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CONTENTS:

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TABLE OF CONTENTS

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The NAR Technical Review is a collection of Research and Development reports and technical papers oriented towards a wider distribution of recent and past works into various aspects of model rocketry. It is hoped that the Technical Review will act as a reference source for those persons interested in learning of recent research efforts, and will help prevent past works from being forgotten and needlessly duplicated.

The issue of the NAR Technical Review was published by the NAR Technical Services Committee (NARTS) with the assistance of the members of the MIT Rocket Society. The editorial staff is composed of the following persons:

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OPTIMIZATION OF THE ZERO VOLUME PISTON LAUNCHER

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INTRODUCTION

One similarity between model rockets and many professional sounding rockets is that, having no internal guidance systems, they employ launch lugs to assure a vertical flight path at liftoff. This external guidance is needed until the vehicle has attained sufficient velocity to permit its fins to provide ample restoring moments for stabilization. These launch lugs are undesirable, however, since they increase drag on the rocket considerably; an R & D report at NARAM-15 found this increase to be as high as 28%[1].

An early solution to this problem was the "pop" launch lug, designed to separate from the rocket as it left its launcher. However, these lugs still required some alteration to the "skin" of the rocket; hence the drag problem was not entirely solved.

The next development gave rise to the closed breech system. With this launcher the rocket is mounted on and thrusts through a moving pressure seal (cylinder) and travels for some distance totally enclosed in a tube. The closed breech launcher not only eliminates lugs of any kind, but also serves as a thrust augmenter. Although the idea looked promising, it had several drawbacks. Igniter lead hookup was complicated, since the entire rocket was within the breech tube. The size of the breech tube itself was governed by the span of the rocket's. If the tube diameter was increased beyond a critical point, sufficient pressure was not built up under the moving piston by low impulse engines. A large breech tube also makes the cooling of exhaust gases significant. These factors actually reduced a rocket's altitude capabilities in some cases. If the size of the breech tube was reduced, it causes a compromise of the fin design. Hence, although the launcher became efficient, the rocket itself was not, canceling out any significant gains in altitude.

The latest development is a modification of the closed breech launcher known as the piston launcher. The rocket is mounted on a moving pressurizable piston as before, but in this case the piston itself also serves as the breech tube. This method avoids the enormous design penalties of the closed breech launcher since the piston tube can be made as small as

[1]Shenosky, Larry "Pop Launch Lugs", Model Rocketeer, Oct. 1973

the diameter of the rocket engine. The pressurization benefits are not compromised, and ignition is made simple, since the rocket is mounted on top of the breech tube/piston, totally exposed for the hookups.

Although it seemed that the piston launcher had totally solved the problem, it became evident that further improvements were still possible. Since the moving piston tube was centered inside another tube, the rocket's exhaust gases had the initial volume of this internal tube to pressurize before the piston could move. Therefor, an obvious step was to eliminate this initial volume.

The zero volume piston launcher as presented in this report consists of a core tube plugged at the forward end and a piston tube of somewhat larger diameter. The piston tube is mounted over the core tube and centered by three small rings, which also form the pressure seal. The rocket engine is friction fitted to the top of the piston tube and is in direct contact with the top of the core tube, which is plugged. Upon ignition the exhaust gases are trapped, forcing the piston tube up. Because there is no initial volume to pressurize, the initial pressure is very high. This results in an augmented velocity at liftoff and consequently a higher peak altitude is achieved than if the rocket employed lugs in an unassisted takeoff. It is the purpose of this report to find the benefits gained by the arrangement and to optimize the design.

THEORY

The problem of calculating the altitude of a model rocket is highly complex. The sheer abundance of factors involved makes an exact, closed form analytical solution impossible. Although digital computers make such a highly iterative process somewhat feasible, it is more desirable to have an easily handled closed form approximation to the altitude solution which can be sued for any model rocket size, weight, and engine. The equations below have been checked against iterative calculations and found to be accurate to within 1.5%

A. CALCULATION OF THEORETICAL ALTITUDE FOR UNASSISTED LIFTOFF[2]

List of Variables:

- F - Average thrust in ounces
- m - Average mass in ounces-sec^2/ft^2 = W_{avg}/g
- m_b- Burnout mass of rocket in ounces-sec^2/ft^2 = W_{bo}/g
- v_b- Burnout velocity in ft/sec
- X_b- Burnout altitude in feet
- H_c- Coast altitude in feet
- H_t- Total altitude in feet
- t_b- Engine burning time in seconds

2 Caporaso, George J. "Model Rocket Altitude Calculations", Model Rocketry Magazine, October 1968.

k - Total drag factor in ounces-sec /ft . This is derived from

$$D = \frac{1}{2} A\rho C_d V^2$$

where ρ is the density of air, A is the frontal cross-sectional area of the tube in square inches, C_d is the dimensionless drag coefficient which depends on the shape and finish of the model, and V is the velocity in feet/sec. Then: $k = 1.54 \times 10^{-4} AC_d$, where $D = kV^2$

1) Powered Portion of Flight:

$F = \frac{dp}{dt}$ where p is the rocket's momentum

$$\frac{dp}{dt} = F(t) - m(t)g - kV^2$$

Now approximate m(t) by m, F(t) by F; then

$\frac{dp}{dt} = F - mg - kV^2$ By integrating both sides,

$$\int_0^{t_b} \frac{dp}{dt} = \int_0^{t_b} F\,dt - \int_0^{t_b} mg\,dt - \int_0^{t_b} kV^2\,dt$$

Now $\int_0^{t_b} kV^2\,dt = kXV \Big| \int_0^{t_b} kXA\,dt$

Approximate this integral by kX_bV_b and $p_b = m_bV_b$

and $m_bV_b = Ft_b - mgt_b - kX_bV_b$ yielding

$$V_b = \frac{t_b\,(F - mg)}{m_b + kX_b}$$

Now let V and t be variables and integrate again:

$$\int_0^{t_b} m_bV\,dt = \int_0^{t_b} Ft\,dt - \int_0^{t_b} mgt\,dt - \int_0^{t_b} kXV\,dt$$

$$\frac{Ft_b^2}{2} - \frac{mgt_b^2}{2} - \frac{kX_b^2}{2} \quad \text{which yields}$$

$$X_b = \frac{-m_b\sqrt{m_b^2 + kt_b^2(F - mg)}}{k} \quad \text{and} \quad V_b = \frac{t_b(F - mg)}{\sqrt{m_b^2 + kt_b^2(F - mg)}}$$

2) After Burnout:

$\frac{dp}{dt} = -m_bg - kV^2$ but since the mass is constant at m_b,

$\frac{m\,dV}{dt} = -m_bg - kV^2$ Now let $\frac{dV}{dt} = \frac{dx}{dt} \times \frac{dV}{dx} = \frac{V\,dV}{dx}$

$m_b \frac{V\,dV}{dx} = -m_bg - kV^2$ and

$$\int_{V_b}^{0} \frac{m\,V\,dV}{m_bg - kV^2} = \int_{H_c}^{0} dx \quad \text{which yields}$$

$$H_c = \frac{m_b}{2K} \ln\left(\frac{kV_b^2 + 1}{m_b g}\right)$$

Thus $H_t = X_b + H_c$

B. THEORETICAL ALTITUDE FOR PISTON ASSISTED LIFTOFF:

1) Calculation of Velocity of Rocket Leaving Piston:

$$W = \int_0^V P\,dv + \int_0^P v\,dP$$ where v = volume, P = pressure

This is from the 1st Law of Thermodynamics.
Assume P to be constant for small time interval (t)

$$W = \int_0^V P\,dv$$ (Work done on the piston)

Since the area of the piston tube is a constant,

$$W = PA\int_0^L dL$$ where L is the length of the piston

$$F = PA\int_0^L \frac{dL}{L}$$ where Q = F x L. By integrating,

$$F = PA\ln(L) + \not{c}^{\,0}$$ (no initial volume)

$$\frac{M\,dV_p}{dt} = PA\ln(L)$$ (substituting $F = \frac{M\,dV}{dt}$) where M = mass

If we divide through by M and integrate again:

$$dV_p = \frac{PA\ln(L)}{M}\,t$$ with V_p in feet/sec.

This solution, however, does not take into account the effects of friction. Therefor, we do an energy balance:

$$\frac{MV_p^2}{2} = \frac{MV_a^2}{2} + F_f L$$

where V_a is the actual velocity leaving the piston, V_p is the velocity of the piston, and F_f is derived from $F = \mu N \Delta L$, ΔL being the change in piston length. We let $F_f = \mu N$ = force needed to move the piston at constant velocity. F in this case is the work due to friction.

In order to find the velocity of the rocket leaving the piston launcher, we must first find the pressure generated in the piston tube by the exhaust of the rocket engine. If we assume an ideal gas, an adiabatic piston tube, and no losses, we may use:

$$Pv = nRT$$

where p = pressure in lbs/in^2
v = volume of piston tube in in^3

$$n = \frac{\text{mass flow rate of propellant x time in piston}}{\text{Molecular weight of gas}}$$

R = Gas constant in ft-lb/mole-^{o}R

T = Temperature of exhaust gas in ^{o}R

Once we calculate a value for P, we can find V_a, the velocity of the rocket leaving the piston. To find H_{ta} (the total height of the piston-assisted case), the following steps are taken:

1) X_b, V_b, and H_t are found for the unassisted case.
2) The time needed for the control rocket to move the length of the piston we are using is calculated having substituted that value in place of X_b.
3) The corresponding velocity is calculated by substituting this new time value in the velocity equation. This velcity is compared with V_a (above) and the difference added to V_b yields V_{ba}.
4) Substitute V_a for V_b in the velocity equation and, using the value of k for the piston-launched rocket, solve for F, the force exerted on the rocket while it is on the piston. This will involve a quadratic equation.
5) Using this new value of F, X_{ba}, H_{ca}, and H_{ta} are found. Remember to use K_p. A comparison can now be made between the piston assisted and unassisted cases.

(Editor's Note: Another analysis of the workings of piston and closed breech launchers was presented by Trip Barber in his article "Pressurization Effect Launchers" (which was published in the January 1974 issue of the Journal of the MIT Rocket Society and reprinted in the July, 1974 issue of the Model Rocketeer). This analysis is in some ways more complete than the one presented above as Trip's analysis takes into account such effects as gas leakage from the piston, cooling ot the exhaust gases, and the decrease of the engine's thrust due to the fact that it is exhausting into a pressurized volume. Trip also presents an easy method to calculate the amount of gas produced by any engine.)

DESIGN OF LAUNCHER AND CONSTRUCTION TECHNIQUES

The first problem in building a zero volume piston launcher is to find the materials that will provide both durability and lightweight design. The piston tube itself and the top surface of the core tube must be able to withstand the heat of the exhaust gases from the engine. Weight is important, since we are dealing with rather small weights in the case of the rocket itself. A model rocket engine has finite limits to its load lifting capabilities.

Another problem is that once we have settled on a specific material, it must conform to the rules and regulations of the NAR. Metals of any type are not allowed; materials with specific gravity greater than three are also excluded.

(Editor's Note: the rule referred to above applies to the construction of the model rocket itself and not to the construction of the launcher. Metal parts may be used in a launcher as long as the metal parts present no safety hazard. For example, metal parts could be used to form the core tube and the centering rings for the piston launcher design presented in this report.)

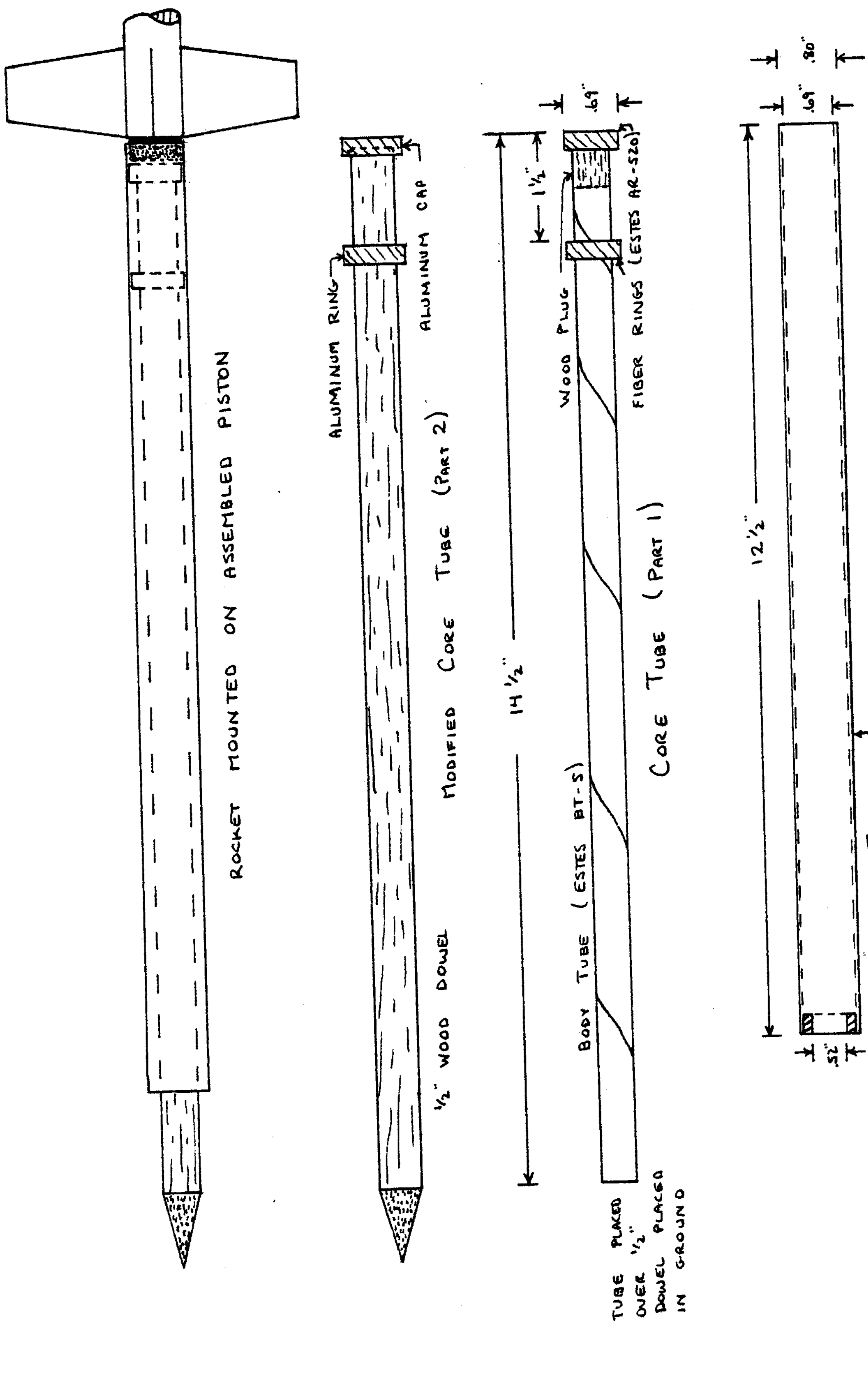
A third point to be considered is that the design must provide for easy and quick setup on the range, as well as easy access for cleaning the piston between flights. These cleanings are a must or else exhaust deposits will increase the friction between the rings and the piston tube.

Our first launcher employed a fiber tube (.74" ID) mounted over a dowel. A string attached between the dowel and the tube acted as the stop when the piston tube was fully extended. The assembled piston employed no rings; the entire external surface of the dowel was in contact with the piston tube. This arrangement proved totally unacceptable. Fiber tubes of this type are normally used for model rocket bodies; they are very light but also fragile. Friction fitting the rocket engine to the top of the tube produced a gradual expansion in the diameter of the tube. Also, the tubes tend to split open under the stress of the friction fits. The tubes in any case simply do not have a long enough life span. They tend to fail structurally by the fifth flight, or sooner if a rocket was friction fitted tightly; this normally burned the tube out. We also felt that there was too much area in contact between the piston tube and dowel, causing excessive friction. Cleaning the piston was also a problem, since the inside of the tube tended to peel.

Limited tests were conducted with plexiglass, but this material was also rejected. It was too heavy and difficult to secure in the proper diameter and wall thickness. Also, tests conducted showed that it would gradually melt due to the heat from the engine's exhaust gases.

Structural problems were solved by the use of plastic Bakelite tubing, perfectly acceptable by NAR regulations. We were able to secure tubes with an 11/16" inner diameter. This provided an ample friction fit with the rocket engine; the strength of the material kept tube expansion to a minimum. The weight of the tubing is only 14 grams/foot. Furthermore, Bakelite is heat resistant, and hence the inside of the tube will not be affected by the hot exhaust gases. These factors give the Bakelite piston a much greater life span than one built with a fiber tube.

The problem of sliding friction between the piston and the core tube was remedied by a better launcher design. The finalized design saw the piston tube centered over a core tube with a 9/16" outer diameter by the use of three fiber rings. Two of the rings were epoxied in place on the core tube. The first was set at the extreme forward end and served as the pressure seal. The second ring was set back $1\frac{1}{2}$" and served as the piston stop. It was set back to avoid piston wobble at


ROCKET MOUNTED ON ASSEMBLED PISTON
ALUMINUM RING
ALUMINUM CAP
MODIFIED CORE TUBE (PART 2)
1/2" WOOD DOWEL
14 1/2"
.69"
1 1/2"
WOOD PLUG
FIBER RINGS (ESTES AR-520)
BODY TUBE (ESTES BT-5)
CORE TUBE (PART 1)
TUBE PLACED OVER 1/2" DOWEL PLACED IN GROUND
.80"
.69"
12 1/2"
.52"
BAKELITE TUBING
PISTON TUBE

full extension. The third ring was set inside the aft end of the piston tube, allowing the tube to be slipped over the core. Hence, these three small rings ($\frac{1}{4}$" long) are the only surfaces in direct contact with the piston tube.

Range setup of this design was much easier since the inner diameter of the core tube ($\frac{1}{2}$") permitted it to be slipped over a dowel of equal diameter that had been previously driven into the ground or otherwise secured. This also facilitates cleaning, since the launcher can easily be pulled off the dowel, separated into its parts, and purged of the exhaust deposits.

DESIGN AND CONSTRUCTION OF TEST VEHICLES

Since a large number of test flights were to be made, criteria were established for the test vehicle to assure the uniformity of results:

1) The rockets had to be durable to withstand the wear and tear of many flights.
2) The rocket design had to be kept clean and simple to avoid introducing extra variables into the tests.
3) A payload compartment of ample size was needed so that weights could be varied.
4) The rocket had to be large enough to make tracking easy.
5) Surface finishes had to be kept constant.
6) Fin and nose cone parameters had to be kept constant.

In view of these factors, we chose a rocket marketed by AVI for the test vehicle. The kit is a scale model of the Tomahawk sounding rocket made by Sandia Corporation, but for the purposes of this project, the rocket is not built to scale; we eliminated all unnecessary parts. The nose cones and fin units are made of prefinished, molded plastic; hence their specifications do not vary from rocket to rocket. The body tubes are white and received no further finishing, keeping this variable constant. Net rocket weight was kept constant, and a $4\frac{1}{2}$" payload section provided ample room for weights to be added. Two of the models employed launch lugs; they were used for the control flights.

Ten rockets wer built; five were primary test vehicles and the other five were backups. The cost of these ten rockets was under five dollars.

SELECTION AND SETUP OF ROCKET ENGINES

For the purposes of this project, it was necessary to choose an engine in the low total impulse range to provide flights under two hundred meters, thus making accurate tracking possible. Low impulse engines are also less expensive, permitting a large number of flights to be made cheaply. We decided on an order of one hundred type A3-2 engines at a cost of fifteen dollars. These engines were individually numbered and weighed on a gram balance accurate to within

1/100 of a gram. Then, as we found that the weights varied a little bit, they were grouped in batches of four; the weight of each batch was kept constant. Twenty-four batches were made up in this manner.

(Editor's Note: an R & D report by Mark Stutman presented at NARAM-15 showed that there was little correlation between an engine's initial weight and its overall performance data, such as total impulse, delay times, etc.. However, he did show that engines from the same package or tube did have fairly similar performance. Thus it is probably a better idea to separate engines according to which tube they come from rather than according to how much they weigh.)

Each engine had a nichrome igniter installed in its nozzle and then the twenty-four batches were bagged, numbered, and assigned a specific run. One batch was used for each piston launching a rocket of specified weight. Therefor, four flights were made for each data point. If a flight had to be redone due to a lost track or poor flight, an engine of equal weight was substituted from the extra engine batches. In some cases, an entire batch was reflown.

EXPERIMENTAL PROCEDURE

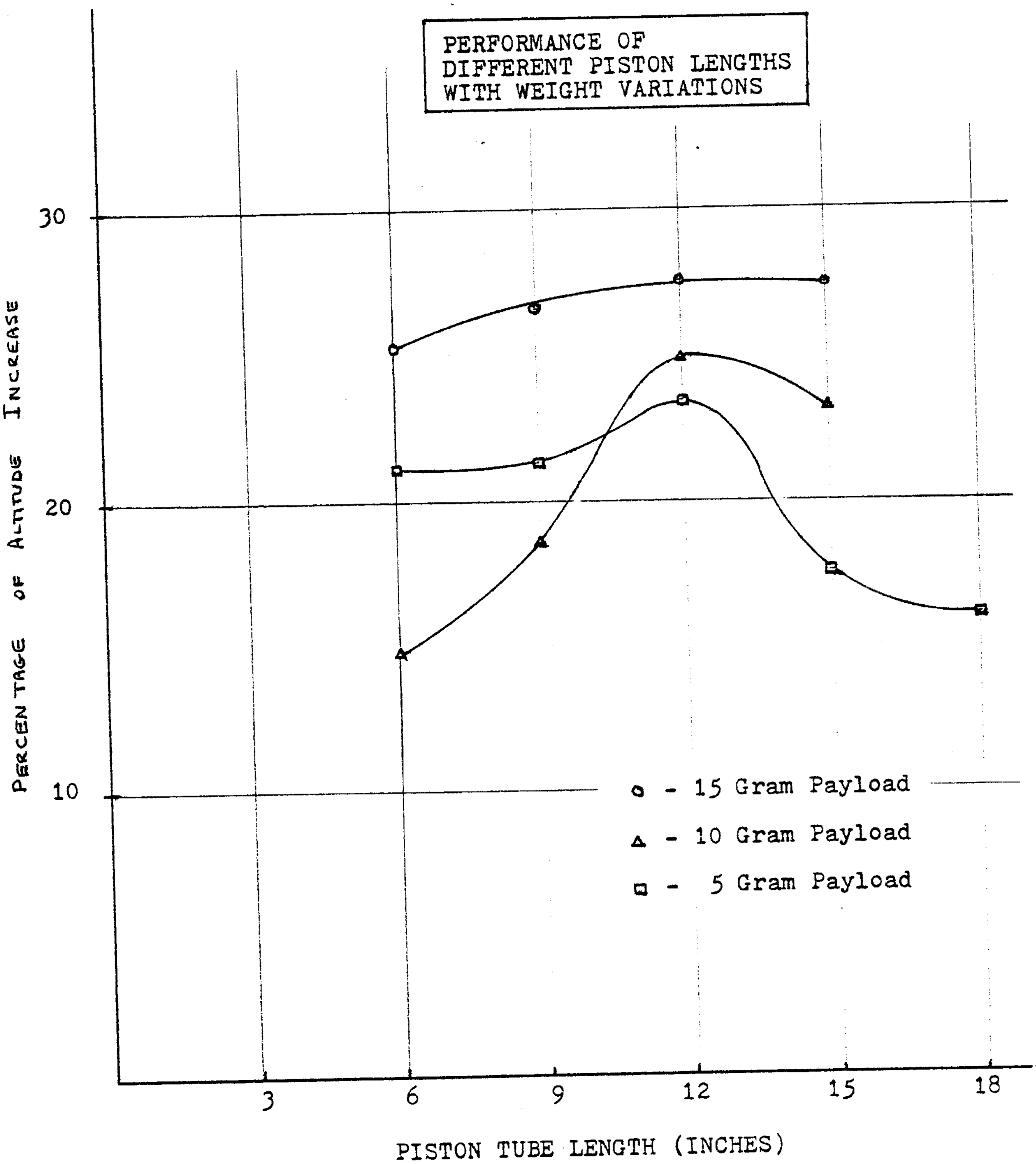
Initially, it was decided that five different piston sizes would be tested against payload weights of 5, 10, and 15 grams. Accordingly, pistons of 6, 9, 12, 15, and 18 inch lengths were built along with their respective core tubes. Care was taken to maintain a gas-tight fit with the rings without causing excessive friction.

The ten rockets were built rather easily; construction was simple due to the one piece fin units and pre-finished parts. Once completed, they were individually weighed and then ballasted until all weighed in at precisely 25.0 grams.

Four flights were made for each test of a payload weight versus a specific piston size. Hence, one engine batch was used per run. A control run was also made for each payload weight. In all, eighty flights were planned; however, the 18" piston kept failing structurally and had to be eliminated from the 10 and 15 gram runs. Some flights did have to be re-flown, and so the final total was seventy-eight flights.

The seventy-eight flights were made on Saturday, November 17 and Friday, November 23, 1973. On both days the temperature was about 70°F and the winds were 5-10 mph. Visibility was excellent for tracking.

Tracking the rocket flights was made possible by the use of two Sky Trak Altitude Finders manufactured by Centuri Engineering Co. These instruments were accurate to within ±5% and take into account the effects of wind drift. The baseline distance between the two trackers was 1000 feet. The altitude of the rockets was calculated by standard NAR altitude data reduction techniques.


PERFORMANCE OF
DIFFERENT PISTON LENGTHS
WITH WEIGHT VARIATIONS
30
20
10
PERCENTAGE OF ALTITUDE INCREASE
o - 15 Gram Payload
Δ - 10 Gram Payload
□ - 5 Gram Payload
3
6
9
12
15
18
PISTON TUBE LENGTH (INCHES)

ZERO VOLUME PISTON LAUNCHER
ALTITUDE DATA

(All Altitude in Meters)

RUN #1 Rocket weight = 25 grams + 5 gram payload

Flight #	1	2	3	4	5	% over C
Control (C)	94.69	85.07	88.00	86.48	88.56	-
6" Piston	106.58	105.33	110.13	106.85	107.22	21.07
9" Piston	103.82	108.04	110.94	107.77	107.64	21.54
12" Piston	110.44	112.62	103.20	112.40	109.67	23.83
15" Piston	107.93	109.11	96.92	103.35	104.32	17.70
18" Piston	102.60	107.26	101.71	100.22	102.94	16.25

RUN #2 Rocket weight = 25 grams + 10 gram payload

Control (C)	82.47	75.53	77.29	70.27	76.39	-
6" Piston	83.83	90.27	87.82	88.16	87.52	14.57
9" Piston	86.78	94.40	91.34	93.01	91.38	19.63
12" Piston	90.29	97.00	96.80	98.33	95.61	25.15
15" Piston	93.50	96.84	95.72	91.31	94.34	23.49

RUN #3 Rocket weight = 25 grams + 15 gram payload

Control (C)	63.27	67.13	59.87	55.73	61.50	-
6" Piston	70.84	76.86	80.15	80.55	77.10	25.37
9" Piston	71.20	74.30	85.69	80.95	78.04	26.89
12" Piston	74.96	73.13	83.13	83.36	78.65	27.89
15" Piston	72.10	79.09	75.19	87.93	78.58	27.77

PART 2

FURTHER TESTS OF THE ZERO VOLUME PISTON LAUNCHER

MODIFICATION OF PISTON DESIGN

In the earlier piston design, the core was made of fiber rings epoxied to a .520" OD body tube, which was then fitted on to a .500" OD wood dowel. This assembly was then slipped into the outer bakelite tube. The disadvantages of the core assembly were that the fibrous parts wore down quickly and caused increasing firction with the piston wall. These problems were corrected by getting rid of the body tube and replacing the fiber rings with a ring and cap machined from aluminum. These were epoxied to the wood dowel and served the same purpose as the fiber rings. The aluminum rings cause much less friction and clean the bakelite tube better than their fiber counterparts.

A problem that was encountered as the new series of tests began was that the old pistons (those used in the initial tests) began to crack near the end where the engine nozzle was inserted. This crack usually extended down the bakelite tube about ¼" and then turned and followed a spiral pattern down about ½" more. Instead of discarding the tube, the end was wrapped with four turns of masking tape. This gave back the tube strength and provided a means of getting a good friction fit without wrapping the engine.

EXPERIMENTAL PROCEDURE

For the most part, basic procedures followed in the initial tests were duplicated in this phase.

The engines selected for this test were: ½A6-2, A8-3, B4-2, B6-2, B14-5, and C6-3, all manufactured by Estes Industries, Inc. Twelve engines of each type were weighed and separated into groups of four. There were three runs for each engine type, totaling 24 runs.

Eight new test vehicles were purchased and six vehicles from the initial tests were refurbished. All vehicles were balasted to weigh 30 grams empty. The first four new vehicles were used as primary vehicles, and the other four were backups. The six extra vehicles were used during the later testing so runs could be pre-prepped and fired in salvos to save time. It was decided that substantial data could be found using 9, 12, and 15 inch pistons. The rocket weights remained constant. In this way data from the 30 gram run of A3-2's could be included for study. A control flight was made for each run. Seventy-two flights were planned, but twelve flights were scrubbed due to structural failures in all pistons during the last run of B14-5's. Also, three flights of B14-5 are missing; one is due to a catastrophic engine failure and the others are due to the rocket carrying the piston away.

A problem that arose during the testing of the B4-2's and B6-2's is that the 12" piston would not extend completely, due to a misalignment of the aluminum ring and cap on the wooden dowel. These data points could be used as a reading for the 6" piston and this is done on the graphs.

The altitude data for this series of tests is presented on the following page.

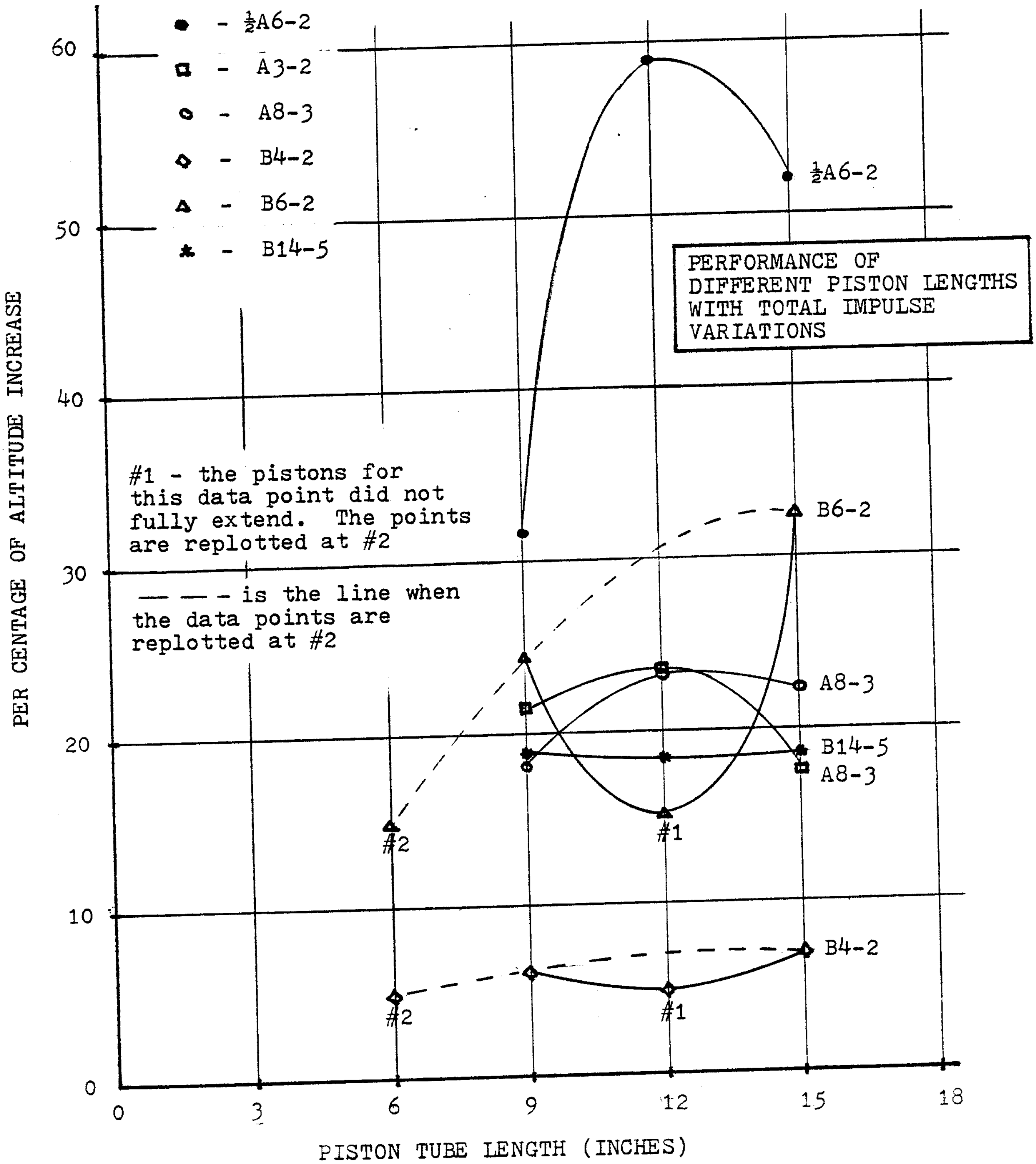
CONCLUSIONS

PART 1

The data from the flights is excellent; this is to the credit of those individuals who spent hours out on the trackers taking the data for us. Although we were not able to obtain any data from the 18 inch piston for the 10 and 15 gram payload runs, the quality and quantity of that which was obtained is more than ample to back our conclusions. The twelve inch piston tube is the most efficient size of the five tested, although the fifteen inch tube also made a good showing, especially as the payload weights were increased. The Zero Volume Piston Launcher will yield altitude increases of better than 23% over standard rod-launched rockets. This makes it about twice as efficient as those piston launchers that have initial volumes to pressurize, as evidenced by Andy Bennett's report.[3]

ZERO VOLUME PISTON LAUNCHER ALTITUDE DATA (IN METERS)

	1	2	3	Average	% Increase
½A6-2					
Control	lost	26.9	26.9	26.9	- - -
9"	27.8	33.1	45.3	35.4	31.59
12"	49.6	42.3	36.6	42.8	59.10
15"	36.6	43.9	42.3	40.1	52.04
A3-2					
Control	94.69	85.07	88.00	88.56	- - -
9"	103.82	108.04	110.94	107.94	21.54
12"	110.44	112.62	103.20	109.67	23.83
15"	107.93	109.11	96.92	103.32	17.80
A8-3					
Control	92.7	74.0	73.5	80.0	- - -
9"	109.3	97.5	76.9	94.5	18.12
12"	95.0	106.2	95.4	98.8	23.50
15"	100.0	101.8	91.7	97.8	22.25
B4-2					
Control	151.6	171.1	93.7	138.8	- - -
9"	135.7	162.6	135.0	144.4	6.0
12"	133.6	152.8	141.2	142.5	5.0
15"	165.3	110.8	170.0	148.7	7.0
B6-2					
Control	160.1	123.6	105.4	129.7	- - -
9"	174.2	190.7	119.1	161.3	24.36
12"	lost	187.3	111.6	149.4	15.22
15"	181.7	203.0	132.3	172.3	32.84
B14-5					
Control	165.6	197.6	242.07	201.0	- - -
9"	211.8	265.7	- - -	238.7	18.75
12"	235.1	241.2	- - -	238.1	18.45
15"	CATO	214.3	262.3	238.3	18.55



● - ½A6-2
◘ - A3-2
o - A8-3
◇ - B4-2
△ - B6-2
✱ - B14-5
PERFORMANCE OF DIFFERENT PISTON LENGTHS WITH TOTAL IMPULSE VARIATIONS
#1 - the pistons for this data point did not fully extend. The points are replotted at #2
— — - is the line when the data points are replotted at #2
½A6-2
B6-2
A8-3
B14-5
A8-3
B4-2
#1
#2
#1
#2
PER CENTAGE OF ALTITUDE INCREASE
60
50
40
30
20
10
0
0
3
6
9
12
15
18
PISTON TUBE LENGTH (INCHES)

Test data also points out that piston launcher efficiency will increase with increasing rocket weight. Thus this type of launcher will be ideally suited for competition rockets flying in eggloft and payload events. In addition, scale rockets would also benefit by using the ZVPL since their appearance no longer needs to be marred by launch lugs that are not to scale.

It would appear upon inspection of the data that the size of the piston tube becomes less significant with increasing payload weight. This is especially true in the fifteen gram payload run; however, it is questionable as to whether our data is sufficient to support such a conclusion. It would probably be of some value to have a 20 and 25 gram payload run to see if this particular trend continues.

Bakelite tubing for the piston seems to be an excellent choice as no wear could be found on any of the tubes after the seventy-eight test flights. However, the fiber rings did show signs of wear, and the BT-5 core tubes do tend to split at the ends from constant handling. In the future, we plan to build our entire launcher assemblies with Bakelite. This will definitely solve the problem.

PART 2

This series of flights backed up one conclusion reached in the first part; that is that for 18mm diameter engines, a 12" piston gives optimum increase over average flights. We also found a slight trend of higher increases with shorter burn-time engines.

After this point, the next step would be to find a physical relationship between some engine characteristics and piston lengths to find the causes of the optimum piston lengths.

SUGGESTIONS FOR FUTURE RESEARCH

Although this project has yielded very positive results, there is still plenty of room for research with regard to the ZVPL. There are many types of rocket engines with different diameters and total impulses. A number of 18 mm engines with different total impulses were tested in Part 2, but no testing has been done on engines of diameters other than 18 mm, such as mini-engines or D, E, or F engines. It's very likely that each engine diameter will have a different optimum piston tube length. Bakelite was found to be a good structural material for the launcher, but there may be others even better with regard to weight and strength. There is also need for a lubricant that will even further reduce sliding friction between the rings and the piston tube.

One item not directly concerned with the ZVPL was observed during the course of the project and also has been studied at MIT; all rocket engines are not alike, weightwise and performance-wise. It seems that in some cases the engine weight is not within acceptable NAR limits. We had to reject a number of engines during testing until we found enough for our flights that were within an acceptable range. Further studies are definitely needed in this area plus approproate action by the NAR Standards and Testing Committee if it becomes necessary.

(Editor's Note: Mark Stutman's R&D report on engine variation will be presented in a future issue of the Tech Review)

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(Editor's Note: This report won Second Place, C Division, in R&D at NARAM-16.)

OPTIMIZATION OF THE ZERO VOLUME PISTON LAUNCHER

REVIEW

The theoretical analysis of the piston-assisted and unassisted rocket flights contain a few errors. The unassisted flight calculations were taken directly from Geroge Caporaso's article in Model Rocketry magazine (October, 1968), and there were a few errors in this article. The corrected equations appear below:

$$\int_0^{t_b} kV^2\,dt = kXV\Big|_0^{t_b} - \int_0^{t_b} kXA\,dt$$

$$X_b = \frac{-m_b + \sqrt{m_b^2 + kt_b^2(F - mg)}}{k}$$

$$\int_{V_b}^{0} \frac{m_b V\,dV}{-m_b g - kV^2} = \int_0^{H_c} dx$$

$$H_c = \frac{m_b}{2K} \ln\left(\frac{kV_b^2}{m_b g} + 1\right)$$

A complete error analysis of the Caporaso equations can be found in Topics in Advanced Model Rocketry.

The piston-assisted calculations are erroneous where F is introduced; the equation whould be $F = PA$, and thus the ln(L) should be replaced by 1. In $Pv = nRT$, R should be in inch-lb/mole-°R.

The theoretical approach outlined is good, but the number of assumptions and lack of knowledge may limit its usefulness. Assumptions of constant pressure, piston travel time equal to free flight travel time along L, and lack of knowledge of F_f and k on the piston would contribute to problems with applying the theoretical approach.

The experimental work, however, has produced fairly accurate results. Multiple tests, launching on the same day, and the use of consistent plastic fins all helped with experimental accuracy. The dashed lines on the graph in Part 2 are somewhat questionable, and more work could be done to confirm this data.

The launch lugs used for the control rockets were molded into the plastic fin units, so both control and piston-launched rockets had the same drag.

PARACHUTE PERFORMANCE

by Jim Rea
NAR 22492

INTRODUCTION

Although parachute recovery is by far the most commonly used system of recovery for model rockets, very little quantitative research has been done in this field. Because of this fact, I decided to do my R&D project on this subject.

The only earlier work in this field was done by Doug Malewicki and Carl Kratzer in 1967 and 1970.[1] Malewicki's early (1967) work was totally theoretical, and it established a formula for finding the descent rate of a parachute system. This formula was based on the assumption that a parachute has a C_d of 1.0. In 1970, Kratzer and Malewicki performed and analyzed drop tests with 20 parachutes and established experimental C_d values for various types and sizes of chutes (see graph #1). They also established the facts that variances in suspended weight do not change the chutes' Cd, and that a large portion of the upward force on a chute is lift due to glidinf. However, these tests left many unanswered questions. I was particularly interested in finding out how three variables affected chute performance: shroud line length, the number of shroud lines, and spill holes.

METHOD OF APPROACH

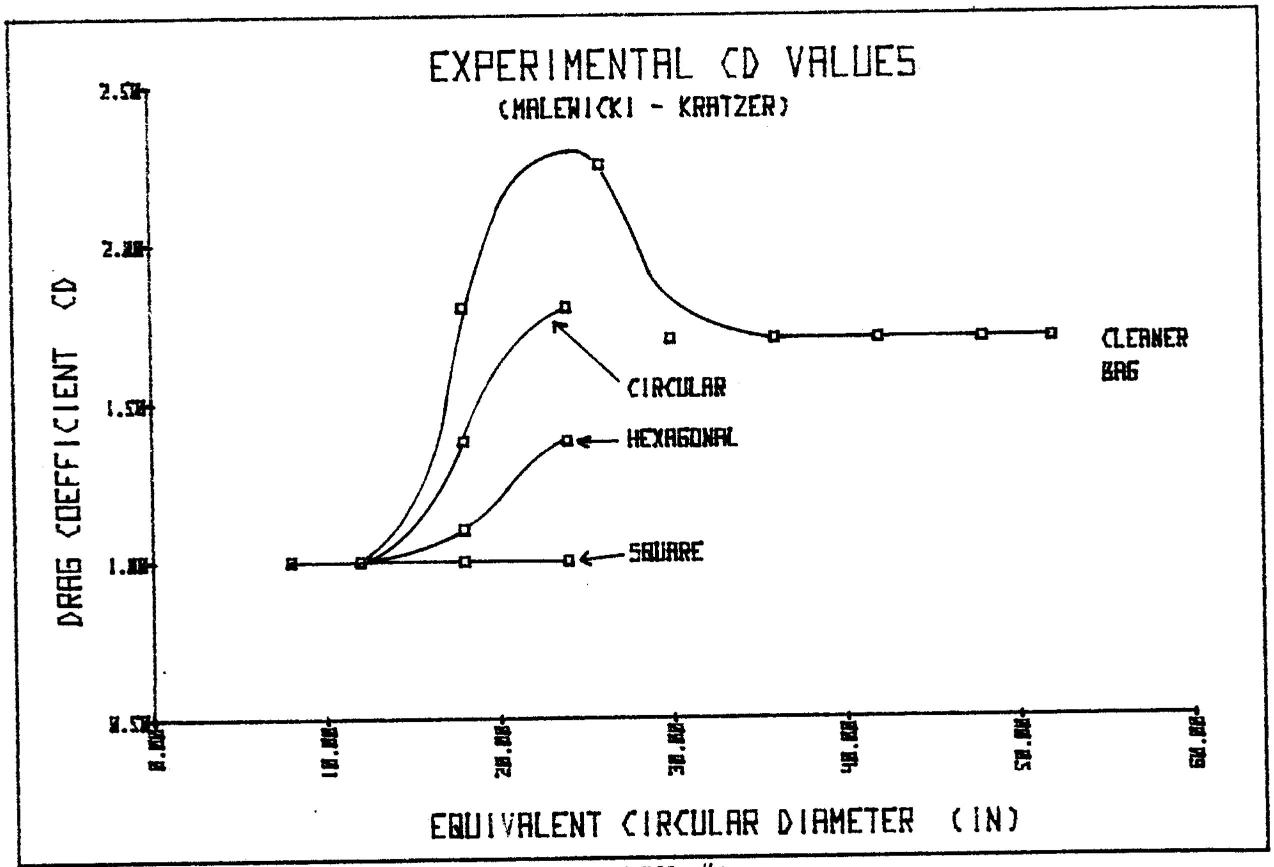
In 1970 when Carl Kratzer performed drop tests, he used a 100 foot high gym for indoor tests. Unfortunately, no such ideal test site was available to me. My first drop tests were made outdoors from a 70 goot high balcony at a local college. I had hoped that by performing the tests in the early morning fog (quite common in Southern California) extraneous variables such as wind and thermals could be eliminated. However, this was not the case and sonsiderable scattering of data points occured. In fact, the chute sometimes went up after being released. A new testing method was needed.

One method that was investigated was strobe photography. The chute is photographed as it falls, with a calibrated strobe providing the illumination. The photo shows a series of images, and velocity can be measured by finding the distance between each image of the chute.

For this purpose, however, a simpler method was devised. A light bulb and batteries were attached to the parachute being tested. When the chute was dropped the light was photographed at $\frac{1}{4}$ second shutter speed on my Pentax Spotmatic, producing a

[1] Malewicki, Douglas "Simplified Parachute Duration Analysis", Model Rocketry magazine, June 1970, P 16-17

[2] Malewicki, Douglas, and Kratzer, Carl "Experimental Parachute Duration Results", Model Rocketry magazine, July 1970 P 30-33


EXPERIMENTAL CD VALUES
(MALEWICKI - KRATZER)
DRAG COEFFICIENT CD
CIRCULAR
HEXAGONAL
SQUARE
CLEANER BAG
EQUIVALENT CIRCULAR DIAMETER (IN)

GRAPH #1

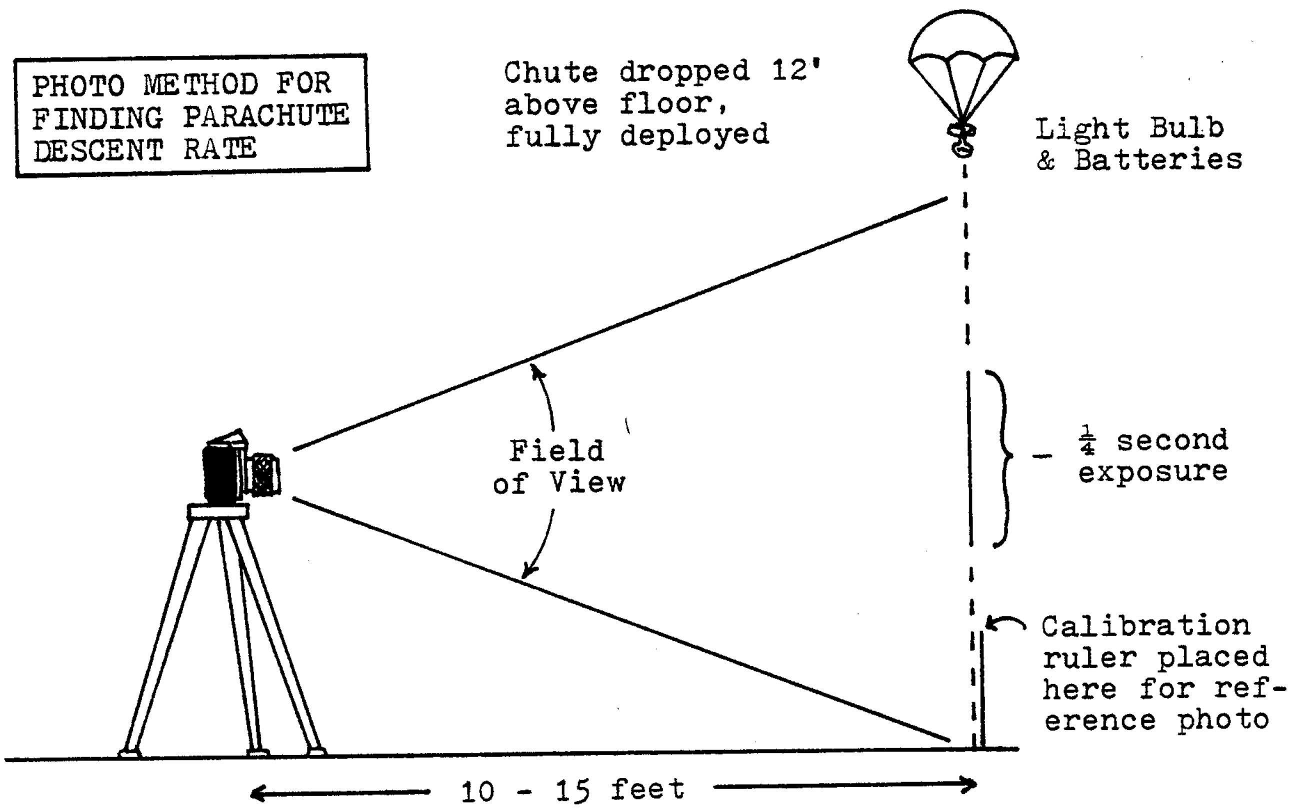


PHOTO METHOD FOR FINDING PARACHUTE DESCENT RATE
Chute dropped 12' above floor, fully deployed
Light Bulb & Batteries
Field of View
¼ second exposure
Calibration ruler placed here for reference photo
10 - 15 feet

bright line. Before the drop tests were conducted, the system was calibrated by photographing a ruler at the same distance as the chute drops. Later this ruler photo was used as a reference to convert distance on the film to actual distances. After this, sixty drop tests were made with various types of chutes. Not all tests produced useful data, as in some cases the chute bounced against the wall or floor during the exposure.

(Editor's Note: When doing time-exposure studies such as this, it is a good idea to calibrate the shutter speed of the camera. If the shutter speed is inaccurate (such as a shutter speed of .2 seconds instead of .25 seconds) it can introduce a large error into the results. Better camera stores will be able to accurately calibrate a camera.

After the tests, the film was developed. Each negative was placed in an enlarger and blown up as large as possible. The lines produced by the time exposures were measured to an accuracy of .05" with a steel rule. The photo of the calibration ruler was also measured. Since the length of the ruler was known, it was possible to determine the ratio of image size and actual distances. Each film line distance was multiplied by this factor to find the distance traveled by the chute in $\frac{1}{4}$ second. This value was multiplied by four to find the distance travelled in one second, which is equal to the velocity in inches per second. Average velocity and standard deviation were calculated, and these values were converted to C_d values by using the standard drag formula ($\frac{1}{2}\rho V^2 C_d A$). This data was compiled into the tables and graphs presented on the following pages.

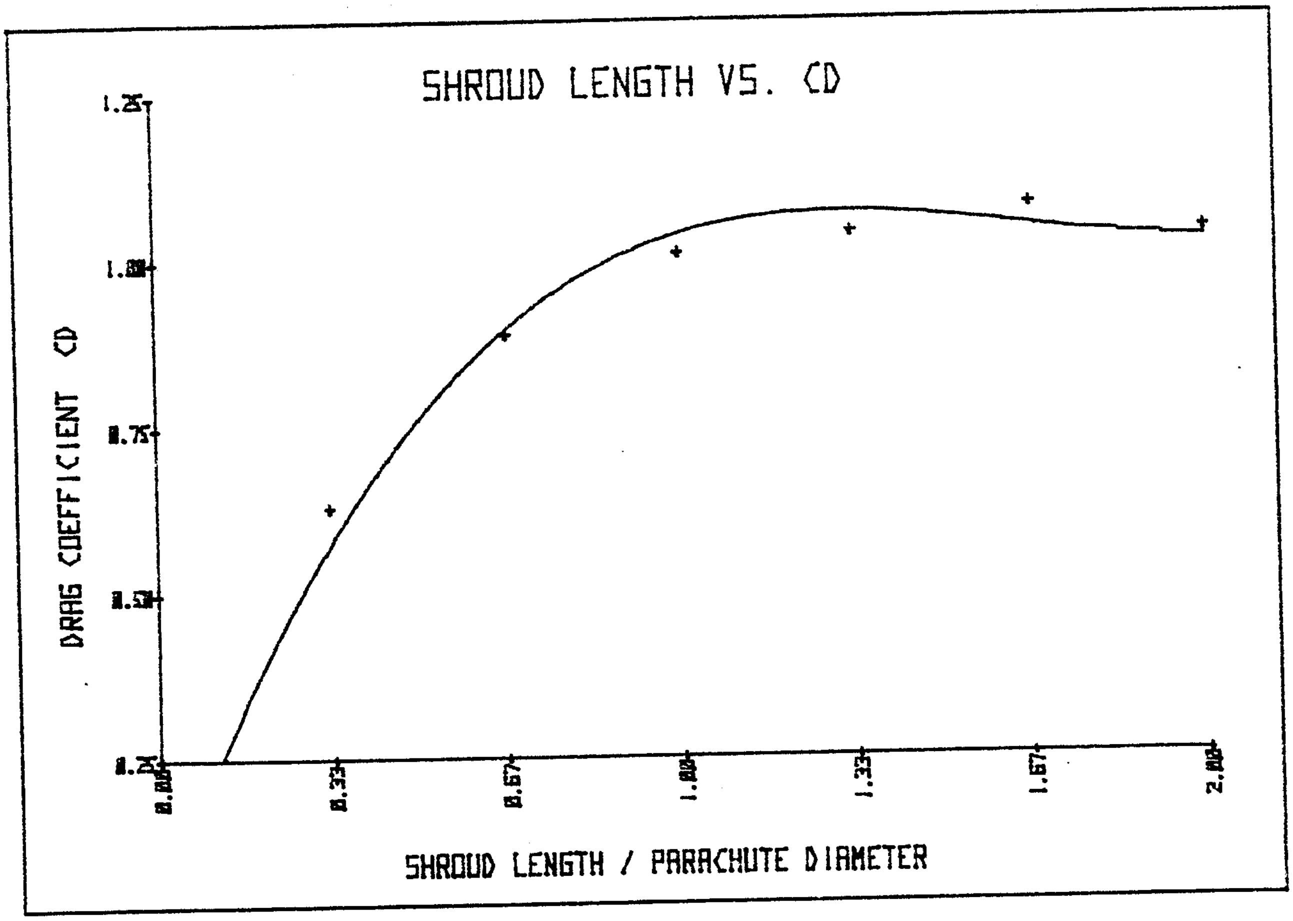
CONCLUSIONS

All three of the experiments conducted produced good results. No great scattering of data points occurred, so the C_d values obtained can be taken as reliable.

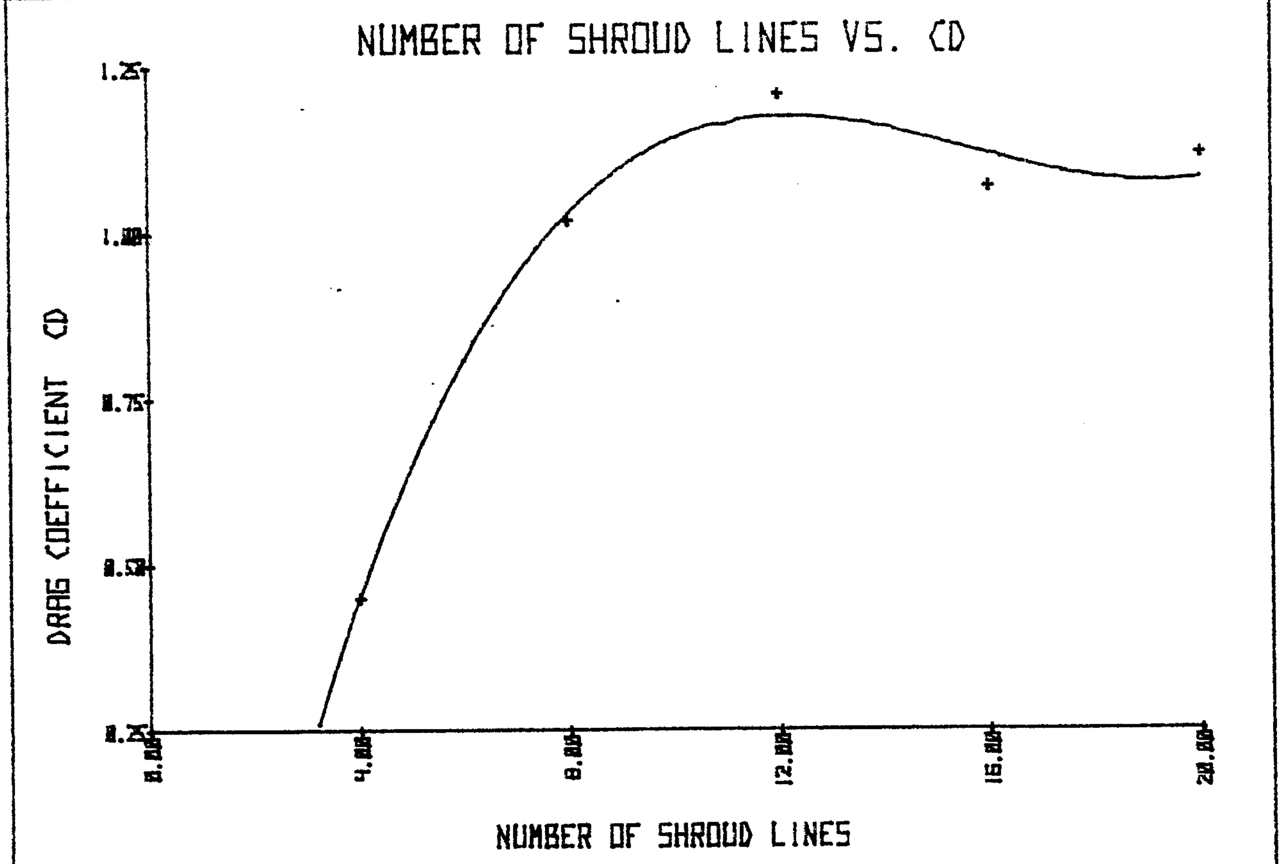
The first experiment, shroud length vs. C_d, showed that reefing the chute produces a considerable decrease in C_d and corresponding increase in descent velocity. The shroud length normally used by most rocketeers, shroud length equal to chute diameter, is quite close to the optimum length. The optimum shroud length for high performance competition-type models appears to be approximately 1.5 times the diameter of the chute. An increase in length beyond this value produces almost no increase in C_d.

The second experiment, number of shrouds vs. C_d, showed that C_d increases tremendously as the number of shrouds increases from 4 to 12. More shrouds do not increase the C_d. An interesting observation from this graph is that a Centuri chute, with eight lines, should habe a significantly higher C_d than an Estes chute which has only six lines.

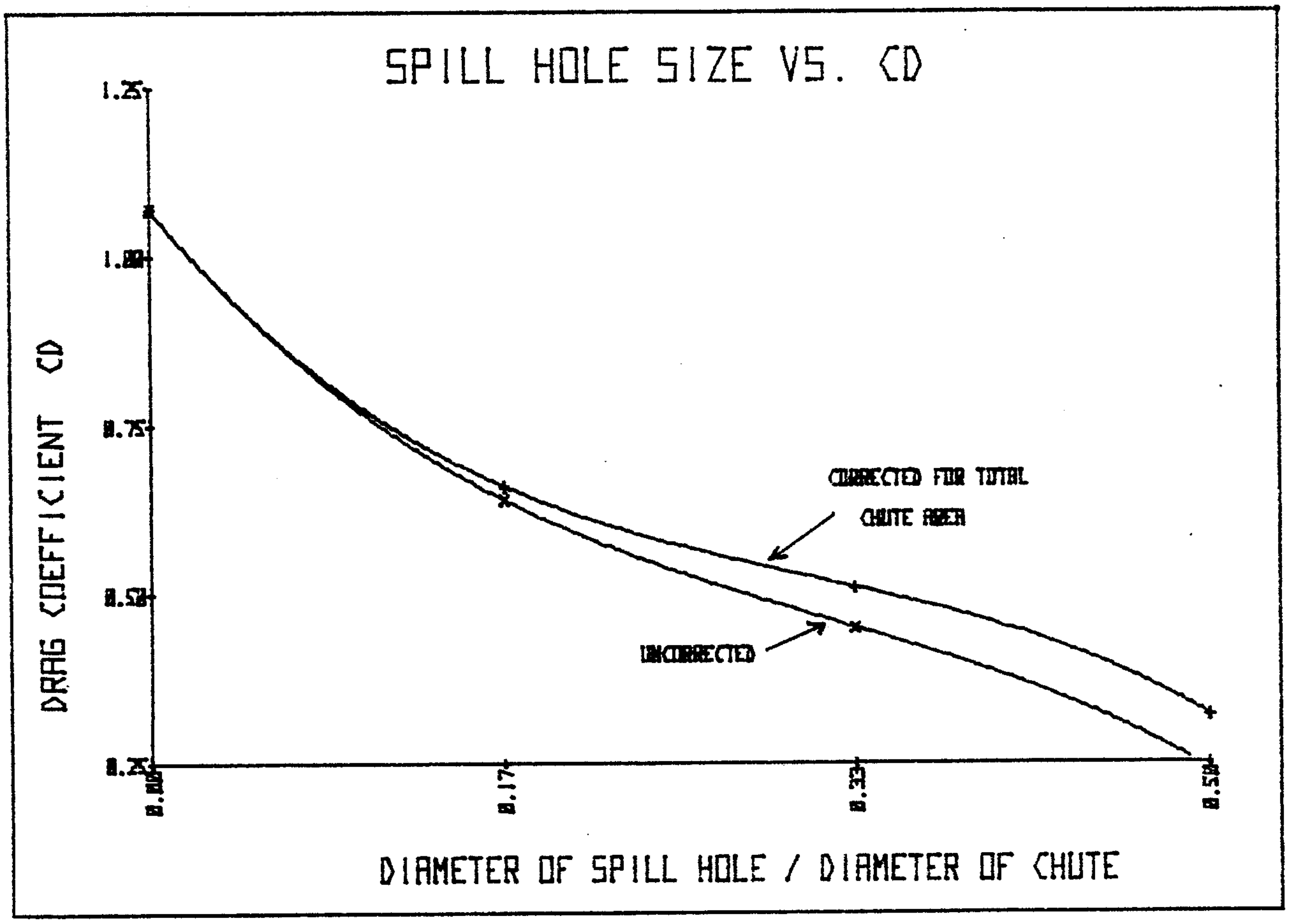
The third experiment, spill hole size vs. C_d, showed that spill holes decrease a parachute's C_d as well as decreasing its total area. This makes spill holes a doubly effective method of retreiving models from high altitudes.



TEST #	Shroud Line Length	Velocity (in/sec)	Average Velocity	Average C_d
1	36"	64.2	64.3 ± .33	1.04 ± .011
2	36"	64.3		
3	36"	65.4		
4	36"	63.1		
5	30"	59.0	63.1 ± 1.2	1.08 ± .041
6	30"	64.2		
7	30"	----		
8	30"	66.0		
9	24"	60.5	64.5 ± .99	1.04 ± .033
10	24"	66.0		
11	24"	66.9		
12	24"	----		
13	18"	----	65.1 ± .71	1.01 ± .022
14	18"	64.1		
15	18"	66.1		
16	18"	----		
17	12"	67.2	69.4 ± .34	.89 ± .009
18	12"	67.8		
19	12"	72.1		
20	12"	70.6		
21	6"	75.7	83.0 ± 1.46	.63 ± .024
22	6"	86.8		
23	6"	86.6		
24	6"	----		



TEST #	Number of Shrouds	Velocity (in/sec)	Average Velocity	Average C_d
1 2 3 4	4 4 4 4	100.5 104.1 95.0 93.2	98.2 ± 1.44	.45 ± .013
5 6 7 8	8 8 8 8	67.3 60.9 65.0 67.1	65.1 ± .58	1.02 ± .019
9 10 11 12	12 12 12 12	59.0 56.9 62.9 59.1	59.5 ± .11	1.21 ± .003
13 14 15 16	16 16 16 16	61.1 63.0 65.2 ----	63.1 ± .88	1.07 ± .029
17 18 19 20	20 20 20 20	60.9 ---- 62.8 ----	61.9 ± .67	1.12 ± .024



TEST #	SPILL HOLE DIAMETER	Velocity (in/sec)	Average Velocity	Average C_d
1	0"	57.3	63.6 ± .43	1.07 ± .018
2	0"	63.0		
3	0"	69.1		
4	0"	65.1		
5	3"	79.4	81.8 ± .34	* .64 ± .006
6	3"	83.3		.66 ± .006
7	3"	----		
8	3"	82.6		
9	6"	93.2	98.1 ± .52	* .45 ± .004
10	6"	----		.51 ± .004
11	6"	104.2		
12	6"	96.8		
13	9" @	-----	133.5 ± 2.58	* .24 ± .009
14	9" @	129.8		.32 ± .009
15	9" @	-----		
16	9" @	137.1		

* - The C_d values marked * are values uncorrected for actual area (chute area - spill hole area)

@ - The tests with 9" spill holes are probably unreliable as the chute did not fully deploy.

FURTHER RESEARCH

Although this project has answered some of the questions concerning parachute behavior, there are still many which are left unanswered. For instance, all the tests in this project were made with 18" parachutes; do the same relationships hold for other diameters? How do parachutes made of different thicknesses of material perform? What are the differences between the performance of mylar and plastic parachutes? For anyone looking for a research topic, the field of parachutes offers a wide variety.

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(Editor's Note: This report won First Place in B Division, R & D at NARAM-16)

PARACHUTE PERFORMANCE

REVIEW

While the testing was well-conducted and the data appears to be consistent, the photographic approach taken is one that can cause a lot of problems, This is because every point in the photo is a different distance from the camera. The ruler in the photographs cannot be used to measure the distance that the parachute falls unless it is right beside the parachute, Otherwise the scale will be distorted, and some error will result. If the parachute drifts towards or away from the camera, errors will also be introduced. This is a primary difficulty with strobe photography of boost gliders.

Malewicki and Kratzer, and others, have shown that a parachute generates more drag when drifting. It is therefor important to know which parachutes drifted sideways and which came straight down, and it is important in the data to make sure all drops were consistent.

The calculations for C_d originally presented with the report were incorrect, and the data presented in this issue were recomputed from the data given. The results show the same trends in factors affecting drag, but the drag coefficients are somewhat lower than those computed by Malewicki (Model Rocketry, July '70). It is important to include data on parachute weights, mounting methods, and atmospheric conditions to account for such discrepencies.

A WIND TUNNEL INVESTIGATION OF THREE EGGLOFTER BODY DESIGNS

by Chris Flanigan NAR# 17540

INTRODUCTION

The event of efflofting presents two main challenges to a rocketeer: to fly an egg as a payload to the highest possible altitude, and to return the egg undamaged. By using the proper padding, it is fairly easy to insure the safe return of the egg. However, lofting an egg to the highest altitude presents a more complicated problem.

There are three solutions to the problem of achieving a high altitude with an egglofter. The solutions are 1) to select the most powerful engine permissable, 2) to build the rocket as light as possible, and 3) to use a low drag design for the model. A high performance engine can be determined by examing a table of static testing results (such as that published by the MIT Rocket Society), and the weight of the model is limited by the craftsmanship of the modeler. As for the third item, very little is currently known as to what constitutes a low drag design for an egglofter, and this project was originated in an attempt to alieviate this situation.

The goal of this project was to accurately measure in a wind tunnel the drag characteristics of a few common egglofter body designs so as to determine what, if any, effect the body design has on the overall drag of an egglofter. No thorough attempts were made to measure the effects of fin size or planform on the overall drag of an egglofter.

Three egglofter designs, all of which are flown quite often in competition, were selected for wind tunnel testing. The designs were 1) a standard "Kuhn Capsule" egglofter, 2) a model using a CMR Humpty Dumpty kit as the eggcapsule, and 3) a model using a hollow laminar-flow spindle section as the egg capsule. The third model will be referred to in the report as the "Wine Bottle" design (it attained this name due to its resemblance to the neck of a wine bottle). These models are described in the next section.

MODEL CONSTRUCTION

There are three mahor parts to a model rocket egglofter: 1) the nose cone, 2) the reducing section, and 3) the body tube. The nose cone and reducing sections are both hollow, and these two items are placed end to end to form the egg capsule. When preparing an egglofter for flight, the egg and necessary padding are placed in the capsule, and then the nose cone and reducing section are taped together to secure the egg within the rocket. This is the standard design of almost all egglofters.

In selecting the designs for the egglofters to be tested, only the shape of the egglofter body was varied; all other factors were kept as constant as possible. All egglofters had the same length (12½"), and the same maximum diameter (1.81"). The models used the same nose cone (the front half of a CMR egg capsule) and the same body tube (CMR RB-77, diameter = .78"). The body tubes of the models and the balsa reducing section of the Wine Bottle model were finished in order to remove all traces of grain and spirals. All nose cones and reducing sections were taped together with a single layer of ½" wide masking tape (.003" thick).

The main item that was changed between models was the shape and length of the reducing section. The body tube length was also varied for each model in order to keep the overall length equal to 12½" and to keep the dynamic stability of each model approximately the same. Three different designs were built and tested: 1) a Kuhn Capsule model, 2) a Wine Bottle model, and 3) a Humpty Dumpty model. Below is a description of each model:

1) Kuhn Capsule. The name of this model is descended from the person who popularized the design, Mr. Howard Kuhn. This model is by far the most popular egglofter used in competition today. The design uses a parabolic plastic cone for the nose and the same cone reversed for the reducing section. A mating section is attached to the rear of the reducing cone so that it will fit a body tube.

The advantages of this model is that it has a low structural mass and is also easy to build. Also, as both the nose cone and reducing section are made of plastic, no finishing is necessary to obtain a smooth surface. However, the design may have some disadvantages. The large amount of curvature of the reducer may tend to cause the flow to separate and increase the drag coefficient. In actual flying, this does not seem to be the case as the design consistantly wins at egglofting contests. It does have a relatively small amount of wetted surface area, so perhaps this factor plays a large role in determining the drag of a model.

2) Wine Bottle. The reducing section of this model bears a resemblance to the neck of a wine bottle, and thus the model derives its name. Actually, the reducing section of this model was originally patterned after some of the NACA laminar-flow airfoils and spindles. It was hoped that by using this type of body, the air flow could be kept attached and laminar, thus reducing the drag of the model.

There are a few disadvantages to this type of model. The laminar reducing section is a complex shape and must be scratch-built. This also means having to finish the surface of the section in order to make it smooth. Finally, this method of construction is somewhat heavier than that of the Kuhn Capsule or Humpty Dumpty. However, if the design is effective in keeping the flow attached and laminar, the reduction of drag would make the extra work and weight worthwhile.

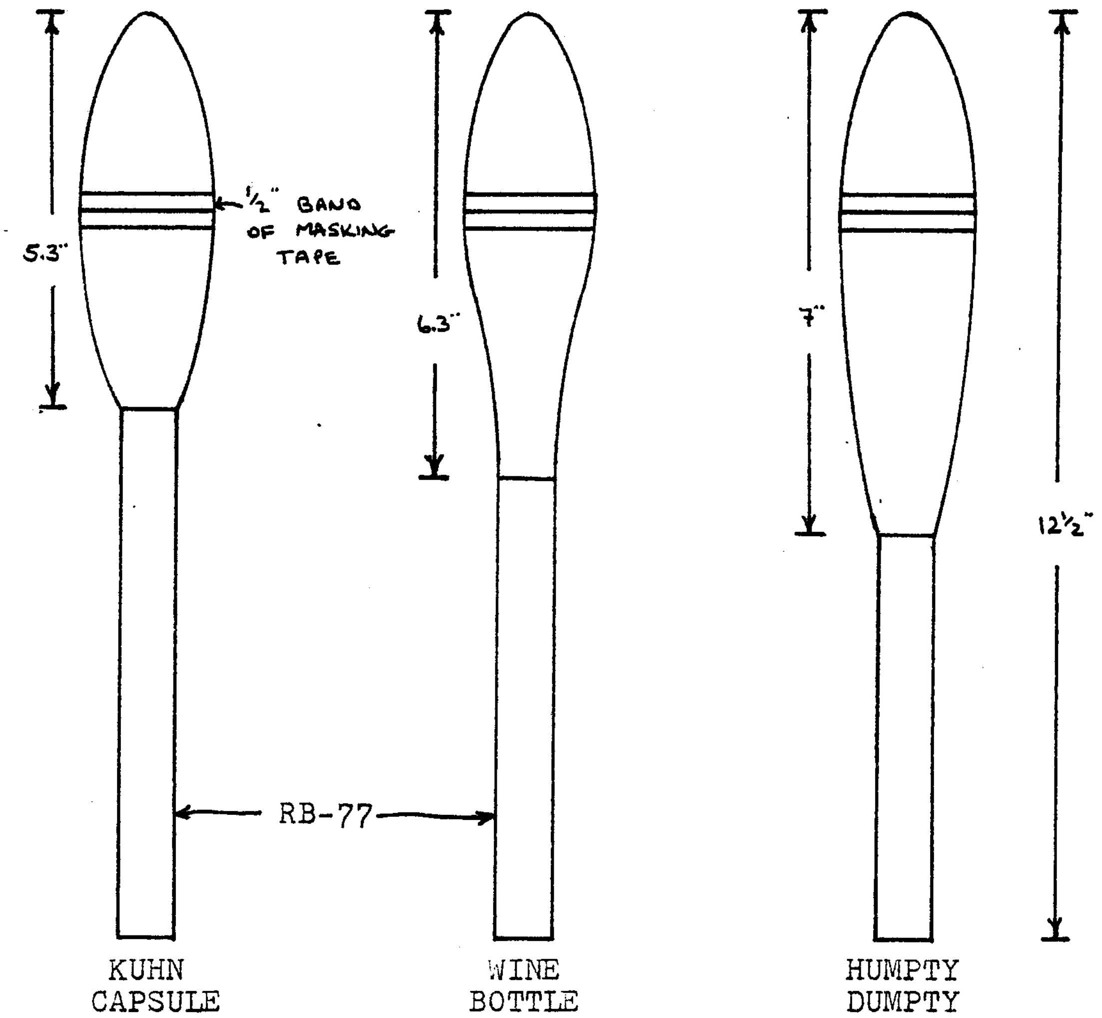


FIGURE 1

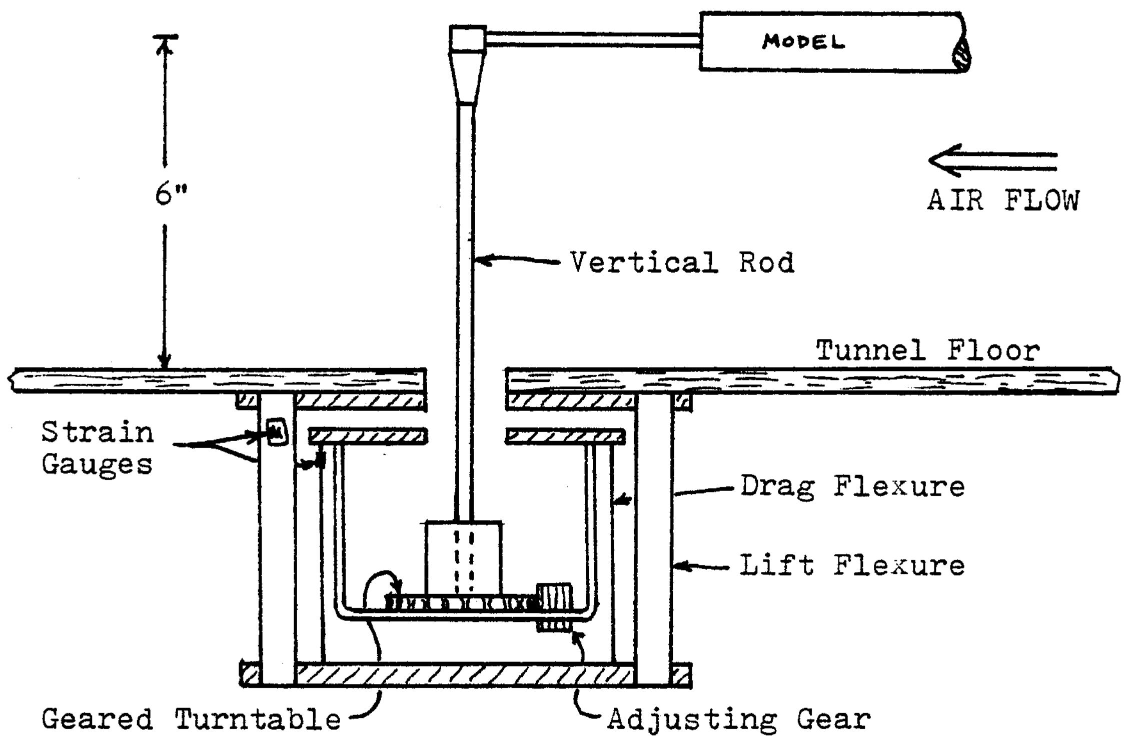


FIGURE 2

On the model tested in this project, the reducing section was turned on a wood lathe from a block of balsa wood. The section was then finished to give it a surface smoothness comparable to that of a plastic nose cone.

3) Humpty Dumpty. When CMR developed the Humpty Dumpty kit, it was originally designed to be a two stage, ultra-small egglofter. However, many people thought that it would make a nice egg capsule to be placed on a regular egglofter.

This model uses a Kuhn Capsule nose cone, and, for the reducing section, it uses a truncated 5:1 plastic ogive. This reducing section has a lower degree of curvature than the Kuhn Capsule model.

After the models were built, they were tested a number of times in a wind tunnel. The testing procedures and apparatus are described in the next section.

TESTING PROCEDURES AND APPARATUS

All testing was conducted in the Building 17A wind tunnel of the MIT Department of Aeronautics and Astronautics. This wind tunnel is an open return design and has a contraction ratio of 16:1. The test section of the tunnel measures 12" x 12", and the maximum velocity through the test section is slightly over 150 ft/sec.

The velocity through the test section was determined by measuring the difference of the static pressure between the settling chamber and the test section of the tunnel. This pressure difference was measured with an alcohol vernier manometer which was accurate to .01". If the pressure difference between the two sections is known, then by using Bernoulli's equation, the velocity through the test section can be calculated. All testing was conducted at a velocity of 100 ± 5 ft/sec, which is the approximate average velocity of a typical Robin Egglofter[1]. As the vehicles were 12½" long, the Reynolds Number of the flow around the model would be on the order of 640,000.

The models were mounted on a 3/16" diameter sting in the center of the test section, and the sting was held in place by a vertical rod. As the sting was of small diameter and located directly in the wake of the model, it was felt that this would not seriously affect the drag measurements. An airfoil-shaped windshield was placed around the vertical rod in order to reduce the tare drag of the system (the tare drag is the amount of drag caused directly or indirectly by the mounting system). The vertical rod passed through a hole in the floor of the tunnel and was mounted on the wind tunnel balance. A drawing of the mounting system and balance is shown in Figure 2.

The balance consisted of a platform mounted on independent sets of .015" steel flexures. Strain gauges were mounted on the flexures to measure the strain induced in the flexures by the drag and lift forces of the model. The two sets of strain gauges are connected to a BLH Corp. Switching and Balancing unit, which is used to select the flexure to be measured

[1]Chris Flanigan, "Methods to Optimise Egglofters", Journal of the MIT Rocket Society, January 1974, pp 9-11

and to set the zero point of the strain output. The signal from the Switching and Balancing unit is sent to a BLH Corp. Strain Indication unit which, for a given gauge factor, will determine the strain in micro-inches per inch of the gauge mounted on the flexure. The Strain Indicator unit will give readings accurate to ±1 micro-inch/inch.

The angle of attack of the model was set by means of a geared turntable mounted on the platform of the balance. The vertical rod was clamped to the turntable, and the turntable could be rotated by adjusting a small, lockable gear mounted on the bottom of the platform. The zero angle of the system was determined by making the distance between the sting and the tunnel wall constant at all locations along the sting, and, while the tunnel was running, by obtaining the zero lift angle of the model. These two measurement methods gave the same readings for the zero angle of attack.

The tare drag of the system was determined by the method of images. An airfoil identical to the airfoil around the vertical rod was mounted to the ceiling of the tunnel, and a small rod end connector was attached to the top of the vertical rod. The image system is shown in Figure 3. With the exception of the sting, this system will double both the drag of the mounting system and the intergerence drag between the mounting system and the model. By knowing what the drag of the system is with and without the image items in place, the tare drag of the system can be measured, and by subtracting the tare drag from the drag of the system without the image items, the drag of the model can be calculated as though there were no mounting system at all. This would be the free-stream drag of the model.

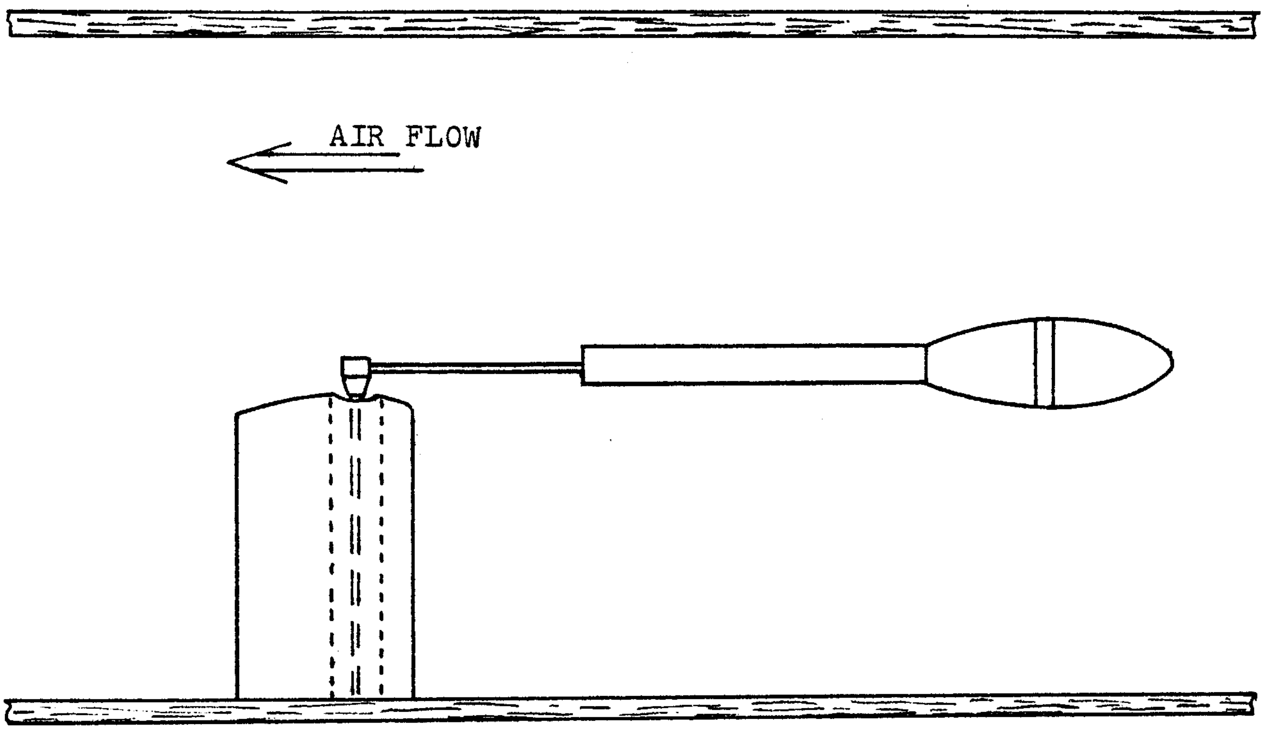
Each of the models was tested at least ten times. The testing procedure is outlined below:

1) The sting is placed at its zero angle of attack location and the model is mounted on the sting. The strain indicator is set to zero.
2) The wind tunnel is started, and the flow is allowed to stabilize at a velocity of 100 ft/sec.
3) The strain of the drag flexure is measured at α (angle of attack) = 0 to 10 degrees. The sting is then reset to $\alpha = 0$ to see if the strain returns to its original amount.
4) The tunnel is shut down, and the image units are inserted. the tunnel is restarted and allowed to stabilize.
5) The drag is measured at $\alpha = 0$ with the image units in place.
6) The tunnel is shut down again. The strain indicator is checked to make sure it returns to zero.

The data obtained from the testing is presented in the next section.

DATA

Each of the three models was tested at least ten separate times; the Kuhn Capsule and Wine Bottle models were tested eleven times each, and the Humpty Dumpty model was tested ten times. The drag reading for $\alpha = 0$ to 10 degrees was recorded for each run, and, after the data was collected, the information



MODEL SET UP FOR NORMAL DRAG MEASUREMENTS

MODEL SET UP WITH TARE UNITS IN PLACE

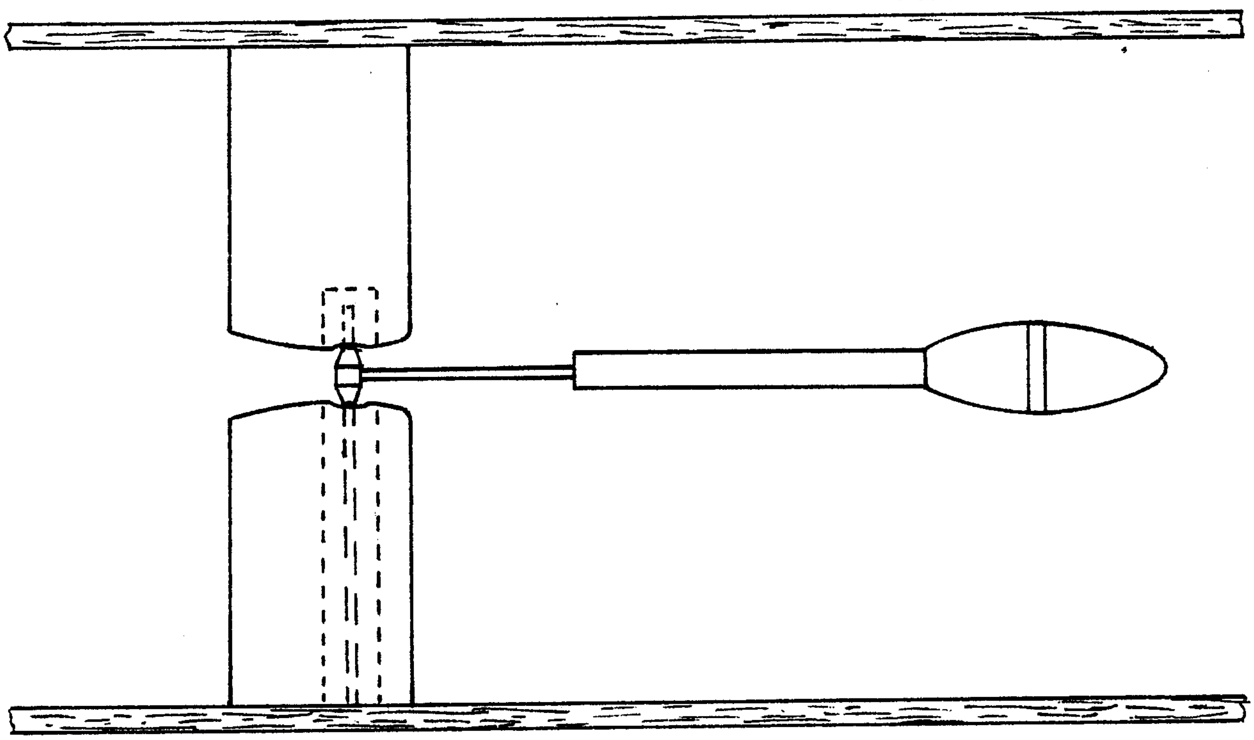


FIGURE 3

was statistically analyzed. Any run which was more than two standard deviations from the mean was eliminated, and two runs of the Wine Bottle model had to be eliminated for this reason. Efforts were made to correct the data for solid blocking and wake blocking effects, but these effects were found to cause less than 1% change in the results, and the corrections were neglected. The results of the testings for the models are given below:

		0	1	2	3	4	5	6	7	8	9	10
KUHN CAPSULE	Force (grams)	8.23	8.23	8.25	8.67	9.18	9.50	9.67	9.90	10.31	10.89	11.72
	σ_M	.17	.16	.15	.16	.16	.13	.14	.16	.16	.16	.15
	C_d	.085	.085	.085	.089	.095	.098	.100	.102	.106	.112	.121
WINE BOTTLE	Force (grams)	7.45	7.64	7.70	8.10	8.64	8.92	9.23	9.45	9.97	10.56	11.13
	σ_M	.23	.24	.25	.23	.27	.23	.23	.21	.21	.22	.18
	C_d	.078	.079	.079	.083	.089	.092	.095	.097	.103	.109	.115
HUMPTY DUMPTY	Force (grams)	6.83	6.48	6.53	7.02	7.55	7.92	8.26	8.60	9.09	9.78	10.64
	σ_M	.17	.15	.22	.24	.23	.28	.22	.22	.21	.21	.24
	C_d	.070	.067	.067	.072	.078	.082	.085	.089	.094	.100	.106

σ_M = standard deviation of the mean

(Note: for ease in getting an understanding of the amount of forces involved, all force measurements are given in grams instead of dynes or newtons.)

The above data is presented in chart form in Figure 4. The information gathered from all of the testing is listed in full in Appendix 1.

As can be seen from the data, the Humpty Dumpty model had the lowest drag coefficient followed by the Wine Bottle and Kuhn Capsule models respectively. This data will be analyzed in the next section.

ANALYSIS OF DATA

When analyzing the data from these tests, the most important thing to realize is that it was gathered at a Reynolds Number of 640,000, whereas an egglofter's Reynolds Number varies from 0 at ignition to nearly 1,500,000 at burnout velocity. Thus this data is truly representative of only part of the egglofter's flight. However, it is very instructive to look closely at the data.

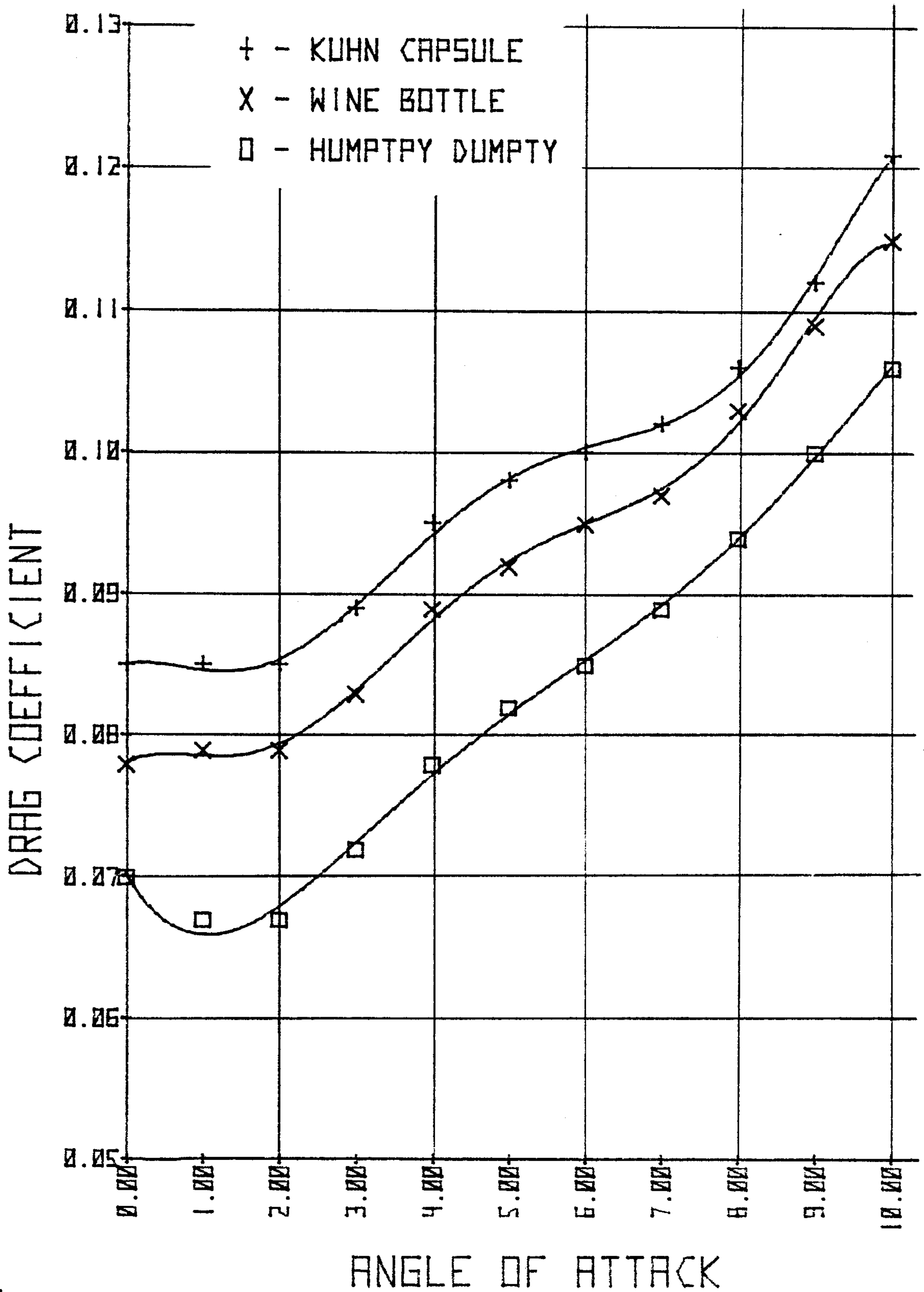

+ - KUHN CAPSULE
X - WINE BOTTLE
□ - HUMPTPY DUMPTY
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
DRAG COEFFICIENT
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
ANGLE OF ATTACK

FIGURE 4

The first thing to notice is that the drag coefficients of the bodies is substantially lower than that observed from actual models, which have C_d's of around .3. This is to be expected as there are no fins on the bodies. However, preliminary tests of finned vehicles have shown drag coefficients of around .15 to .2, which is still substantially lower than the commonly accepted C_d for an egglofter. Thus, something is happening at some other speed which increases the drag of the model. It is hoped that future tests will determine the cause of this drag increase.

The second thing to notice is that the difference between the drag coefficients of the Humpty Dumpty and the Kuhn Capsule is only .015. This small change in drag coefficient would have little effect on the altitude achieved by the model, probably less than five meters difference[2]. This increase in altitude could be easily eliminated by the heavier weight of a Humpty Dumpty capsule; with the padding included, a Humpty Dumpty capsule weighs 15 grams, whereas a Kuhn Capsule weighs only 13 grams. For a Robin Egglofter, a change in weight of two grams would cause a change in altitude of about four meters[3]. Thus, based on this report's drag data, the Humpty Dumpty would have no advantage over a Kuhn Capsule. The Wine Bottle, which weighs nearly 20 grams, would be at a definite disadvantage.

The most difficult thing to determine is why each model behaves as it does. Tests conducted by Guppy on a clamshell-type egg capsule of a design similar to a Wine Bottle has shown that separation of the boundary layer occurs at the high point of the capsule if there is no layer of tape there, but if a strip of tape is there, the boundary layer stays attached, although it probably transitions into turbulent flow. One can reasonably assume that on the three tests models, there is laminar flow over the nose of the vehicle and that it transitions into turbulent flow at the tape joint of the capsule.

In turbulent attached boundary layer flow, the skin friction drag of a model increases greatly, and thus the amount of wetted surface area of the model is extremely important. The model with the least wetted surface area,in this the Kuhn Capsule design, should have a lower C_d than a model with a larger amount of wetted surface area, such as a Humpty Dumpty. However, the data indicates the reverse is true. Therefor, one could guess that the boundary layer, even though it is turbulent, probably separates somewhere on the reducing section of the models. The Humpty Dumpty's reducing section has the least severe degree of curvature tested, followed by the Wine Bottle and then the Kuhn Capsule. It should be noted that this is the order of the lowest drag coefficients; so, at least in this Reynolds Number region, the reducing section plays a very important role in the overall drag of the model. However, if one carries this thought to an extreme, the model should be a long teardrop shape with a very small degree of curvature. Competition experience has shown that this type of model doesn't

[2] Ibid.

[3] Ibid.

perform as well as the standard egglofters, although the cause of this poor performance could be that the teardrop models are much heavier than the standard models.

Another possible way to make a low drag egglofter design is to take advantage of the fact that there is laminar flow over the nose of the model. If the flow could be kept laminar over a large amount of the vehicle, the drag coefficient might be substantially reduced. This might be done by placing the highpoint of the nose at about 50 to 60% of the vehicle's length. If the flow could be kept laminar all the way back to the 60% line and then kept turbulent and attached over the remainder of the model, the model should have a very low drag coefficient. Future tests will show whether or not this is possible.

Tests planned for the future include the testing of a number of other designs, such as the 60% highpoint model and a full-length teardrop model. Also, all of the designs will be run at various speeds ranging from 25 to 150 ft/sec. This data should give a complete record of the drag coefficient of the egglofter as a function of velocity and would enable one to select the best overall design. Finally, it would be nice to know if there is an optimum value of the tradeoff between the length of the nose and the severity of the taper of the reducing section. The longer the nose is, the more laminar flow there will be; however, a long nose implies a short reducing section with a high degree of taper which has been shown to be a cause of high drag coefficients. Perhaps there is an optimum combination of nose and reducer lengths.

CONCLUSIONS

Three designs of egglofter bodies (a Kuhn Capsule, a Wine Bottle, and a Humpty Dumpty model) were tested at a Reynolds Number of 640,000. It was determined that the Humpty Dumpty had the lowest drag coefficient of the three, but the difference between the three drag coefficients was very small. When viewed along with the weights of the three models, it is doubtful if either the Humpty Dumpty or the Kuhn Capsule has an advantage over the other, and, because of the weight of the design, the Wine Bottle would be the worst of the three models.

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A WIND TUNNEL INVESTIGATION OF THREE EGGLOFTER BODY DESIGNS

REVIEW

This project approached the problems of experimental error very well, and, with the redundant data, the conclusions are believable. Notice that while the difference between the drag coefficients of the models is small, the error margins for the figures are extremely small, and thus the measurements are reliable.

As the author pointed out, the drag of egglofter bodies is highly dependent on boundary layer behavior - that is, where the flow is laminar, turbulent, and separated. For this reason, velocity effects are very important, and more velocity data is needed to make adequate general conclusions. Wind tunnel turbulence is also very important when flight velocities are considered. A similar study using some sort of boundary layer detection technique (such as oil flow) would be valuable and easy to perform. For more information on the subject of boundary layer detection, see the NARTS report TER-2 "Flow Visualization Techniques" and also the article "Oil Flow Visualization Applied to Model Rocketry" in the September, 1974 MODEL ROCKETEER.

The "Wine Bottle" shape should not be rejected on the basis of weight. Could it be produced by a vacuum form process similar to the other two shapes? It may also be possible to manufacture the "Wine Bottle shape with lightweight fiberglass which is very strong and yet weighs no more than the plastic used in the CMR egg capsules.

The drop in the drag curve at low angles of attack for the Humpty Dumpty capsule is significant and interesting -- but inexplicable.