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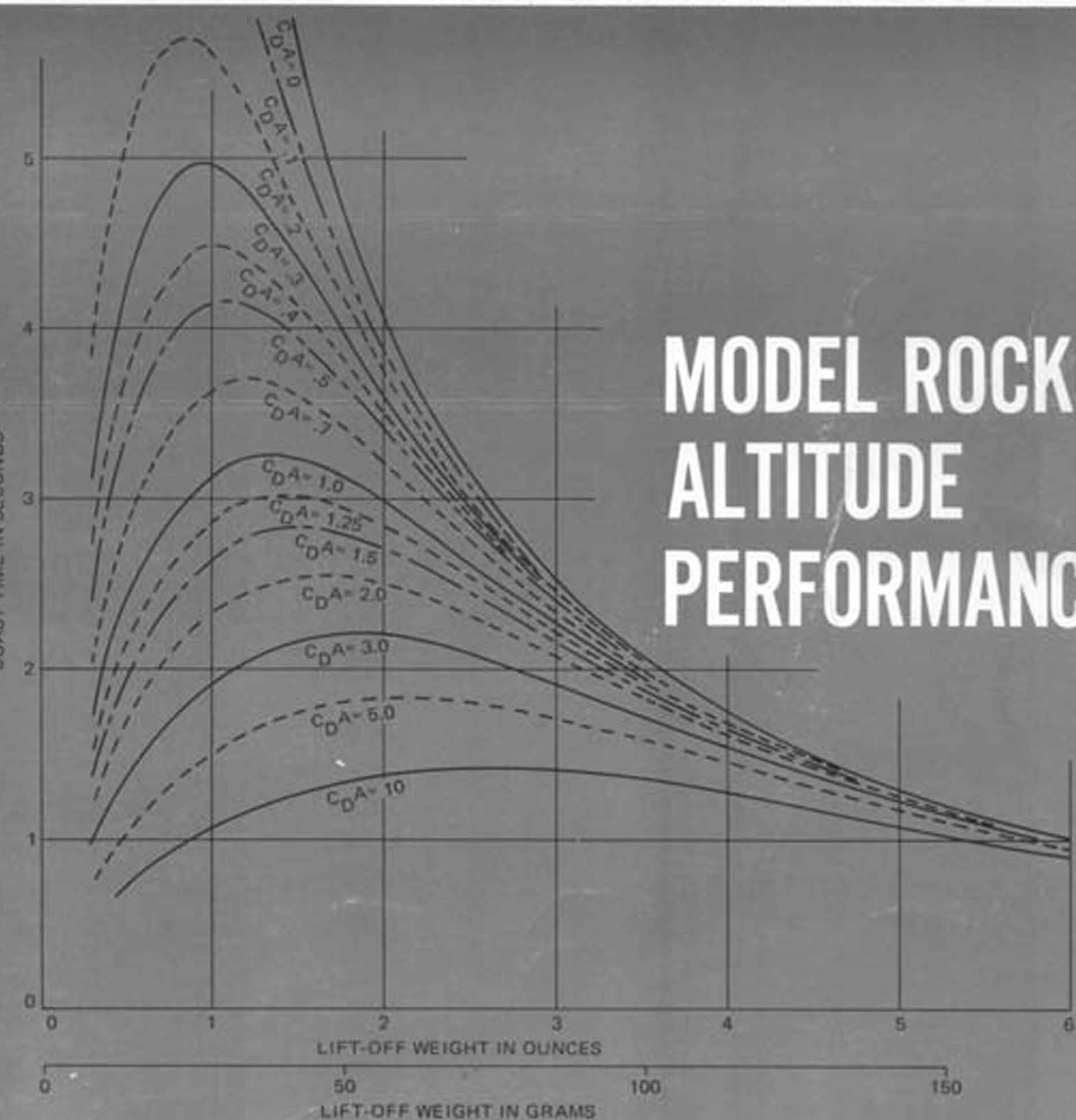
TECHNICAL INFORMATION REPORT

MODEL ROCKET ALTITUDE PERFORMANCE



Centuri

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MODEL ROCKET ALTITUDE PERFORMANCE

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PROLOGUE

This report presents easy-to-use graphs for accurately predicting the maximum altitudes which can be reached by single-stage rockets using "¼A" thru "F" type engines. Also included are graphs for selecting the best delay time to use. No mathematical calculations, whatever, are involved in finding altitudes or engine delay times. These graphs, along with the discussion sections of this report, should be most useful in helping the rocketeer develop a real understanding of how engine power, rocket weight, and aerodynamic drag on various nose and body shapes are interrelated in their affects on performance. All the altitude data in this report is based entirely on Centuri's latest model rocket engines.

The National Association of Rocketry (NAR), the Federation Aeronautique Internationale (FAI), and the United States Model Rocket Manufacturers Association have all recently adopted the Metric System of measurement. As a result, Centuri model rocket engines were redesigned to give the maximum Total Impulse allowed in each new Metric category. These modifications mean that the new engines have slightly different average thrust levels and thrust duration characteristics than the old engines and this report properly reflects these changes.

Also note that altitude performance graphs for the new "C" type engines with time delays are included. These new engines have 50 per cent more Total Impulse than the old "C.8-0" booster engines and twice the Total Impulse of the old "B" type engines.

INTRODUCTION

To determine the maximum altitude of a model rocket, you must first determine what forces are acting on the rocket and then determine how they actually affect the performance of the rocket. If you were to study this problem, you would soon conclude that there are only three basic forces acting on a rocket in flight, so let's begin by examining these three forces.

THE THREE FORCES THAT DETERMINE ALTITUDE

ENGINE POWER (TOTAL IMPULSE)

The first force that we shall consider is the upward force due to the thrusting power of the rocket engine. The greater the total power, the greater the upward force on the rocket.

Model rocketeers are already aware that the total power of a rocket engine is represented by its Total Impulse. The Total Impulse of a model rocket engine can be determined by selecting a particular type engine from the Model Rocket Engine Data Chart (Page 4) once the Engine Coding System is understood (Page 3).

You will need to know the Total Impulse of the rocket to determine its altitude.

MODEL ROCKET ENGINE CODING

All model rocket engines are marked with a code which, when understood, provides the rocketeer with useful information concerning the primary performance characteristics of the engine.

"A" The first letter specifies the TOTAL IMPULSE group to which an engine belongs. The new official National Association of Rocketry (NAR) TOTAL IMPULSE classifications in both the Metric and English measurement systems are as follows:

CODED TOTAL IMPULSE CHART

TYPE	TOTAL IMPULSE (NEWTON-SECONDS)	TOTAL IMPULSE (LB–SECONDS)
¼A	0.00 to 0.625	0.00 to 0.14
½A	0.626 to 1.25	0.15 to 0.28
A	1.26 to 2.50	0.29 to 0.56
B	2.51 to 5.00	0.57 to 1.12
C	5.01 to 10.00	1.13 to 2.24
D	10.01 to 20.00	2.25 to 4.48
E	20.01 to 40.00	4.49 to 8.96
F	40.01 to 80.00	8.97 to 17.92

"5" The number following the Total Impulse code letter specifies the engine's AVERAGE THRUST rounded off to the nearest Newton (4.45 Newtons of thrust is equivalent to one pound of thrust).

"–2" The third symbol represents the time for the burning of the delay charge rounded off to the nearest second. A zero "0" delay time means that the engine is a booster.

This report will be a valuable aid in determining the proper delay times to use with any given motor type, rocket shape, size, and weight.

MODEL ROCKET ENGINE DATA CHART

TYPE	TOTAL IMPULSE	AVERAGE THRUST	THRUST DURATION	PROPELLANT WEIGHT	INITIAL WEIGHT GRAMS	INITIAL WEIGHT OUNCES
¼A3-1	.625 n-sec	2.59 n	.24 sec	.780 gm	13.6	.48
-1S	or	or		or	10.2	.36
-2	.14 lb-sec	9.33 oz		.0275 oz	14.2	.50
-2S					10.8	.38
-4					14.5	.51
-4S					11.1	.39
½A6-0	1.25 n-sec	6.23 n	.20 sec	1.560 gm	13.6	.48
-0S	or	or		or	10.2	.36
-2	.28 lb-sec	22.40 oz		.0550 oz	15.0	.53
-2S					11.6	.41
-4					15.3	.54
-4S					11.9	.42
A5-2	2.50 n-sec	4.98 n	.50 sec	3.115 gm	16.7	.59
-4	or	17.92 oz		or	18.1	.64
A8-0	.56 lb-sec	5.92 n	.42 sec	.1100 oz	14.5	.51
-3		or			16.2	.57
-5		21.33 oz			17.6	.62
B4-2	5.00 n-sec	4.15 n	1.20 sec	8.330 gm	19.8	.70
-4	or	or		or	21.0	.74
-6	1.12 lb-sec	14.93 oz		.2940 oz	22.1	.78
B6-0		6.00 n	.83 sec	6.231 gm	16.4	.58
-4		or		or	19.0	.67
-6		21.59 oz		.2200 oz	20.1	.71
B14-0		14.23 n	.35 sec		17.3	.61
-5		or			19.6	.69
-6		51.2 oz			20.1	.71
-7					20.7	.73
C6-0	10.00 n-sec	5.86 n	1.70 sec	12.47 gm	22.7	.80
-5	or	or		or	25.8	.91
-7	2.24 lb-sec	21.08 oz		.4400 oz	26.9	.95
D9-3	14.2 n-sec	8.9 n	1.6 sec	24.0 gm	79.4	2.8
	or	or		or		
	3.2 lb-sec	32 oz		.85 oz		
D7-4	17.3 n-sec	6.7 n	2.6 sec	25.35 gm	85.1	3.0
	or	or		or		
	3.9 lb-sec	24 oz		1.00 oz		
D17-4		17.3 n	1.0 sec		85.1	3.0
-6		or			87.9	3.1
		62.4 oz				
E6-4	25.4 n-sec	5.8 n	4.4 sec	39.70 gm	96.4	3.4
-6	or	or		or	99.2	3.5
	5.72 lb-sec	20.8 oz		1.40 oz		
E16-4	24.9 n-sec	15.6 n	1.6 sec		96.4	3.4
-6	or	or			99.2	3.5
	5.6 lb-sec	56.0 oz				
F44-0	37.8 n-sec	44.5 n	.85 sec	57.70 gm	124.7	4.4
-4	or	or		or	130.4	4.6
-8	8.5 lb-sec	160.0 oz		2.00 oz	136.0	4.8
F62-0	37.3 n-sec	62.3 n	.60 sec		124.7	4.4
-4	or	or			130.4	4.6
-8	8.4 lb-sec	224.0 oz			136.0	4.8

MEASUREMENT SYSTEM CONVERSIONS

4.45 Newtons = 1 pound
.3048 meters = 1 foot
28.35 grams = 1 ounce
16 ounces = 1 pound

ABBREVIATIONS

lb = pound
n = newton
ft = feet
sec = second
gm = gram
oz = ounce

GRAVITY (LIFT-OFF WEIGHT)

The second force acting on a model rocket is due to the force of gravity. To determine the effect of this force, all you need to do is determine the total weight of the rocket at lift-off. You can do this in numerous ways. For instance, you could weigh the rocket with all of its components (i.e., engine, recovery device, wadding, etc.) or you could first determine the empty weight of the rocket and then add the particular engine weight as you select the engines you wish to use.

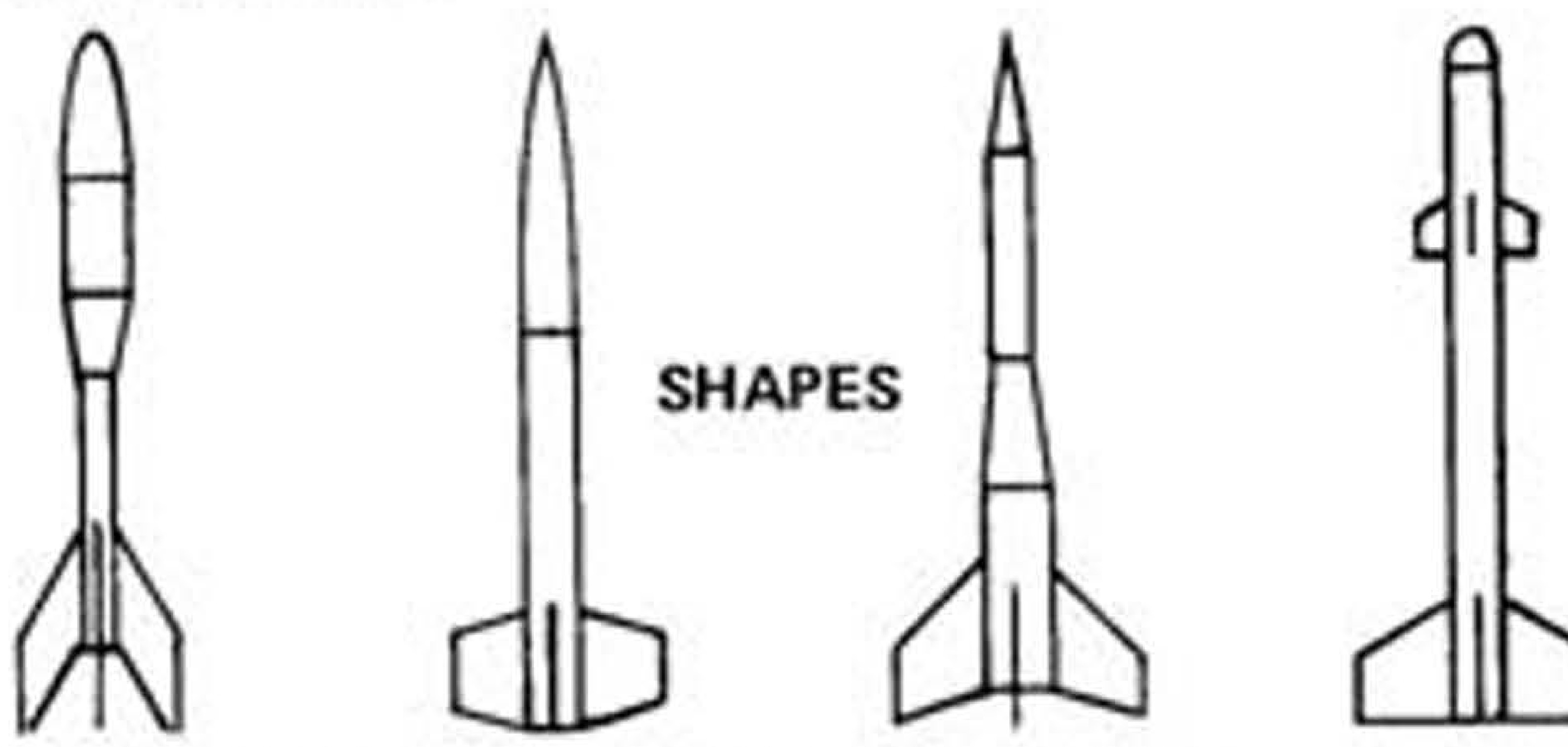
You will need to know the Lift-Off Weight of the rocket to determine its altitude.

DRAG FORCE (DRAGFORM FACTOR)

The third force acting on a rocket is due to the resistance of the air in the atmosphere. This is the force we call drag. It is a very complicated force and is not easy to compute mathematically.

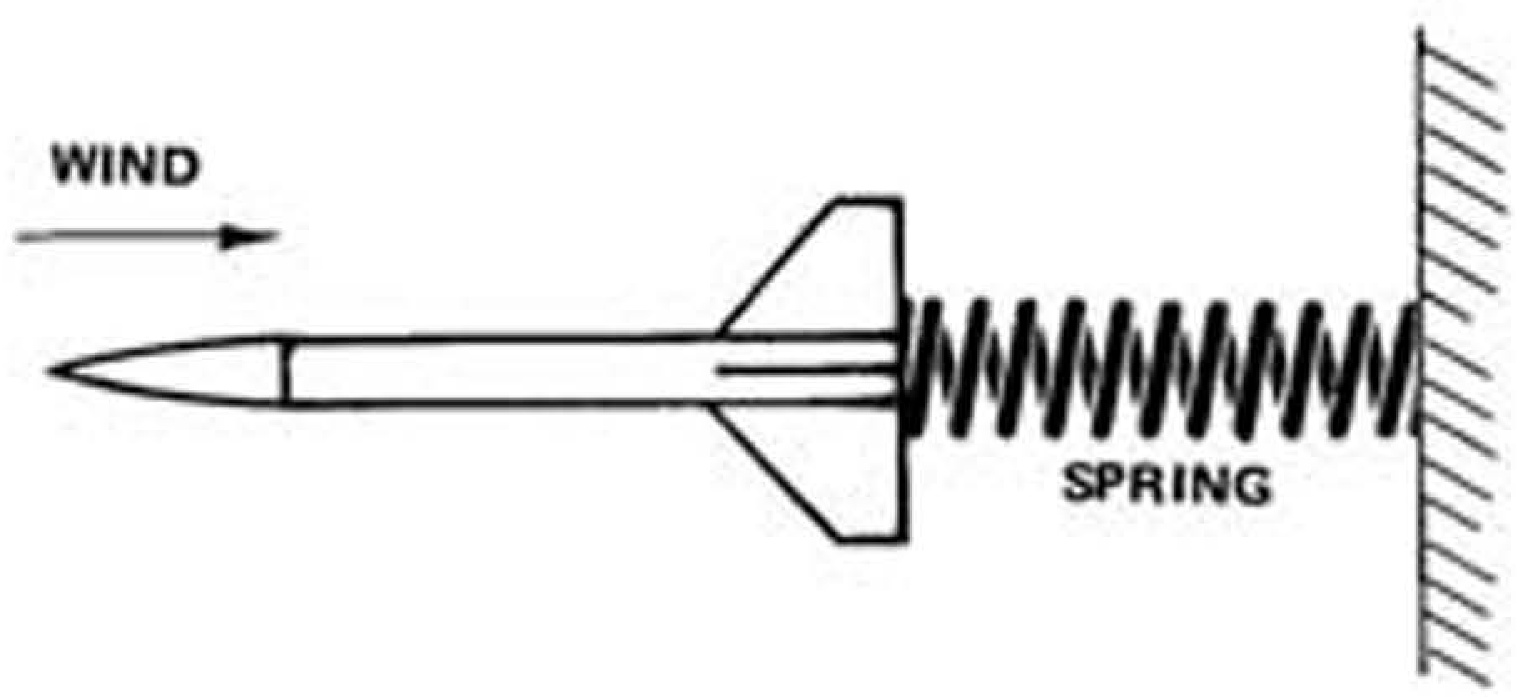
Because the Drag Force on a model rocket is directly related to both the shape and the size of the rocket, you must consider the effects of both of these factors.

The shape of a rocket will determine how streamlined it is and how easily it will slip through the air. The more streamlined (i.e., the better the shape), the less the aerodynamic resistance (or drag force). The factor that describes the efficiency of the shape and the "streamlineness" of the rocket is called the Drag Coefficient and is represented by the symbol C_D. Although the Drag Coefficient (C_D) of a rocket can vary over a wide range of values, the C_D for a typical model rocket usually lies between .6 and .8. Drag Coefficients are dimensionless values (i.e., they don't have any units, such as feet, seconds, etc.), they are simply numbers that tell you something about the design of a rocket.



SHAPES

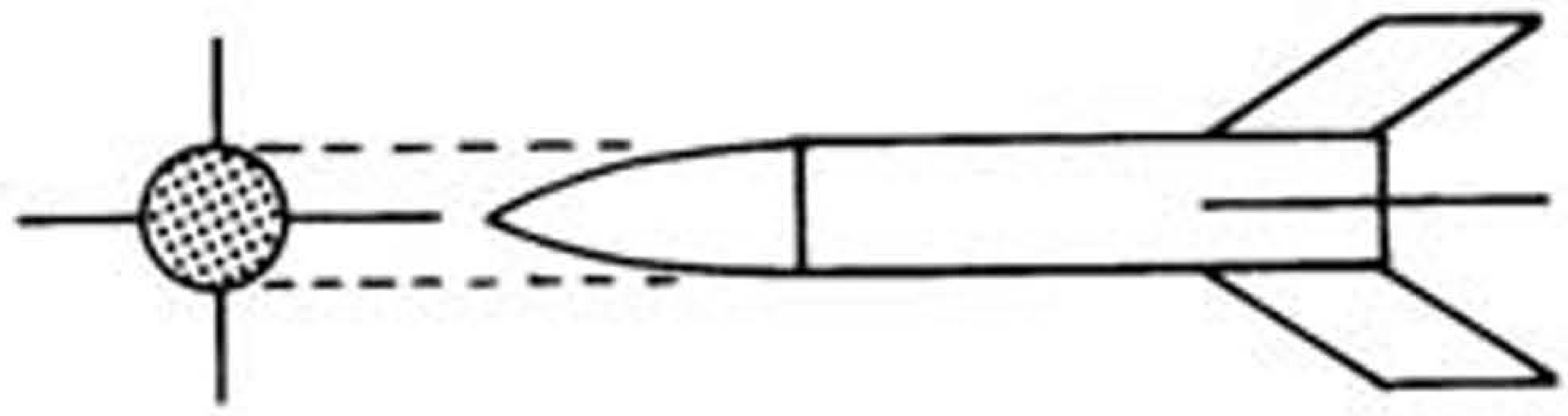
Drag Coefficients are usually determined in expensive and sensitive wind tunnels. As the wind flows by a rocket, it will "drag" or push the rocket back a certain distance – the further the rocket is pushed back, the greater its resistance to the air and, therefore, the greater its Drag Coefficient (C_D).



If you do not have a way of actually measuring the C_D of a rocket (and most of us do not), you may assume a value of .75 for preliminary estimates. This value has proven to be an acceptable value for typical model rocket designs.

In addition to understanding how the shape affects the drag force on a rocket, you must also understand that the size of the shape is equally important in determining the drag on a rocket.

SIZES



For all practical purposes you can consider the cross-sectional area of the largest part of the rocket's body as representing the size factor of a rocket. It should be obvious that for identical shapes the greater the size (cross-sectional area A) of a rocket, the greater the amount of drag it will create.

If you know the outside diameter (d) of the largest body tube section used on a rocket, you can easily compute its cross-sectional area (A) from the following formula.

$$A = \pi \frac{d^2}{4}, \text{ where } \pi = 3.14$$

The cross-sectional area A, as you can see, can be easily computed. However, if you are using standard Centuri body tubes you will be able to use a specially prepared graph (the Drag Form Factor graph), which we will explain a little later.

If you understand that the Drag Force on a rocket is a result of two equally important factors and you understand how these factors affect the rocket's flight, you will now be able to understand that we can combine these two factors into a new term known as the Drag Form Factor. That is, if we multiply the Drag Coefficient (C_D) times the cross-sectional (A), we obtain the Drag Form Factor (C_DA).

You will need to know the Drag Form Factor of the rocket to determine its altitude.

We will be using this factor throughout the remainder of this report to represent the Drag Force acting on a model rocket.

HOW TO USE THE GRAPHS

DETERMINE THE THREE VALUES

You can determine the altitude of a model rocket, using the graphs in this report, if you know the values of the three (3) forces acting on the rocket. This means that you need to:

1. Determine the Total Impulse of the rocket.

2. Determine the Lift-Off Weight of the rocket.

3. Determine the Drag Form Factor (C_DA) of the rocket.

Although the Total Impulse and Lift-Off Weight of a rocket are easy to determine, the Drag Form Factor can be difficult. To help simplify this problem, we have prepared a special graph (Figure 1) to help in determining the Drag Form Factor (C_DA) of a model rocket.

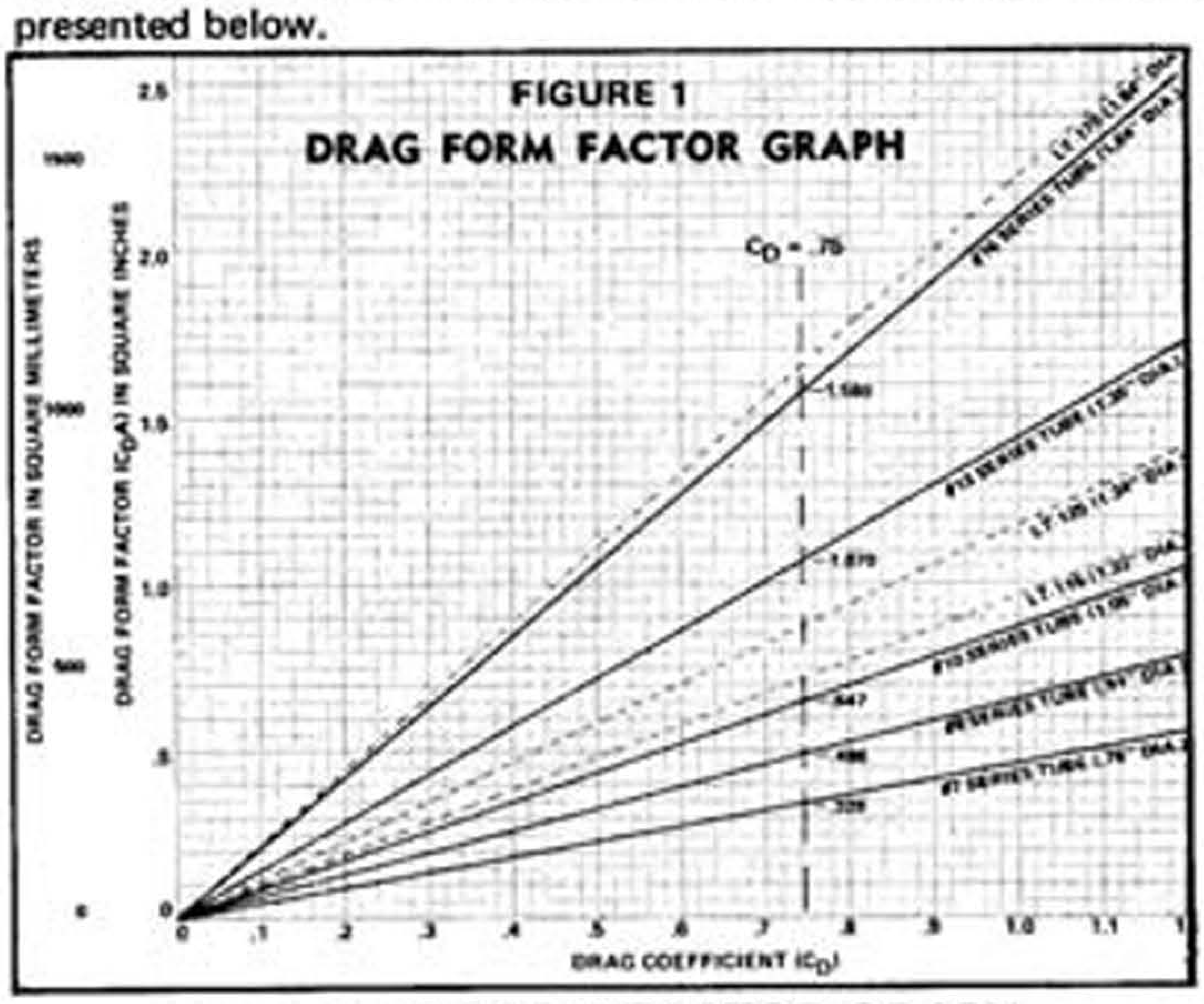
The Drag Form Factor (C_DA), as you remember, is actually the product of:

a. The Drag Coefficient (C_D) which is related to the shape of the rocket,

and

b. The cross-sectional area (A) which is related to the size of the rocket.

Unless the Drag Coefficient (C_D) of the rocket is known, assume a value of .75 for preliminary estimates. The cross-sectional areas (A) for various size model rockets are represented by the bold lines on the Drag Form Factor graph presented below.



THE DRAG FORM FACTOR GRAPH

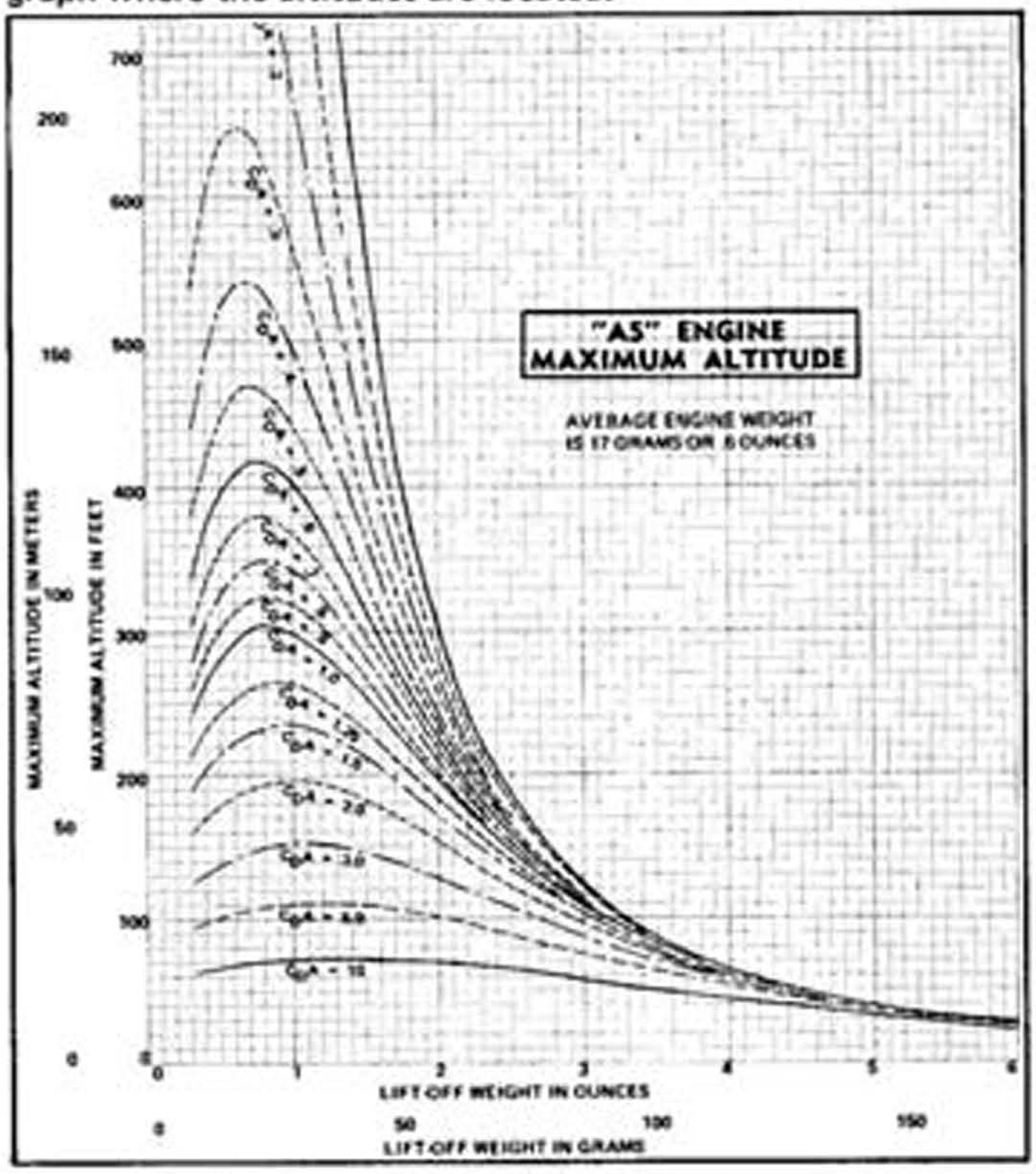
To use this graph you must first locate the value of the Drag Coefficient (C_D) of the rocket along the bottom line of the graph. Next, follow this value up the graph until it intersects the line representing the rocket's body size. You can now determine the Drag Form Factor of the rocket by following this point of intersection over to the left side of the graph where the (C_DA) values are located.

If you understand how to find the values of the three forces acting on the rocket, we will now discuss how to use the Altitude graph.

DETERMINE THE MAXIMUM ALTITUDE

The first thing you must do is determine which Altitude graph to use. Because each type of engine has its own graph, you will need to know the Total Impulse of your engine in order to select the proper graph.

To use the graph corresponding to the type of engine you have chosen, you must first locate the value that corresponds to the Lift-Off Weight of the rocket along the bottom line of the graph. Next, follow this value up the graph until it intersects the curved line representing the Drag Form Factor of the rocket. You can now determine the altitude of the rocket by following this point of intersection over to the left side of the graph where the altitudes are located.



REACHING MAXIMUM ALTITUDE

Once you have computed the altitude that a rocket could achieve, you should next determine how high the rocket will coast during its flight upward so that you will know how long of an engine delay time you will need. For instance, if the rocket was powered by one of the "B4-4" engines and it coasted for 5.5 seconds before reaching maximum altitude, you would not want the ejection charge to ignite too soon. This information tells you that although the "B4-4" engine has three different delay times (2 sec., 4 sec., and 6 sec.), you should choose the 6 second delay to achieve maximum altitude.

DETERMINE THE COAST TIME

You can determine the coast time for each type of engine, using the graphs in this report, in the same way you determined the altitude.

THE COAST TIME GRAPH

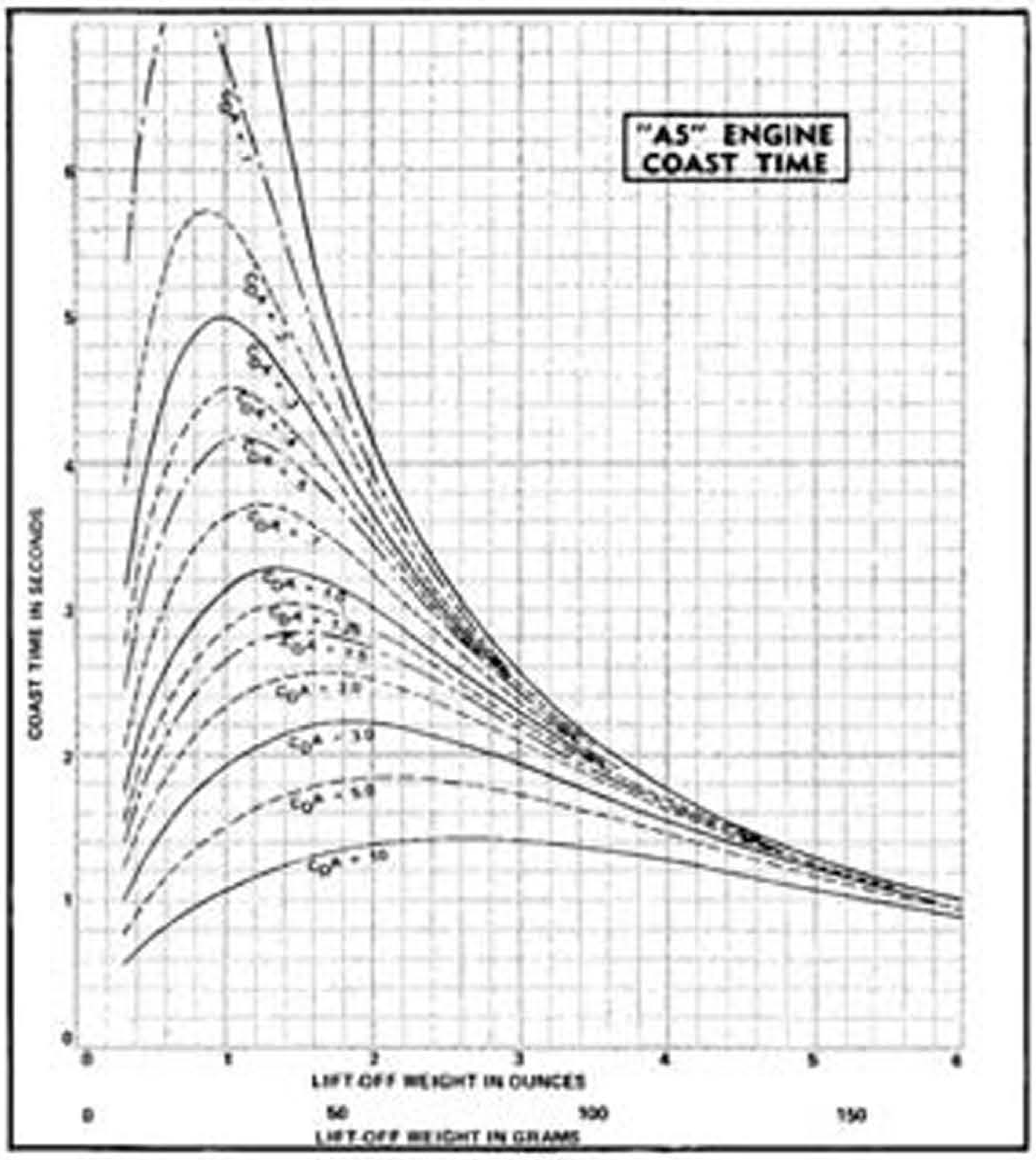
The first thing you must do is choose the Coast Time graph that corresponds to the type of (Total Impulse) engine you are using.

Using the proper graph, you should first locate the Lift-Off Weight of the rocket along the bottom line of the graph. Next, follow this value up the graph until it intersects the curved line representing the Drag Form Factor of the rocket. You can now determine the coast time by following this point of intersection over to the left of the graph where the coast times are located.

SELECTING DELAY TIME

Selecting the engine with the proper delay time is simply a matter of knowing how long the rocket will coast before it reaches its maximum altitude.

Once the coast time has been determined from the graph, you will then know which delay time to use to achieve maximum altitude.



USING THE GRAPHS

If you understand how to use the three graphs we have just discussed, you can easily determine the maximum altitude of a model rocket. To help you in your understanding of the use of these graphs for altitude computation, we have presented the following sample problem.

SAMPLE PROBLEM

Imagine that you have constructed a rocket of a #7 series tube and its total weight with an "A5-4" engine, parachute and wadding is 1.5 oz. Find its altitude and its coast time.

It helps to organize your information.

1. Total Impulse: Use the "A5" graph
2. Lift-Off Weight = 1.5 oz.
3. Drag Form Factor: (C_DA)
   a. Drag Coefficient (C_D): Assume C_D = .75
   b. Cross-sectional area (A): #7 series tube

Step 1

The Drag Form Factor graph gives C_DA = .339 square inches for a C_D of .75 and the cross-sectional area of a #7 series tube.

Step 2

The Maximum Altitude graph gives a height of about 380 feet for a C_DA of .339 and a weight of 1.5 ounces.

Step 3

The Engine Coast Time graph gives a coast time of about 4.3 seconds.

This tells you that a 4 second delay will be your best choice and that ejection will occur just slightly before the rocket reaches its maximum altitude.

THEORETICAL AND ACTUAL ALTITUDES

If the power (Total Impulse) of the engine and gravity (Lift-Off Weight) were the only two forces acting on a model rocket, we could compute the theoretical (no drag) altitude very easily with simple mathematical formulas. Theoretical altitudes, however, would be much greater than the actual altitudes achieved by rockets. You can compare theoretical and actual altitudes with the aid of the graphs in this report. To determine Theoretical Altitudes, using the graphs, simply neglect the Drag Force by using a Drag Form Factor equal to zero ($C_DA = 0$).

To determine actual altitudes, you must consider the Drag Force. If you were to attempt to compute actual altitudes, you would find yourself involved with some very complicated mathematics. Due to the complexity of the computations, we enlisted the aid of a computer (refer to Page 52, The Computer) to help in the preparation of the graphs in this report. With these graphs, rocketeers can now easily determine the actual altitudes achieved by their model rockets.

IN REVIEW

To determine the maximum altitude and coast time of a model rocket, using the graphs in this report, you need to first determine:

1. Total Impulse (from the Code)
2. Lift-Off Weight (from a scale or balance)
3. Drag Form Factor (from the Graph)

EXAMPLE PROBLEMS

In order to help you develop a greater understanding of the material presented in this Technical Information Report, the following examples have been worked out in detail. After each step-by-step example, we have presented one or more similar problems for you to solve yourself. The correct answers to these problems are presented at the end of this section.

For these problems, you should refer to the Drag Form Factor graph on Page 11 and the Maximum Altitude and Coast Time graphs for each engine type on Pages 12 through 43.

The Maximum Altitude and Coast Time graphs are arranged in order according to their Total Impulse. The "¼A" engine graphs are at the beginning of Section 6 and the Mini-Max "F" engine graphs are at the end of the Section.

EXAMPLE 1
SELECTING THE PROPER ENGINE DELAY TIME

Assume that you have a rocket constructed of a #10 series tube. The rocket's weight without an engine, but with parachute and wadding, is 1.3 ounces. You have a "B4-2", "B4-4" and "B4-6" engine on hand. Which engine should you use if you want the parachute to eject as close as possible to the peak altitude?

First we find the "B4" graphs which will be used on this problem. Next, we need to determine the Lift-Off Weight of the rocket in order to use the graphs. An approximate or average engine weight of .7 ounces is given in the "engine characteristics data" on the "B4" MAXIMUM ALTITUDE graph and this value has to be added to the empty rocket weight to find the total Lift-Off Weight.

Lift-Off Weight = Empty Weight + Engine Weight

= 1.3 ounce + .7 ounce

Lift-Off Weight = 2.0 ounces

You might note that in reality, the Lift-Off Weight of the rocket would vary slightly depending on if the "B4-2", "B4-4" or "B4-6" engine was used.

The reason that we do not use the exact engine weights (as given in the Engine Data Chart) to calculate three separate Lift-Off Weights is that the aerodynamic Drag Coefficient (C_D) is just a preliminary estimate. Since the C_D of the rocket has not been accurately measured, we can't really say that our maximum altitude and coast time answers will be completely accurate. Working with the rounded off engine weight of .7 ounce to represent all three engines is simply more convenient and still is well within the accuracy of the drag data being used.

Now we need to establish the Drag Form Factor of the rocket. Again we assume a Drag Coefficient value of C_D = .75 for this preliminary estimate. The Drag Form Factor graph gives a C_DA = .647 square inches for a C_D of .75 and the cross-sectional area of a #10 series tube.

Organizing the basic information, we have:

1. Total Impulse: Use the "B4" graphs
2. Lift-Off Weight = 2.0 ounces
3. Drag Form Factor: C_DA = .647 square inches

This information is then used to find:

4. MAXIMUM ALTITUDE = 665 feet
5. COAST TIME = 4.4 seconds

The best choice of engine for this rocket would be a "B4-4" which would eject the parachute after coasting for 4 seconds.

6. BEST ENGINE DELAY = 4 seconds

PROBLEM 1a

Imagine that another rocket is constructed of a #16 series tube and that its empty weight is 4.0 ounces. Which of the following engines "B4-2", "B4-4" or "B4-6" should be used in the rocket in order to obtain parachute ejection right near the peak altitude? (Again assume a Drag Coefficient value of C_D = .75 is reasonable for this rocket's shape). First fill in the basic information.

1. Total Impulse: Use the ____graphs
2. Lift-Off Weight =____ ounces
3. Drag Form Factor: C_DA =___ in^2

Then use this information to find:

4. MAXIMUM ALTITUDE = ____feet
5. COAST TIME =____ seconds
6. BEST ENGINE DELAY = __ seconds

PROBLEM 1b

If a rocket, constructed with a #7 series tube, has a Lift-Off Weight of 1.3 ounces including a "B4-2" engine, parachute and wadding, determine its maximum altitude and also decide whether or not the 2 second delay is the best engine delay time to use.

EXAMPLE 2
EFFECTS OF TOTAL IMPULSE

How high will a "½A6" powered MICRON kit (#7 series body tube) go if it weighs 1.05 ounces at lift-off? How much higher will this same rocket go if the power is increased to an "A8" engine?

The Drag Form Factor graph gives a C_DA of .339 square inches for a #7 tube and a Drag Coefficient of C_D = .75. The results are summarized below:

1. Total Impulse: Use the "½A6" graphs
2. Lift-Off Weight = 1.05 ounces
3. Drag Form Factor: C_DA = .339 in^2
4. MAXIMUM ALTITUDE = 210 feet
5. COAST TIME = 3.3 seconds
6. BEST DELAY TIME = 4 seconds

Next we "fly" the rocket with an "A8" motor. The weight difference between various Total Impulse engines is significant, whereas the weight differences between engines of various delay times in the same Total Impulse category is not.

We first must find the empty weight of the rocket by subtracting .5 oz, the average weight of a "½A6" engine.

$$\text{EMPTY WEIGHT} = \text{LIFT-OFF WEIGHT} - \text{"½A6" ENGINE WEIGHT}$$

$$= 1.05 \text{ ounce} - .5 \text{ ounce}$$

$$\text{EMPTY WEIGHT} = .55 \text{ ounce}$$

Then the .6 ounce average weight of the heavier, more powerful "A8" motor is added to the empty weight to find the new Lift-Off Weight.

$$\text{LIFT-OFF WEIGHT} = \text{EMPTY WEIGHT} + \text{"A8" ENGINE WEIGHT}$$

$$= .55 \text{ ounce} + .6 \text{ ounce}$$

$$\text{LIFT-OFF WEIGHT} = 1.15 \text{ ounces}$$

Alternatively, you could have just noticed the difference in the weight between the "½A6" and "A8" motors and added that amount directly. Having the average weights rounded off helps make this technique very convenient and the addition can be done mentally very easily with little practice.

The altitude of the MICRON, when using the "A8" motor, is found in the usual way.

1. Total Impulse: Use the "A8" graphs
2. Lift-Off Weight = 1.15 ounces
3. Drag Form Factor: C_DA = .339 in^2
4. MAXIMUM ALTITUDE = 500 feet
5. COAST TIME = 4.8 seconds
6. BEST DELAY TIME = 5 seconds

The "½A6" motor lifts the MICRON to 210 feet and the "A8" motor lifts it to 500 feet. Thus we can conclude for this case that doubling the Total Impulse of the engine more than doubles the maximum altitude reached by the rocket.

PROBLEM 2a

Will doubling the Total Impulse again to that of a "B6" motor more than double the maximum altitude of 500 feet reached by the "A8" powered MICRON?

1. Total Impulse: Use the "B6" graphs

2a. Average "B6" Engine Weight = _____ ounces
2b. New Lift-Off Weight = _____ ounces

3. Drag Form Factor: C_DA = .339 in^2

4. MAXIMUM ALTITUDE = _____ feet

5. COAST TIME = _____ seconds

6. BEST DELAY TIME = _____ seconds

7. HAS HEIGHT DOUBLED? ☐ YES ☐ NO

PROBLEM 2b

Compare the effect of using a "C6" engine to the "B6" engine. That is, will the "C6" cause the MICRON to reach twice the altitude of a "B6"? If not, how are they related? Which engine, the "B6" or "C6", will require the longest delay when used in the above example?

EXAMPLE 3

CLUSTER POWERED ROCKETS

The graphs in this report can also be used to analyze single-stage cluster powered model rockets as long as all the engines used in the cluster are identical.

The Lift-Off Weight and the Drag Form Factor (C_DA) values must both be divided by the number of engines in the cluster before reading the graphs. The new values are then used in the graphs as previously described to determine MAXIMUM ALTITUDE and COAST TIME.

For 2 engine clusters:

$$\text{Lift-Off Weight} = \frac{\text{Actual Lift-Off Weight}}{2}$$

$$C_DA = \frac{\text{Actual } C_DA}{2}$$

For 3 engine clusters:

$$\text{Lift-Off Weight} = \frac{\text{Actual Lift-Off Weight}}{3}$$

$$C_DA = \frac{\text{Actual } C_DA}{3}$$

With 4 engines, you divide by 4, etc.

By dividing the total weight and drag on the rocket by the number of engines in the cluster you are, in essence, creating an equivalent single-engine powered rocket. Each engine can now be thought of as separately thrusting against its proportionate share of the total weight and aerodynamic resistance. With this background information, we can now proceed to the first cluster example.

Imagine that we have a Defender kit which is powered by a cluster of 3 "B4" engines. It weighs 4.5 ounces with engine, chute and wadding and is constructed of a #16 series body tube. What will be its maximum altitude and what engine delay time (2, 4, or 6 seconds) should be used?

Organizing the information, we have:

1. Total Impulse: Use the "B4" graphs
2. Actual Lift-Off Weight = 4.5 ounces
3. Actual Drag Form Factor: C_DA = 1.58 in^2

Next, we must divide the total Lift-Off Weight and Drag Form Factor by the number of engines in the cluster (3 in this case) to find the values to use with the graphs.

2a. Lift-Off Weight = $\frac{4.5 \text{ ounces}}{3}$ = 1.5 ounces

3a. $C_DA = \frac{1.58 \text{ in}^2}{3} = .53 \text{ in}^2$

Now we use the graphs to find:

4. MAXIMUM ALTITUDE = 710 feet
5. COAST TIME = 4.9 seconds
6. BEST ENGINE DELAY = 4 seconds

PROBLEM 3a

How high will the above "B4" powered Defender go if a payload weighing 1.5 ounces is carried along? Also, what engine delay time should be chosen?

1. Total Impulse: Use "B4" graphs
2. New Actual Lift-Off Weight =_____ounces
2a. Use a Lift-Off Weight =_____ounces
3. Actual Drag Form Factor: C_DA = 1.58 in^2
3a. Use C_DA = .53 in^2
4. MAXIMUM ALTITUDE =_____feet
5. COAST TIME =_____seconds
6. BEST ENGINE DELAY =_____seconds

PROBLEM 3b

How high will the Defender go if its payload is 3.0 ounces instead of 1.5 ounces? Again, what engine delay should be chosen?

PROBLEM 3c

Assuming that the Defender is aerodynamically stable even if only two of its engines successfully ignite, what would its maximum altitude with the 3 ounce payload be and how many seconds after the peak would parachute ejection occur?

ANSWERS

Problem 1a

1. "B4"
2. 4.7
3. 1.58
4. About 140
5. About 2.3
6. 2

Problem 1b

MAXIMUM ALTITUDE = 950 feet
COAST TIME = 5.7 seconds
Use a "B4-6" engine instead of a "B4-2"

Problem 2a

2a. .7
2b. 1.25
4. About 940
5. About 5.9
6. 6
7. Not Quite

Problem 2b

New Lift-Off Weight = 1.45 ounces
MAXIMUM ALTITUDE = 1580 feet
COAST TIME = 6.2 seconds
BEST DELAY TIME = 7 seconds
Increasing the Total Impulse 100% only increased the altitude by about 60%
The "C6" coasts longer than the "B6".

Problem 3a

2. 6.0
2a. 2.0
4. About 615
5. About 4.8
6. 4

Problem 3b

MAXIMUM ALTITUDE = 490 feet
COAST TIME = About 4.5 seconds
BEST ENGINE DELAY = 4 seconds

Problem 3c

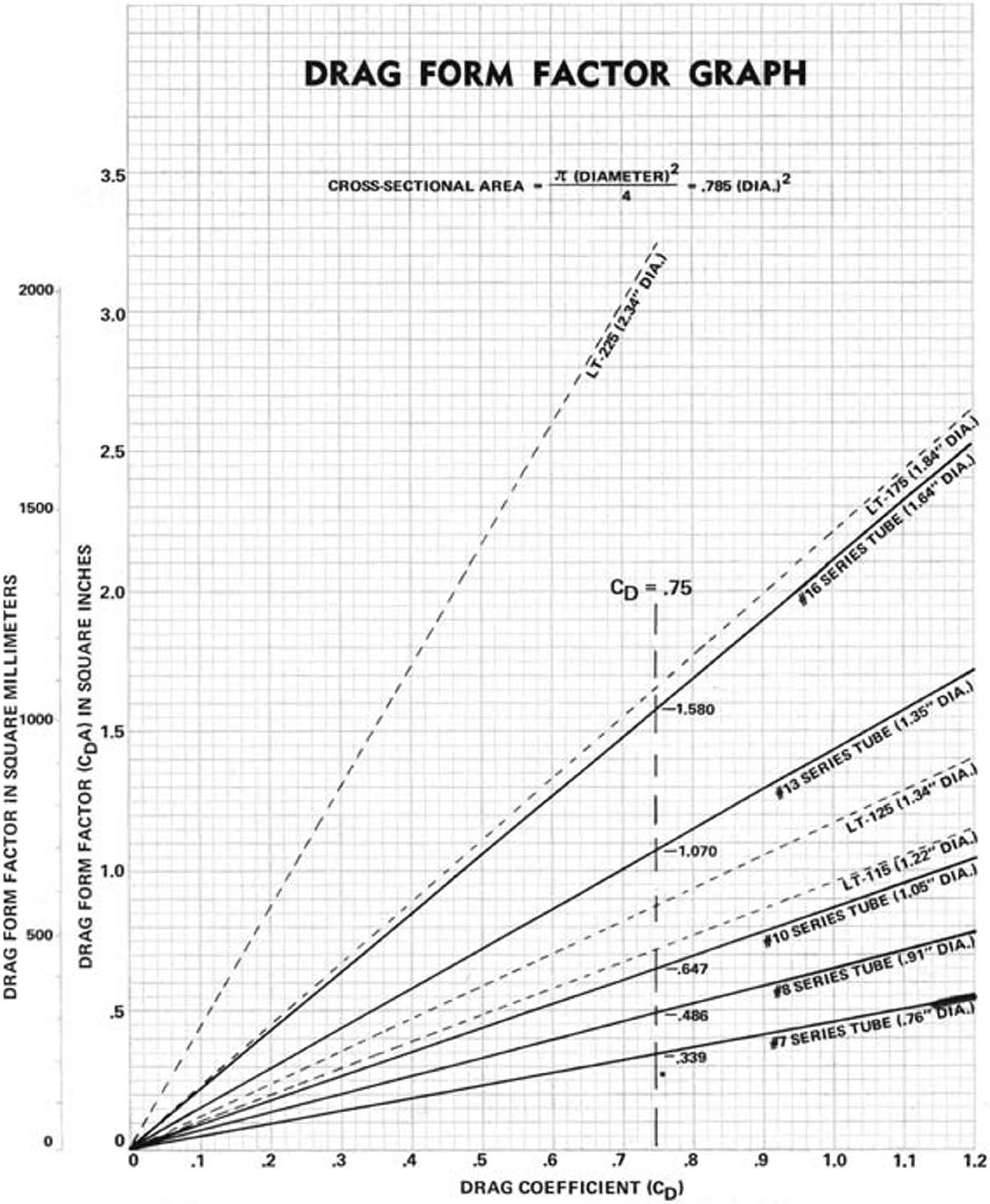
2. Actual Lift-Off Weight = 7.5 ounces
2a. Use Lift-Off Weight = $\frac{7.5}{2}$ = 3.75 ounces
3. Actual Drag Form Factor: C_DA = 1.58 in^2
3a. Use $C_DA = \frac{1.58}{2} = .79 \text{ in}^2$
4. MAXIMUM ALTITUDE = 245 feet
5. COAST TIME = 3.2 seconds
6. Parachute ejects .8 second after reaching peak.

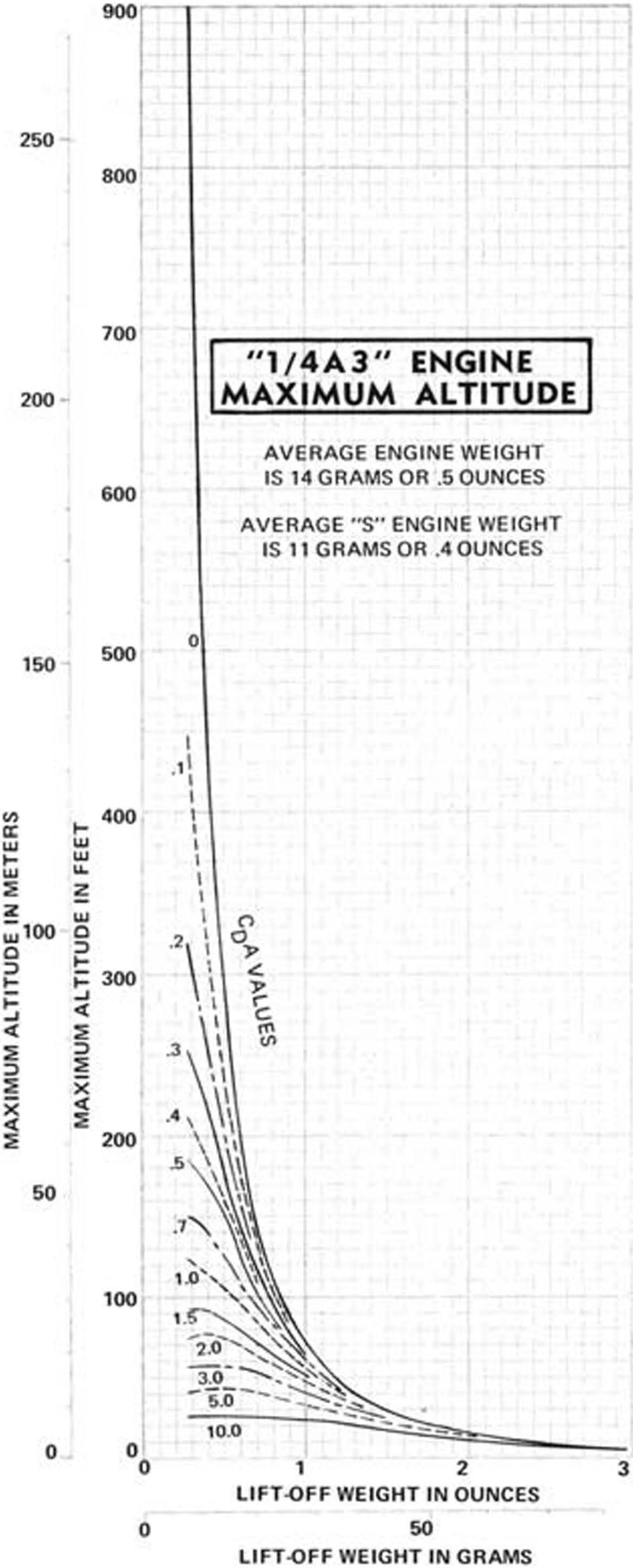
TEST YOURSELF

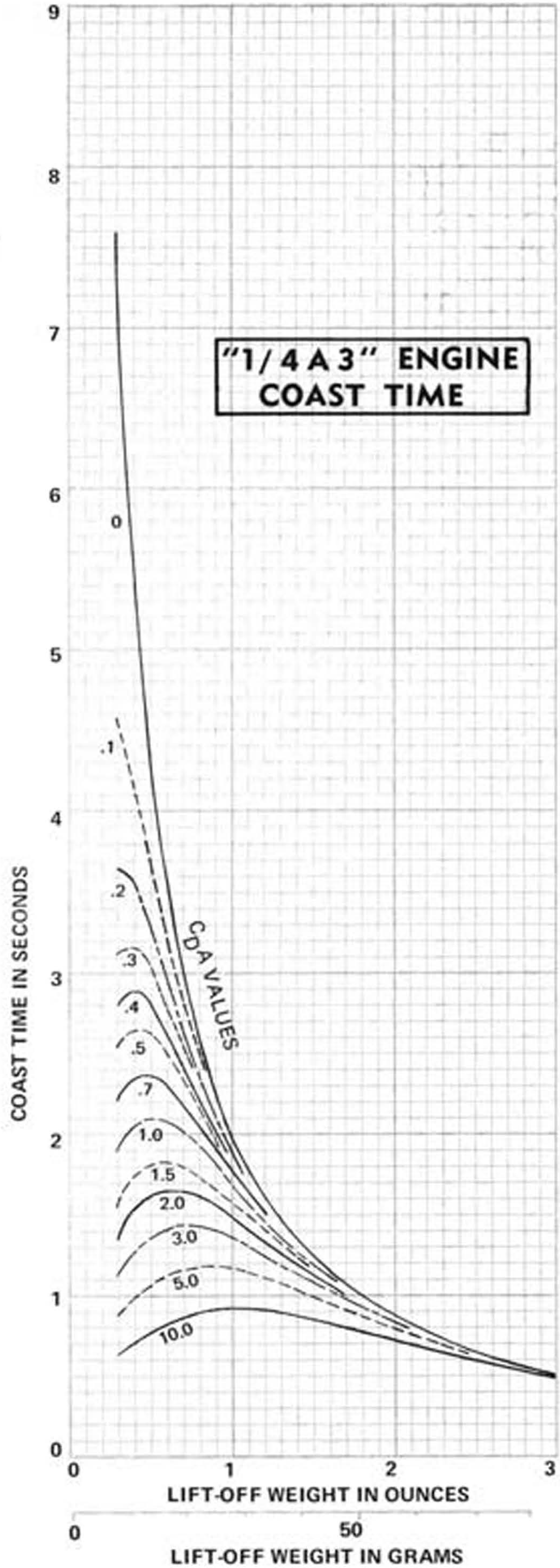
After you have studied the remaining sections of this report, you can test yourself to see how well you understand the information by taking the TIR-100 Examination.

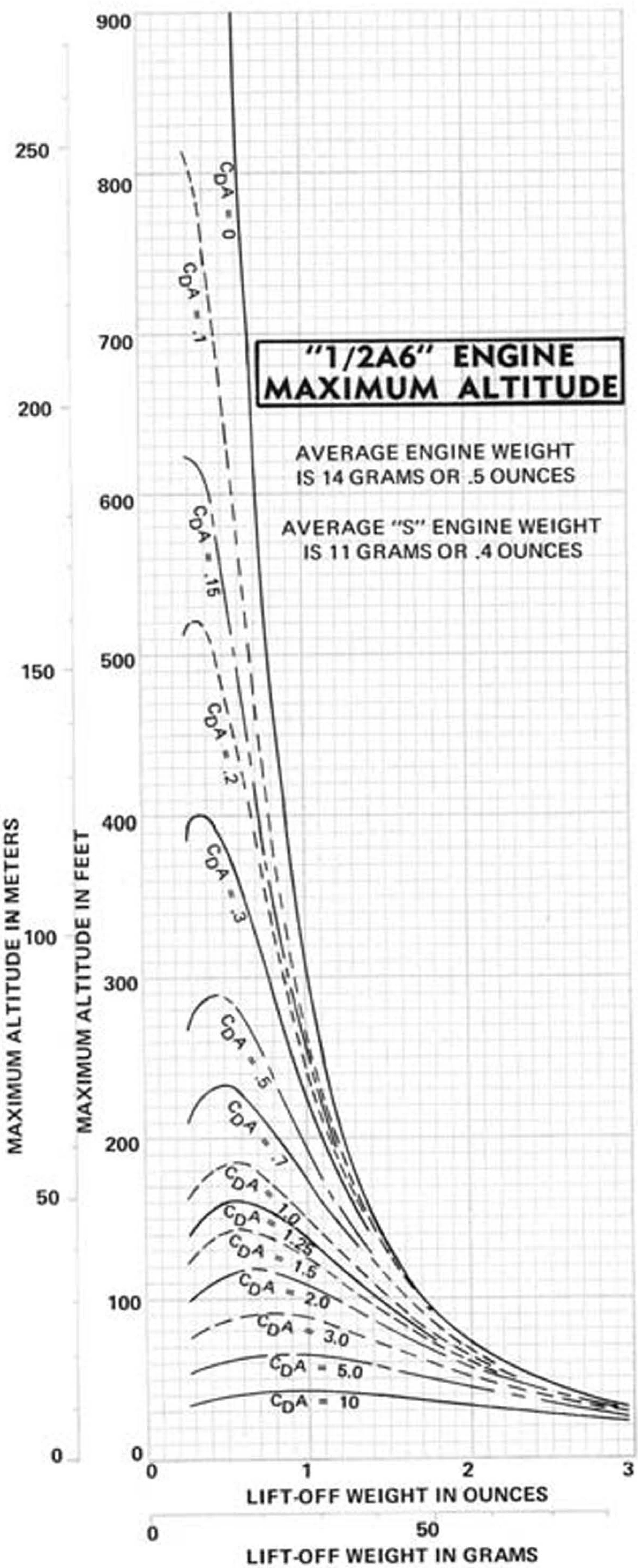
THE PERFORMANCE GRAPHS

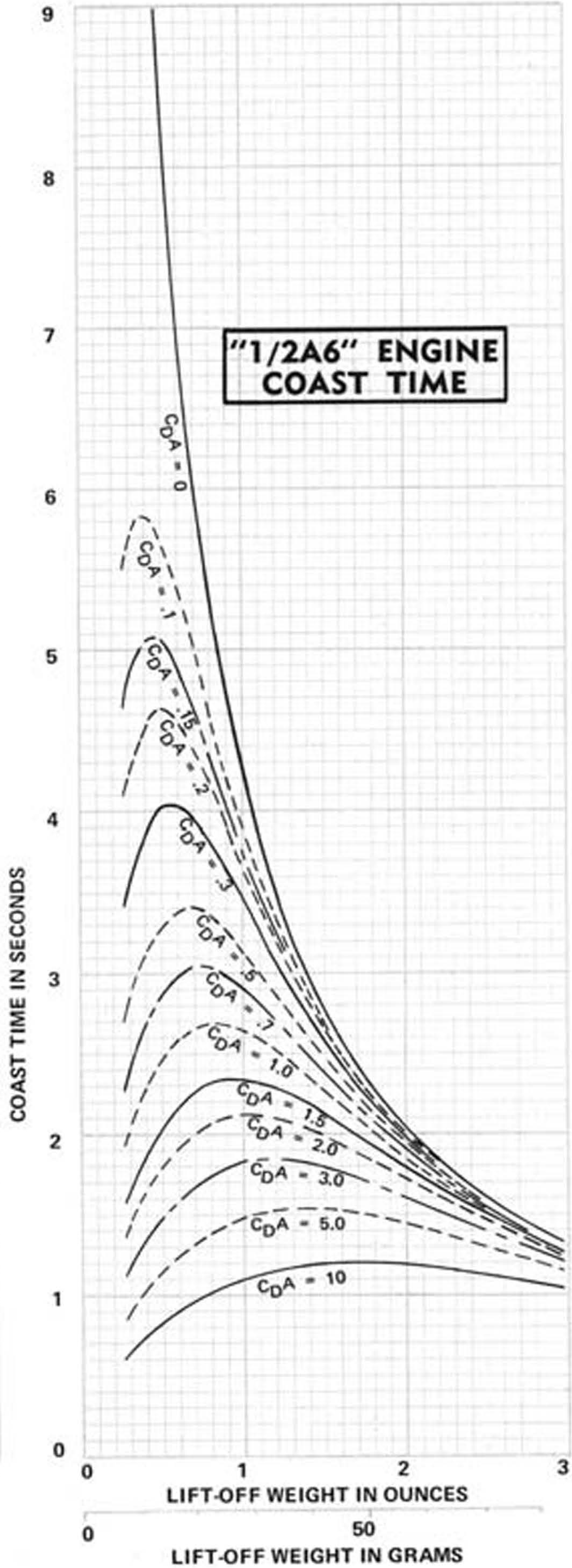
The MAXIMUM ALTITUDE and COAST TIME graphs for all engines are presented on Pages 12 through 43.

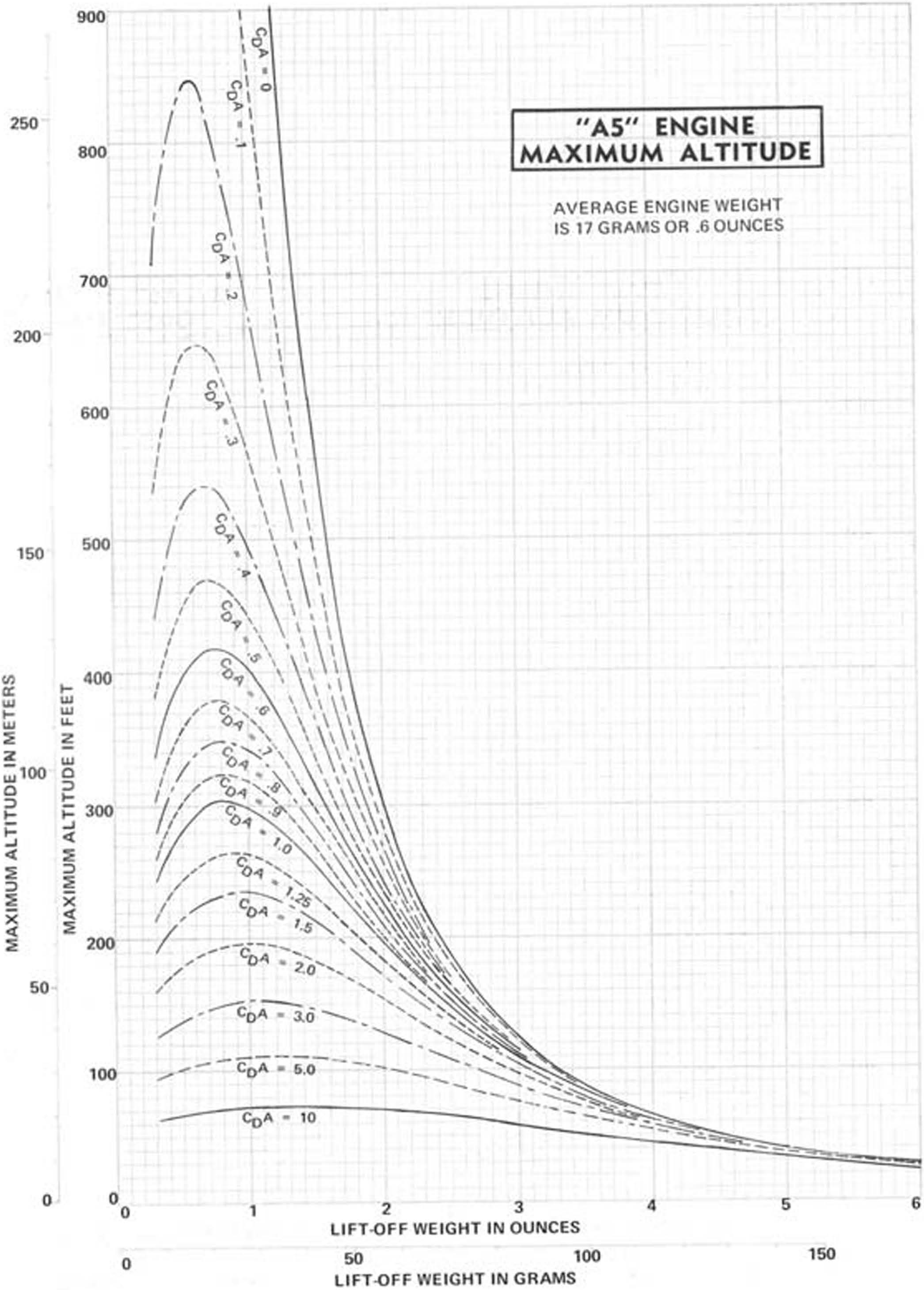



"1/4A3" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 14 GRAMS OR .5 OUNCES
AVERAGE "S" ENGINE WEIGHT
IS 11 GRAMS OR .4 OUNCES
C_DA VALUES
0
.1
.2
.3
.4
.5
.7
1.0
1.5
2.0
3.0
5.0
10.0
MAXIMUM ALTITUDE IN METERS
0
50
100
150
200
250
MAXIMUM ALTITUDE IN FEET
0
100
200
300
400
500
600
700
800
900
LIFT-OFF WEIGHT IN OUNCES
0
1
2
3
LIFT-OFF WEIGHT IN GRAMS
0
50


"1/4A3" ENGINE
COAST TIME
C_DA VALUES
0
.1
.2
.3
.4
.5
.7
1.0
1.5
2.0
3.0
5.0
10.0
COAST TIME IN SECONDS
0
1
2
3
4
5
6
7
8
9
LIFT-OFF WEIGHT IN OUNCES
0
1
2
3
LIFT-OFF WEIGHT IN GRAMS
0
50


"1/2A6" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 14 GRAMS OR .5 OUNCES
AVERAGE "S" ENGINE WEIGHT
IS 11 GRAMS OR .4 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .3
C_DA = .5
C_DA = .7
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
50
100
150
200
250
0
100
200
300
400
500
600
700
800
900
0
1
2
3
0
50

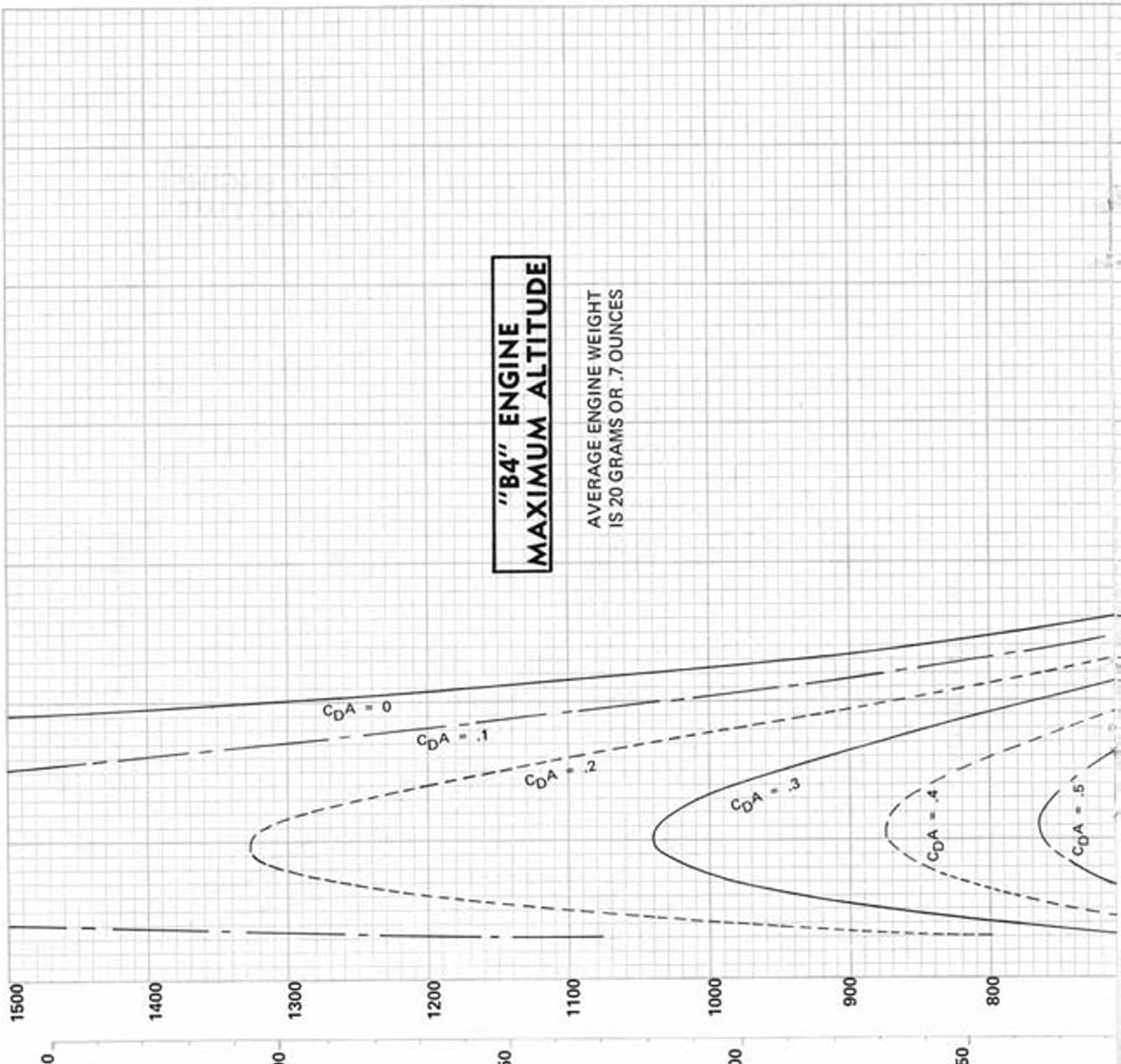

"1/2A6" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .3
C_DA = .5
C_DA = .7
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
1
2
3
4
5
6
7
8
9
0
1
2
3
0
50

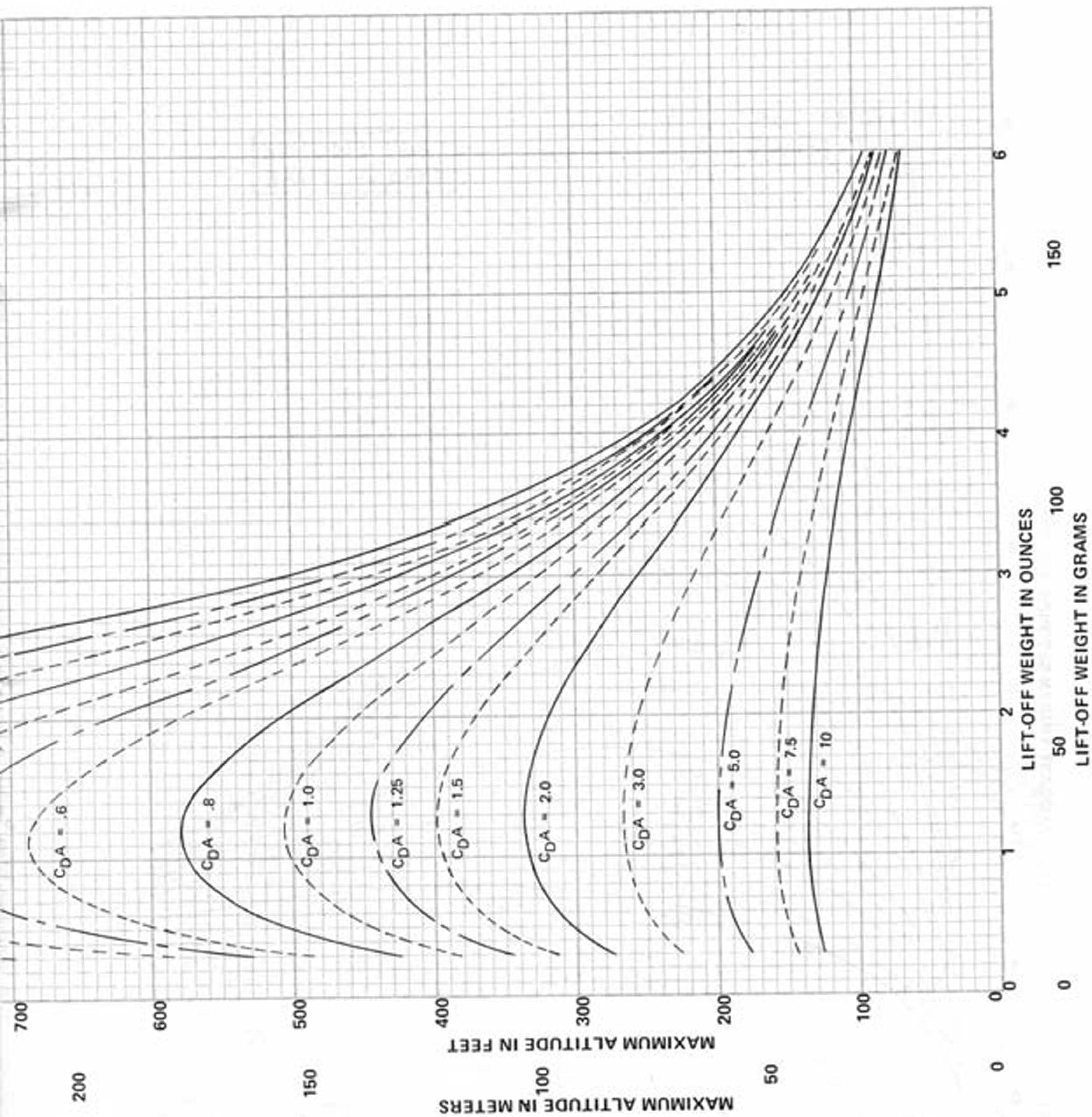

"A5" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 17 GRAMS OR .6 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
$C_DA = 0$
$C_DA = .1$
$C_DA = .2$
$C_DA = .3$
$C_DA = .4$
$C_DA = .5$
$C_DA = .6$
$C_DA = .7$
$C_DA = .8$
$C_DA = .9$
$C_DA = 1.0$
$C_DA = 1.25$
$C_DA = 1.5$
$C_DA = 2.0$
$C_DA = 3.0$
$C_DA = 5.0$
$C_DA = 10$


"A5" ENGINE COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .2
C_DA = .3
C_DA = .4
C_DA = .5
C_DA = .7
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
0
50
100
150

"A8" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 17 GRAMS OR .6 OUNCES
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .3
C_DA = .4
C_DA = .5
C_DA = .6
C_DA = .7
C_DA = .8
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS


"A8" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .3
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
0
50
100
150

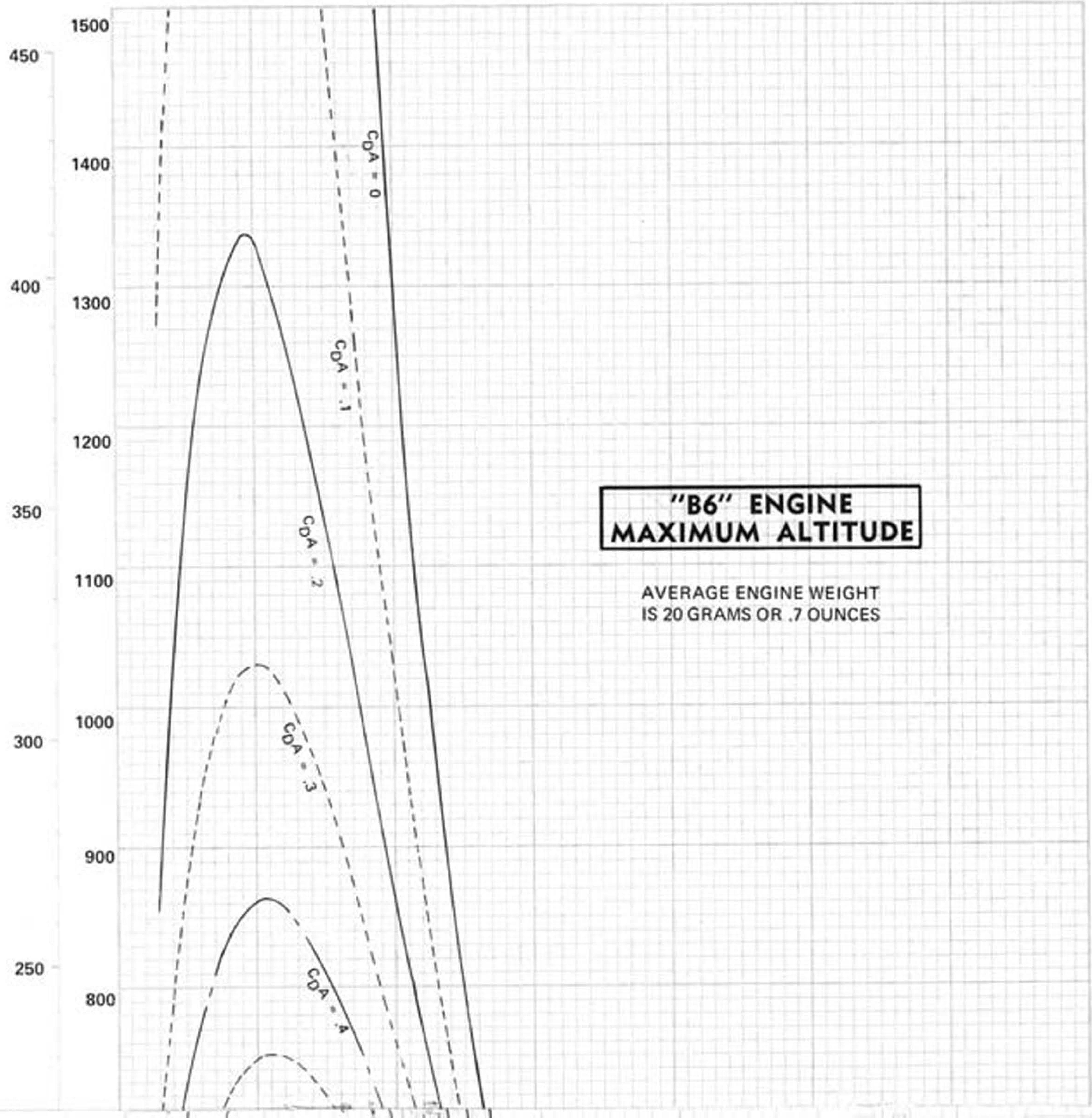

"B4" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 20 GRAMS OR .7 OUNCES
C_DA = 0
C_DA = .1
C_DA = .2
C_DA = .3
C_DA = .4
C_DA = .5
1500
1400
1300
1200
1100
1000
900
800
450
400
350
300
250

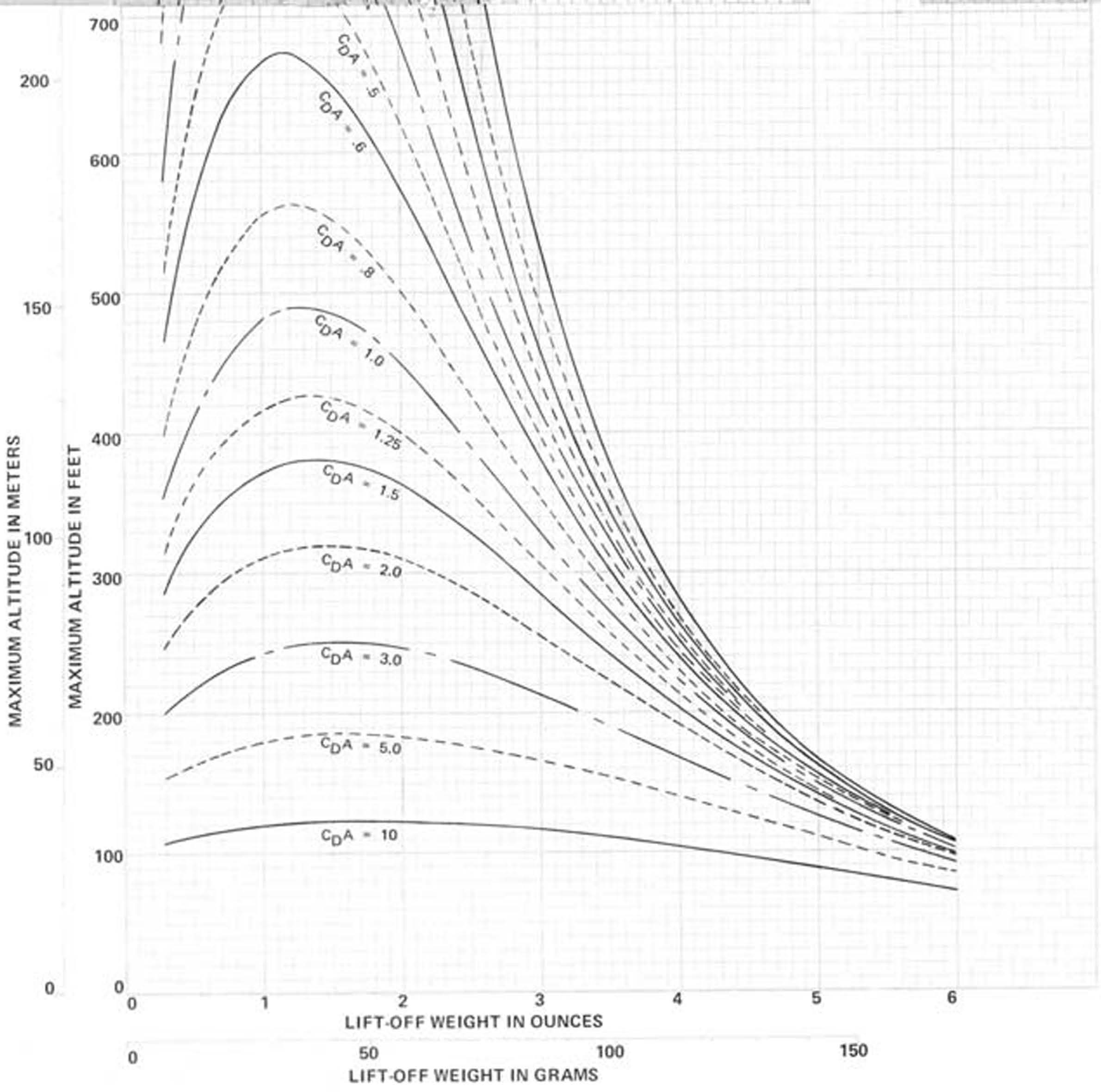


LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
MAXIMUM ALTITUDE IN FEET
MAXIMUM ALTITUDE IN METERS
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 7.5
C_DA = 10

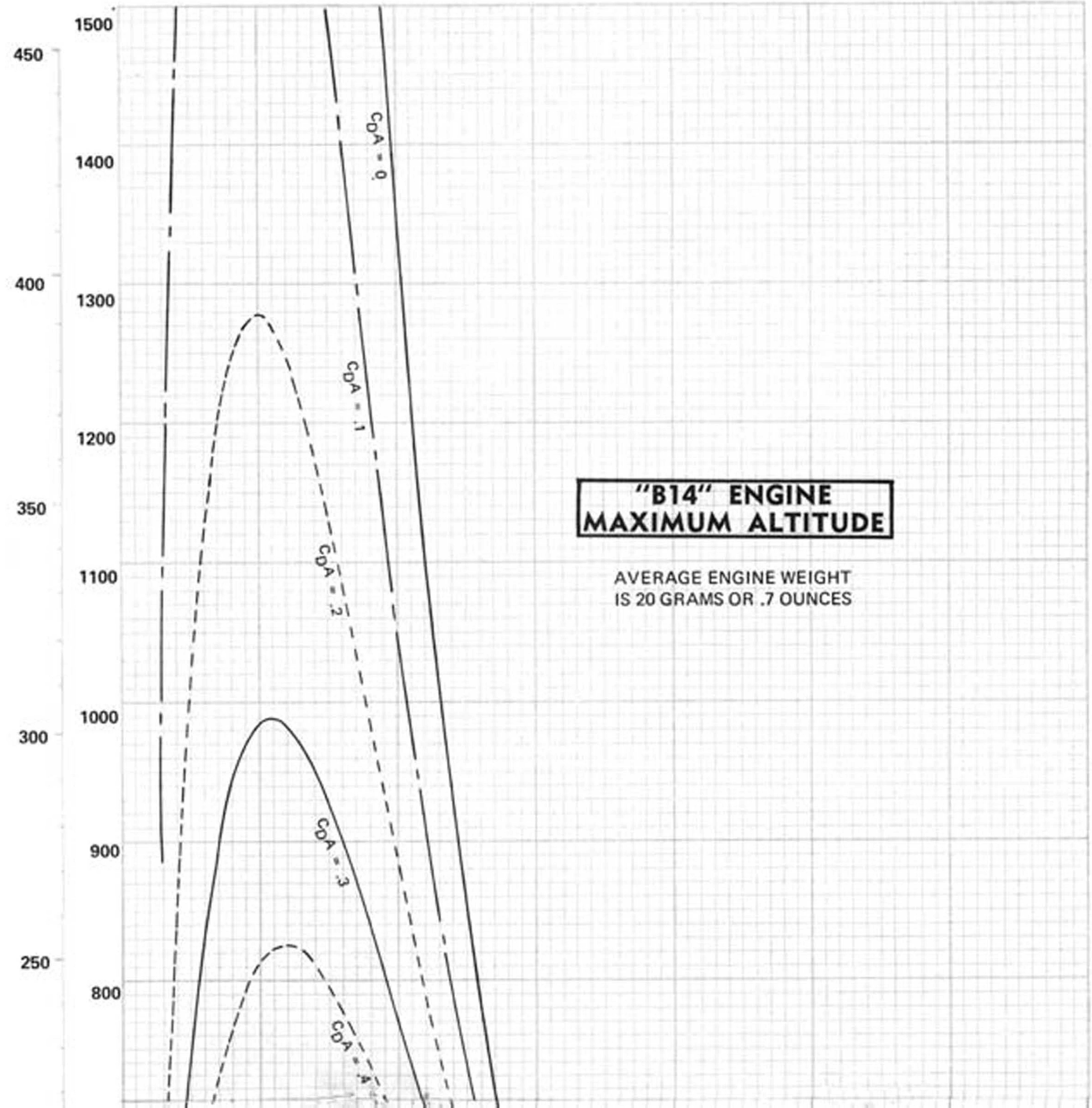

"B4" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 5.0
C_DA = 7.5
C_DA = 10
0
1
2
3
4
5
6
7
8
9
0
50
100
150


"B6" ENGINE
COAST TIME
COAST TIME IN SECONDS
9
8
7
6
5
4
3
2
1
0
$C_DA = 0$
$C_DA = .1$
$C_DA = .2$
$C_DA = .4$
$C_DA = .6$
$C_DA = .8$
$C_DA = 1.0$
$C_DA = 1.5$
$C_DA = 2.0$
$C_DA = 3.0$
$C_DA = 5.0$
$C_DA = 10$
0
1
2
3
4
5
6
LIFT-OFF WEIGHT IN OUNCES
0
50
100
150
LIFT-OFF WEIGHT IN GRAMS

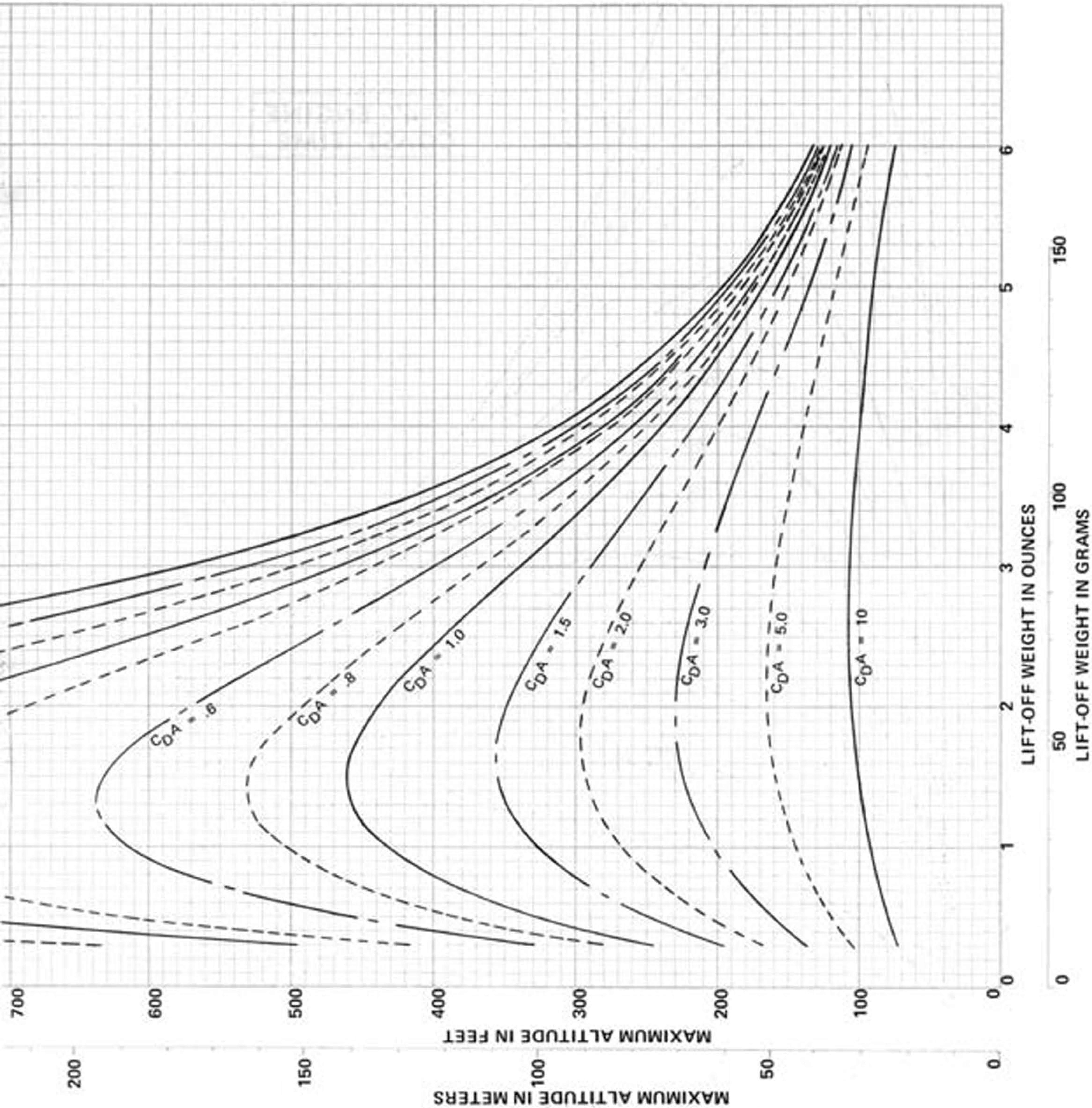

"B6" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 20 GRAMS OR .7 OUNCES
C_DA = 0
C_DA = .1
C_DA = .2
C_DA = .3
C_DA = .4
1500
1400
1300
1200
1100
1000
900
800
450
400
350
300
250

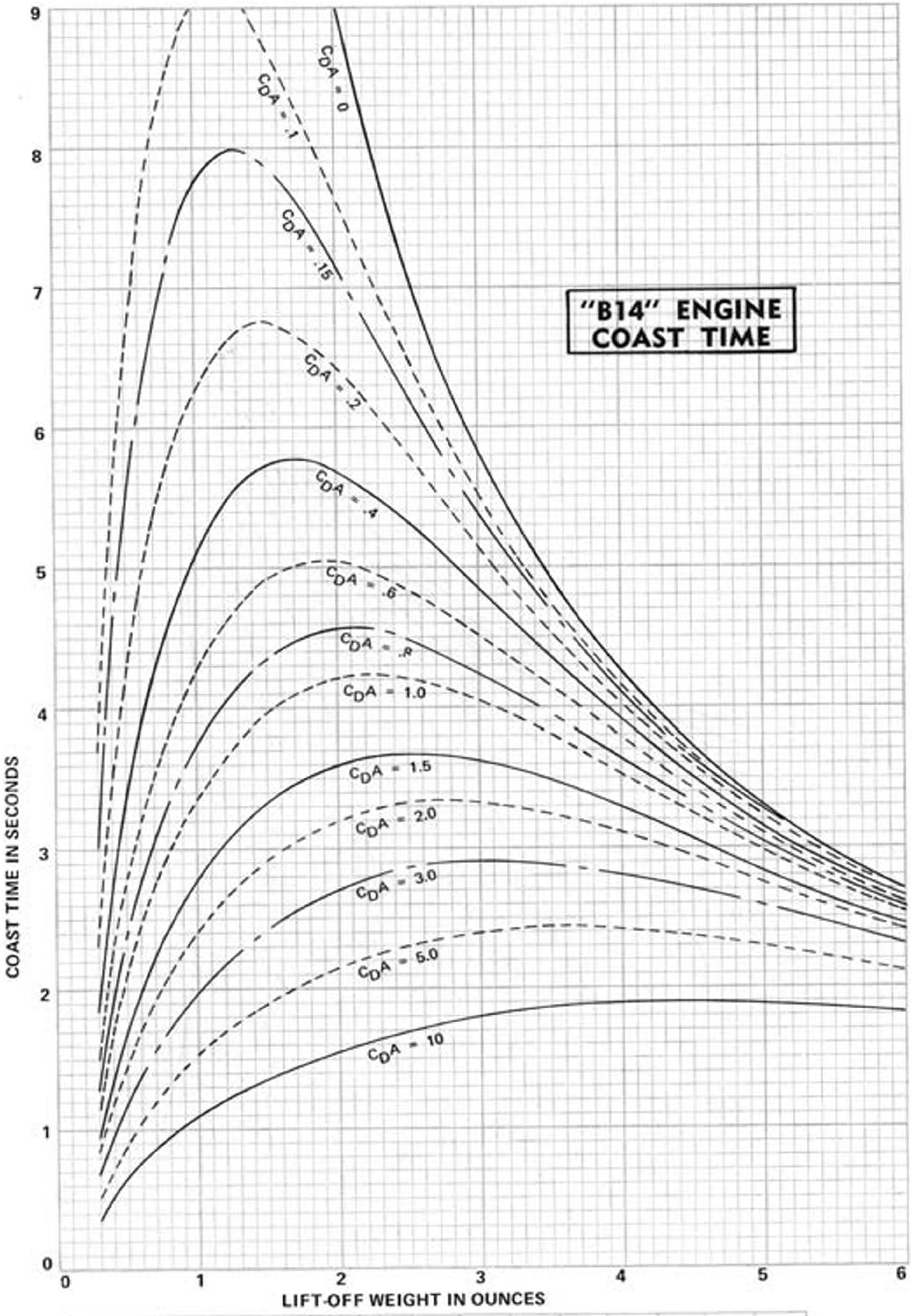


MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = .5
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
50
100
150
200
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
0
50
100
150

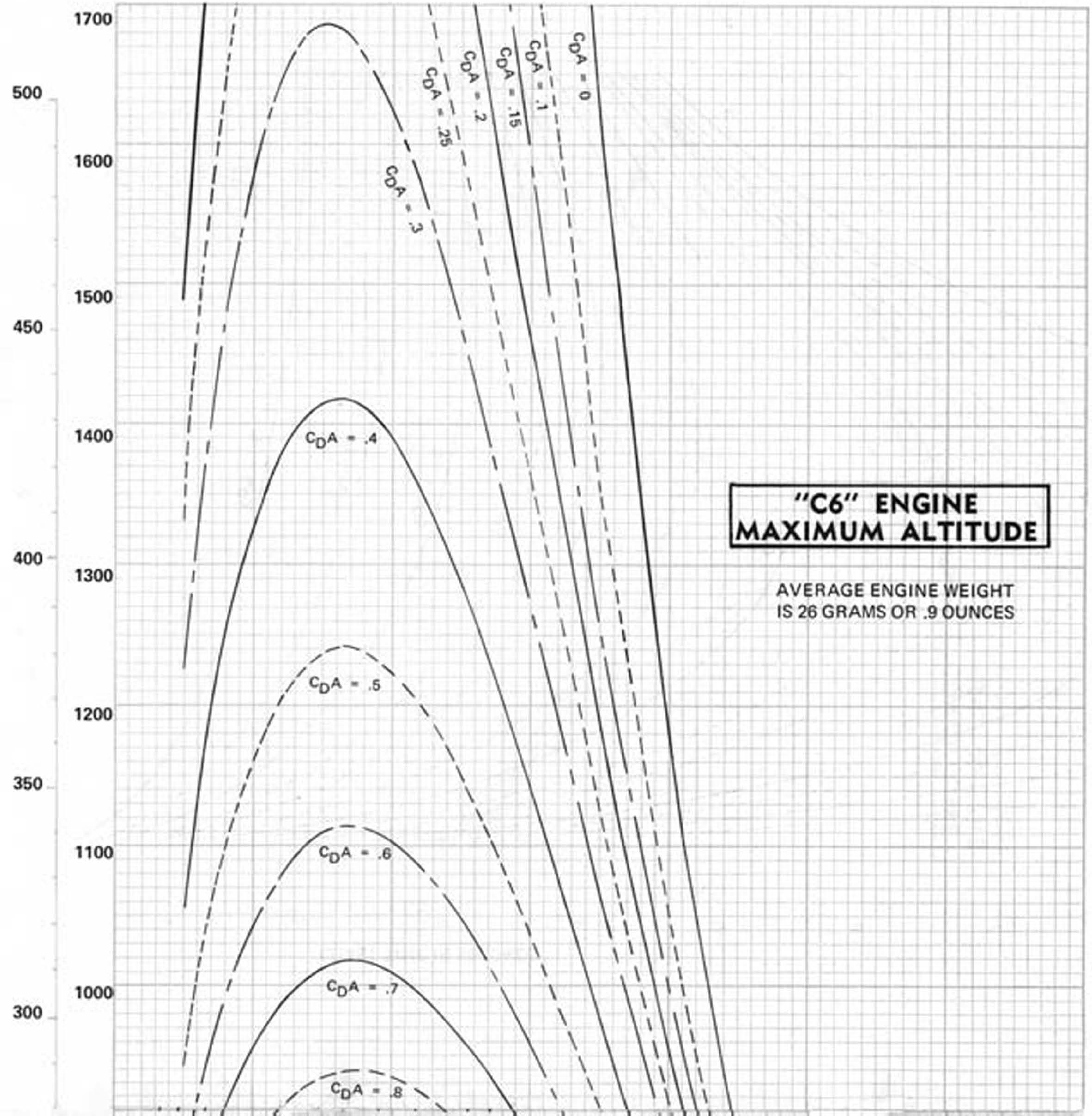


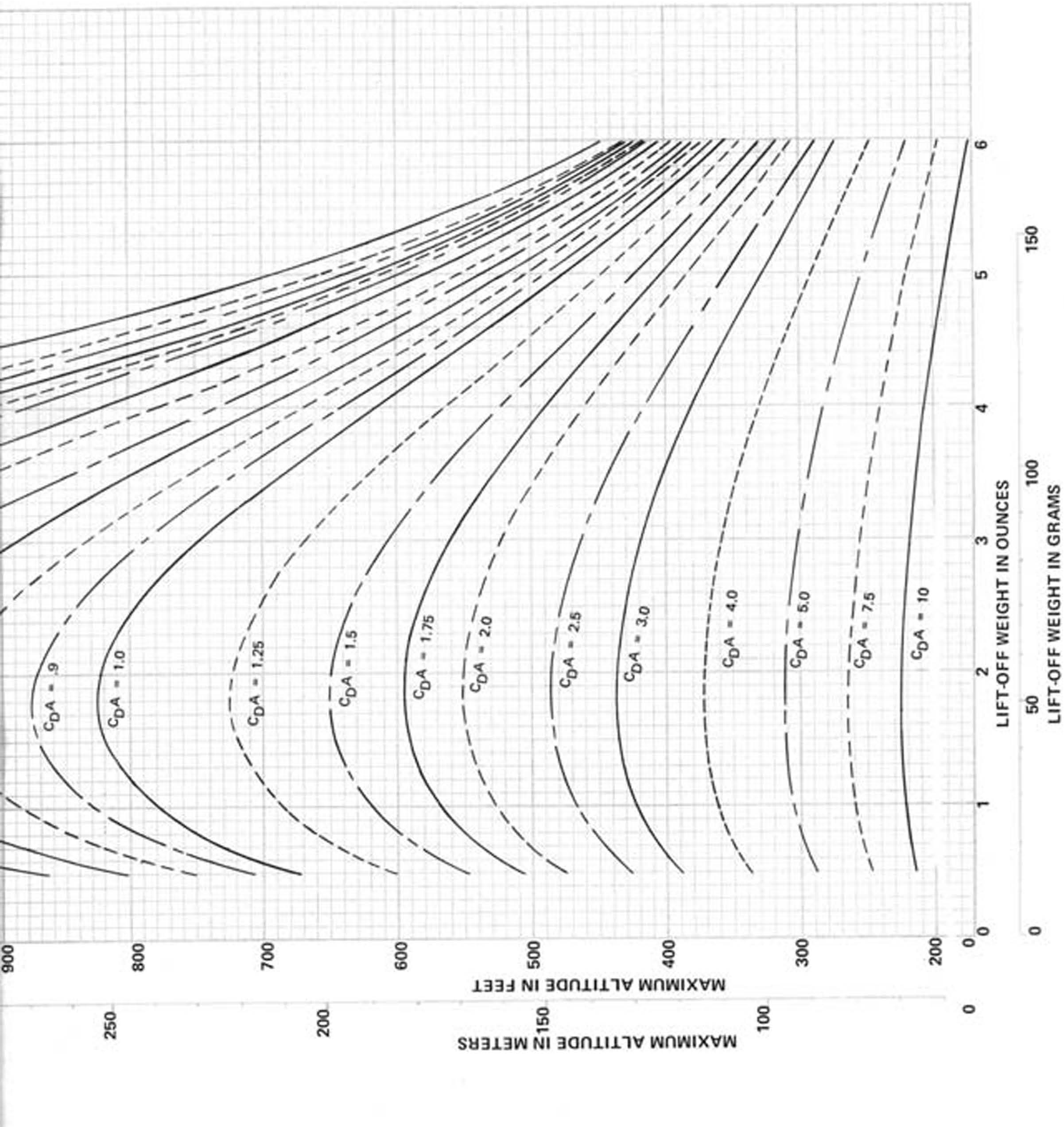
"B14" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 20 GRAMS OR .7 OUNCES
CDA = 0
CDA = .1
CDA = .2
CDA = .3
CDA = .4
1500
1400
1300
1200
1100
1000
900
800
450
400
350
300
250


MAXIMUM ALTITUDE IN FEET
MAXIMUM ALTITUDE IN METERS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10


"B14" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10
0
1
2
3
4
5
6
7
8
9
50
100
150


"C6" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
0
1
2
3
4
5
6
7
8
9
0
50
100
150
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .25
C_DA = .3
C_DA = .4
C_DA = .5
C_DA = .7
C_DA = 1.0
C_DA = 1.5
C_DA = 2.0
C_DA = 3.0
C_DA = 5.0
C_DA = 10

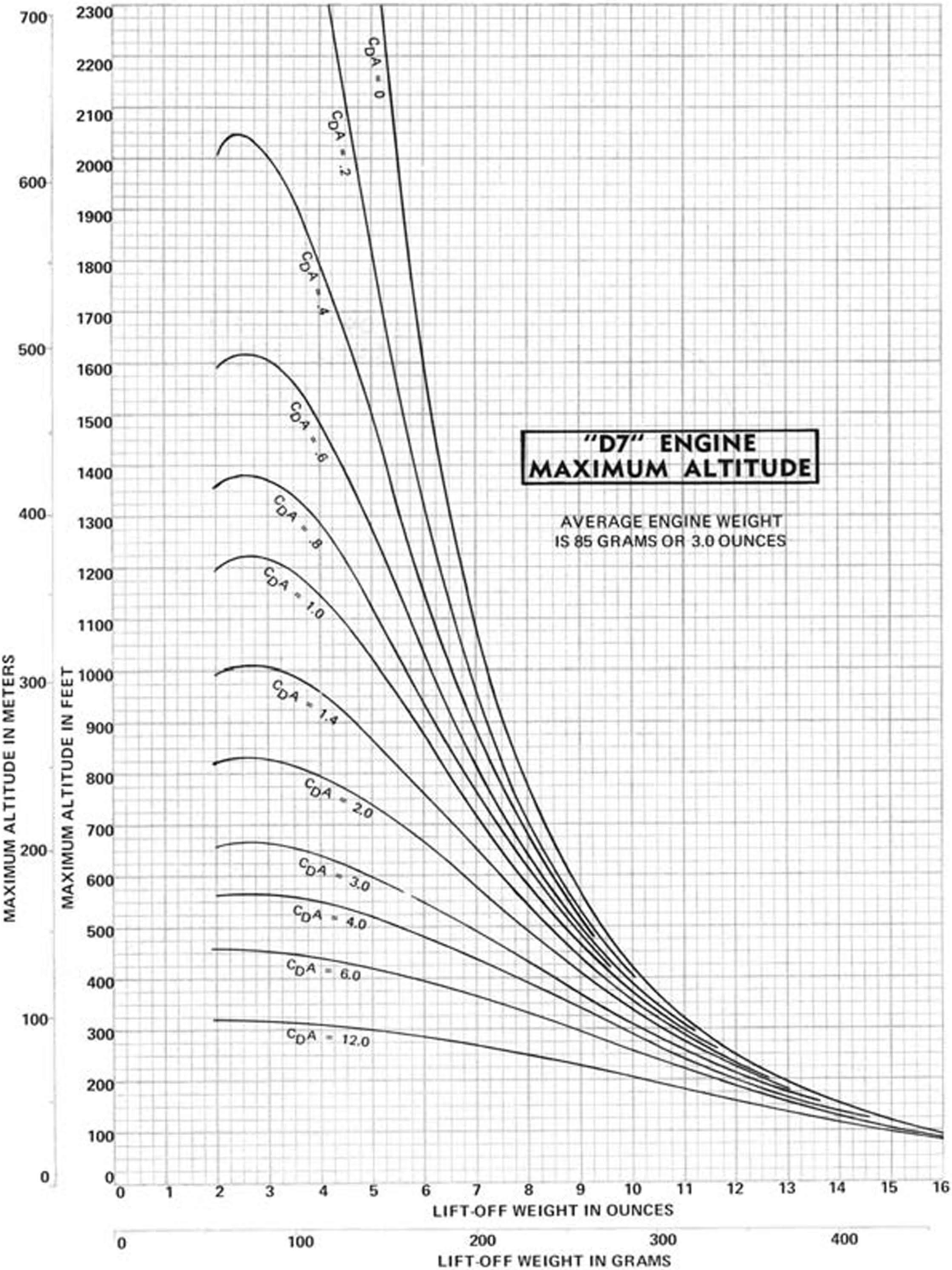

"C6" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 26 GRAMS OR .9 OUNCES
C_DA = 0
C_DA = .1
C_DA = .15
C_DA = .2
C_DA = .25
C_DA = .3
C_DA = .4
C_DA = .5
C_DA = .6
C_DA = .7
C_DA = .8
1700
1600
1500
1400
1300
1200
1100
1000
500
450
400
350
300



LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
MAXIMUM ALTITUDE IN FEET
MAXIMUM ALTITUDE IN METERS
C_DA = .9
C_DA = 1.0
C_DA = 1.25
C_DA = 1.5
C_DA = 1.75
C_DA = 2.0
C_DA = 2.5
C_DA = 3.0
C_DA = 4.0
C_DA = 5.0
C_DA = 7.5
C_DA = 10
0
1
2
3
4
5
6
0
50
100
150
200
300
400
500
600
700
800
900
0
100
150
200
250


"D9" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 80 GRAMS OR 2.8 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
CDA = 0
CDA = .2
CDA = .4
CDA = .6
CDA = .8
CDA = 1.0
CDA = 1.4
CDA = 2.0
CDA = 3.0
CDA = 4.0
CDA = 6.0
CDA = 12.0


"D9" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
$C_DA = 0$
$C_DA = .2$
$C_DA = .4$
$C_DA = .6$
$C_DA = .8$
$C_DA = 1.0$
$C_DA = 1.4$
$C_DA = 2.0$
$C_DA = 3.0$
$C_DA = 4.0$
$C_DA = 6.0$
$C_DA = 12.0$
0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 100 200 300 400



"D7" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 85 GRAMS OR 3.0 OUNCES
$C_DA = 0$
$C_DA = .2$
$C_DA = .4$
$C_DA = .6$
$C_DA = .8$
$C_DA = 1.0$
$C_DA = 1.4$
$C_DA = 2.0$
$C_DA = 3.0$
$C_DA = 4.0$
$C_DA = 6.0$
$C_DA = 12.0$
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS

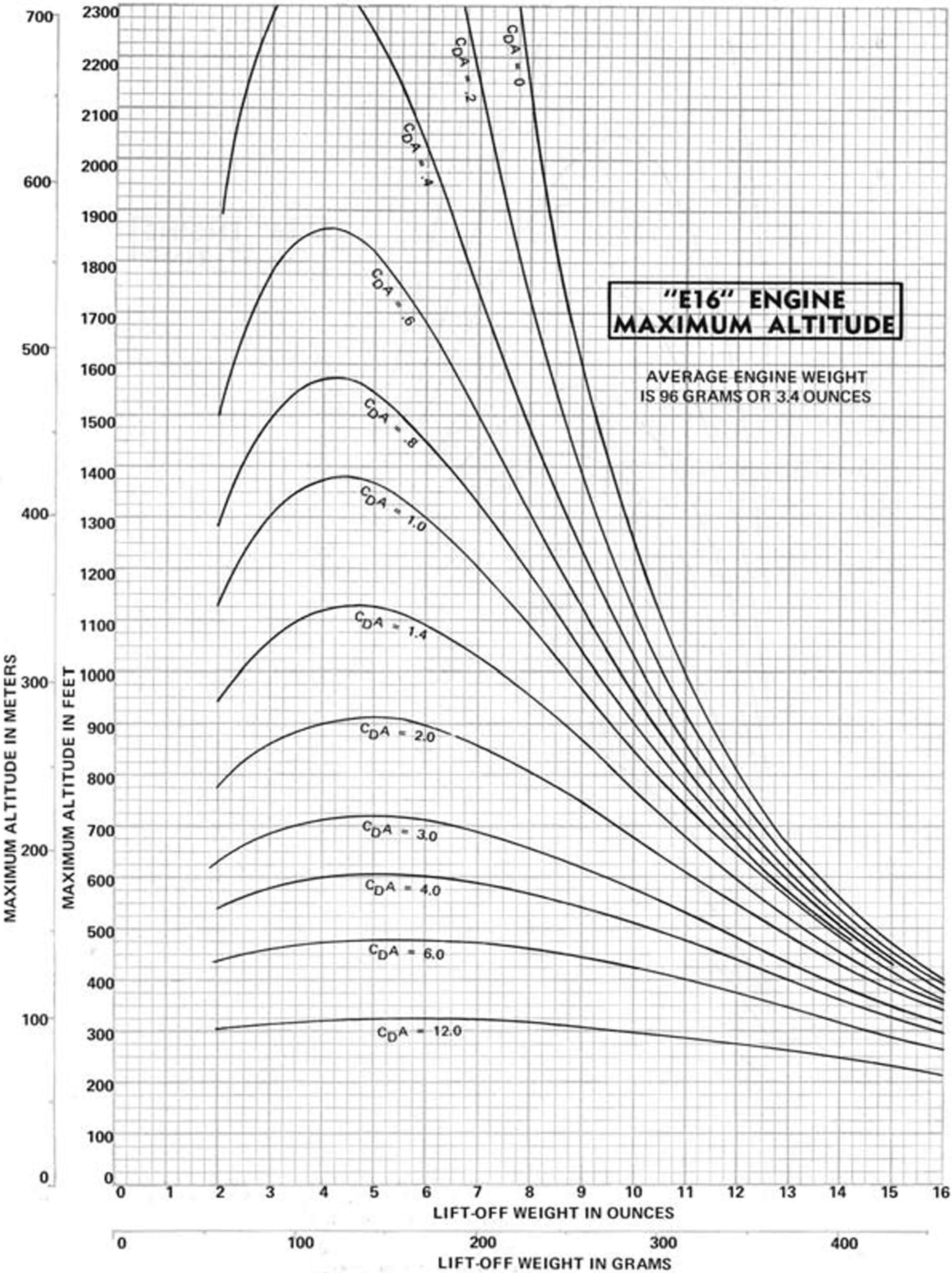

"D7" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
100
200
300
400


"D17" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 85 GRAMS OR 3.0 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .2
C_DA = .3
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0
0 100 200 300 400 500 600 700
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 100 200 300 400


"D17" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
CDA = 0
CDA = .2
CDA = .4
CDA = .6
CDA = .8
CDA = 1.0
CDA = 1.4
CDA = 2.0
CDA = 3.0
CDA = 4.0
CDA = 6.0
CDA = 12.0


"E6" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 96 GRAMS OR 3.4 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0

"E6" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
$C_DA = 0$
$C_DA = .2$
$C_DA = .4$
$C_DA = .6$
$C_DA = .8$
$C_DA = 1.0$
$C_DA = 1.4$
$C_DA = 2.0$
$C_DA = 3.0$
$C_DA = 4.0$
$C_DA = 6.0$
$C_DA = 12.0$
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
100
200
300
400



"E16" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 96 GRAMS OR 3.4 OUNCES
C_DA = 0
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0
MAXIMUM ALTITUDE IN METERS
0
100
200
300
400
500
600
700
MAXIMUM ALTITUDE IN FEET
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LIFT-OFF WEIGHT IN OUNCES
0
100
200
300
400
LIFT-OFF WEIGHT IN GRAMS


"E16" ENGINE
COAST TIME
CDA = 0
CDA = .2
CDA = .4
CDA = .6
CDA = .8
CDA = 1.0
CDA = 1.4
CDA = 2.0
CDA = 3.0
CDA = 4.0
CDA = 6.0
CDA = 12.0
COAST TIME IN SECONDS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LIFT-OFF WEIGHT IN OUNCES
0
100
200
300
400
LIFT-OFF WEIGHT IN GRAMS


"F44" ENGINE
MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT
IS 130 GRAMS OR 4.6 OUNCES
MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
CDA = 0
CDA = .2
CDA = .4
CDA = .6
CDA = .8
CDA = 1.0
CDA = 1.4
CDA = 2.0
CDA = 3.0
CDA = 4.0
CDA = 6.0
CDA = 12.0


"F44" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0
0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 100 200 300 400

MAXIMUM ALTITUDE IN METERS
MAXIMUM ALTITUDE IN FEET
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .1
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0
"F62" ENGINE MAXIMUM ALTITUDE
AVERAGE ENGINE WEIGHT IS 130 GRAMS OR 4.6 OUNCES

"F62" ENGINE
COAST TIME
COAST TIME IN SECONDS
LIFT-OFF WEIGHT IN OUNCES
LIFT-OFF WEIGHT IN GRAMS
C_DA = 0
C_DA = .2
C_DA = .4
C_DA = .6
C_DA = .8
C_DA = 1.0
C_DA = 1.4
C_DA = 2.0
C_DA = 3.0
C_DA = 4.0
C_DA = 6.0
C_DA = 12.0

AERODYNAMIC DRAG

DISCUSSION

The Drag Force on any object depends on how streamlined it is, how large it is, how fast it is moving, and what is it moving through.

All of the variables that affect the magnitude of the Drag Force can be combined into the single equation:

$$D = C_D A ½ \rho V^2$$

The above symbols represent a shorthand notation to help you remember how each of the variables influences total drag. An explanation of each symbol follows:

D — the result on the left-hand side of the equation represents the total aerodynamic Drag Force on the rocket.

C_D — represents the aerodynamic Drag Coefficient. When known, it immediately tells you how streamlined an arbitrary shape is.

A — represents the reference area that indicates the size of the rocket. For model rocket aerodynamic drag studies, we use a cross-sectional area based on the largest body tube diameter used in the rocket.

ρ — the Greek letter rho (pronounced row) represents the density of the air.

V — represents the velocity of the rocket as it travels through still air, or in the case of a model rocket in a wind tunnel, it represents the velocity of the air rushing over the still rocket. V^2 means velocity is squared or multiplied by itself.

The above formula is not magic, it simply happens to realistically represent the physical entity called aerodynamic drag.

The following discussion should help you understand that the Drag Force is properly represented by the above mathematical equation.

VELOCITY (V)

One of the most important influences on the total Drag Force (D) of the rocket is the velocity of the rocket. Drag has been found to be proportional to the square of velocity (V^2). This means that doubling the velocity increases the total Drag Force by a factor of four ($2^2 = 4$), while tripling the velocity gives nine times the drag ($3^2 = 9$).

REFERENCE AREA (A)

As expected, the aerodynamic Drag Force (D) on a rocket increases with the size of the rocket. If the rocket had zero cross-sectional area (A), you can see that there would be zero Drag Force (D). Similarly, you can see that as area (meaning size) increases, so does the Drag Force (D) on the left-hand side of the equation.

DRAG COEFFICIENT (C_D)

Because the Drag Coefficient directly affects the Drag Force, the smaller the Drag Coefficient (C_D) of a rocket of a given size, the lower will be the total Drag Force (D) at any given density and velocity condition.

The effects due to the shapes of the various parts of the rocket have been lumped into the C_D term. Because the surface finish on the rocket also helps to reduce the total drag on the rocket, this condition is also reflected in the C_D term.

If the nose of the rocket is squared instead of streamlined, it will mean a higher drag and C_D for the rocket. If the fins have an airfoil rather than a squared-off shape, they will be more streamlined and thus will help to decrease the magnitude of the C_D. If the fins have a smooth fillet of glue where they are attached to the body, it will allow the air to flow by more smoothly. Thus, fillets help to reduce C_D. Gluing a launch lug on the side of the body tube increases the drag on the rocket and this shows up as a slight increase in the aerodynamic Drag Coefficient (C_D).

Referring back to the equation again you can see that as C_D increases, the Drag Force (D) on the left-hand side of the equation increases accordingly.

DENSITY (ρ)

Density also affects the Drag Force on an object. As density increases, the drag increases — as density decreases, the Drag Force can be seen to decrease accordingly. You may ask, what is density and how does it vary?

Density is basically a measure of the weight of a given material in a given volume of space. For instance, the density of water is 62.4 pounds per cubic foot under "standard conditions" (a temperature of 59° Fahrenheit and at sea level), while the density of air is 1.22 ounces per cubic foot under "standard conditions". As you can see, water is much "denser" than air.

Why the specified temperature and altitude conditions? Because the density of air changes with both temperature and altitude. Air expands and thins out (density decreases) as temperature increases. Also, as altitude increases, the earth's atmosphere thins out (air density decreases). When you reach outer space, the density of air has diminished to zero and, as can be seen from the drag equation, the Drag Force (D) also diminishes to zero irregardless of the size and shape of an object or its velocity (e.g., satellites and space ships have no drag once in outer space).

Getting back down to earth, the rocketeer will be interested in knowing how much of a change occurs in the density of air in the altitude regions in which model rockets are flown. This information can be obtained from the Air Density Compensation graph on the next page. It shows exactly how altitude and temperature variations change the density of the air.

You can find the amount of change (% ρ) by first locating the temperature and altitude values, that fit your situation, along the sides of the graph. The density reduction factor (% ρ) is found by extending the temperature and altitude values on the grid until they intersect. For example, the density reduction factor (% ρ) for a temperature of 80° at an elevation of 5000 feet is % ρ = .83.

When using the Maximum Altitude and Coast Time graphs in this report, you can accurately account for the affect of thinner (less dense) air by simply multiplying the rocket's Actual Drag Form Factor (C_DA) by the density reduction factor (% ρ). That is,

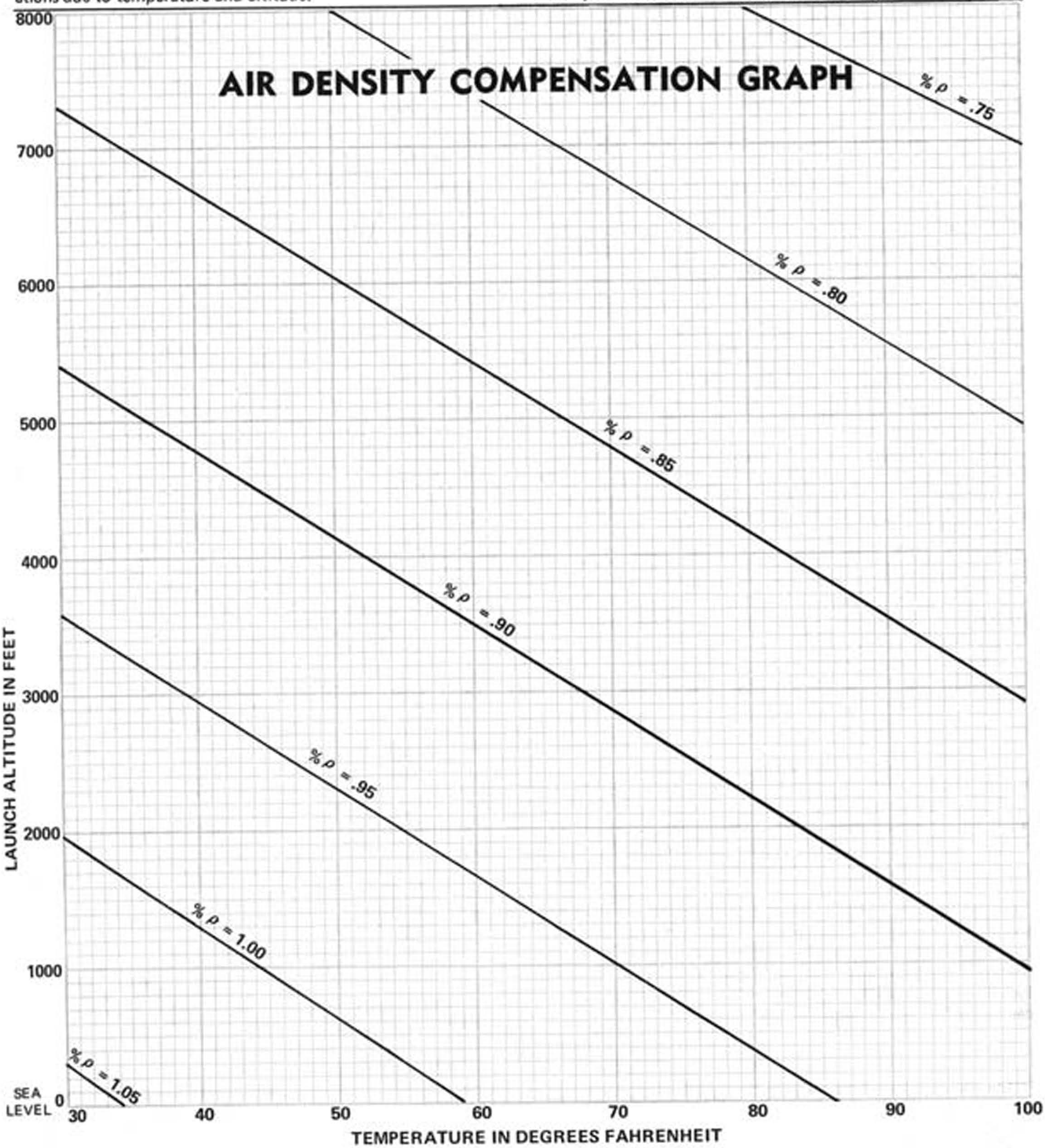
$$C_DA = (\text{Actual } C_DA) \times (\% \rho)$$

gives you a C_DA which has been corrected for density variations due to temperature and altitude.

From the basic drag equation

$$D = C_DA \tfrac{1}{2} \rho V^2$$

we can see that as air density (ρ) is reduced, the total Drag Force (D) is reduced. From this and the Density Compensation graph we can conclude that if a rocket is launched from the top of a mountain on a hot day, the Drag Force which resists the upward motion of the rocket is reduced due to lower air density and the rocket will achieve more height.



DRAG AND WEIGHT

At high weights, the rocket does not build up very much speed and thus the effect of aerodynamic drag is not a very strong influence on the altitude performance of the rocket. Light-weight rockets with their high acceleration and exceedingly fast velocities, on the other hand, are dramatically influenced by the streamlineness of the shape and the magnitude of the frontal cross-sectional area.

For instance, the computer gives a zero drag altitude of 20,500 feet for a 1.2 ounce "C6" powered rocket; whereas an actual rocket with a realistic minimum Drag Form Factor of $C_DA = .3\ in^2$ at the same weight only reaches a height of about 1645 feet. Something to think about!

You'll also note that increasing the weight of this "C6" powered rocket from 1.2 ounces to 1.5 ounces increases the altitude from 1645 to about 1685 feet. Any additional weight increase, however, reduces the peak altitude. Apparently the graphs are telling us that an optimum weight exists and that lower as well as higher values of lift-off weights do not result in the maximum possible altitude performance.

With the graphs it is easy enough to determine this optimum weight, but why does it exist and why doesn't the rocket go higher the lighter it gets? The reason, of course, is aerodynamic drag. Under zero drag conditions, it is true that the lighter the rocket, the higher it goes.

For an example of an impossibly super-light rocket, let's imagine that 1) we eliminate the engine casing weight so that the "C6" motor is reduced to just the weight of the propellant (.44 ounces), and 2) we also reduce the rocket's body weight so that it is as light as a feather, say .01 ounce.

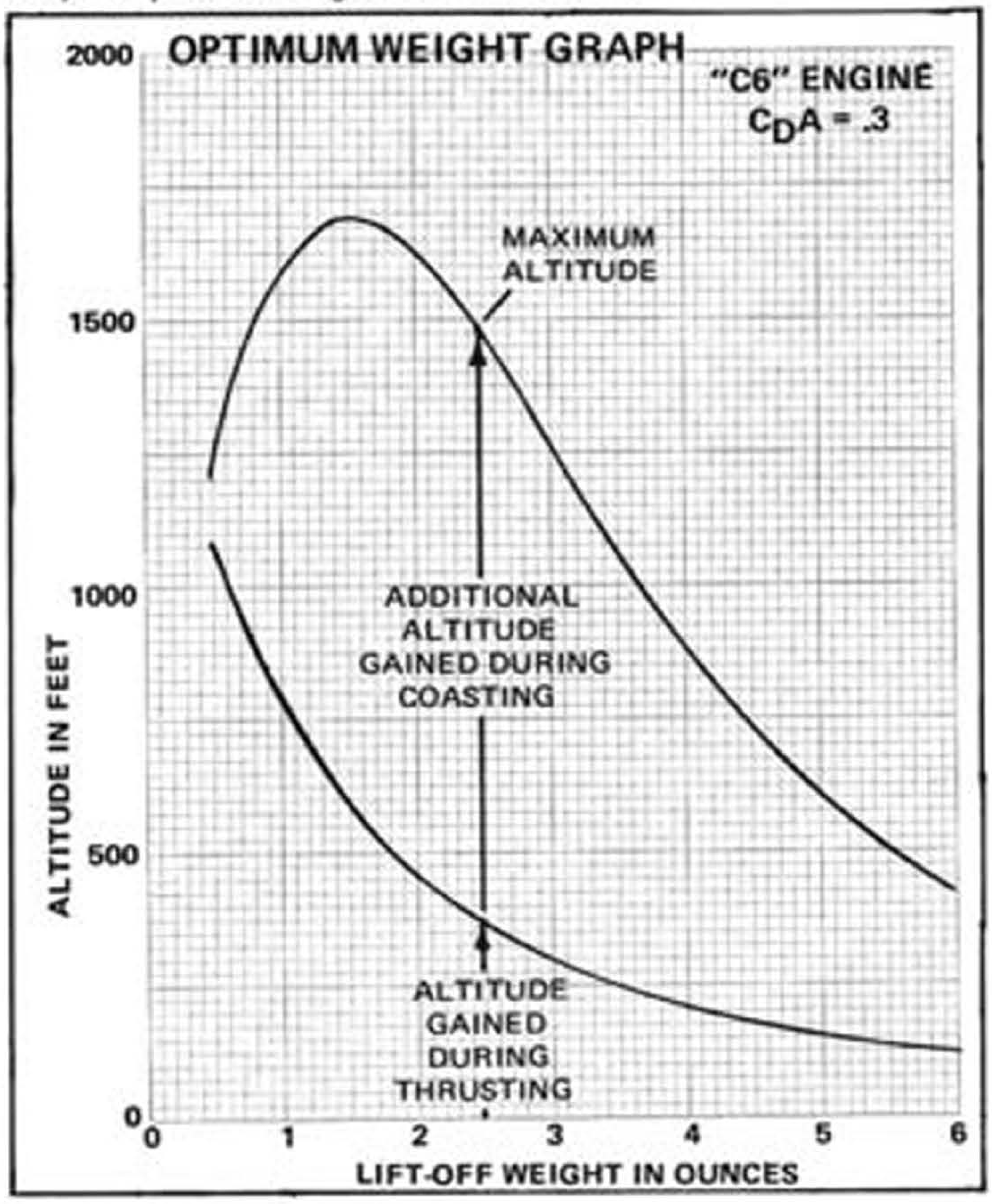
This .45 ounce total lift-off weight rocket could then reach a theoretical altitude of 400,000 feet if there was no aerodynamic drag. It would have reached a burnout velocity of 5000 feet per second at an altitude of just 4000 feet and would have coasted the rest of the way. Without aerodynamic resistance, it takes a long time for the earth's gravitation alone to dissipate the kinetic energy stored in a body moving at 5000 feet per second.

Next, let's take this unrealistic light-weight model rocket and at least give it a realistic, though minimum, Drag Form Factor of $C_DA = .3$ square inches. In this case, the rocket would reach a burnout velocity of just 725 feet per second at an altitude of just 1120 feet. At burnout, all the propellant has been used up and now the rocket only weighs .01 ounce.

Basically, it is a "feather" traveling at 725 feet per second and the aerodynamic drag (with a small help from gravity) completely stops the high drag lightweight "feather" in the next 60 feet of travel. The total MAXIMUM ALTITUDE including aerodynamic drag affects is thus about 1180 feet as can be verified by checking the "C6" graph.

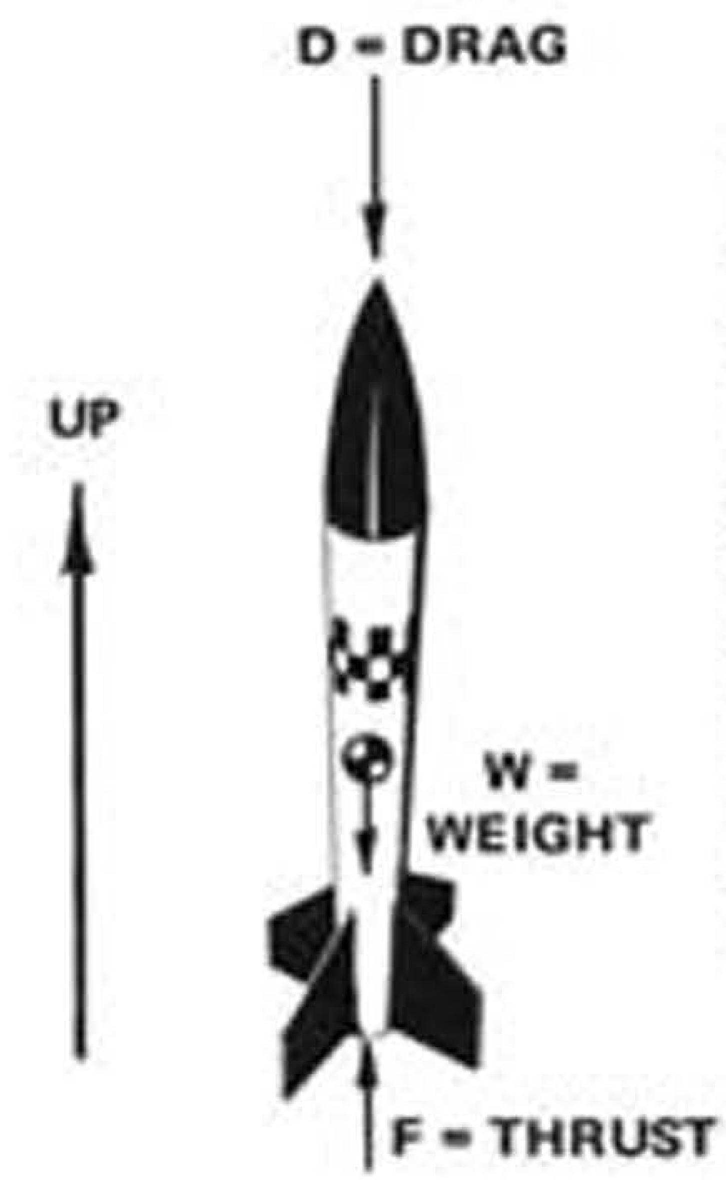
If the rocket would have weighed more at burnout, it would not have been stopped so fast and would have coasted higher. However, if it weighs more, it wouldn't reach as high an altitude nor as high a velocity at burnout.

The following graph shows the burnout altitude, coast altitude, and total maximum altitude for various lift-off weights of the $C_DA = .3\ in^2$. The "C6" powered rocket should help illustrate why an optimum weight condition exists.



EVALUATING AERODYNAMIC DRAG

The graph on the opposing page has been included for those who would like to find the actual aerodynamic Drag Force on their rocket in ounces for any given Drag Form Factor (C_DA) and Velocity (V).



The values are for standard sea-level conditions. As with the Maximum Altitude and Coast Time graphs, however, variations in temperature and altitude can be accurately accounted for by the density compensation factor. Thus, for any given velocity you can easily study the effect of aerodynamic drag on the acceleration of your rocket using the following relation:

$$\text{Rocket Acceleration in g's} = \frac{\left(\text{Average Thrust In Ounces}\right) - \left(\text{Aerodynamic Drag In Ounces}\right) - \left(\text{Weight In Ounces}\right)}{\text{Weight In Ounces}}$$

From this relation, you can see that if the drag was zero, the rocket would have a higher acceleration during thrusting, as expected. Similarly, the relation shows that when the engine is through burning and thrust falls off to zero, the acceleration is negative or tending to slow the rocket down.

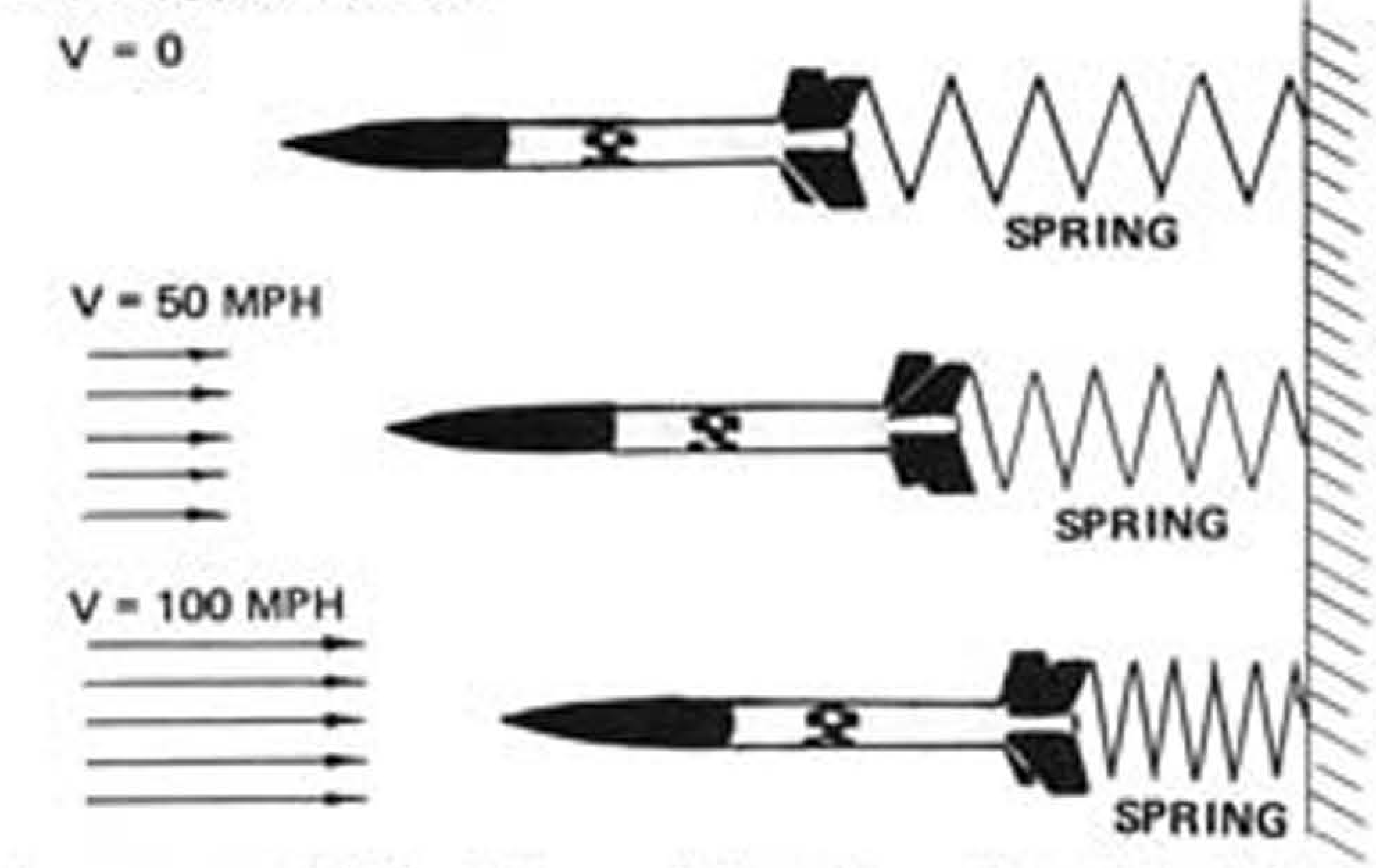
DRAG DETERMINATION GRAPH
DRAG (D) IN OUNCES
60.0
50.0
40.0
30.0
20.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10
20
30
40
50
70
100
200
300
400
500
700
VELOCITY (V) IN FEET PER SECOND
C_DA = 10
C_DA = 8.0
C_DA = 6.0
C_DA = 4.0
C_DA = 3.0
C_DA = 2.0
C_DA = 1.0
C_DA = .8
C_DA = .6
C_DA = .4
C_DA = .3
C_DA = .2
C_DA = .1

PRELIMINARY WIND TUNNEL TEST RESULTS

In order to precisely determine how the Drag Coefficient of a model rocket is affected by nose shape, body tube, base, fin shape and surface finish, Centuri enlisted the aid of Mark Mercer, a model rocketeer from Bethesda, Maryland. Over a period of several years, Mark has constructed and gradually perfected what we at Centuri consider to be the country's finest wind tunnel specifically built for model rocket applications.

A WIND TUNNEL allows you to measure the drag force on a variety of shapes under known repeatable velocity and density conditions.

The drag FORCE on the rocket can be measured in wind tunnels by simply noting how far a support spring compresses at various velocities.



In more sophisticated wind tunnels, such as Mark Mercer's, an instrument similar to a balance weighing scale is used so that the Drag Force on the rocket can be read directly to the nearest 1/100 ounce.

Once the Drag Force has been measured and the Wind Velocity and air density determined, it is a simple matter to establish the rocket's Drag Coefficient by rearranging the aerodynamic drag force equation

$$D = C_D A \tfrac{1}{2} \rho V^2$$

into

$$\boxed{C_D A = \frac{D}{\tfrac{1}{2} \rho V^2}}$$

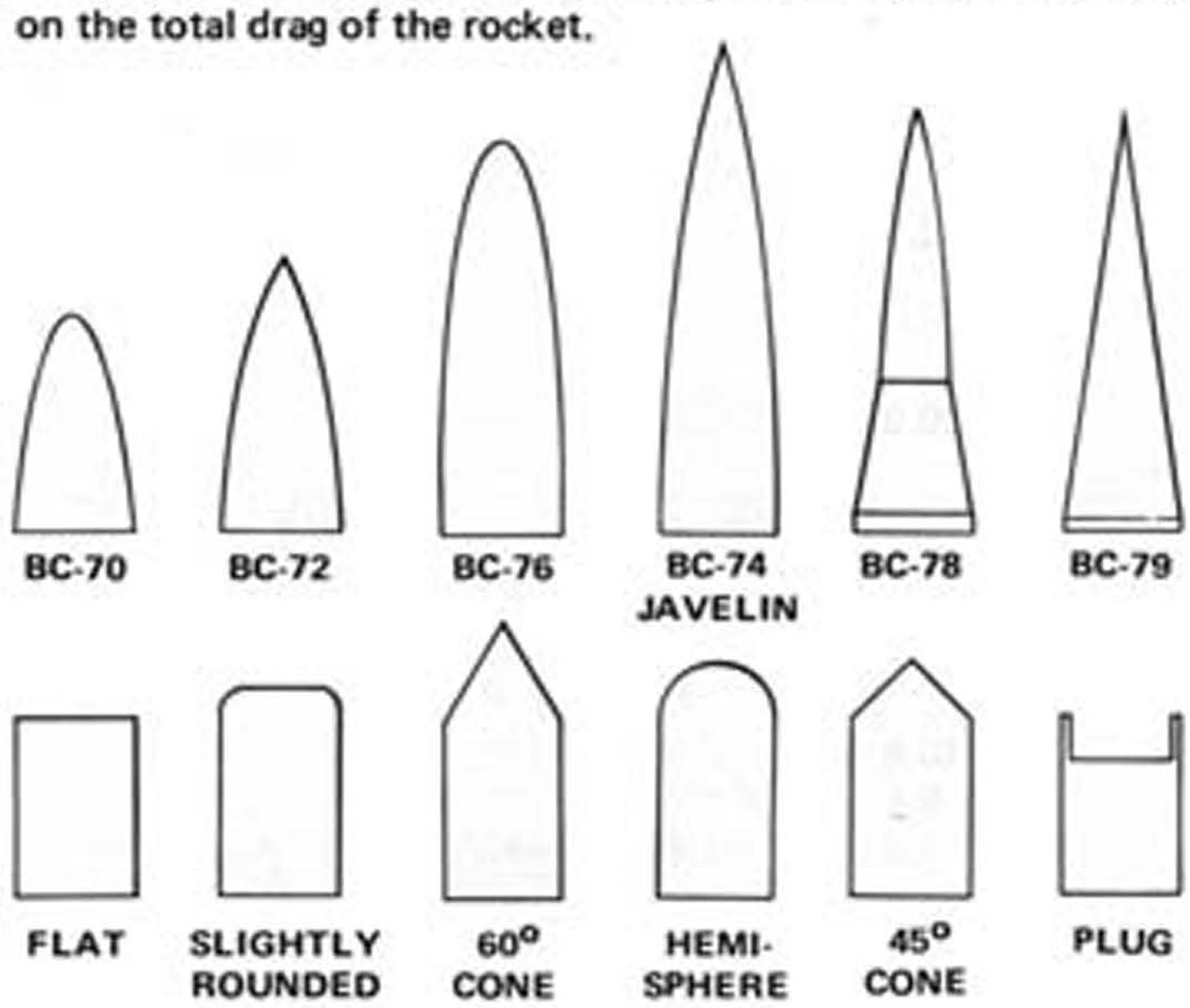
The KNOWN values on the right-hand side of the equation determine the UNKNOWN Drag Form Factor ($C_D A$) of the rocket.

Once the $C_D A$ is known, it is a simple matter to divide by the reference area (A) to find the actual value for the rocket's aerodynamic drag coefficient (C_D).

$$\boxed{C_D = \frac{C_D A}{A}}$$

Again the reference area for model rockets is the body tube cross-sectional area.

From these preliminary tests we were interested in finding out first, how much affect the following nose shapes would have on the total drag of the rocket.



Secondly, what would be the difference between completely painted rockets with glasslike finishes where in one case the fins have a streamlined airfoil cross-section and in the other case a rectangular cross-section. The basic model used for these preliminary tests was Centuri's Javelin Beginner's Kit.

The Drag Coefficient for the Javelin with and without streamlined fins was found by the previously mentioned technique using each type of nose cone. Launch lugs were not used on any of these models.

Also, we wanted to find out how a completely unpainted, unsanded Javelin with Javelin nose cone, squared-off fins and a launch lug would compare with the painted Javelin. In order to find out exactly how much drag a launch lug would add, we also later glued one to each of the two-painted versions of the standard Javelin configuration.

The results of Mark Mercer's actual measurements are graphically portrayed on the following page. Note that the best or most streamlined nose shapes have been grouped at the bottom and the poorest at the top.

CONCLUSIONS

The first thing you probably noticed was that there was really not a significant variation in total rocket drag on the standard catalog nose shapes. Only when you got to the special test shapes did drag of the entire rocket increase. Most people already have an intuitive feel that such shapes would not be as streamlined, but now we have actual numbers to compare and rank them accordingly.

By far, the most important effect on drag for the Javelin rocket was whether or not the fins had an airfoil shape. Since these were preliminary tests, we cannot conclude as yet that the effect is as great on other rocket sizes and shapes. There has to be some of the same effect, however, but until more testing of other than the basic Javelin, we can't say how much. We are quite curious as to what general changes occur when using 3, 5, or 6 fins instead of 4 fins and will be running more tests in the future to find out. We will also be conducting additional tests concerning the affect of conical shoulders and boattails.

EXPERIMENTAL DRAG COEFFICIENT GRAPH

EXAMINATION TIR-100 ALTITUDE PERFORMANCE

This examination is designed to test your understanding of the information presented in this report and to demonstrate the usefulness of TIR-100.

TRUE – FALSE

Place a "T" or "F" in the blanks provided.

1__Gravity, the total power of the engine, and the resistance due to the atmosphere represent three forces that affect the altitude performance of a model rocket.

2__All that you need to know to determine the maximum altitude of a model rocket, using the graphs in TIR-100, are the following three factors: Total Impulse, Lift-Off Weight, and the Drag Coefficient.

3__The smoothness of the finish on a model rocket will affect the rocket's C_D value.

4__The shape of the fins will not affect the Drag Form Factor.

5__An increase in altitude generally means an increase in drag.

6__An increase in the temperature of the air means an increase in drag.

7__The lighter the rocket, the higher it will go.

8__If the velocity of a rocket is doubled, the Drag Force will also be doubled.

9__The graphs in TIR-100 are based upon the assumption that the rocket rises vertically without weathercocking.

10__If the Total Impulse of an engine is doubled, the altitude will double.

11__You can compute both theoretical (no drag) and actual (with drag) altitudes with the information contained in this report.

12__All that you need to know to determine the Drag Coefficient of a model rocket using the graphs in this report are the following four factors: The maximum altitude, the weight of the rocket, the Drag Form Factor, and the Total Impulse of the rocket's engine.

13__The air density compensation factor (% ρ) equals zero at sea level.

14__To use the graphs to determine theoretical (no drag) altitudes, you simply allow the Drag Form Factor to equal zero ($C_DA = 0$).

15__A single engine powered rocket will achieve the same altitude as a clustered powered rocket if they use the same type of engines, are equal in weight, and have the same Drag Form Factor.

ESSAY

Complete on a separate sheet of paper.

Describe what each symbol represents in the aerodynamic drag equation:

$$D = C_D A \tfrac{1}{2} \rho V^2$$

(D) – (C_D) – (A) – (ρ) – (V^2)

MULTIPLE CHOICE

Circle the best answer.

SECTION A

(1) If a one-ounce rocket is constructed of a #8 body tube and is powered by an "A5" engine, what will be its maximum altitude? (Assume a C_D of .75)

(a) 300 ft (b) 350 ft (c) 400 ft (d) 450 ft (e) 500 ft

(2) What will be the coast time for this rocket?

(a) 2.0 sec (b) 3.1 sec (c) 4.2 sec (d) 5.3 sec (e) 6.4 sec

(3) Which of its delay times will be the best?

(a) 2 sec (b) 4 sec

(4) If the rocket referred to in Problem 1 was to use a "B6" engine, how much higher would it travel?

(a) 320 ft (b) 430 ft (c) 540 ft (d) 650 ft (e) 760 ft

(5) Which delay time should be used to have the parachute ejected nearest the maximum altitude?

(a) 4 sec (b) 6 sec

(6) What would be the altitude of the rocket if you neglect the Drag Force.

(a) 500 ft (b) 750 ft (c) 1000 ft (d) 1500 ft
(e) cannot be determined from the graph

(7) If two rockets had identical Drag Form Factors ($C_DA = .6$), identical weights (1 oz), and the same Total Impulse, how would their altitudes compare if (rocket #1) was powered by a single "A8" type engine, while (rocket #2) was powered by two "½A6" type engines. (Remember, two "½A" engines produce the same Total Impulse as one "A" type engine).

(a) #1 would go slightly higher (b) #2 would go slightly higher
(c) the maximum altitudes would be identical
(d) You cannot solve with the graphs

(8) The maximum altitudes would have been identical if the two engines in the clustered powered rocket would have had average thrusts equal to:

(a) the "A" engine (b) twice the "A" engine
(c) one half the "A" engine

SECTION B

(1) If a 4.4 ounce rocket had an airframe 1.8 inches in diameter and was powered by a cluster of four "B4" engines, how high would it go if it had a C_D of .8?

(a) 330 ft (b) 550 ft (c) 770 ft (d) 990 ft (e) 1100 ft

(2) How high would it have gone if only two of the engines had fired? (Assume it remained stable)

(a) 150 ft (b) 220 ft (c) 370 ft (d) 430 ft (e) 510 ft

(3) If the rocket with two engines "out" (i.e., not firing) used delay times of 4 seconds, would the parachute be ejected before or after the peak altitude?

(a) after (b) before (c) same time

(4) Assume that with altitude tracking instruments you have, after launching and tracking a rocket several times, determined the maximum altitude of the rocket to be 500 feet. If the rocket was powered by a "B6" engine and weighed 2 ounces at lift-off, what was the rocket's Drag Form Factor (C_DA)?

(a) .3 in^2 (b) .65 in^2 (c) .8 in^2 (d) 1.0 in^2 (e) 1.5 in^2

(5) If the above mentioned rocket used a #13 series body tube, what was its Drag Coefficient?

(a) .40 (b) .56 (c) .75 (d) .88 (e) 1.2

(6) Using the "B6" delay times, could the parachute have been ejected before the rocket reached maximum altitude?

(a) Yes (b) No

The altitude and coast time for a rocket (constructed of a #10 series tube, weighing 1.6 ounces at lift-off and powered by a "B4-6" engine which thrusts for 1.2 seconds) were determined from the graphs to be 610 feet and 4.5 seconds by assuming the Drag Coefficient C_D = .75. If this rocket was flown and the total time from lift-off to maximum altitude was found, with an accurate stop watch, to be 6.2 seconds, what can we conclude?

Hint: Use the "B4" Coast Time graph and note that the "real" coast time was 5 seconds instead of 4.5 seconds (i.e., the new coast time of 5 seconds was found by subtracting the thrust time of 1.2 seconds from the total flight time of 6.2 seconds).

(7) The rocket's "real" Drag Coefficient was:

(a) .46 (b) .64 (c) .75 (d) .58 (e) .85

(8) The "real" Drag Coefficient tells us that the rocket was:

(a) more streamlined than expected
(b) less streamlined than expected
(c) exactly as expected

(9) The "real" altitude was:

(a) 410 ft (b) 510 ft (c) 610 ft (d) 710 ft (e) 810 ft

SECTION C

(1) If you had a light (one ounce) rocket with a C_DA of 1.0 and two engines of equal Total Impulse ("B6" and "B14") which engine would boost the rocket to its greatest altitude – the end burning "B6" or the faster accelerating, port burning "B14".

(a) "B6" (b) "B14"

(2) Which engine would produce the greatest altitude if you increased the weight of the rocket to 4 ounces.

(a) "B6" (b) "B14"

(3) What would have to be the weight of the rocket for the engines to produce identical altitudes.

(a) 1.6 oz (b) 2.0 oz (c) 2.4 oz (d) 2.8 oz (e) 3.2 oz

(4) If the rocket described in Section A, Problem 1, used a "C6" engine and was launched in the morning under "standard conditions" (sea level 59°F) and again from an elevation of 7000 feet at 2:00 p.m. with a temperature of 66°F, would the afternoon flight be higher or lower?

(a) higher (b) lower

(5) What is the difference in feet between the morning and afternoon altitude?

(a) 50 ft (b) 125 ft (c) 238 ft (d) 574 ft (e) 1190 ft

(6) What would be the optimum weight for this rocket?

(a) .5 oz (b) 1.2 oz (c) 1.6 oz (d) 2.1 oz (e) 3.3 oz

(7) If the Drag Force on a model rocket in a wind tunnel is measured to be (7 ounces) and the velocity of the wind is 300 ft/sec., what will be the Drag Coefficient of the rocket? We will assume the density of air to be 1.2 ounces per cubic foot and that the rocket was constructed of a #10 series body tube.

Hint: There are two ways to work this problem – with a formula or with a graph. You might try both and compare the results. If you use the formula, divide the density by 32.2 ft/sec^2 to convert from weight to mass.

(a) .6 (b) .7 (c) .8 (d) .9 (e) 1.0

ANSWERS

ANSWERS

TRUE–FALSE:
1T, 2F, 3T, 4F, 5F, 6F, 7F, 8F, 9T, 10F, 11T, 12T, 13F, 14T, 15F
ESSAY: Refer to Page 44
MULTIPLE CHOICE:
Section A: 1d, 2c, 3b, 4a, 5a, 6e, 7a, 8c, Section B: 1c, 2d, 3b, 4c, 5b, 6a, 7d, 8a, 9d, Section C: 1a, 2b, 3c, 4a, 5c, 6c, 7b

THE COMPUTER

$$\text{MAXIMUM ALTITUDE} = \frac{1}{g}\,\frac{W_I - \frac{1}{2}W_P}{C_D A \frac{1}{2}\rho}\;\ln\cosh\left\{ g\sqrt{\left(\frac{F_{AVE}}{W_I - \frac{1}{2}W_P} - 1\right)\frac{C_D A \frac{1}{2}\rho}{W_I - \frac{1}{2}W_P}}\; t_B \right\}$$

$$+\frac{1}{2g}\,\frac{W_I - W_P}{C_D A \frac{1}{2}\rho}\;\ln\left\{ 1 + \left(\frac{W_I - \frac{1}{2}W_P}{W_I - W_P}\right)\left(\frac{F_{AVE}}{W_I - \frac{1}{2}W_P} - 1\right)\tanh^2\left[g\sqrt{\left(\frac{F_{AVE}}{W_I - \frac{1}{2}W_P} - 1\right)\frac{C_D A \frac{1}{2}\rho}{W_I - \frac{1}{2}W_P}}\; t_B \right]\right\}$$

$$\text{COAST TIME} = \frac{1}{g}\sqrt{\frac{W_I - \frac{1}{2}W_P}{C_D A \frac{1}{2}\rho}}\;\tan^{-1}\left\{ \sqrt{\left(\frac{W_I - \frac{1}{2}W_P}{W_I - W_P}\right)\left(\frac{F_{AVE}}{W_I - \frac{1}{2}W_P} - 1\right)}\;\tanh\left[g\sqrt{\left(\frac{F_{AVE}}{W_I - \frac{1}{2}W_P} - 1\right)\frac{C_D A \frac{1}{2}\rho}{W_I - \frac{1}{2}W_P}}\; t_B \right]\right\}$$

The graphs in this report are based on the closed-form Integral Calculus solutions of the rocket's basic equations of motion. Both the Altitude equation and the Coast Time equation, as you can see, are horrendous monsters and it takes approximately 1/2 hour of hand computation time to come up with the answers for one specific rocket size, weight, and engine.

The amount of data points used to generate all the TIR-100 graphs represent 13,500 of these 1/2 hour calculations – at 40 hours a week this would take 3.2 years to complete. What we actually did to get all the necessary data was to spend half a day writing a computer program in the FORTRAN language. The program sheets were then dropped off at the UNIVAC building (shown at the right) here in Phoenix. The next day the job was completely finished – it took just under 2.0 minutes of actual time on their Thin Film Memory 1107 machine (shown below) or just 9/1000's of a second per maximum Altitude and Coast Time condition. Computers are quite a useful scientific tool! We hope you make use of the 1107's final results.