid material in the banner to maintain the banner shape during flight.

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REFERENCES

[1] Auman, LM, & Dahlke, CW. (2001). “Drag characteristics of ribbons”. *AIAA Aerodynamic Decelerator Systems Conferences*, number AIAA 2001-2011, pages 131–136, Boston, MA.
[2] Carruthers, A., & Filippone, A. (2005) “On the Aerodynamic Drag of Streamers and Flags”. Journal of Aircraft, Vol. 42, No. 4, pp. 976 - 1000.
[3] Rubin, D., & Morr, G. (1978). “Drag Investigations of Towed Target Banners”. Redstone Arsenal, Alabama: US Army Missile Research and Development Command. (pp. 3-4, Tech. No. T-79-5)
[4] Fairthorne, RA. (May 1930). “Drag of Flags”. Technical Report 1345, ARC Reports & Memoranda,
[5] Cengel, Y. A., & Cimbala, J. M. (2018). Fluid mechanics: Fundamentals and applications. In Fluid mechanics: Fundamentals and applications. New York, NY: McGraw-Hill Education.
[6] MATLAB R2018a. 1994-2020 The MathWorks, Inc., accessed February 2020. https://matlab.mathworks.com/