Reentry Tutorial with Glideslope MFD 2.x

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Introduction

This tutorial provides a description of the four phases to get from orbit to a safe landing, without needing any power. Hopefully this will help you understand more of the big picture objectives, and how to adjust things when necessary. Remember – it takes at least a few dozen landings before you start to get a feel for what is happening, and even then you will always see something different on the next landing. Good luck, and be safe out there!

(By the way – the assumption is that you are landing on Earth. The principles apply equally on other planets and bodies with an atmosphere, but you may need to use hover-thrusters and/or retros for thicker or thinner atmospheres to prevent burn-up or to prevent overshoot.)

Stage 1: Deorbit Burn to Entry Interface

This first stage gets us from orbit down to the edge of the atmosphere (called the Entry Interface). We want to arrive at the Entry Interface on a descent trajectory that gets us close to our landing base, descending not so steeply that we burn up, and not so shallowly that we skip off the atmosphere. We want to hit the outer atmosphere at the right anticipation (meaning the angle from the entry interface to the base, measured from the center of the planet), so that by the time we have come down to 10km altitude in final approach, the base is in front of us. How do you do this predictably every time? Use BaseSync MFD. BaseSync shows you the closest crossrange distance to base on the upcoming several orbits, allowing you to select the best one for your deorbit burn. Select the target base, enter the reentry parameters, wait for the spaceship to hit the marker, retro burn exactly the amount shown by BaseSync, and you are on the way down. A suggested Earth reentry using BaseSync would be an entry Altitude of 120km, an Anticipation of 75 degrees and a reentry Angle of 0.7 degrees. (Doing this deorbit burn from say a 200km circular orbit only takes 2-3 secs of burn in an XR-series spaceship.) Using the suggested settings here would bring you to the Entry Interface at 120km/400kft, about a quarter orbit from the base, on a relatively gentle 0.7 degree glide slope. For the more accommodating ships (DG, XR, etc) we can take a more aggressive approach, with less anticipation and a steeper reentry angle, but for more realistic ships like the Shuttle, the tolerances are quite tight around this value. For practical purposes, we won't see much atmospheric drag until about 80km altitude, but 400kft/120km is a good benchmark to start the entry, and it's where we should start to see the dynamic pressure gauge start to flicker into life.

Before deorbiting, we want our crossrange to be within a few hundred kilometers. If not, or if we simply have fuel to burn and want to be precisely on track, use the BaseSync MFD to burn Normal on the

BaseSync node points (these node points mark where your orbital plane intersects with the optimal orbital plane to fly you right over the base). As we burn Normal at these node points, we will drive the crossrange down (if not, we are burning the wrong way, so switch to retros, wait half an orbit and try again on mains!).

There is actually have a quite substantial ability to fly in a banked turn to correct this crossrange error without fuel usage on the Main Descent phase, up to hundreds of km, so no need to be precise to the meter!

Once we complete the deorbit burn, select Surface HUD, roll wings level, yaw to point forwards towards your velocity vector (ie take out any side slip), and then pitch up to 40 degrees. If the ship has an attitude autopilot, then use it for these settings. Take this time to secure your spaceship for reentry, stowing radiators, shutting nose cone, closing retros or hover thrusters, and so on.

At this point, bring up Glideslope 2 on one of the MFDs. Your first task is to hit PR (Previous Runway) or NR (Next Runway) to scroll through to get to your target runway. You can also hit UNT (Unit Select) to toggle from US to Metric units. Once this is done, hit MOD (Mode Select) until you find mode 1, the vertical situation display. This is the screen with the yellow and green trace lines. Yellow is the altitude, green is the true airspeed, plotted against range to base. If you have brought up this display earlier in orbit, you will have made two horizontal lines already - the green showing your orbital velocity, and the yellow showing your range to base varying as you flew in orbit overhead. As we start to descend from orbital altitude, you will see the yellow trace start to descend, with the green staying constant. This is normal for this phase, as we have not hit any atmosphere yet to slow us up (bar a couple of stray nitrogen or oxygen molecules, that is!)

As we head down to the Entry Interface, look at how the yellow altitude trace starts to line up with the reference glideslope. If our burn was good, we should intersect the reference altitude glideslope at exactly the right range, with the right slope angle. If not, you have work to do immediately to get onto the reference slope, by adjusting your descent rate to trend towards the reference. Ideally though, tune those deorbit burn parameters to make this a stress-free part of the descent.

Stage 2: Main Descent, from Entry Interface to the HAC pre-entry.

The second stage of the reentry gets us from the Entry Interface down to the HAC turn. On this main descent, we will go through the peak of the reentry plasma heat, burning off our spaceship's orbital energy, and we will adjust our heading to enter the HAC in great shape.

To set up for this stage, we are going to continue to use the vertical situation display on one of our MFD's, and now we will bring up a second instance of Glideslope 2 on the other MFD, or on an external MFD if you prefer. Select mode 3, the Digital Descent Data on this new MFD. This display gives you a readout of your critical information compared to a reference Glideslope. Green is good, white is high and red is low, as you would expect. All the information is important, but pay particular attention to your Delta Azimuth (ie bearing error from your trajectory to the HAC), your AoA (angle of attack of the wings into the airstream), your total energy (sum of potential energy from your altitude, and kinetic energy from your velocity), and the range to the HAC. Continue to look at the Glideslope for the altitude and air speed trends. You will notice that the spaceship becomes increasingly sensitive to AoA changes: even 0.5 degrees change will change the vertical speed rates. You can choose to engage the Glideslope autopilot (hit AUT), but if your spaceship has its own autopilot, use that in preference.

(If you prefer a more visual version of the descent parameters, then select mode 2, the visual tapes display. Personally, I wrote the digital display so I could immediately see the numbers rather than trying to work out what the actual and desired values were on the tape format! You should be able to get much of the same information from this screen as from the digital data.)

As we pass the Entry Interface, expect to see the True Air Speed blip up a tiny amount, then start to fall. Our dynamic pressure gauge will also start to rise. At this point, the Angle of Attack (AoA, or Alpha angle) becomes valid, and you should switch to use this to control your autopilot from here to touchdown.

Heading down the upper part of this descent, we want to maintain a relatively constant vertical speed (around -80 m/s). (Actually, some would argue for a constant deceleration rate rather than a constant sink rate, but for our purposes, a relatively constant sink rate works just fine.)

There's two ways to maintain this sink rate... a technical way, or an easier way, depending on the spaceship and your flying style. Let's start with the technical way (as used by Shuttle): steeply banked S-turns with Roll Reversals. This method is critical when you have little tolerance for adjusting your AoA. The idea is to roll anywhere from 60 degrees to 120 degrees (ie partially inverted), whilst keeping a constant AoA. As you do this, our vertical component of lift from the wing will be reduced to zero or a bit negative, and therefore we will fall more quickly. Adjust roll to achieve the desired descent rate. Of course, the horizontal component of lift will now be non-zero at the same time, so we will start to arc away from our desired azimuth. Each time we get too far off course (Delta Azimuth of say 10 degrees or more), we can smoothly reverse our roll and come back the other way, to make an elegant series of S-turns in the sky.

What is the easier way? It's simply to adjust the AoA to maintain our desired vertical speed. If you are too shallow, add some degrees of AoA to increase resistance, or drop your AoA if you are too steep. We will typically be in a 35-45 degree range, which is usually fine for an XR-series spaceship, but for the Shuttle, it may well result either in too much heat on the thermal protection tiles (too high AoA), or a breach of the cockpit or leading edge of the tail (too low AoA).

With you preference of control technique for vertical speed, and turning to keep the Delta Azimuth low, we can continue down the main descent to approximately 30km from the HAC entry. (as shown on the Digital Descent Parameters screen). You want to get to this pre-HAC point on track (DelAz of zero), on Energy, on Altitude and on Airspeed.

The next part of the descent is where things get interesting.

Stage 3: HAC Turn, Pre-Entry to Exit

The HAC (variously called Heading Alignment Circle, Cylinder or Cone), is a real-world flight technique used for the Shuttle. The goal is to align the ship for final approach and landing, whilst burning off the reserve energy capacity (both Potential Energy from the altitude and Kinetic Energy from the airspeed). Given the lack of engine restart capability on the Shuttle post-deorbit, it was a critical safety feature to be able to have some contingency at this point, to cater for unexpected wind conditions, to change ends of the runway, or to be able to adjust the trajectory or location of the HAC for over- or under-energy situations. Whether you think of it as a cylinder, a circle or a cone, the basic purpose is the same – align onto final at the right height and speed to execute the final approach and landing.

This Glideslope 2 utility gives you the opportunity to fly a relatively realistic HAC, and to adjust for several different scenarios. Let's first explain the ideal scenario, and then look at the extensive set of options to deal with your actual situation.

For this phase, through to landing, you need to use Glideslope mode 4, the Horizontal Situation display. You can put this up on an External MFD or replacing the vertical situation screen, as you prefer.

Your entry to the HAC is actually from 20-30 km back, at the end of the Main Descent. The goal through that phase was to fly with a stalled wing, generating a lot of drag to slow us down ready for the final stages of the glide. For this phase, we want the ship to fly more like an airplane, albeit still at multiple times the speed of sound. In order to do this, the wing needs to be un-stalled, and the ship balanced in straight and level flight, so we are ready to enter the HAC. To do this, smoothly drop your AoA to around -1 degrees, and then control the vertical speed with AoA to end up close to level. Make sure that as you do this, you do not allow the vertical airspeed to balloon up to +100m/s or more, which it will definitely try to do if you loiter at say 10 degrees of AoA as you bring the nose down! Doing this would leave you high and slow on entry to the HAC, which would not be ideal.

You are now ready to enter the HAC turn, hopefully at around 600-900 m/s.

The entry into the HAC turn requires very positive input. You will typically need both a 60 degree bank, plus 10-15 degrees of positive AoA, to pull the nose up into the turn. Watch your vertical speed carefully to make sure you do not start climbing, as this will quickly bleed off your vertical speed. Instead, control AoA to try to get to around -30 m/s of descent, which will help maintain air speed.

As you go round the HAC, adjust your bank angle to keep on the HAC circle, and then adjust AoA to reset the vertical speed. For example, as the true air speed declines, the ship will tend to tighten on the turn, which you counter by rolling off some bank, which then generates more lift component, which you counter by dropping the nose a degree or two. It's a dance! Whilst doing this dance, you are also watching how much speed you ate carrying, and how the Glideslope angle for the final approach (right scale on the horizontal situation display) is moving. If all is good, you will maintain around 200 m/s air speed, -30 m/s vertical speed, stay on the HAC, and watch the Glideslope come up from -8 degrees to the benchmark -20 degrees, just as the HAC angle winds down to zero. At this point, you are perfectly positioned at the top of the final approach. Before discussing this, let's consider what could go wrong and what options you have to rescue your approach.

You will generally have one or more of three issues: too low energy, too high energy, or poor alignment/overshoot. You have no less than 6 buttons on the Glideslope 2 MFD to handle these situations: the HAC geometry button (HAC) and its reset (RST), the HAC Radius +/- override buttons and the Manual View Zoom +/- override buttons.

The HAC geometry allows you to select a left-handed entry or a right-handed entry. Left handed typically puts the HAC circle before the extended runway centerline, and right handed puts it after the centerline. If you are low energy, you want a left entry, and conversely you want a right entry if you are high energy.

You can also select an open or closed HAC turn. The closed turn requires a full lap around the HAC to open it up, whereas the open HAC just requires you to go around the HAC enough to get aligned with the runway. If you are normal or high energy, consider going round a loop before exiting, whereas if you are low energy, you want to do the minimum possible approach.

You can adjust the size of the HAC circle radius. This also adjusts the length of the final approach to the runway. You can adjust this radius mid-HAC turn if you wish, for example to create a tightening cone if you are losing too much energy mid-HAC. Likewise, if you are coming in very fast (e.g. 1400 m/s), you will not be able to turn into a tight HAC, and therefore you will need a larger radius turn.

In order to see the overall situation, you may wish to override the default auto-zoom capabilities of the horizontal situation display and zoom it out to see the bigger picture. Likewise, you may want to zoom in tighter on your actual course, and ignore the rest of the glide slope trace for now.

If you get stuck, or you want to reset the HAC settings, hit RST to go back to default. (Remember too, if all else fails, you always have the other end of the runway you can select, if you have blasted through your HAC turn window!)

Stage 4: Final Approach and Landing

If you get to this stage, you should be able to locate the runway in front of you somewhere, and you are ready for the last few seconds of your descent. The desired profile here is a 20 degree outer glide slope descent towards the PAPI lights, which should be a couple of kilometers in front of the runway, followed by gear down and a 3 degree inner glide slope from about 1000 feet altitude above the PAPIs down to the touchdown point next to the VASI lights. (If you have tried the KSC33 approach on the latest D3D9 graphics client, you will know exactly what this looks like).

We want to do this two-stage final approach so that we continue to maintain airspeed until very shortly before touchdown, then pre-flare and get stabilized as we cross the runway threshold, and on to a very gentle touch down on the centerline.

To arrive at the top of the final approach at the right glideslope angle, pay attention to the glideslope indicator on the Glideslope 2 horizontal situation display as you come around the last 90-120 degrees of arc. You should see the glideslope gradually increase from around 8-10 degrees toward 20 degrees, as you maintain you velocity vector at maybe -8 degrees on the surface HUD. If you are high, then the glideslope will be over 20 degrees, and you should consider steepening your vertical air speed to bring it back in range. Likewise if low, then try to trim your spacecraft for best range, with clean wings and less bank. (You may need to cut the corner of the HAC to achieve this, and go right ahead and do this).

As you roll out of the HAC and onto final, you should zoom the screen (using Z and X) to something comfortable – e.g. 20-25 degrees – so you can focus on a good final alignment. Push the nose down and get onto the desired glideslope, pointing towards the PAPI lights. You will probably need to extend your air brakes (Ctrl B) at this stage, to keep your air speed to 220 m/s or below. (Higher than this will cause problems for the gear deployment in a minute.)

You should get to the PAPI point at around 1 km altitude and around 200-220 m/s. At this point, retract your air brake if necessary, extend landing gear and pull up to target the Ball-Bar Light system (the VASI lights in our simulation). Make final corrections to alignment with the extended centerline, and then focus on getting the vertical air speed to track to one tenth of the altitude. In other words, as you get to 800m Altitude, have a vertical speed of -80m/s, 500m Altitude, -50m/s, and so on down to the runway threshold. Finally, get your spacecraft stable and in a gentle flare for landing, settling down at below -2 m/s of vertical speed, at around 150-180 m/s.

Congratulations – “what a ride, what a ride”…

If that was an awesome landing, then his SAV to save it away to potentially become your new reference glide slope. If it went horribly wrong, then also save it away so you can look where it got away from you! It’s all a learning experience, and you will do it better next time.

If you have any comments or questions, drop me a PM at ADSWNJ on Orbiter Forum.
Regards, Andrew Stokes (ADSWNJ) December 2012