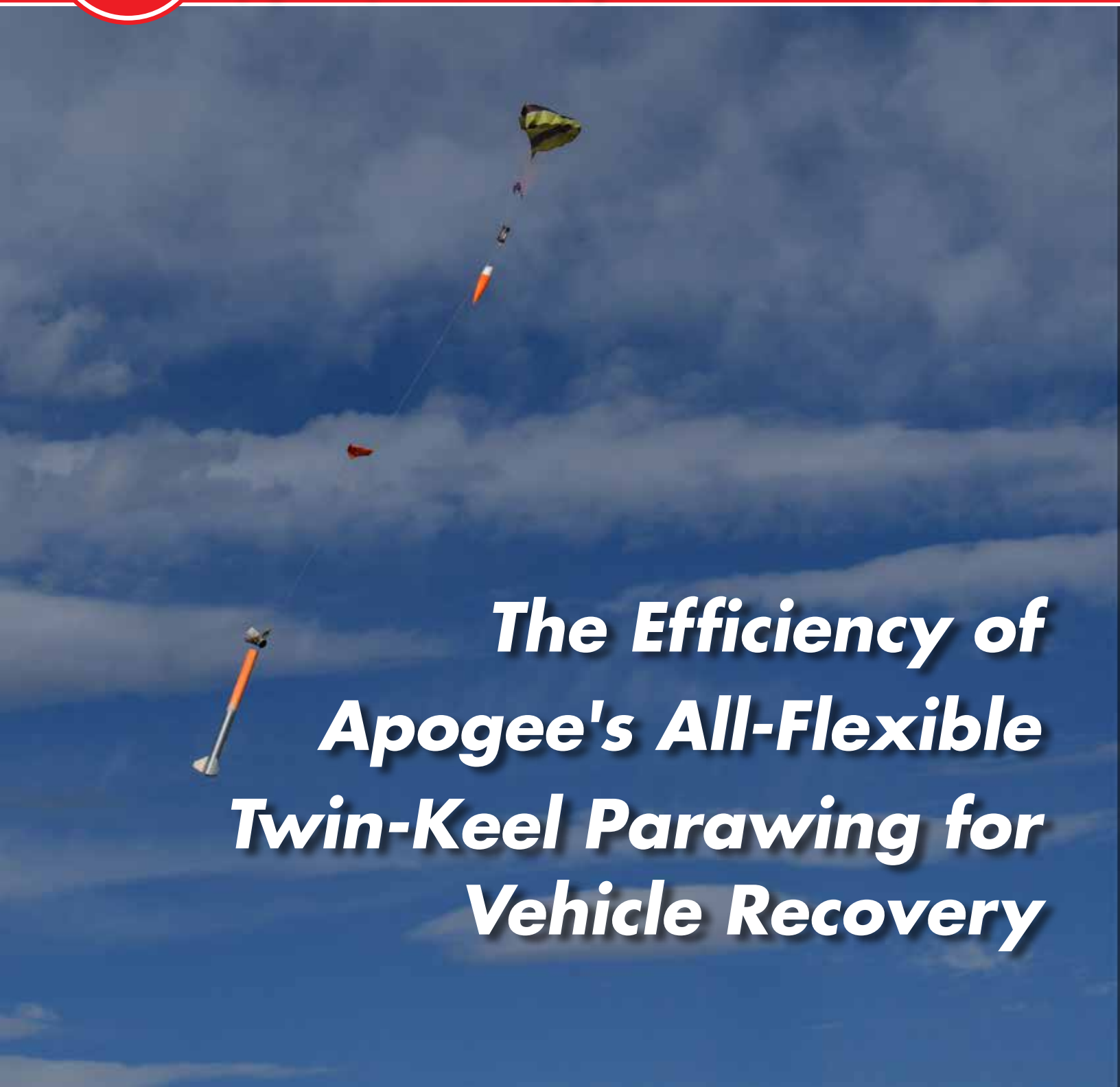
Issue 658 / August 12th, 2025

PEAK OF FLIGHT NEWSLETTER

Apogee Components, Inc. / ApogeeRockets.com / Colorado Springs, CO



The Efficiency of Apogee's All-Flexible Twin-Keel Parawing for Vehicle Recovery

PEAK OF FLIGHT NEWSLETTER

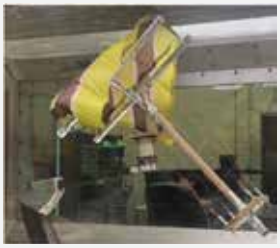
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COVER PHOTO



The 24" Gliding Parachute Brings Home A Rocket Near the Launch Pad

FEATURED ARTICLES



The Efficency of Apogee's All-Flexible Twin-Keek Parawing for Vehicle Recovery

by Mason A. Hensley, Caleb J. Perkins, Zephan M. Rodriguez, and Peter Stuhlsatz

How do you compare the descent rate of a parawing to a conventional parachute? This report does the actual wind tunnel testing.

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Editor-in-Chief: Tim Van Milligan
Managing Editor: Michelle Mason
Content Editor: Martin Jay McKee
Layout Design: Tim Van Milligan

Snake Eye Rocket plan (from *Peak-of-Flight Newsletter #551)* takes flight. This rocket uses Drag-Brake Recovery instead of a parachute.



Would you like to see your launch photo featured in the *Peak-of-Flight* newsletter? Submit your photo at apogeerockets.com.

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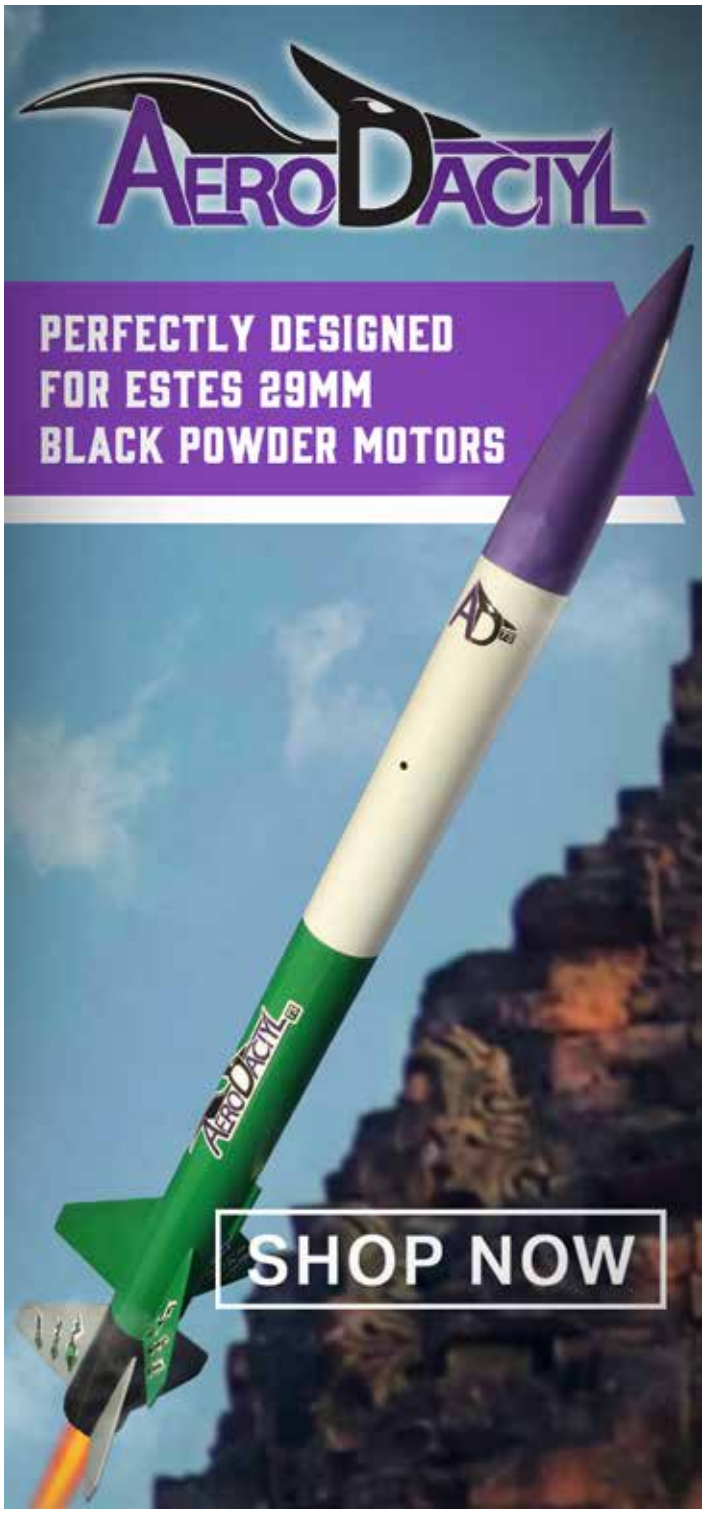
By Mason A. Hensley, Caleb J. Perkins, Zephan M. Rodriguez, and Peter Stuhlsatz. Wichita State University, Wichita, Kansas

The purpose of this investigation is to test Apogee Components' controllable gliding parawing, which is currently experimental, and compare its efficiency to that of a circular parachute. The goal of a parawing is to have the lowest vertical velocity but the highest horizontal velocity. This controllable gliding parawing is based on the design of the twin-keel Rogallo parawing designed by NASA for the Gemini and Mercury missions. The parawing was wind tunnel tested. In the wind tunnel, a structured mount was used to change the angle of attack to gather the lift, drag, and pitching moment at different angles.

The parawing was determined to be at a stable flight angle if the slope of the pitching moment versus the angle of attack graph was negative. The horizontal and vertical velocities of the parawing were calculated from the lift and drag forces. Lastly, the vertical velocity of the parawing was compared to a similar wetted-area circular parachute. The results were Apogee Components' Parawing is stable between 30° and 60°. The best angle of attack for the parawing is 30° for a compromise between the lowest descent velocity and the largest horizontal velocity. The parawing has a lower descent rate than a conventional parachute.

Nomenclature

α = Angle of Attack
ϕ = Angle Between V_H and V_V
c.g. = Center of Gravity
C_D = Drag Coefficient
C_L = Lift Coefficient
C^M = Pitching Moment Coefficient
C_N = Normal Coefficient
C_R = Resultant Coefficient
C_T = Tangential coefficient
D = Drag Force
D_T = Tangential Drag Force
L = Lift Force
L/D = Lift to Drag Ratio (Glide) Ratio
$(L/D)_{max}$ = Maximum Lift to Drag Ratio
M = Pitching Moment
N = Normal Force
q = Dynamic Pressure



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V = Velocity
V_H = Horizontal Velocity
V_T = Tangential Velocity
V_V = Vertical Velocity

I. Introduction

The all-flexible twin-keel parawing has been studied for its ability to provide lift as it decelerates with its payload. This allows the parawing to be controlled to glide down to a specific target, thus making the twin-keel parawing an interest to researchers as an alternate method to a conventional parachute to recover space vehicles or to be used with hang gliders. The research results on all-flexible twin-keel parawings have focused on determining the aerodynamic forces generated by parawing and what characteristics contribute to the change of the aerodynamic forces. Due to the parawing producing lift and drag, a horizontal velocity component is created, which in turn adds maneuverability while in the air so the payload can have a controlled landing.

A model rocketry company, Apogee Components, believes that these parawings can be utilized for model rocket recovery. The company has created a couple of different-sized models of the parawing with keel lines of 24, 36, and 48 inches. [1]

For experimental testing, the group utilized the 24-inch parawing model for the research project. Since these specific parawings are experimental from Apogee, they agreed to exchange was a parawing model for wind tunnel data. Wichita State University's 3 x 4 ft. wind tunnel was utilized for the wind tunnel tests.

The investigation led to the question of what the best overall stable angle of attack for a twin-keel Rogallo parawing is for a compromise between maneuverability and descent rate in comparison to a conventional parachute. This problem statement led to four major goals for the experiment: determine the pitch stability, determine the correlation of angle of attack to vertical velocity, determine the correlation of angle of attack to horizontal velocity, and compare the descent rates of the twin-keel parawing to those of a traditional parachute.

II. Literature Review

An all-flexible twin-keel parawing is made from a fabric that forms its cylindrical canopy when it is in tension with its connected lines to the payload, called shroud lines. The shape of the twin-keel parawing is a delta wing split in half with a rectangular shape added in the middle connected to the sides of the delta wing. The connection curve between the rectangular shape and the delta wing sides is called a keel. This explains the name of the all-flexible twin-keel parawing, because there are two keels on the paraw-

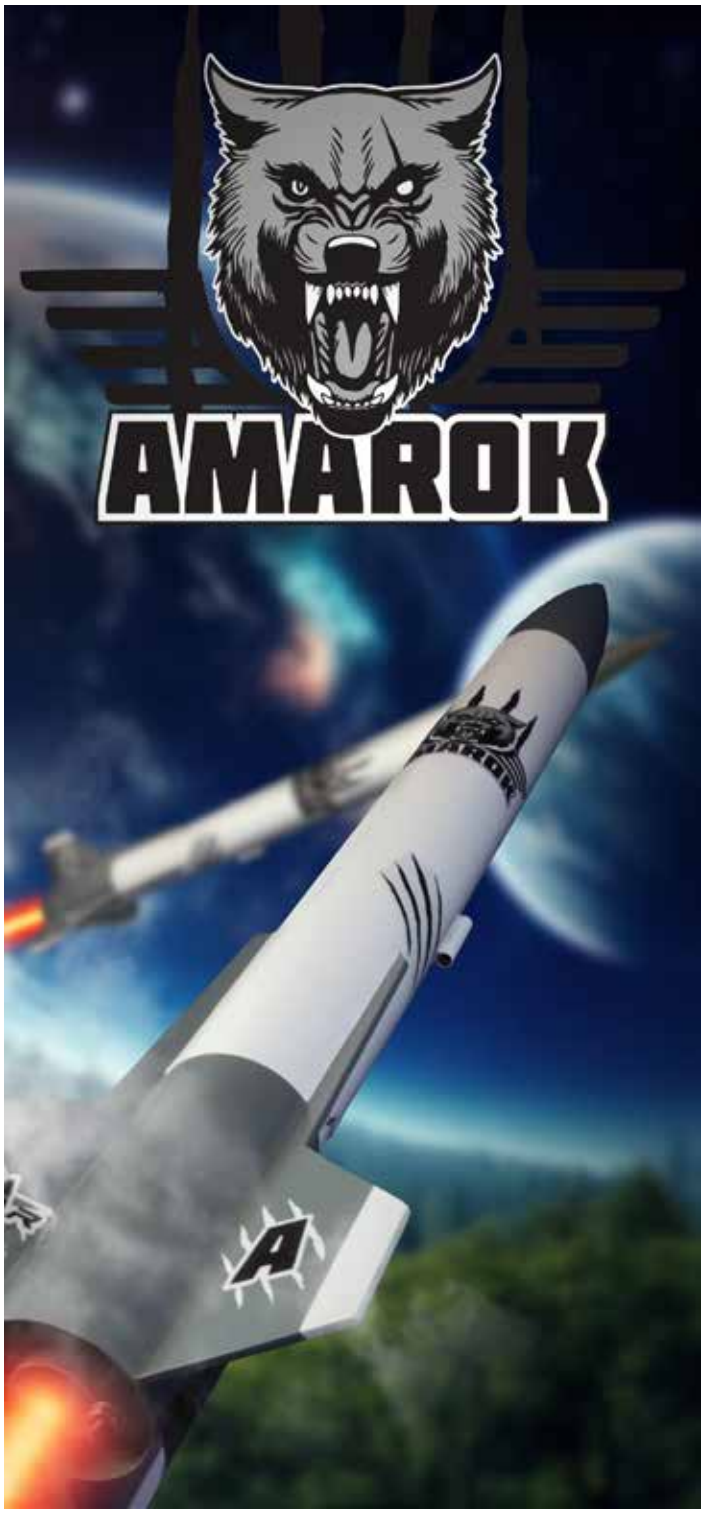


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ing on both sides of the rectangular shape.

In discussing twin-keel parawings, the understanding of a parachute is pertinent. Parachutes are used for emergency escape from aircraft, troops, supply airdrops, the recovery of missiles, spacecraft, rockets, and the stabilization of falling objects. The use of parachutes is vast, but the objective is similar for most, which is the slowing down and non-destructive return to the ground.

When a parachute is deployed, it "transfers the momentum of the moving payload to the atmosphere by accelerating the ambient air" [2], causing the payload to decelerate to a desired descent rate. The descent rate of the parachute varies mostly with respect to the weight of the payload and the surface area of the parachute.

Parachutes are categorized by their size and drag coefficient. This is based on the surface area of the parachute [3]. The most efficient parachutes have a C_D typically around 1.75 [4], with the drag in the opposite direction to the descent velocity, as shown in Fig. 3. [5]

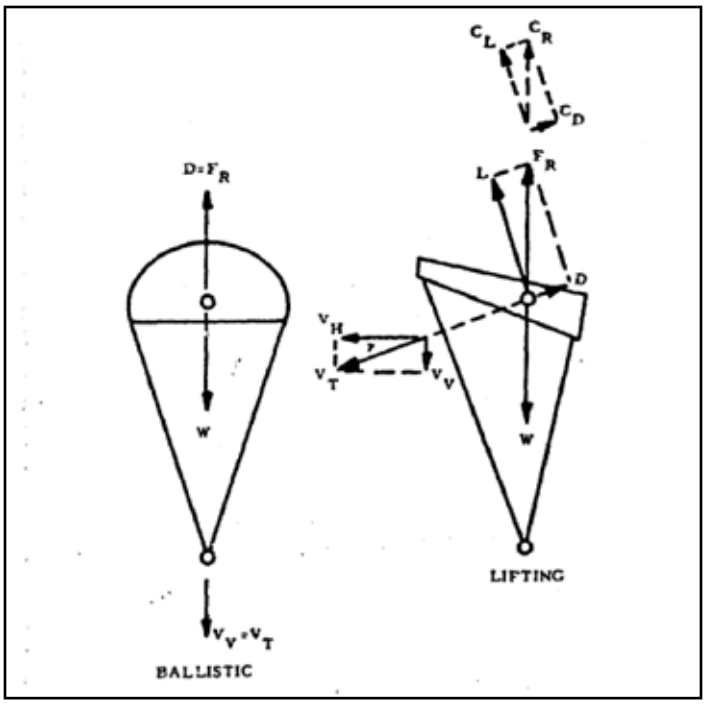


Figure 1: Free body diagram of conventional parachute and parawing [6].

While parachutes are very effective at decelerating objects, there is no effective way to control where they land. The twin-keel parawing, however, is controllable. Like a parachute, parawing experiences drag but also lift. A parawing is like a parachute that is suspended in the shape of a wing. Like a parachute, the paraw-

ing experiences both lift and drag, which allows the parawing to glide. The addition of glide allows for control of the trajectory of the payload that is suspended by the parawing. As shown in Fig. 4, R is the resultant vector of L and D. [5] This is comparable to the drag of a parachute. After converting from R to C_R, the twin-keel parawing can be compared to the parachute's C_D. To compare the twin-keel parawing to other parawings, consider the glide ratio. [5]

The idea of an all-flexible twin-keel parawing started with a description of a steerable parachute found in the November 1874 issue of *"Scientific America."* [6] It shows a picture of the "DeGroof Parachute." The inventor, DeGroof, had an idea to use a semi-rigid parachute to escape from balloons. His idea stopped after his first jump from a height of 80 ft. ended in his death.

Systematic steerable parachutes started to be researched more after WWI. The U.S. Army Air Service Parachute Branch created a triangular-shaped parachute that could be steered by pulling suspension lines. [6] These early iterations of the steerable parachutes were then used by both the Allies and the Axis powers in WWII.

The advancement of steerable parachutes gained momentum due to the need to land a spacecraft capsule on Earth from a rocket in space. Between 1945 and 1958, Francis Rogallo and his wife Gertrude Rogallo privately studied how to create an all-flexible steerable parachute. [7]

In December of 1958, Mr. Rogallo presented his work as an all-flexible twin-keel parachute to the newly formed National Aeronautics and Space Administration (NASA) at the Langley Aeronautical Research Laboratory in Virginia. [8] Rogallo was given a laboratory at Langley to continue his work. His all-flexible steerable parachute was named an all-flexible twin-keel parawing, and NASA wanted to use it for its landing system on the Gemini missions. Due to a rigid timeline, internal politics, and competing demands for resources for the Gemini mission, the parawing idea was canceled. [8] Although the Rogallo idea for parawings failed during the space race, parawings became known as "Rogallo Wings." [9]

III. Methods and Apparatus

A. Model

Testing was done on the 24-in. Gliding Parachute made by Apogee Components. The model has a span of 36.75 in. and a keel length of 24 in., allowing for an area of 3.84 ft^2. It is in the shape of a Twin-Keel Rogallo Wing and made of Rip-Stop Nylon Cloth, resulting in a weight of .32 lbs. The shroud lines measure from 14 to 24 in. and are connected to a 4.5 x 4.5 in. base.



Figure 2 - CAD Model of Testing Apparatus

B. Testing Procedures

Wind tunnel tests were conducted in the Wichita State University 3 x 4 ft. open return wind tunnel. Testing was conducted at a dynamic pressure of 1 lb/ft^2.

The Reynold's number used based on a 24-in. keel length at



the given dynamic pressure was $3.5x10^5$. Testing was done using two setups, as described below. A static tare was taken with the model in the wind tunnel with the motor off and the door closed. A dynamic tare was taken with the setup at the given dynamic pressure and through the same sweep of angles.

C. Tethered Method (No Data)

This method consists of a mount attached to the 3-axis system of the wind tunnel. The mount was modeled off the normal connection points of the parawing; the mount also had a separate connection for the rear keel shroud lines located aft of the normal connection points. This was to improve stability and allow for changing the angle of attack by shortening the shroud lines using a rolling attachment. Due to the size of the parawing compared to the wind tunnel, this setup led to aggressive oscillations, and data was not able to be taken. To address this issue, the rear keel shroud lines were moved further aft and joined by the rear tip shroud lines, which were also moved outboard to try to stabilize the model in roll attitude. Though this process dampened the oscillations, the model still behaved less than ideally, and data was not collected. This method was scrapped and replaced by the constrained method detailed below.

D. Constrained Method

A support was used to hold the keel lines in place and hold the model still in roll and pitch. The support maintained the designed connection point for the tip lines, while the keel lines were constrained to the support structure. A mount was attached to the 6-axis system of the wind tunnel, then a pin was inserted through the mount and a hole on the upper portion of the support. A constant angle was held through the contact of the support and mount. Washers were added to increase the angle for a second run. The model was then run through a sweep of angles by changing the angle of the wind tunnel sting, thus changing the held angle of the parawing: angles 15° to 45° by increments of 5° for the first configuration and angles 20° to 60° by increments of 5° for the second configuration. Two runs were conducted to prevent contact between the parawing and the top of the wind tunnel and due to the range of angles from the wind tunnel sting.

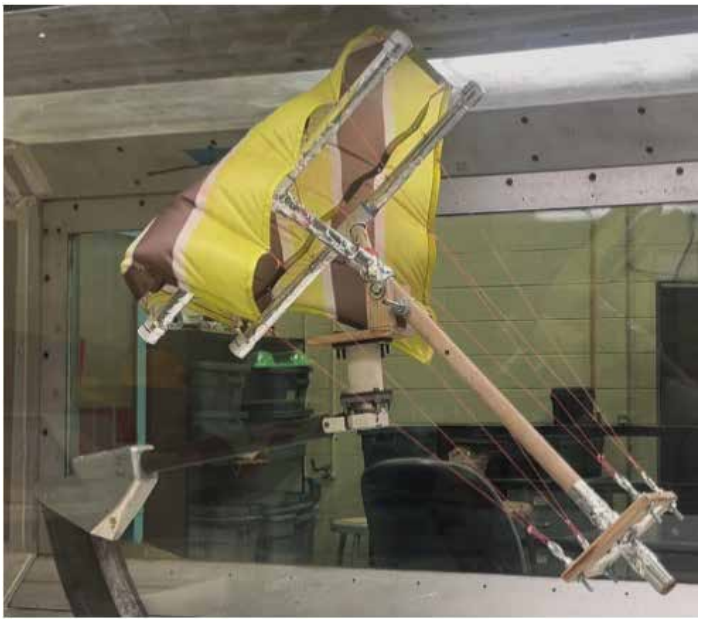


Figure 3 - Picture of Constrained Method (2nd Configuration)

E. Angle of Attack Measurements

The angle of attack was measured between the support arm and a perpendicular plane to the base of the wind tunnel. These measurements were recorded before testing using a digital level. The wind tunnel sting was set to the corresponding angle for each angle desired through the sweep.

F. Engineering Estimates

Based on analysis of similarly structured parawings, [10] C_d values ranging from 0.2875 to 0.575, C_l values ranging from 0.8



to 1.1, C_m values ranging from -0.025 to -0.015, C_r values ranging from 0.95 to 1.3, and lift-to-drag ratio values ranging from 2.1 to 2.9 are expected. These values correspond to drag forces of 1.10 to 2.21 pounds, lift forces of 3.07 to 4.22 pounds, and moment forces of -0.94 to -1.565 pounds. The range of values will vary based on the angle of attack, with lower angles correlating to smaller forces, smaller coefficients, and a higher lift-to-drag ratio. On the other hand, higher angles produce higher forces, higher coefficients, and smaller lift-to-drag ratios.

IV. Results

A. Tares & Corrections

After the data was collected, the data was reduced with the static and dynamic tares. The data was also corrected using 2-D blockage corrections from *"Low-Speed Wind Tunnel Testing"* [11]. For the 2-D blockage correction, the shape factor of a symmetrical airfoil was used. The line on the graph for the symmetrical airfoil from Figure 9.16 was interpolated to find the best body shape factor for the parawing's fineness ratio at that angle of attack. The 2-D wake blockage correction was also used from *"Low-Speed Wind Tunnel Testing."* [11]

B. Corrected Data

The data was adjusted using the stated corrections and can be found in Tables 1 and 2.

Figure 4 shows the coefficient of moment plotted against the corresponding angle of attack with a tracing line shown. It can be concluded that angles of 25 degrees and lower are unstable due to an increasing coefficient of moment with angle of attack. The objective of this experiment is to seek stable angles for launch, so these unstable points will be labeled as such in some of the following graphs.

This data was used to produce the following graphs of interest:

Figure 4 shows the coefficient of moment plotted against the corresponding angle of attack with a tracing line shown. It can be

Mount Alpha (deg)	Q (psf)	Lift (lb)	C_l	Drag (lb)	C_d	C_R	Gliding Ratio	V_V (ft/s)	V_H (ft/s)	Pitch (lb-ft)	Corrected C_m
45.000	0.950	2.333	0.613	2.618	0.819	1.023	0.748	12.581	9.408	1.022	0.012
40.000	0.941	2.231	0.587	2.183	0.761	0.961	0.772	12.832	9.902	0.950	0.179
35.000	1.093	2.716	0.620	2.305	0.769	0.987	0.807	12.445	10.039	1.199	0.351
30.000	1.053	2.627	0.635	1.926	0.750	0.982	0.847	12.236	10.359	1.195	2.179
25.000	0.919	2.132	0.611	1.395	0.736	0.957	0.830	12.501	10.374	1.035	2.113
20.000	0.914	1.586	0.483	1.107	0.688	0.840	0.702	14.184	9.963	0.884	0.903
15.000	0.974	1.149	0.337	1.037	0.642	0.725	0.525	16.514	8.675	0.749	1.050

Table 1: Corrected Data for 15-45 Run at a Reynolds Number of $3.5x10^5$

Mount Alpha (deg)	Q (psf)	Lift (lb)	C_l	Drag (lb)	C_d	C_R	Gliding Ratio	V_V (ft/s)	V_H (ft/s)	Pitch (lb-ft)	Corrected C_m
60.000	1.064	2.225	0.520	4.195	1.061	1.182	0.490	13.124	6.436	0.007	-0.199
55.000	1.048	2.449	0.568	3.839	1.050	1.194	0.541	12.788	6.918	0.007	-0.066
50.000	0.990	2.394	0.586	3.213	1.000	1.159	0.586	12.736	7.458	0.005	0.080
45.000	0.983	2.472	0.616	2.777	0.953	1.134	0.646	12.529	8.098	0.007	0.195
40.000	0.998	2.509	0.632	2.437	0.919	1.116	0.688	12.393	8.525	0.007	0.340
35.000	0.971	2.393	0.642	2.037	0.884	1.093	0.726	12.299	8.930	0.009	0.489
30.000	0.984	2.530	0.705	1.824	0.881	1.129	0.800	11.676	9.346	0.008	2.548
25.000	1.051	2.598	0.716	1.651	0.846	1.108	0.846	11.524	9.744	0.017	2.483
20.000	0.991	1.894	0.626	1.219	0.863	1.066	0.726	12.453	9.039	0.021	1.082

Table 2: Corrected Data for 20-60 Run

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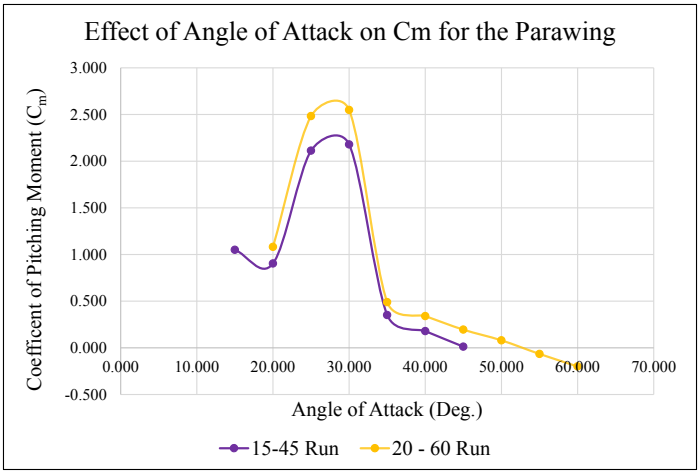


Figure 4

concluded that angles of 25 degrees and lower are unstable due to an increasing coefficient of moment with angle of attack. The objective of this experiment is to seek stable angles for launch, so these unstable points will be labeled as such in some of the following graphs.

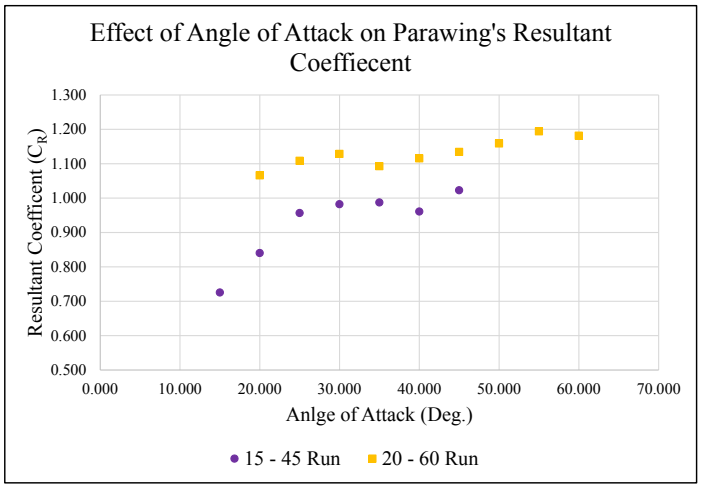


Figure 5

Figure 5 shows the resultant coefficient plotted against the angle of attack. The resultant coefficient is calculated by Eq (1):

Eq.(1) $C_R=\sqrt{(C_D)^2+(C_L)^2}$

This coefficient is necessary for future calculations.

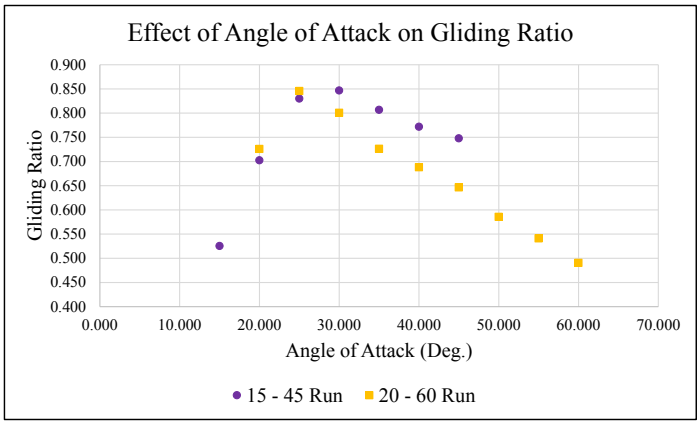


Figure 6

Figure 6 shows the gliding ratio plotted against the angle of attack. The gliding ratio is calculated by Eq (2):

$$Eq.(2)\ Gliding\ Ratio = \frac{C_L}{C_D}$$

This ratio is necessary for future calculations.







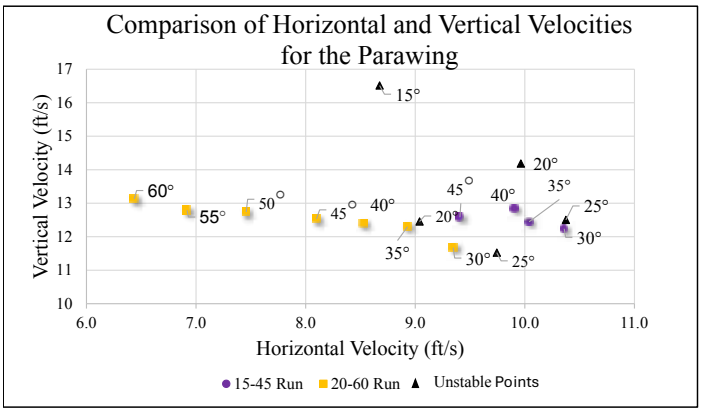


Figure 7

Horizontal and vertical velocities are very important quantities for understanding the performance of a gliding parachute and are calculated using Eq (3) and (4) respectively (assuming a weight of 1.1 lbs. (500 g.) and air density of Wichita, KS (2.2743x10-3)). A greater horizontal velocity will allow for more movement in the air while a small vertical velocity allows the body to remain in the air longer and aids safer vehicle recovery.

Eq. (3): $V_H = \sqrt{\frac{2W}{\rho * S * C_R}} * cos(\varphi)$ (Where W is weight, ρ is air density, S is area, and φ is given by Eq. (5))

Eq. (4): $V_V = \sqrt{\frac{2W}{\rho * S * C_R}} * sin(\varphi)$ (Where W is weight, ρ is air density, S is area, and φ is given by Eq. (5))

Eq. (5): $\gamma = cot^{-1}(\frac{C_L}{C_D})$

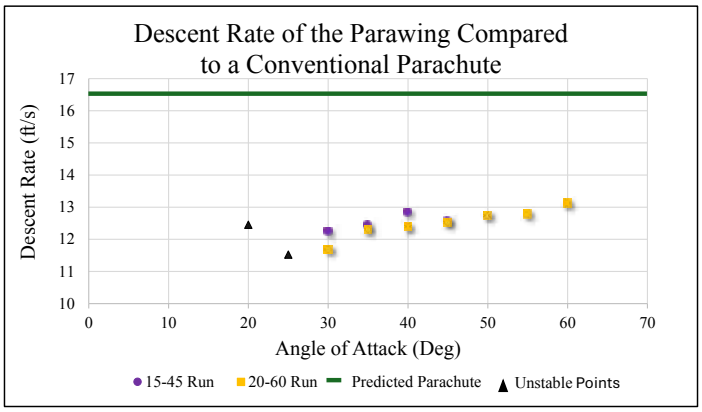


Figure 8

Figure 8 shows a comparison between the descent rate (vertical velocity) of a conventional parachute with a similar area (a 26" parachute correlating to an area of 3.66 ft² and C_D of .97). The weight used was 1.1 lbs., because that would be weight of the rocket, we would use to test the parachute vs parawing. The descent rate for a parachute is given by Eq. (6).

Eq. (6): $V_V = \sqrt{\frac{2W}{\rho * S * C_D}}$

Intervals were calculated using the following equation: $\Delta = z\sigma/\sqrt{n}$. Where z is correlated to 95%, thestandard deviation is given by the wind tunnel instruments in Table 4, and n is the number of samples (in this case 400). Confidence intervals were calculated using this equation for the values for which standard deviation is given.The confidence intervals for calculated variables were solved using a method like the uncertainty analysis, resulting in Table 5. [12]

Run	Mount Alpha (deg)	Q uncertainty	Lift Uncertainty	C_l Uncertainty	Drag Uncertainty	C_D Uncertainty	Resultant Uncertainty	C_R Uncertainty	Gliding Ratio Uncertainty	Pitch (lb-ft) Uncertainty	C_m Uncertainty
1	45	4.75E-04	2.33E-02	6.40E-03	3.27E-02	8.98E-03	3.62E-02	9.76E-03	1.13E-02	1.02E-02	1.40E-03
1	40	4.71E-04	2.23E-02	6.18E-03	2.73E-02	7.56E-03	3.16E-02	8.45E-03	1.12E-02	9.50E-03	1.32E-03
1	35	5.46E-04	2.72E-02	6.48E-03	2.88E-02	6.87E-03	3.55E-02	7.99E-03	1.11E-02	1.20E-02	1.43E-03
1	30	5.27E-04	2.63E-02	6.50E-03	2.41E-02	5.96E-03	3.21E-02	7.29E-03	1.10E-02	1.20E-02	1.48E-03
1	25	4.60E-04	2.13E-02	6.05E-03	1.74E-02	4.94E-03	2.49E-02	6.27E-03	9.93E-03	1.04E-02	1.47E-03
1	20	4.57E-04	1.59E-02	4.52E-03	1.38E-02	3.94E-03	1.90E-02	4.72E-03	7.71E-03	8.84E-03	1.26E-03
1	15	4.87E-04	1.15E-02	3.08E-03	1.30E-02	3.47E-03	1.55E-02	3.75E-03	5.57E-03	7.49E-03	1.00E-03
2	60	5.32E-04	2.23E-02	5.45E-03	5.24E-02	1.28E-02	5.35E-02	1.31E-02	7.85E-03	1.64E-02	2.01E-03
2	55	5.24E-04	2.45E-02	6.09E-03	4.80E-02	1.19E-02	4.98E-02	1.23E-02	8.45E-03	1.53E-02	1.90E-03
2	50	4.95E-04	2.39E-02	6.31E-03	4.02E-02	1.06E-02	4.26E-02	1.10E-02	8.84E-03	1.29E-02	1.69E-03
2	45	4.91E-04	2.47E-02	6.56E-03	3.47E-02	9.21E-03	3.84E-02	9.87E-03	9.30E-03	1.14E-02	1.51E-03
2	40	4.99E-04	2.51E-02	6.55E-03	3.05E-02	7.95E-03	3.54E-02	8.78E-03	9.29E-03	9.99E-03	1.31E-03
2	35	4.85E-04	2.39E-02	6.43E-03	2.55E-02	6.84E-03	3.13E-02	7.81E-03	9.18E-03	8.66E-03	1.16E-03
2	30	4.92E-04	2.53E-02	6.71E-03	2.28E-02	6.04E-03	3.07E-02	7.35E-03	9.38E-03	9.02E-03	1.20E-03
2	25	5.25E-04	2.60E-02	6.45E-03	2.06E-02	5.12E-03	3.01E-02	6.60E-03	9.17E-03	9.43E-03	1.17E-03
2	20	4.95E-04	1.89E-02	4.98E-03	1.52E-02	4.01E-03	2.20E-02	4.96E-03	6.69E-03	6.33E-03	8.33E-04

Table 3 - Uncertainties of Relevant Values

C. Confidence Intervals and Uncertainties

Some uncertainties were present in the instrumentation of the wind tunnel including a .05% for dynamic pressure,

1% for lift, 1.25% for drag, and 1% for pitch. The uncertainty for other values was found using uncertainty propagation equations, resulting in the uncertainties presented in Table 3. [12] Confidence





Run	Mount Alpha (deg)	Lift StDev (lb)	Drag StDev (lb)	Pitch StDev (lb-ft)	Q StDev (psf)
1	45	0.338	0.251	0.069	0.308
1	40	0.370	0.197	0.066	0.304
1	35	0.576	0.326	0.136	0.327
1	30	0.562	0.247	0.128	0.322
1	25	0.473	0.254	0.094	0.310
1	20	0.705	0.403	0.161	0.294
1	15	0.873	0.474	0.187	0.316
2	60	0.380	0.262	0.087	0.285
2	55	0.342	0.196	0.087	0.289
2	50	0.325	0.165	0.065	0.277
2	45	0.335	0.182	0.084	0.277
2	40	0.326	0.182	0.080	0.280
2	35	0.413	0.235	0.104	0.278
2	30	0.567	0.263	0.094	0.281
2	25	0.997	0.679	0.201	0.297
2	20	1.584	0.967	0.260	0.298

Table 4: Standard Deviations Produced by Wind Tunnel

Confidence intervals and uncertainties were small enough to not be included in the graphs above.

V. Conclusion

The results support the conclusion that Apogee Components' 24-in. gliding parawing is more efficient than a circular parachute of the same wetted area. When looking at the stable range of angles of attack, 30° to 60°, the fastest descent rate of the gliding parachute is about 13 ft/s, which is 18% slower than the descent rate of the conventional parachute, which has a descent velocity of 16.5 ft/s. These descent velocities have been calculated with the assumption of a payload weight of 1.1 lbs. (500 grams).

The most efficient angle of attack for the gliding parawing can be found by finding the best compromise between the fastest horizontal velocity and the slowest descent velocity. The fastest horizontal velocities and slowest descent velocities were 9.35–10.35 ft/s and 11.68–12.24 ft/s, respectively. Both maximums and minimums correspond to an angle of attack of 30°; hence, this would be the most efficient angle of attack.

The major limitations of this experiment were time and the size

Run	Mount Alpha (deg)	Δ Q (psf)	Δ Lift (lb)	Δ Cl	Δ Drag (lb)	Δ Cd	Δ Resultant Force (lb)	Δ Cr	Δ Gliding Ratio	Δ VV(ft/s)	Δ VH (ft/s)	Δ VT (ft/s)	Δ Cdeff	Δ Pitch (lb-ft)	Δ Cm
1	45	6.51E-04	2.86E-02	1.25E-02	2.12E-02	1.01E-02	2.85E-02	1.26E-02	1.78E-02	1.47E-01	1.10E-01	-9.66E-02	-3.90E-02	5.71E-03	1.57E-03
1	40	7.74E-04	3.11E-02	1.42E-02	1.67E-02	8.04E-03	2.78E-02	1.18E-02	2.03E-02	1.82E-01	1.41E-01	-9.97E-02	-4.57E-02	5.51E-03	1.23E-03
1	35	7.85E-04	4.81E-02	1.77E-02	2.72E-02	9.57E-03	4.57E-02	1.47E-02	2.51E-02	2.20E-01	1.78E-01	-1.19E-01	-6.05E-02	1.13E-02	1.69E-03
1	30	7.81E-04	4.71E-02	1.73E-02	2.08E-02	8.40E-03	4.33E-02	1.40E-02	2.50E-02	2.19E-01	1.85E-01	-1.14E-01	-6.32E-02	1.06E-02	1.62E-03
1	25	8.03E-04	3.97E-02	1.64E-02	2.14E-02	1.19E-02	3.96E-02	1.59E-02	2.61E-02	2.22E-01	1.84E-01	-1.35E-01	-6.02E-02	7.87E-03	1.58E-03
1	20	8.51E-04	5.89E-02	2.06E-02	3.38E-02	1.43E-02	5.89E-02	1.85E-02	3.33E-02	3.15E-01	2.22E-01	-1.91E-01	-5.86E-02	1.34E-02	2.33E-03
1	15	8.72E-04	7.27E-02	2.38E-02	3.96E-02	1.57E-02	6.69E-02	1.92E-02	3.92E-02	4.29E-01	2.25E-01	-2.47E-01	-5.04E-02	1.55E-02	2.51E-03
2	60	2.34E-02	3.12E-02	1.85E-02	2.15E-02	2.70E-02	2.60E-02	2.82E-02	2.15E-02	1.25E-01	6.12E-02	-1.75E-01	-2.92E-02	7.20E-03	5.31E-03
2	55	2.38E-02	2.81E-02	2.00E-02	1.61E-02	2.50E-02	2.21E-02	2.67E-02	2.30E-02	1.51E-01	8.16E-02	-1.63E-01	-3.82E-02	7.13E-03	5.04E-03
2	50	2.28E-02	2.67E-02	2.13E-02	1.36E-02	2.26E-02	2.10E-02	2.50E-02	2.51E-02	1.82E-01	1.06E-01	-1.59E-01	-4.66E-02	5.32E-03	4.49E-03
2	45	2.28E-02	2.76E-02	2.23E-02	1.50E-02	2.13E-02	2.37E-02	2.45E-02	2.75E-02	2.09E-01	1.35E-01	-1.61E-01	-5.64E-02	6.93E-03	4.04E-03
2	40	2.30E-02	2.68E-02	2.12E-02	1.49E-02	2.09E-02	2.44E-02	2.41E-02	2.78E-02	2.11E-01	1.45E-01	-1.62E-01	-5.88E-02	6.58E-03	3.63E-03
2	35	2.28E-02	3.40E-02	2.17E-02	1.93E-02	2.08E-02	3.23E-02	2.44E-02	2.99E-02	2.31E-01	1.68E-01	-1.70E-01	-6.57E-02	8.52E-03	3.63E-03
2	30	2.31E-02	4.66E-02	2.44E-02	2.16E-02	2.10E-02	4.36E-02	2.59E-02	3.36E-02	2.58E-01	2.07E-01	-1.72E-01	-8.60E-02	7.73E-03	3.77E-03
2	25	2.44E-02	8.20E-02	3.00E-02	5.58E-02	2.66E-02	8.89E-02	3.29E-02	4.43E-02	3.39E-01	2.87E-01	-2.24E-01	-1.17E-01	1.65E-02	4.37E-03
2	20	2.45E-02	1.30E-01	4.21E-02	7.95E-02	3.62E-02	1.35E-01	4.38E-02	5.75E-02	4.60E-01	3.34E-01	-3.16E-01	-1.26E-01	2.14E-02	4.76E-03

Table 5: Confidence Intervals for Relevant Data



of the test article compared to the 3 x 4 ft. wind tunnel. An example of the limitations in the experiment is the gap in the data between the two different runs. It has been concluded that this gap is due to the very large blockage factor and due to one of the runs being closer to the ceiling than the other. Expanding on this testing should be done in a way where the parawing would only block up to 10% of the tunnel's frontal area to help prevent this discrepancy in the data. This would require testing in a bigger wind tunnel or scaling down the parawing and manufacturing one that is smaller. Since three wind tunnel tests take a lot of time, there haven't been any real-world tests to confirm the wind tunnel results. This would be done by launching a rocket that weighs 500 grams with the parawing as the recovery method. The rocket would have had a flight computer that would have returned the data needed to compare to the wind tunnel tests. Then there would also be a test with a conventional parachute so that the two different tests could be compared directly to each other (preferably within an hour to keep the outside conditions similar).

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Caleb is working towards completing his L2 Certification with an Apogee Katana Rocketry Kit (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-4-Model-Rocket-Kits/Katana). He is also starting a full time position as a Flight Test Engineer for Textron Aviation.

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