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"From the Earth to the ISS" an Orbiter 2016 Stock Atlantis Full Mission Tutorial -Part 1
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"From the Earth to the ISS" an Orbiter 2016 P1
Stock Atlantis Full Mission Tutorial
Part-1

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Section

1.0 SUMMARY

1.1 Document Title: "From the Earth to the ISS" an Orbiter 2016 P1 Stock Atlantis Full Mission Tutorial Part-1
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1.2 Document Information: A Space Shuttle to ISS Scenario Tutorial for a nominal launch and rendezvous for docking with ISS(ZARYA) using no external addons besides Sound 5.0. This tutorial must be used with the scenario provided in order to view the same conditions to conduct the same procedures that are normally automated in the default Space Shuttle to ISS.scn scenario provided with Orbiter 2016 to launch and rendezvous with the ISS.

This tutorial will also teach a new user to Orbiter 2016 how to complete this mission manually in order to better understand the concepts behind using stock MFDs used in the provided playback tutorial that usually accompanies this scenario in Orbiter 2016 and how to use the tools provided to complete this mission.

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2.0 INTRODUCTION

2.1 Flight Director’s Forward:

The NASA Mercury Program was designed to put a man into space, assess human capabilities in space, and ensure safe recovery. The Space Race began with the 1957 launch of the Soviet satellite Sputnik 1 and then after many trials and errors, America achieved its goal and even leapfrogged the Soviets by being first to put a man into orbit. The Gemini Project’s key achievements included long-duration missions, **rendezvous and docking techniques**, spacewalks, and perfecting re-entry and landing methods.

The Gemini program was pivotal in developing and testing **rendezvous and docking techniques**, crucial for future lunar and ORBITER missions. Gemini missions demonstrated the ability to maneuver spacecraft into the same orbit and then achieve a controlled docking, a process involving two separate spacecraft joining together in space.

Some ORBITER missions require that the ORBITER meet, or rendezvous with, a satellite in orbit. If this satellite, or "TARGET," is in orbit prior to the launch of the shuttle, the rendezvous is called a "ground-up rendezvous."

Space rendezvous and docking with a "TARGET" traveling in orbit at 7.684km/s and an altitude 372.2km above the Earth is no small feat. Docking with the International Space Station or ISS(ZARYA), which has limited control thrusters for stabilizing its orientation, makes it even harder. We will take the information available from various sources and join them into this tutorial in order to achieve these two goals -space rendezvous and controlled docking in the Stock Space Shuttle Atlantis (STS-101) Atlantis.

We will be using a scenario provided in Orbiter 2016 that has been stripped of its playback tutorial so that you can follow the steps in that tutorial yourself manually. We will also show you how to use an online YouTube video of STS-1’s actual launch to sync your simulation with that video’s launch and then conduct your launch while watching/listening to the video (windowed mode required).

This scenario that we will use is from the playback tutorial “Space Shuttle to ISS.scn”. As it turns out there was no actual Space Shuttle flight with a launch date of March 23, 2010. But this is an Orbiter 2016 tutorial scenario that shows how to fly the Space Shuttle to ZARYA but has been modified to remove the playback aspect of that scenario.

The original scenario is located in the ..\Orbiter 2016\Scenarios\2016 Edition\ folder. Normally when you play that scenario, a tutorial takes over your flight and shows you information and instructions on the screen in purple on what is being done to launch the stock Space Shuttle into orbit using the AscentAP MFD. But only to a certain point. You are left contriving the rest of the mission yourself. So, here at **Mission Control Houston** we have made it our mission to complete this flight using this scenario without the playback tutorial aspect. It was quite easy to tear out the playback part of this scenario(see Appendix B. - Scenario Creation).

This tutorial will show you how to strip that automated playback from the scenario and the instructions/information from your screen and allow you to take control of the flight yourself.

And this tutorial will provide this stripped scenario as a downloadable *.scn file so you don’t have to create it yourself. You simply need to paste it into your Scenarios folder and then run it in your Orbiter Launchpad.

When you run it you will need to do all the procedures to get to ISS(ZARYA) yourself using only default MFDs provided in the Orbiter 2016 install, and complete all the steps provided in this tutorial to be mission complete.

3.0 SCENARIO INFORMATION

3.1 Scenario Name: Space Shuttle to ISS-0005-0010.scn
Original Scenario: Space Shuttle to ISS.scn
File Location: ..\Orbiter 2016\Scenarios\2016 Edition\

3.2 Scenario Description:
Space Shuttle to ISS

Space Shuttle to ISS.scn without the automated tutorial provided in the original scenario.

Launch the Space Shuttle Atlantis (STS-101) to orbit using the AscentAP MFD then follow my tutorial to rendezvous with the ISS and dock.

Mission starts on Tue Mar 23, 2010 at 11:57:04 (T-80s to lift off). The Autopilot is pre-configured for launch with the correct settings if you launch at T+80s from the start of this flight.

Although the date of this flight does not correspond to any historic flight done by NASA, the ISS is on a descending orbit near the Cape and in a perfect position for launch to intercept.

Press the "L" button in the L-MFD at Sim: 80s to liftoff at Tue Mar 23 11:58:24 2010 (MJD: 55278.4989).

Good Luck!!

3.3 Scenario Initial Parameters and Preflight Analysis:
State: (Paused)
Initial View: External Camera

Tgt: Atlantis
Cam track: (rel-pos)
FoV: 50°
Dst: 78.40

View: Cockpit

Tgt: Atlantis
Cam Cockpit
FoV: 50°

Hud: Surface Earth
Azumuth: 180°
Pitch: +90°
TAS: 5.42
R: 47.38 ALT

Date: Tue Mar 23 11:57:04 2010
MJD: 55278.4980
Sim: 0

Engines:
Main Prop: 719k
Main Eng: 0.00
Hover Eng: 0.00
RCS: ROT
Trim: 0.0

L-MFD: AscentAP MFD
Ascent P1/4

MET: 00:00:00.0
Launch azimuth: 137.1°
Orbit inc: 51.6°
Orbit altitude: 350.0km
OMS2 scheduled: yes

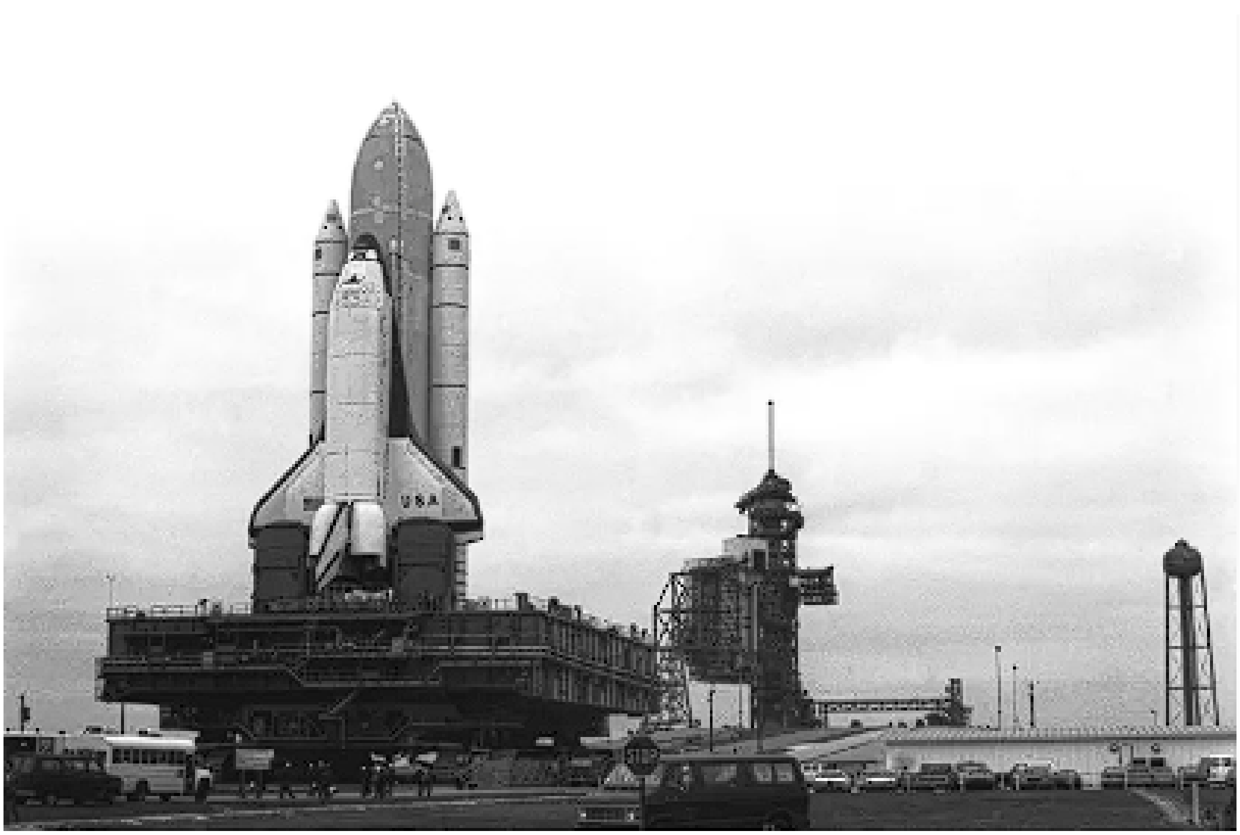
R-MFD: Map
Map: Earth
SHP: Atlantis [80.62°W 28.63°N, Alt 52.36, Crs 270.0°]
TGT: ISS [121.97°W 49.59°N, Alt 372.2K]

3.4 Scenario Understanding:

To start with you will need to get the scenario ready to use. To achieve this see section below: Appendix B. - Scenario Creation and Appendix C. - Scenario for Use With This Tutorial <code>:

3.5 Original Scenario Time:
The scenario's mission start time was chosen by Dr. Martin Schweiger. The scenario starts on Tue Mar 23, 2010 at 11:57:04 UTC. The liftoff date and time turns out to be Tue Mar 23 11:58:24 2010 which is T+80s after un-pausing the scenario. The time of liftoff that was chosen to launch is the correct time for a nominal launch so we will mirror that launch time.

We know that it takes us roughly 870 seconds to complete the first phase of our orbit. So, 870s plus our 80s to launch is 950 seconds from the beginning of the scenario. We also have a Launch azimuth of 137.11° from start. We will conduct calculations for how this was determined in a later tutorial but the information is here for your knowledge.



4.0 MISSION

4.1 Mission Objectives:
This mission is designed to launch the Space Shuttle Orbiter (STS-101) into a nominal orbit for rendezvous with the ISS(ZARYA), then proceed to dock. After this, the deployment and addition of the Leonardo module to ISS(ZARYA) if possible, and then to return safely to Earth at either the Shuttle Landing Facility at Kennedy Space Center (KSC) in Florida or Edwards Air Force Base in California. (Note: While Edwards Air Force Base served as a frequent backup landing site, the Kennedy Space Center was the preferred location for most landings due to its proximity to the launch site.

For this tutorial (Part-1 and 2), we will only cover the launch to Low Earth Orbit(LEO) and the rendezvous and docking procedures.

4.2 Mission Duration:
Approximately 8 to 12 days Mission Elapsed Time (MET).

4.3 MFDs Needed for This Flight:
MapMFD
AscentAP MFD
OrbitMFD
Sync Orbit MFD
Docking MFD
Attitude RCS MFD

4.4. Mission Launch to Orbit:

Video Syncing During Launch Phase - Use: [STS-1 - The Launch - Complete Day 1 (40th Anniversary)]

1. Start your scenario first and at Sim 20s Tue Mar 23 11:57:24 2010 (MJD 55278.4982) start the video at timestamp: 02:52:35 (T-1:00 to video's liftoff). The video is of STS-1, NASA's first Space Shuttle Orbiter's flight. It is an option to listen/watch this video while conducting your own simulated launch for realism. The video will slowly get off your own MET timer but it still does well for listening to during your launch and other parts of the flight as ambient sound.

I. Launch to the ISS(ZARYA)
As the 120-ton space shuttle sits surrounded by almost 4 million pounds of rocket fuel, exhaling noxious fumes, visibly impatient to defy gravity, its on-board computers take command.
The NASA Space Shuttle used a sophisticated flight control system called the Primary Avionics Software System (PASS). This system, built around five IBM main computers, managed all aspects of flight control, from launch to landing. To ensure reliability, the PASS utilized a redundant system with four synchronized computers that "voted" on commands.

A. Pre-launch Procedure.
   1. Press Ctrl+P to un-pause the simulation.
   2. After unpausing, wait until Sim 20s to start the above video at timestamp: 02:52:35 (T-01:00).
   3. At Sim 40 seconds Development Flight Instrumentation Recorders ON
   4. At Sim 56 seconds Go for Auto Sequence Start
   5. Watch either the "Sim" amount until it gets to 80s or watch the time for Mar 23 11:58:24 2010 to launch.
   6. At Sim 80s, press the "L" button in the L-MFD (AscentAP MFD) to start the autopilot(PASS) launch sequence (MET 00:00:00.00).
   7. LIFTOFF

B. Automated PASS Launch Procedures and Observations During Liftoff.
(Note: Do not move your ship or save your scenario during liftoff, after the OMS-1 cutoff, or try to replay a saved scenario until after OMS-2 expecting the AscentAP MFD to burn again at OMS-2. It will not).

1. **Liftoff** at Tue Mar 23 11:58:24 2010 MET 00:00:00.00. (You can see your MET in the top right corner of your AscentAP MFD).
   Roll Program at MET 00:00:06.00
2. **Roll Complete** at MET 00:00:15.00.
3. **Max Q** (Maximum dynamic Pressure) at around MET 00:00:43.00.
4. **Go at throttle up** at MET 00:01:13.00.
5. Negative C at MET 00:01:47.00.
6. Go for SRB Sep at 00:01:56.00.
7. **STAGING -SRB (Solid Rocket Booster)Separation (Sep)** at MET 00:02:07.00 (MET 126s)
8. Powered Explicit Guidance (PEG 1) convergence MET 00:30:00.00
9. At MET 00:03:44.00 You are at a return status "Green" to continue with launch from Flight Director Neil Hutchinson.
10. Press to MECO at MET 00:04:06.00.
11. Negative return at MET 00:04:19.00.
12. **Gimbal Roll Maneuver** starts at MET 00:05:46.00.
13. At MET 00:06:13.00 Gimbal Roll complete
14. At MET 00:06:20.00 pitch to +30° posigrade attitude complete.
15. At MET 00:06:21.00 Single Engine ROTA capability.
16. Single Engine Press to MECO at MET 00:07:16.00.
17. At MET 00:07:37.00 the crew experiences up to 3Gs.
18. **MECO** at MET 00:08:28.00 (508s) (Sim 593s from start of scenario).
19. Main Engine (SSME) POGO observed by crew.
    (Note: at this point the video's scheduled burns are different from our ignitions).
20. At MET 08:51:00.00 Go for Nominal OMS-1
21. **Tank Separation and Nominal OMS-1 Ignition** at MET 00:08:58.00.
22. Pitch Manuvere to +25° complete at MET 00:09:11.00
23. Open up a new MFD window and select OrbitMFD. Press FRM, PRJ, and DST to view your orbit.
24. **OMS-1 Cutoff/Shutdown** at MET 00:14:29.60 (869s) (Sim 953s) with an orbit of about 22.62 x 350.0k. No dV residuals hopefully. Your remaining fuel should be about 15881kg with a current vehicle mass of 256.012klbm and an empty vehicle mass of 229.999klbm.
25. Coast to OMS-2 burn.
    (Note: do not maneuver during this coast or the AscentAP MFD will not fire the OMS-2 burn also, a Plane Alignment opportunity occurs during this wait at about MET 00:31:13.00 but we must forgo this burn at this time due to the Ascent AP MFD program already in progress).
26. OMS-1 bleed in progress.
27. Go for OMS-2 at MET 00:15:56.00
28. Please follow section II Procedure for Opening the Cargo Bay Doors below then return to monitor the rest of this list.
29. Shuttle Orbiter switches from Operational Sequence (OPS) 1 on-orbit computer software to OBS 2 onboard.
30. OMS-2 Crossfeed Q information transmission.
31. **Nominal OMS-2 Ignition** at MET 00:37:59.00 [at a Time to Apoapsis (ApT) of 69.87s with a burn duration of 00:03:48.35 (229s).
32. **OMS-2 Cutoff** at MET 00:41:47.35 (Sim 2592 with an orbit of about 332.6 x 352.3k (yours may be slightly different).
33. End of PASS computer automated launch processes.
34. At this time switch to your external view (F1) and save your scenario state for later. (Mine is titled: "Space Shuttle to ISS-0005-0010 0001.scn").
35. Your remaining fuel should be around 11.8kg to 12.0kg (1195kg). You are now in space. Traveling at over 18,000 miles per hour (28968.192 km/hour).
36. Keep your AscendAP MFD open!! so you can keep an eye on your Mission Elapsed Time (MET) as it will be useful for our flight and syncing up with this tutorial.
37. Please quickly follow the procedures below in Section III Plane Change Burn (NPC)/NC-1 Burn as the Align Plane Change may occur soon after cutoff.

5.1 ON ORBIT PROCEDURES

II. Procedure for Opening the Cargo Bay Doors

A. Procedure: Open Shuttle Bay Doors

1. Press CTRL+Space bar - Then press Payload Door Operation.
2. The Atlantis Payload Bay Operation panel appears.
3. Set PL BAY DOOR, SYS 1 and 2 to ENABLE.
4. Turn on PL BAY MECH PWR, SYS 1 and 2 to ON.
5. Unlatch both bay doors under LATCH CONTROL by setting SYS A and SYS B to RELEASE.
6. When the readout says “REL” on both, turn both LATCH CONTROL, SYS A and B to OFF.
7. Set payload bay doors to deploy by setting PL BAY DOOR switch to OPEN.
8. When they are deployed you will see under PL BAY DOOR will read OP.
9. Set PL BAY DOOR setting switch to STOP.
10. Deploy both radiators under RADIATOR CONTROL, SYS A and B to DEPLOY.
11. When both displays read “DPL” then set SYS A and B to OFF.
12. Set the KU ANTENNA from GND to DEPLOY.
13. When the KU ANTENNA display reads DPL, set KU ANTENNA switch to GND.
14. Disable PL BAY DOORs and PL BAY MECH PWR to DISABLE and OFF respectively.
15. Close the Atlantis: Payload Bay Operation panel by clicking the red “X”.
16. Close the Atlantis Control panel.

III. Plane Change Burn (NPC)/NC-1 Burn

(Nodal Crossing 1): This burn aligns the shuttle's orbital plane with that of the ISS. The timing is crucial to minimize the need for costly plane changes.

A. After your OMS-2 Cutoff you will want to adjust your orbital plane to be closer to the ISS’s orbital plane.

1. Open up Align Planes MFD on page 1 of your MFD list.
2. Press the “TGT” button and scroll to “Spacecraft” with your arrow buttons then to “ISS” for your target.
3. If the orbit went nominally, you should be approaching the Descending Node (DN) in your orbit (P) in about 1.7k seconds (Tn 1.7xx seconds and about 00:29:45.00) from OMS-2 cut off. This is an estimate so you should go ahead and set up an OMS burn in the NML + direction fairly soon just in case.
4. We will use the Attitude RCS MFD to accomplish a +15° OMS burn due to the OMS engines being tilted at a 15° angle from the nose of the Shuttle. The Orbital Maneuvering System (OMS) is a system of hypergolic liquid-propellant rocket engines.
5. At about MET 01:01:00.00 or 12:59:30 UTC you can begin setting up this burn.
6. Open Attitude RCS MFD in another MFD screen.
7. Press “SET” then “BAS” to select the Basemode setting to “normal” and then press R+ to add a pitch function.
8. Press +V button until the + pitch reads +15.
9. At Time to Node (Tn) 120.0 seconds(about MET 01:04:45.5) in Align Plane MFD, please conduct an external view save at this point prior to the alignment burn in case anything goes wrong. I have called my save “Space Shuttle to ISS-0005-0010 0002.scn”.
10. At Tn 90s (around MET 01:04:15.10) in Align Plane MFD, you are now ready to press GO to start your RCS Attitude change to prograde +15°. Do not do this earlier because it can use up fuel holding that attitude and you will want to cancel this hold attitude program after the burn below for the same reason.
11. Once Attitude RCS MFD points you at +15° NML +, you can either wait until Align PlaneMFD “Tn” is half of the estimated (Est) thrust T (time) needed for TthD, or you can let Align Plane MFD tell you when to burn (You will see “Engage Thrust” in red), and “Kill Thrust” when to cut your OMS thrust.
12. As you burn, watch the relative inclination (RInc) slowly dropping down to zero.

13. When the Align Plane MFD tells you to “Kill Thrust”, you will kill all thrust. Note: This can be a little glitchy at times so when you see TthD at 00.00 or close to it then this is when to cut engines. If “Engage Thrust” stays on after your cutoff, just click on SEL to select a different MFD and then click back on and the issue should be fixed.
14. Once this is done you will want to also stop the Attitude RCS from holding attitude by pressing RTN, then END. You are now in near perfect alignment with the orbital plane of the ISS.
15. Your remaining fuel should be about 11356kg out of 21600kg. You should see 11.3kg next to MAIN PROP in the top left of your cockpit view.
16. After the align plane burn and adjustment I recommend another save in the external view to save your progress. My save is called “Space Shuttle to ISS-0005-0010 0003.scn”.

IV. Sunlit Orbital Burn to Increase the Orbital Period/Create Rendezvous Point

This was referred to as the Terminal Phase Initiation (TI) burn.

A. At MET 01:27:02.00 you should start to see the sunrise on your ship in an external view. This is a good way to measure if you are on time in your orbit.
B. Now is also a good time to prepare for increasing your orbital period and create your rendezvous point with the ISS(ZARYA).
    1. Press PRO GRD in your hud to start the Prograde Autopilot. Once it finds it and stabilizes, press KILL ROT or PRO GRD again to deactivate the Prograde AP and to save fuel.
C. Once the sun is up and you can see the Earth well underneath you (crossing the Earth’s terminator), you can begin the next step D.
D. At approximately MET 01:33:18.50 you will cross the Earth’s terminator. (Note: See alternative rendezvous points below).
E. It is a good time to start to set your intersection point as your periapsis in sunlight using Sync Orbit MFD and early in the sunlit time is a good idea to give you a lot of time for docking.
    1. To conduct an OMS Prograde Burn and create our new PeA I will use RCS Attitude MFD and Sync Orbit MFD to set the rendezvous orbit.
    2. Open these two MFDs if you don’t already have them open.
    3. Our Terminal Phase Initiation (TI) burn time choice will be at MET 01:35:00.00
    4. At about T-5 min to OMS burn (MET 01:30:00.00) set up your Sync Orbit MFD.
    5. Press TGT to set the target to the ISS.
    6. Press the MOD button until it shows a list of times on the right side of the MFD screen.
    7. You should also see “Ref: Sh periapsis” in the top left. If you do not press MOD until you do.
    8. Press the LEN button and enter 15.
    9. Now set up your burn using RCS Attitude MFD.
    10. Press the SET button until it shows “prograde” in the “Basemod:” area.
    11. Press the “+R” button to see the “+ pitch” subsection underneath “Basemode:”.
    12. Press the “+V” button until it reads +15.
    13. At about MET 01:32:00.00 save your sim in the external view before you conduct your attitude and burn. Mine is called “Space Shuttle to ISS-0005-0010 0004.scn”.
    14. At about MET 01:34:30.00 press the “GO” button to engage attitude change for the OMS burn.
    15. At MET 01:35:00.00 you can engage your OMS thrust by pressing and holding the num pad “+” on your keyboard.
    16. Watch the list of two times in Sync Orbit MFD (Sh-ToR and Tg-Tor) in yellow. As you burn the yellow numbers move to the bottom of that list at orbit (Ob) #14.
    17. You will continue to burn until you see the DTmin go to 0.00.
    18. At DTmin 0.00 Cut engines by letting go of the num pad “+”.
    19. In the Space Shuttle Atlantis, you have a very limited amount of fuel so we are stuck with the longer rendezvous time of having to wait for almost 14 orbits to save on fuel.

20. After this burn it would be wise to make another external view save of your scenario. “Space Shuttle to ISS-0005-0010 0005.scn”.
21. Keep your Sync Orbit MFD open for the next segment of your flight.

V. Note ISS’s Radial Altitude (RAD) at your Periapsis (PeA)

A. You have now set your intersection point for rendezvous with the ISS in a daylit part of your orbit. In order to meet the ISS at our intersection point (our PeA) we must now take note of the ISS’s radial altitude at our PeR so we will note the radial and normal altitude of the ISS while it passes over your periapsis (PeA). You want your radial altitude to be about the same and as close to the ISS’s RAD as possible when we rendezvous but first we need to know ISS’s RAD over our Periapsis.
To see this altitude you will need two MFDs. OrbitMFD and Sync Orbit MFD. Follow the steps below:
1. Open OrbitMFD if you do not already have it open and set the Form (FRM) to “Equatorial” EQU (Frm ECL).
2. Set the Projection (PRJ) to SHP.
3. Now add the ISS as your target. Press TGT then select the ISS from the list.
4. Now ensure that the distances are set to view everything in radials from the center of the Earth by pressing DST until you can see your PeA as PeR and your Alt will show as RAD. So will the ISS’s altitude be displayed as a RAD. This is the amount we are interested in from OrbitMFD.
5. You will be looking at two things. In Sync Orbit MFD you will notice that the column on the right “Tg-ToR” is counting down. This the time the ISS is to your Periapsis.
6. When this number Tg-ToR reaches 90.00 you will want to make an external save point in case you miss the time Tg-ToR goes to 0.00. Mine is called “Space Shuttle to ISS-0005-0010 0006.scn”.
7. When the Tg-ToR reaches 0.00 you can pause your sim, and then make a note of the reading in Orbit MFD of what the IIS’s yellow RAD amount is. You can also switch to Altitude mode by pressing the DST button in OrbitMFD to see the ISS’s Altitude in km above the Earth’s surface if you want both amounts. You will need one of them later.
8. Keep both the Sync Orbit MFD and the OrbitMFD open and move on to the next section.

VI. Match your PeA to ISS RAD/Alt at our own ApA

Now we need to set our Periapsis altitude PeR/PeA to what the ISS’s RAD/Alt was at our intersection point (our apoapsis) in the last orbit. This is done by burning prograde or retrograde at our Apoapsis. And this is based on if your PeR is above or below the ISS’s RAD when passing over your periapsis.

A. You can wait around or fast forward until your own next Apoapsis or when your next **ApT** is about 180 (seconds). Use OrbitMFD to watch for this time.
B. At this time it is a good idea to save your sim in the external view in case you mess this burn. I have named my save point as “Space Shuttle to ISS-0005-0010 0007.scn”.
C. This gives you some time to set up another RCS Attitude +15° OMS burn.
D. You will want to see if your PeR is currently higher or lower than the amount you wrote down from the ISS’s RAD when it passed your periapsis.
   1. If it is higher, then you will burn your OMS retrograde to lower your PeR.
   2. If it is lower then you will burn your OMS prograde to raise your PeR.
E. For this example we will be raising our PeR because my PeR was 6.723M and it needs to be what I wrote down which was 6.739M.
F. So we will burn OMS prograde at +15°.
G. If your burn requires a retrograde burn you can do everything below the same except choose retrograde in RCS Attitude MFD.
H. You will be using the Sync Orbit MFD again so keep it viewable.
   1. Set up your RCS Attitude for a +15 prograde burn by pressing GO at about your 80s Time to Apoapsis (ApT).

I. Burn **EXACTLY** at your ApR (ApT 0.000) to set our PeR to ISS's RAD (radial) altitude so as not to change your intersection point too much.
   1. At **precisely** ApT 0.0 you must burn keeping an eye on your PeR until it comes up (or down) to the RAD that the ISS had at our PeR.
   2. After the OMS burn you can now cancel your RCS Attitude MFD hold on prograde pitch +15° by hitting RTN then END.
   3. Once you're done with the burn you can save your sim in an external view. I have called mine: "Space Shuttle to ISS-0005-0010 0008.scn".
   4. By doing this your orbit in Sync Orbit MFD has moved your intercept up a few orbits from where it was. This is good. You had chosen a fairly long intercept orbit (Ob #14) earlier when raising our ApA to minimize the fuel needed for docking with the ISS.
   5. The lower the number of orbits are in Sync Orbit MFD, the earlier your rendezvous, the more fuel you will need to rendezvous with the ISS. We chose a cheaper intercept orbit by choosing #14 which gives a longer time you must wait to rendezvous.
   6. All other burns from here on will ONLY be at your periapsis. Do not change your PeA/PeR from your Apoapsis from her on. Only change your Apoapsis from your Periapsis or you will destroy your rendezvous intercept point we have just created.
   7. Hopefully our remaining fuel will be about 9.82kg (9823kg) at this point in the flight.

J. In Sync Orbit MFD you will be keeping an eye on your orbit position, the DTmin amount as well as the relative inclination RInc. You will now want to keep DTmin and RInc near 0.00° and the DTmin low as well for the remaining periapsis RCS thrust maneuvers or OMS burns.
   1. Up to now these maneuvers and burns have been the main rendezvous maneuvers needed to rendezvous. The rest should be small adjustments using the Space Shuttle's RCS thrusters to keep those two numbers low.

VII. Small Align Plane Adjustments NC-2 Burn If Needed

A. If everything has been done correctly, RInc should still be very close to 0.00°. If it gets to be more than 0.50° then you will need to reload your saved scenario "Space Shuttle to ISS-0005-0010 0002.scn" and redo your previous plane's alignment again.

B. And then readjust your apoapsis to match the ISS's altitude again by following the steps above.

C. If RInc is more than 1.00°, the Sync Orbit MFD will not work.

D. If it is less than 0.05° then you are good to move on but if it goes near 0.05° then you will need to repeat the NC-1 burn above.

E. If you get close to 0.05° and want to try and adjust it, you can do so every time you come upon an Alignment Node (Tn).

F. It should be a very small burn so if needed you can wait until the correct time using Align PlaneMFD and then conduct a small RCS adjustment in Normal + or Normal - directions.

G. In Align Plane MFD you may see that there is a small amount of thrust needed to align. This can be done using your RCS thrusters.

H. To do this ensure that your RCS configuration is in LIN (or linear mode).
   1. When the Align Plane MFD shows the Tn value of about 120.0s, you will note the node (AN or DN) line that you are closest to.
      a) If you are close to the DN position (in yellow), you will set up the attitude using the NML + autopilot.
      b) If you are close to the AN position (in yellow), you will set up the attitude using the NML - autopilot.
   2. After the autopilot points you at the correct Node, you will then need to conduct an RCS thruster maneuver until "Est thrust T" for your needed node (TthA or TthD) is 0.
   3. TthA is only for the Ascending Node (AN) pointing alignment, and TthD is for the Descending Node (DN) pointing alignment.
   4. Whichever node you are pointing to, you will need to zero out the number in seconds shown for your direction.
   5. If you use OMS to make the adjustment, you must use the +15° RCS Attitude MFD at normal or antinormal and start OBS throttle up at 1/2 the time shown for that direction and cutoff when the time gets to 0.00 for the node you are burning towards.

6. In other words if you (P) are closest to the AN yellow line, you will use the NML - autopilot (or antinormal +15° in RCS Attitude) to point in the correct attitude and look at the TthA amount in seconds. If it is 5.00, then you will need to begin your burn at 2.50 seconds shown in Tn and end when it reaches 0.00.

VIII. Small to Medium DTmin and Period Adjustment Burn at Your Periapsis

A. On the first orbit after completing part VI Match your PeA to ISS RAD/Alt at our own ApA of this tutorial, you may need to adjust your period to be closer to the ISS's period. This can be done ONLY at your Periapsis. As you approach your first Periapsis after part VI, look at your DTmin in Sync Orbit MFD. It might be a bit large (i.e > 5.00). If it is you may need to complete the steps below:

1. Set your Autopilot to turn prograde (PRO GRD).
2. While that is happening check your OrbitMFD's PeT. When it reaches 120s, create an external save point in preparation for the RCS adjustments or OMS burn you will be making soon. My save is called "Space Shuttle to ISS-0005-0010 0009.scn".
   a) If your DTmin is more than 5.00, you should use a pitch +15° prograde OMS burn.
   b) If your DTmin is less than 5.00, you can use your RCS Linear (LIN) thrusters to null out your DTmin variance.
3. When your PeT gets to 80s, set the RCS Attitude MFD to a prograde without pitch (for RCS burn) or a prograde with a + pitch of +15° (OMS burn) depending on the conditions in part 2. a) or b) above.
4. Once you are pointed prograde, do an OMS burn when your PeT goes to 0.00 until your DTmin goes to 0.00. Or,
5. When your PeT goes to 0.00 use RCS thrust forward or backward while facing the prograde direction using (Numpad 6) or backward (Numpad 9) to bring Sync Orbit MFD's DTmin to 0.00.
6. You can also fine tune the DTmin 0.00 using RCS by using the left CTRL + Numpad key on your keyboard to make even smaller adjustments to get it exactly at 0.00. It is ok after that, if it starts to go up again. This is normal.
7. After this adjustment burn you should choose to save your progress. My save is called "Space Shuttle to ISS-0005-0010 0010.scn"
   Note: It is a good habit to save before and after burns in Orbiter. Both should be done in an external view only so you can keep the camera angle you want. Otherwise if you save in cockpit mode, your external camera view will default to a view behind the Space Shuttle.
8. If things look good in Sync Orbit MFD (RInc stays below 0.50° per orbit, and your period DTmin near your Periapsis stays below 15.00 per orbit, you can fast forward until either of these amounts go above these tolerances.
9. Continue to keep an eye on these while fast forwarding until you are at Orbit (Ob) #2 in Sync Orbit MFD.
   (Note: your orbit # may jump around as you fast forward. This is normal as your relative velocity to the ISS will go up and down as your altitude goes up and down while in orbit.

IX. Get To Orbit #2

A. After your orbit goes to the No. 2 position in Sync Orbit MFD and stays (it should show a time of about 16.x k at the beginning) you can fast forward or wait until you are about T-200s before your PeA (OrbitMFD PeT 200.0)(Sync Orbit MFD Sh-ToR 11.2xk), and then you should make an external save point. My save point is called: "Space Shuttle to ISS-0005-0011.scn".

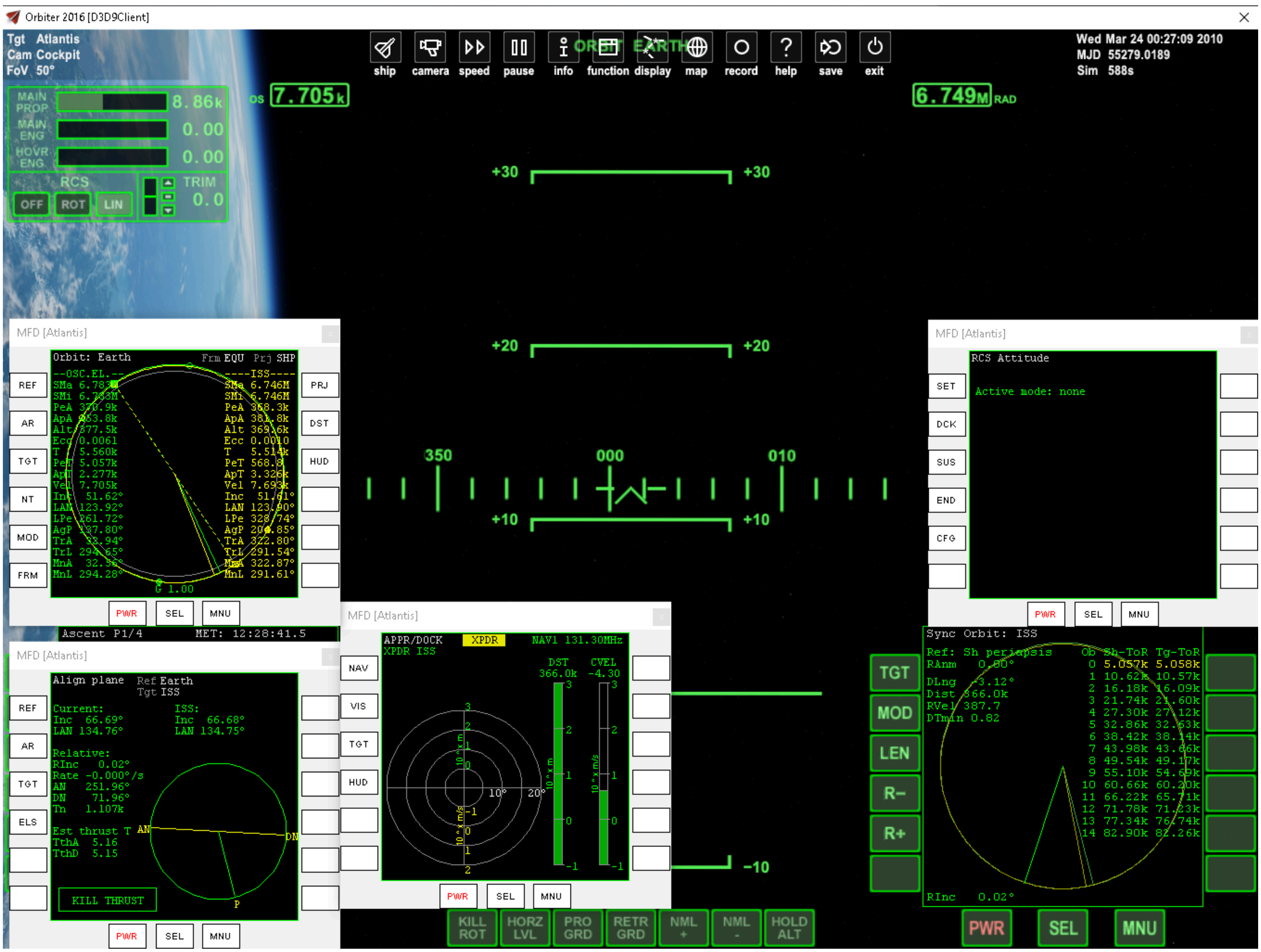
B. At this point you should make some observations in Sync Orbit MFD. Since you are before your intersection point, then you will want to check your DTmin.
   a) If your DTmin is less than 1.00 then you will not need to do anything on this orbit and you can go on to part D below.
   b) If your DTmin is more than 1.00 then you will need to make a short OMS burn and possibly an RCS thruster burn to keep your DTmin timing low. This is important to do now because you are getting close to your rendezvous.

2. Begin your attitude to prograde at pitch +15* using Sync Orbit MFD at T-80s to PeA.

3. At **EXACTLY** PeT 0.000 you will make your OMS burn until DTmin reaches 0.00.
4. If you want to fine tune it further simply turn off your RCS Attitude MFD and use the Shuttle's PRO GRD autopilot to point your nose at Prograde attitude and use your RCS thrusters forward and back to adjust the DTmin to 0.00
5. After you make the burn, make an external save point. Mine is called: "Space Shuttle to ISS-0005-0012.scn".
6. From here on, every time you get close to your Periapsis, you will need to adjust this unless it is 0.00. It needs to be as close to 0.00 as possible for the rendezvous to be successful.
7. In some cases doing this burn may change your orbit from #2 to #1 and/or #0. This is ok. Either way, when you get near Orbit #1, or #0 you need to be keeping a closer eye on the numbers of your rendezvous.

X. <u>Orbit #1 or #0</u>

A. After your orbit goes to the No. 0 position in Sync Orbit MFD wait until you are about T-400s before your last Pe before rendezvous point (PeT 400.000) of orbit #0.
B. You should make an external save point. My save point is called: "Space Shuttle to ISS-0005-0010-0013.scn".
C. You are now close to the intersection, you can begin your prep for rendezvous.
D. Here are the stock MFDs you should have open when you get to the last orbit. In the glass cockpit I like to have Ascent AP MFD in L-MFD, Sync Orbit MFD in the R-MFD, OrbitMFD set with the ISS as the target above the L-MFD, Align Plane MFD (target ISS) covering the

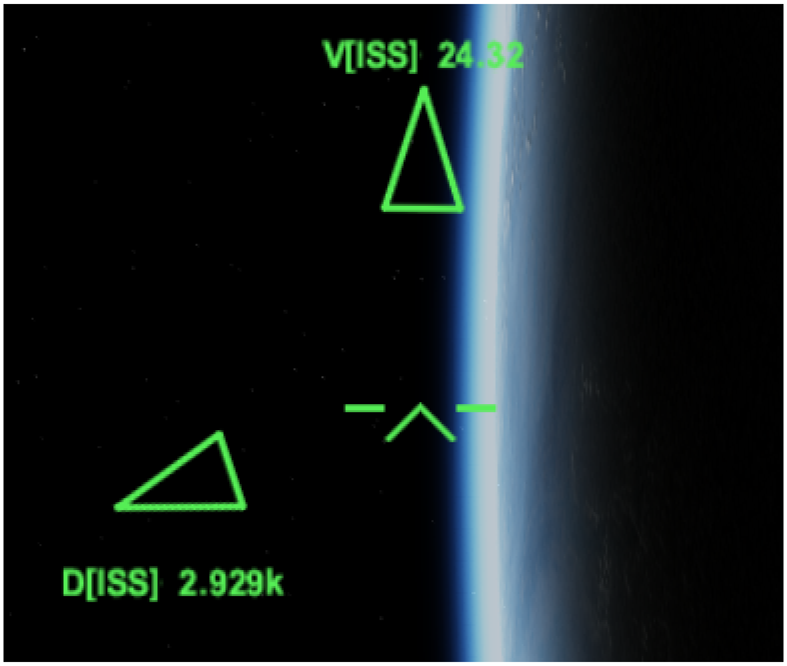


Ascent AP MFD (accept for the MET info), Docking MFD (target ISS) next to the L-MFD, and RCS Attitude MFD above the R-MFD. As seen below, you are now set for your rendezvous.

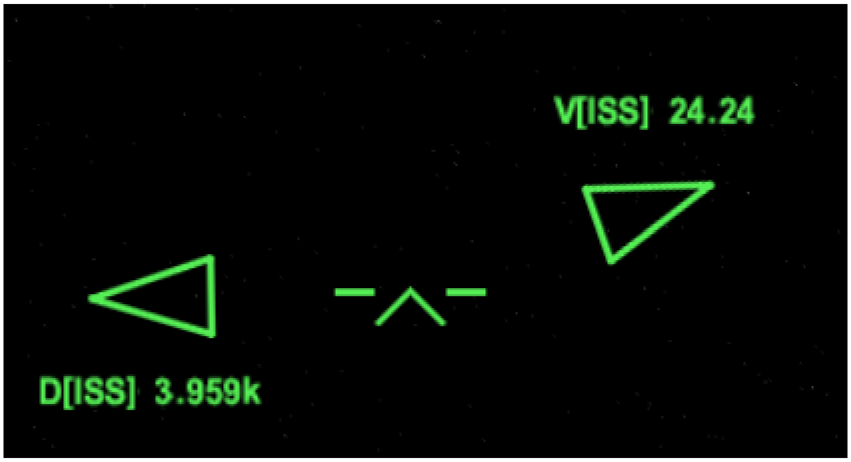
XI. <u>Rendezvous Burn with OMS</u>

A. After making the save you will want to look at Docking MFD and select TGT to select ISS from the list.
B. Press the HUD button and begin to search for the ISS using your Rotation (ROT) RCS jets. Before you look, you may see something that looks like the below image.

C. In the image below you can see a triangle on your screen that is titled “D[ISS]” That is the direction to the ISS and your distance to the ISS.



D. It is easier to use your pitch and yaw thrusters to find the ISS by rolling to where the bottom of the arrow to the ISS is flat at your top, bottom, left, or right.

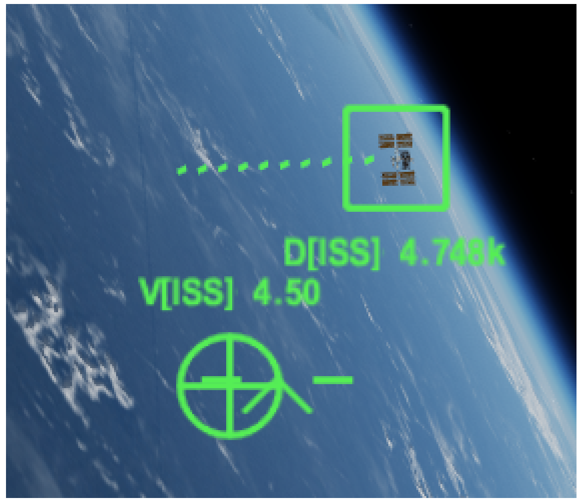


E. In the image above you can see that it is much easier to yaw to the port (left) direction to find the ISS now that it is directly to the port.
F. Use the RCS in rotation (ROT) mode to turn toward that arrow until you can see a square. In this case you would use the Numpad 1 to yaw to port.
G. It should have a D[ISS] under a square where the ISS is. Next to the D[ISS] should be a number which is the distance to the ISS from your current location.

H. Once you find it you should also see a triangle labeled “V[ISS]” somewhere on your screen. If you don’t, it is because the relative velocity vector **target** is somewhere on your screen already in the view you are already facing. Look for it. It looks like this:

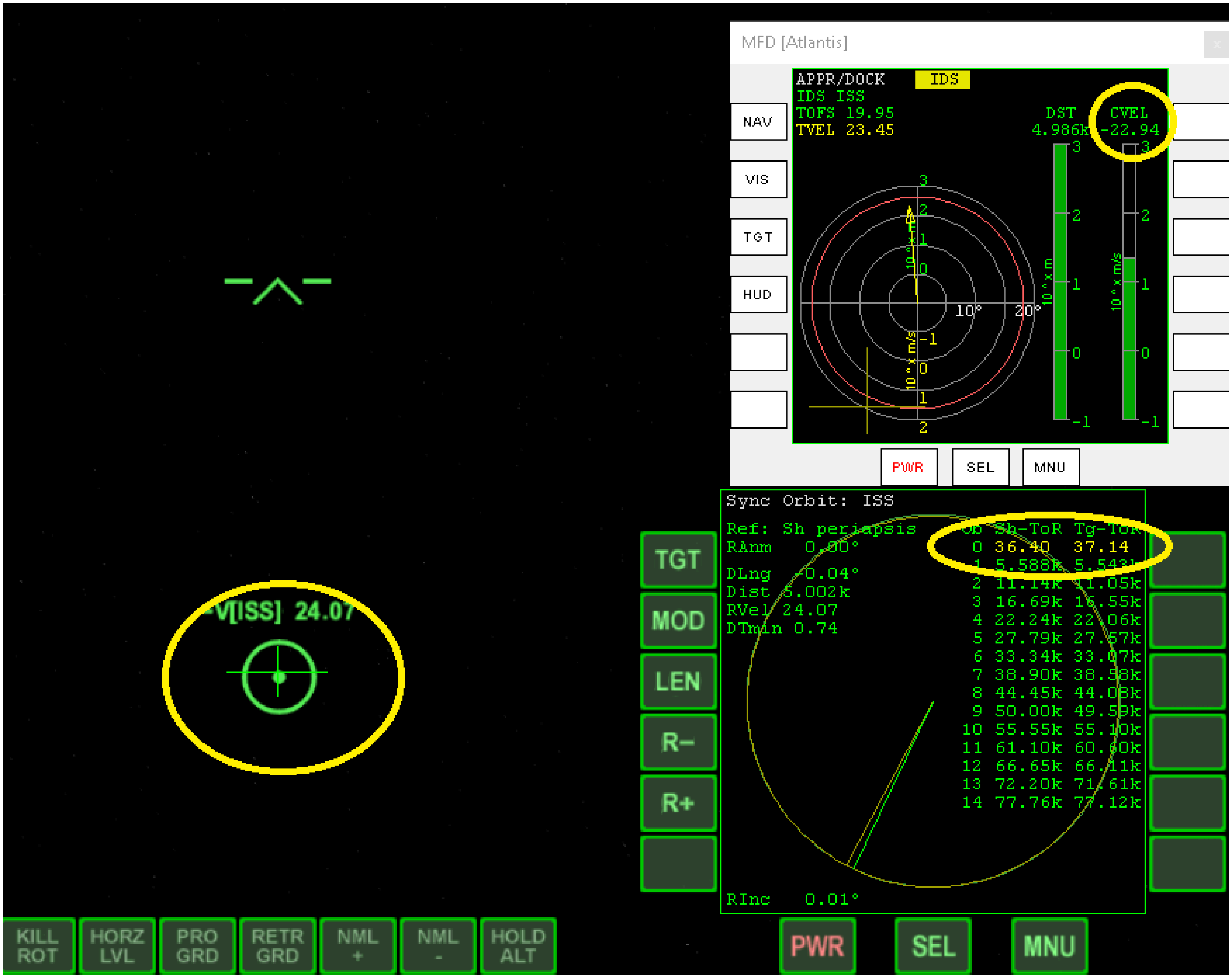
I. If you don’t see the target, find it by following the arrow toward the V[ISS] until you are pointing toward it like the image above.
J. Once you have found the V[ISS] target we will now look for the **negative** relative velocity vector. It is 180* opposite of the direction of the V[ISS] now you can rotate 180* up, down, left, or right until you find the -V[ISS] target.

K. If you see the -V[ISS] on your screen simply go to part I below.

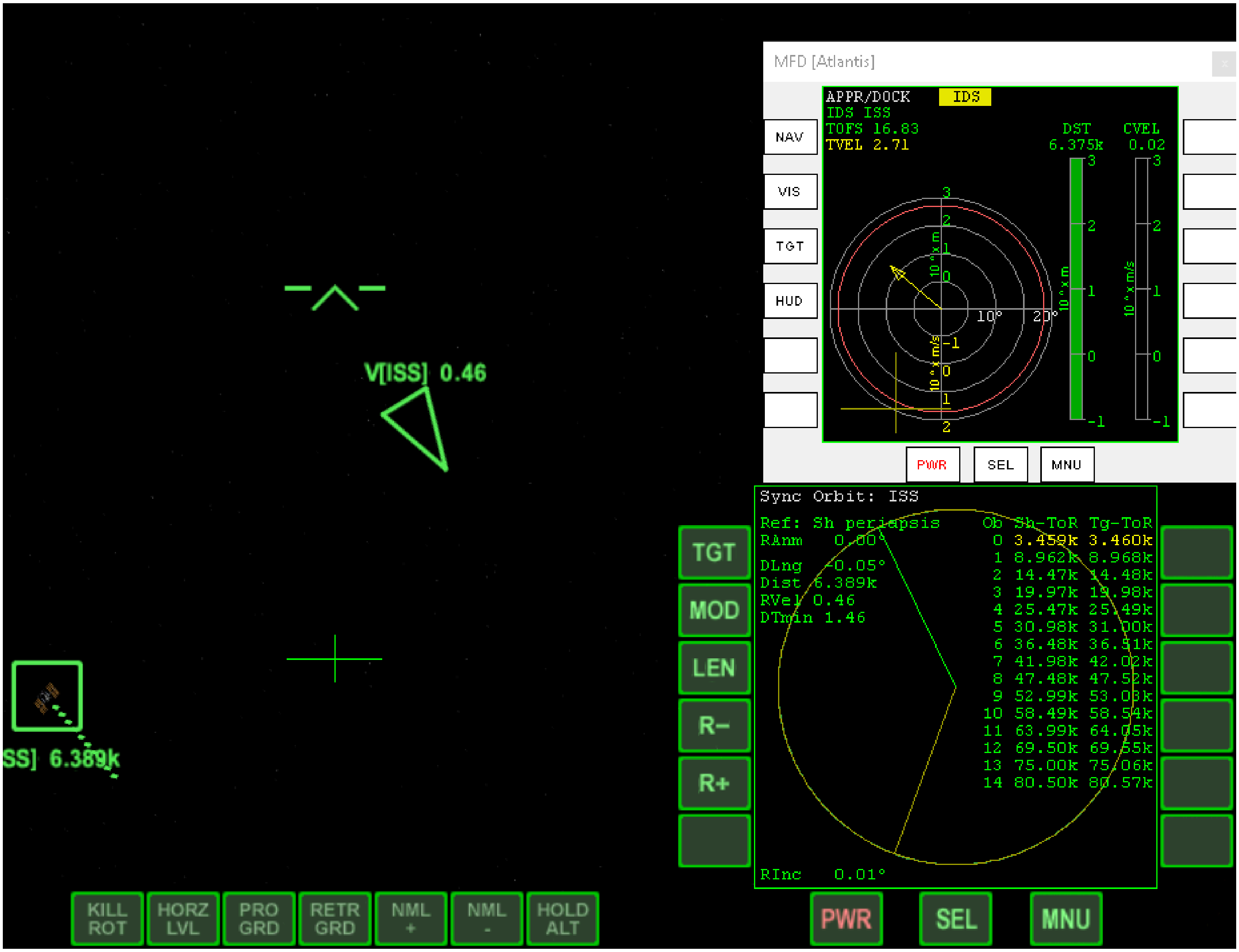


L. Rotate up, down or sideways to find the -V[ISS] target by pitching or yawing away from the "V[ISS" arrow/target until you find the target and put your -15* mark (green cross) on top of the "-V[ISS] target as seen below.

M. Now check to see if you are near your PeA as viewed in OrbitMFD or Sync Orbit MFD. If you are getting close, then wait until the time gets to about 30.00s and then look to see if your CVEL is positive or negative (it should be negative but in case it is not):
   1. If the CVEL is negative then burn your OMS at full throttle until your CVEL goes to 0.00.
   2. If your CVEL is not negative yet wait until it is and then burn OMS to null your relative velocity until CVEL gets to 0.00.



N. Note the image above shows you are ready to thrust with your OMS engines to null the relative negative velocity of -24.07 m/s and you have 36.4 seconds until throttle up.
O. When your CVEL in DockMFD goes to 0.00 then cut your engines. Your relative velocity with respect to the ISS is now 0.00. This will change over time but don't worry.
P. The image below shows the relative velocity has been effectively nullified.
Q. When this is done you can make an external save point. I called mine "Space Shuttle to ISS-0005-0010-0014.scn".



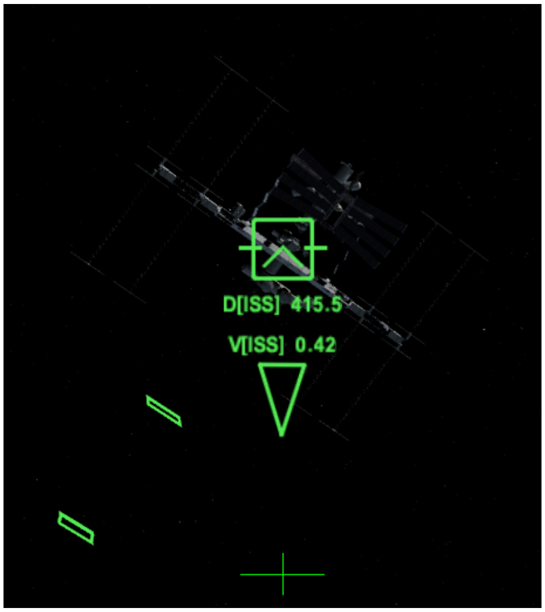
XII. <u>You are Go for Rendezvous and Docking</u>

A. You will now point your nose “-^-” directly at the ISS.
B. Use your Reaction Control System (RCS)jets to rotate toward the ISS. There is an arrow labeled D[ISS] that points to the ISS.
C. Note the position of the V[ISS] arrow in relation to your nose. Whichever direction it is pointing to V[ISS], you will want to use RCS in LIN mode to thrust in the arrow direction to bring the V[ISS] to line up directly on top of the D[ISS] target.
D. So if the arrow is pointing down then press Numpad 2 to make it go up. If it points to the left, use the thruster on Numpad 3 to make it come to the right.
E. Once the V[ISS] target is on top of the ISS, you may use your Numpad 6 to thrust toward the ISS.
F. Hold your RCS thruster toward the ISS until your CVEL goes to about 1 x 10^x m/s or ten meters per second. If you prefer you can choose a smaller amount. It depends on how far you are away from the ISS.
G. As you're thrusting toward the ISS try and keep your velocity vector on the ISS as you reach 10 m/s.

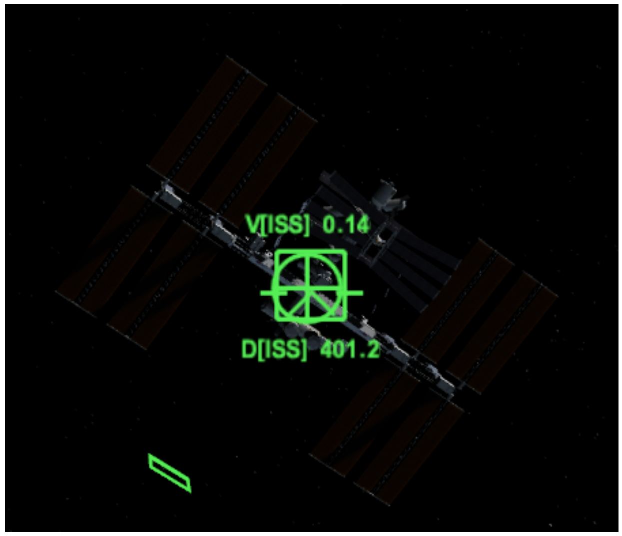
H. You should add about 2.00 m/s if the ISS is less than a kilometer away. If you have a distance of about 1-10km then 5 m/s is more appropriate. Remember you do need to rendezvous when it is daylight.
I. Note that however much thrust you use to get to the ISS you will need the same amount to stop once you're there. Also, you may not rendezvous when the sun is lighting your two vessels. This is why it is very helpful for these HUD icons to be on your screen as you will not need to see the target to rendezvous using your HUD.
J. You may have to do the above process (steps A - I) several times if you are a good distance away until you close the distance to the ISS.
K. When you reach the ISS and are about 700 m away, you will point at the ISS and thrust in reverse (Numpad 9) in LIN mode until you are back at CVEL 0.00.
L. you can make an external save point. I called mine “Space Shuttle to ISS-0005-0010-0015.scn”.
M. When you arrive at the ISS, you will want to set your Docking MFD to show you the docking port approach vector.
N. Select TGT in Docking MFD and choose the ISS, then use your right arrow key to select ISS, dock 1.
O. Now click HUD again on Docking MFD.
P. You will now see docking approach markers displayed on the HUD. These markers expand outward from the docking port you have selected. They provide a visual approach path for you to use to get roughly aligned with the docking port.
Q. If all goes well you should be at about 7.22kg of fuel when you arrive near ISS at 500m distance.
R. You will need about 3.00 kg of fuel to de-orbit burn so do not let your fuel go below 3.00 kg.
S. You must maneuver the Space Shuttle into that docking vector path using your RCS jets. This tutorial will show you an easy way.

XIII. <u>Docking with the ISS</u>

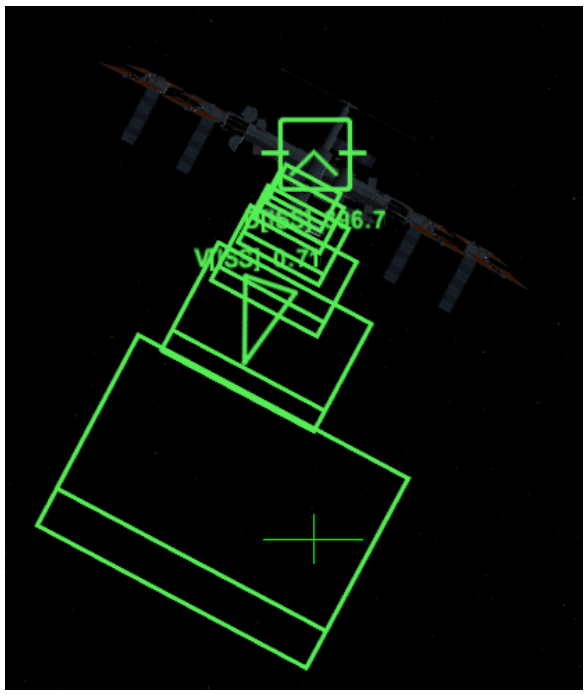
A. First face the ISS.
B. Rotate until the V[ISS] is directly below, above, or to either side. The image shows the V[ISS] below our Space Shuttle.



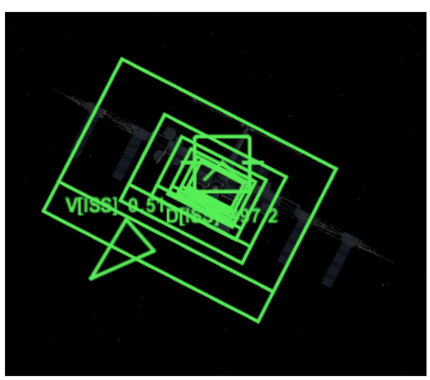
C. Once rotated, you will use RCS in linear mode (LIN) to bring the V[ISS] to the ISS and on top of the square as we did earlier.



D. Now you will want to put yourself inside the path leading to the docking collar Dock 1.

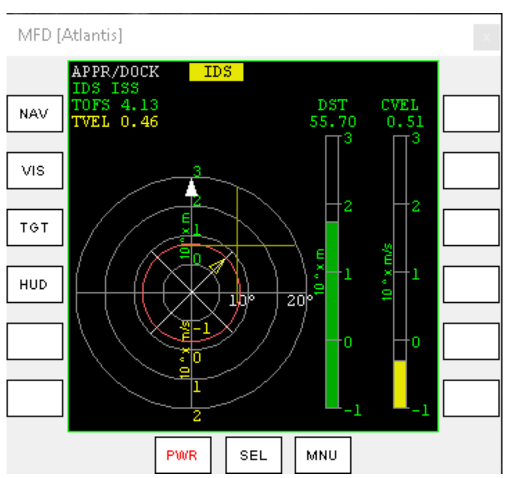


E. As seen above we are almost inside the docking path until it looks like the image below.



F. Once your view looks like the above image, you can open up your RCS Attitude MFD and make sure your KILL ROT is not currently ON and then press the DCK button. It should already have NAV 1 131.30MHz as the transponder (XPDR) for the ISS. We want to set it to the docking port we have targeted. If you remember we selected dock 1.
G. Click the NAV button until you see NAV2 108.05MHz IDS D-01 ISS in the top right corner of RCS Attitude MFD.
H. Now press ACT to activate the alignment feature of this MFD. The RCS Attitude MFD will align your docking port with dock 1 of the ISS.
I. Now all you have to do is thrust upward to dock. Use Numpad 2 to move upward toward the ISS dock 1.
J. Watch your CVEL that it goes up to 1.00 to 2.00 or so as you begin your approach. You will notice that RCS Attitude has aligned your docking port to be the correct rotational direction to dock as the white arrow will show as being straight up in the 12:00 position. See below image:

K. Now that you are heading upward to the ISS dock, you need to control your vertical and horizontal alignment to dock 1. This is seen by the yellow cross. As you can see above, the yellow cross/plus indicator is too far to the top right area. You need to have that directly in the middle of your target. There is also a yellow arrow near the center of your docking target. That arrow shows which direction along the horizontal plane you are heading. As you move upward, you simply need to aim that arrow toward the yellow cross and have it stable on your center by the time you reach the docking port on ISS.
L. Start by making the yellow arrow point to the center of your yellow cross as seen below:



M. It takes some getting used to but know that to control the forward, back, left and right directions (which is all you need for this segment of docking), you only need these Numpad keys: forward = 6, backward = 9, left = 1, and right = 3. Only use these four directions to get the yellow cross onto your center target. If your CVEL starts to go into the negative simply press Numpad 6 to begin to go back toward the ISS's dock 1 port.
N. After this just keep your yellow cross at the center and your movement toward dock 1 and you should dock with little problem. It very much beats doing the alignment all manually.
O. After you dock you should pat yourself on the back and realize that you have done something that is not easy to do AT ALL in Orbiter 2016. Celebrate and then save an external save point. I named mine "Space Shuttle to ISS-0005-0010-0016.scn".

Appendix A. - List of Saved Scenarios:

1. Space Shuttle to ISS-0005-0010 0001.scn Orbit Complete save point.
2. Space Shuttle to ISS-0005-0010 0002.scn Before Align Plane save point.
3. Space Shuttle to ISS-0005-0010 0003.scn After Align Plane save point.
4. Space Shuttle to ISS-0005-0010 0004.scn Before setting up your sunlit Periapsis rendezvous point.
5. Space Shuttle to ISS-0005-0010 0005.scn After setting up your sunlit Periapsis rendezvous point.
6. Space Shuttle to ISS-0005-0010 0006.scn 120s before the ISS passes your Periapsis to take note of.
7. Space Shuttle to ISS-0005-0010 0007.scn Before matching your PeR to the ISS's RAD altitude.
8. Space Shuttle to ISS-0005-0010 0008.scn After matching your PeR to the ISS's RAD altitude.
9. Space Shuttle to ISS-0005-0010 0009.scn Before a small to medium burn to fix DTmin
10. Space Shuttle to ISS-0005-0010 0010.scn After a small to medium burn to fix DTmin
11. Space Shuttle to ISS-0005-0010 0011.scn Orbit #2 just before a period adjustment burn.
12. Space Shuttle to ISS-0005-0010 0012.scn Orbit #2 just after a period adjustment burn.
13. Space Shuttle to ISS-0005-0010 0013.scn Orbit #0 just before your last DTmin adjustment burn.
14. Space Shuttle to ISS-0005-0010-0014.scn Orbit #0 you have just nullified your relative velocity.
15. Space Shuttle to ISS-0005-0010-0015.scn 700m from the ISS.
16. Space Shuttle to ISS-0005-0010-0016.scn Docked with the ISS docking port 1.

Appendix B. - Scenario Creation:

In order to do this tutorial you can either download the scenario provided by this add-on, or make your own scenario using the instructions below:

To create your own workable version of the original playback scenario "Space Shuttle to ISS.scn", you will need to:

1. Find the original file named: "Space Shuttle to ISS.scn" in your Orbiter file system here: ..\Orbiter 2016\Scenarios\2016 Edition\
2. Copy the original scenario file to the root "Scenarios" directory and rename the file. I have re-named mine "Space Shuttle to ISS-0005-0010.scn" This breaks the playback settings in the system.dat file located here: ..\Orbiter 2016\Flights\Space Shuttle to ISS, which ties the playback for this file into any scenario named "Space Shuttle to ISS.scn" and starts the playback for that scenario that is named that filename. In fact you could name any scenario as "Space Shuttle to ISS.scn" and it would run the playback aspect when you launch the scenario.
3. Next, edit the renamed file using a text editor such as Notepad++ and copy the code listed in the next section Appendix C. - Scenario for Use With This Tutorial <code> into your new file.

This will effectively "gut" the playback aspect of this scenario and keep the starting settings of the original for use with this tutorial. I have also added some camera views and taken out some un-needed vessels to help with the stability of the simulation.

Appendix C. - Scenario for Use With This Tutorial <code>:

I have included the code in this tutorial of the starter scenario needed to follow this tutorial. See below.
“Space Shuttle to ISS-0005-0010.scn”

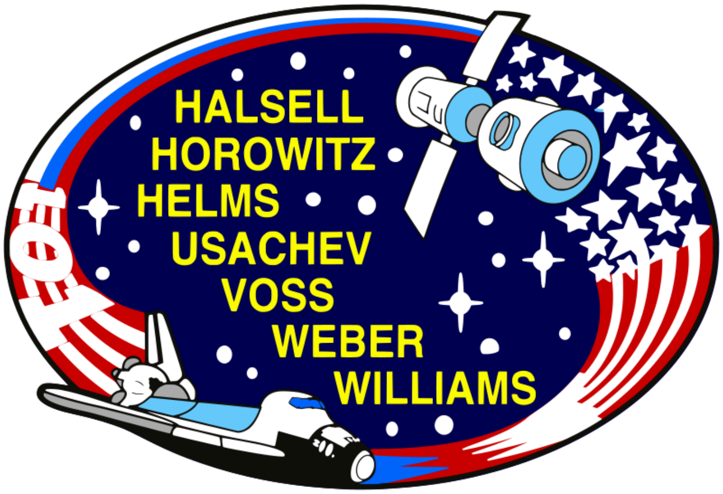
```
BEGIN_HYPERDESC
<h1>Space Shuttle to ISS</h1>
<p><b>Space Shuttle to ISS.scn</b> without the automated tutorial provided in the original
scenario.</p><br><br>

<ul style="list-style-type:
square;margin-left:20px;margin-top:10px;margin-bottom:10px;margin-right:0px;padding:0px;">
<li><p>Launch the Space Shuttle Atlantis (STS-101) to orbit using the AscentAP MFD then follow my
tutorial to rendezvous with the ISS and dock.</p></li>


<li><p>Mission starts on Tue Mar 23, 2010 at 11:57:04 (T-80s to lift off). The Autopilot is
pre-configured for launch with the correct settings if you launch at T+80s from the start of this
flight.</p></li>


<li><p>Although the date of this flight does not correspond to any historic flight done by NASA, the
ISS is on a descending orbit near the Cape and in a perfect position for launch to intercept.</p></li>


<li><p>Press the "L" button in the L-MFD at Sim: 80s to liftoff at Tue Mar 23 11:58:24 2010 (MJD:
55278.4989).</p></li>


<p>Good Luck!!</p>
<div style="margin-left:40%">polaris149Tiberius  - 2025<br>
<a href="https://www.orbiter-forum.com/members/polaris149tiberius.507/"
target="_blank">https://www.orbiter-forum.com/members/polaris149tiberius.507/</a></div>
END_HYPERDESC

END_DESC

BEGIN_ENVIRONMENT
  System Sol
  Date MJD 55278.4979646848
END_ENVIRONMENT

BEGIN_FOCUS
  Ship Atlantis
END_FOCUS

BEGIN_CAMERA
  TARGET Atlantis
  MODE Extern
  POS 4.000000 -179.908748 0.000000
  TRACKMODE TargetRelative
  FOV 50.00
  BEGIN_PRESET
```

```
    Cockpit:Atlantis:50.38
    Track:ISS:40.00:RELATIVE 1.983 -0.474 -0.522
    Ground:Atlantis:10.00:Earth -80.64956 28.58345 20.00
    Ground:Atlantis:10.00:Earth -80.62091 28.61734 13.00
    Ground:Atlantis:10.00:Earth -80.62043 28.62695 30.00 2.83 0.09
    Ground:Atlantis:15.13:Earth -80.62028 28.62644 13.00 2.27 0.24
    Ground:Atlantis:15.27:Earth -80.62036 28.62704 67.00 2.99 -0.07
    Ground:Atlantis:10.00:Earth -80.62363 28.61974 1.00
    Ground:Atlantis:10.00:Earth -80.62250 28.62220 1.00
    Track:Atlantis:50.00:RELATIVE 2.890 -0.009 -1.229
    Track:Atlantis:50.00:RELATIVE 4.317 0.000 3.063
    Track:Atlantis:50.00:RELATIVE 4.317 3.141 0.079
    Track:Atlantis:50.00:RELATIVE 2.882 0.000 3.003
    Track:Atlantis:50.00:RELATIVE 4.000 0.528 0.000
    Track:Atlantis:50.00:RELATIVE 4.000 1.479 0.000
    Track:Atlantis:50.00:RELATIVE 4.000 -0.010 0.000
    Track:Atlantis:50.00:RELATIVE 4.000 -1.604 0.000
    Track:Atlantis:50.00:RELATIVE 4.000 -0.010 -0.643
    Track:Atlantis:50.00:RELATIVE 4.000 -0.010 -1.730
    Track:Atlantis:50.00:RELATIVE 4.000 -3.140 -1.599
    Track:Atlantis:50.00:RELATIVE 4.000 -3.140 0.000
    Track:Atlantis:50.00:GLOBAL 4.000 -3.098 1.107
    Track:Atlantis:50.00:RELATIVE 4.000 -3.140 -0.717
    Track:Atlantis:22.60:RELATIVE 4.000 -3.140 -0.717
    Track:Atlantis:50.00:RELATIVE 4.000 -3.140 0.000
  END_PRESET
END_CAMERA

BEGIN_HUD
  TYPE Surface
END_HUD

BEGIN_MFD Left
  TYPE User
  MODE AscentAP
END_MFD

BEGIN_MFD Right
  TYPE Map
  REF Earth
  TARGET ISS
  ZOOM 4
  DISP 62639
END_MFD

BEGIN_SHIPS
ISS:ProjectAlpha_ISS
  STATUS Orbiting Earth
  RPOS -2332086.423 6182445.211 -1345307.918
  RVEL 5336.1922 821.0606 -5467.3974
  AROT -127.055 1.840 -42.434
  VROT 0.1001 -0.0289 -0.0620
  AFCMODE 7
  PRPLEVEL 0:1.000000
  IDS 0:1 100 1:2 100 2:3 100 3:4 100 4:5 100
  NAVFREQ 0 0
```

```
  XPDR 466
  FLIGHTDATA
END
Atlantis:Atlantis
  STATUS Landed Earth
  POS -80.6208629 28.6270922
  HEADING 180.02
  ALT 47.360
  AROT 151.068 -8.226 4.507
  AFCMODE 7
  PRPLEVEL 0:1.000000
  DOCKINFO 1:0,Atlantis_ET
  NAVFREQ 466 1
  FLIGHTDATA
  CONFIGURATION 0
  GEAR 0 0.0000
  ARM_STATUS 0.5000 0.0000 0.0000 0.5000 0.5000 0.5000
  SAT_OFS_X 0.000000
  SAT_OFS_Y 0.000000
  SAT_OFS_Z 0.000000
  MET 0.000 0.000 0.000 0.000
  ASCENTAP 0 0 1 350000 2.3937 -1.40710 0.49964
END
Leonardo:Leonardo_mplm
  STATUS Landed Earth
  POS -80.6208629 28.6270886
  HEADING 180.02
  ALT 47.360
  AROT 0.000 -0.000 0.000
  ATTACHED 0:0,Atlantis
  AFCMODE 7
  NAVFREQ 0 0
  XPDR 477
  FLIGHTDATA
END
Atlantis_ET:Atlantis_Tank
  STATUS Landed Earth
  POS -80.6208628 28.6271639
  HEADING 180.02
  ALT 60.978
  AROT 151.068 -8.226 4.507
  AFCMODE 7
  PRPLEVEL 0:1.000000
  DOCKINFO 0:1,Atlantis 1:0,Atlantis-SRB1 2:0,Atlantis-SRB2
  FLIGHTDATA
END
Atlantis-SRB1:Atlantis_SRB
  STATUS Landed Earth
  POS -80.6209264 28.6271640
  HEADING 179.87
  ALT 49.578
  AROT 151.068 -8.226 4.507
  AFCMODE 7
  PRPLEVEL 0:1.000000
  DOCKINFO 0:1,Atlantis_ET
  FLIGHTDATA
```

```
END
Atlantis-SRB2:Atlantis_SRB
  STATUS Landed Earth
  POS -80.6207993 28.6271639
  HEADING 180.18
  ALT 49.578
  AROT 151.068 -8.226 -175.493
  AFCMODE 7
  PRPLEVEL 0:1.000000
  DOCKINFO 0:2,Atlantis_ET
  FLIGHTDATA
END
END_SHIPS

BEGIN_ExtMFD
END
```

STS-101 Mission Patch and Crew of STS-101 Atlantis



Appendix D. - NASA Terminology:

“Mission Elapsed Time (MET)” - is the amount of time that has passed since a spacecraft's launch, essentially a timer that starts at zero upon liftoff and counts forward in normal time units. It's used to track mission progress, especially in space missions, and to schedule events, ensuring consistency even if the launch is delayed.

“Press to MECO” - a point in the Launch where the Space Shuttle Atlantis can continue the current nominal mission profile to the point of Main Engine Cutoff and still reach their planned orbit if they lose one engine.

“Negative Return” - a "negative return" meant that the Atlantis space shuttle could no longer make an emergency return-to-launch-site abort landing at Kennedy Space Center due to a problem during ascent.

“Single Engine ROTA” - Rota Spain is a naval base in Rota, Spain. Atlantis can safely land in Rota, Spain even if two of the three main engines should fail.

“Residuals”: Astronauts like Buzz Aldrin referred to Delta-V "residuals" when describing the difference between the actual velocity change (delta-v) achieved by a thruster burn and the expected, ideal delta-v. In a perfect burn, the guidance computer would display residuals of 0, 0, 0 in all three axes. However, any deviation would be shown as a small value, typically in tenths of a foot per second. During the descent, it seems engineers focused on nulling the X (vertical) and Z (fore/aft) residuals, meaning they aimed to correct any deviations in these directions to avoid landing too long or short. The Y (left to right) residual was considered less critical and was not actively corrected. These corrections were performed by firing the Reaction Control System (RCS) with the hand controller.

“S-band”: The Space Shuttle used the S-band frequency range, specifically between 2 and 4 GHz, for communication with ground stations and other spacecraft. This band was part of the Unified S-band (USB) system, which combined tracking, ranging, command, voice, and television into a single system.

“POGO on the engines”: POGO, short for Progressive Oscillation, Generated Oscillation, is a type of vibration that can occur in liquid-fueled rocket engines. It's a self-excited oscillation caused by the interaction between the engine and the rocket's structure, specifically the propellant feed lines. In the context of the Space Shuttle, POGO oscillations were a concern, particularly during ascent, and required careful mitigation strategies.

“State Vector” - In orbital mechanics, a state vector might include the position and velocity of a satellite or spacecraft, allowing calculation of its trajectory. Orbital state vectors come in many forms including the traditional Position-Velocity vectors, Two-line element set (TLE), and Vector Covariance Matrix (VCM).

Appendix E. - Links to Useful Websites:

Credits to sites that inspired this tutorial:

https://smithplanet.com/stuff/orbiter/orbitaloperations.htm
https://www.orbiter-forum.com/
https://www.orbiterwiki.org/wiki/Surface_MFD
https://www.satsig.net/orbit-research/orbit-height-and-speed.htm
https://www.orbiterwiki.org/wiki/MFD
https://live.ariss.org/tle/
https://wiki.flightgear.org/Shuttle_guidance_-_Ascent_guidance_Powered_Explicit_Guidance_(PEG)
https://www.orbiterwiki.org/wiki/Powered_Explicit_Guidance
https://ntrs.nasa.gov/api/citations/20205004411/downloads/GUIDimprovements.pdf
https://ntrs.nasa.gov/api/citations/20180002035/downloads/20180002035.pdf

Calculators:

https://www.calculator.net/time-calculator.html?tcday1=0&tchour1=2&tcminute1=23&tcsecond1=0&Op=-&tcday2=0&tchour2=1&tcminute2=27&tcsecond2=02&tcday3=&tchour3=&tcminute3=3&tcsecond3=49&ctype=1&x=Calculate
https://www.calculatorsoup.com/calculators/time/time-calculator.php
https://www.inchcalculator.com/seconds-to-time-calculator/
https://ti84calc.com/ti84calc
https://ti89.com/Online-Calculators/
https://www.satnow.com/calculators/orbital-speed-calculation

Other Useful Unused sites:

https://www.satnow.com/calculators/rocket-acceleration-calculator
http://orbiter.dansteph.com/forum/index.php?page=welcome
https://www.rapidtables.com/calc/math/Cos_Calculator.html
https://www.ticalc.org/basics/calculators/ti-81.html

Articles:

https://ntrs.nasa.gov/api/citations/20240003182/downloads/Introduction%20To%20Space%20Shuttle%20Rendezvous.pdf
https://www.orbiterwiki.org/wiki/Launch_Azimuth
http://orbiter.dansteph.com/forum/index.php?topic=10321.0
https://xenforo.orbiter-forum.com/threads/launch-mfd-v-1-6-6-for-orbiter-2016.587/page-3
https://www.orbiter-forum.com/threads/manual-launch-of-the-shuttle-in-orbiter-2016.37618/
https://www.orbiter-forum.com/threads/orbiter-2016-re-launch-re-open-quick-save-scenario-causes-atlantis-to-fly-off-the-pad-after-un-pausing-solved.42334/
https://www.reddit.com/r/RealSolarSystem/comments/732q3b/how_to_launch_into_mars_orbital_plane/
https://www.orbiter-forum.com/threads/understanding-inclination-and-launch-azimuth.34033/
http://orbiter.dansteph.com/downloadround/tempdgIV/doc/res/DGIV_Documentation_en.pdf
https://rjallain.medium.com/calculating-the-speed-to-get-to-low-earth-orbit-and-other-calculations-c4df88f4cd2e
https://space.stackexchange.com/questions/64728/in-circle-orbit-give-a-delta-v-to-a-satellite-how-to-find-final-orbit-altitude

Videos:

(Notable moments in the accompanying video for this tutorial):
STS-1 - The Launch - Complete Day 1 (40th Anniversary) (TV camera view from inside Columbia’s cockpit)
https://www.youtube.com/watch?v=SS7MNPWES-E
https://www.youtube.com/watch?v=xTvbjEEBs7s
https://www.youtube.com/watch?v=UDJFtQGRhIo
https://www.youtube.com/watch?v=9cGZNWkKFUc
https://www.youtube.com/watch?v=fGY7QH_F49c

Other Reference and Info:

https://space.stackexchange.com/questions/64728/in-circle-orbit-give-a-delta-v-to-a-satellite-how-to-find-final-orbit-altitude

Appendix F. - Alternative Rendezvous Intersection Points
Sunset should happen at about MET 02:19:10.00. This gives a half period of about 00:45:52.00 (2,752s). Half of that or when the sun will be as high as it can be is about 00:22:56.00 after sunrise. We can use this if we want our rendezvous point to be at the middle of the sunlit period. If you want to choose the exact middle of the day period of your orbit, you would simply add 00:22:56.0 to the sunrise point which was MET 01:27:02.00 which comes to = MET 01:56:14.00 to burn. This is just an option. Also for your records you can see that your orbit period is about 01:31:44.00 (2,752 * 2 = 5,504s). You can check this with a seconds to hours calculator located here:
https://www.inchcalculator.com/seconds-to-time-calculator/.
OrbitMFD's T = 5.473k seconds = 01:31:13.00. We were close. It's good to know these things.
You can also choose to burn as close to ISS's PeA as possible if you like; however this will make your rendezvous happen mostly in the dark. This is not recommended.

Appendix G. - Calculations:

Find the Launch Azimuth for Launch from KSC to ISS:
azimuth(Az)
arcsin = sin^{-1}

The formula for finding the Launch Azimuth (direction of launch on a compass heading) is:
azimuth(Az) = arcsin [cos(inclination)/cos(latitude)]

Example:
Mir/ISS/Etc orbit at around 52° (degrees) inclination (Inc), and the Cape is at about 28° latitude:

Az=arcsin(cos(52°)/cos(28°))
Az=arcsin(0.6156614753/cos(28°))
Az=arcsin(0.6156614753/0.8829475929)

ISS = 51.59°
Our latitude at KSC = 28.63°
Az=arcsin(cos(51.59°)/cos(28.63°))
Az=arcsin(0.6594627°)
Az=41.3° degrees

The cosine of 51.59 degrees is approximately 0.621284551.
In a right-angled triangle, the cosine of an angle is defined as the ratio of the length of the adjacent side to the length of the hypotenuse. The formula is:
cos(θ) = Adjacent / Hypotenuse
It is important to ensure that your calculator is in degree mode when calculating the cosine of an angle in degrees.

To calculate cos(51.59°)/cos(28.63°)

1. Calculate the cos of 51.59°
   Cos * 51.59°
   cos(51.59°) = 0.621284551
2. Calculate the cos of 28.63°
   Cos * 28.63°
   Cos(28.63°) = 0.877732213

3. Divide the results:
   0.621284551/0.877732213
   = 0.7078292693

4. Take the arcsin (sin^{-1})of the answer
   sin^{-1}(0.7078292693) = 45.05857205°

5. azimuth = 45.05857205° + 90° because of it being a descending node past the normal = 135.01°

   Launch MFD says we need to head at 137.09° Now we need to compensate for the time it takes to get in orbit. Time to Node is 415.9s. The earth spins at 408m/s at 90° and the height of our orbit is 350km. Which makes our speed at 350km around 7697.07m/s or 7.69707km/s.
   Our launch time to a close Inclination is 870s which means the earth will have moved 408m in 870s by the time we are in the first part of our orbit. 408m/s * 870s = 354,960m in the time it takes us to get basically in-line with the ISS.

   Distance to ISS is 4.239M at the beginning of the simulation.

   The time to lift off is 80s. At the time of our launch the ISS is traveling at an altitude of 372.2K according to MapMFD. The ISS’s velocity is 4.777 according to https://www.omnicalculator.com/physics/earth-orbit

   HTML:
   To calculate \(\frac{cos(51.59^{\circ })}{cos(28.63^{\circ })}\): Calculate \(cos(51.59^{\circ })\): 0.621284551Calculate \(cos(28.63^{\circ })\): 0.877732213Divide the results: \(\frac{0.621284551}{0.877732213}\approx 0.70782927\) Therefore, \(\frac{cos(51.59^{\circ })}{cos(28.63^{\circ })}\approx 0.70782927\).

   \sin^{-1}\left(0.7078292693\right)

   To determine the launch azimuth for Orbiter 2016, you need to calculate the angle between North and the desired launch direction, taking into account the desired orbital inclination and the launch site's latitude. This involves using spherical trigonometry to find the launch azimuth that will result in the desired orbital inclination when combined with the Earth's rotation.
   Here's a more detailed explanation:
   1. Understand Launch Azimuth:
   Launch azimuth is the compass direction (measured clockwise from North) in which a spacecraft is launched.
   It's crucial for achieving the desired orbital inclination, which is the angle between the orbital plane and the Earth's equator.
   2. The Relationship Between Azimuth and Inclination:
   Launching eastward (azimuth of 90 degrees) from a location on Earth will result in an orbital inclination approximately equal to the latitude of the launch site.
   To achieve higher inclinations, you need to launch at an angle to the east (azimuth greater than 90 degrees).
   The exact relationship is defined by spherical trigonometry:
   cos(inclination) = cos(latitude) ° sin(azimuth)
   3. Calculating Launch Azimuth:
   To find the required azimuth (β) for a given inclination (i) and latitude (φ), you can rearrange the formula:
   β = arcsin(cos(i) / cos(φ))
   If the inclination is equal to the latitude, the azimuth will be 90 degrees (due east).
   For retrograde orbits (orbiting in the opposite direction of Earth's rotation), the azimuth will be between 270 and 90 degrees.
   4. Using Orbiter Tools:
   Orbiter 2016 provides tools like LaunchMFD to calculate launch azimuth and insertion profiles for specific orbits or targets.
   You can also use TransX or BaseSyncMFD for transfer orbit insertion and deorbit burns.
   You'll need to set the correct frame of reference (equatorial) in Orbiter before calculating the launch azimuth.
   5. Considerations:
   The Earth's rotation provides a free velocity boost when launching eastward.
   The amount of this boost depends on the launch site's latitude.
   Vector addition is used to combine the launch velocity with the rotational velocity to achieve the desired orbital velocity and inclination.

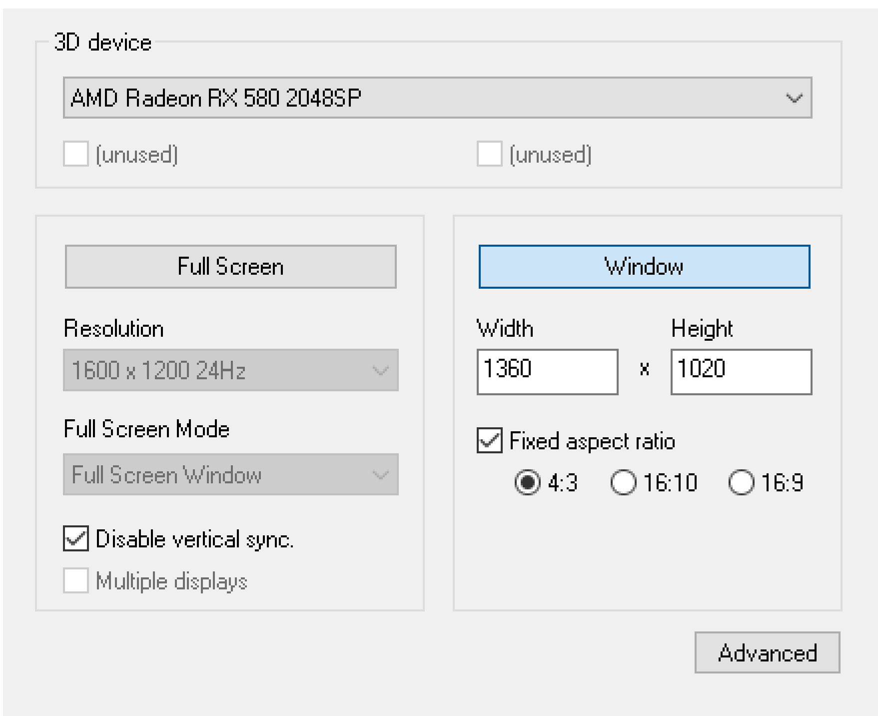
By understanding these concepts and utilizing the tools available in Orbiter 2016, you can accurately determine the launch azimuth for your desired orbital inclination.

The Space Shuttle Atlantis primarily landed at two locations: the Shuttle Landing Facility at Kennedy Space Center in Florida and Edwards Air Force Base in California. While Edwards Air Force Base served as a frequent backup landing site, the Kennedy Space Center was the preferred location for most landings due to its proximity to the launch site.
Here's a more detailed breakdown:
Kennedy Space Center (KSC), Florida:
.
This was the designated primary landing site for most missions. The Shuttle Landing Facility at KSC was a purpose-built runway designed specifically for shuttle landings.
Edwards Air Force Base, California:
.
Edwards served as the primary backup landing site and was utilized when weather conditions or other factors prevented a landing at KSC.

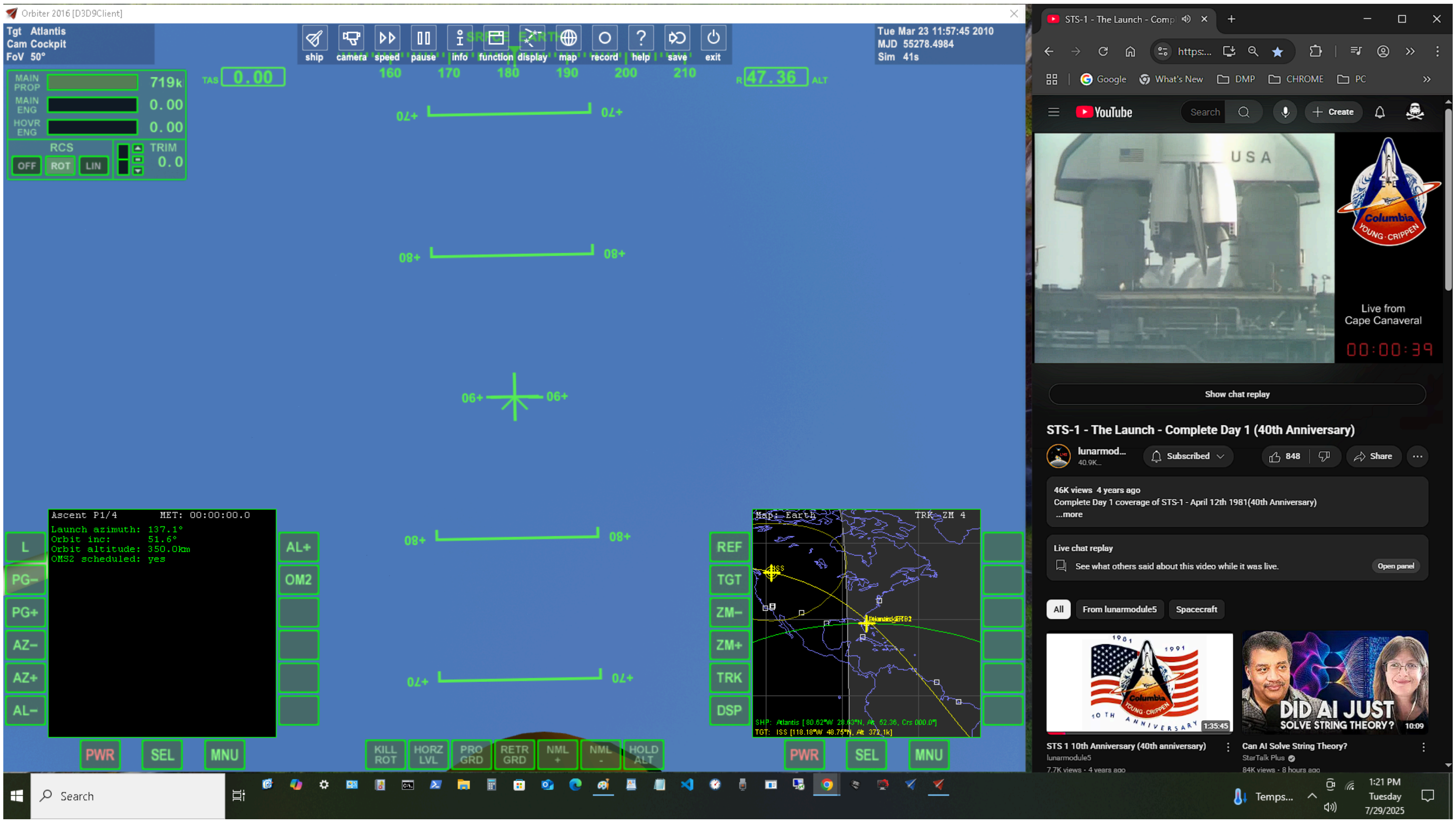
The cosine of 51.59 degrees is approximately 0.621284551.
In a right-angled triangle, the cosine of an angle is defined as the ratio of the length of the adjacent side to the length of the hypotenuse. The formula is:
cos(θ) = Adjacent / Hypotenuse
It is important to ensure that your calculator is in degree mode when calculating the cosine of an angle in degrees.

<u>Appendix H. - Set Up Orbiter 2016 to Watch Video/View Tutorial</u>

1. If you want to be able to watch the video of STS-1 launch while doing your own launch in Orbiter 2016 and be able to read your tutorial during launch you can simply select the Window mode of Orbiter in the Launchpad’s Video tab and set up these video settings. As seen here:



2. Now you can slide your browser with the video and your pdf download to view while making your flight.



Appendix I. - Notes

On board computer info:

https://space.stackexchange.com/questions/19006/what-operating-systems-were-used-in-the-space-shuttle
https://www.slideshare.net/slideshow/space-shuttle-flight-software-pass-loss-of-crew-errors-jk-orr-20150827-52150515/52150515#7
https://sova.si.edu/record/nasm.2006.0013/ref190?s=0&n=10&t=K&q=*&i=0
https://klabs.org/DEI/Processor/shuttle/
https://en.wikipedia.org/wiki/IBM_System/4_Pi#AP-101
https://sourceforge.net/p/fgspaceshuttledev/code/ci/development/tree/Nasal/PFD/
https://wiki.flightgear.org/Space_Shuttle_Avionics
https://klabs.org/DEI/Processor/shuttle/