# SECTION 3

# •WEATHER AND ALTITUDE
# •THE PHYSICS OF TARGET FLIGHT

## TEST 11. Air Density: Temperature, Pressure, Humidity, and Altitude

The two the most resilient misconceptions about target flight involve 1) the heaviness of air and 2) the effect of altitude.

"Heaviness" is a shorthand term for air density; density in general is defined as the weight of a certain volume of a substance. Air density in the US is standardized at sea level with these conditions: 59 degrees Fahrenheit, a pressure of 29.92 inches of mercury, zero humidity. A cubic foot of such air weighs 0.076 pounds.

These three determinants of density – temperature, pressure, and humidity – are all interchangeable. You can duplicate a change in pressure by changing the temperature the other way; humidity can do the same over a very limited range.

When you heat air its density is decreased; even in ordinary situations the effect is substantial. Between the setting of targets in the morning at 67 degrees and shooting them at noon at 90 degrees, the air density has fallen by 4 percent.

Wetter (high-humidity) air is lighter air. The average molecular weight of the mixture of gasses which is air is about 29, the molecular weight of water vapor is 18. If you replace some heavy air molecules with lighter water vapor molecules the resulting mixture is less dense.

The density-reducing effect of humidity is only worth considering at high temperatures, and even there it is minor compared to the effects of temperature and pressure. Ninety degree air at 70% humidity is like dry air at 97 – the "wetness" of a really sticky day causes about a 1% decrease in air density.

Altitude is what really changes air density. The altitude in the Midwest (and in Phoenix too) is commonly about 1000 feet above sea level, while Denver lives up to its slogan "The Mile High City." Air pressure falls about one inch of mercury per thousand feet of increased altitude. The air density in Denver is about 15% less than in Dayton under similar conditions.

In June, 1999, I went to Ray Stafford's Mile High club to get these last critical data. Ray not only provided free targets and let me mess with his traps on the morning of his state shoot's Championship Handicap, he even sent me home with more Blue Rocks to make my test at Metro perfectly comparable.

Conditions at Mile High were as follows: Temperature 70, barometer 25.6 inches, relative humidity 40%. There was no wind; an observer called target-fall guided by graduated rules from the fifty-yard stake as usual.

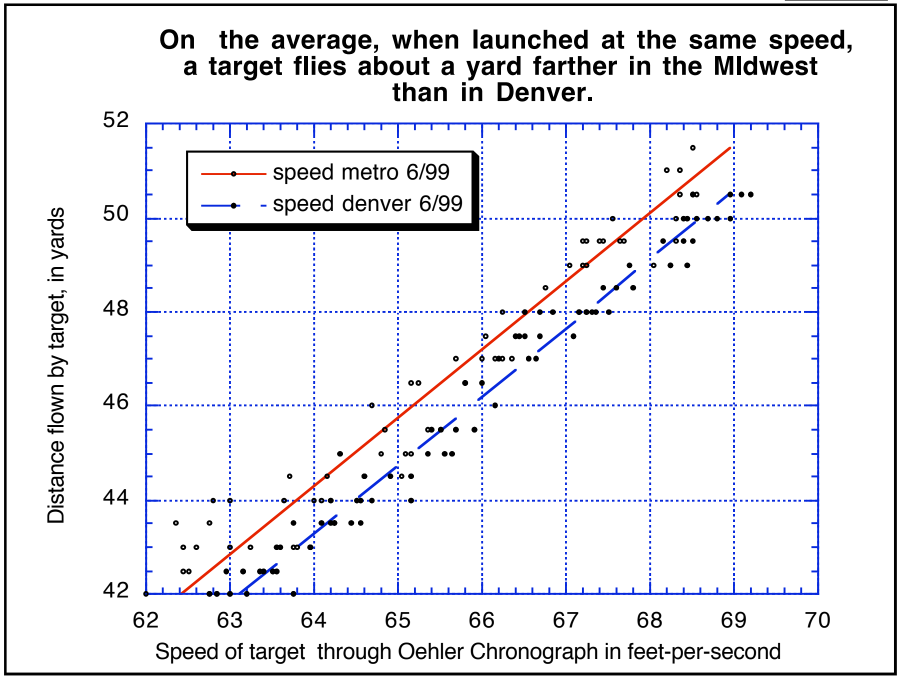
Using a Pat Trap and my Oehler #55 chronograph, I threw ten Blue Rocks at a speed which arced them about 42 yards. Then I increased the spring tension by one turn and threw ten more targets. I continued this until I was throwing them fast enough to get to the stake, fifty yards.

I drove back to Metro in Blaine. There the temperature and humidity were nearly the same as in Denver, but the barometer now read 29.7. This 4.1 inch difference in air pressure from Denver is just what the airman's rule of thumb (1000 ft.= 1 in.) predicts.

Using a Pat Trap and Denver's own birds, I followed the same procedure I had used the previous week.

The results of the test are presented in the graph on the next page.

fig. 3.1




This scatter plot reports the speed and distance of every target thrown at both locations. The filled circles and the dashed line represent birds thrown at Denver, at an altitude of 5300 feet; the open circles and solid line represent Metro, at 900 feet.

The slanting solid and dashed lines through the data are something new. They are linear curve fits and they represent the straight line which most faithfully summarizes the data.

A target thrown at a certain speed flies a yard further in the Midwest than it would in Denver or, conversely, you have to throw a high-altitude target a foot-per-second faster than one at the Grand and still reach the stake.

Though this difference is right at the limit of our precision, the consistency and sheer amount of the data make me think the distinction is real. It is not significant in shooting, it probably couldn't even be reliably set by distance or measured with a ProChrono, but it's there.

How do I square these results with the oft-told tale of the Grand American trap which crated up and sent west where it threw the targets much farther? There's a saying in science that if you didn't write it down it didn't happen. Well, I did these tests and wrote them down. I'm sticking to my story.

## The Physics of Flight

Why doesn't the reduced drag of Denver's thinner air let the target fly farther? To get that answer we have to know just a bit about the physics of flight.

If you threw a shot-put at the same speed and angle as we do a target it would go about the same distance. If there were no air we could throw anything – a shot-put, a target, a feather – and get the same result. As we bleed air into this vacuum we add more and more resistance which we call drag. We need a second force, lift, to keep our object in the air longer so we can use its forward speed to cover the same distance.

There are three forces which determine a target's flight. Gravity pulls it down, drag slows it down, and lift keeps it in the air.

A target derives its lift from two sources. The shape, humped on top and flat on the bottom, causes air to travel faster on the upper surface of the target than its lower, and in accordance with Bernoulli's principle, the air pressure is reduced at the upper surface. The higher pressure below pushes the bird up.

The angle that the target is tipped up, commonly about 20 degrees, is called the angle of attack. Because of this angle of attack the target pushes some of the air it hits down, and as described by Newton's Third Law, the air pushes back (up) in exactly the same amount.

Drag too comes from several sources. There's pressure drag caused by air pushing back when it is pushed on as in the lift example. There's also skin friction drag: air is a little sticky and clings to objects being pushed through it. Last there is a component of drag caused by lift itself, induced drag.

Drag and lift are both directly dependent on air density. When you throw targets at high altitude they suffer less from drag, but they also benefit less from lift. In theory there should be no difference at all in flight between the two locations based on air density; my experiment found a difference, but it was minor.

The theory which predicts longer high-altitude targets is wrong because it focuses only on drag and neglects lift.

And what about flight changes due to high afternoon temperatures? Air density could make a change of half a yard; the changes you do see must be due to something else, maybe machine warming

## Spin

When I listed the sources of lift I listed them all and didn't mention spin. That's because spin adds no lift, spin only provides stability.

Everything that flies needs a stabilizer: birds have tails, rockets have fins, and clay targets have spin. It's the rotation of the target – specifically its angular momentum – which keeps the angle of attack constant and permits controlled flight. The "wind" from the front keeps trying to tip the nose of the target up; the angular momentum creates the force which resists this tendency. Sometimes under conditions of a big headwind this restorative force isn't large enough to overcome the tipping force and the target flips up and goes out of control.

The target rolls down the throwing arm and the friction between the target and the rubber (or plastic) strip in the arm ensures that the target actually rolls rather than just slides. The rate of spin is determined by 1) the diameter of the target, 2) the speed the target is thrown, and 3) the effectiveness of the friction between the rubber strip and the target. The rate of spin is not determined by the length of the target arm (except to the extent that length may influence friction, and this can be argued either way).

The target isn't on the arm for even a full turn and yet if everything is working right it picks up a spin of about 3000 RPM. And every machine gives the target enough spin. From my observer's spot at the 50-yard stake I've watched thousands and thousands of targets land and I've never seen one go out of control at the end; they all had enough spin. Based on this experience, I've just quit worrying about spin and suggest you do the same.

## Wind

I regret I have no data on the effects of wind. The fact is that just getting the still-air data was a much bigger project than I had bargained for. I hope to have some information by next year.

Once I, or someone else, publishes that data we're still going to be faced with an important question, one which only years of experience with and without chronographs will answer. I think that in windy conditions a chronograph will let you set the speed of a target more accurately than will setting it by distance. But what we really want is the most breakable target, not necessarily a target of a certain speed. It may be that an experienced target setter can work with the wind and give you more of the target you want to shoot at than would a slavish obedience to a number flashing on an LCD. This is the task of the advocates of chronographs: to show that they work better than anything else in the wind.

Regardless of how that particular controversy turns out I'm looking forward to doing some head- and tail-wind testing. When a shooter says "They were throwing them directly into a 20 mile-an-hour wind and they we hitting right at the stake so I *know* they were hot!"– I want to know if he's right or not.

## You've bought a ProChrono. Now what?

Don't go out and set targets for a registered shoot. Just as you know you have to get used to a new gun before you can exploit its performance, understand that you are going to have to get to know your chronograph before you put it to any real work.

Try some of the early tests in this report. Get an idea how much precision you can expect, how careful you have to be in using it, how to recognize errors.

Then throw some 48 or 50 yard targets and see how fast *your chronograph* said you threw them. Use an observer at the stake and give him some kind of distance scale out there to aid his judgement. Do this throwing the target several different heights.

Keep records of the last tests and put them up on the club bulletin board. Just so shooters know what's going on.

Then use ProChrono to set targets. Maybe all the time, maybe just when you think you need it.

And then tell the rest of us how it worked out.

# Conclusions

While this report seemed to be about testing chronographs, it was at the same time and in equal measure a test of the current ATA height and distance standard. Any conclusion I've drawn about chronographs could be restated in terms of height and distance. For example: "Precision of foot-per-second will keep a target within a yard" could be put just as well "Precision of a yard will get you within a foot-per-second." Another example: "Chronographs don't care about target weight, brand of trap, or altitude" and the equally true "Neither does the 50-yard rule."

What I've decided after doing all of this is that speed and distance really are just two sides if the same coin, two equal ways of getting the target we want.

My summary in one sentence: The quality of the target is not dependent on the *method* so much as the *care* used in setting it.

# Editorial

We're getting to the point where the ATA is going to have to deal officially with the issue of chronographs, and not for reasons I'd like.

Right now we're registering targets set by ATA height and distance rules or by chronograph, even though the rule book specifies only the former. We even registered a Grand American set by chronograph.

But we're under two conflicting pressures, and it's time to solve the first so we can go on to deal with the second.

We don't have a chronograph rule because we don't as yet have any standards. My ProChrono is pretty honest, but how about the next one? We have no information whatever on the sample-to-sample variability of that instrument. To continue registering chronograph-set targets we must require the manufacturer(s) of target chronographs to supply a certificate of calibration with each (serial numbered) unit and provide retro-calibration for already-sold units. This is a trivial technical problem. If they can built them, surely they can test them. Then the ATA should use one (or better several) of these calibrated instruments to throw some 48- to 52-yards targets and transfer those results to the rule book. As this report demonstrates, they can throw them in Dayton and the results will be close enough to apply anywhere else.

Once this issue – calibration – is dealt with we can start on the sec ond problem. Readers of this report must have noticed that the speed I have been talking about (66, 67, 68 feet-per-second to get a 48- to 50 yard target) are a lot higher than any clubs are actually using. And m ProChrono reads a little slow (figure 1.2). I suppose it's possible that got the fastest-reading ProChrono ever built, but I think that is askin too much of coincidence. Still, I have heard from reliable peopl who have done careful testing and they're getting 48-yard tar gets with 63 or 64 feet-per-second launching speeds. I think the ProChronos are simply giving them the wrong numbers. Thi only underlines our need for calibrated instruments.

But I think I know many of where those 63 or 64 foot-per-secon standards they are using came from. Either they "heard it some where" or they threw a few targets, using none of the controls ou lined in this report, and accepted the lowest numbers they dared to This is no different than setting the 50-yard stake by sending a few guys out to pace it off and pounding it in where the closest one stop If this isn't cheating it is at best unacceptable inattention to detail, a worst it's pushing the rules to just short of the point where you migh get caught.

Clubs are even removing the 50-yard stake altogether! How the could defend a protest of their target distance I don't know – remem ber no speed standard is authorized in the rule book.

I like chronographs; you must have guessed that from the time I'v spent verifying them, but they are being misused. When the ATA set a standard, and I'm betting their testing with calibrated instrument will require them to be in the 66 to 68 feet-per-second range; then th people using chronographs will find out quick enough how to alig them right and get the highest reading possible.

We can give the manufacture(s) a year or so to certify their produc Then we can set standards using the certified instruments, put thos standards in the rule book, and keep on registering chronographe targets. If these two things don't both happen we have to someday sa that the targets set by (only) chronograph were not thrown accordin to ATA rules and cannot be registered. A shooter has the right to know that his average-competitor at next club is shooting at an equally-di ficult target; clubs must be assured that a nearby rival isn't getting fa off easy targets. We've got to get this right, and fair, or quit registerin chronographed targets altogether. If we don't we're closing our eye to a problem I think we all know exists.