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ADVANCED INFORMATION REPORT #5

BOOSTED DART THEORY

COMPUTER RUNS, DRAWINGS AND REPORT

By Jerry Irvine

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Advanced Information Report 5
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INTRODUCTION TO THE BOOSTED DART CONCEPT

The boosted dart procedure is designed to obtain additional altitude performance from existing power rocket motors compared with conventional rockets. This is accomplished by reducing the drag and increasing the density during coast, resulting in a longer coast time.

A boosted dart is powered during the initial phase. At burnout the unpowered, low drag dart vehicle is released. This dart is much smaller in diameter than a conventional rocket, one source of added performance. The strategy is to shift most of the weight to the dart if possible. This is done by constructing a minimum diameter and weight vehicle and calculating the optimum weight. Put all added weight in the dart payload section.

The U.S. Rockets Hi-Test Boosted Dart is the first kit to employ an unpowered upper stage. The purpose of the boosted dart system is to achieve increased altitude performance by manipulating optimum weight, burnout velocity, and coast time. To achieve this, the Hi-Test Boosted Dart boosts a high density unpowered projectile using a conventional booster. The sustainer design minimizes drag, thus permitting increased coast time to apogee. The high density of the dart gives it excellent momentum in relation to vehicles of similar drag characteristics.

In short, the U.S. Rockets Hi-Test Boosted Dart is a quantum leap in altitude performance technology. With the newly available composite flatburners (moonburners and short endburners) the performance increase is even more pronounced!

QUESTION: Can you think of a better reason to add a payload to a vehicle than to increase its performance?

BOOST PERFORMANCE PENALTIES

As a rocket increases its flight velocity it becomes increasingly difficult to overcome the drag forces. This is illustrated by the "drag force vs. velocity curve". It is interesting to note that just beyond Mach 1.05 there is a flattening of the drag force. This explains why a rocket, once over Mach 1, can travel quite easily to Mach 1.3 or so. Drag force is low at the velocity of Mach 0.85 and lower. Thus this is the optimum "cruising range" from the standpoint of drag.

With a powered rocket, the maximum velocity is a function of thrust level, weight and drag forces. In the case of an unpowered vehicle or dart there is no thrust so the remaining factors are drag, weight and momentum.

A powered rocket can gain significant altitude advantages simply through velocity and thrust management as proven by "endburners". Thus it makes sense that an unpowered projectile can take advantage of "managed" momentum (maximized) and drag (minimized).

FIGURE 1: U.S. Rockets Boosted Dart Kit Design

SPECIFICATIONS: 11-7 BOOSTED DART

Length: 26/14"
Diameter: 1.22/.76"
Drag-CDr: .668/.28
Skill level: 5
Net dry weight: 50/25g

SPECIFICATIONS: 9-5 BOOSTED DART

Length: 25/13"
Diameter: 1.0/.565"
Drag-CDr: .654/.383
Skill level: 5
Net Dry Weight: 45/20g

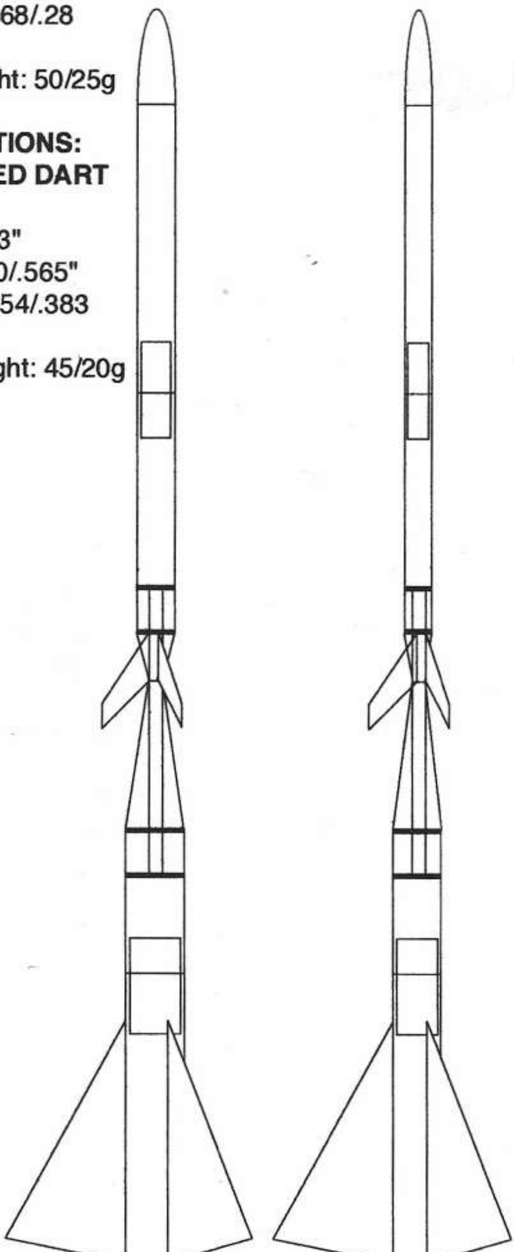


FIGURE 2: High Performance Design

SPECIFICATIONS 9-5 BOOSTED DART HP

Length: 21/13"
Diameter: 1.0/.565"
Drag-CDr: .427/.39
Skill level: 5
Net dry weight: 43/18g

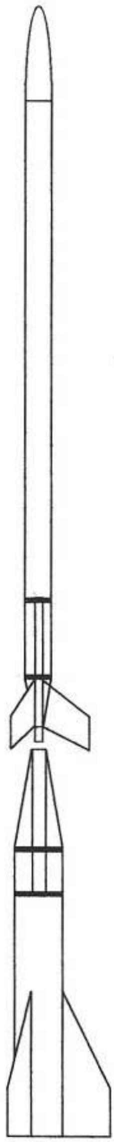
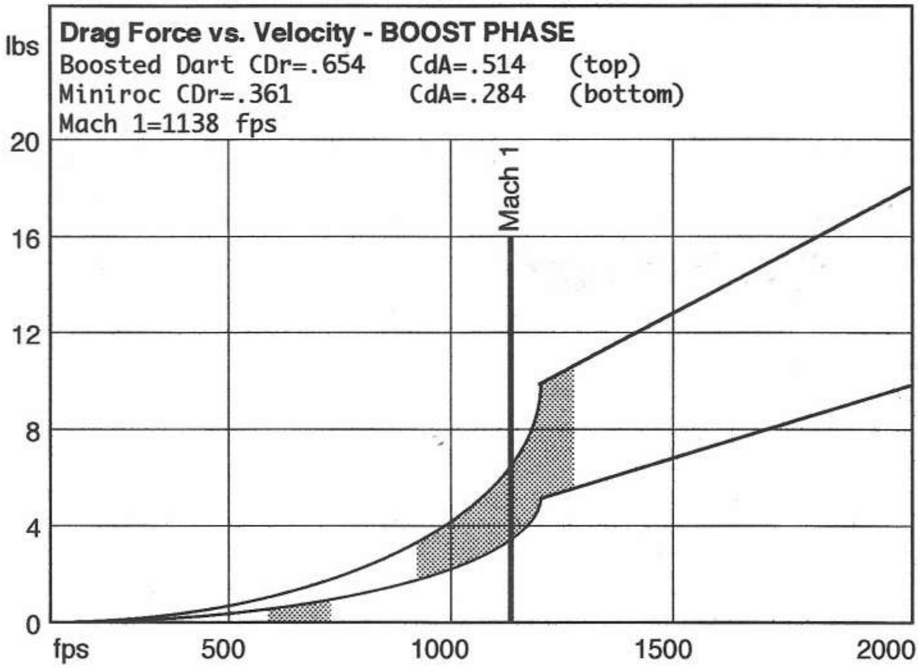


FIGURE 3: Drag Force vs. Velocity for Boost Phase Boosted Dart vs. Miniorc 2 Upper Stage



DRAG ADVANTAGE

To optimize the altitude prior to seperation, it is necessary to keep the flight velocity as low as possible to minimize drag. Near seperation, however, it is best to be at the highest velocity. For this reason it is good to have a long burn motor with a progressive flight velocity curve. A progressive motor achieves seperation sooner and at higher velocity with some energy wasted to that point. A flat thrust curve, on the other hand, flys longer prior to seperation and has nearly the same final velocity (limited by thrust level) due to the exponential drag increase near Mach 1. A large difference in drag results in a small difference in velocity near and above Mach 1.

Therefore, a boosted dart can achieve the highest altitude with a flat thrust trace motor (given the mach problems) by seperating at nearly the same velocity at higher altitude!! With an F67 the dart may coast from 3000 feet for 20-25 seconds. With the F15 it may coast from 5000 feet for 20 seconds! Thus one source for a 50 percent increase in altitude.

One other source of the boosted dart's advantage over common vehicles is the fact that endburner rockets are typically over optimum weight. The coreburner rockets, even optimally weighted, tend to run up against the Mach 1 brick wall of drag.

Boosted dart vehicles are attached to the booster rocket during the first postion of the flight. The delay between burnout and seperation should be as short as possible to release the dart at highest velocity. Once released, the dart has substantially less drag than the combined vehicle. Thus, at a higher velocity it will coast a longer distance. The actual altitude it will achieve is maximized if the dart is at optimum weight, it is released at maximum altitude and at maximum velocity. As a practical matter it is best to release at booster burnout in all cases. At optimum weight as much mass should be distributed to the dart as possible.

COAST PERFORMANCE ADVANTAGES

The substantially lower drag design of the dart vehicle has an average operating velocity much lower than the conventional rocket. This is due to lower deceleration during the low velocity portion of the flight. That is, both types of rockets slow down quite quickly at first, but the dart vehicle coasts longer in the lower velocity range due to much lower drag.

When considering drag there are two major components: Coefficient of Drag (CD) and frontal area (A). The dart has the advantage of a smaller frontal area. The dart also does not need to have a flat rear end where the motor goes so it can have a boattail, thus lower CD. In short, its lower CDA beats the pants off a conventional rocket in coast phase drag forces.

A major factor in boosted dart advantages is higher density which produces beter coasting performance. The small diameter dart has a weight added to bring the rocket to optimum weight. In the case of some high power small diameter darts, optimum weight can only be achieved with solid metallic airframes and nose cones! Not discussed here.

FIGURE 6: DRAG FORCE VS. VELOCITY FOR COAST PHASE BOOSTED DART VS. MINIROC 2

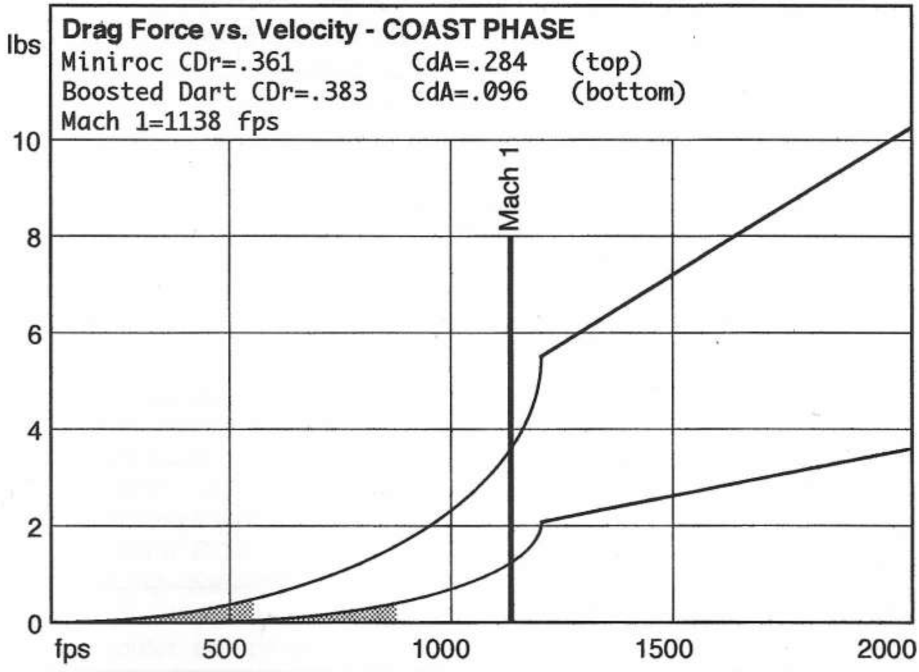


FIGURE 4: Altitdue vs. weight for USR Miniroc with E6, E28 and E55

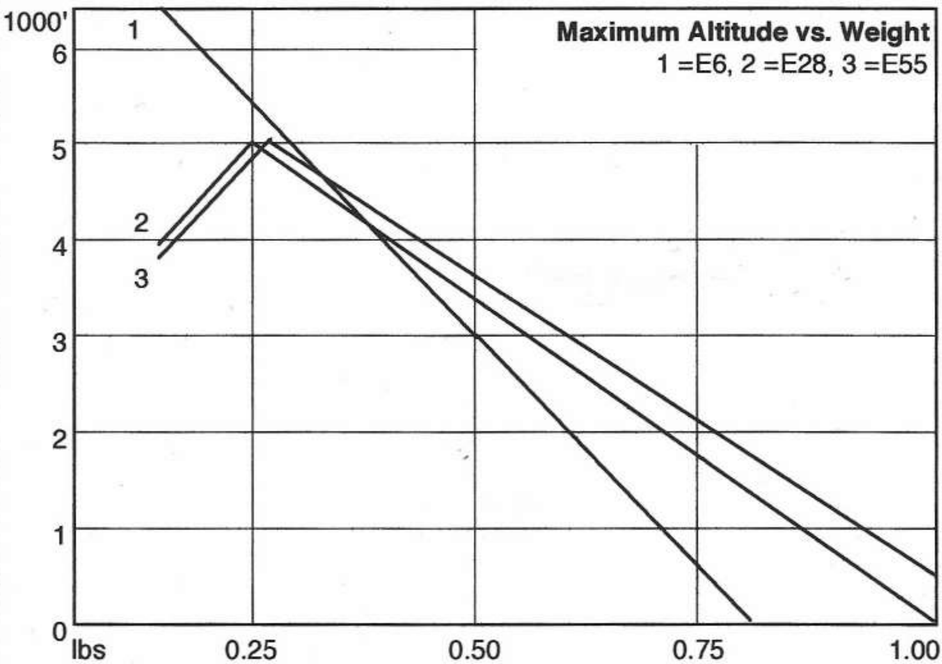


FIGURE 5: Velocity vs. weight for USR Miniroc with E6, E28 and E55

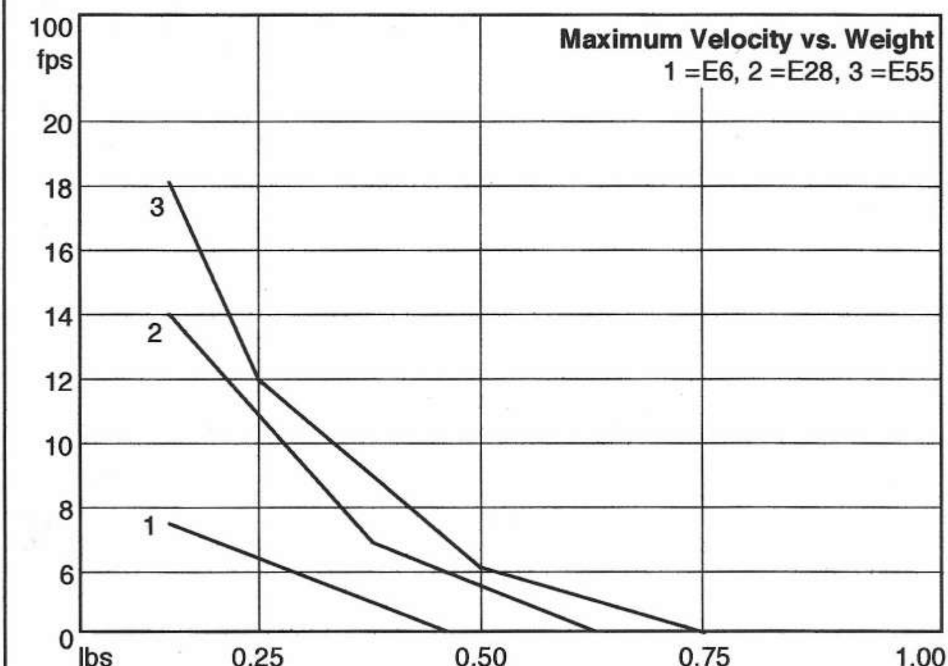
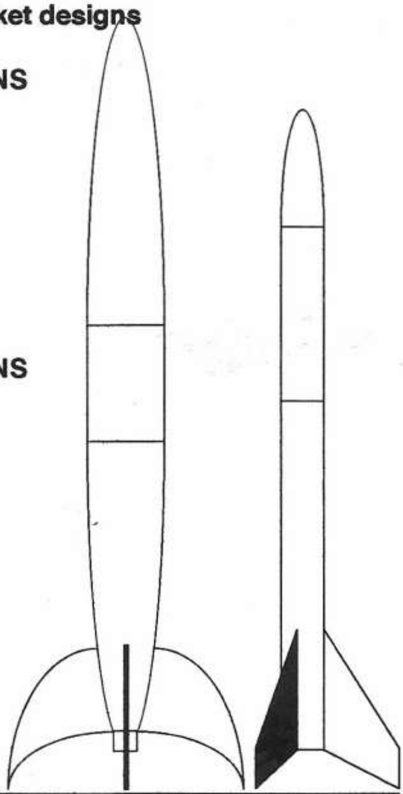


FIGURE 6: Conventional rocket designs

MINIROC 1.0 SPECIFICATIONS
(Miniroc 2 upper stage)
24mm reference rocket
Length: 16"
Diameter: 1.0"
Drag-CDr: .361
Skill level: 1
Net dry weight: 24g

MINIROC 1.2 SPECIFICATIONS
29mm reference rocket
Length: 19"
Diameter: 1.22"
Drag-CDr: .361
Skill level: 1
Net dry weight: 36g

Data:	**Shark**	**Aero-Roc**
Length	38"	35"
Diameter	4.0"	2.25"
Drag-CDr	0.174	0.42
Weight	400g	250g
Motor	29mm	29mm



Ace SonicShark   U.S.Rockets Aero-Roc

ALL IMPORTANT CDA

There is a need to explain the importance of CDA or coefficient of drag times frontal area. CDA is simply the all important factor in rocket performance besides overall size and power. By combining drag and diameter to a single number, different rockets with similar flight characreristics can be grouped. Also rockets of different flight characteristics can be compared. This is the basis for "Malewicki Charts" (named after Doug Malewicki) which compare altitude, coast time and velocity versus weight for a variety of CDA combinations.

It is also important to note that the CDA of a slippery fat rocket may be the same as a basic skinny rocket. A good example of this is the ACE Sonic Shark with a CD of .174 and a diameter of 4". It has a CDA close to the Aero-Roc with a CD of .42 and diameter of 2.25".

CD and diameter are important inputs for most computer altitude programs as well.

OPTIMUM WEIGHT FOR ALTITUDE

Calculations comparing conventional altitude models with the U.S. Rockets Hi-Test Boosted Dart show improvements in altitude ranging from 10 to 50 percent!! All figures assume minimum drag and optimum weight.

All computer simulations assume a launch altitude of 3000 feet (27.66 in-hg) and 80 degrees temperature. Motor and rocket performance varies with temperature in particular. A change from 60 to 80 degrees can add up to 15% to performance primarily from propellant reaction improvements.

As total impulse and thrust level increases performance advantages to boosted darts become more predominent. Boosted darts are used by weather agencies around the world as the new standard for economical high altitude sounding.

FIGURE 7: Comparison of computer simulated boosted darts and minimum diameter conventional rockets

MOTOR	BD OPT WEIGHT	BD DELAY	BD OPT ALTUDE	BD MX MACH	CONV OPT WT	CONV DELAY	C OPT ALTUDE	C MAX MACH
				24mm				
E6-0	.282#	9.3s	4689'	.410	.141#	9.0s	6505'	.659
E28	.332	13.9	5028	.684	.241	12.8	4846	.971
E55	.332	15.1	5891	.825	.291	13.9	5036	.940
F44	.485	18.7	8847	.876	.494	17.0	7519	.969
F101	.485	19.4	8851	.960	.494	17.1	6918	.995
G70	.615	21.5	10767	.891	.665	19.0	8904	1.022
				29mm				
F10	.420	10.4	5751	.436	.234	9.2	7355	.752
F15	.459	13.1	5979	.566	.323	11.7	6509	.873
F41	.432	17.2	7652	.843	.532	15.1	6115	.946
F80	.520	17.6	7600	.889	.532	15.0	5669	.932
G25	.647	14.4	7108	.565	.561	14.2	7851	.911
G65	.747	20.3	9933	.880	.761	17.3	7754	1.005
G125	.797	21.9	10736	.968	.811	17.9	7559	1.011
G80	.942	22.5	11441	.914	.953	18.8	8673	1.018
H120	1.091	24.7	14272	1.071	1.050	20.5	11135	1.367

ANALYSIS TECHNIQUES

As you might imagine, it would be a plus for you to own a computer with several programs such as altitude estimation, drag force and optimum weight. The capability to plot velocity over time for different motors is needed. Also altitude over time to compare different motors for maximum release altitude. In any case, proving the results of an actual flight is even more of a challenge!

The computer programs are available from California Rocketry Publishing, Box 1242, Claremont, CA 91711. This booklet is designed to aid in estimating the delay times and weights required for Boosted Dart kits and similar designs. Thus, hopefully the program is not required to fly your rocket successfully.

NO ADVANTAGE FROM DELAY STAGING

In the case of boosted darts there is no advantage to delay staging. This is because the maximum amount of weight is distributed in the dart and the high drag booster is dumped as early as possible. In short, it would defeat the entire purpose to keep the booster on.

In the case of conventional rockets there are some cases where delayed staging is beneficial for altitude. But even in these cases, it would likely be a vast improvement to dump the booster and let the upper stage coast prior to air-start.

APPLICATIONS

The most interesting aspect of this system is that it works best with the motors that are most commonly available, and are unsuitable for altitude events in conventional models. For a normal vehicle, the highest altitude (optimum altitude) is achieved by using the longest available thrust duration powerplant so optimum weight will be minimum weight. A good example is the F10 which has been tracked in performance vehicles to over 6000'. The Hi-Test Boosted Dart, on the other hand, works best with higher thrust motors or progressive motors where final thrust is the point of maximum velocity. Examples: 24mm E50, F100, G140, and 29mm F80, G120or H320.

RECOVERY OPTIONS

Under the assumption that you will be using a boosted dart vehicle in FAI or NAR competition or an event where similar rules are followed, recovery is mandatory. Furthermore, specific recovery provisions may be required. Where permissible allow the booster to tumble down. If a streamer is required, it will be necessary to employ "discontinuous staging" (tm). See AIR-3 for information.

ACTUATION

Upon boost completion, the dart seperates from the booster by booster ejection charge, burn-through, or actuated staging and the delay is started. The dart utilizes the velocity imparted by the booster, the momentum provided by the payload weight, and the very low base drag to surpass all previously achievable performances.

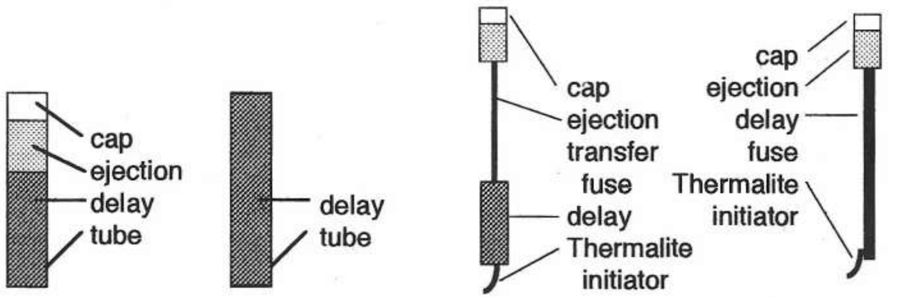
The heart of this system is the utilization of a U.S. Rockets "Delay Charge™", designed by Jerry Irvine. This delay, which contains the ejection charge as well, is seperate from a motor and thus can be in a much smaller diameter. The smaller diameter permits substantially reduced base drag of the dart sustainer vehicle. The delay elements are available in lengths suitable for modification to your specific needs.

The delay is started by a piece of "Thermalite" wick or fuse. This fuse is actuated by the booster motor "burn-through" or by actuated staging of some sort.

DELAY MODIFICATION

The delay comes in a length which is too long for any application. This is primarilly due to manufacturing constraints, but permits the use of the same delay elements for all motors from D to L. Cut the delay element to the length specified in the "Flight Sheet™", following the instructions in the "Delay Charge™" package. The ejection charge is integrated into the "Delay Charge™".

FIGURE 8: Delay Modification



USR Delay Charge™ w/ejection

USR Delay Charge™ wo/ejection

USR Delay Charge™ w/Thermalite extended ejection

Dart delay using green fuse w/ ejection

Test at least one exact copy before use in flight.

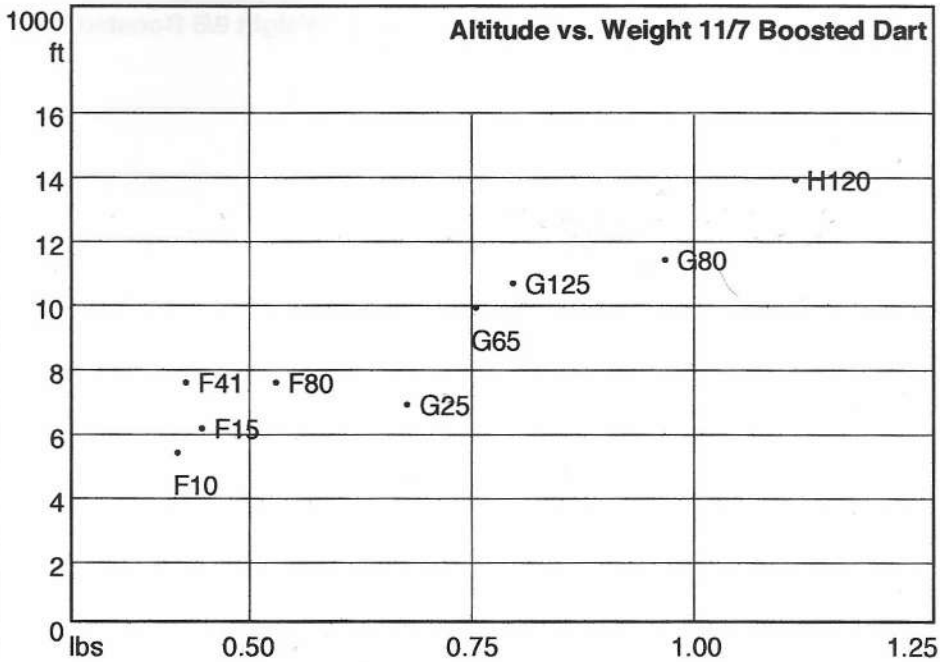
TIMING

Thermalite burn rate: .40 ips
Green fuse burn rate: 2.5 ips
Delay Charge burn rate: .25 ips
Nominal-subject to testing

FLIGHT PHASES

BOOST: During motor burn
COAST: Deceleration and coast
STAGING: Separation and dart ignition
COAST: Free coast of dart vehicle
EJECTION: Deployment of recovery

FIGURE 9: BT-11/7 Boosted Dart Flight Sheet



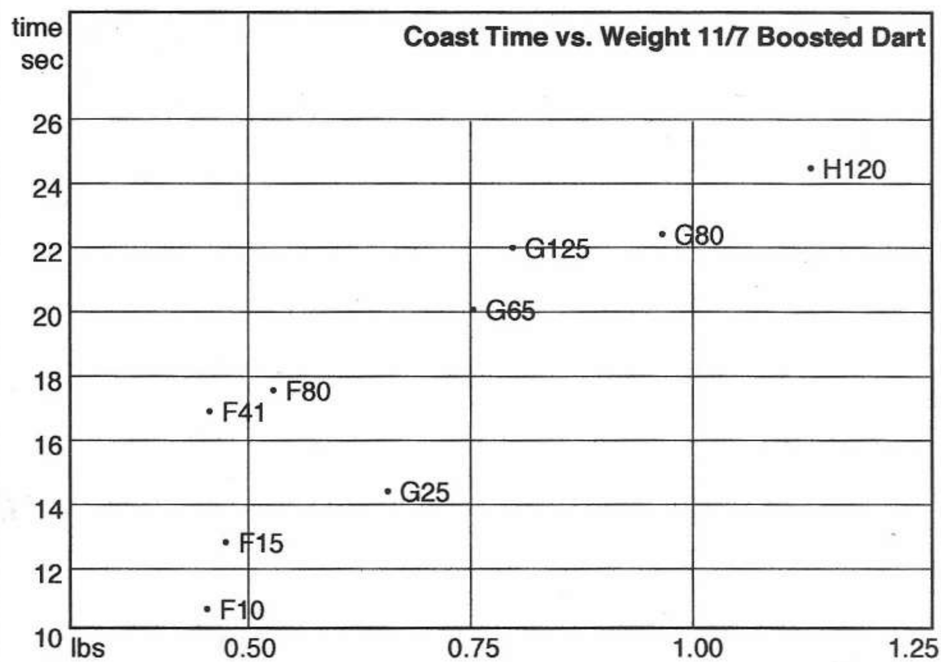
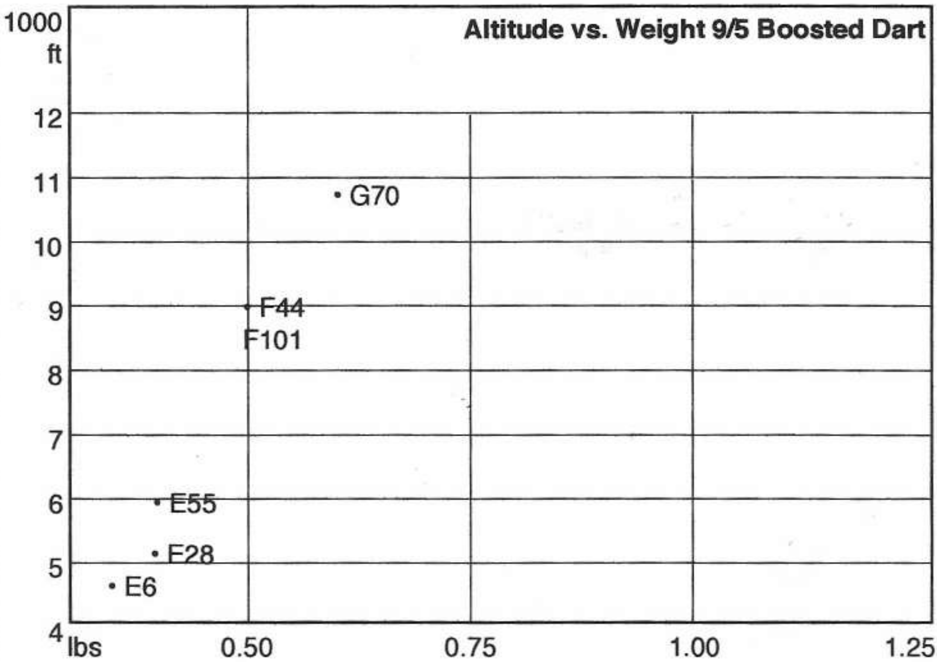


FIGURE 10: BT-9/5 Boosted Dart Flight Sheet



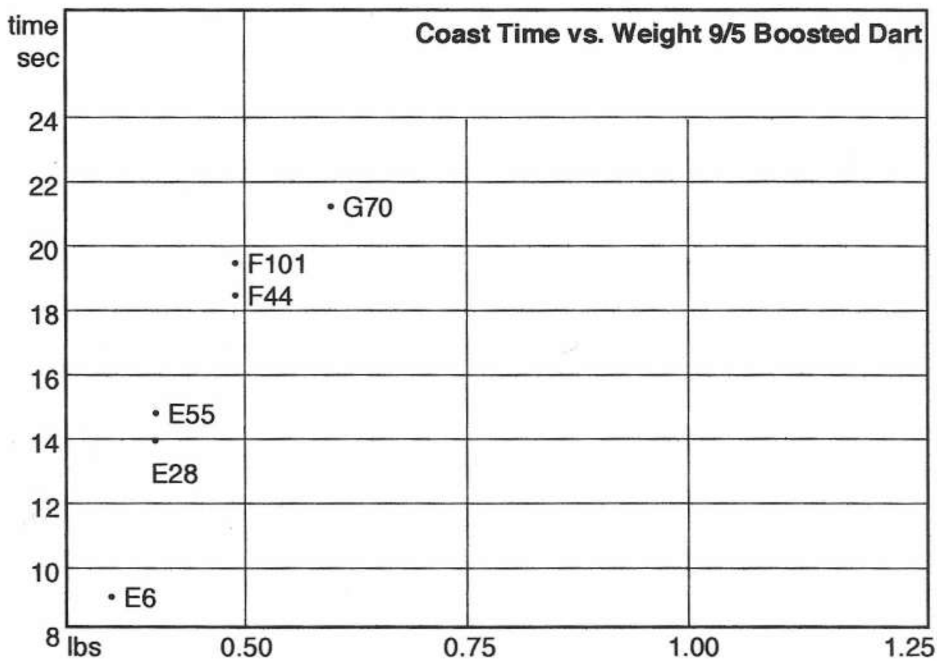
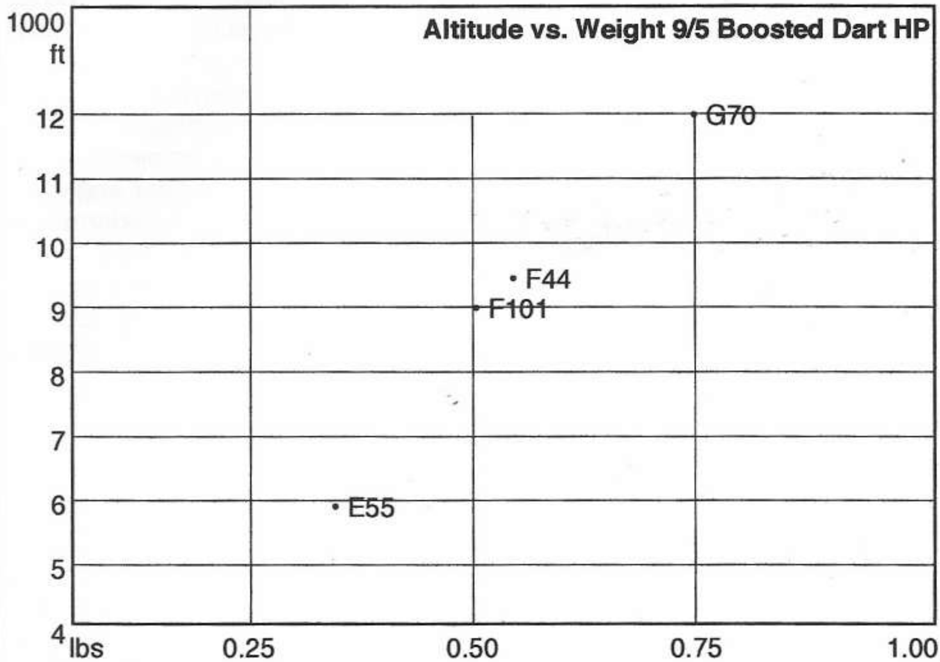
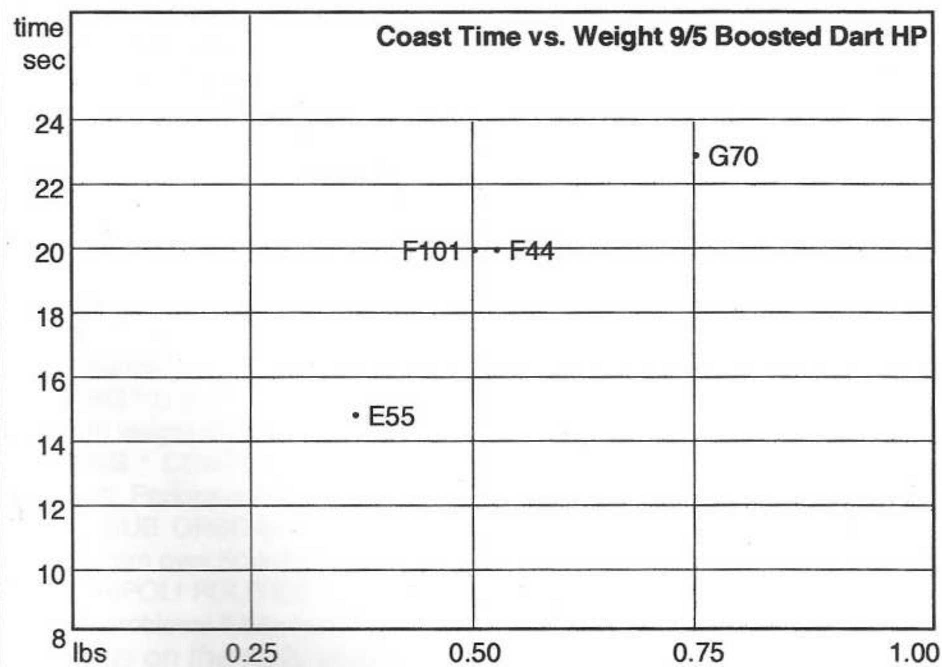


FIGURE 11: BT-9/5 Boosted Dart Flight Sheet





OPERATION

The booster and darts are prepped in the conventional manner using tracking powder and streamer recovery. The staging system varies depending on the type of booster motor used and whether a booster recovery system is used.

Assuming you have selected to make your booster recover by a method other than tumble, it will have an obstruction between the booster motor and upper delay. To ignite the delay, it is necessary to use an electrical or pyrotechnic staging system. An electrical system is heavier and more technical as a rule. A fuse type ignitor to the delay is best for performance applications. Consult AIR-3 on staging for additional information.

Always fly the U.S. Rockets Hi-Test Boosted Dart straight up to maximize altitude and minimize weathercocking and gravity turns. Do test flights with low power black powder motors and short delays in the dart for visibility and practice.

Use the longest possible rod or tower for guidance. A five foot long launcher on a steady wood base should be considered a minimum. Guidance is critical for performance and safety. Launch from a distance of 100 feet for safety and a better view of the flight. For performance applications a tower launcher should be utilized to eliminate the launch lug, a source of a 20% drag increase!

The Hi-Test Boosted Dart was designed and developed by Jerry Irvine to provide an esoteric kit to the performance minded rocketeers. This is an advanced design utilizing many new concepts. Please use it with the utmost caution.

Fly high, fly big, fly fast, but above all fly safely!!

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