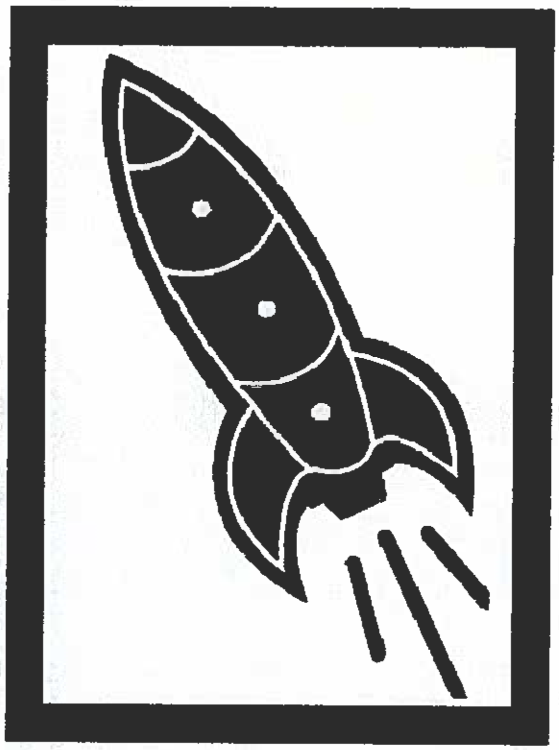
Colorado State University

Extension

MC1306A, Unit 6
Member's Manual



4-H Designer Model Rocketry

TO MEMBERS:

Welcome to unit 6 rocketry, a world that has no limits. In designing your own rockets you learn what model rocketry is all about, such as what limits you can go to and what slows a rocket down.

REVIEW OF UNIT 5

Some areas of discussion in unit 5:

- rocket stability
- how to build a wind tunnel
- aerial photography
- rocketronics
- why you need cluster rockets
- glossary of terms
- what kits to build
- completion of the unit
- bill of materials for wind tunnel
- assembly instructions
- stability using wind tunnel
- hand powered wind tunnel
- top and side views of tunnel
- calipers
- adaptable electronic kits available
- available CB transmit crystals and CB receiver crystals
- information and data on transroc
- non-rocketry uses of rocketronics
- engine arrangements for cluster rockets
- how to mount engines for clustering
- what engines to use
- how to install igniters
- how to connect igniters properly

REQUIREMENTS TO BE COMPLETED

1. Answer all questions in this unit.
2. Complete the project record.
3. Design and build your own rockets (not a pre-assembled or purchased kit).
4. Exhibit your rocket and record book at the county fair with your design of the rocket.

TABLE OF CONTENTS

ADVENTURE XXI - WHY THE TECHNOLOGY OF SPACE AGE IS IMPORTANT

99. INTRODUCTION - The main reason for this adventure is to acquaint you with the importance of the technology through the space program prior to designing your own rocket. Several areas will be discussed such as the theory of flight, the modern history of jets and rockets and others.

100. FLIGHT IN THEORY - Start with the basic type of propulsion, the propeller-driven aircraft. How does the propeller work? How does it help raise the aircaft? An aircraft with propellers gets thrust from rotation, designed to create thrust in a forward direction by accelerating air rearward. It needs the support of airfoils to sustain it in flight. The principle of airfoils was discovered by Daniel Bernoulli, a Swiss mathematician. His principle states that when speed increases, the pressure decreases as measured at an angle of 90 degrees from which the velocity flows. Reverse the process and the pressure increases. Missiles and rockets theory of flight is based on Newton's Third Law of Motion as discussed in detail earlier in unit 4.

101. HISTORY OF JETS AND ROCKETS - In unit 2 there was a brief outline of the history of rocketry. Areas not covered before are included in this unit. By the 15th century, rockets were well known as the French and English developed several types. Francis Scott Key wrote: "Rockets red glare, bombs bursting in air;" so rocketry has a part in our national anthem. Approximately about 1846 Colonel A. Boxer successfully built and flew a two-stage rocket concept, igniting the second stage while in flight. A Romanian professor named Hermann Oberth discussed the advantages and disadvantages of space travel in his book, "The Rocket Into Interplanetary Space".

In the 1930s rocket engines were built by the American Rocket Society. The V1 used a pulsejet engine and the V2 used a rocket engine. The first manned flight by the U.S. was on a Redstone rocket piloted by Alan Shepard. The Mercury program used the Atlas rocket. The Saturn was used by the Apollo program. The Titan 2 was used during the Gemini 2 program.

102. TYPES OF POWER PLANTS - Aircraft reciprocating engines operate on the same principle as a lawnmower single-cylinder engine, except the aircraft engine has more cylinders and moving parts. Thus, it is more complex. One of the simplest jet engines is the ramjet. The best way to explain a ramjet is: the air is rammed in one end and forced out the other by the cylinder moving at a very high rate of speed. The difference between the pulsejet and the ramjet is the use of a grill-like structure and flaps. The flaps open to let air in, then fuel is sprayed and fuel and air are ignited. There are several other types of jet engine power plants such as the turbojet, turboprop and fan jet.

103. THE SYSTEMS OF ROCKET PROPULSION - There are two types of rocket propulsion systems: liquid and solid propellants. Liquid rockets are or were the most difficult to develop because they require exceptional engineering and manufacturing. In larger missiles the fuel and oxidizer tanks are the main structure of a rocket. Tank size will vary according to the propellant and fuel oxidizer ratio needed for maximum power efficiency. These liquid rockets are generally started by a gas generator. Some of the liquid propellants are hypergolic; they ignite

immediately upon contact in the thrust chamber. Solid propellants are a mixture of fuel and oxidizer joined by a binder in a solid state. They are mixed to obtain the desired physical and chemical characteristics.

Below are listed some of the advantages or characteristics that a solid propellant should possess.

1. easily manufactured
2. easily handled with safety
3. stable and easily stored
4. burns uniformly and ignites easily
5. burning surface can be easily maintained
6. will not absorb water vapor easily
7. smokeless and flashless

The burning rate is measured in inches per second. Most engines have a nozzle at the end of the propellant with the design contingent on the propellant used.

104. GUIDANCE SYSTEMS AND FLIGHT CONTROLS - Three areas of rotation are referred to as: yaw (right and left movement), pitch (up and down motion), and roll (as the name indicates, a rolling motion). Different ways of controlling these movements depend on the craft being used. The use of ailerons on an aircraft is for the roll movements, which are controlled by raising one aileron and lowering the other. Pitch is controlled by elevators. By lowering or raising the elevators the aircraft goes up and down. (The elevators are located on the tail section). Yaw control is done by a rudder which is turned right or left. By turning the rudder right, the nose goes left and the opposite if the rudder is turned left.

In a wingless aircraft, the yaw, roll and pitch are controlled by two methods. The first is to use a small nozzle called a Vernier rocket. It works the same way as a large rocket engine and is located to control all three movements. The second method is called gimbaling. A gimbal is a moveable nozzle used to change the three movements.

There are two types of guidance systems. The first is the inertial guidance which is generally preset or adjusted before the rocket is fired. The equipment used is normally gyroscopes and accelerometers which control the roll, yaw and pitch of the missile. A variation of the inertial system is the homing method. This method is guided by radiation, light, heat, etc., reflected by the target. The previous method is radio controlled and is generally tracked by use of radar to pinpoint the missile. The radio command system has a distinct advantage. The rocket's path can be changed at any time.

105. ABBREVIATIONS USED IN MISSILE SHOP TALK - The following terms have been used by all forms of the news media.

ABM	ANTI BALLISTIC MISSILE
ICBM	INTER CONTINENTAL BALLISTIC MISSILE
IRBM	INTER RANGE BALLISTIC MISSILE (TERM NO LONGER USED)
SSM	SURFACE TO SURFACE MISSILE
SAM	SURFACE TO AIR MISSILE
SUM	SURFACE TO UNDERWATER MISSILE
ASM	AIR TO SURFACE MISSILE
AAM	AIR TO AIR MISSILE
USM	UNDERWATER TO SURFACE MISSILE
UAM	UNDERWATER TO AIR MISSILE

There are letters which identify the branch of armed forces which use the missiles, such as "A" for Air Force, "N" for Navy and "G" for Army.

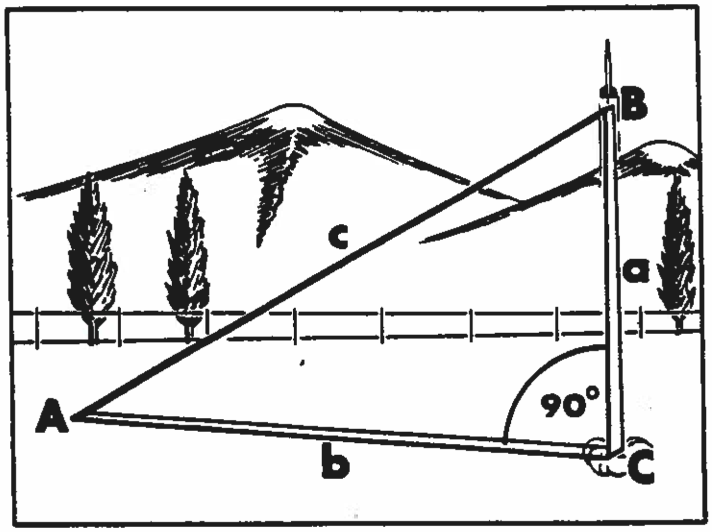
Please complete questions for Adventure XXI found on page 35.

ADVENTURE XXII - ESTIMATE YOUR ALTITUDE

106. SINGLE-STATION METHOD OF TRACKING - Single-station tracking is one of the simplest and most inaccurate systems used. The only way of measuring accurately is with optical equipment. This requires some knowledge of mathematics. The basics of this math can be applied by any rocketeer to help in tracking.

Two types of data needed to obtain altitude are angles and distances. In trigonometry, capital letters represent an angle and small case letters designate a side. Small "a" represents the side opposite angle A; same applies to "b" and "c". Two capital letters represent a distance. BC designates the relative distance from angle B to angle C, or side "a". (See Figure 1.)

Figure 1

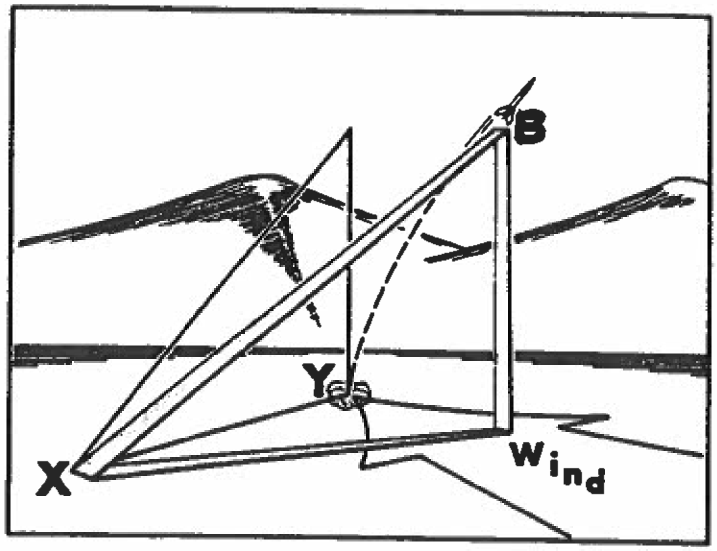


Courtesy of Estes Industries

When firing your rocket, A is found when you lock your scope at the peak altitude of the rocket. With only one tracker, you have the disadvantage of knowing only one side and angle and will not have enough information to solve the other sides and angles of the triangle. You must guess at the unknown angle or angles, and by this method only have an approximation of the height. When using only one tracker, it is a good idea to set up the station at a right angle to the wind. This is so the error rate is less than it could be.

If you track downwind or upwind you will get too much error in elevation readings due to the weather cocking of the rocket. However, the closer the rocket is to vertical, the more accurate the figures obtained. (See Figure 2.)

Figure 2



Courtesy of Estes Industries

The following method will be used by a single tracker. Assume that the rocket goes up vertically or near a vertical altitude. Call the angle C the right angle and work from there. (See figure 1.) In this case, angle B is equal to 90 degrees minus A (the sum of the angles in a triangle is 180 degrees, half of this or 90 degrees is taken by angle C).

Height of the rocket:

Base (distance from tracker to launcher) = 250 feet
Tan = (see table of sines and tangents)
$\angle A$ = 62 degrees

Height = (Tan $\angle A$)(Base) = 1.88 x 250 = 470 feet

You can substitute any distance (tracker to launcher), preferably 100 feet and above. A distance of 1000 feet is preferred because of more accurate reading, providing you have the room. Each .01 tangent is equal to 2.5 feet in height so if your tracking device is between two angles, you can divide by two or one-half the difference of tangent numbers and you will be fairly accurate. For example: if your angle is 63.5 degrees, the tangent would be .045 difference or a height of 501.25 feet. You can subtract the tangent heights 63 from 64 and divide by two and add to height of angle 63 and you will get the same results.

107. TWO-STATION WAY OF TRACKING - When using two-station tracking, a higher degree of accuracy is possible. When the azimuth angles are not used, the trackers must be on opposite sides of the launcher. It will depend on the wind whether they are north and south or east and west. They must be in line with the wind. They should be equal distances apart from the launcher. Here the sine will be used not the tangent.

ESTES SINES AND TANGENTS

ANGLE	SIN	TAN	ANGLE	SIN	TAN	ANGLE	SIN	TAN	ANGLE	SIN	TAN
1	.02	.02	19	.33	.34	37	.60	.75	55	.82	1.43
2	.03	.03	20	.34	.36	38	.62	.78	56	.83	1.48
3	.05	.05	21	.36	.38	39	.63	.81	57	.84	1.54
4	.07	.07	22	.37	.40	40	.64	.84	58	.85	1.60
5	.09	.09	23	.39	.42	41	.66	.87	59	.86	1.66
6	.10	.11	24	.41	.45	42	.67	.90	60	.87	1.73
7	.12	.12	25	.42	.47	43	.68	.93	61	.87	1.80
8	.14	.14	26	.44	.49	44	.69	.97	62	.88	1.88
9	.16	.16	27	.45	.51	45	.71	1.00	63	.89	1.96
10	.17	.18	28	.47	.53	46	.72	1.04	64	.90	2.05
11	.19	.19	29	.48	.55	47	.73	1.07	65	.91	2.14
12	.21	.21	30	.50	.58	48	.74	1.11	66	.91	2.25
13	.22	.23	31	.52	.60	49	.75	1.15	67	.92	2.36
14	.24	.25	32	.53	.62	50	.77	1.19	68	.93	2.48
15	.26	.27	33	.54	.65	51	.78	1.23	69	.93	2.61
16	.28	.29	34	.56	.67	52	.79	1.28	70	.94	2.75
17	.29	.31	35	.57	.70	53	.80	1.33	71	.95	2.90
18	.31	.32	36	.59	.73	54	.81	1.38	72	.95	3.08
73	.96	3.27	75	.97	3.73	77	.97	4.33	79	.98	5.14
74	.96	3.49	76	.97	4.01	78	.98	4.70	80	.98	5.67

If you want a more accurate reading, refer back to unit 2. The sine and tangent are rounded off for your convenience.

Please complete questions to Adventure XXII found on page 36.

ADVENTURE XXIII - STABLE DESIGNING IN ROCKETRY

108. METHOD OF DESIGNING - The first thing you should decide is the type of rocket and the parts you will be using in designing your rocket. Then start weighing each item for the purpose of your design. For now the fins will be ignored. Using the weights of all the items, find the center of gravity of the rocket. Determine the cross-sectional area of each item that will be exposed to the airflow: the nose cone that protrudes from the body tube; body tube; and the part of the engine that extends out of the end of the body tube. Now, you can calculate the center of pressure.

109. DESIGN WITH CENTER OF GRAVITY IN MIND - The center of gravity for a complete rocket is found by weighing each part accurately or by finding the center of gravity of each part and applying the principle of moments. For explanation of moments and cenroids, refer to the following books in your local library.

    1. Singer, Ferdinand L. Engineering Mechanics 2nd Edition, 1954 Chapter 7.

2. McLean, W.C., and Nelson, E.W. Theory and Problems of Engineering Mechanics Chapter 9.

A table should be made of all the weights and distances of the C/G's. The C/G's should be taken from a point starting at the tip of the nose cone. A chart should be set up for the items, weights, distances of C/G and weight times distance, as well as total.

Figure 3

ITEMS	WEIGHT	DISTANCE OF CG FROM THE REF. LINE	WEIGHT TIMES DISTANCE
NOSE CONE	W_1	D_1	$W_1 D_1$
PARACHUTE	W_2	D_2	$W_2 D_2$
ENGINE BLOCK	W_3	D_3	$W_3 D_3$
BODY TUBE	W_4	D_4	$W_4 D_4$
LOADED ENGINE	W_5	D_5	$W_5 D_5$
TOTAL, (Σ)	ΣW		ΣWD

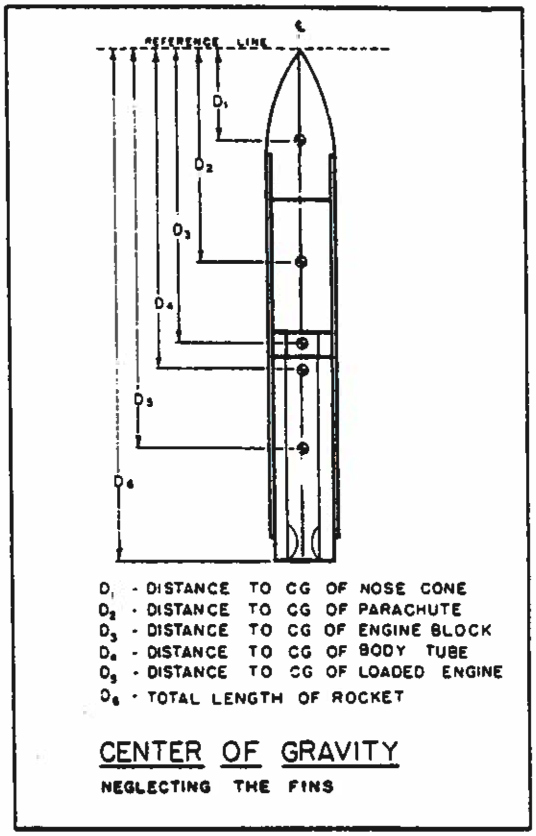
W - WEIGHT OF ITEM
D - DISTANCE OF ITEM CG FROM REFERENCE LINE
Σ - GREEK LETTER SIGMA, MEANING THE TOTAL

CENTER OF GRAVITY : (CG)

$$CG = \frac{\Sigma WD}{\Sigma W}$$

The weight and weight times distance column will each be added. The next item for consideration is the distance to each of the individual C/G's. This can be found by balancing each item on a knife edge, then measuring the balance point to the farthest forward point. (See Figure 4.)

Figure 4



Courtesy of Estes Industries

Taking the weight, multiply it times the distance and put it in column "Weight Times Distance". This will be done for each item. The total of all this is "moment summation" (WD). (Figure 2a.)

110. C/P AND THE NOSE CONE - Center of pressure is found by calculating the cross-sectional area of the parts of the rocket that will be exposed to the air stream while in flight. The part of the nose cone that is inserted in the body tube is not used in calculation. The body tube will be used in its entirety since its surface is exposed to the free-stream. The 1/4 to 1/2-inch that the engine protrudes from the body tube will also have to be counted. You will notice that the fins have not been considered. List the areas in the column under area, add these areas. (See Figure 5.)

Figure 5

ITEMS	AREA	DISTANCE OF CP FROM THE REF. LINE	AREA TIMES DISTANCE
NOSE CONE	A_1	D_1	$A_1 D_1$
BODY TUBE	A_2	D_2	$A_2 D_2$
ENGINE EXTENSION	A_3	D_3	$A_3 D_3$
TOTAL, (Σ)	ΣA		ΣAD

A - AREA OF ITEM

D - DISTANCE OF ITEM CP FROM REFERENCE LINE

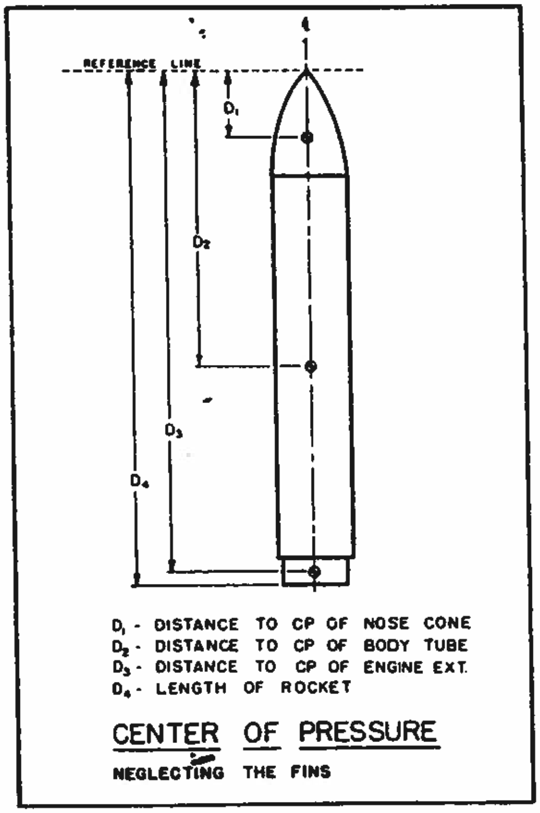
Σ - GREEK LETTER SIGMA, MEANING THE TOTAL

CENTER OF PRESSURE: (CP)

$$CP = \frac{\Sigma AD}{\Sigma A}$$

Next, determine the distance from the reference line to each C/P. Center of pressure of a rectangle (body tube cross-section) always lies half-way between its sides (1/2 of the length of the body tube). This distance is added to the exposed length of the nose cone. This gives the distance from reference line to C/P of the body. The exposed section of the engine is also a rectangle. (Its C/P is exactly 1/2 of the exposed length). These three areas are added up to give its C/P distance from the reference line. (See Figure 6.)

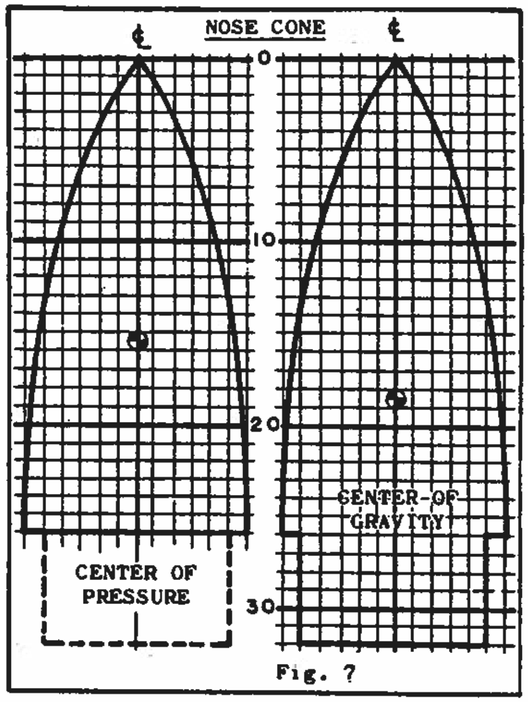
Figure 6



Courtesy of Estes Industries

The graph that shows the center of pressure shows only the area that will be exposed to the airstream while in flight. The other graph shows the entire nose cone, which is used to find the C/G. Each square is 1/5-inch wide and 1/5-inch long making each square 1/25th of a square inch. The cross-sectional area can be found by counting the total number of squares within the area and dividing by 25 to give the area in square inches. (See Figure 7.)

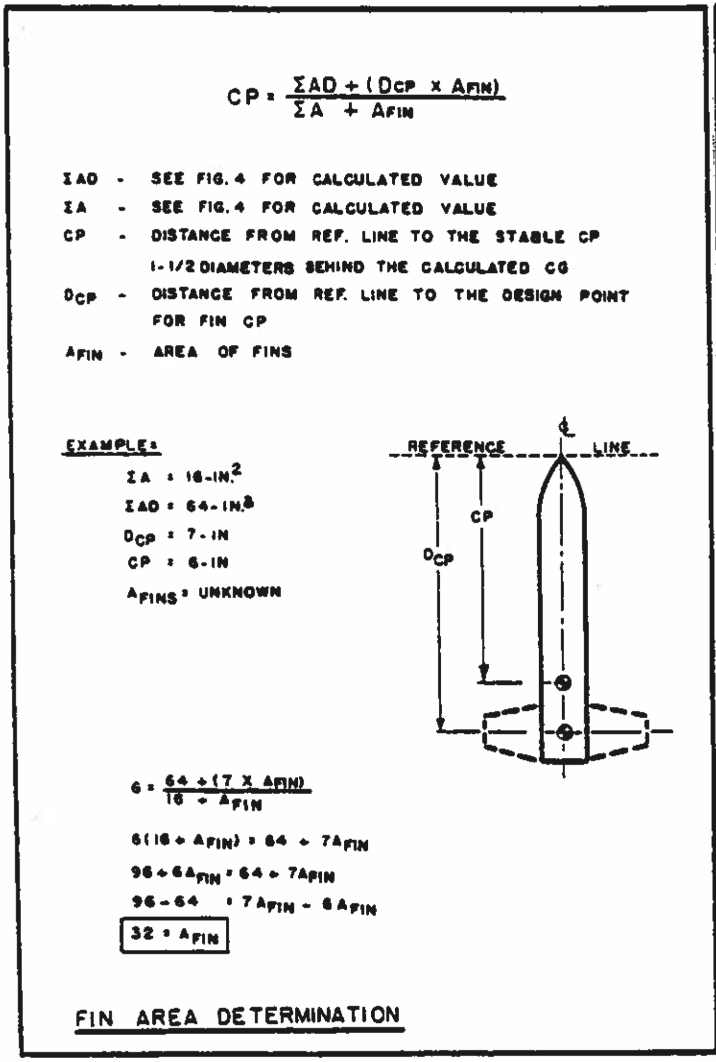
Figure 7

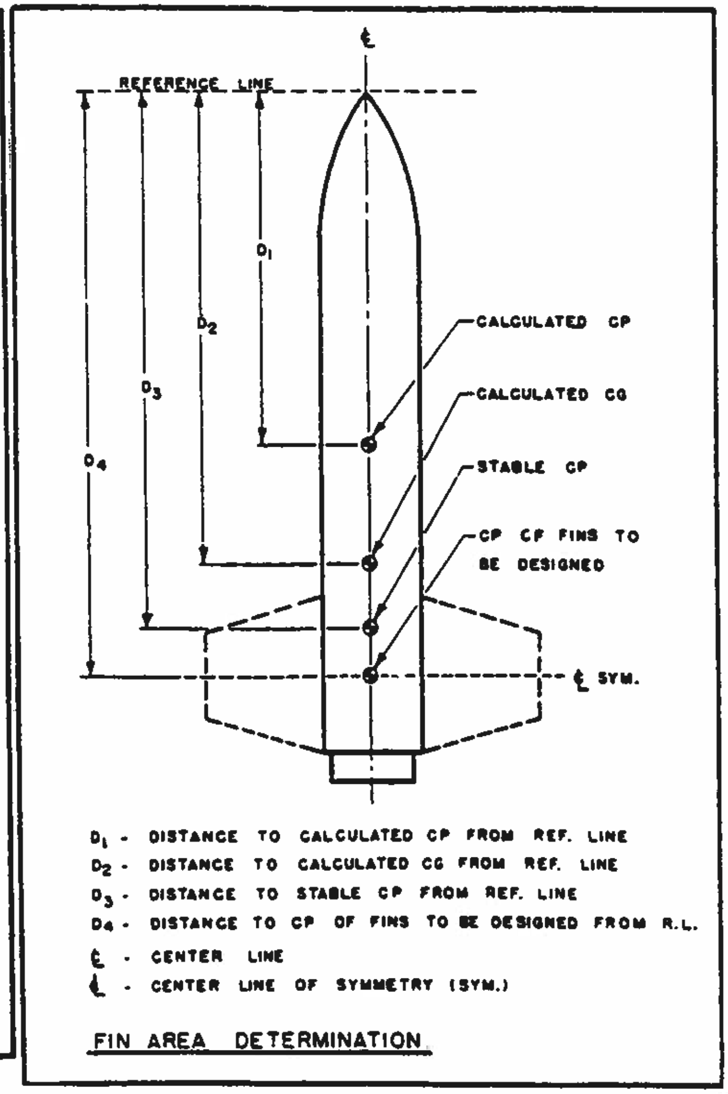


Courtesy of Estes Industries

111. DETERMINING THE FIN AREA - The next two figures will show and tell how to determine a rocket C/P with its fins on. Up to now, the rocket's C/P has been determined without its fins. (See Figures 8 and 9.)

Figures 8 and 9





Courtesy of Estes Industries

Figure 8 is used to determine the necessary cross-sectional area of the fin by use of the formula shown within the chart. The stable C/P is found 1 1/2 body diameter. Fins move the C/G rearward very slightly. The 1 1/2 body tube diameters should be sufficient to allow for this movement. If you design a four-finned rocket, you must divide the calculated area by two for the area of one fin. A three-fin rocket must be divided by 1.5 for the area of one fin. The final C/G is done in much the same way as in the chart for C/G, except you add the weight of the fins to the rest of the weights to get the WD summation and that is to be divided by W summation as was done before. Now you have achieved final C/G.

112. FIN DESIGN COMPUTATION - For fins that cannot be readily figured as previously mentioned, they can be figured in the same manner as a nose cone. The formula for a simple swept-back fin is as follows:

$$CP = \frac{\Sigma AD}{\Sigma A}$$

SIMPLE SWEPT BACK FINS

ITEM	AREA	CP DISTANCE FROM THE REFERENCE LINE	AREA TIMES DISTANCE
ABCD	(+) AB X BD	1/2 BD	(+)
ABE	(-) 1/2(ABXAE)	1/3 AE	(-)
CDF	(-) 1/2(CD)(DF)	BF + 2/3(DF)	(-)
	Σ A		Σ AD

The complex swept-back fins formula is more complex and will not be discussed.

Before you attempt the flight of your rocket, be sure and go over your calculations and make sure no mistakes have been made.

Please complete questions for Adventure XXIII found on page 37.

ADVENTURE XXIV - ALTITUDE DOES NOT HAVE TO BE A DRAG

113. WHAT IS DRAG? - Webster defines drag as it relates to an airplane or rocket as "the retarding force acting on a body moving through a fluid parallel and opposite to the direction of motion." Understanding the effects that drag has on a model rocket can help you understand why a rocket will only go so high. The first question you would probably have is, "Why does my rocket only go so high even with the largest recommended engine?" Take an example of a one-inch rocket with a speed of 100 feet per second. With the Loschmidts number (this tells the number of molecules in a cubic centimeter of gas under normal atmosphere) you can find the number of air molecules hitting or colliding with the rocket every second. When the rocket is traveling at 100 feet per second, it has to push its way through 4×10^{23} molecules. This is for each second of flight time. The drag force of the molecules can add up to a force of one ounce acting continuously at a speed of 100 feet per second. The effect of the molecules hitting a surface is commonly known as aerodynamic drag or plain "drag".

The rule or law of drag is as follows:

$$D = C_D A \rho V^2$$

D = the drag force
CD = a dimensionless aerodynamic drag coefficient that will depend on shape and smoothness of the surface of the rocket
A = the cross-sectional area of the body tube as the reference area for a model rocket
ρ (pronounced Row) = the density of the water, air, etc. through which the object is moving (the density symbol "ρ" is the greek letter Rho)
V = the velocity of the object

It is hoped that this adventure will give you a better understanding of the effects drag has on the rockets you design and build. The full effect of drag can be avoided by streamlining and having smooth surfaces on the rocket. CD is a measure of how easily a given shape moves through or passes by the molecules of air. (CD is also known as the aerodynamic drag coefficient.) The CD for the following items is as stated:

OBJECT	CD
cube (flat side)	1.05
sphere	.47
"clipped" teardrop (1/3 trailing edge removed)	.1
streamlined teardrop	.05

The frontal area of an object is referred to as the drag form factor (CDA). The following information will give you an idea of the effect streamlining has on drag.

For example, a one-inch cube moving with a flat side forward would have a **drag form factor** of 1.05 $inch^2$ (1.05 square inches). The data below provides additional examples to show the tremendous effect streamlining has on the drag of a body as reflected in the object's **drag form factor**. To provide easy comparisons, a **drag form factor** ($C_D A$) of 1.05 $inch^2$ has been selected.

Frontal Area of Object	x	Drag Coefficient	=	Drag Form Factor
A	x	C_D	=	$C_D A$
1 $inch^2$ cube	x	1.05	=	1.05 $inch^2$
2.23 $inch^2$ sphere	x	.47	=	1.05 $inch^2$
10.5 $inch^2$ clipped teardrop	x	.1	=	1.05 $inch^2$
21 $inch^2$ teardrop	x	.05	=	1.05 $inch^2$

The formula for ballistic coefficient is written :

$\beta = \frac{W}{C_D A}$ (β is the greek letter Beta).

β = ballistic coefficient
W = rocket weight
CDA = drag-form factor
A = frontal area (based on body tube cross-section area)

Ballistic coefficient is used by rifle designers to speed up a bullet or make the speed last longer. It is also used by aerospace engineers to help slow down a re-entry vehicle.

114. HOW TO USE GRAPHS - There are eight basic steps which are used in calculating the altitude which will be reached by a specific rocket and engine.

Step 1. Gathering information
   a. find frontal area of model rocket
   b. determine weight of rocket without engine
   c. determine weight of engine plus weight of propellant
Step 2. Determine drag-form factor (CDA) (See Figure 6)
Step 3. Calculate the ballistic coefficient during thrust
Step 4. Read burnout altitude (SB) and the burnout velocity (VB) from the appropriate graphs
Step 5. Calculate the new ballistic coefficient during coasting
Step 6. Read coasting altitude
Step 7. Altitude is determined by adding coasting altitude to the burnout altitude
Step 8. Determine coast time from chart and select engine with proper delay

115. GRAPHS FOR BURNOUT ALTITUDE AND VELOCITY - Charts or graphs here are selected at random.

116. COASTING GRAPHS - The graphs show altitude gained and time in seconds. (All of the following graphs are Courtesy of Estes Industries.)

The graph on page 16 shows the drag-form factors. By using the graphs, you can gain tremendous knowledge. These charts help you determine height, coasting time, weight factors and drag factors on the rocket you design. These graphs or charts can save tremendous time and energy because all or most of the math has been done for you.

Figure 10

Drag Form Factors

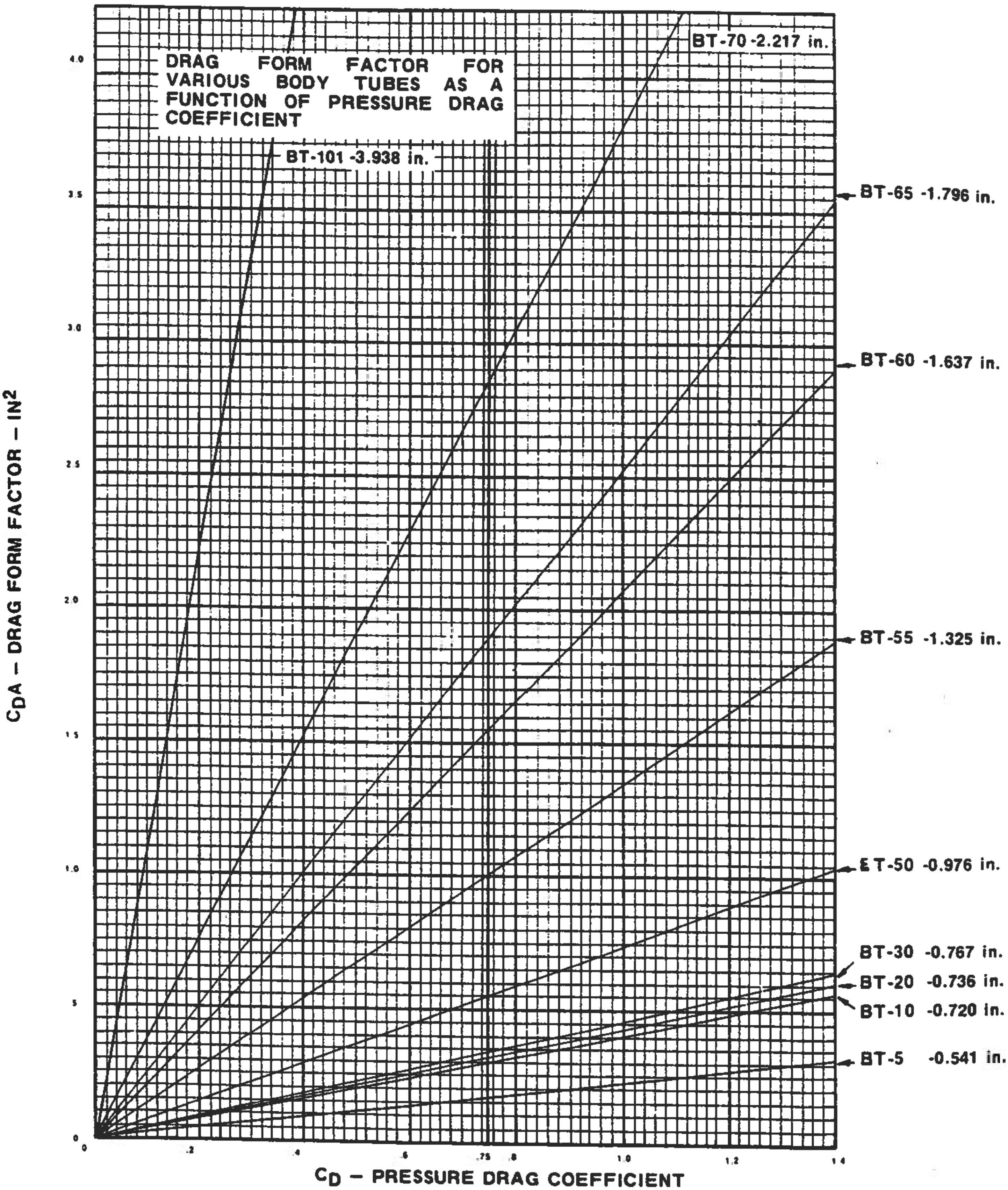


Figure 11

Burnout Altitude (S_B) as a function of Initial Weight (W_I) and Ballistic Coefficient (β_t).

1/4 A3
Burn Time t_b = .24 Sec.
Propellent Weight Wp = .0270 Oz.
1/2 Wp = .0135 Oz.
Average Thrust T = 9 Oz.

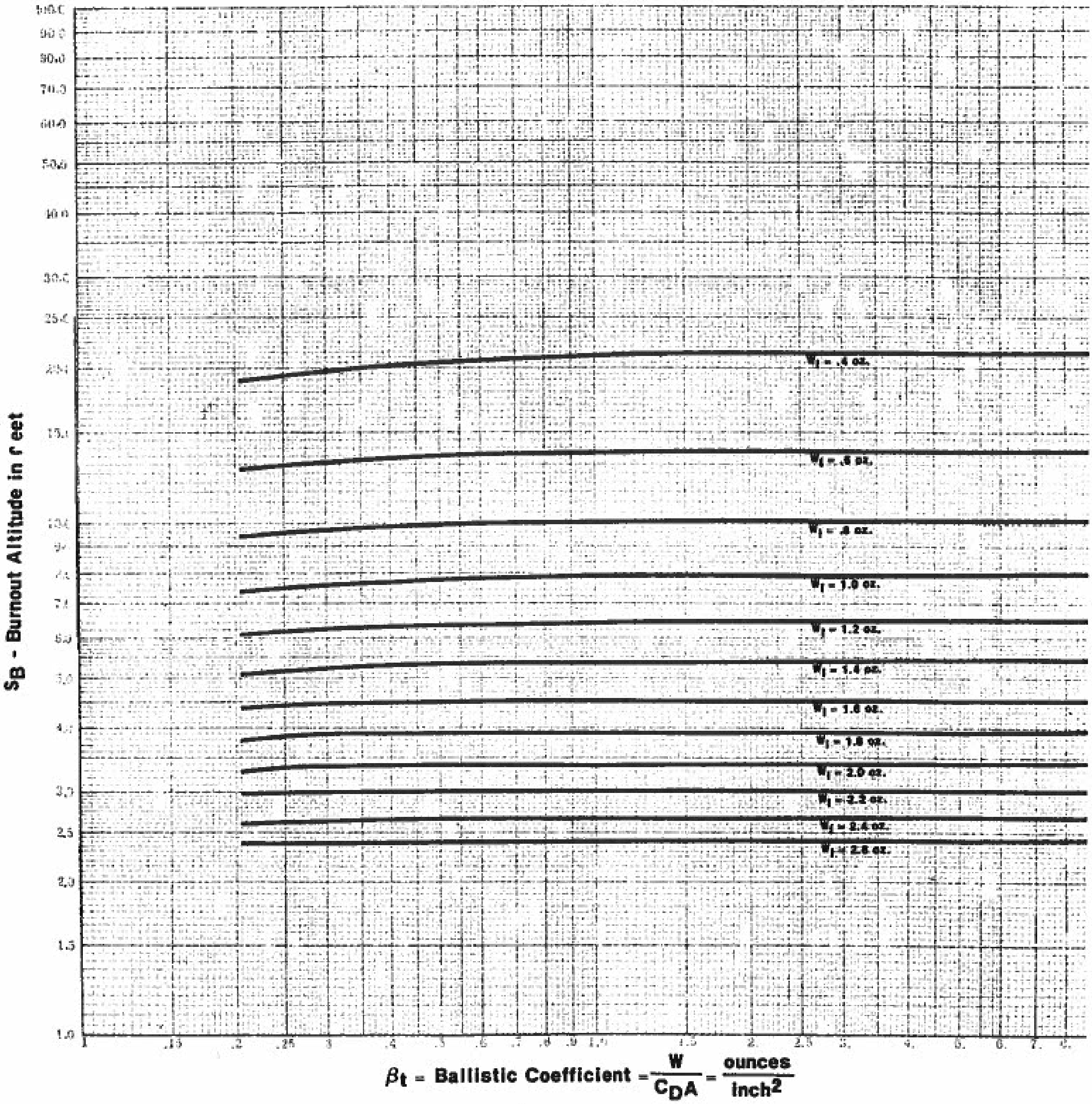
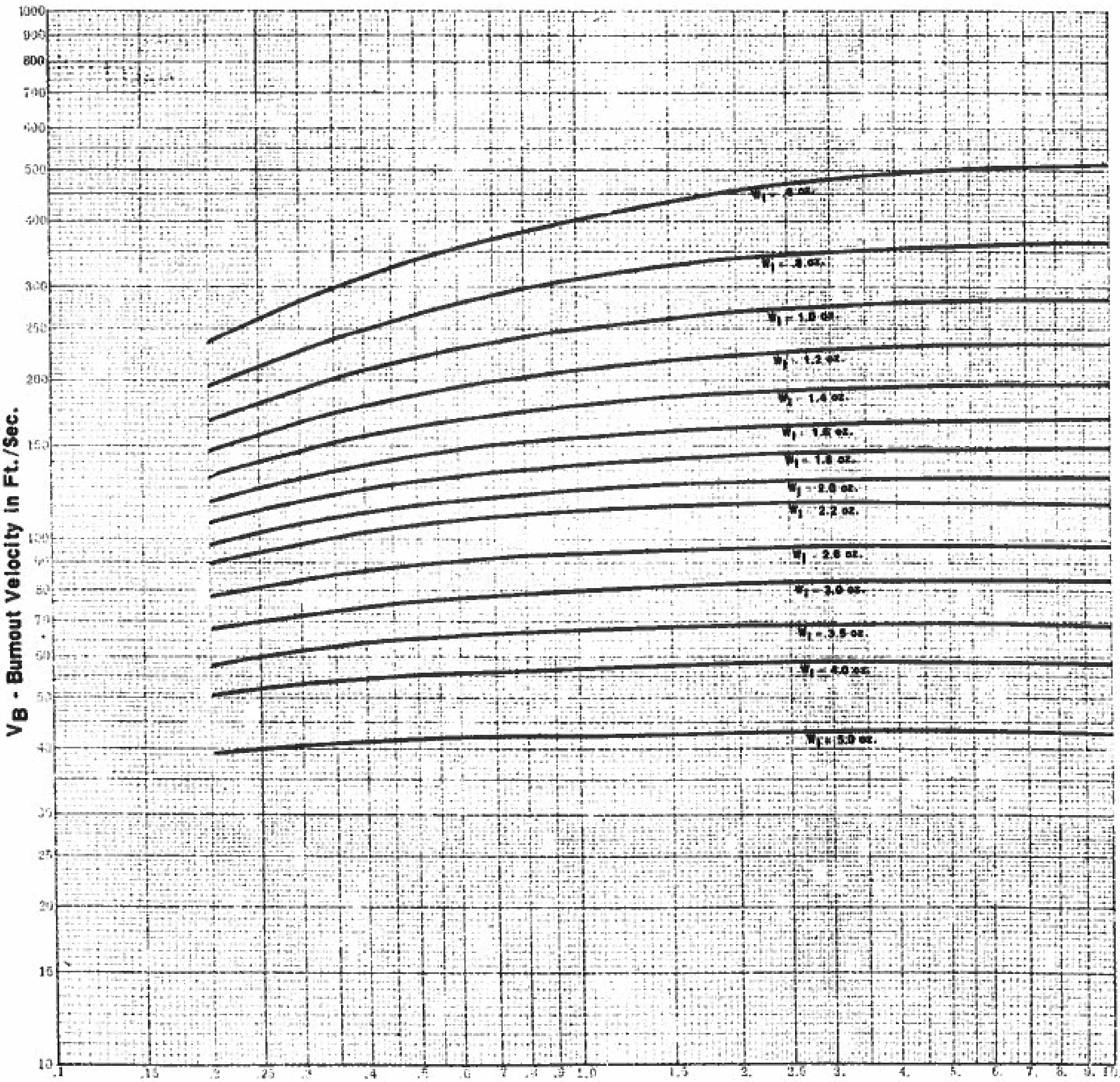


Figure 12

Burnout Velocity (V_B) as a function of Initial Weight (W_I) and Ballistic Coefficient (β_t).

A8
Burn Time t_b = .32 Sec.
Propellent Weight W_p = .110 Oz.
1/2 W_p = .055 Oz.
Average Thrust T = 28 Oz.

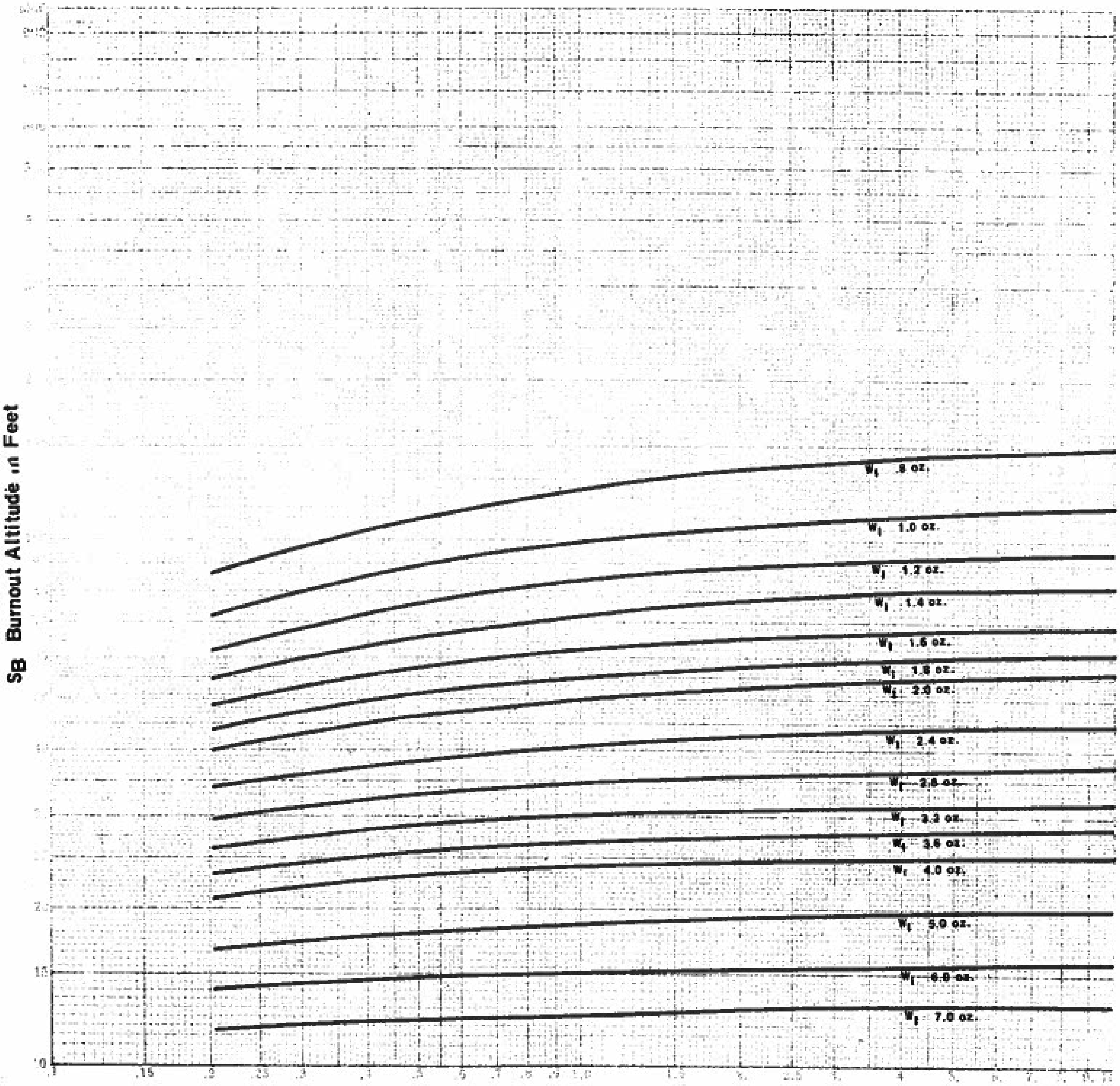


β_t = Ballistic Coefficient = $\frac{W}{C_D A}$ = $\frac{\text{ounces}}{\text{inch}^2}$

Figure 13

Burnout Altitude (S_B) as a function of Initial Weight (W_I) and Ballistic Coefficient (β_t).

B14
Burn Time t_b = .35 Sec.
Propellent Weight W_P = .220 Oz.
1/2 W_P = .110 Oz.
Average Thrust T = 51 Oz.



β_t = Ballistic Coefficient = $\frac{W}{C_D A} = \frac{\text{ounces}}{\text{inch}^2}$

Figure 14

Burnout Velocity (V_B) as a function of Initial Weight (W_i) and Ballistic Coefficient (β_t).

C6
Burn Time t_b = 1.7 Sec.
Propellent Weight W_p = .440 Oz.
1/2 W_p = .220 Oz.
Average Thrust T = 21 Oz.

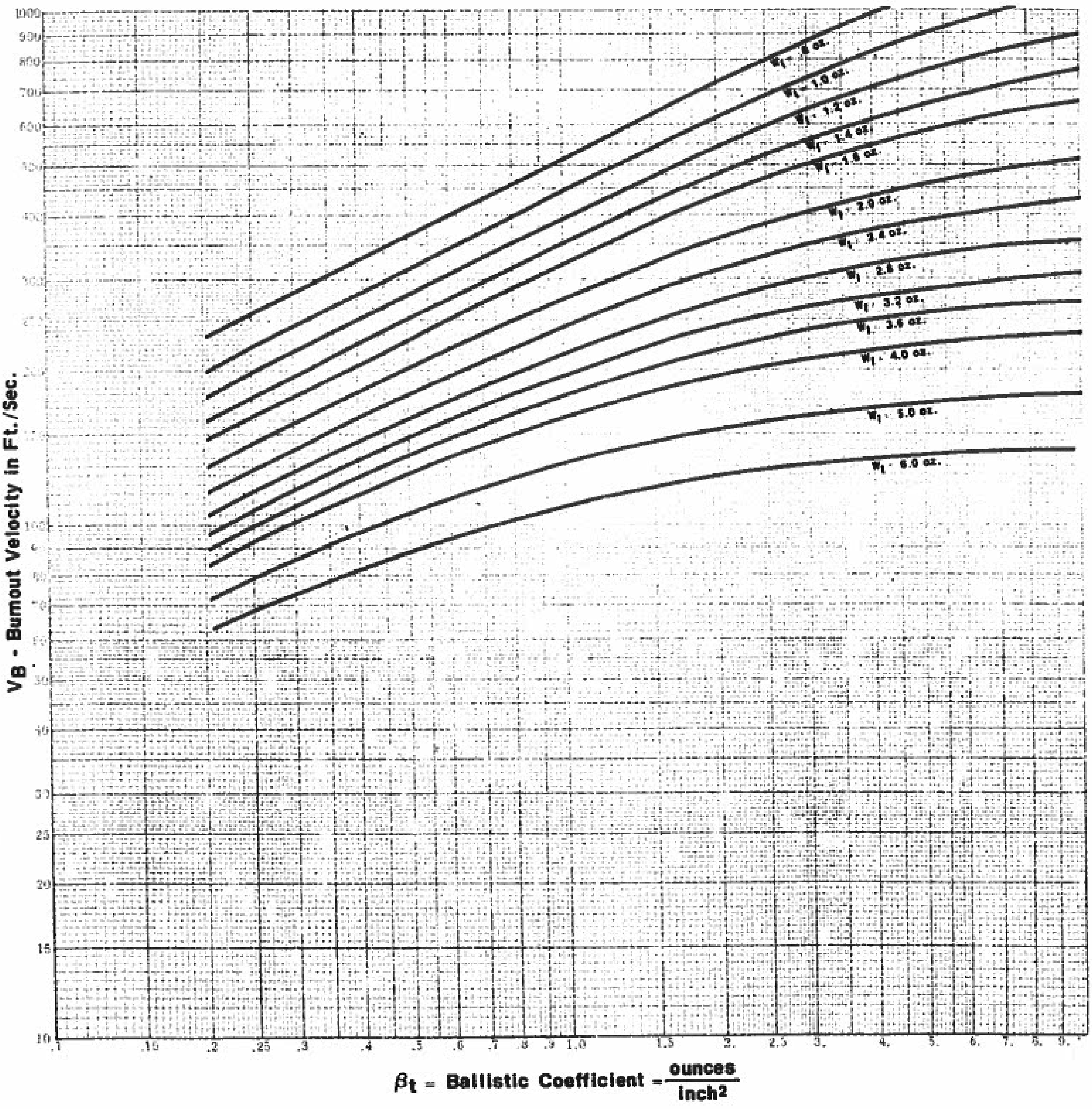
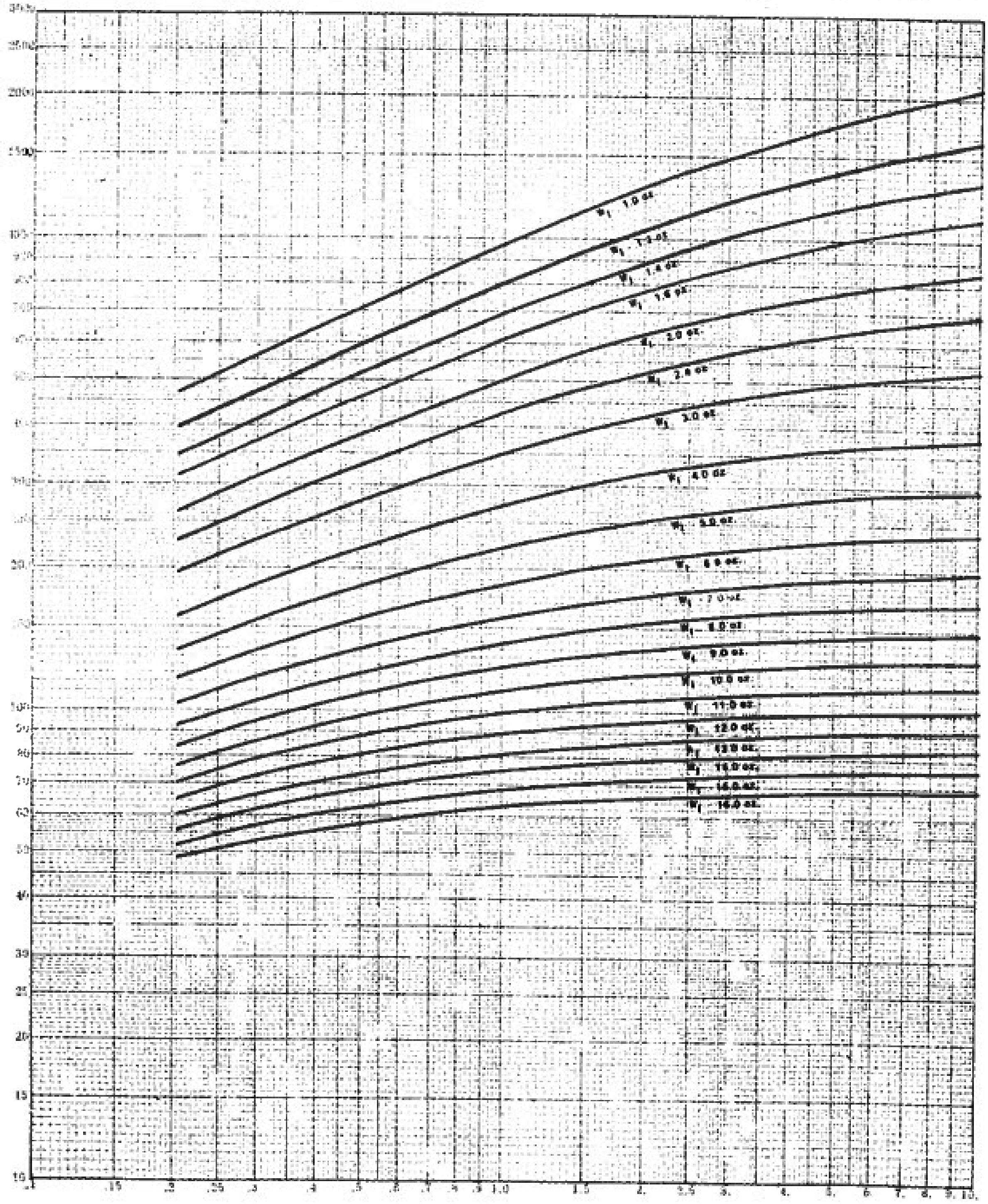


Figure 15

Burnout Altitude (S_B) as a function of Initial Weight (W_i) and Ballistic Coefficient (β_t).

D12
Burn Time t_b = 1.48 Sec.
Propellent Weight W_p = .879 Oz.
1/2 W_p = .4395 Oz.
Average Thrust T = 48 Oz.

S_B - Burnout Altitude in Feet

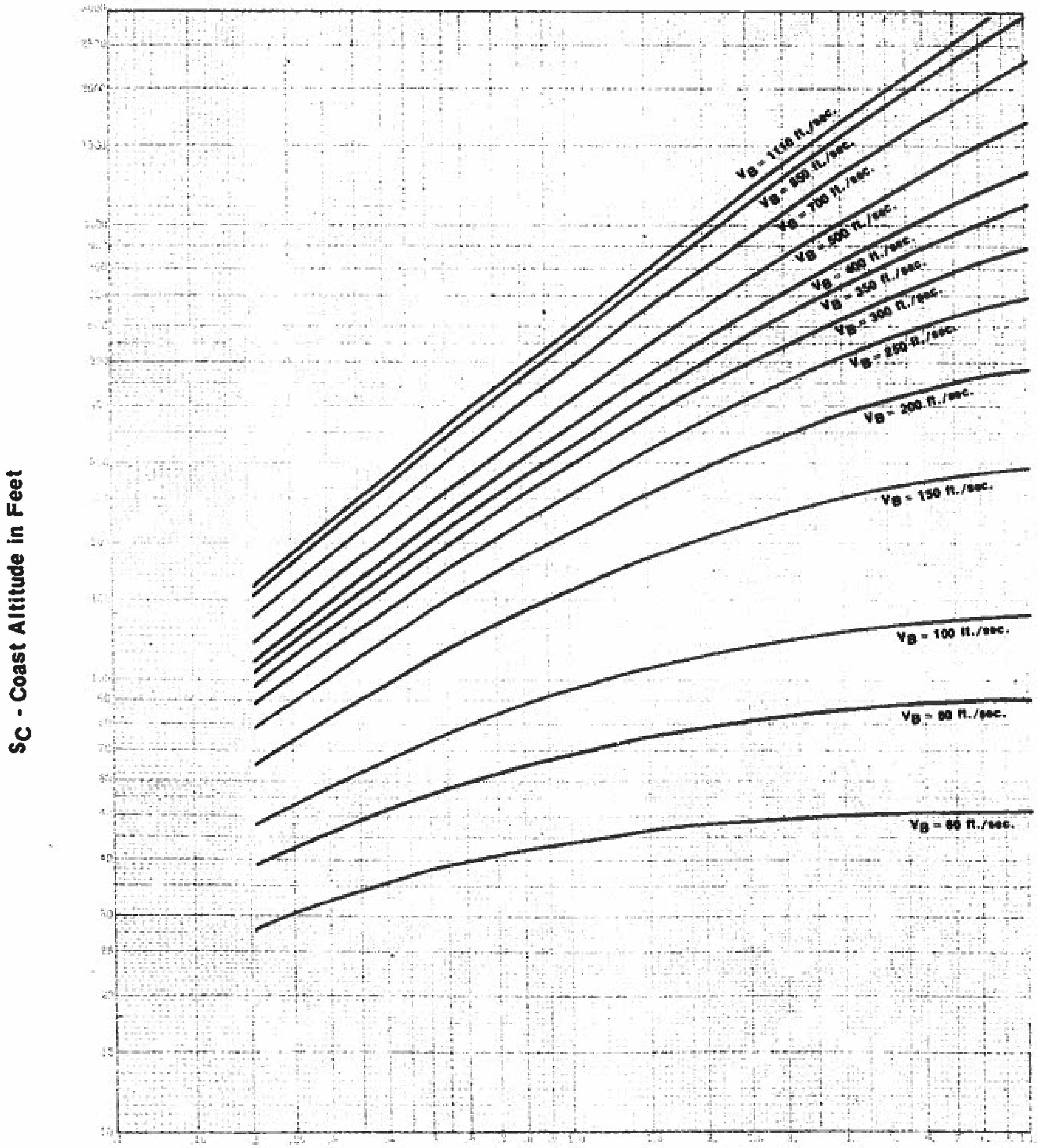


$$\beta_t = \text{Ballistic Coefficient} = \frac{W}{C_{DA}} = \frac{\text{ounces}}{\text{inch}^2}$$

Figure 16

COAST ALTITUDES

Altitude (S_C) Gained During Coast Phase as a function of Burnout Velocity (V_B) and Ballistic Coefficient (β_c).

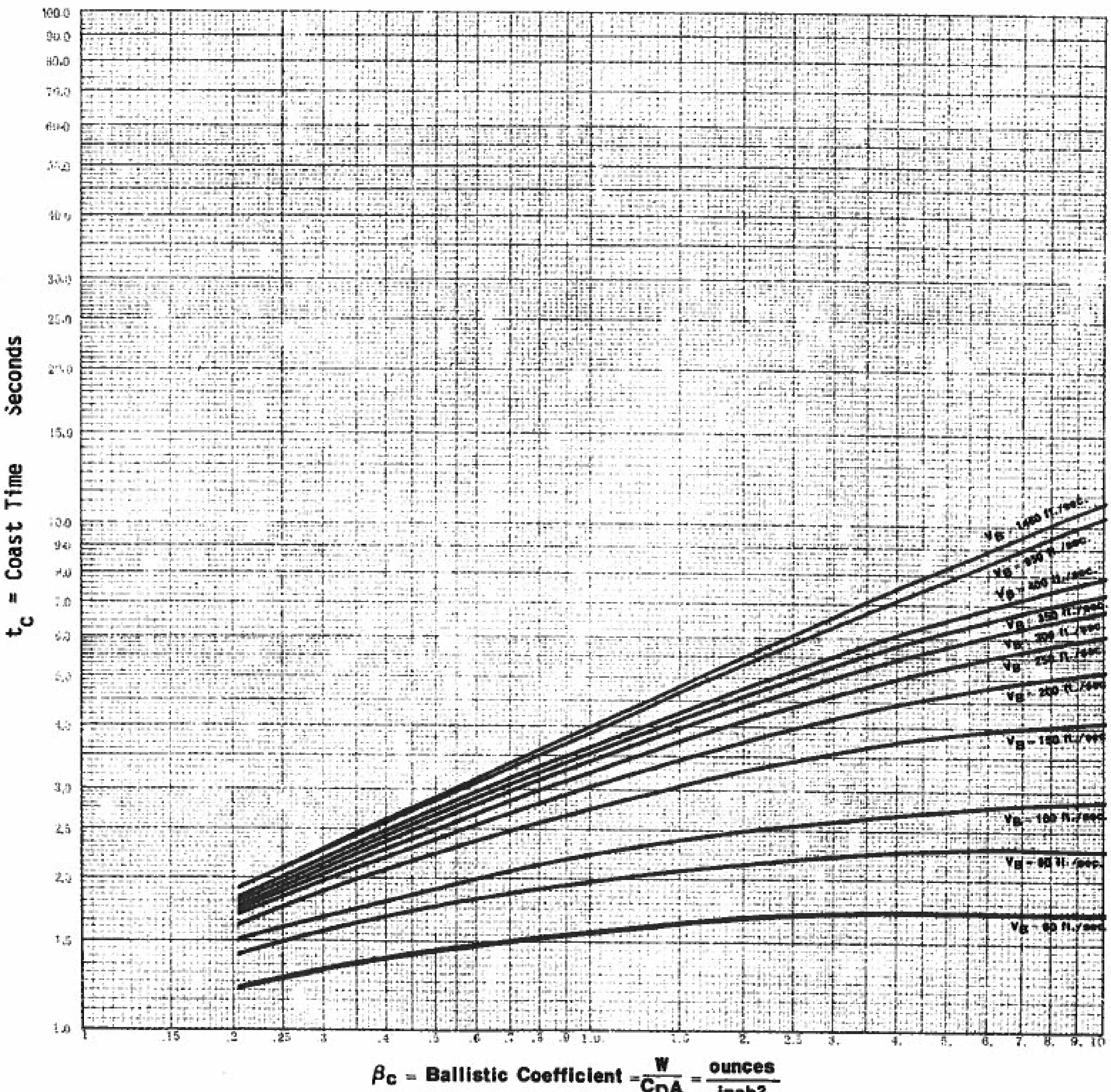


β_c = Ballistic Coefficient = $\frac{W}{C_D A}$ = $\frac{\text{ounces}}{\text{inch}^2}$

Figure 17

COAST TIMES

Time (t_c) in Seconds from Burnout to Peak Altitude as a function of Burnout Velocity (V_B) and Ballistic Coefficient (β_c).



117. DRAG EXPERIMENT - The following experiment requires exact measurement of altitude, plus the setting up of the two station tracking mentioned in unit 2. A scale to weigh your rocket(s) and a stop watch will be very helpful.

EXPERIMENT IN DRAG COEFFICIENT MEASUREMENT - Up to now you have used the drag coefficient of CD = .75 as the standard for all rockets. This coefficient was established by tests conducted in a very expensive wind tunnel. Calculate altitude totals for various assumed drag coefficient values for your rocket from figure 7a. The reason you do not use a greater ballistic coefficient of B = 10, can be seen by looking at the drag-form factors thrusting charts. The curves are almost flat and any other values of B will give no significant increase in value. Once you measure the actual altitude, start working backward with this chart/graph. Find the altitude point on the curve and mark it. Take at least three or four readings of your altitude and plot those for comparison; there will be a slight difference between flights. (Then you can come up with an average drag coefficient.) The total flight time is simply stated as the sum of the meter burn time plus the coast time (tTotal = tB + tC). By timing your flight and getting measurement of altitude, you have two data points which save you time and money. You will find it very interesting if you use different total impulse meters.

5A MODEL NAME ________

WORK AREA

1. Body diameter =
   Rocket empty weight =
   Engine = D13-7
   weight =
   propellant weight =

   W_1 = Rocket empty weight + engine weight

   =

   =

2. C_DA =

3. Thrusting B = $\frac{W - W}{C_DA}$

   = ________

   = ________

   = ________

   =

4. Burnout altitude from figure 10A =
   Burnout velocity from figure 10B =

5. Coasting B = $\frac{W - W}{C_DA}$

   = ________

   = ________

   =

6. Coasting altitude =

7. Apogee point = burnout altitude + coasting altitude,

   =

   =

8. Coasting time =

Check your answers with those on the next page.

5B CHEROKEE-D

1. Body diameter = BT-55-1.325 inches
   Rocket empty weight = 2.75 ounces
   Engine = D13-7
   weight = 1.55 ounces
   propellant weight = W_p = 0.879 ounce

   W_1 = Rocket empty weight + Engine weight
   = 2.75 oz. + 1.55 oz.
   = 4.30 ounces

2. $C_DA = 1.00 \text{ inch}^2$

3. Thrusting B = $\frac{W - W}{C_DA}$

   $= \frac{4.30 \text{ oz.} - (0.879 \text{ oz.})}{1.00 \text{ inch}^2}$

   $= \frac{4.30 \text{ oz.} - 0.440 \text{ oz.}}{1.00 \text{ inch}^2}$

   $= \frac{3.86 \text{ oz.}}{1.00 \text{ inch}^2}$

   = 3.86 ounces/inches^2

4. Burnout altitude from figure 10A = 320 feet
   Burnout velocity from figure 10B = 430 feet per second

5. Coasting B = $\frac{W - W}{C_DA}$

   $= \frac{4.3 \text{ oz.} - 0.879 \text{ oz.}}{1.00 \text{ inch}^2}$

   $= \frac{3.421 \text{ oz.}}{1.00 \text{ inch}^2}$

   = 3.421 ounce/inch^2

6. Coasting altitude = 820 feet

7. Apogee point = burnout altitude + coasting altitude

   = 320 ft. + 820 ft.

   = 1140 feet

8. Coasting time = 5.8 seconds

To minimize lateral drift of the rocket as it descends under its parachute during recovery, it is desirable to use an engine with a delay to permit the rocket to begin to descend before the parachute ejection occurs. Thus, the D13-7 would be an appropriate engine to use.

Please complete questions for Adventure XXIV found on page 38.

ADVENTURE XXV - DO NOT PUT A DRAG, DRAG, DRAG ON YOUR ROCKET, ROCKET, ROCKET

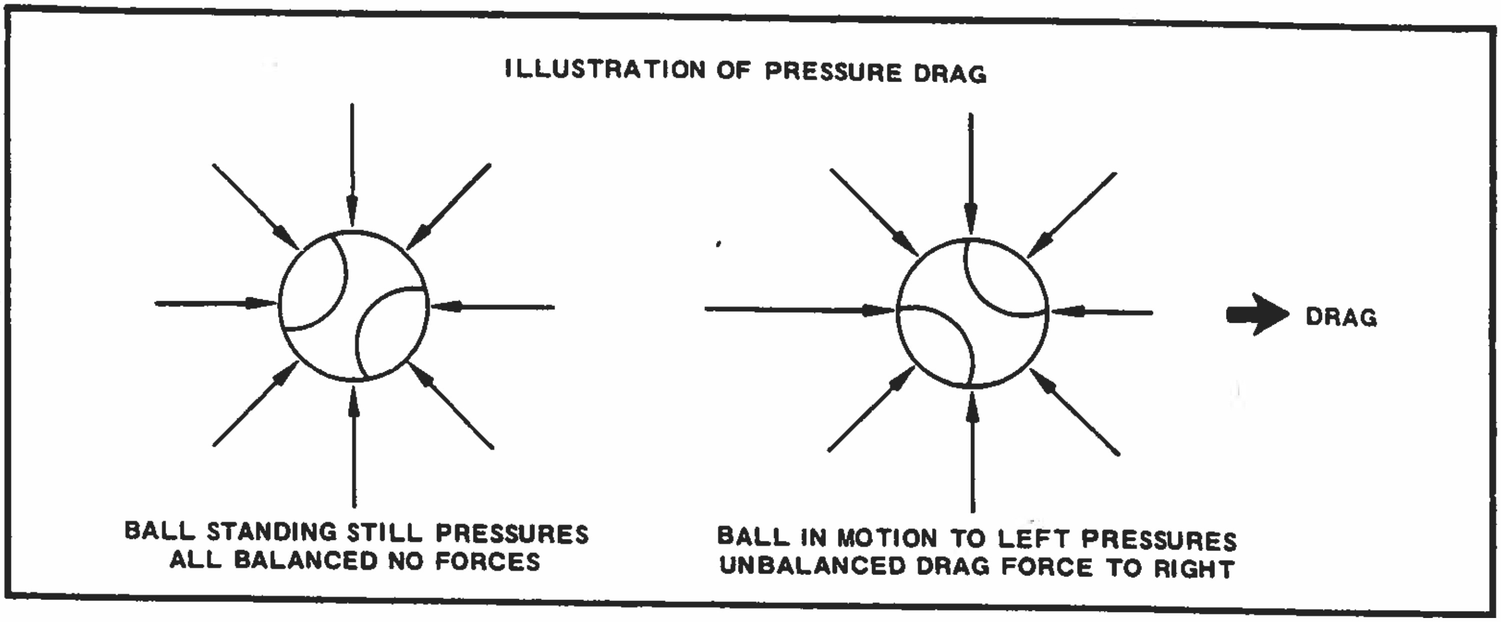
118. MODEL ROCKET AERODYNAMIC DRAG - When you launched your first rocket, remember the thrill you had when you started the countdown, the acceleration, ejection of the recovery system and then watched your model come down slowly. Was there a slight twisting motion in your model or did it go up slower than other models like it? Notice after models come down if other models have a smoother finish, the fins are airfoiled or they have a better paint job. Then ask, "was it worth all the work that you put into it?" The reply: "You saw the performance of the rockets." Is it worth the extra time and effort to cut down the drag (better known as aerodynamic drag)? Drag is defined as the resistance which is caused by the motion of any body through fluids like air or water.

Why bother with drag? If you want your model to reach maximum performance (height, acceleration and coast phase) you need to consider and reconsider drag.

119. CONCEPTS OF THE BASICS THAT AFFECT DRAG - One of the simplest methods of determining the drag on any object is to stick your hand out the window of a car. As the car slowly takes off, you notice very little pressure against your hand. As the car speeds up, you notice the pressure increasing until you cannot hold your hand steady. If you turn your hand to the side, you will notice less resistance. Size of the surface is one of the factors that affect drag. Wind velocity is another factor which affected your hand as you placed it outside the car window. Another factor that affects drag is the density of air or the amount of moisture in the air. Otherwise called relative humidity. Another way to explain density is the amount of material present in a given area, space or volume. This is the reason why it is harder to move your hand through water than it is to move it through air. Size, speed, shape and density of the air were all contributing factors brought together to cause more or less drag as your experiments indicated. There are only two ways to explain where drag comes: (1) an unbalance in air pressure on your rocket; (2) friction of air sliding over its surface.

Did you know that 90 percent of the drag on a sphere comes from pressure drag? Pressure drag can be best described as: the air starts moving around the sphere causing an unbalanced pressure on the sphere which causes the sphere to move. Friction drag is the air rubbing on the surface of an object and confined to a thin region close to the body surface.

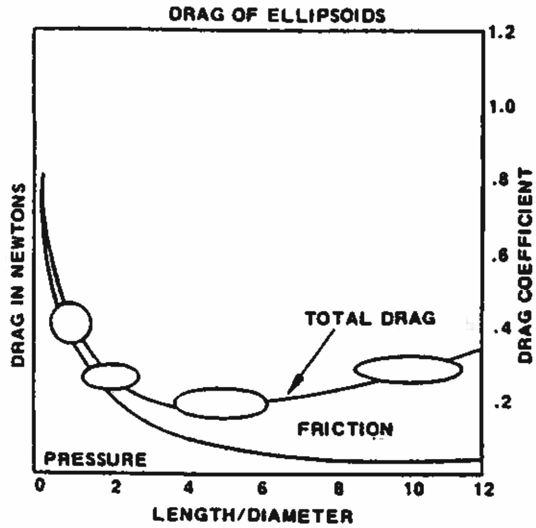
Figure 18

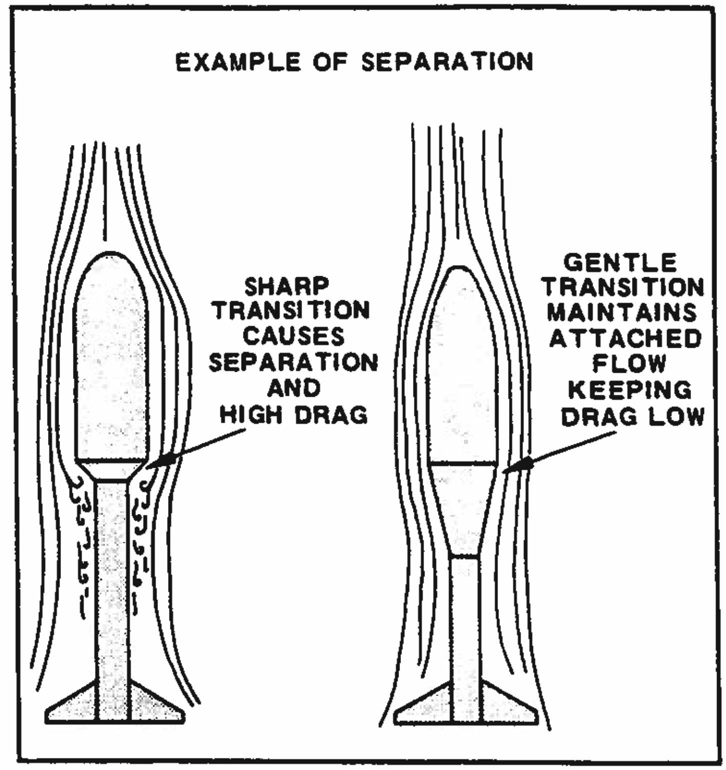


Courtesy of Estes Industries

Viscosity is measuring the resistance of a fluid to flow over surface. Viscosity plays a very important part on both types of drags. (See Figures 19 and 20.)

Figures 19 and 20





Courtesy of Estes Industries

When you have a sharp transition, it causes separation and high drag. A gentle transition keeps drag low. Use aerodynamic shapes that are rounded gently and never have any sharp changes in direction. Be sure the angle at transition is less than 5 degrees and you will have or maintain a lower drag design with attached flow.

What is the difference between the laminar flow and the turbulent flow? The air rushing past has a direct effect on your rocket and this air has boundaries where it affects the rocket. This area is called the boundary layer region. There is a reaction of air on the rocket due to its aerodynamic shape. If a rocket has a smooth transition from nose cone to tail fins you will have a straight flow of air in layers from the rocket's surface to the outer boundaries (laminar flow). If you have a sharp transition, it will cause an uneven or turbulent flow where all or part of the layers of air mix or flow unevenly past the surface to the outer boundaries. That directly affects the rocket's performance.

Reynolds found that he could obtain a number which allowed him to predict whether the viscous flow would be laminar or turbulent. The formula used is:

$$\text{Reynolds Number} = \frac{\text{density x velocity x length}}{\text{viscosity}}$$

For air flow with RN numbers 100,000 or less, the boundary layer is laminar. Any RN above 1,000,000 will have a turbulent boundary layer. Between these two limits either laminar or turbulent boundary layer flaws can exist.

120. DRAG ANALYSIS INTRODUCTION TO ROCKETS - The purpose of any rocket designer (professional or model) is to reduce the drag of any new design. There are four basic areas where drag comes from on a rocket: (1) the nose cone, (2) body tube, (3) base and (4) fins. All these drag factors add up to total component drag.

As a math problem, it is written as follows:

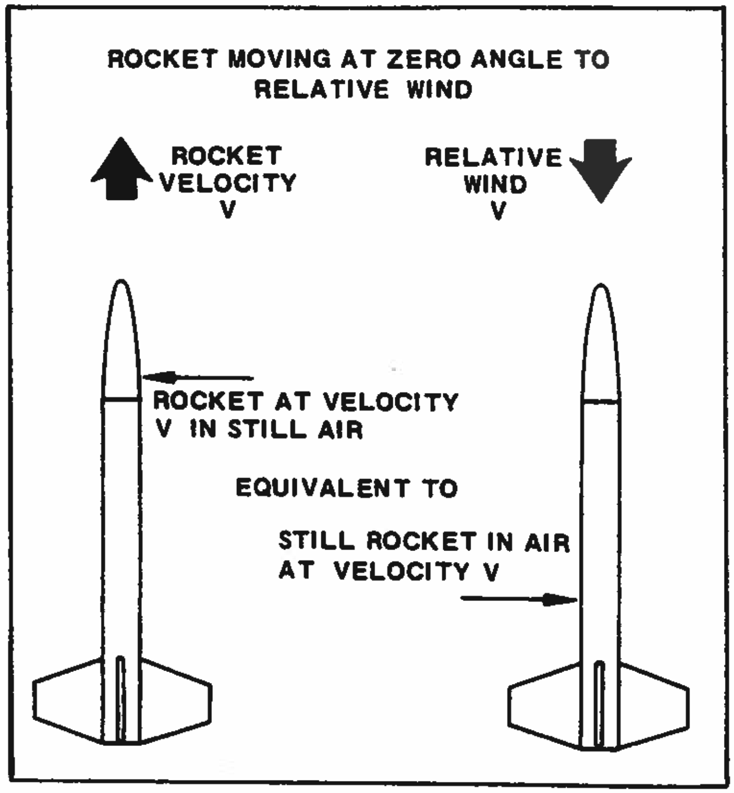
CDN + CDBT + CDB + CDF = CDC

CDN is the drag coefficient of the nose cone shape
CDBT is the drag coefficient of the body tube
CDB is the drag coefficient of the base
CDF is the drag coefficient of the fins
CDC is the drag coefficient of the sum of the components

What is interference drag? When you join the fins to the body tube, the air flows around the body tube and the fins tend to interfere with each other along with other rocket parts such as launch, lug, etc. This is interference drag.

What is induced drag? It is the drag which comes from the angle of attack to the relative wind.

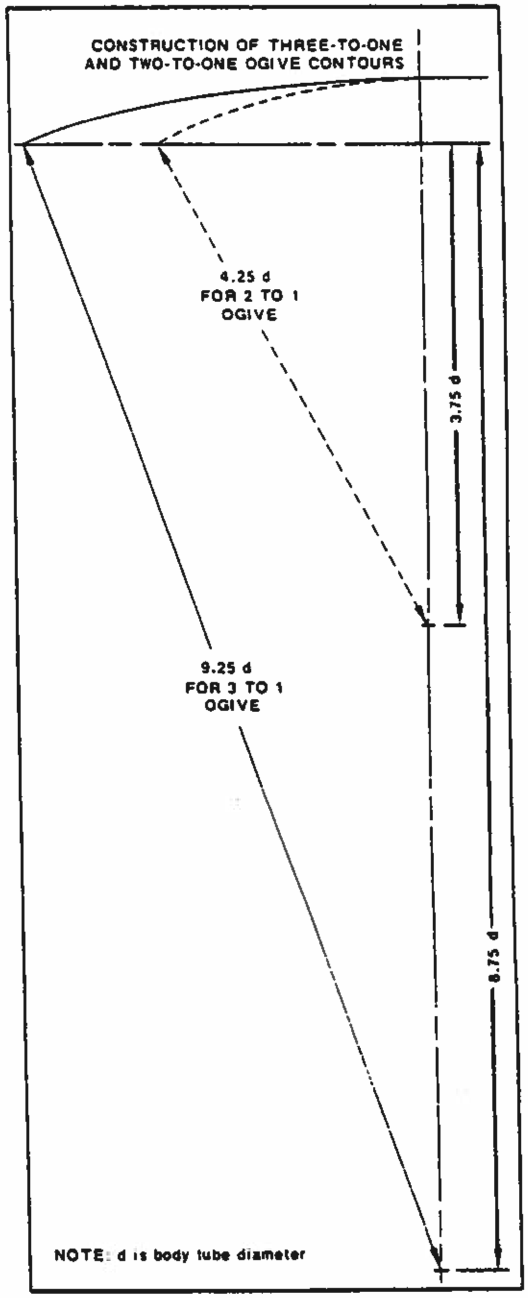
Figure 21



Courtesy of Estes Industries

121. DRAG OF ROCKET BODIES, FINS AND TOTAL ROCKET DRAG - The topmost part of the rocket is the nose cone. The nose cone causes two types of drag; pressure drag and skin-friction drag. Probably the worst nose cone would be blunt or have a flat surface and the best type is the ogive nose cone. To illustrate this point, use a real rocket that goes faster than sound and causes shock waves. They need a sharp pointed nose cone. But model rockets are subsonic and cause no shock or sound waves, so it is unnecessary to use such a shape since the ogive nose cone helps in thrust of rocket and separation of air flow. A three to one ogive has a length three times its diameter. (See Figure 22.)

Figure 22



Courtesy of Estes Industries

Include the nose cone in figuring the drag of the body tube. The body tube itself is an ellipsoid. The drag on an ellipsoid depends upon the ratio of its length to its diameter (L/D). Model rockets, which usually have high L/D, will encounter a large amount of skin friction. To keep the drag low, keep the laminar boundary intact and do not let it become turbulent. Skin friction is dependent upon the rocket speed, air density and air viscosity as well as rocket size. (See formula for Reynolds Number).

Base drag is due to low pressure at the rear of the rocket caused by flow separation. This relates to the coasting phase as exhaust fills the void during lift-off and powered flight phase. One method to cut down base drag is to boat-tail the base area, helping to fill the void and eliminate the vacuum area (or most of it).

In determining drag of the fins, take into consideration the four basic shapes of fins, which are rectangular, straight-tapered, swept-tapered and elliptical. These shapes are called planforms. Planform shapes are not the only factors in figuring drag on fins. The cross-sectional shape also contributes to drag. Another factor is airfoiling of the fins. Airfoiling can reduce drag by 50 percent if properly done (streamlining your fins). Swirling flow patterns are called vortex flow patterns (a circular or twisting motion after the air flow passes fins).

Total rocket drag is the combination of all the areas of the rocket such as nose cone, body tube, base, fins and their shape and launch lug.

122. TECHNIQUES OF DRAG REDUCTION - There are five basic rules for drag reduction. If you follow these, you should not have any great problems with drag.

Rule 1 - USE GOOD WORKMANSHIP - Beginning with model construction, take time to sand all parts for good fit; match nose cone/body tube junction carefully, round leading edge and sharpen trailing edge of fins. This work is necessary to reduce the pressure drag of the rocket.

Rule 2 - ALIGN FINS AND LAUNCH LUGS PROPERLY - Correcting the alignment for fins will keep the rocket from rolling during ascent. Misalignment of the launch lug will cause flow separation on body tube and extreme pressure drag.

Rule 3 - PUT A SMOOTH FINISH ON THE MODEL - It not only looks good but helps delay the turbulent boundary layer condition. A smooth surface will have less drag than a rough surface.

Rule 4 - FILLET THE FINS - This helps reduce the interference drag in the fin/body tube junction area.

Rule 5 - BOAT-TAIL WHENEVER POSSIBLE - The base drag contributes tremendously to the total drag and will be cut drastically by the boat-tail.

123. GETTING IT ALL TOGETHER - Review all phases of drag. Look back at the theoretical problems that can arise as discussed in unit 2. Use the charts as you design your rockets. Explore more about the subjects discussed and learn to understand and appreciate this fun, educational hobby or sport.

Please complete questions for Adventure XXV found on page 39.

124. GLOSSARY OF TERMS

A. ABLATION - The melting of nose cone materials during re-entry of spacecraft to keep the craft from getting so hot that it burns.

B. ACCELEROMETER - A device for measuring changes in rate of motion.

C. ACTUATOR - A device to move control surfaces or thrust directors of a missile.

D. ASTRODYNAMICS - The study of the motion of bodies outside earth's atmosphere and the forces affecting their motion.

E. BIPROPELLANT - A rocket propellant consisting of fuel and oxidizer kept separate until they enter the combustion chamber.

F. COMBUSTION CHAMBER - An enclosed space in a rocket or jet in which fuel is burned to develop thrust.

G. CRYOGENIC FUEL - A rocket fuel that must be kept at a very low temperature.

H. EXHAUST VELOCITY - Velocity of gases that exhaust from a rocket engine or motor, relative to its nozzle.

I. GRAIN - Solid propellant used in a rocket; it is shaped to burn at a rate that will provide the desired thrust characteristics.

J. HYBRID ROCKET - A rocket that is part solid propellant and part liquid propellant.

K. IONOSPHERE - An outer layer of the earth's atmosphere consisting of electrically charged particles of air.

L. MASS RATIO - The ratio between mass of a fully fueled vehicle at take-off and the final mass of the vehicle and payload.

M. PERIGEE - The point in satellite's orbit at which it is closest to earth.

N. RETROROCKET - A rocket unit designed to be fired to decelerate the craft.

O. SOLAR CELL - An electrical power source energized by the effect of the sun's radiation.

P. SQUIB - A device to start ignition of a solid propellant.

Q. TRANSDUCER - A device for sensing and measuring characteristic data and converting it for launching.

R. WEIGHTLESSNESS - The property of having mass without weight because of absence of gravitational pull.

QUESTIONS TO ADVENTURE XXI

1. What is the most basic type of propulsion?

___

2. Whose theory is used for airfoiling?

___

3. Which of Newton's Laws is used in missile and rocket flights?

___

4. Does rocketry have a part in our national anthem?

___

5. What rocket was used on the first manned flight and who was it piloted by?

___

6. Explain how the ramjet works.

___

___

___

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4-H member signature

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4-H leader signature

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Date of completion

QUESTIONS TO ADVENTURE XXII

1. What is the simplest method of tracking?

2. What do capital and small letters mean in tracking?

3. At what angle should a single tracker be located?

4. Is two-station tracking more accurate than single station? Why or why not?

5. Is the tangent used in two-station tracking?

4-H member signature

4-H leader signature

Date of completion

QUESTIONS TO ADVENTURE XXIII

1. How is the center of gravity found on a rocket?

____

____

2. What does   mean?

____

3. Will all of the nose cone area be used for C/P calculations?

____

4. A four-finned rocket is divided by ____ for the area of one fin to achieve what?

____

5. A three-finned rocket is divided by ____ for the area of one fin to achieve what?

____

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QUESTIONS TO ADVENTURE XXIV

1. What is drag?

____

____

____

2. Molecules hitting a surface are known as:

____

____

____

3. Formula for drag is written as:

____

____

4. The drag coefficient (CD) for a cube is?

____

5. Is the drag coefficient (CD) for a streamlined teardrop?

____

6. The formula for ballistic coefficient is written:

____

____

______________________ ______________________

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Date of completion

QUESTIONS TO ADVENTURE XXV

1. Describe aerodynamic drag.

____

____

____

2. Are wind, density of air and mass factors to drag?

____

____

3. List or name the four areas drag comes from.

____

____

____

4. Are each of the four areas mentioned important in reducing drag?

____

____

5. What are the five rules for drag reduction (just the titles).

____

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