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# The Problem of the Pullout

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*You stare at a windscreen full of rapidly approaching ground. As the altimeter quickly unwinds and the airspeed builds, the sound of wind rushing by outside the cockpit gets louder by the second. With the onset of ground rush and only seconds to react, you must make the correct decision now. No second chances. No time to analyze the situation. You've got to rely on your training. How good was it?*

Far fetched? Not to anyone who's ever flown in the fighter or trainer community. Student pilots specialize in putting their instructors into just such situations, while fighter pilots routinely do it to themselves for tactical advantage. **In a nose-low situation, there are two basic approaches to recovery. Common sense tells us that we need to pull as hard as the airframe and aerodynamics will allow. At issue is "where to put the throttle."**

**Here's the bottom line up front: The seemingly mad act of pushing up the power in a nose-low, altitude-critical situation is the correct move.** By pushing up the power, you minimize the parameter of primary importance in this situation—altitude lost during the dive pullout.

This solution is not intuitive and requires a discussion of basic turn performance and turn performance in the vertical plane. I'll then tie the two concepts together to show how the effect of the earth's gravity on turn performance is the key to understanding how to minimize altitude loss in a nose-low recovery.

### Turn Rate and Radius: The Critical Parameters

To understand how to minimize the altitude lost during a dive, we must first delve into how an airplane turns. To make the discussion more relevant, I'll use numbers from the F-4G and the T-3A.

Figure 1 shows a fictitious but reasonable flight strength envelope for the T-3. The actual flight strength envelope isn't included in the Dash 1, so I extrapolated the envelope from other Dash 1 parameters. This "unofficial" diagram is about as simple as they come—parabolic aerodynamic limit curves [$n \propto V^2$], constant redline speeds and constant structural limits.

A flight strength envelope plotted like figure 1 is also known as a V-n diagram, as the horizontal axis is the aircraft's airspeed (V) while the vertical axis is the load factor (n), or (very loosely) the number of Gs being pulled. The horizontal lines at +6 and -3 Gs are the structural limits. The vertical line at 195 knots is the redline airspeed. The two curved lines that start at the origin and arc up to the structural limit lines are the aerodynamic stall limits. An attempt to fly with a combination of airspeed and G-loading above and to the left of the positive-G stall line will result in a stall. In general, an aircraft may be safely operated anywhere inside of its flight envelope without fear of breaking or stalling the plane.

It's obvious that, in our altitude-lost-during-a-dive problem, turn radius is a critical parameter. It's not as obvious that turn rate is just as important. Both of these parameters have extraordinary effects on the decision to use idle or full power. Take me at my word when I tell you that turn radius is proportional to the square of the airspeed and inversely proportional to the number of Gs pulled [$R \propto V^2/n$]. When the airspeed goes up, the turn radius increases very quickly if we hold Gs constant. Hold the airspeed constant and the turn radius decreases when the load factor goes up. Contrast this to the relationships for turn rate. Turn rate ($\omega$) is inversely proportional to airspeed [$\omega \propto n/V$] and proportional to Gs. As you go faster, turn rate decreases. Conversely, the turn rate increases as you pull more on the pole.

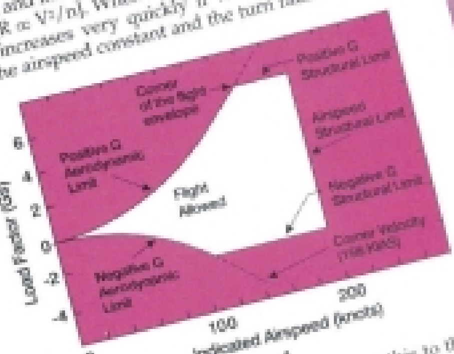


Figure 1

**To maximize turn performance, we need to *minimize* our turn radius and *maximize* our turn rate. Doing both of these things will also minimize the altitude loss. Optimal turn performance will occur when we pull lots of Gs at a slow airspeed.** Let's look at the V-n diagram again. Ignoring gravity for now, the turn radius stays pretty fairly constant along the stall line since we increase available G much faster than we increase airspeed. In other words, turn radius is proportional to the square of the airspeed and inversely proportional to the G pulled. G available is also just about proportional to the square of the airspeed, so the airspeed increase cancels out and turn radius stays relatively constant as long as you're pulling to the aerodynamic limit. Once we reach the +6 G structural limit, the turn radius begins to rapidly increase since we're holding allowable G constant while continuing to increase the airspeed. It would seem, then, that our minimum turn radius could be obtained by flying *anywhere* along the stall line. Figure 2 is

continued on next page

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*Something has gone terribly wrong. You're staring at a windscreen full of rapidly approaching ground. Your altimeter is quickly unwinding, your airspeed is building rapidly, and the sound of wind rushing by outside the cockpit is getting louder by the second. You know it's going to be close, as you are starting to feel a bit of ground rush. You have only seconds to react, and you must make the correct decision now. No second chances. No time to think about the right procedure. You've got to rely on your years of training, so you sincerely hope that training's been good. What will you do?* **……….**

Far-fetched scenario? Not to anyone who's ever flown in the fighter or trainer community. Student pilots specialize in putting their instructors into just such situations, while fighter pilots routinely do it to themselves for tactical advantage. In a nose-low recovery situation, there are two basic approaches to solving the problem of the pullout. Common sense tells us that we need to pull as hard as the airframe and aerodynamics will allow so we can to try to get the plane turning as best as it possibly can. That tells us what to do with the right hand, but the true problem lies in how to handle the other hand that's sitting there on the throttle. You can either pull the throttle back to idle, or perhaps perform the insane act of pushing it forward just as far as it will go, possibly hurtling yourself downward even faster toward certain doom.

In this paper I intend to show that the seemingly mad act of pushing up the power in a nose-low, altitude-critical situation is the correct move. By pushing up the power, you will minimize that one parameter that is of primary importance to you in this situation—altitude lost during the dive pullout. This counterintuitive procedure needs to be taught and drilled into every pilot who is likely to encounter this type of unusual attitude so that it happens instinctively. To quote Homer Simpson, "In times of stress, you gotta go with what you know."

This problem does not have an easy answer. Though most people are uncomfortable with high-powered equations and graphs, please don't go "up-and-locked" on me and miss the very important punch line. Remember, the time to think about nose-low, altitude-critical recoveries is while training at a safe altitude or while reading this paper so you know exactly what to do when that time-critical situation arises. I'll attempt to explain this concept primarily with words, pictures, and graphs, while saving the math for a short appendix to this article. As an overview, I plan to discuss basic turn performance, turn performance in the vertical plane, and then tie the two concepts together to show how the effect of the earth's gravity on turn performance is the key to understanding how to minimize altitude loss in a nose-low recovery.

### *Turn Rate and Radius: The Critical Parameters*

In order to understand how to minimize the altitude lost during a dive, we must first delve into how an airplane turns. We need to understand the basics of turn performance so we can understand how to maximize the parameters critical to getting the plane to turn. In order to make the discussion more 0relevant, I'll use actual numbers from two aircraft: the venerable F-4G Wild Weasel and the Air Force's new flight screener, the propeller-driven T-3A Firefly.

On our road to understanding turn performance, the first place we need to turn is that old standby of UPT aerodynamics class, the flight strength envelope. Figure 1 shows a fictitious but reasonable flight strength envelope for the T-3. The actual flight strength envelope isn't included in the "Dash-1" (the Air Force technical manual for an aircraft). I have extrapolated the envelope from other parameters in the Firefly's Dash-1. We'll look at this "unofficial" diagram because it is about as simple as they come—parabolic aerodynamic limit curves ($n \propto v^2$), constant redline speeds and constant structural limits. The flight strength diagrams for other aircraft may not be as simple as the Firefly's, but the points we review here will still apply to those charts.

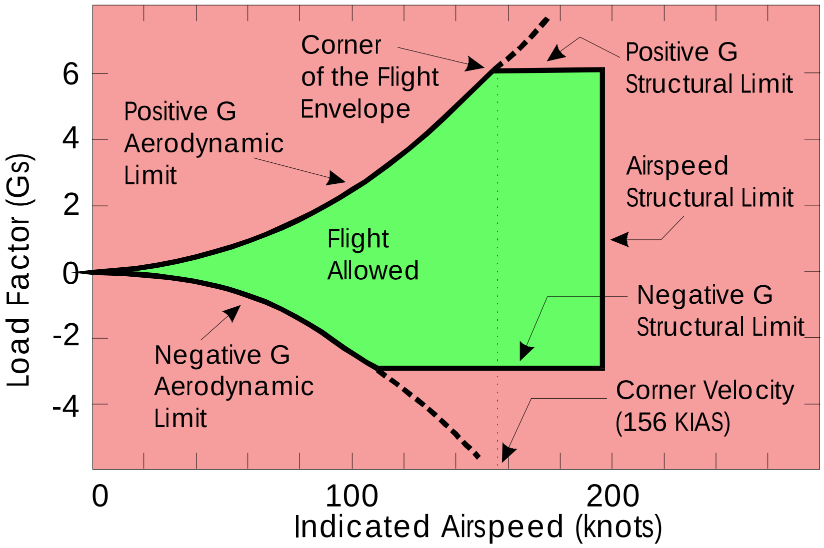


**Figure 1: The Flight Strength Envelope for the T-3.**

As a quick review, a flight strength envelope plotted like Figure 1 is also known as a V-n diagram, as the horizontal axis is the aircraft's airspeed (V) while the vertical axis is the load factor (n), or (*very* loosely) the number of Gs being pulled by the aircraft. The horizontal lines at +6 and –3 Gs are the aircraft's structural limits. If you want to rip the wings off the plane, these are the limits to exceed. The vertical line at 195 knots is the aircraft's redline airspeed. All sorts of nasty things like resonant wing twisting (flutter) and negative control feedback can occur if you venture to the right of this line. The two curved lines that start at the origin and arc up to the structural limit lines are the aerodynamic stall limits. An attempt to fly with a combination of airspeed and G-loading above and to the left of the positive-G stall line will result in, what else, a stall. Flying below and to the left of the negative-G stall line is one of those masochistic things left for test pilots to accomplish; the results are neither comfortable nor pretty. Note that the negative-G stall line in this figure is purely notional, as no data concerning negative G stalls is given in the appropriate technical publications. In general, an aircraft may be safely operated anywhere inside of its flight envelope without fear of breaking or stalling the plane.

It seems pretty apparent that in our altitude-lost-during-a-dive problem, a parameter we'll be interested in is turn radius. It's not quite so obvious that a parameter that's just as important will be turn rate. Both of these parameters have extraordinary effects on the decision to use idle or full power, so we'll investigate both of them. As previously stated, I'll not go into a lot of equations until the appendix. Unfortunately, that means you'll have to take me at my word when I tell you that turn radius is proportional to the square of the airspeed and inversely proportional to the number of Gs pulled [$R \propto V^2/n$]. This means that when the airspeed goes up, the turn radius increases very quickly if we hold n constant. Holding airspeed constant, when the load factor goes up, the turn radius decreases. Contrast this to the relationships for turn rate. Turn rate ($\omega$) is inversely proportional to airspeed [$\omega \propto n/V$] and proportional to Gs pulled. This means that as you get faster, the turn rate decreases but as you pull more on the pole, the turn rate increases.

In general, to maximize our turn performance, we need to *minimize our turn radius and maximize our turn rate*. Doing both of these things will also minimize the altitude loss in our scenario. A quick look at the above relationships shows that optimal turn performance will occur when we pull lots of Gs at a slow airspeed. Let's look at the V-n diagram again, and assume that we can ignore the effects of gravity for now. We'll add gravitational effects back in later in this article. When ignoring gravity, it can be shown that along the stall line the turn radius stays pretty fairly constant since we're increasing the available G much faster than we're increasing the airspeed. In other words, using the relationships we discussed above, turn radius is proportional to the square of the airspeed and inversely proportional to the G pulled. But the available G is also just about proportional to the square of the airspeed, so the increase in airspeed cancels out and turn radius stays relatively constant as long as you're pulling to the aerodynamic limit. In mathematical terms, $R \propto V^2/n$ and $n \propto V^2$, so $R \propto V^2/V^2$, or $R$ = constant. Once we reach the +6G structural limit, the turn radius begins to rapidly increase since we're holding allowable G constant while continuing to increase the airspeed. It would seem, then, that our minimum turn radius could be obtained by flying *anywhere* along the stall line. Figure 2 is a plot of turn radius vs. airspeed, given that the G for the airspeed in question is either the maximum allowed by aerodynamics or structure. It is easy to see that

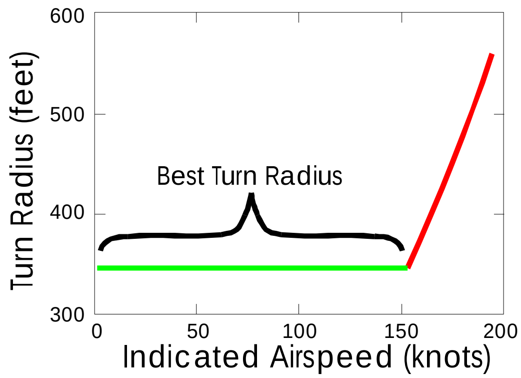


**Figure 2: Maximum Performance Instantaneous Turn Radius vs. Airspeed (ignoring gravitational effects).**

once the T-3's 6G structural limit is reached at 156 knots, the
radius begins to increase.

Our question now is whether there's some preferred airspeed to fly along the stall line so that turn rate is maximized. Again, looking at the relationship for turn rate and the allowable combinations of airspeed and load factor from the flight strength diagram, we see that as we decrease our airspeed from redline to 156 knots, the maximum G we can pull remains constant. This implies that the turn rate increases quickly as we slow down. However, once we start to become limited by the stall line, the rate begins to rapidly decrease again. Figure 3 graphically shows this result.

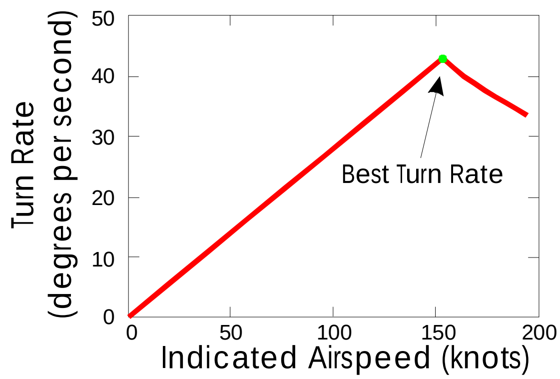


**Figure 3: Maximum Performance Instantaneous Turn Rate vs. Airspeed for the T-3 (ignoring gravitational effects).**

Therefore, it would seem that the only place where both rate and radius are optimized occurs when the aircraft is pulling 6Gs at 156 knots. This result is by no means unique to the T-3. Turn performance is optimized when any aircraft is flown at the slowest airspeed where it can first pull its structural limit without stalling. In fact, this location is so common that it is called the "corner velocity" by fighter pilots since it occurs at the corner of the flight envelope. An aircraft's corner velocity is one of those numbers that every fighter pilot knows by heart, since when they really need to turn to make or avoid a shot, that's where they'll usually try to do it.

### *Radial G and the Energy Egg*

The final piece of the basic turn performance puzzle is called radial G. The easiest way to explain this concept is to examine an airplane performing a constant airspeed, constant G loop. Admittedly, this is not the easiest loop to fly, if it's possible to do it at all. However, this is a simple dynamical analysis used in all undergraduate physics texts. It highlights the two variables in the turn performance relationships and allows us to examine the other major player in a nose-low recovery—the influence of the earth's gravity.

Up until now, we've only discussed turn performance in terms of G, which you probably assumed was exactly what you read on your G meter. Unfortunately, when you're airborne the G meter really only measures the effects of the lift force on the aircraft. The force that turns the aircraft is a combination of both the lift force and the force of gravity due to the earth. We'll call the *vector* sum of the lift force and the gravitational force "radial G". In our previous discussion of turn rate and radius, we really need to replace the term n with $G_r$, radial G. Thus, our relationships become $R \approx V^2/G_r$ and $\omega \approx G_r/V$.

To fly our constant airspeed, constant G loop, all we do is pull on the stick to maintain a constant reading on the G meter and modulate the throttle to maintain a constant airspeed. As you first consider this maneuver, you may be convinced that this will turn out to be a perfectly circular loop. After all, turn radius is related only to G and V, so if both are constant, then the radius must be constant, right?

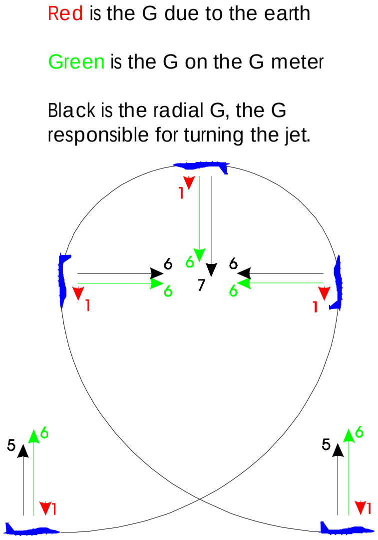


**Figure 4: The Energy Egg.**

A glance at Figure 4, commonly called the "energy egg," will hopefully convince you that the loop will be anything but circular. What we forgot in our circular loop assumption was the effect of gravity. At the bottom of the loop, we're holding 6Gs on the G meter, but the earth's gravity is acting in the opposite direction from our lift. This means that our radial G, the vector sum of G due to lift and g due to the earth will be only 5Gs. Our turn performance will be less than maximum as the earth's gravity is working against us.

A bit later in the loop, we're pointed straight up. At this point, we still have 6Gs on our meter due to lift acting horizontally but the earth's gravity is still acting down, at right angles to us. This means gravity doesn't add to the G due to lift, so radial G equals the G on our G-meter. Our turn performance here is better than it was at the bottom of the loop, proportional to 6Gs vs. 5Gs, since gravity at least isn't working against us.

Soon, we find ourselves upside down in our constant G, constant airspeed loop. At this point, both forces turning our plane are acting in the same direction, so gravity actually helps us turn the aircraft here. Our radial G becomes 7Gs and our turn performance is maximized. As we continue around the loop, we come to the point where we're pointing straight down. This situation is similar to the previously discussed point where we were on our backs; gravity neither helps nor hurts us here, so our radial G is again 6Gs.

This hopefully explains why our circular loop looks a bit more like an egg. We have less effective force turning our plane at the bottom of the loop, so our radius is large and our rate is low. The further toward the top of the loop we travel, the higher our radial G gets, so our radius continually decreases and our rate continually increases. As we travel back down the back side of the loop, our turn performance parameters worsen again until they hit their worst values at the bottom of the loop. Obviously our best turn performance must then occur when our lift vector is below the horizon, since in those cases, gravity is assisting our turn.

Combining this newfound knowledge about the energy egg with another look at Figures 2 and 3 will show that they actually only apply when the aircraft is pointed straight up or straight down, the only two times that gravity has no influence on the radial G. If we were to look at a more general case of a maximum performance level turn, these two plots would be a little more complicated, but they would still indicate that the combination of minimum turn radius and maximum turn rate occur only at the corner velocity. Figures 5 and 6 show the maximum performance turn radius and rate for a level turn in the T-3.

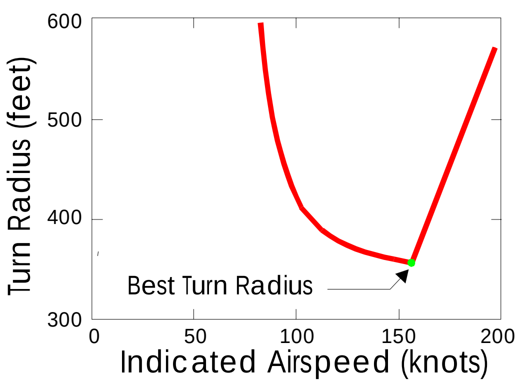


**Figure 5: Maximum Performance Instantaneous Turn Radius vs. Airspeed for the T-3 in a Level Turn.**

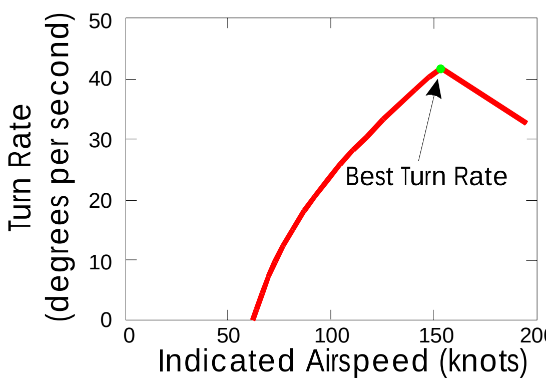


**Figure 6: Maximum Performance Instantaneous Turn Rate vs. Airspeed for the T-3 in a Level Turn.**

So what does this discussion of the energy egg have to do with maximizing turn performance? How will it help us decide what to do with our left hand? The question still remains: idle or full power? Don't both solutions have to turn the same angle to get us out of our nose-low situation? Won't both turns be affected by gravity the same? The answer to this question will come in the next section.

***Tying It All Together***

Hang with me! We're really on the track of the solution to our idle-or-full-power problem. We've got a pretty good handle on how to optimize our turn: in simplistic terms, fly near corner velocity and pull just short of bending the plane. In fact, to optimize our turn *radius*, all we really have to do is fly below corner velocity while pulling to the aerodynamic limit. We've also seen that the closer we get toward a level pull, our desired end-state, the more gravity hurts our ability to turn. We've just got a little way to go to put all of these concepts together to let us see the answer to the problem of the pullout.

Let's go back and perform a thought-experiment. What if radial G didn't care whether gravity was working or not? What if radial G was only a function of the G on the G-meter? Let's look at two cases of nose-low turns at two different constant airspeeds that both turn from 90 degrees nose-low back to level flight. If we assume that both airspeeds are below corner velocity and that we pull to the aerodynamic limit in both turns, then both turn radii should be the same because of our no-gravity situation.

How much time does it take to perform the pullout from the dive? Figure 7 shows the paths taken by our two aircraft, with small aircraft spaced along the arcs at regular distances related to their respective airspeeds. From this figure, it's obvious that it takes less time for the faster aircraft to pull out of the dive (three vs. nine time units). This aircraft has a higher *turn rate* (less time to turn the same angle). This is the crux of the answer to our problem. Let's now add back in the gravity that we originally neglected in this thought experiment. Gravity's effect on turn performance during this nose-low portion of a vertical turn is to subtract a progressively greater and greater amount from the radial G that is turning the plane. This means that the longer it takes to pull out of the dive, the longer gravity has to act against the Gs the aircraft has available due to aerodynamics. In effect, the slower plane has to endure the turn-hindering effect of gravity for a longer time, so it ends up with a much larger average turn radius and ends up losing much more altitude. What does this mean? With all else being equal, *the aircraft that can sustain the highest turn rate loses the least altitude*.

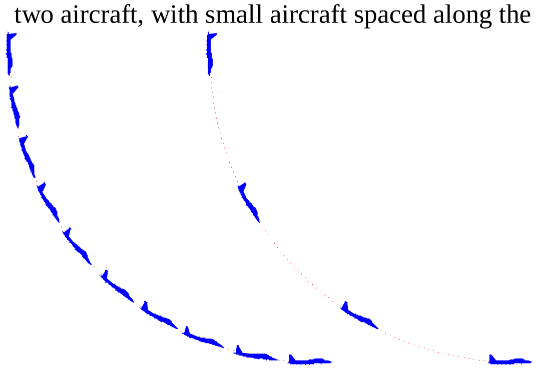

**Figure 7: Turns Ignoring Gravitational Effects at Two Different Airspeeds below Corner Velocity.**

The bottom line is that the faster you can go while staying below corner velocity, the less altitude you'll lose in the dive recovery. From this, it sounds like the correct solution to the scenario stated at the beginning of this paper is to immediately begin to pull to the aerodynamic limit and then quickly advance the throttle to full power so you can get your airspeed to build just as rapidly as you can. I need to emphasize that I am <u>not</u> advocating delaying the pull to get your airspeed to build. Again, the solution seems to be to *immediately* begin the pull and *only then* worry about putting in the power.

***Solutions of a Dynamic Nature: Comparing the Idle and Full Power Techniques for Jets***

The above thought-experiment, while it gives a reasonably good explanation of which plane will lose less altitude during the dive, is much too simplistic for us to use to get any numbers (or even a good qualitative feel) for our altitude loss comparison. What we really need to know is *how much* better is it for us to make the pullout at a faster airspeed, and what is the optimum airspeed for the pullout. To do this, we'll have to resort to a computer model. A complete description of the model is beyond the scope of this article. Suffice it to say that it is reasonably straightforward. It takes pertinent parameters from the aircraft at an instant in time, parameters such as position, airspeed, pitch angle, available G, and acceleration capability at idle or full power. It then calculates turn rate and radius for a very short time interval. The program then recalculates the aircraft's parameters and uses these new parameters to come up with new rates and radii, and so on until the cyber-aircraft returns to level flight. Warning: simplifying assumptions run rampant throughout this model, so you need to read the appendix and fully understand the program before you start quoting the numerical results as gospel. However, the assumptions do not significantly affect the qualitative result, only the exact numbers quoted in the figures.

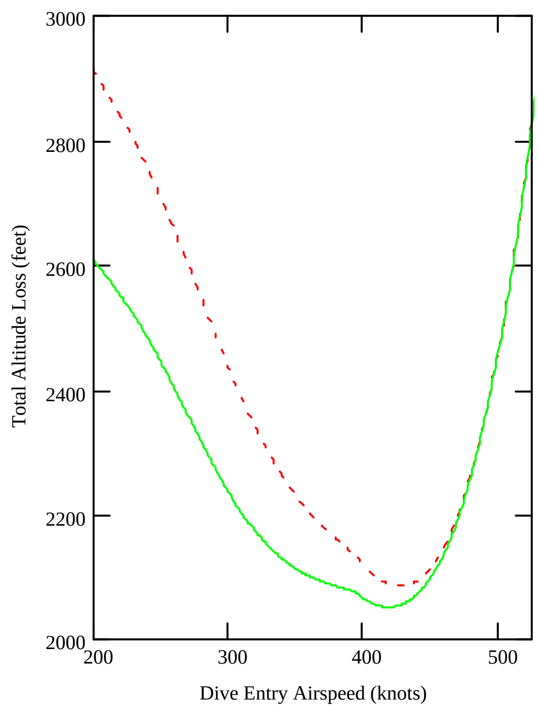


**Figure 8: F-4 Altitude Loss Vs. Entry Airspeed For a 90-Degree Dive Pullout at 5000 feet. The solid green curve is a recovery using maximum afterburner and the dotted red curve is a recovery using 50% thrust.**

What are the results for this simulation? Figure 8 shows the altitudes lost by an F-4 pulling out of dives from 90 degrees nose-low back to horizontal for a variety of airspeeds. The red curve shows recoveries using 50% thrust (18,500 lbs.) and a pull to aircraft limits (aerodynamic and structural, as driven by airspeed). The green curve shows recoveries using maximum afterburner (37,000 lbs. thrust) and a pull to the aircraft limits. In both cases, once the lightweight F-4's 8G corner velocity of 420 knots was exceeded, the throttle was immediately reduced to idle and the load factor was limited to structural limits. If the jet's airspeed again fell below corner velocity, the throttle was re-advanced to maximum afterburner or 50% power and the pull was readjusted to aerodynamic limits. Notice that the absolute minimum altitude lost during the dive occurred when the dive was entered at corner velocity and the throttle was modulated between idle and full as required to maintain that airspeed. Eventually, both curves match up, as the turn is started above corner velocity and both recoveries must use identical idle power methods to attempt to prevent an over speed/over-G.

The important thing to compare in this figure is the difference in altitude lost for a given entry airspeed. For example, a dive entered at 300 knots will lose 2400 feet using the 50% power recovery method (the red curve), while only losing 2200 feet in maximum afterburner (the green curve). Moving your left hand fully forward can save you a full 200 feet in this case. That 200 feet might be the difference between a good story at the bar and a smoking hole!

It's obvious which method will yield the best results, as the green curve is in every case lower than the red curve. Figure 9 shows a plot the flight paths of two F-4s recovering from identical 90-degree dives entered at 200 knots. As above, the two plots are based upon 50% thrust and maximum afterburner recoveries, again pulling to aircraft limits. The dots along the curve indicate where the respective aircraft are at one-second intervals. Notice how much faster the maximum afterburner aircraft (the green curve) accelerates (the dots get farther apart) as it quickly completes its turn. You can see that the full power recovery not only loses less altitude, but it takes less horizontal distance and a lot less time to complete. For this case, the altitude savings are even greater than the previous example: 300 feet less altitude loss completed in 7 seconds less time.

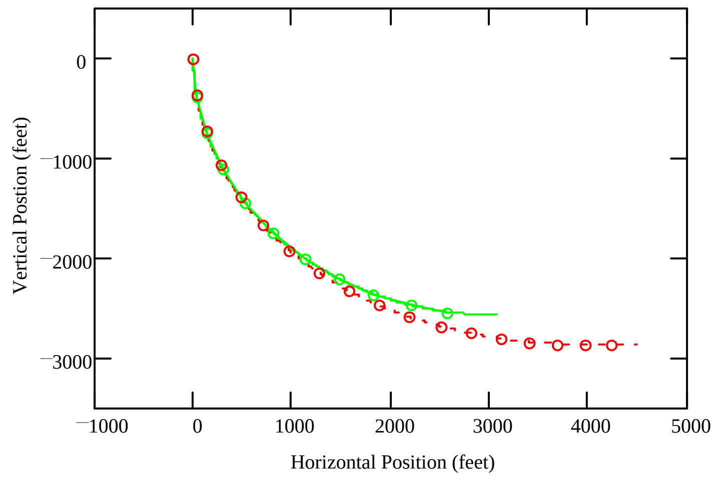


**Figure 9: Flight Paths of an F-4 Recovering From a 200 Kt Dive at 5000 feet. The solid green curve is a recovery using maximum afterburner and the dashed red curve is a recovery using 50% thrust. The dots are spaced at 1-second intervals.**

***Even More Impressive Results for High-Performance Props***

I used the F-4 as my first example since I was intimately familiar with its performance from experience gained during a previous tour. Understanding these results for jet aircraft is important to a large portion of the trainer and fighter world, but now being a member of the Mighty Firefly community, I was also interested in how it would affect propeller-driven aircraft. In fact, with the JPATS aircraft coming on line, the results for prop aircraft would seem to take on an even greater significance.

As impressive as the numbers were for the Wild Weasel, they're even better for a prop. In a jet, the thrust exits the aircraft aft of the wing. In most props, the thrust comes out ahead of the wing and significantly affects the airflow over the wing. Unfortunately, I do not know of any wind tunnel data which would allow me to quantify the difference between idle and full power nose-low recovery methods. You'll just have to accept a touchy-feely explanation of why the full power recovery is enhanced in propeller aircraft.

In idle power, all of the negative consequences for jets discussed above occur. In full power, all of the jet benefits are felt, as well as the benefit of having your thrust blown across your wings. As soon as you advance the power to full, the airflow across your wings immediately accelerates. Since, below corner velocity, available G is directly related to the square of the airspeed *across the wing*, this "blown wing" immediately produces more lift and hence allows more Gs to be pulled. In the case of a prop, the airspeed across the wing is not necessarily the same speed that is registered on the airspeed indicator. Since turn radius and rate are both helped by increasing the available G, your turn performance gets an immediate boost without immediately suffering the negative consequence of actually increasing the aircraft's airspeed, which would tend to decrease turn performance.

I've included figures from a model of the T-3's turn performance in a dive that are similar to the plots for the F-4 from above. The assumptions used to model the additional lift due to the blown wing are tenuous at best, so these plots should in no way be used to quote definitive numbers. They do, however, allow me to better compare and contrast three T-3 dive recovery methods. The three methods discussed are the full and idle power methods used above for the F-4 models (without afterburner, of course!), and the recommended method for recovering from a dive following a spin described in the T-3 Dash-1. The Dash-1 method

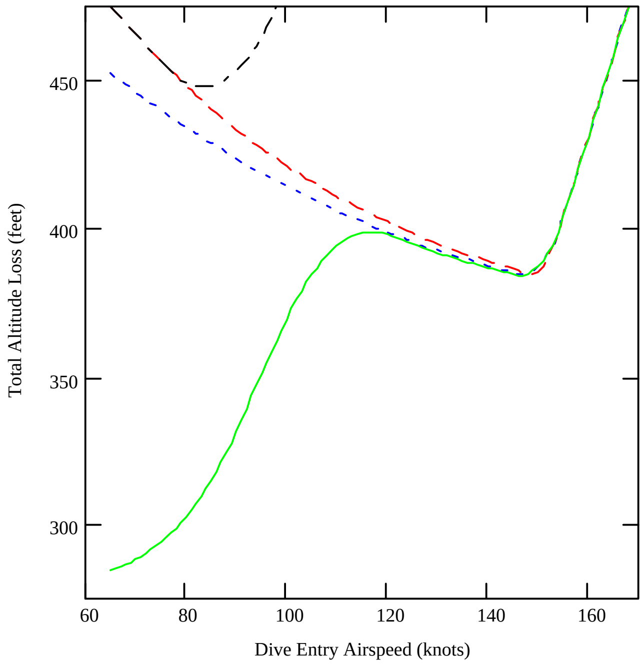


**Figure 10: T-3 Altitude Loss Vs. Entry Airspeed For a 90-Degree Dive Pullout at 10,000 feet. The dash-dot black curve is a recovery following current Dash-1 procedures. The dashed red curve is an idle power, best pull recovery. The dotted blue curve is a full power, best pull recovery, not considering blown wing effects, and the solid green curve is a full power, best pull recovery that takes into account the blown wing effect.**

prescribes a 3G pullout from the dive recovery, period. As increasing the power during a dive recovery is also inexplicably discouraged in AETCM 11-206 (the how-to-fly-the T-3 instruction), the modeled method consists of using idle power, pulling to the aerodynamic limit until 3 Gs are reached, and then pulling 3 Gs for the remainder of the recovery. The way I chose to model the blown wing effect is detailed in the appendix, however I feel that at worst it is a conservative estimate of the actual, observed effect.

Figure 10 shows the altitude lost in the T-3 during 90-degree dives entered at various airspeeds. The black curve shows the altitude lost using the Dash-1 procedure. The red line shows an idle power, maximum-performance pull recovery. (By maximum performance pull recovery, I mean that you pull to either the aerodynamic or structural limit, whichever is less.) The blue line shows a full power recovery not including blown wing effects, and the green curve shows the altitude lost when full power is used and the blown wing is taken into account.

Several notable things can be seen in this figure. First, the T-3 Dash-1's method obviously doesn't take advantage of the increased performance due to increased airspeed or the blown wing. Second, the effect of a blown wing is extremely significant at lower airspeeds. Just look at the difference between the blown (green curve) and the non-blown (blue curve) full power methods at 70 to 90 knots, the very airspeeds at which one normally exits a spin in the T-3. The altitude saving due to the blown wing is by far the predominant effect. Figure 11 shows the flight path of just such a recovery. In this case, the dots on the curves are spaced at ¼ second intervals. Just as the jet data showed for the F-4, these figures show that the proper recovery method for the T-3 should be to get on the pull and then add full power just as soon as possible.

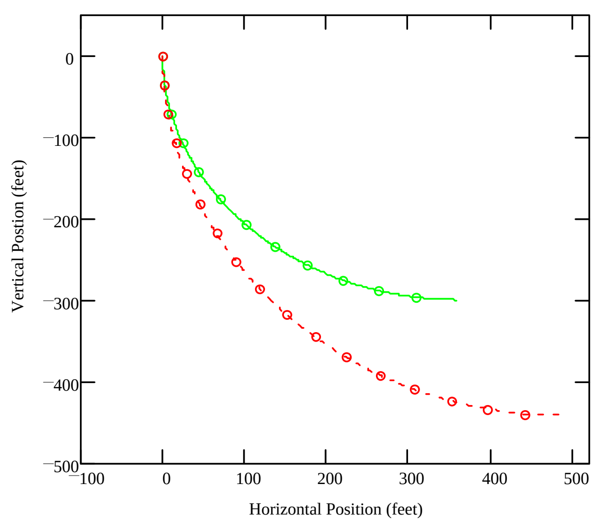


**Figure 11: Flight Paths of a T-3 Recovering From an 80 Kt Dive at 10,000 feet. The solid green curve is a recovery using full power and the dashed red curve is a recovery using idle power. The dots are spaced at ¼ second intervals.**

***Train like You Fight and You'll Fight like You Train: Summary, Conclusions, and Recommendations***

If you're still not convinced, I'll try one final thought-argument. Let's say you're flying at very low altitude and an airspeed below corner velocity headed for a very tall cliff. How do you avoid a collision? Full power and a level pull! Now, imagine you're in a nose-low overshooting final turn. How many of you would suggest an idle power pull to correct back to the runway? Probably no one would suggest any course but another full power pull. So where's the cutoff? If in a level turn you pull with full power and in a slightly nose-low, overshooting final turn you pull with full power, where does idle power start to be the correct solution? My answer to this question is simple: once you see that you're going to exceed corner velocity, it's time to yank back on the throttle *but not before*.

In summary, we've seen that the problem of the pullout is a complicated, dynamic problem that needs a computer model to fully analyze the solution. The key to that solution is to know what the corner velocity for your aircraft is and to use it. If you're in an altitude-critical situation, you need to pull to the buffet and choose full power if you're below corner and idle power if you're above it. Again, DO NOT DELAY THE PULL WAITING FOR A PARTICULAR AIRSPEED—GET THE PLANE TURNING FIRST.

Some conclusions and recommendations follow. This recovery method is valid for both jet and prop aircraft, and even more so for props since the blown wing contributes immediately to the available radial G. With JPATS coming on line soon, every prospective Air Force pilot will have ample opportunity to experience the improved performance that comes with increasing the power. As a recommendation, I would also change the way that nose-low recoveries are taught in flight screening and pilot training. These procedures should be justified by appropriate emphasis in basic aerodynamic classes where more attention needs to be paid to the flight envelope and the concept of corner velocity. As is the case today, students need to be taught to pay attention to airspeed clues including stick feel, audible clues, and even the occasional glance at their instruments before deciding whether to select idle power. However, they also need to be taught to select full power if they really need to get the plane turning when they're below corner velocity. The only way they're going to learn this is if our instructor pilots fully understand and begin to feel comfortable with this recovery procedure, practice it both with and without students on board. One must <u>experiment</u> within the bounds of good flight discipline! All Air Force instructor pilots must believe that this technique really does work and that it may one day save them from impact with *terra firma*.

I have solicited input on this article from sources in the USAF and RAF test pilot communities, physicists and aeronautical engineers from the USAF Academy, and T-3 instructor pilots from the USAF and RAF. During this technical review process I received several questions from pilots that were along the lines of "why are you so worried about a mere 200 foot savings of altitude? After all, we practice these maneuvers at relatively high altitudes, don't we?" Again, I must fall back on the adage "you fight like you train." We don't teach our students to do power on stalls, traffic pattern stalls, unusual attitude recoveries, and spins because they'll be doing them as part of their operational mission later in their careers. We do them because we want to prepare the students for the worst-case scenarios they might encounter in the extremely unforgiving business of flying. We already demand that our students master minimization of altitude loss in their traffic pattern and power on stalls. We do this not because we expect them to go out and stall at low altitude, but we want to prepare them for that once-in-a-career situation where they really need to avoid hitting the ground. We hammer the procedures into them time and time again so that some day they may be able to avoid an accident. There is no logical reason why we don't require the same level of proficiency from our students during nose low recoveries and spin/spin prevention recoveries. The requirement for minimization of altitude loss is no less important here than in stalls. Implementation of the procedures detailed in this article will simply bring the training received during these maneuvers into line with our other save-your-life maneuvers. If we don't demand it during training, then when the windscreen's actually full of ground they probably won't react appropriately. We are creatures of habit. Because of this, we have to constantly strive to make those habits the most effective ones possible.

*………The years of dedicated training kick in and you instantly reach back into that valuable unusual attitude training that you've received ever since your initial flight-screening program and make the correct choice. You quickly start a pull to the aerodynamic buffet to get your max performance turn started. Hearing very little wind rush outside and feeling relatively loose controls, you correctly surmise that*

*you're well below corner and immediately push up the power. The Gs increase quickly, as does your turn rate until you pull out just a few feet above the ground. After you get back to altitude, you thank your lucky stars for that demanding IP that long ago forced you to learn to feel the buffet, listen for the wind, and push up the power in a slow-speed dive.*

### *Acknowledgements*

A great deal of thanks goes to Maj Ken "Mountain" Gurley for his in-flight assistance in obtaining specific excess power data for the T-3. Additionally, he served as my primary sounding board for many of the ideas contained in this paper. Additional thanks go to Maj Eddie "Muddy" Waters, who was also instrumental in helping to obtain the specific excess power numbers. Lt Col Andy Gerner's in-flight assistance was invaluable in helping me obtain T-3 drag data that was unobtainable from the manufacturer or the Air Force.

### *References*

Data on the F-4 was taken from the F-4 Dash-1 and Maj Charlie Bretana's *Air to Air Reference Text* used in the F-4 upgrade course. Data on the T-3 was obtained from the T-3 Dash-1 and personally conducted in-flight tests. Data on the T-3 engine was from Lycoming's Engine Performance Data Curve Number 12958.

### *Appendix: Mathematical Summary and Description of the Computer Model*

This appendix will be brief and nowhere near complete. However, it's a good start toward understanding the math behind the models. Variables used in the following derivations are as follows: F = force; m = mass; a = acceleration; r = the radial direction (when used as a subscript) or radius; $G_r$ = radial G; g = the gravitational acceleration of the the earth; W = weight; L = lift; θ = the pitch angle (0 denotes horizontal flight to the right and angles are measured counterclockwise); n = load factor; v = airspeed; ω = turn rate; E = energy; $W_{nc}$ = non-conservative work; $P_s$ = specific excess power; d = distance.

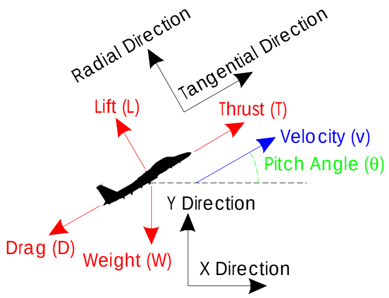


**Figure 12: Conventions Used in the Mathematical Model.**

Before we can get expressions for turn rate and radius, we need an expression for radial G in terms of load factor and pitch angle. Starting with Newton's second law, **ΣF** = m**a**, the following equations apply:

$$\frac{\Sigma F_r}{m} = a_r$$

$$G_r \equiv \frac{a_r}{g}$$

$$W \equiv mg$$

$$G_r = \frac{\Sigma F_r}{W}$$

$$G_r = \frac{L - W\cos\theta}{W}$$

$$n \equiv \frac{L}{W}$$

$$G_r = n - \cos\theta$$

Now, to define the turn radius, we again start with Newton:

$$\frac{\Sigma F_r}{m} = a_r$$

$$\frac{\Sigma F_r}{W} = \frac{a_r}{g}$$

$$G_r \equiv \frac{a_r}{g}$$

$$a_r = \frac{v^2}{r}$$

$$G_r = \frac{v^2}{rg}$$

$$r = \frac{v^2}{gG_r}$$

Defining turn rate, we start with the transformation between linear and circular velocities and then use the turn radius result:

$$\omega = \frac{v}{r}$$

$$\omega = \frac{v}{v^2 / gG_r}$$

$$\omega = \frac{gG_r}{v}$$

Looking at these two equations, we can see that both rate and radius depend on how fast the plane is going and how many Gs it is pulling. Their values will also change in rather non-intuitive ways as v and $G_r$ change.

In order to understand the models, one must examine the concept of specific excess power, $P_s$. $P_s$ is just a way of seeing how quickly the engines and drag can cause an aircraft to accelerate. We will be using our derived $P_s$ in a computer model that steps through very short intervals of time and distance, so we can assume that all of our variables are constant over that time period or length. This will allow us to pull their constant values through any time integrations, simplifying our derivation considerably. Of the four forces of flight, weight is conservative and lift does no work, as it is always perpendicular to the velocity. Thrust and drag, then, are the only non-conservative forces we'll need to consider in our conservation of energy problem. Fortunately, they act parallel to the velocity, so their dot product with distance reduces to simple scalar multiplication.

$$\Delta E = W_{nc}$$

$$W_{nc} \equiv \int \overline{F}_{nc} \bullet d\overline{x}$$

$$\Delta E = \overline{F}_{nc} \bullet \overline{\Delta d}$$

$$\Delta E = \overline{T} \bullet \overline{\Delta d} - \overline{D} \bullet \overline{\Delta d}$$

$$\Delta E = (T - D)\Delta d$$

$$P = \frac{\Delta E}{\Delta t} = \frac{(T-D)\Delta d}{\Delta t}$$

$$P = (T - D)v$$

$$P_s \equiv \frac{P}{W}$$

$$P_s = \frac{(T-D)v}{W}$$

Knowing that all of the non-conservative forces act in the tangential direction allows us to use $P_s$ to derive an expression for the tangential acceleration of the aircraft, or the rate of change of airspeed:

$$\Sigma F_t = ma_t$$

$$T - D - W\sin\theta = ma_t$$

$$T - D = ma_t + W\sin\theta$$

$$P_s = \frac{(ma_t + W\sin\theta)v}{W}$$

$$P_s = \frac{a_t v}{g} + v\sin\theta$$

$$P_s = \frac{a_t v}{g} + \frac{\Delta y}{\Delta t}$$

$$a_t = (P_s - \frac{\Delta y}{\Delta t})\frac{g}{v}$$

Now we have all the tools we should need to talk about developing a model for how an aircraft turns. The method I used is a relatively simple numerical technique called the Euler method. This method takes a set of initial conditions and uses an expression for acceleration to see how those conditions change over very short time intervals. The conditions change because the velocity changes ever so slightly through the equation $v_{new} = v_{old} + (a_{old})(\Delta t)$.

In my model, I defined the initial conditions for the aircraft's airspeed, pitch, position, and load factor. From these conditions, I calculated the maximum possible load factor (limited by the stall line or the structural limit), the specific excess energy, the radial G, the turn rate, the turn radius, and the tangential acceleration. Knowing the acceleration, I was able to calculate a new value for the airspeed, and I recalculated how the other parameters had to change based on this short, straight-line motion based on the old position, direction of flight, and airspeed. I continued doing this process until the pitch angle was zero, or the aircraft returned to level flight. Sound pretty simple so far?

The difficult portion of this problem was getting accurate data on the flight envelopes for the two aircraft in question. The F-4 $P_s$ data for maximum afterburner was available in a chart, but I needed to convert the chart data into the form of $P_s = f(n,v)$ so I could use it in my program. This took quite a bit of curve fitting from relatively inaccurate data. The 50% thrust $P_s$ data is not available at all, so I had to approximate it by deriving an equation for $P_s$ at some power setting other than the known one. I chose the 50% thrust point instead of idle since at idle power the F-4 wouldn't make it back to level flight without a stall or a significant unload during the dive recovery, a condition which my model wasn't designed to handle and which involves a large number of arbitrary, unpredictable pilot choices.

As difficult as getting data on the F-4 was, getting data for the T-3 was even worse. $P_s$ diagrams for any aircraft but fighters are rare. I could not even find a V-n diagram for the Firefly, so I was forced to derive one from the four stall speeds given in the Dash-1 (during the course of which, I discovered an error in the published Dash-1 corner velocity which is currently being corrected). In order to derive $P_s$ curves for the T-3, I also needed to know drag coefficients, which no one at the manufacturer or in the Air Force seemed to be able to find. This forced me to get the data from airborne tests, assisted by a USAF test pilot, Lt Col Andy Gerner. These data were fairly inaccurate, but close enough for the purposes of this qualitative model. Again, I had to approximate the $P_s$ values for the T-3 in idle power, as the data we collected was only valid for full power.

Finally, the $P_s$ data for the T-3 is based in part on knowing the propeller efficiency, which seems to be proprietary information. At the advice of Lt Col Gerner, I assumed a value of 84% at cruise airspeed for this number, realizing that it will be quite inaccurate in the high- and low-airspeed regimes. Finally, my assumptions for the blown wing are as follows: since the T-3 can sustain level flight at 120 knots, the propwash velocity should be on the order of 120 knots(it will actually be higher, but I kept my model on the conservative side). However, it does not affect the entire wing, its effect becoming less pronounced toward the wingtips. My model for the blown wing was then based on the aircraft's airspeed. If the airspeed was below 100 knots, I added 20 knots to the airflow over the wing, which helped the plane turn tighter and faster by increasing the maximum allowable load factor without an immediate, corresponding airspeed increase. If the airspeed was between 100 and 120 knots, the blown velocity was set to 120 knots. If the airspeed was greater than 120 knots, the blown airspeed was set equal to the aircraft's airspeed. Careful consideration of this model might help explain the shape of the blown altitude-loss curve. Admittedly, this is a crude model, but as a first approximation I feel it is reasonable.

A multitude of errors could have been introduced with these curve fits, assumptions and approximations, which is why I heavily discourage the use of the numerical data presented above. The qualitative results (the shapes and relative positions of the curves) should be fairly accurate, but the numbers will definitely be off. If you are interested in a more detailed discussion of these models and the underlying assumptions, please contact me in care of this journal.

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