KSP
Space Plane Construction
and
Operation

with Special Consideration of Transport Space Planes in Career Mode



Disclaimer

Warranty void if used to construct or operate space planes in KSP

Version
Document Version: 1.01
Contents based on KSP Version: 0.24.2

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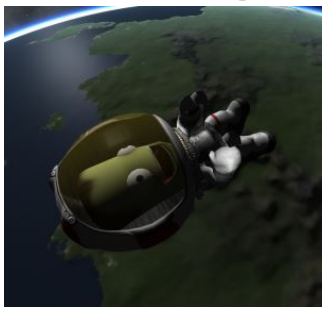
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1. Introduction

1.1. Document Version History

Version	When	What
1.01	2014-08-14	• Chapter about asymmetric thrust • Added lots of example planes, now a total of 9 examples • Added craft files in subfolder of zip-file rather than using links to them • Description how to copy craft files to own save game folder
1.00	2014-07-29	• Created, published first version on 2014-08-13 on Curse.

1.2. The Art of Space Plane Construction



There is hardly any Kerbal who doesn't dream the **Dream of Flying.** Yet it's not so easy as it might seem, at least if you want to do it in a somewhat kerbalized manner without causing too much collateral implications.
One way to do it is to create rockets. This way is fairly easy since you basically put stuff on top of other stuff and in most cases if flies somewhat ok for a little while.
As opposed to that, many are not too aware of the fact that a good space plane is a product of extreme precise and balanced construction. The sloppiness of slapping together stuff for a rocket can be pretty deadly here.
Teaching this mostly totally secret knowledge about space plane construction and operation, enriched with wisdom about quirks in KSP's inner mystics that partially need to be demystified by the Gods of KSP, is the main concern of this document.

1.3. My Expertise

I'm kind of addicted to space planes in KSP. I estimate my space plane production reaches easily 80+ designs. I have also some knowledge on how to construct and fly real world air craft, not to mention the PPL I made 25 years ago. And I played 'Orbiter', a free space simulator, long before KSP even existed. This is where i learned the basics of orbital operations.



Also not to forget this. Spielzeit = Gametime.

1.4. Your Expertise

You should be familiar with KSP somewhat and know the basics of what key does what and how to slap together stuff in SPH/VAB. Yet this is still intended for players new to the matter and I also explain quite some basics as well as special keys and stuff that might not be known by too many KSP players. And you don't need to be a mathematical genius or something like that. I won't bother you with too many calculations or formulas. We will do everything 'the kerbal way'. That is common sense, gut feeling and trust in the thrust.

1.5. Why Space Planes in Career Mode?

The answer is fairly obvious. Because it's fun! On a side note, it also cuts down on launch costs dramatically. That is, if you don't mess up too much constructing and testing them. This document covers not only space plane construction and operation in general, but also special considerations on transport space planes that can

be used to launch even pretty heavy payloads just for the cost of fuel into a low Kerbin orbit (LKO).

1.6. Stock Game Only

All descriptions are based on stock game only. Although the work of modders is very much appreciated, I prefer to play my games without mods. I also know that there are mods like KER, FAR, NEAR (still waiting on IN BETWEEN) and others that are helpful, fix 'features' and stuff, but the normal and / or new player should know how to play without mods first.
Covers also related topics about secrets on how to use Space Plane Hangar (SPH) or Vehicle Assembly Building (VAB) and how to organize and use subassemblies. Not to mention the basics of orbital operations and docking.

1.7. How To's vs Checklists

This is more a documentation than a tutorial explaining everything in a bit more depth. To make it also useful for more experienced players I offer 'How To's' as well as 'Checklists'. How To's describe more and use images to illustrate while checklists are just that: a condensed collection of items useful as quick reference and intentionally designed for printing out.

1.8. What Should I Have Researched?

Actually all the space plane parts and a few other high level research items such as the Meta-Materials (n-way-connectors especially since they are needed to attach the huge amount of air intakes needed).
For new players I urgently recommend to experiment in sandbox mode first, not in career mode. There research is also no problem.

2. Space Plane Construction

2.1. What's a Space Plane?

As opposed to what I would call a 'normal' plane, a space plane is an apparatus that uses a planets atmosphere as part of fuel to accelerate and to produce lift until the atmosphere gets too thin and then continues it's way into final orbit with rocket engines that take their oxygen from tanks.
A normal plane can't go into orbit since it usually lacks the rocket engines and canned oxygen. Of course most construction principles apply to all types of planes.
A space plane can also be called an SSTO - single stage to orbit - craft as opposed to a chaotic pile of junk that slowly disassembles as it's ascending into orbit, also known as rocket.

2.2. Pros and Cons of Space Planes

Before we go into the construction of space planes lets quickly see what's the advantages and disadvantages of them.

Pro	Con
• Usually 100% recoverable • Use a lot less fuel for a launch than rockets since they take oxygen and use lift from atmosphere as long as possible • Can precisely return to the runway at KSC which will yield most payback of funds. (The farther away the lower the payback) • Ship / Payload ratio around 70% / 30% as opposed to rockets which are around 90% / 10%	• A launch of payload into LKO is usually slower than using rockets. It can take up to 30 minutes to get something into orbit. • A well performing space plane is way harder to construct than a rocket due to the precision needed for alignment of CoM-CoL and CoM-CoT and a few other aspects

2.3. So What's the Trick with Space Planes

The important thing with a space plane is to get as much speed as possible using air breathing engines which need a lot less fuel than rocket engines plus using the atmospheres lift to get to some reasonable altitude before rocket engines need to be used for final insertion into LKO. Most priority has speed, altitude comes kind of automatically with it. Normal LKO speed is around 2200m/s. The more of this speed you gain without using LOX the better since this dramatically reduces the weight of the craft necessary to get into orbit.

2.4. Numbers You Should Know BEFORE Construction



These numbers are the result of building many planes and experimenting with them. They are very helpful to know when you plan to make a new space plane. All these numbers are based on R.A.P.I.E.R Engines. I use only those for the moment since they are most efficient and therefore most useful for the lazy kerbal rocket - I mean space plane - scientist. You see that it combines actually two engines, a jet engine and a rocket engine at the cost of only 1 - in words: one - engine.
Another advantage of the rapier engine is, that it can switch automatically between air breathing and rocket mode which helps prevent weird behaviour of the craft when air gets too thin.

Max TOW (take off weight) per RAPIER engine	13t
TOW per delta wing. Sometimes can't have enough wings. The main reason for a rule here is to keep the angle of attack of airstream at high altitudes somewhat small (~15°) for the sake of efficiency of air intakes and less drag	~2.3t
Rudders (yaw) per engine At high altitudes close to the point where engines want to switch to rocket mode often one engine gets deprived of oxygen which lets the craft break out to left or right side. The main purpose of the rudders is there to keep it under control. A one engine craft only needs one since this engine is right on the roll axis, but any craft with multiple engines sitting not right on the roll axis need quite an amount of rudders. Also depends on how far off the yaw axis the stabilizers are (strength of lever action). Paperman (10 engine, 130t TOW) uses 20 Sparrow (5 engine, 65t TOW) uses 12 Dove (3-engine, 39t TOW) uses 8	1 - 2.5
Pitch Elevators (pitch) per t max TOW No real rule here. Like with any control surfaces it mostly depends on how far off the pitch axis they are. Also sometimes adding control surfaces just to move CoL a little more forward/backward or	No Rule

up/down to get it into right alignment with CoM. Paperman (10 engine, 130t TOW) uses 12. Sparrow (5-engine, 65t TOW) uses 12. Dove (3-engine, 39t TOW) uses 8. Sparrow needs that many because Sparrows front and end doesn't extend far off the pitch axis.	
Ailerons (roll) per t max TOW Like with other control surfaces it depends on how far off the roll axis they are (strength of lever action). Also adding in some at times to better align CoL and CoM. Paperman (10 engine, 130t TOW) uses 12. Sparrow (5 engine, 65t TOW) uses 6. Dove (3 engine, 39t TOW) uses 4. NOTE: some control surfaces from Paperman and Sparrow have a double function as elevators and ailerons.	~0.1
kN SAS per t TOW Example: if a plane has 3 rapier engines and therefore 3x13=39t max TOW you will need 39x1.5 kN SAS = 58.5kN = 2x big gray SAS module	1.5kN/t
LF (Liquid Fuel) per t TOW and switch speed 1850m/s	39 units
LOX (Liquid Oxygen) per t TOW and switch speed 1850m/s	19 units
LF (Liquid Fuel) per t TOW and switch speed 1750m/s	39 units
LOX (Liquid Oxygen) per t TOW and switch speed 1750m/s	29 units
Best angle of attack at critical altitudes (27km+)	12° to 15°

Switch speed is the speed at which the engine switches from air breathing to rocket mode. This is of course not triggered by a certain speed but when the atmosphere gets too thin to fuel air breathing engines. The higher this switch speed is the less LF and LOX is burned by comparatively inefficient rocket engines. See the difference between 1850m/s and 1750m/s switch speed LOX consumption.
The fuel numbers given are for the full mission envelope, that is take off, ascend, get to LKO, dock to something at LKO around 100-110km, do a de-orbit burn, fool (not fuel) around a bit in atmosphere, land at KSC (Kerbal Space Center)

2.5. Some Basics about (Space) Plane Construction

2.5.1. What we do and don't want

There are lots of Kerbals showing off their creations, but to be honest, I have serious doubts that even 20% off them actually fullfill the mentioned tasks satisfyingly. I can already tell from the looks of the planes that the construction follows whatever wrong or no principles at all. I mean, create a space plane for the looks of it is certainly a viable motivation, but that's not what we want here.

As already mentioned before, a space plane needs extreme precise alignment and arrangement of certain items or it won't work or cease to work at some point. A lot of planes might actually work fairly well during the first 3 minutes after takeoff but then they start to spin around or do other nasty stuff. This is NOT what we want.

This tutorial is about the high art of building space planes with stock KSP that do their job from their first drop of fuel used until the last drop is flown out without even using SAS if we don't want to. Yes this is possible. Yet, SAS comes of course in too handy for the lazy Kerbal, so we are actually going to use it. Just saying, that we don't have too use it for flying the plane precise and controllable in any situation we encounter. That's kind of important in KSP's Career Mode, isn't it?

2.5.2. Some More Considerations and Priorities



One of my biggest concerns when creating anything in KSP is part count. High **part count** means also danger of physics lag, not to mention that each part also has **drag**. And if you play like me assembling large entities in orbit and send them around in the Kerbalverse, then you want single objects to have the least number of parts possible. To make it short: I extremely rarely attach something just for the looks, every part has it's meaning and role and nothing is coincidence. No fluff stuff. This might explain the partially unusual look of my planes. The image above shows one of my biggest space transporters to date while hauling a 27t space station core into orbit. Max payload is around 47t. It only remotely resembles air craft you know from Humanverse. It actually kind of looks like a sales display of assorted panels and cans stuff at Home Depot rather than a space plane. But it works perfect and flies like a charm. And that is all that really matters to me.

Another important factor is **weight**. Especially transport planes should be extremely efficient in that respect to allow as much payload as possible. I often hesitate to add parts just for artificially balancing the craft. The balance must be inherent in the construction if possible. Sometimes it might not be avoidable though if other considerations such as geometry have priority.

2.6. Let's Get to Work

2.6.1. Basic Construction Plan for a 3-Engine Space Transporter

We are in the lucky situation that we have the table from chapter 2.4. Numbers You Should Know BEFORE Construction.

Given the numbers in this table we can already determine the following stats and information:

Max TOW: 3 * 13t = 39t
LF for max TOW: 39 * 39t = 1521 units
LOX for max TOW: 23 * 39t = 858 units (23 is a conservative guess between 19 and 29)
Delta Wings: 39t / 2.3t = 16.9
SAS Modules: 39t * 1.5kN/t = 58.5kN

Alone from using the numbers from the table we can already predict a lot about the future space transporter.

2.6.2. Fuel Tank Setup - Jet Fuel Tanks vs Rocket Tanks



Knowing how much fuel we need lets us determine the tanks. Lets quickly discuss this aspect. When space planes were added, also Jet Fuel tanks that contain LF only were added. So usually part of the LF we need we would add as these Jet Fuel tanks. And the other part we would add as normal rocket tanks since we also partially need the LOX. Now this is probably a good solution as for weight but not for part count, drag and ease of design and balancing. Bigger planes with multiple engines need huge amounts of these relatively small tanks extremely increasing part count. So all my 'modern' creations use rocket tanks only which are partially stripped off of LOX and even of LF sometimes.
That way, all my craft have either 1 (normal planes) or 2 tanks (space transporters) but not 10, 20 or 30 or even more.
That reduces also the need of fuel lines, wobbliness of craft, and massively drag. Using one tank stripped of LOX is usually around 5-10% heavier than using the same amount of single Jet Fuel tanks but the reduced part count (drag) and stuff makes up for that by far.

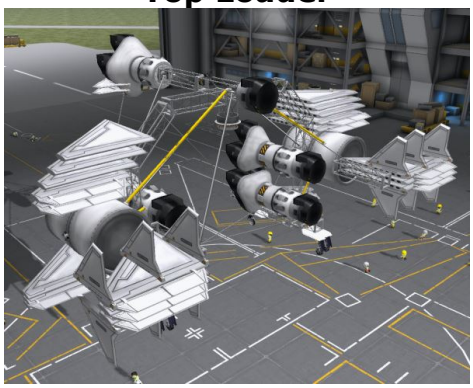
2.6.3. Basic Layout of a Transport Space Plane

Another consideration is the basic layout of the transport space plane. They need to offer a cargo bay for the payload. That alone

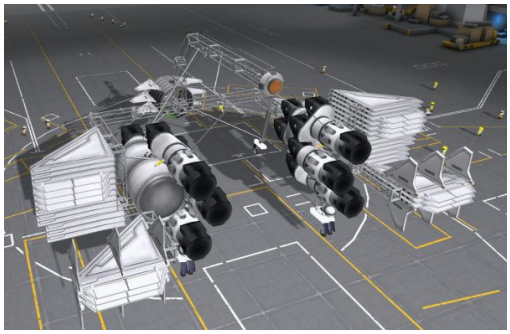
makes construction of space transporters pretty much different to normal space planes. Space transporters need to reserve their center as cargo bay, while normal space planes usually have their tank(s) there.

I use two different layouts for transport space planes:

Top Loader



Front Loader



Both have their center free for payload. The top loaders payload is usually attached to the arc or spine on top. The front loaders payload is usually attached near the front and secured with space tape to the spine.
In this tutorial we are going to make a front loader since it's usually easier to correctly align and attach payload and to construct payload for them.

So our final goal will be a 3-engine front loader space transporter.

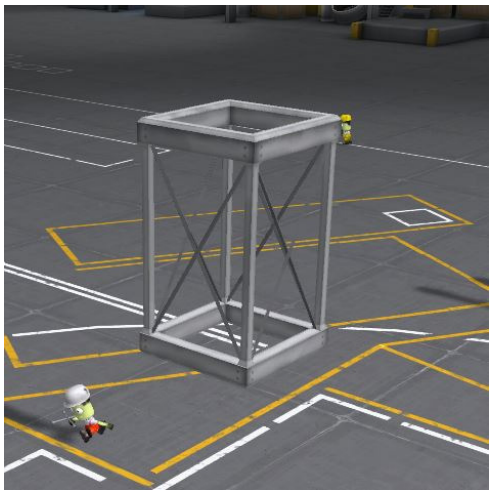
2.6.4. SPH - Space Plane Hangar Keys and Stuff Good to Know

Some really useful keys to know are:

Key	Used for
(Shift+) W,S A,D Q,E	Lets rotate the selected part (and all connected parts) around the 3 axis. Used without shift, the rotation angle is 90°, when using shift+Key rotation is 5°. Very useful. Which key turns which angle around which axis is best tried out. It also depends on the state of the angle snap feature, the current weather and some other less well known factors.
X	Increment current symmetry. (In SPH there is just 1 setting so it just toggles on/off). The left of these 2 buttons selects symmetry when clicked. 
Shift+X	Decrement current symmetry (In SPH there is just 1

	setting so it just toggles on/off like X)
C	Toggle angle snap on/off. When off (button shows round symbol), stuff might be attachable to other stuff with respect to other stuffs surface, if it shows the diamond type symbol it will snap to certain angles. Angle snap is the right of these 2 buttons. I excessively use both settings since some effects can't be achieved without one or another. It's a matter of exercise. The right one of these two buttons is the angle snap. 
CTRL+Z	Undo key. Often doesn't work though (bug) so that part that you just chipped off accidentally can't be put back. This is the reason why I save after attaching every part or every change so that I can reload instead. Would be nice to see this fixed.
Spacebar	When spacebar is hit then the current part(s) attached to mouse cursor are rotated back into their initial rotation
ALT + Left Click	ALT + Left Click on a part with the mouse creates a copy of that part with the same rotational and property settings. Comes in handy when many of the same parts need to be attached like the stacks of wings in my plane designs.

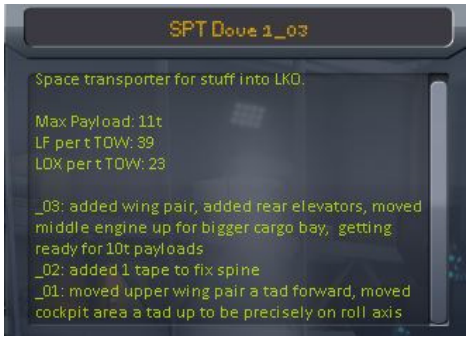
2.6.5. The Root Part (First Part)



Most people use a cockpit as root part. This is ok for normal space planes. For transporters I prefer to use the 'neck piece', this is the piece to which all 'arms' of the transporters frame are connected. The root part of a design can't be changed (I hope this will be implemented in some version of KSP).

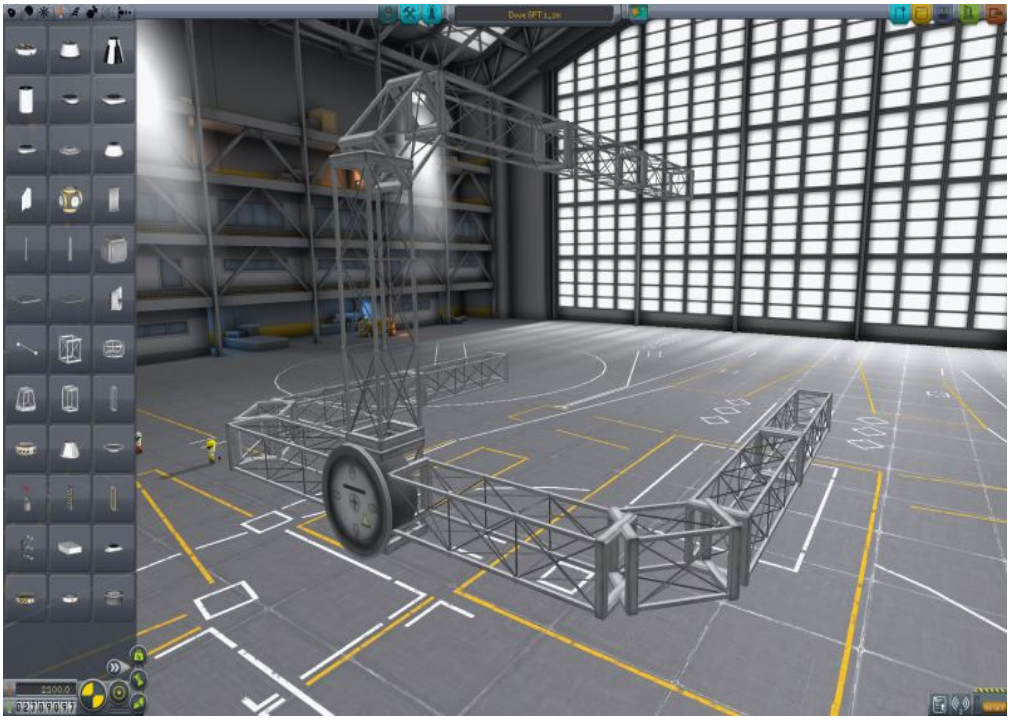
We use a Modular Girder Segment as root part and turn it upright. This has the advantage that we can later move stuff up and down as needed to align it with the space planes CoM (Center of Mass). There will be no need to move stuff sideways since the 'neck piece' will always be in the middle.

2.6.6. Save Frequently, Reasonable Names, Log Changes



Save frequently. I often save after each little modification because the CTRL+Z undo function is bugged and often doesn't work.
Give your designs reasonable names. I usually give them a type designator (SPT=Space Plane Transporter), a type name (Dove) and a Variant_Version (1_03) combo. Later when I change something on the plane or try out different versions I use the version number to separate versions. Usually I document the changes per version so that i later know what I have to undo. The variant number is usually for separating really different variations such as a water plane from a runway using plane. I also sometimes use flag characters in the names like L=Long Range, V=VTOL etc.

2.6.7. The Frame Around Cargo Bay



Now we build the frame around the cargo bay to which all other parts will get attached. Using girder segments for that and radial attachment point for the command module stuff. The diagonal girders are attached using non-angle-snap and hitting shift+A or shift+S 9 times (=45° since 1 hit is 5°, see above).
The two arms on left and right side are made using the symmetry tool. Always use the symmetry tool when you do symmetric stuff. This will ensure that both sides of the plane are identical. In case the 'I don't like symmetry bug' hits you, that is you can't attach

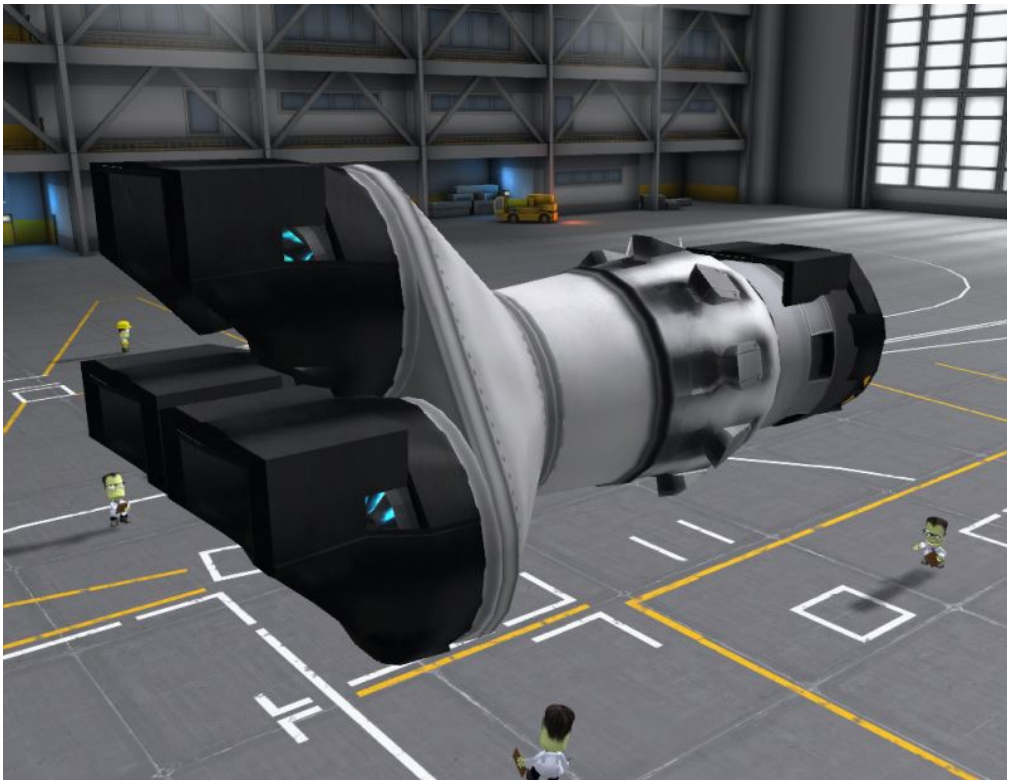
items symmetric, just one of them, you switch to non-symmetry, attach whatever. Then you chip off and reattach the left or right arm to the neck piece and boom your symmetry is restored perfectly. Backdraw of this is that then you are for sure victim of the symmetry action group bug. But this is unavoidable. More about that later when we get to action groups.

2.6.8. The Fuel Tank Setup

The alpha and omega of space plane construction is, that the space plane is built and centered around the tank setup. Ideally the CoM (Center of Mass) is in the center of all fuel tanks. Also in chapter 2.6.1. Basic Construction Plan for a 3-Engine Space Transporter we have determined that we need 1521 units of fuel for a max TOW of 39t. Since the geometric center is reserved for payload we can't just slap in a tank there. Instead we will go with two Rockomax X200-16 Fuel Tanks with 720 LF a pop. The LOX amount needed will fit in there anyway. 2x720 isn't really 1521, so unlike my usual habbits we will also use the small tanks in engine nacelles (40 fuel a pop) as additional tanks. 3 of them give us another 120 fuel, so we are on the safe side. Usually i use them empty just as air intake.

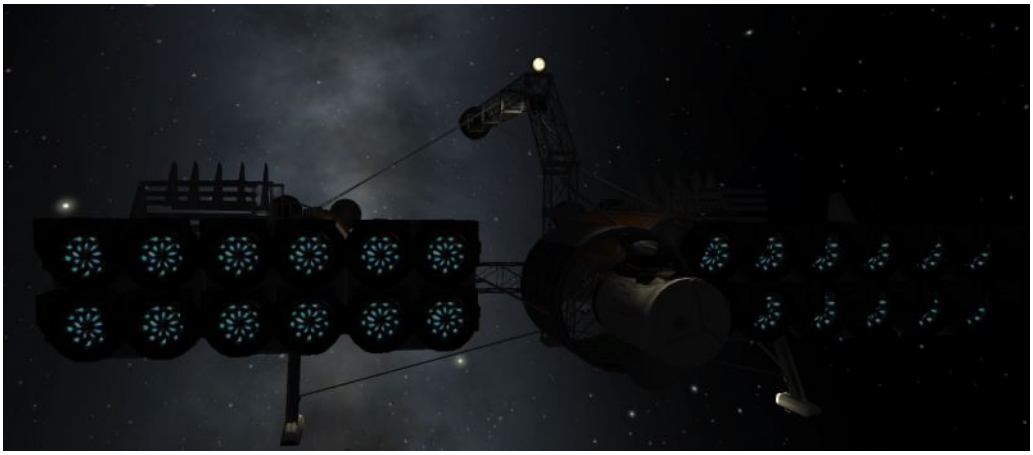


2.6.9. The Basic Engine Construction



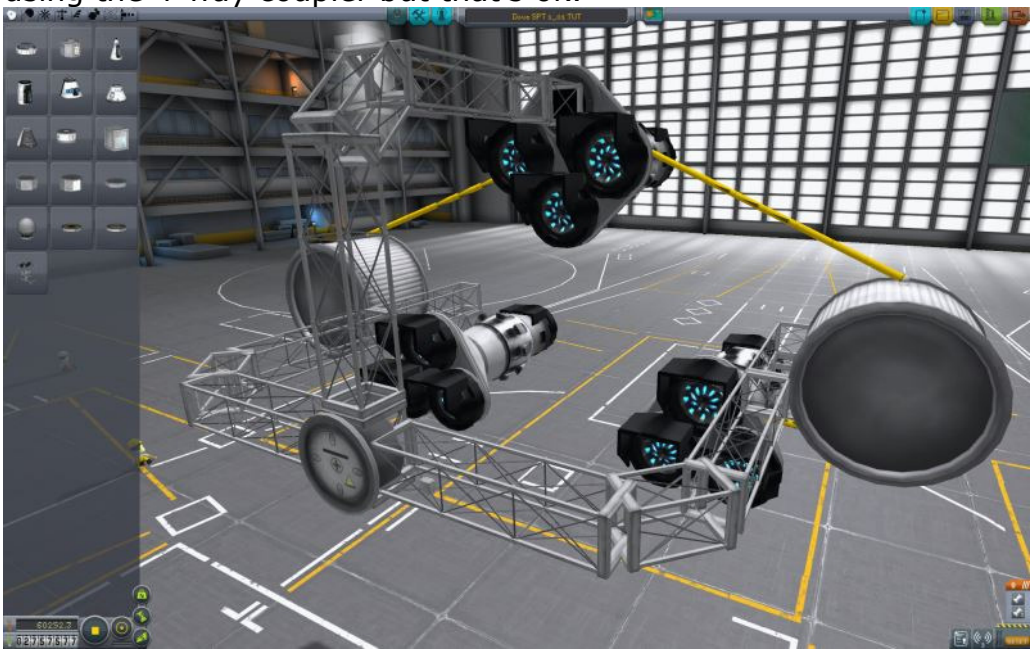
First of all, there is a secret about engine creation. You don't just slap 3 engines and a couple air intakes somewhere on the frame and it will work. For some real mystic reasons, there can be extreme differences in efficiency of engines depending on how they are built.
The engine setup shown consists of a tri-coupler with 3 air intakes followed by an engine nacelle (which is also a little tank and air intake), the rapier engine and clipped into the rapier another air intake. Engines built like this can go up to 36km+ and get to 2000+ m/s speed in air breathing mode under ideal conditions.
I use this type practically for all bigger space planes, really small ones can even get into LKO with less air intakes.

The following is an example of a bad setup. I never really found out why it didn't work. The air intakes are in front of the plane on quad-couplers and the engines are at the rear end. Despite the number of intakes matching the design rules of the above engine the space plane never got above 28km in air breathing mode and barely over 1500m/s. Completely dissatisfying and unusable.



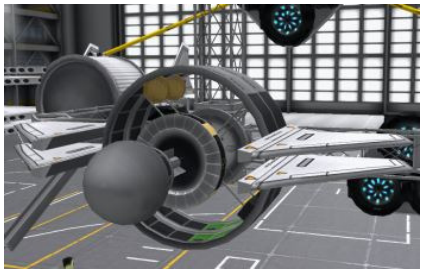
So back to our engines. Actually the engine nacelles are crappy intakes and only little tanks but they are side-mountable and that makes them really valuable in aircraft design. Using them you get a side-mount, an intake and some fuel in one part. Isn't that just great? If you call now and order immediately ...

Lets create the engines. The two side engines follow precisely the setup, the middle engine for obvious reasons is a little variant using the 4-way coupler but that's ok.



Also notice the yellow fuel lines. Fuel usually is only taken automatically out of tanks if they are in one line with the engine and all parts in between are fuel cross feed capable. Some parts aren't like the metal plates. I will explain basics about fuel flow and fuel lines in a separate chapter.

2.6.10. Cockpit Area



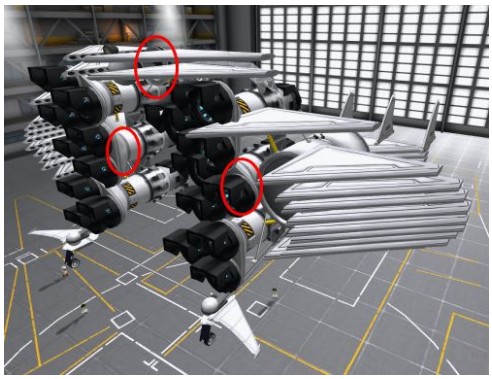
In previous versions of KSP I often used cockpits with kerbals. But nowadays in career mode I prefer to use probe cores. The simple reason is that space planes are dangerous, especially on their first test flights. I damaged my reputation quite a bit with occasional dying Kerbals. And it's not that great for the funds either. Yet with sticking to the rules you will be successful even on your first test flights.

Cockpit area has these parts:

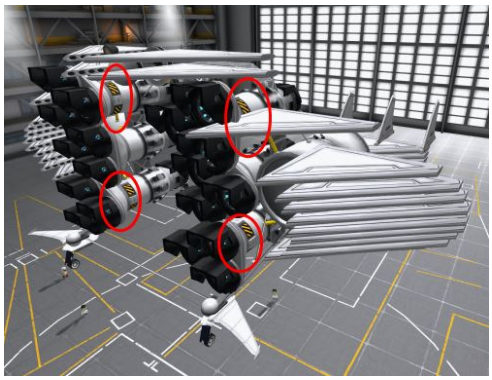
- Probe Core
- Nuclear Generator
- 1000 unit Battery
- 2x 30kn SAS Modules

2.6.11. SAS Modules

A word on SAS Modules. On space planes they are used to keep the flight path somewhat stable while making coffee on a long winded ascend and like all other craft to change the crafts attitude without using limited resources such as monopropellant. Especially heavy transporters need quite a few SAS modules. Depending on the shape of the plane they sometimes can't be attached on the roll axis which is usually the best place. This can cause trouble, which is often not obvious at lower altitudes since the control surfaces can make up for the trouble caused by SAS modules. At higher altitudes around 20km+ it then happens that the space plane suddenly gets uncontrollable. To correct that, the SAS modules must be arranged as balanced as possible around the roll axis.



The first version of Ouzel had two SAS modules attached to the 2 middle engines and one to the cockpit area. This was actually not very well balanced since the roll axis goes right thru the middle of the middle engines leaving the lower part un-SASed. The reward was an increasingly uncontrollable behaviour at altitudes above 20km.



The final version now has 4 SAS modules on the upper and lower engine pairs which make it pretty balanced around the roll axis. This setup causes no trouble at all.

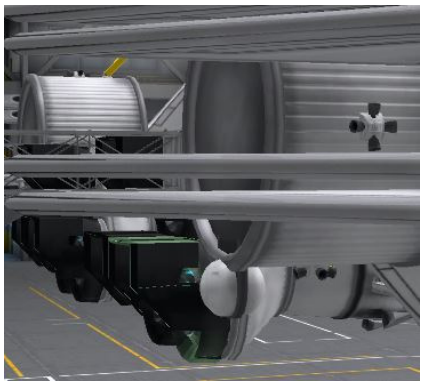
So what we learn here is that even SAS setup must be done cautious and with some precision if SAS modules can't be attached on the roll axis of a plane.

2.6.12. Wing Setup



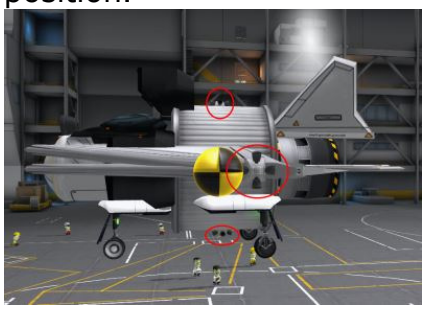
In our original plan we calculated that for 39t max TOW we need 16.9 delta wings. We are going to cheat and use 18! Yeah! That is 9 per side.
Where they are attached doesn't matter that much as long as the resulting CoL (Center of Lift) is within the limits. This is discussed later. In case of our plane I used 3 delta wings at the rear end, 4 pairs attached to the big tanks and one pair up on the 'spine' of the plane. Also added 8 vertical stabilizers (yaw, 4 above and 4 below the rear wings), 8 horizontal stabilizers (pitch, 4 at the rear end, 4 near the probe core) and 4 rudders (roll). Keep in mind that the stabilizers also add to the CoL position and have significant lift.

2.6.13. RCS Setup



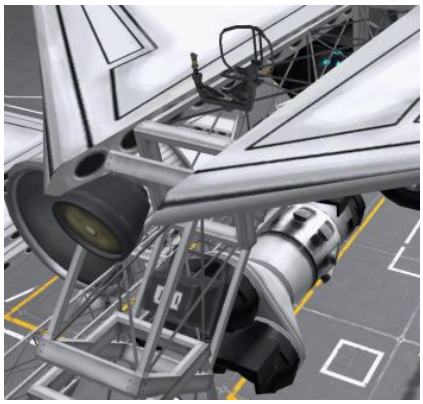
There are 3 pairs of RCS thrusters attached. One pair below the main tanks, one pair on the outside of the main tanks, one pair on top of the main tanks (can see it on the tank farther away). The monopropellant tanks (attached below main tanks) are usually the only parts that I use for finishing touches to the overall balance of CoM.
RCS thrusters in KSP only need to be used for translation, that is moving sideways or up/down or forward/backward. They are not used for changing attitude (rolling around axis), this is the domain of SAS modules. That said, actually 4 RCS thrusters are enough for a normal space plane built around CoM.

Transporters are a bit of an exception here since you can hardly attach 4 RCS thrusters to the hot air called cargo bay in the middle of the plane. So we use the 6-thruster setup.
Also note that the thrusters are grouped precisely around CoM position.



A conventional plane with center tank uses 4 RCS thrusters which are always located around CoM. This is enough for even the biggest planes with up to 200t TOW. Even all my landers, lifters and the like use the very same setup. Just saying that because a lot of new players often dramatically overdo the RCS part.

2.6.14. Lights and Other Stuff



I added a landing light, a lamp for the cargo bay and a seat to rescue kerbals. Kerbals rescued with a seat is still bugged in 0.24.2. The intermediate step doesn't get rewarded, but the final does and the kerbal is added to the team. I often pick up kerbals that way when I have delivered payload to a space station or space train.

2.6.15. Most Important: Alignment of CoM, CoL and CoT

CoM = Center of Mass (also named CoG=Center of Gravity)
CoL = Center of Lift
CoT = Center of Thrust



You can toggle all three tools on and off with buttons at the left bottom corner of the SPH/VAB window. The upper button is CoM, middle button is CoT and lower button is CoL.

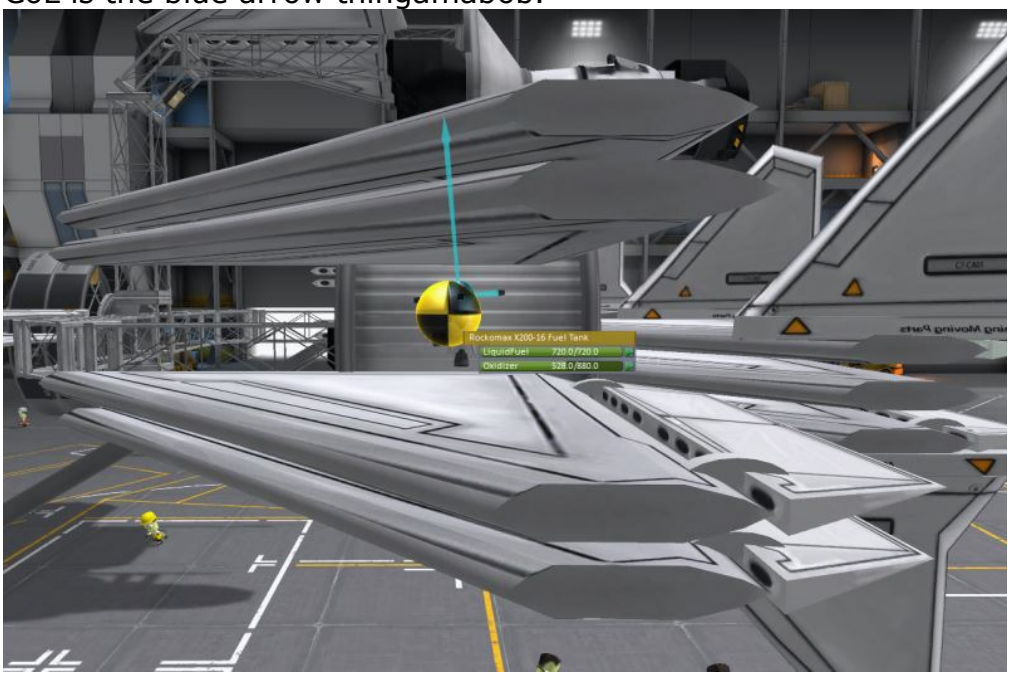
Since we have now all stuff **except landing gears** attached to the plane we can start centering and aligning stuff right. Actually I have used the tools already in the process of attaching the wings and moved tanks and engines a little up and down and stuff. But now that everything is attached we can do final touches to the balance and discuss how the result should look like.

NOTE: there is a severe Bug in the CoM tool since 0.23 or 0.23.5. In SPH and VAB the 'Small Gear Bay' has a weight of 0.5t and

adds to the position of CoM. In the game though when launched the Small Gear Bay's are physicsless and have no weight. So the CoM displayed in SPH and VAB is wrong as long as the gear bays are attached. This is why we detach them to do the aligning and balancing stuff.

2.6.16. Alignment of CoM <-> CoL

CoM is the yellow ball.
CoL is the blue arrow thingamabob.



CoL must be a little behind and above CoM. That way the plane has a slightly tendency to lower it's nose if we don't pull up a little when flying manually w/o SAS. This is precisely what we want. CoL must never ever get in front or below CoM! This will result in a mostly unflyable craft and this situation can occur when CoL moves only millimeters forward or downward! That is the reason why correct alignment and balancing is so important in space plane creation and also explains why most of the planes you see in the forums are best case 5 mins flyable.



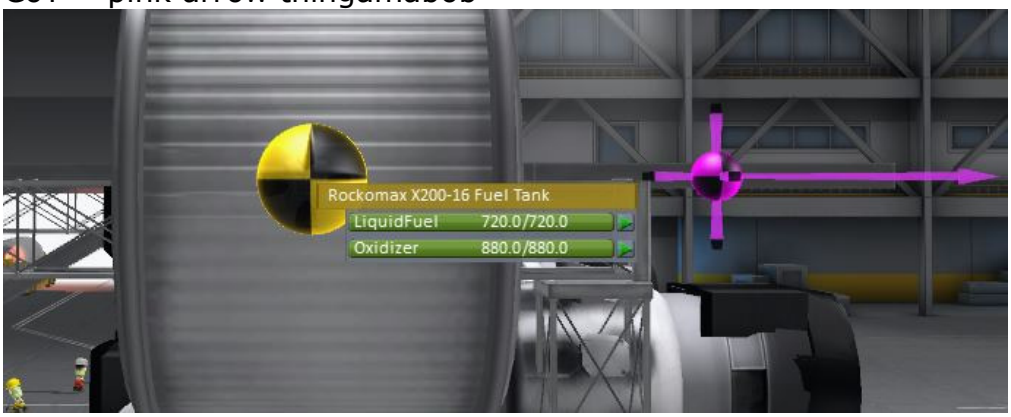
It's no coincidence that the image also shows the current default tank load. The reason is, that of course the fill grade of the tank has influence on the CoM's position. As you fly out fuel from the tanks, the position of CoM might wander off to another position. And the real high art of creating space planes that separates grand masters from n00bs is, that you also check the CoM<->CoL alignment with empty tanks. CoM shouldn't move at all! As you can see, the

alignment didn't change! This plane is extremely well aligned throughout it's whole mission envelope, well at least CoM<->CoL wise.

In case CoM moves forward when changing tanks from full to empty, you need to move the tank a little forward and vice versa. In case CoM moves up when changing from full to empty tanks, you need to move the tank a little upward and likewise if it moves down. Do this until CoM doesn't move anymore when you change from full to empty. That way you can be sure that the plane will fly controllable and stable from it's first to the last drop of fuel even without SAS if necessary.

2.6.17. Alignment of CoM <-> CoT

CoT = pink arrow thingamabob



The CoT must be precisely in the middle of CoM. If it's above, and even only a little bit, the engines will push the aircrafts nose down. It it's below CoM then the engines will push the aircrafts nose up. At lower altitudes usually control surfaces can make up for it, but when the air gets thinner they can't control it and the space plane might start to extremely push down or up until it starts spinning.
I attached helper items (I-beams) that you can see behind the CoT so that I can actually see the correct alignment. I wish the Gods of KSP would have made the tools extents scale somewhat to the planes size so that you don't need such helper constructions for even relatively small planes.

2.6.18. Engine Setup and Asymmetric Thrust

Despite CoT being centered right in the middle horizontally behind CoM asymmetric thrust can occur at high altitudes when one engine starts to get deprived from oxygen. Then this engine produces lower thrust than others and the plane starts to break out to one side. Due to the algorithm used it's most likely the last engine that got attached to the model that gets deprived first. So make sure the last one attached is the closest to the roll axis. In a setup with an odd number of engines it's ideally the middle one.

Otherwise you have to work against this effect by adding rudders, pitch elevators if it's up/down or SAS modules which is only the 2nd best choice (part count, drag).

2.6.19. The Landing Gear

As outlined above, we need to correct the alignments of CoM, CoT and CoL without landing gears. Now that we are done with that step, we can actually attach the Small Gear Bays which are the only gears that can survive average landings. There are a few things to know about where and how to attach gears and how to set them up correctly.



First thing you notice after attaching the gears is, that now the alignment of CoM and CoT is completely wrong. People who don't know about the bug that gears are physicsless in game but not in VAB/SPH do their alignments this way (if they do them at all) and wonder why their plane doesn't work correct.

Don't attach rear gears too far behind CoM. If you do, it takes a lot more force to lift the planes nose on take off. They must be behind CoM but close. People often chip off their engines on take off and thats because they need to fully pull because the landing gear is too far behind CoM.

Also you can see that the front gears are on ground while the rear gears are hoovering a little bit above ground in SPH. This will lift the planes nose already a bit by default when launched again making it easier to rotate at take off. Especially important when we get to attach heavy payload.

Finally you need to set correct attributes on front gears. Disable Brakes and Unlock Steering on front gears. This is most important! You need to do that for both gears, even if they are mirrored. I also disable their light (setting RGB to 0,0,0).

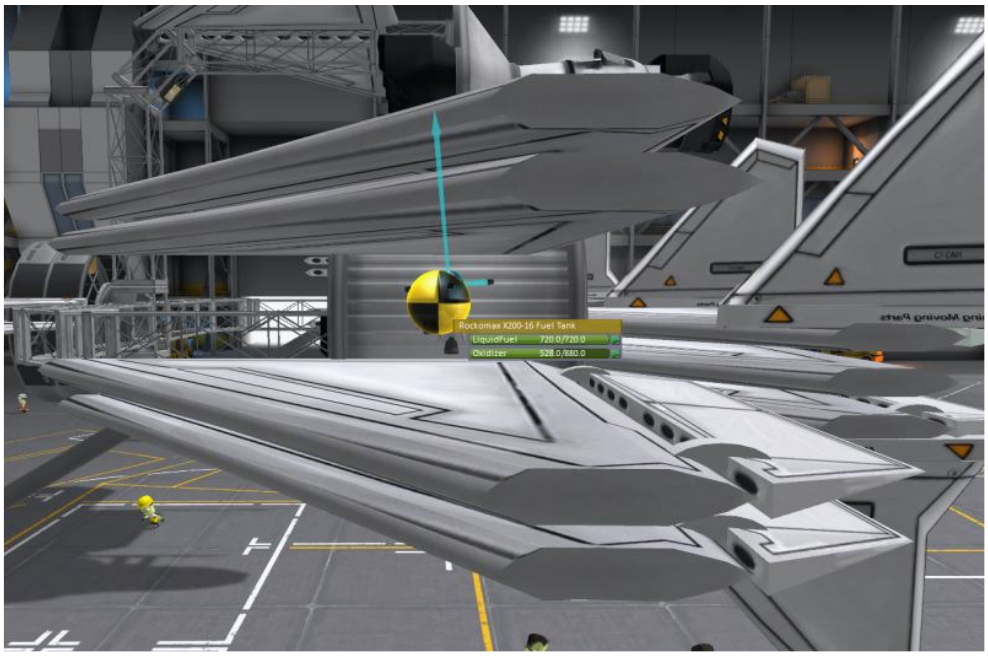
Rear gears are actually two pairs to get enough breaking efficiency, but I also disabled the lights on one pair because 4 gear lights are too bright, 2 are enough. Especially with the landing light on top of the plane and the cargo bay lamp.

2.6.20. Control Surfaces

The control surfaces, that is horizontal and vertical stabilizers and the rudders can be set to either roll, pitch or yaw only. I usually do this. Avoids unwanted surprises in flight such as under

steering, over steering, sudden spinning and the like. Not likely to happen with our well balanced and aligned plane though but again better safe than sorry.

2.6.21. Setting Fuel



It is important to set the final fuel correctly. This makes a huge difference in weight. For the targeted max TOW of 39t we calculated that we need 1521 LF and 858 LOX. So I sat the main tanks to 720 LF and 528 LOX. The total LF is 2x720+3x40 (nacelles) = 1560 and 2x528 LOX = 1056 LOX. So both our fuel needs for TOW = 39t are fullfilled.

2.6.22. Fix Staging

The automatically determined staging in 0.24.2 is incredible bad so if your aircraft contains more than just engines you will have to fix it manually. I often tend to forget about it and if you detach and re-attach stuff the automatism usually destroys your settings so you will have to fix it so that the parachutes aren't triggered before take off and stuff.

2.6.23. Setting Up Action Groups

First off: Due to the bugs listed in the appendix I recommend doing this as last step when all stuff is attached and aligned correctly.

Sounds sophisticated but is simple. Basically action groups can be used to trigger/switch stuff on parts using hotkeys 1-9 and 0. There are also some default action groups into which default actions go that you can edit too such as breaking for example.

My typical action group setup for this type of rapier based space planes is as follows:

1 = toggle engines on/off
4 = switch mode air breathing / closed cycle (rocket-mode) used on re-entry
0 = shutdown all engines (comes in handy when docking at a space station with multiple other stuff docked. Toggling engines there doesn't really pull it because it would toggle all other crafts engines back on).



Enter action group edit mode by hitting the middle button of these 3 buttons.



Now click on the action group button that you want to edit. You can see that there are 'well known' action groups that refer to functions such as toggling SAS and RCS, breaking, etc. as well as Custom01 to Custom10 which refer to the keyboard keys 1-9 and 0. The yellow names indicate that there is already listed something in Custom01, Custom04 and Custom10. In this image I have already added my above listed action group setups to the respective action groups.



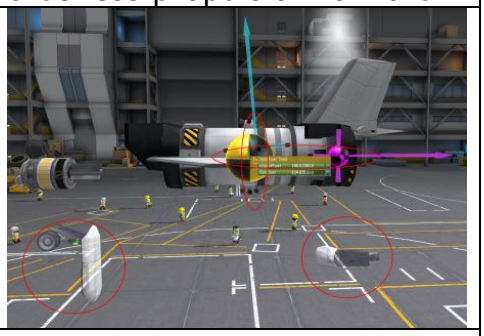
This example shows how to set up the Toggle Engine action for the RAPIER's in action group Custom01.
To add an engine to the group simply click on the engine on the space plane. This will bring up the engine's actions in the rightmost 'Selection' column. Then click on the action you want in the group, in this case the 'Toggle Engine' action. This action will now get moved into the middle column 'Group Actions'. Now this engine can be toggled by simply pressing the 1-key on the keyboard. There are only two engines listed since for mirrored parts only need to be listed once, not for all mirrored parts (but this is bugged when you detach mirrored parts, see section about bugs and above).
If you want to remove something from the action groups, then simply click on the action name ('Toggle Engine') in the column 'Group Actions' and it will get pushed back into the right 'Selection' column.

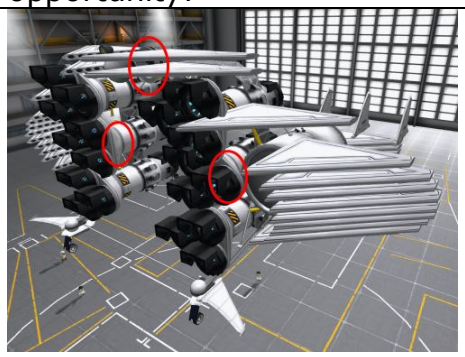
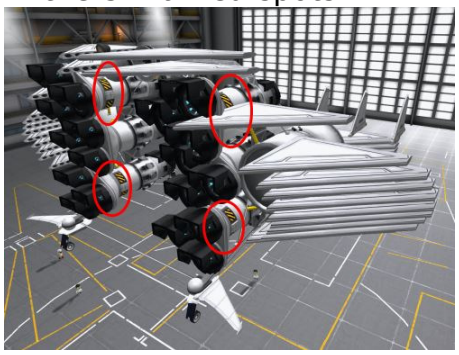
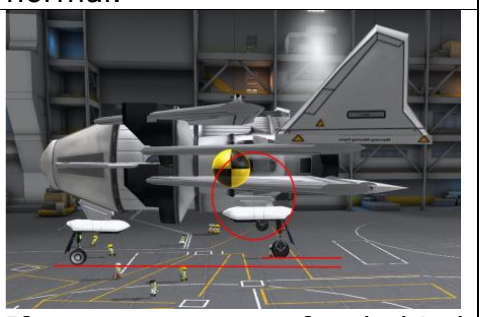
You can also add stuff to the 'named' action groups which correspond to the respective keys in game like SAS (T), RCS (R) and so on. I often set up parachutes in the Abort group for example (Backspace).

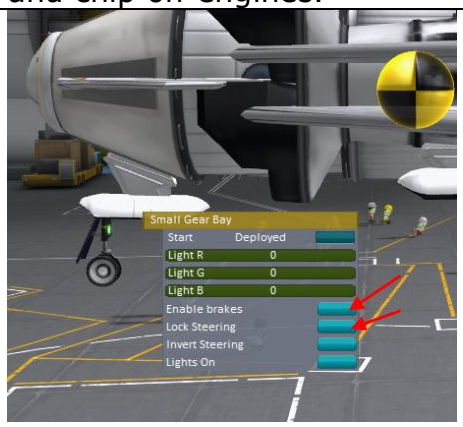
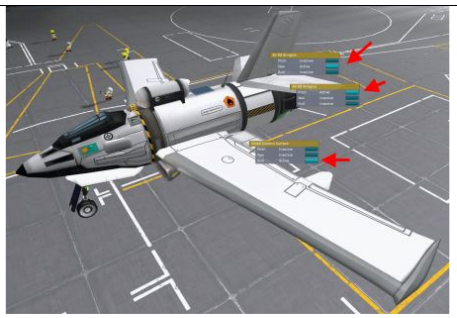
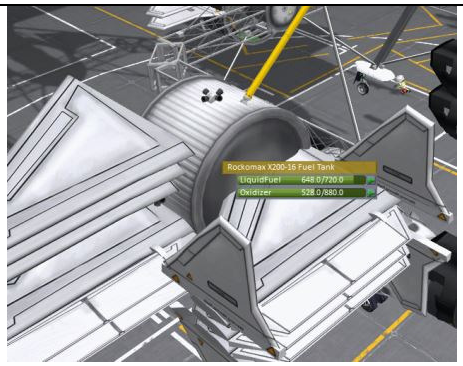
Once the action groups are set up, we are ready to go! Yay!

2.7. Quick Reference for Space Plane Construction

2.7.1. Checklist: Basic Space Plane Construction

#	Check	Test	Expected Result
1.		Do numbers of parts roughly match rules in chapter 2.4. Numbers You Should Know BEFORE Construction	Those values are based on experience. For example too much TOW for the engines attached can result in not being able to get to LKO at all, not enough wings might do the same having a too big angle of attack in thin air and thus less propulsion forward.
2.		Gears detached for alignment tests (since 0.23.5) due to massless parts bug of CoM in SPH / VAB	
3.		CoM-CoL alignment	CoM a little in front and below CoL. Should give plane a tendency to slowly lower it's nose which makes it way easier to control.
4.		CoM-CoT alignment	CoT horizontally aligned with the center of CoM. If it's above or below CoM the plane will have a tendency to uncontrollably steer down or up especially in thin air.
5.		Full<->Empty tank test: CoM position shouldn't move when tanks are set empty. At least the overall picture should stay the same (CoM in front and below CoL, CoT in center behind CoM).	
6.		Re-attach gears (since 0.23.5)	I'm a specialist in saving planes without gears after fine tuning alignments. Thank

			you Gods of KSP for this completely unnecessary opportunity!
7.		SAS alignment correct around roll axis on planes that need SAS being attached away from roll axis due to their geometry such as transport planes.	 Above is an example for a bad SAS configuration that can get out of control. In the first version of the plane the SAS modules were attached in the 3 marked spots.  After balancing it around the roll axis using one more SAS module, behaviour was normal.
8.		Rear gears not too far behind CoM	 If gears are too far behind CoM then it might even get impossible to lift it's nose on takeoff.
9.		Front gears a little lower than rear gears	Makes takeoff also a bit easier when plane on runway has already a little angle of attack. Less need to pull hard

			and chip off engines.
10.		Front gear properties: Steering enabled, Breaks disabled. These properties must be set for each single front gear if the plane has multiple, they are not mirrored!	 If steering isn't enabled turn radius is much bigger. If breaks are enabled then the rear of the plane is pushing against the front probably forcing it to break out and get uncontrollable.
11.		Ailerons set correctly	 Control surfaces should be set to only work on the axis they are primarily intended for. Otherwise they might lead to uncontrollable behaviour in extreme situations.
12.		Pitch elevators set correctly	
13.		Rudders set correctly	
14.		Fuel set correctly	 Space planes solely based on

			rocket tanks usually have way too much LOX on board. Setting fuel amounts to reasonable values saves a lot of TOW and improves max payload. Safe values for new planes are: LF per t TOW: 39 LOX per t TOW: 23
15.		Batteries?	
16.		Generators / solar panels?	
17.		Lights?	I usually disable lights on front gear if it's attached turned around and disable lights on some rear gears if there is more than one pair of gears.

3. Advanced Construction Concepts

3.1. Fuel

Fuel is a very important if not the most important topic in space plane construction. Basically space planes of any kind are always constructed around their fuel tank setup. CoM is usually always right in the center of the tank setup so that CoM doesn't move as the fuel is consumed.
Sure you can create a space plane that is well balanced when fuel is full but if you don't test and make sure that CoM remains same when fuel is flown out you will end up with an uncontrollable plane after a few minutes of flight.
So you need to take care of balance as well as balanced consumption, for example make sure that side tanks are flown out simultaneously and not one after the other.

3.1.1. Fuel Transfer Rules (No Fuel Lines)

Rules for fuel consumption without fuel lines:

1. Fuel (LF, LOX) is always taken from the tank farthest away from the engine first. When this is empty, then fuel is taken from next closest tank and so on. The 'distance' of a tank isn't defined by it's geometric distance. Distance here is the number of connects away or parts in between the tank and the engine.
2. Fuel is usually only accessible / transferred between parts that are in one stack, that is parts connected via their top or bottom connectors. Fuel isn't transferred automatically from / to side mounted parts. There are some exceptions like girder segments.
3. If two tanks have the same distance (as defined in 1.) to the engine, then both tanks are drained simultanously.
4. Some parts don't allow fuel cross feed, such as the structural panels, decouplers and separators.

If you are uncertain about the consumption behaviour of your craft then just launch and test. This is also in the first test checklists.

3.1.2. Fuel Lines

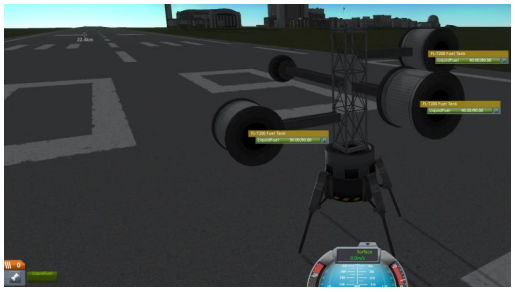
Yellow fuel lines allow to manipulate the order in which fuel is consumed from tanks. Rules for fuel lines:

1. Fuel lines work only in one direction, from-end is connected first, to-end is connected last.
2. If a fuel line is connected directly to an engine, tank or cross feed capable part, then the fuel draw algorithm follows the

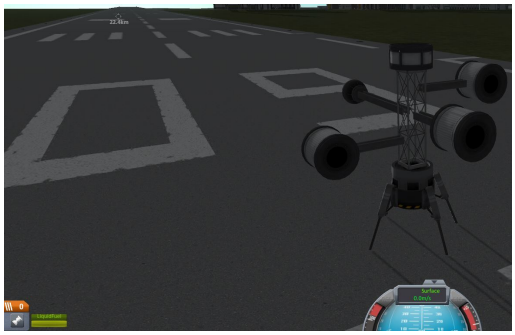
fuel line first and only when no fuel is found continues up the stack of that part or takes fuel from that part if it's a tank. So if a fuel line is connected to the engine, then fuel is drawn first through the fuel line and then from the engines stack, even if the engine is directly connected to a tank.

3. If multiple fuel lines are connected to an engine or cross feed capable part, then the fuel is drawn simultaneously and synchronously through all lines from tanks of the same 'distance'. Only if none of the lines draws anymore fuel, the algorithm continues draws from the part to which the lines were connected or continues search up the parts stack.

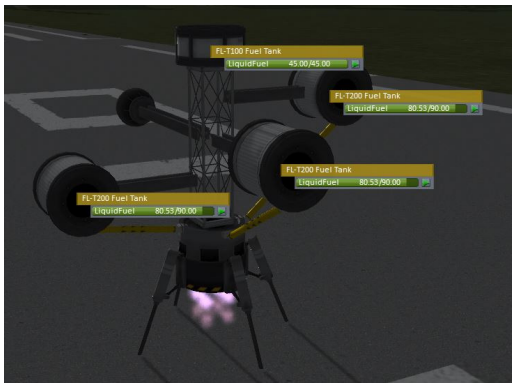
3.1.3. Fuel Examples



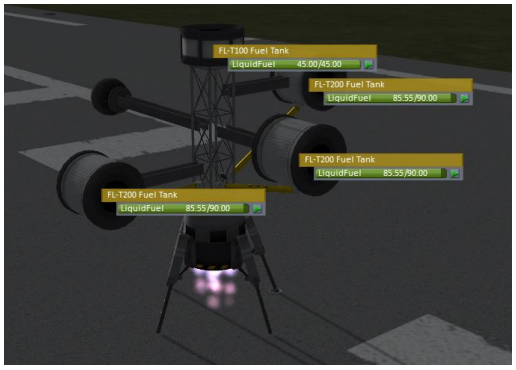
Here you see my supersophisticated fuel test apparatus. In the lower left corner you can see that despite the full tanks the engine has no access to fuel. Thats because the I-Beams to which the tanks are mounted are not cross feed capable and 2 of the tanks are side mounted too.



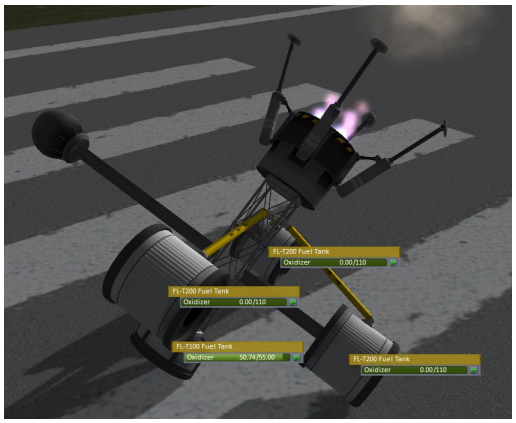
I added a small tank to the engines stack. Since this is in the engines stack and girder segments are cross feed capable you can see in the lower left corner now that the engine has access to fuel.



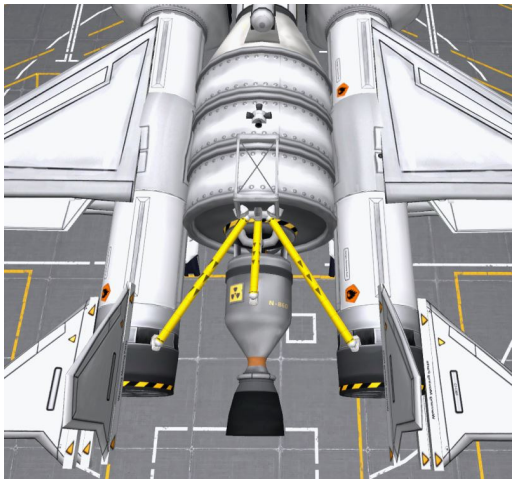
Now fuel lines are added from the side tanks to the engine. The engine now draws from the fuel lines first and simultaneously, the small tank further up the stack is still full.



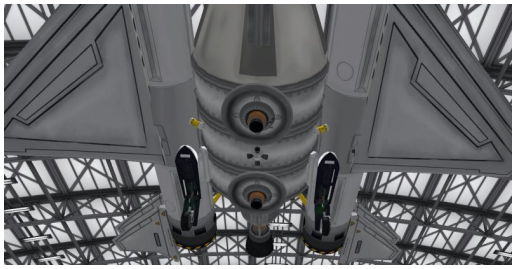
Now the fuel lines are connected to the girder segment. Still fuel is taken following the fuel lines first before it's taken from the little tank on top of the engines stack.



When there is no more fuel left in the tanks connected via fuel lines, then the fuel draw algorithm searches further up the engines stack and finds the small tank from which it now draws fuel. The extremely sophisticated apparatus recognized an orientation change opportunity as the tanks emptied and quickly decided to make use of it.



This is Columbus, a 2-engine long range research craft (mainly for Minmus). It's design is a bit old school but a great example for the use of fuel lines. The reason why I used 3 tanks in the center is as outlined above that a craft's CoM is in the center of the tank setup. To make sure that fuel is flown out balanced, I needed to connect all engines to the center tank. To do so i had to connect a girder segment to the center tank which is crossfeed capable for geometric reasons and then ran fuel lines from there to all engines. That way all engines draw first via the lines from center tank and center tank draws first from the side tanks connected to it. Side tanks draw first from front and rear side tank. When all side tanks are empty then front and rear main tanks are drawn. Last main center tank is emptied. This ensures balanced fuel load during the whole flight time.



This image shows the fuel lines at the bottom going from side tanks to center tank. These lines are connected to the middle side tank which then draws first from it's front and rear side tank.

Didn't add any lines for the 2 little VTOL engines used for landing and takeoff at Mun or Minmus since they draw balanced from front and rear main tanks, good enough.

3.1.4. Lock / Unlock Tanks



Fuel tanks can be locked and unlocked in SPH / VAB as well as when craft is launched. Just right click the tank and click on the small button right of the tanks contents display.

3.1.5. Set Fuel Levels



As was already shown before, fuel levels can be set for any tank already in SPH and VAB which comes in handy when designing space planes with just 1 or 2 tanks. Saves a lot of weight which is better used for payload. Just right click the tank and click on the green fuel level bars. Sadly the fuel level can only be set in 10% increments which is way too rough especially when it comes to large tanks where 10% = 8t.

3.1.6. Disable Crossfeed on Docking Ports

You can disable crossfeed on docking ports. Comes in handy when flying a lander docked to a rocket to the Mun. Then at the Mun you see that the landers fuel is empty because the rocket sucked all fuel out of it's tanks. To prevent this to happen, you can right click on docking ports and disable crossfeed. Yet this can only be done when craft is launched and must be done everytime the craft is activated (going to craft via tracking station, tabbing to etc.). It would be great if the current state would be saved and could be preset in SPH and VAB though because that's something you always forget to redo.

3.1.7. Fuel Transfer between Tanks



It is possible to transfer fuel between any 2 tanks anywhere on an assembly (as in multiple crafts docked to a space station for example).
Just ALT-rightclick on source and target tank and use the In and Out buttons to transfer LF and LOX.
That works also for monopropellant or any other tank (Xenon).

3.1.8. Monopropellant



Monopropellant is used for rcs thrusters and available craft wide. rcs thrusters draw from every monopropellant tank of a craft at the same time no matter how many decouplers, docking ports and non cross feed parts are between the thruster and the tank.
In the image to the left there is just about anything that would prevent fuel from being transferred (from bottom to top: decoupler, no crossfeed structural panel, docking ports set to no crossfeed) but rcs is transferred no matter what.

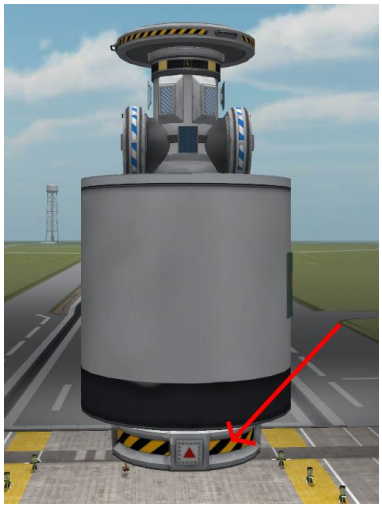
3.1.9. Xenon

Xenon for PB-ION engines is like monopropellant found and taken from everywhere on the assembly, no matter whats inbetween the engine and the tanks.

3.2. Working with Subassemblies

Subassemblies allow to save assemblies (=slapped together stuff from parts) for reuse in many other assemblies.
Subassemblies need a root part (like full assemblies) and they can only attach to other craft via one connector on this root part. Need to keep this in mind when planning a subassembly.
Another advantage of subassemblies can be, that all subassemblies can be loaded in SPH and VAB regardless where they have been created. Normal assemblies can only be loaded in the building in which they were built.

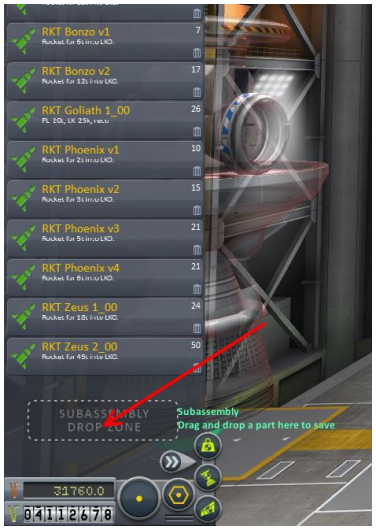
3.2.1. How to: Create a Subassembly



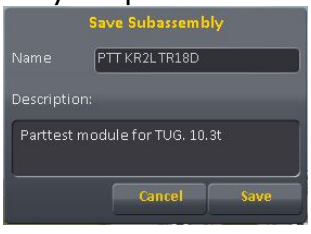
I typically create all payloads (landers, satellites, lifters, stations and station modules, base modules, space train modules etc.) as subassemblies. So i can use them often on multiple types of crafts and rockets as needed. Since payloads usually are attached above a decoupler, I use a decoupler as starting part (arrow) and construct the payload bottom up on this adapter. The example in this image is a mission cargo featuring a KR2L engine (here in it's fairings due to the decoupler at the bottom) and test decouplers for two career mode missions.



Once created you can save the subassembly by pulling up the subassembly panel on the left side of SPH or VAB window by clicking on the subassembly button.

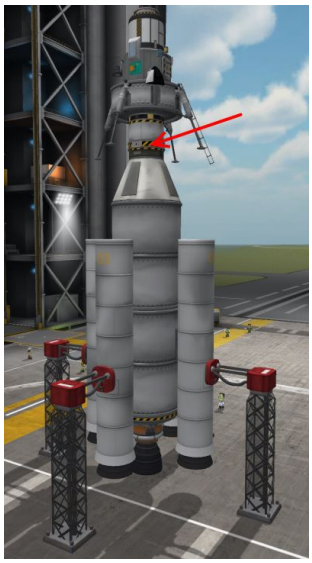


Then you drag and drop the subassembly (without decoupler) on the drop area for subassemblies and enter information such as name and information and click save. Sadly only part count is display automatically but no weight, would be very helpful.



As you can see, each subassembly is then created as button on this side panel. Clicking on a subassembly button loads the subassembly and you can attach it to your current assembly also using symmetry and stuff.
To resave an existing subassembly you can simply drag the updated model onto it's button which will bring up the save dialog again preset with the name and information you provided on last save.

Unlike payloads I design rockets top down below an initial decoupler for more or less obvious reasons.



Then when I need a rocket and a payload I can usually start with a decoupler (red arrow), then select a proper rocket for the payload's weight from subassemblies and attach it below the decoupler and get me the payload and attach it above. Voilà you have a finished rocket which will most likely work well if the subassemblies have been tested before. Minimizing risks which is a good thing in career mode.

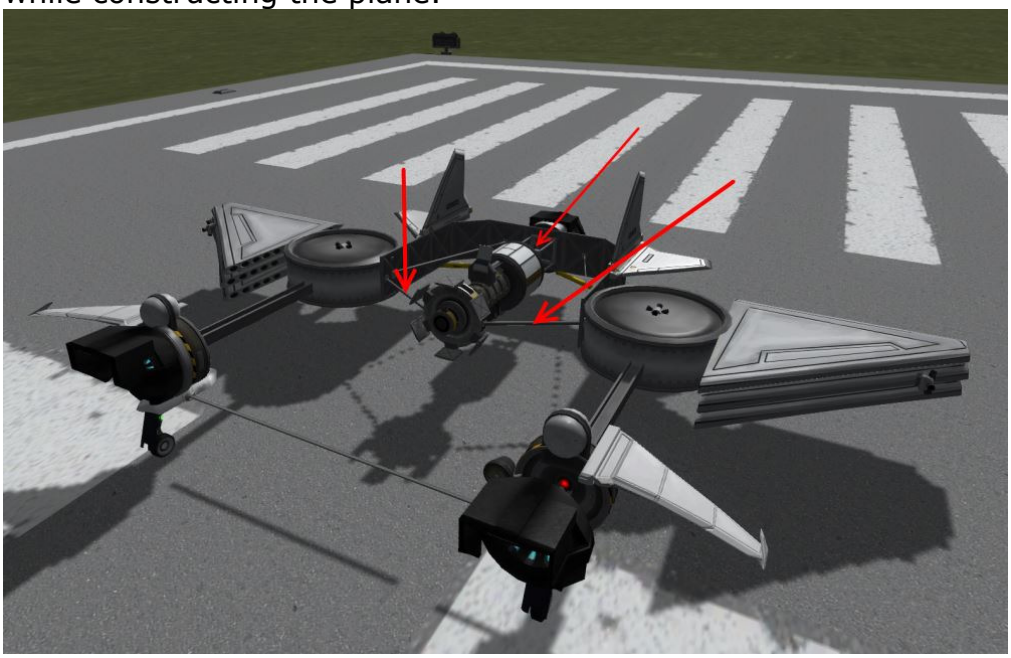


Then I also save combos from launchers and payloads as normal assemblies since they are often a little altered as in adding some struts to keep the payload stable plus if the same total assembly is needed again it can simply be loaded again. Save name for the combo is usually simply rocket name + payload name (and versions).

Unlike rockets I don't save space planes as subassemblies simply because there is no necessity for it.

3.2.2. How to: Attach a Subassembly to a Space Plane

Attaching rockets and payloads usually is simple since CoM alignment for rockets only needs CoM to be somewhere on the vertical axis of the rocket, more or less.
As opposed to that, attaching a payload to a space plane transporter needs a lot more accuracy. The same rules for alignment of CoM, CoL and CoT apply that were already used while constructing the plane.



Ideally CoM simply doesn't move when the payload is attached, provided CoM was already correctly aligned before attaching the payload. So drag the payload assembly to and away from it's connecting point to see how CoM would move. Add in fluff structural stuff (girder segment in the example) until the alignment is correct. Finally add some struts (red arrows) to fix the payload within the cargo bay. Usually a transporter with payload attached is less wobbly than one without.

Like with rockets I usually also save combos of space planes and payloads in case I need to reuse them.



What you get when you work too sloppy adding payload is this: an outside landing far away from KSC. This is the best case, though ...

4. Space Plane Operations

This part covers all kinds of operations with space planes. Most of the descriptions such as orbital manoeuvres also apply to any other craft.

4.1. Kerbonaut in Under 5 Minutes

4.1.1. Basics of Space Flight

If you thought that getting a Kerbonaut takes many years and stuff and all, then you are wrong. It takes around 5 minutes, but only if you are a slow reader. All you need to know and adhere to are a few facts combined with a small dose of logic thinking:

- Always raise or lower orbital altitude at either AP or PE unless you have really good reasons otherwise (such as a de-orbit burn). This is the most fuel efficient way to do it.
- Always change inclination of your orbit (for example to match it with another crafts or moons orbit) at AN or DN marker. It's not really perfectly possible at any other point. If you need to meet another object, always get inclination to 0.0 if possible.
- Objects on higher orbits are slower (especially angle velocity) than objects on lower orbits which are faster. If you want to meet with a space station and the station is ahead of you, you want to stay on a lower orbit (=faster) until you catch up and vice versa.
- To raise altitude of orbit, do a pro-grade (forward) burn at either AP or PE nodes to raise the opposite node.
- To lower altitude of orbit, do a retro-grade (backward) burn at either AP or PE nodes to lower the opposite node.
- Always go to toilet **before** take off. Rumours say that in humanverse they even pee on tires at times prior to launch.
- Now watch youtube videos and be amused about how few Kerbonauts actually know these basic rules of orbital manoeuvres.

Well that's it actually, or did you expect more?

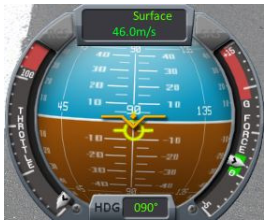
4.1.2. Best Orbit

Sometimes the question arises 'What's the best orbit'. Usually meant by this is the best orbit for space stations around Kerbin to make rendezvous and docking fairly easy. Sometimes also refers to orbits around other bodies.
The simple answer, although also a bit a matter of taste and mambo jambo and experts and such, is roughly an orbit around 30km - 50km above a celestial bodies atmosphere (if present) or ground (if no atmosphere). For Kerbin an average parking orbit for a space station therefore would be around 110km.
The reason for this altitude above atmosphere or ground is simply that a craft on a lower orbit can catch up with a craft on a higher orbit. So the station should be high enough so that catching up is somewhat fast doable. For the Mun or other atmosphere less bodies this would be 40km above ground. For Duna it would be around 80km. Just look at the bodies description when selected in map view to see it's atmosphere height and add 40km to it.

Another aspect especially with orbits around Kerbin is the inclination of the orbit. The gods of Kerbalverse made it so that Mun by total coincidence orbits precisely on a 90° inclined (with respect to Kerbins rotation axis) plane around Kerbin making it a tremendously good reference for any kind of 'standard' orbit. Usually when launching something most people do a gravity turn East (towards 90° on compass) automatically anyway. So turning this way will already get you in an orbit nearly synchronous with the Mun's orbit depending on how precise you actually hold 90° heading. Usually the deviation between your orbit and the Mun's is then <= 0.5°. But it's a best practice when installing a space station or "space train" to get it's orbital inclination with the Mun's orbit to 0.0 (or NaN). To do so all you have to do is target the Mun and do a burn at either AN or DN node up or down until AN / DN are down to 0.0 inclination, of course using a node for that.

(I bet NaN is caused by an underflow in this case).

4.1.3. The Navball

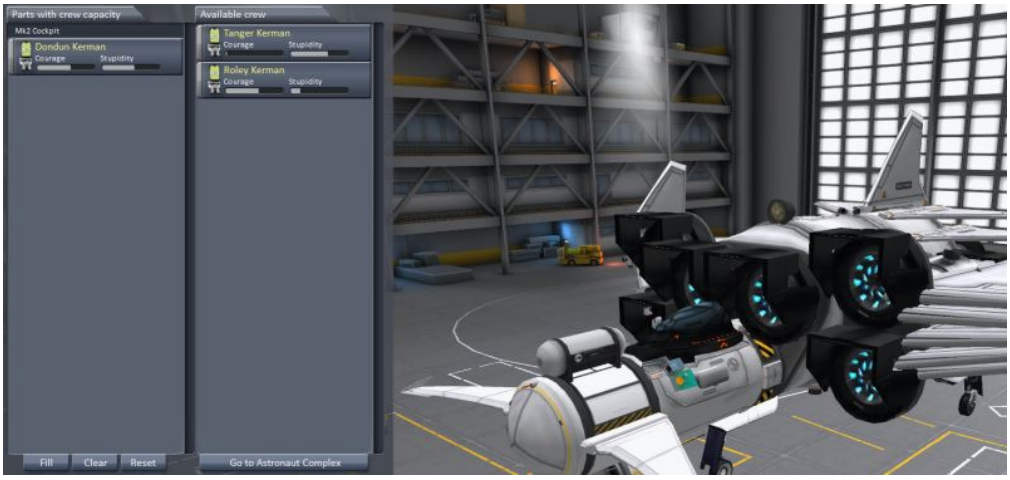


This is the navball, your best friend. The orange 'winged' symbol with the dot in the center always shows where your nose points. It always stays in the center.
The yellow circle with the short arms left and right is your pro-grade marker. It shows the direction into which you need to point your nose to have it precisely on your current trajectory.
The white horizontal lines with the fancy numbers at their side show your angle between your nose and the horizon. This is what I refer to as climb angle in some of the descriptions. Here you see a climb angle just a little above 0°.
Above the navball you see your current speed with respect to either: surface, orbit or target! Usually the navball switches automatically between those 3 if needed, but you can also click on the speed display area to switch the reference manually. This is important to know, yet a lot new players don't know it.

4.2. Pre Launch: Who's Gonna Fly?



The third button in this row lets us determine who's going to sit where in the craft or if anyone is in there at all.



This brings up the crew selection windows that lets you populate your cockpits. You can move Kerbals between the cockpits and your available crew. In case you don't have enough crew you can use the button 'Go to Astronaut Complex' to get more crew. Our example has no cockpit but just to show it off I use a long range research space plane here.

Sadly the crew-state doesn't get saved, so you better check this every time you launch something. The reason is that every loss of a Kerbal in career mode costs 20 reputation and believe me that hurts if you want to get it to 1000.

4.3. First Test / First Test after Modifications

Now comes the thrilling moment to test your craft for the first time. I have kind of a fixed test program for testing my space planes.
Also since the gods of KSP find it funny to deprive the craft creator of practically all important statistical values (such as part count, weight, drag, LF, LOX, mono, electricity etc.) in SPH/VAB, this is the first time we actually see the crafts stats. Most important to me is total weight and part count.



So lets see what we have: Our mini space transporter uses 113 parts and has an empty TOW of 27.39t. That's actually pretty good, it leaves us with 39t - 27.39t = 11.61t of payload capacity! Lets say 11t to be safe. Ratio is 28% payload and 72% ship. Typical ratio for rockets is around 10% payload and 90% ship. Plus unlike multistage rockets we are fully recoverable.
Part count is pretty low for a 3-engine space plane too. I wish at least part count and weight would be visible in SPH/VAB!

I'll continue this part as checklists that you can print out and use for your own developments.

Nevertheless I want to show off the first launch. Of course it had to be night ...



4.3.1. Checklist: First Test on Runway

#	Check	Test	Expected Result
1.		Switch off thrust and click on break button at top center of screen to engage parking breaks. Hit toggle RAPIER engines key (1). Hit (4) to toggle engine mode from air breathing to close cycle and again to switch back. Hit shutdown RAPIER key (0)	Do all engines toggle on/off, switch and shutdown or did you again forget to restore action groups after re-attaching mirrored engines?
2.		Hit U key to test light setup	Light setup working correct?
3.		Test rudders / front wheels by hitting A and D keys	Do only control surfaces move that are designated rudders? Do front wheels steer or did you forget to set that again?
4.		Test pitch elevators by hitting W and S keys	Do only designated pitch elevators move?
5.		Test ailerons by hitting Q and E keys	Do only designated ailerons move?
6.		Right click fuel tanks and check whether the correct amounts of LF and LOX are loaded.	You should have the correct amounts of LF and LOX. You should have more LF than LOX since engines will run much longer in air breathing than in closed cycle (rocket) mode.
7.		Taxi test. Release parking breaks (click on break button again), toggle thrust on if it's off and careful apply little thrust (left-SHIFT, left-CTRL keys). Don't drive faster than 15-20m/s. Then carefully steer left and right.	Do especially the front gears understeer or oversteer or twist in unwanted ways making it hard to drive a straight line. Often well balanced planes don't die flying but they die taxiing on the runway! Take a look at the space tapes that secure the front gears in our example.

8.		Break test. Do an emergency breaking. Hit and hold B key until the craft stands still.	Does the aircraft move straight on or does it start to break out. If so you need more space tape or to disable breaking on front gears. Extremely important!
9.		Fuel consumption test. Engage parking breaks. Set little thrust. Toggle engines on. If craft has multiple engine sets (such as normal, VTOL, Nukes) then do this step for all engine sets.	Each engine set must fly out fuel balanced from tanks. If not then you either need fuel lines or fuel lines (symmetric) are 'broken' and need to be redone.

4.3.2. Checklist: Test Flight Near KSC

#	Check	Test	Expected Result
1.		Launch craft, toggle on engines in air breathing mode.	
2.		Turn on thrust to full and accelerate. Pull elevators to lift it's nose. Nose should raise somewhere between 50 and 70 m/s at the latest. Don't use SAS!	Aircraft should accelerate in a straight line or best case with tiny but controllable deviations. If does uncontrollable things you need more space tape. If it doesn't lift nose in the range of 50-70 either rear gears are too far behind CoM, or you don't have enough elevators or wings or your nose is lower than the rear or all of the above.
3.		Take off and climb a little. No SAS. Release the elevator buttons and let the craft just fly.	If correct balanced the craft should slowly lower it's nose below horizontal flight.
4.		Climb again. No SAS. Then turn off engines.	If correct balanced the craft should slowly lower it's nose below horizontal flight. The speed at which the craft lowers it's nose without thrust should be same as with thrust. If full thrust moves the crafts nose up instead, then the CoT is way too much below CoM. If the crafts nose moves down faster then without thrust then CoT is above CoM. Both situations are very bad in thin air.
5.		Turn on engines again at full thrust, climb slowly and engage SAS. Switch RAPIER engines to closed cycle mode.	The crafts attitude (pitch, yaw) shouldn't change a bit. Do tests 3. and 4. again with rocket engines. They are much stronger so effects of missaligned CoT and CoM are much stronger.
6.		Fly out all fuel in tanks. You should	The space planes behaviour with empty tanks should be

		have loaded more LF than LOX though. If so, just fly and wait until LOX is all gone. This will usually be after like 2 minutes. Then switch back to air breathing mode and repeat tests 3. and 4. again.	same as with full tanks. If that's not the same or if it starts to behave uncontrollably (spinning etc.) then emptying the fuel tanks moves CoM out of proper alignment with CoT and/or CoL. Rebalance the craft as outlined with testing the alignments with full/empty tanks. If the behaviour stays the same you can be sure that your craft will be easy controllable after return from space.
7.		Return to KSC and land. Landing should easily be possible without SAS. Lower thrust to a minimum at approach and turn off on landing. Sink rate should be around 5m/s or lower. Touchdown speed usually is around or below 50m/s. Recover craft.	You should recover craft in one piece and get most of your money back.

4.4. Space Plane Flight into Orbit

4.4.1. How To: Space Plane Flight into Orbit

The principle of flying a space plane into orbit is that you gain as much altitude and speed using the atmosphere's oxygen as fuel and lift produced by the wings.
So always keep in mind, your top priority is gain as much speed as possible while engines are in air breathing mode. Altitude is only your 2nd priority.
Atmosphere density plays a major role in this game. As atmosphere gets thinner you need to build more and more speed to get enough intake air for the engines as well as enough lift off of the wings. This is why we also have the 2.5t per delta wing rule.
Atmosphere density on Kerbin decreases to 1/2 every 5000m, that is at 0m density = 1, at 5000m density = 0.5, at 10000m density = 0.25 and so on.



So lets take off an gain some height. On the image you can see that Dove climbs really well at low altitudes.

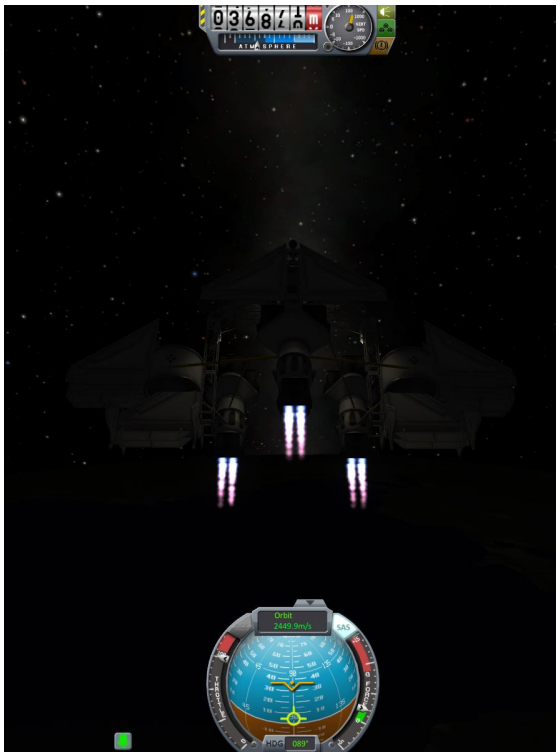
While being lower than 15000m density will always be ok for intakes (using my engines anyway) but then it gets more and more important to gain speed quickly and keep speed maxed out for the altitude given. You can see whether it's close to max by how fast speed increases. If it's slow increasing then you are close to max, if not you need to fly with a flatter angle to keep it maxed.

The following table shows the Dove's climb profile up to the altitude where engines switch to rocket mode. Dove had no payload on board, so TOW was 27t.

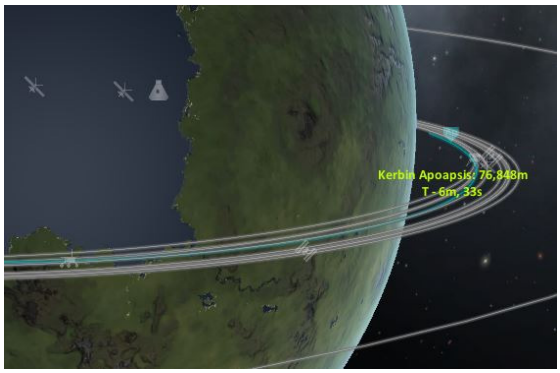
Altitude m	Set Climb Angle on Navball to ° at Altitude	Speed at Altitude m/s	Climb Rate m/s
0	70-80	0-180	~nearly airspeed
10000	50-60 (normal 40)	180-200	~50-100
15000	40	300	Insane
20000	25	560	Insane
25000	15	1170	Insane
27500	12	1565	~10-20
30000	10	1730	~10
32000	10	1866	10
33000	10	1919	10
34000	8	1965	>10
35000	8	2019	>10
35300	8	2054 Engine switched!	>10

The following table shows the Dove's climb profile with a TOW of 37t. This is closer to an average climb profile. You can see it's a lot slower but still pretty good for a transport.

Altitude m	Set Climb Angle on Navball to ° at Altitude	Speed at Altitude m/s	Climb Rate m/s
0	40-50	0-158	~50-70
10000	30	158	~50-70
15000	25	328	~50
20000	20	635	~40
25000	15	1120	~40
27500	<=15	1450	~10-20
30000	<=15	1600	~10-20
33000	<=15	1794	~10-20
34800	<=15	1870 Engine switched!	>=10



Once the engines switch to closed cycle (rocket) mode, pull up to 40° climb angle to make the plane climb fast. Now that you burn lots of fuel and oxygen from your tanks you want to get out of the atmosphere quickly.



Switch to map view and watch your AP until it's around 80km. Switch off thrust. Lower nose back down to get it a tad above your pro-grade marker (yellow circle) on the navball to produce as low drag as possible. If AP sinks below 70km (max height of atmosphere) give a little thrust to make it climb above 70km again. AP will degrade as you move up through the atmosphere.



Once a stable AP above 70km is achieved, switch to map view and add a manoeuver node right at your AP to get PE above 70km as well. That should be a burn around dv = 200m/s for normal space planes. For the empty Dove it is more like 100m/s since it got to insane speeds even before engines switched.

NOTE: you can click on the AP and PE markers and when you get lucky and ate your desert last dinner it will show it's information even without hovering the mouse over it. This is why you can see both their information at the same time in the above image.

4.4.2. Checklist: Space Plane Flight into Orbit

Normal flight into orbit. All the steps require you to exactly keep 90° angle on the navball (unless you want into a non-standard orbit) and exactly keep your wings straight (try not to roll) for maximum lift, especially in thin air.

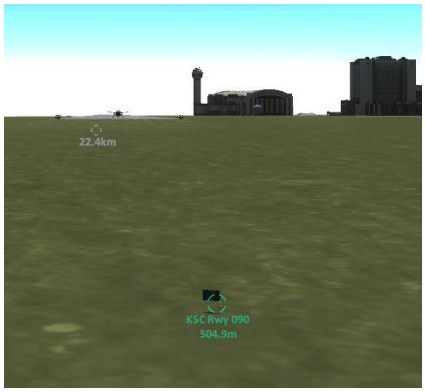
#	Check	Test	Expected Result
1.		Launch craft	
2.		Check crew	Enough crew? No crew needed?
3.		Check fuel	Enough LF? Enough LOX? Enough mono?
4.		Switch to map view (M), pull up navball to unlock controls and turn Kerbin so that you have a clear view on your soon to come trajectory.	Have map view prepared for use in flight.
5.		Check navball in normal view whether it actually shows horizon below sky and nose points to 90° (East). If not use 'Control from Here' on any suitable probe core, command pod or docking port.	Sometimes when a craft has multiple command pods or rcu's the one from which the craft is controlled is selected automatically by a not so overly bright algorithm.
6.		Toggle engines on.	Did all engines toggle on or do we have that action group bug again? NOTE: don't test the switch engine mode group action because this will shut off automatic switching between air breathing and closed cycle and this can't be re-enabled.
7.		Apply full thrust. Take off. Engange SAS. Pull nose up until you have a 40° climb angle or better on navball. Climb like this until you get to 15000m.	
8.		15000m: climb angle 30°	Build up speed.
9.		20000m: climb angle 20°	

10.		25000m: climb angle 15°	
11.		27500m: climb angle 12°	Vertical speed ~10-20m/s
12.		30000m: climb angle 10° or even below that	Vertical speed ~10-20m/s
13.		A multi engine plane might start to break out left or right closing in on switch speed. Try to keep the plane straight on course as long as possible.	
14.		The RAPIER engines switched to closed cycle (rocket) mode. Pull nose up to 35° - 40° on navball immediately. Switch to map view (M) and observe AP marker on your orbit. Once AP marker reaches an altitude of around 75-80km switch off thrust.	You level up nose simply because you want to get out of atmosphere now quickly.
15.		After switching off thrust move nose back down so that nose marker is only a tad above pro-grade marker. If AP (Apoapsis) falls below 70km, then just add a little thrust to move it back up. Shouldn't happen too much.	The main purpose is that this way you have the least resistance in the remaining thin air.
16.		Once AP marker stays up above 70km. Set a manoeuver node right at AP and move PE (Periapsis) up to slightly above 70km too. dV needed should be in the vicinity of 200m/s.	Circularize orbit at above 70km (Kerbins atmosphere goes to 70km max, above that your orbit won't degrade).
17.		You are in orbit.	

4.5. De-Orbit Back to KSC

4.5.1. Set Up Flag at KSC Runway as Marker

Set up a flag a bit before the runway at KSC. It makes it easy to recognize the position of KSC, especially at night when you can't see KSC even in map mode. And it's of course a good reference for planning de-orbit burn nodes.



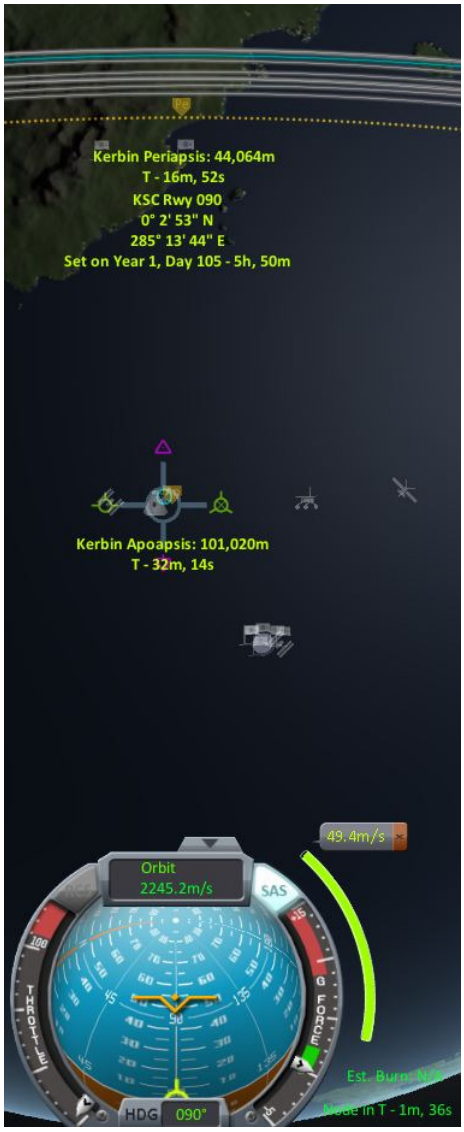
As you can see, I have placed mine roughly 450m away from start of runway. Too close it might get victim of unwanted accidents or get salvaged when the cleaning kerbals come at night cleaning the runway of debris from last launch.

Now you are prepared to do some really cool landings at KSC which will maximize refunds when recovering your space craft. The farther away from KSC the less you get refunded in career mode.

4.5.2. Kerbin Rotation and Lead Angles for De-Orbit Nodes

Of course Kerbin rotates and with Kerbin also KSC rotates away from your planned de-orbit nodes. So you always need to calculate some lead angle in your nodes position depending on how far away your craft is from a manoeuver node. Yet the wise gods of Kerbalverse have made it kind of easy to calculate necessary lead angles. Kerbin rotates once every 6 hours around it's axis. 6 hours = 360 minutes. And oh coincidence, a full circle also has 360 degrees! That means for each minute your craft is away from hitting your manoeuver node you need to plan a lead angle of 1°.

4.5.3. How To: Slow De-Orbit to KSC

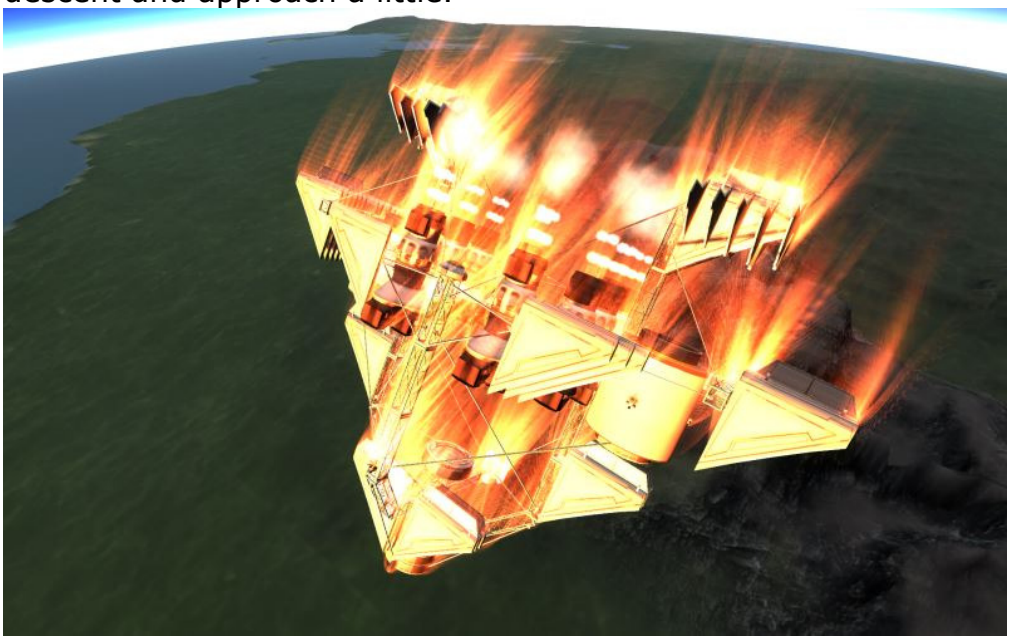


Advantage of slow de-orbit is that the de-orbit burn only takes little fuel which is good for nearly dry space transporters that launched a max TOW. Usually in the vicinity of 30-70 dV. That depends on your orbit from which you de-orbit.
Disadvantage is that it's a flat and long winded de-orbit.
To plan a slow de-orbit, add a manoeuver node on the opposite side of Kerbin of KSC. In the image you see the node but it's on the other side of Kerbin.
Plan a retro-grade burn, that will bring your orbits PE down to precisely 44000m right above the flag that we discussed in the previous chapter.
If your orbit is higher than 100km then you might want to set a lower PE, if your orbit is lower then you might want to set a higher PE. It's a matter of experience.
If you are more than one or two minutes away from the node plan a lead angle with 1° per minute. PE would have to be further on the right side on this image if I needed a lead angle.
The table at the end of this chapter shows a few starting orbital heights along with the altitude to which to set PE to above KSC.
You will actually not end up 44km above Kerbin when you are above the flag because drag from atmosphere will have you decelerated and lowered down already as well as KSC rotating away during your descend so that the outcome is actually a lot lower.



After planning and executing a descent like this there is often no more need to apply thrust. You can basically use this method with unpowered capsules too.

But if you are impatient or need a potty break and have some fuel and nerves left you can speed up descent and approach a little.

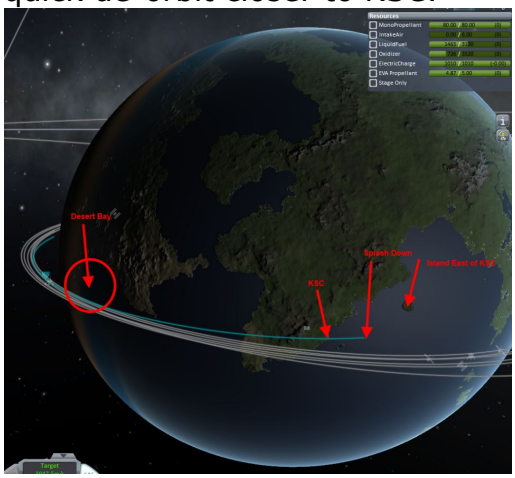


The following table lists some altitudes to set PE to when using this method from different starting orbital heights.

Starting Orbital Height	Plan PE above KSC for De-Orbit
72,000m	45,500m
100,000m	44,000m

4.5.4. How To: Faster De-Orbit to KSC

If you have some more fuel left to spend you can do any type of quick de-orbit closer to KSC.



The de-orbit burn starts usually in the area of the circle on the left side of the image above the desert bay area and costs around ~250dV. Burn until the trajectory shows a splashdown in the middle between KSC and the big island East of KSC. Of course due to drag and rotation while descend you will end up gliding right onto runway at KSC (or pretty close there).

4.5.5. Checklist: De-Orbit and Return to KSC

Space planes have one big advantage over rockets: they can fly horizontally with only little fuel in an atmosphere. This permits us to always precisely land at KSC unlike rockets and we get the most refunds possible.

#	Check	Test	Expected Result
1.		Create a manoeuver node for the de-orbit burn as outlined in previous chapters.	A node
2.		Reaching the node, make sure KSC didn't rotate too far away. Move node a bit if necessary.	If you plan the node long ahead before reaching it (as in a couple of minutes), Kerbin and therefore KSC tends to rotate away until you reach the node.
3.		Do the de-orbit burn.	Make sure the new trajectory matches what you have planned in map mode.
4.		Turn craft around to pro-grade. Switch engine mode to air breathing for all RAPIER engines. Make sure SAS is engaged.	
5.		You can accelerate time if you are above 70km. Time acceleration will automatically stop once you get below 70km.	Quick descend to 70km.
6.		Check SAS engaged. Keep nose slightly above pro-grade marker on navball.	Aero break with SAS engaged just to avoid surprises.
7.		Around 10-15km altitude navigate to KSC and Land. Engage / disengage SAS and thrust as needed.	
8.		Disengage SAS and thrust before touchdown.	

		Touchdown speed with a nearly dry space plane is around 40m/s or below. (NOTE: Landing in rough terrain keep SAS engaged, this will diminish effects of bumps).	
9.		Don't forget to take notes on fuel used if you want to create statistics specific to that plane / payload BEFORE using the recover button.	I always forget this

4.6. Rendezvous and Docking

Since there are no female Kerbals they need to rendezvous with stuff in orbit. Like any other rendezvous this isn't a trivial task.

4.6.1. How To: Pre-Launch Preparations for Rendezvous

Rendezvous targets are basically best in a 100-110km orbit for the simple reason, that it's easy to catch up with them on a 30-40km lower orbit. So lets assume that we want to meet with a space station at 110km.

The most efficient way to meet with a target is, when as soon as we reach an altitude of 70km, the target is 100-120km ahead of us on it's orbit. From chapter 4.1.1. Basics of Space Flight we know that a target at a higher orbit moves slower, so if our space station is at 110km then we can easily catch up being at 70km.

If the distance is bigger than 100-120km or if the target is behind or less than 100km ahead of us we need to either catch up some or fall behind. The worst case is if the target is behind us. In this case we need to reach an orbit higher than the targets orbit, fall back to let target catch up and then descend to the targets orbit. All that is pretty fuel inefficient as compared to being just a little (100-120km) behind it on our ascend path.

So before launching for meeting with a target in orbit, we simply wait until the target is close enough behind us in orbit so that when we hit space target is in an (almost) perfect position.



If you just launch without waiting for the perfect 'launch window' then Murphy Kerman's laws hit you merciless and you always end up with something like this: SPN Shuttle 2_00 was launched to meet the currently in orbit assembled Duna station but ended up being perfectly on the other side of Kerbin. It will take a couple orbits to catch up with it.

Of course the most important thing to know is, how long does it take to get into orbit? Because that determines our lead angle that we need to have at launch. A typical space plane launch with a space plane close to max TOW takes around 20 minutes. Space planes significantly under max TOW can get there in 5 minutes or even quicker, such as small drones.

What we need to know therefore are two facts: Orbital durations at certain orbital heights and time it takes to get our plane into orbit.

Orbital Altitude	Duration of one Orbit
71000m	30:30
110000m	33:00

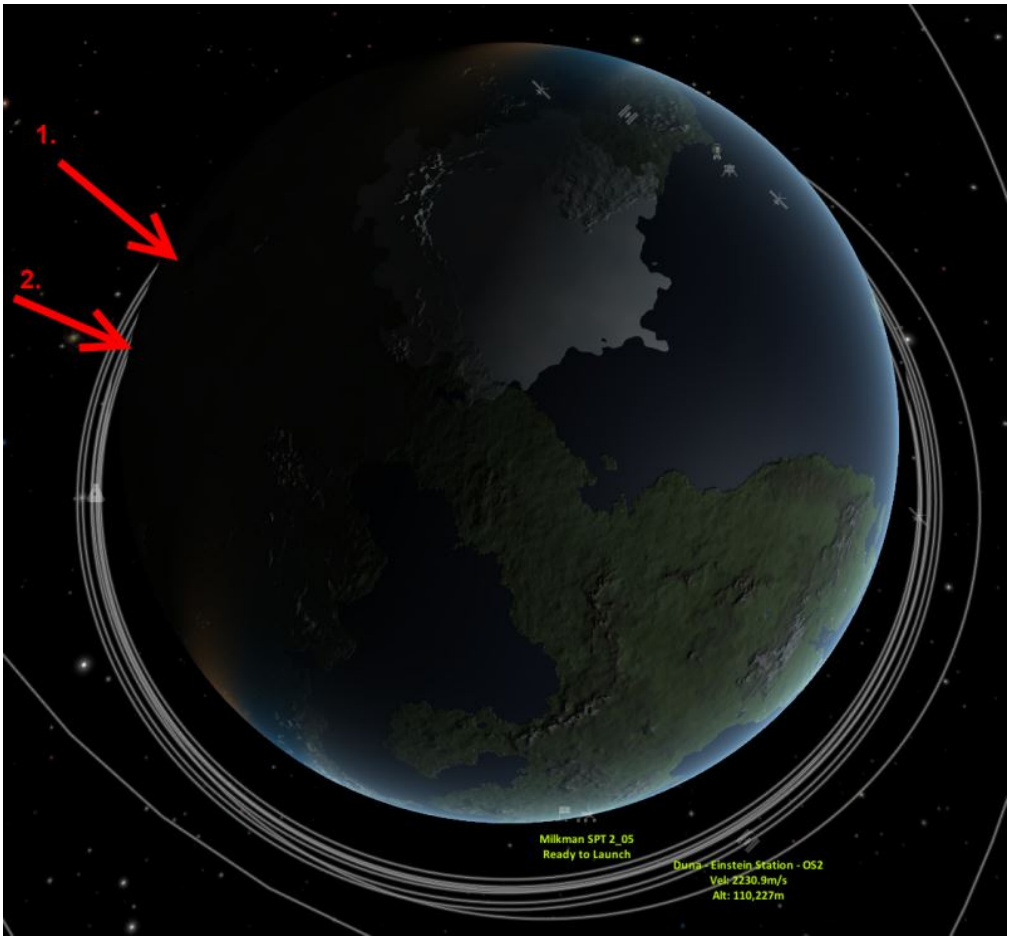
The table shows that there isn't too much difference in orbital durations.

The next table shows examples of space planes times to 70km where the time is measured from take off to hitting 70km first time. Not necessarily the final orbital insert burn because that might very well include already an ascend burn for rendezvous if we planned perfectly. Also be aware that times to 70km can differ depending on how good your ascend path is or whether you mess up in between.

Plane	TOW	Max TOW	Time to 70km
Ouzel (6 engines)	47t	78t	15:00
Ouzel / Payload (6 engines)	68t	78t	21:00
Milkman (8 engines)	101t	104t	23:00-25:00
Paperman 1_00 / Payload (overweight, 10 engines)	140t	130t	29:00
Paperman 2_00 (11 engines)	94t	143t	12:00
Paperman 2_00 / Payload (11 engines)	143t	143t	25:00

As we fly up to orbit we already move in the targets direction. To make this effect easy, we simply say that the lead angle is 1/2 of our time to orbit, not the full time.

We always want, that the target is at least 100km ahead of us! So we also plan in some safety. It doesn't actually matter too much if it's 200km or even 400km ahead of us. Those are distances that can be cought up easily.



Summing that up lets make an example: It takes Milkman 23:00 minutes to get to orbit. 1/2 of that is 11:30 Minutes which is roughly 1/3 orbit at 110km (full orbit = 33 minutes). So we know now our lead angle is 1/3 orbit of target - (minus!) a slice of 100km that target needs to be ahead of us minimum.

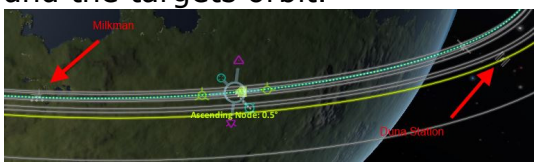
If in the image above we would take off right now, then we would end up with a situation pretty much like the one in the first image of this chapter, that is our station being right on the opposite side of Kerbin as we hit orbit with milkman.

Instead we accelerate time now until station reaches the position in orbit at which we need to launch. The position it should get to is where arrow 2. points to. Arrow 1. is the position of 1/3 orbit and arrow 2. is the 'minus 100km'.

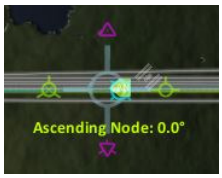
Note to Gods of KSP: a toggleable coordinate system on celestial bodies in map mode, aside of brightening shadows to be able to see surface features on a **map**, would clearly be the icing, wouldn't it?

4.6.2. How To: Rendezvous and Docking

Since chapter 4.4.1. How To: Space Plane Flight into Orbit covers already how to get into orbit, i'll skip this here. So lets assume we have already achieved a stable orbit around 70km above Kerbin's surface.
What we want now is to get close to our target so that we can dock.
Lets assume also we have done the launch right and are like 200km behind the target in orbit. To see how the situation currently looks like, we switch to map mode (M) and, click on the target and use the 'Select as Target' button. If we haven't done so already. This will highlight the targets orbit features and we can now see the targets AP, PE and the AN and DN nodes between our and the targets orbit.

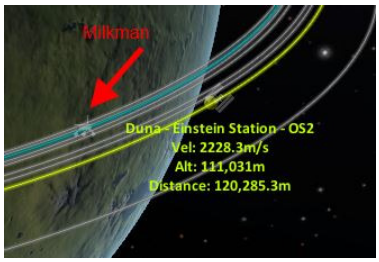


In this example we luckily have an AN (or DN) node between us and the target and notice that there is an inclination of about 0.5° which is a tad to big. So we plan a burn to correct it right at the AN or DN node. Just fiddle with the pink levers until AN/DN shows 0.0 (or NaN), then execute the burn when it's time.

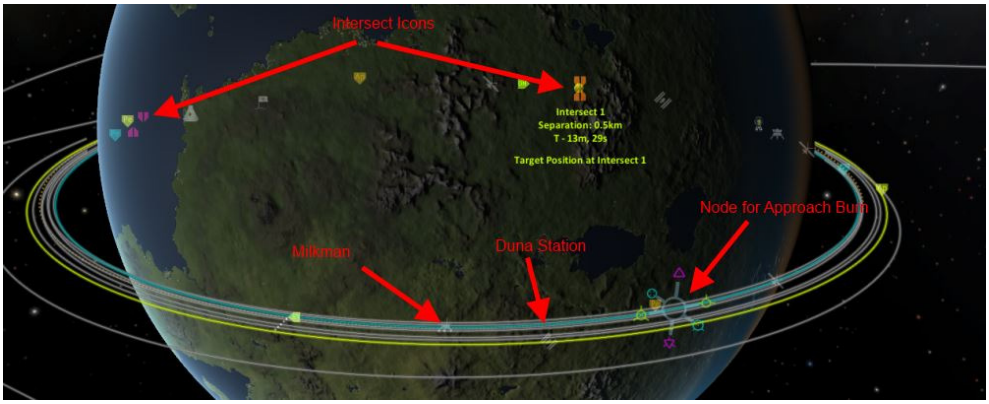


The Result should look like this. The execution of this burn must be as precise as possible.

All we need to do now is to wait, until the distance between us and the target is down to around 100-120km. Often a case for using time acceleration.



Now the distance for the approach burn is about right. I usually plan it when the distance is around 120km. This gives us still some time to make decisions, turn the craft, have a potty break and the like.



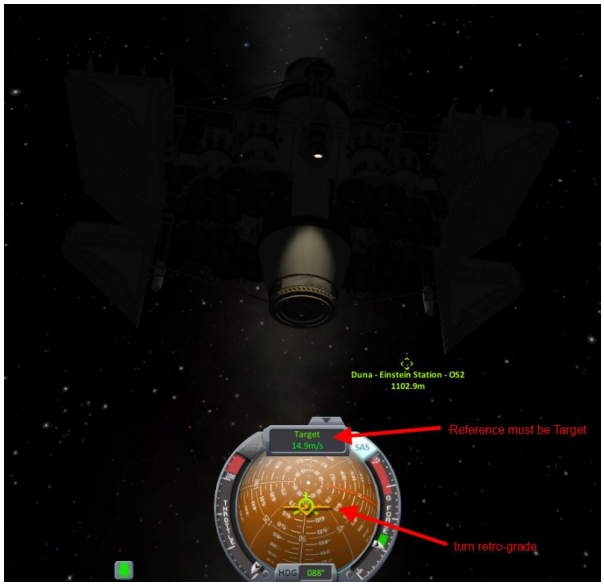
To plan the approach burn we do a pro-grade burn to get to the higher orbit of our target. The pro-grade burn lifts our orbit a bit above the targets orbit and we can see the icons for the coming two intersections. Usually we plan for the first intersection. Move the manoeuver node a bit forward and backward on the orbit until the separation shown on intersect 1 is minimized, often <= 0.5km, which is very well. You can even force two things together with a distance of 4km or more if necessary but usually it's better to work a tiny tad more precise.

Just in case you end up being ahead of your target when reaching orbit which is what you don't like, you have to do the approach by the following steps. First you go to an orbit 40-50km above your targets orbit to be slower so that target can catch up and do the inclination burn as usual if you hit an AN or DN node in between. Once your orbit is higher than the target you wait until target is within 200km! distance behind you. Then plan and execute a retro-grade burn to make your orbit intersect with the targets orbit for the approach and move node back and forth to find the closest separation as usual.

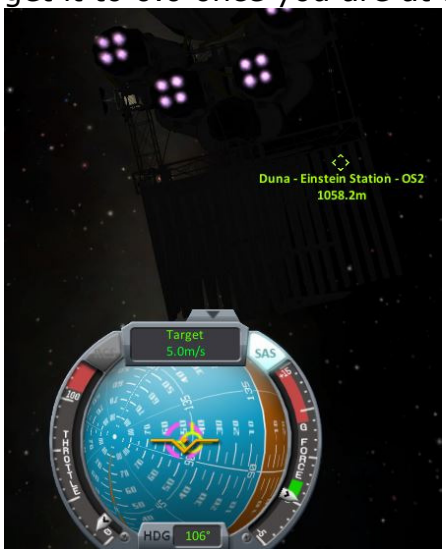


After the approach burn is executed there is nothing left to do for a while. As you can see at the intersection 1 icon in previous image, both objects will meet in 13 minutes after the burn. So time for some time compression. Go to normal view, point ship in direction of target and just watch target as it comes closer.
When it turns out that I'm too close to target once I reach orbit so that there is no more time to do an inclination burn before the approach burn is

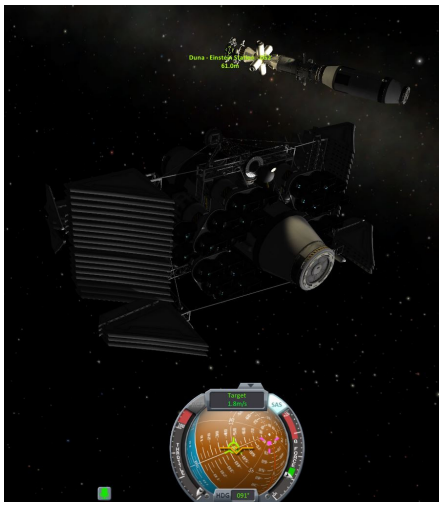
needed, I try to improve the result of the approach burn by using the pink levers to minimize separation which is good as well. Also do that when I'm lazy.



Now the final approach begins where we are seriously closing in on target. We will repeat the next steps as often as necessary to get really close to the target as in something like 50-100m away.
When the distance shrunk to something around 2.5-2.3km and the target gets actually loaded (you often notice that by the little stuttering at 2.3km), it gets time to turn retro-grade and break. Make sure the speed display is in 'Target' mode. If it's not then click on the speed display above navball until it shows 'Target' as reference. Usually it switches automatically to target mode as you close in on target. If this is the case, then all icons on navball are shown with respect to the target. The speed is our speed relative to the target. We want to get it to 0.0 when we are at the closest point to the target. Usually the speed difference on first approach is like 30-60m/s, pretty fast in close proximity. So do a retro-grade burn to get it to 0.0 once you are at the closest point of the approach.



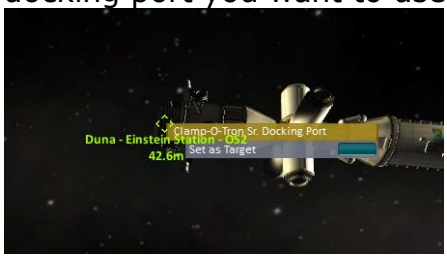
Then turn nose to target (pink round icon on navball) and accelerate again. My speed limit here is no more than 1/50 of the distance to target (for example 4m/s when at 200m distance). But really depends also on how clunky the space craft is.
Once near closest point turn retro-grade again, kill speed to 0.0. Then if necessary turn to target again, accelerate and so on until you are within 100m of the target to begin the final docking.



One of Murphy Kerman's laws holds in most cases true in this situation: You are always on the night-side when you try to dock to something! So make sure your craft and probably target too has some lights.

Here on the final approach waiting for the last retro-grade burn to break since the milk bottle is about to be attached on the far end of the station.

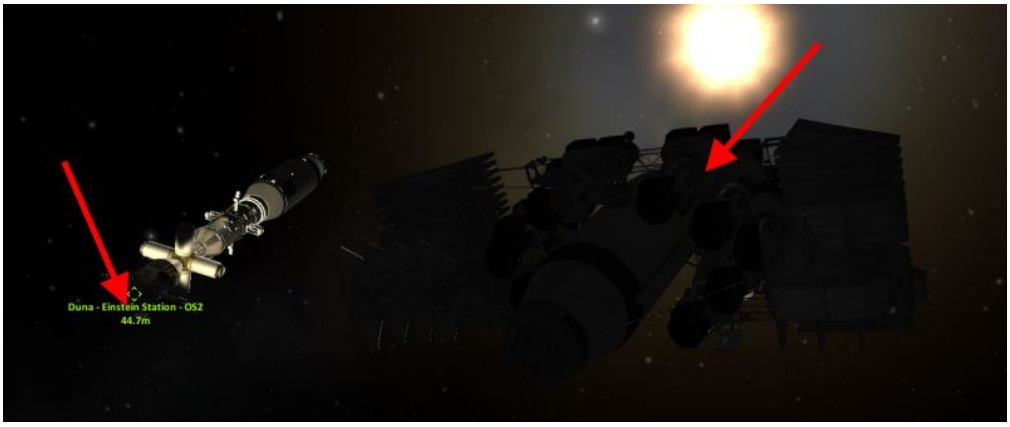
Ok now getting ready to dock: Start with right-clicking on the docking port you want to use and select 'Control from Here'.



Right click on the docking port on the target and select 'Set as Target'. This sadly doesn't do what it should but we all hope the Gods of KSP will someday make it so that the distance marker and value is shown at the selected target port and that the navball target icons are shown referring to this port. Currently it doesn't change anything, we just practice.

Then switch on RCS thrusters (R) and switch camera view to 'Chase' (V). We use chase for final docking since this gives us a unique reference with respect to the craft (or better port selected above) when using the RCS-keys. The following table shows RCS-keys for translation (=movement sideways, up/down, backward/forward). As mentioned earlier you don't use RCS for attitude changes since that is a waste of resources. That's what we have SAS for.

Key	**Action**
K	Move upward
I	Move downward
J	Move left
L	Move right
H	Move forward
N	Move NOT to target (backward)



Now also turn the craft roughly to the correct orientation so that the desired ports on current craft and target are aligned. In our case the bow port docks to the stations rear port.
Once this is done, use the RCS controls to bring the two docking ports together. I usually just hit the controls for fractions of a second. With a little exercise you will be able to dock even biggest craft like Milkman with less than 20 units of monoprop.

After docking switch engines off to avoid accidents, switch off RCS, engage/disengage SAS as desired and set lights as needed. Sometimes after docking the station freaks a bit out, then turn off SAS immediately.

All my craft use hotkey 0 (action group 10) to shutdown all engines which is especially for this situation when multiple craft are docked somewhere.

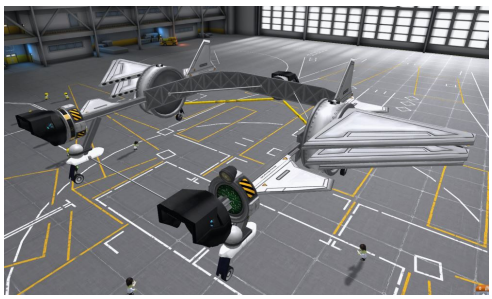
4.6.3. Checklist: Rendezvous and Docking

#	Check	Test	Expected Result
1.		Get to stable altitude of 70km+, do a burn to circularize orbit at 70km+ if needed.	Stay clear of any restaurants.
2.		Select target in map view.	
3.		If hitting an AN or DN node before ascend burn is needed, then do an inclination burn to get inclination between current craft and target to 0.0.	Match orbits.
4.		Plan node for ascend burn and intersection once at 120km distance or less. Separation at intersection 1 should be <= 0.5km	Close in on target.
5.		Execute ascend burn, then switch to normal view and wait (time compression) until target is around 4-2km away.	
6.		Make sure navball speed and icons are shown in target mode. If not click on speed display until it's in target mode.	
7.		At closest point of intersection do a retro-grade burn (usually can slow down some before that to have better control) to get speed relative to target to 0.0.	
8.		If distance to target > 100m then turn to target (pink circle marker on navball),	Get really really close.

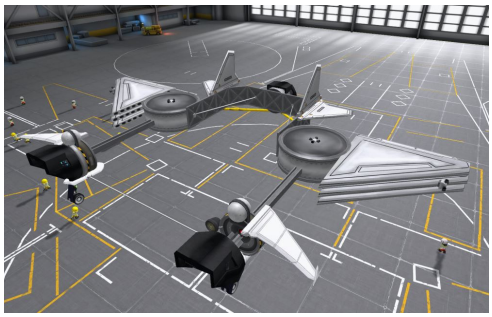
		and apply throttle until speed 1/50 of distance to target (4m/s if 200m distance). At closest point turn retro-grade and break again to 0.0. Repeat this until distance to target < 100m.	
9.		Right click on docking port that is supposed to dock and select 'Control from Here'	
10.		Right click on target docking port and select 'Select as Target'	Just an exercise.
11.		Turn ship so that both docking ports are aligned correctly for docking.	
12.		Switch to 'chase' camera (V)	
13.		Switch on RCS (R)	
14.		Use translation keys to move close and dock (K,I,J,L,H,N).	
15.		When ports close enough so that the magnetic forces take over switch off RCS and SAS.	SAS can prevent ports from docking by trying to work against the ports magnetic forces.
16.		Set SAS as needed when docked. Some stations might move ecstatically when SAS is engaged, then switch off immediately.	
17.		Switch off all engines to avoid accidents.	
18.		Set lights as needed.	

5. Stories and Thoughts

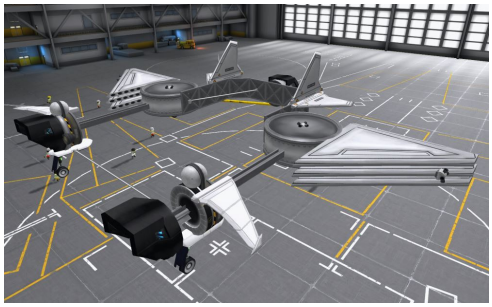
5.1. Evolution of Designs and More Advanced Concepts



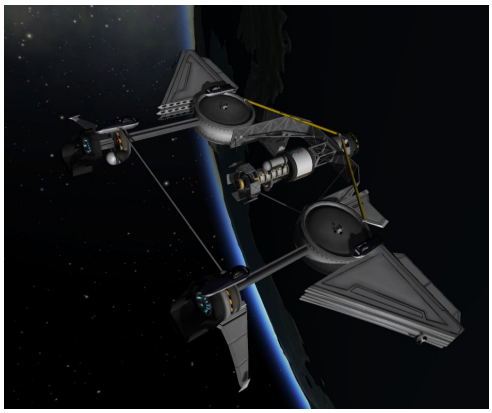
Probably one of the most fascinating and fun parts of KSP is the evolution of space craft designs. Often every launch leads to changes to the craft (hopefully) improving the crafts performance. When developing space transporters it can happen that after testing her with payload for the first time fairly major redesigns are necessary.
The image above shows the first version of 'Jumper', a 1-engine space transporter. It had an empty weight around 10.5t leaving a payload capacity of 2.5t. Also part count with 66 parts was quite a bit high for a 1-engine craft. Using lightweight structural panels was one of the major design decisions necessary to actually being able to create a 1-engine transporter with reasonable payload at all.



This is the 2nd version. Removed a total of 6 structural panels and rearranged tanks a bit for easier balancing/aligning. Removed the heavy I-beams by which the front gears were attached. Replaced SAS modules by slightly heavier ones since balancing craft with weightless gears can be a real pain (ARRRGGGHHH! DEVS!) if you don't want to add fluff stuff. Ended up with 56 parts in final version and a weight of 9.7t which now has a lot less drag and 3.3t cargo capacity.

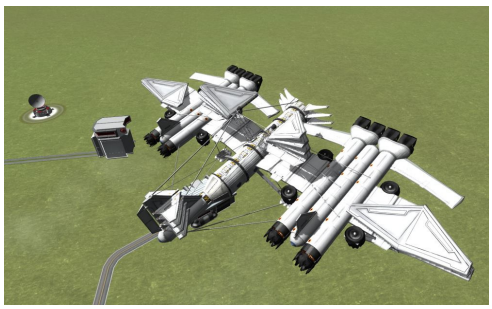


Now the final version, officially named 'SPT Jumper 1_02' was necessary because I simply forgot to add a battery in version 1_01. Glad the payload test transported with 1_01 had a big one to steal from.



Here's 'SPT Jumper 1_01' delivering his first payload (the one with the battery) into LKO around 72km altitude.

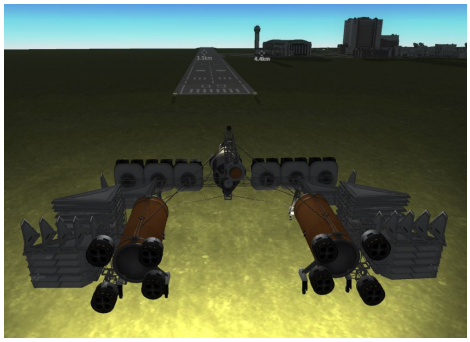
But the evolution of designs can not only be observed within one type of craft. As experience with designing crafts grows you also learn a lot about how the game and parts work and constantly refine your designs to better ones in many aspects. 'Jumper' is currently the peak in space transporter design (not size wise) summing up all my 'modern' construction principles such as using super lightweight structural panels instead of heavier girder segments or I-beams.



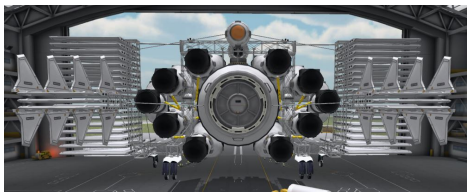
When I started designing planes in KSP, I usually used, being well behaved, the jet fuel tanks. Because why would I carry oxidizer when I don't need it? As the planes got bigger, had more engines and needed larger range this ended up in ever more tanks dramatically increasing part count and drag.



I finally had the idea, that part count for planes can dramatically be reduced when I just use 1 or 2 rocket tanks stripped off of oxidizer. This adds probably a little weight, but it's a lot less dramatic (like 10% for the tank setup) than the tremendous amount of jet fuel tanks needed to get the same amount of fuel. Easier to construct and balance, a lot less drag and wobbliness. The above example of 'Goose' has only 1 big tank which equals 11 jet fuel tanks.

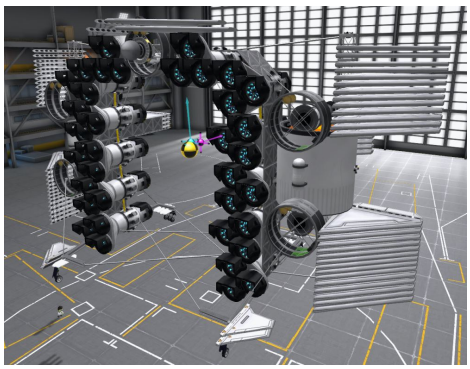


When I started to design space plane transporters for career mode, I first came up with designs like the one to the left. But weirdly they had a bad performance, switching rapiers to closed cycle around 28km altitude and somewhere between 1500 and 1600m/s. Not really useful since that burns way too much rocket fuel. Need higher switch altitude and more speed. Experimenting with many different setups, adding and removing air intakes, even giving it as many air intakes as the engine design in the tutorial part didn't change the result. I finally came to the conclusion that the distance of the engines to the center (roll) axis of the plane must have some mysterious influence (Geometrical Distortion of Plane / Bug / Misconception?). Actually, keeping the engines as close as possible to the roll axis has two benefits: it seems to remedy that mysterious effect plus when air gets so thin that the first engine ceases to work at full power and the plane starts to break out due to the resulting thrust imbalance the plane stays a lot more controllable because the closer engines are to roll axis the lower the lever action of unbalanced thrust.



So now you might slowly understand, why my more 'modern' designs of space transporters are all constructed with a 'circle' of engines as close as possible around the roll axis while anything else is moved outside like the tanks. One extreme example of this is 'Milkman', the guy who comes in the morning to space stations to deliver milk - oh ... and fuel.

Another design concept is the setup of control surfaces such as Milkman's rudders. Minimize amount of surfaces needed by setting them as far away from CoM as possible to maximize their lever action.



The concept of ease of rebalance. Especially big planes with lots of everything can be a pain when the need arises to realign and rebalance stuff. So even if the wings for 'Repoman' could be attached to the side of the tanks I preferred a more modular approach for the main 26 wing

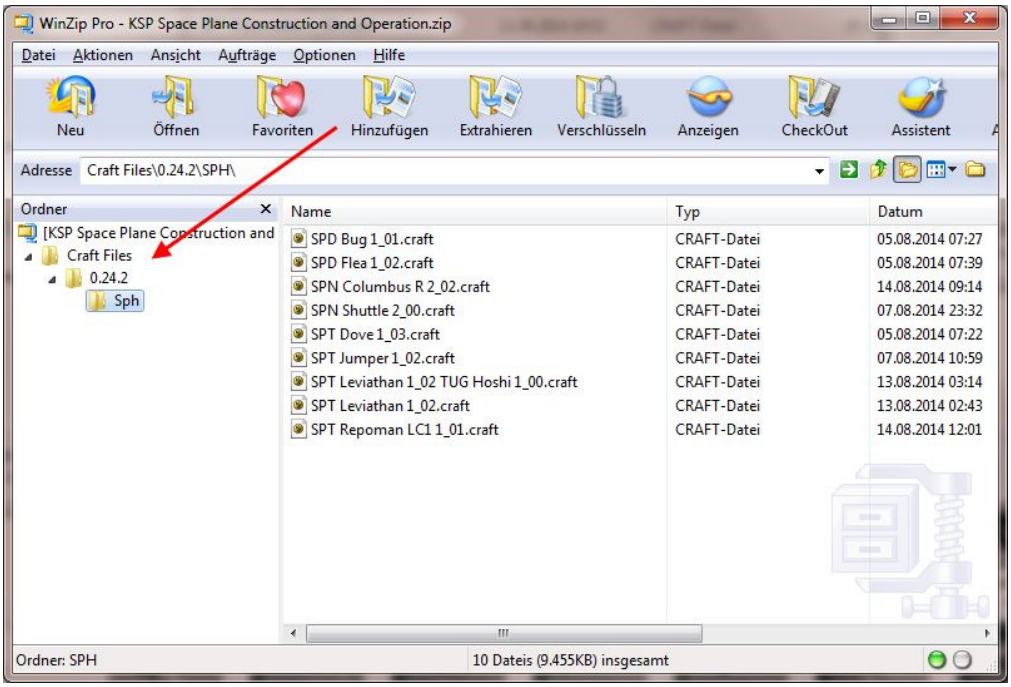
pairs and attached them to 2 girder segments above and below the tanks so that CoL can be realigned with just 2 moves. Paperman is so huge though, that the engines are already again dangerously far away from the roll axis so that switch altitude is around 29km. Yet it's main purpose is to repossess debris and burned out main stages in orbit around Kerbin so it usually launches without payload and so it's not so dramatic.

Something else to keep in mind, especially when it comes to such big models, is, that part count needs to be reduced as much as possible. So you won't find any swept wings or control surfaces with less than 0.7 lift on my designs simply because you always go for the most bang for the part.

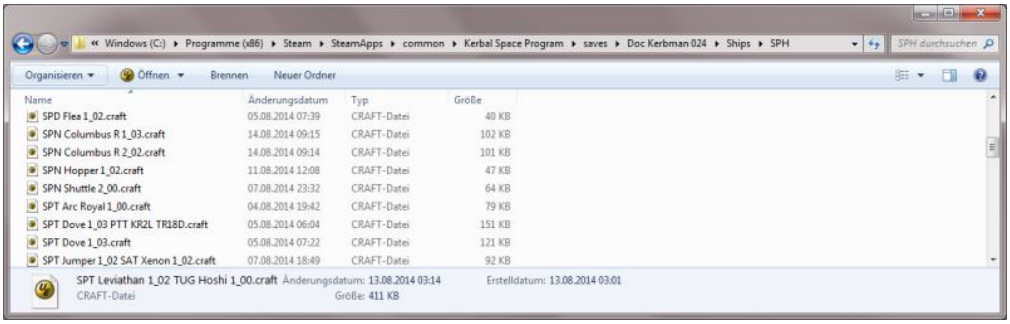
6. Space Planes and Craft Files

6.1. HowTo: Copy Sample Craft Files

This section contains descriptions of space plane examples. All related craft files are contained within the documents zip file in subfolder 'Craft Files'. Also added version subfolder to handle future KSP versions.



To use the craft files, simply open the zip file, then open your KSP save game folder in windows explorer which looks most likely similar to this (in Windows 7) in a default Steam installation:



Then just drag the craft file from zip-file window to the save game window to copy it there.

6.2. SPD - Space Plane Drones

Small and cheap drones. Using them for part tests or for testing atmospheres whether they contain enough oxygen for air breathing engines.

6.2.1. SPD Flea 1_02



Role	Cheap part and atmosphere test drone
Part Count	24
Weight	3.98t
Engines	1 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	Small - Intended for use on space trains to other planets and moons with atmosphere
Cost in Career Mode	21,741.1
Remarks	Doesn't really need wings to get into orbit due to the insane TWR. Not overly well equipped with fuel.
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

6.2.2. SPD Bug 1_01



Role	Cheap part and atmosphere test drone
Part Count	31
Weight	6.4t
Engines	1 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	Small - Intended for use on space trains to other planets and moons with atmosphere
Cost in Career Mode	31,076.2
Remarks	Big brother of Flea.
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

6.3. SPN - Normal Space Planes

All kinds of space planes that don't match any other category.

6.3.1. SPN Shuttle 2_00



Role	Crew shuttle for quick and safe transfer of space station and ship crews into LKO.
Part Count	47
Weight	14.56t
Engines	2 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU (Crew stored in non-cockpit hitchhiker can)
Docking Port	Normal
Cost in Career Mode	57,961.6
Remarks	It is usually a lot safer to get crew into a space station by a well tested shuttle rather than launching the crew with the station.
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

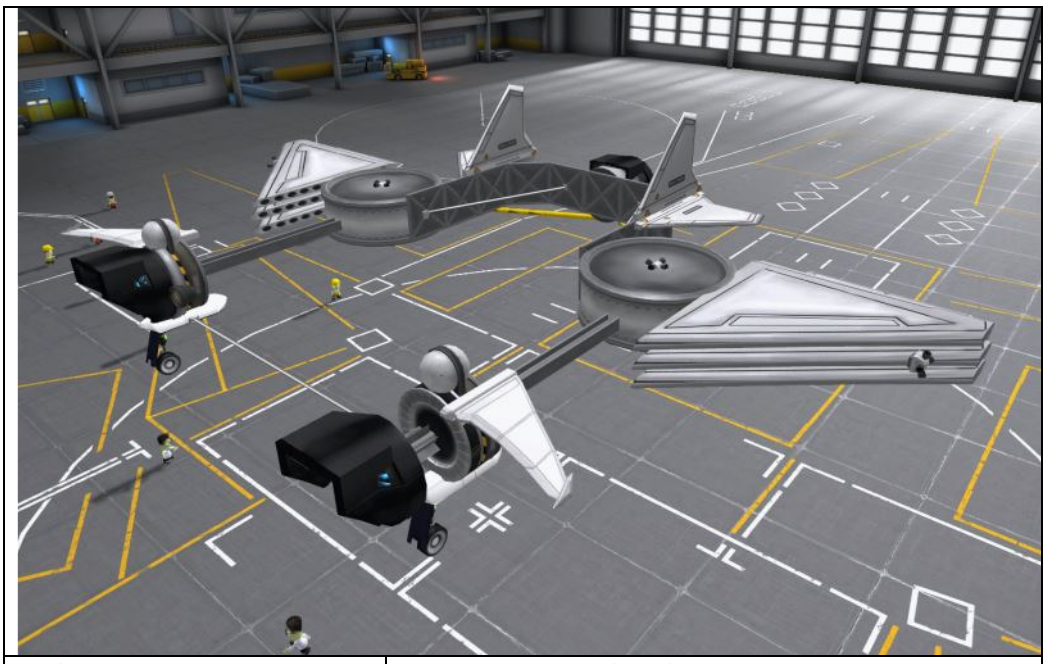
6.3.2. SPN Columbus R 2_02



Role	Long range research space plane
Part Count	71
Weight	24.57t
Engines	2 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and Cockpit for 1 Kerbal
Docking Port	Normal
Cost in Career Mode	104,405.0
Remarks	Usually used for Mun and Minmus research. LV-N for final orbital insertion and long range space flight, 2 x Rockomax 48-7S for VTOL on Mun and Minmus. Has all scientific experiments and an antenna.
Action Groups	1 = Toggle R.A.P.I.E.R's 2 = Toggle LV-N 3 = Toggle Rockomax 48-7S 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

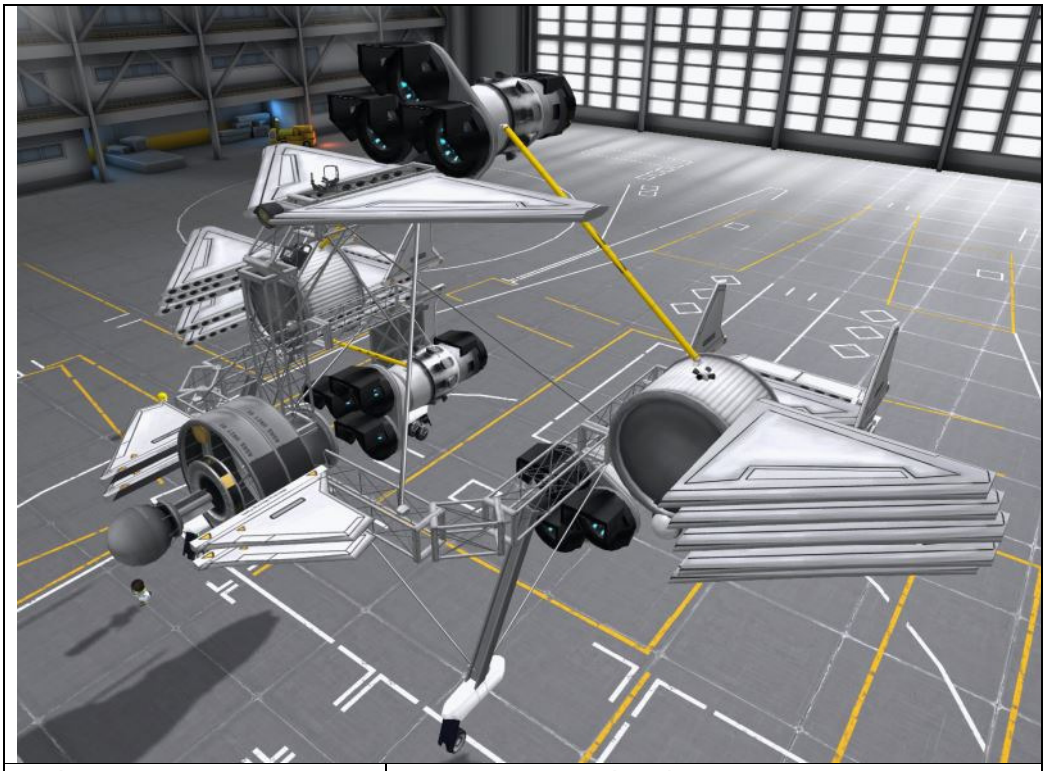
6.4. SPT - Transport Space Planes

6.4.1. SPT Jumper 1_02 (9.7/3.3)



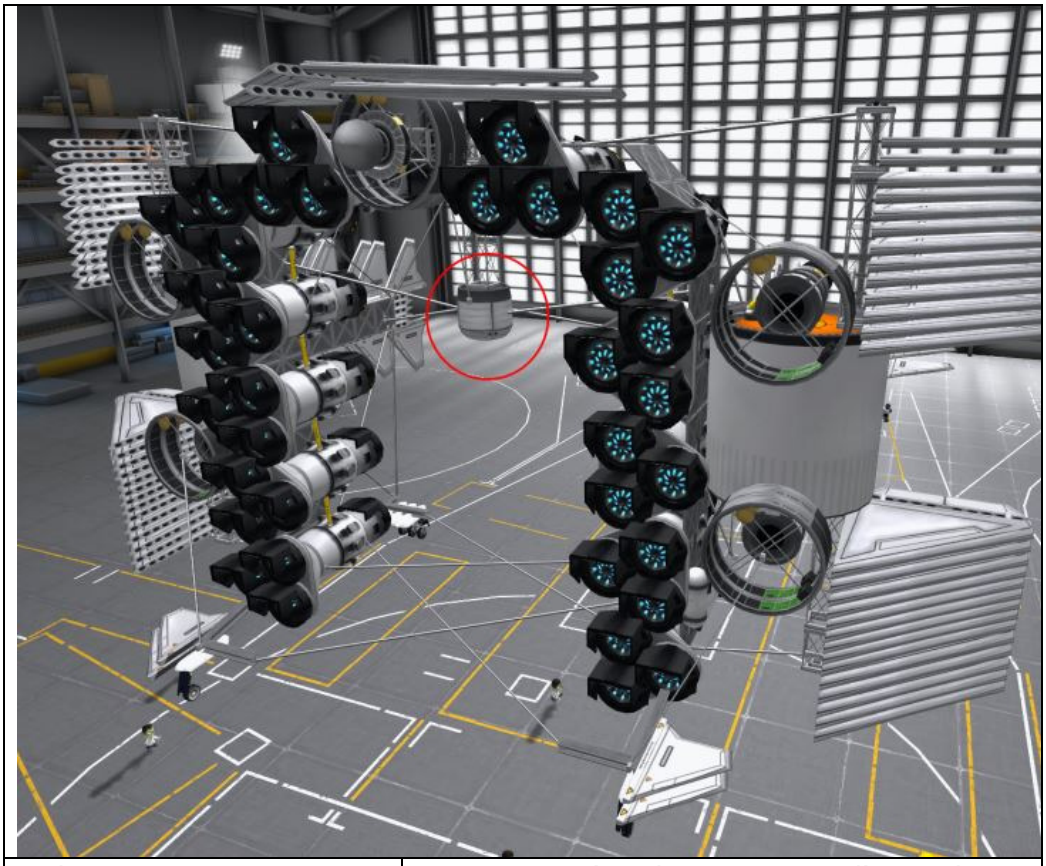
Role	Transport Payload to LKO
Part Count	56
Weight	9.77t
Max Payload	3.3t
Cargo Bay Type	Rear Loader (the only one)
Engines	1 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU
Docking Port	No
Cost in Career Mode	36,868.2
Remarks	The smallest of all transport planes. NOTE: Asymmetric (but balanced) front
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

6.4.2. SPT Dove 1_03 (27/11)

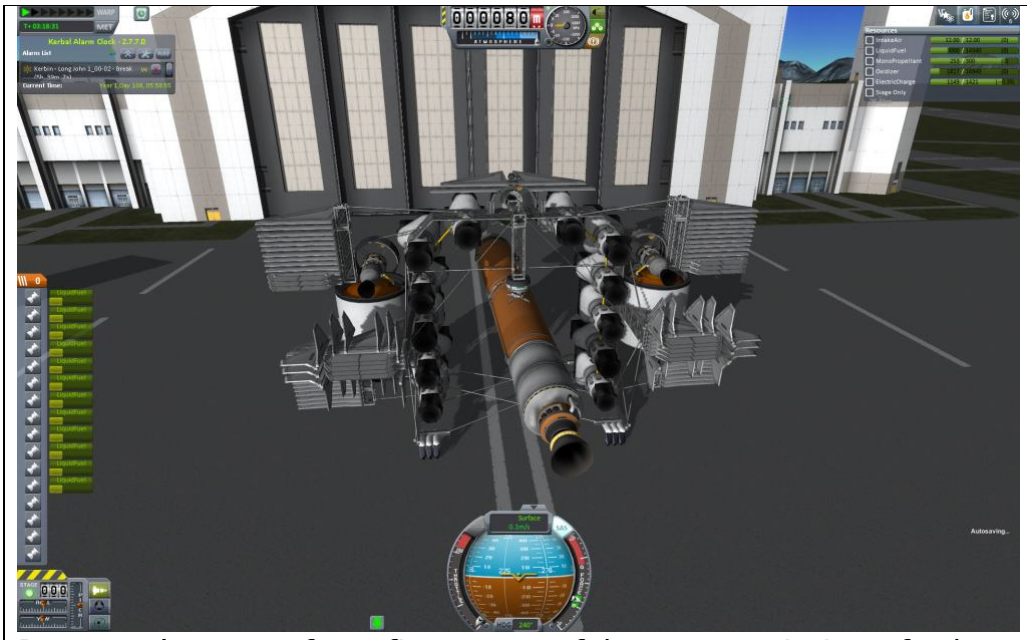


Role	Transport Payload to LKO
Part Count	118
Weight	27t
Max Payload	11t
Cargo Bay Type	Front Loader
Engines	3 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	No
Cost in Career Mode	105,180.1
Remarks	
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

6.4.3. SPT Repoman LC1 1_01 (113/42)

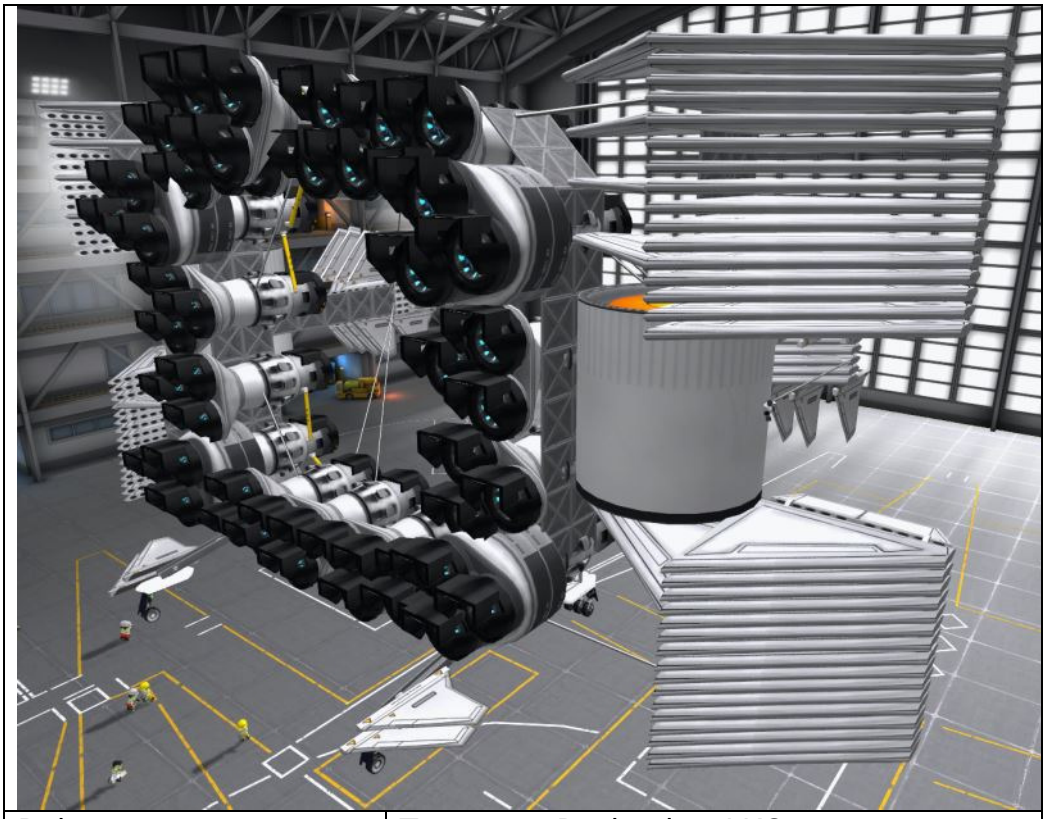


Role	Reposses (Rockomax sized) junk in Kerbin system
Part Count	339
Weight	113.2t
Max Payload	42t
Cargo Bay Type	Top Loader
Engines	12 x R.A.P.I.E.R 4 x LV-N Atomic Rocket Motor
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	No
Cost in Career Mode	391,641.2
Remarks	Built to catch and transport Rockomax diameter sized junk back from anywhere in Kerbin system to KSC. Use LV-N's for final orbital insert and any space operations for efficiency.
Action Groups	1 = Toggle R.A.P.I.E.R's 2 = Toggle LV-N's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines



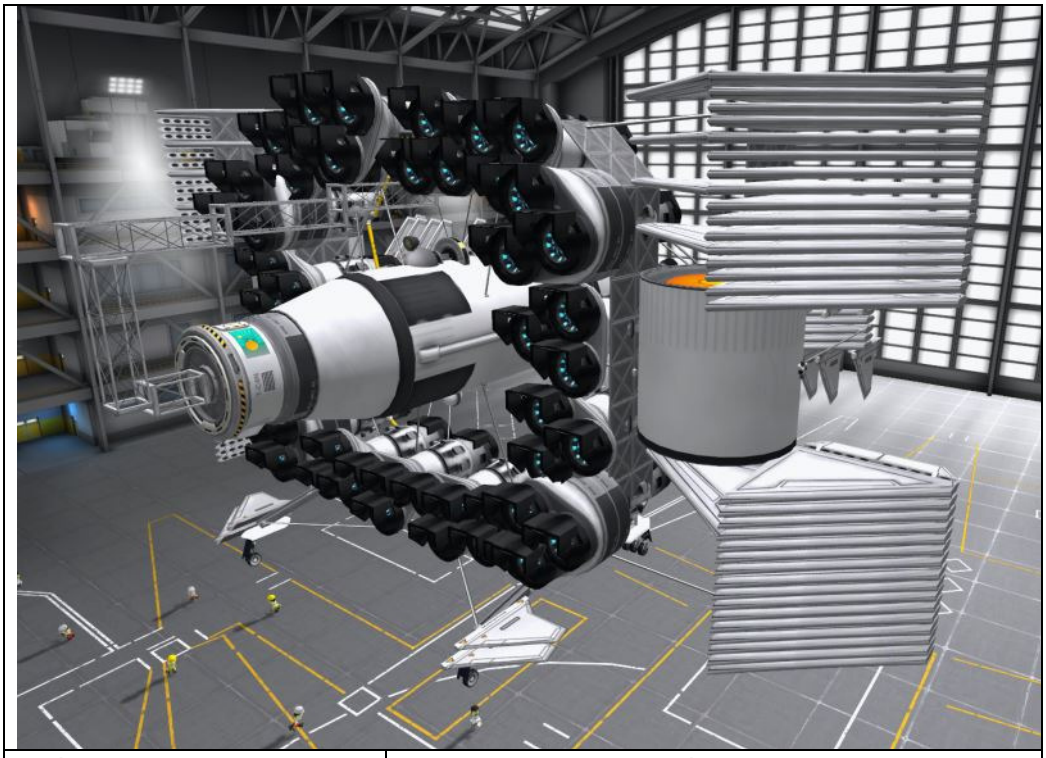
Repoman's return from first successful reposes mission of a large test main stage to remedy the Kessler Syndrome in Kerbin's LKO area a bit.

6.4.4. SPT Leviathan 1_02 (117/93)



Role	Transport Payload to LKO
Part Count	370
Weight	116.47
Max Payload	93t
Cargo Bay Type	Top Loader
Engines	17 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	No
Cost in Career Mode	443,997.8
Remarks	Make sure your dishes are stored away safely when the engines ignite.
Action Groups	1 = Toggle R.A.P.I.E.R's 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

6.4.5. SPT Leviathan 1_02 TUG Hoshi 1_00 (211)



Role	Transport TUG Hoshi to LKO
Part Count	404
Weight	211.19t
Max Payload	93t
Cargo Bay Type	Top Loader
Engines	17 x R.A.P.I.E.R
RCS	Yes
Cockpit	RCU and External Seat
Docking Port	No
Cost in Career Mode	514,593.8
Remarks	This is maximum payload. Can barely get to 70km orbit. Use LV-N's of Hoshi to do orbital insert. Might have to steal some LF from Hoshi for de-orbit. Undock Hoshi at 70km orbit and let Hoshi fly on own engines to destination. The weird construction by which Hoshi is connected to Leviathan is necessary because there is no switch root part function in stock KSP which would make it possible to design Hoshi with a top mounted docking port (Hello Gods of KSP :)). Yet Leviathan was intentionally designed as top loader because they simply have a lower part count than front loaders

	which is a good thing with this huge space plane.
Action Groups	1 = Toggle R.A.P.I.E.R's AND LV-N's 2 = Toggle LV-N's (Hoshi's) 4 = Switch Mode for R.A.P.I.E.R's 0 = Shutdown all engines

7. Appendix

7.1. Related BUGs in KSP

7.1.1. Can't Attach Mirrored Part Bug

It often happens, that when trying to attach something that is mirrored, then the original part is green while it's mirrored counterpart is red. Often you can remedy this by fiddling around a bit but sometimes not. So you need to switch to non-mirrored mode, attach the item, switch back to mirrored mode, detach and re-attach the whole mirrored 'leg' to get it mirrored. Now this often includes also mirrored engines which might be in action groups and you get victim of the bug listed in chapter 7.1.2. Action Group Restore Bug on Mirrored Parts. Those two bugs can really drive you crazy developing something and the 'god' responsible for not fixing them for so long time can rest assured that he'd get an immediate career change opportunity in my company. Fix it god dammit!

7.1.2. Action Group Restore Bug on Mirrored Parts

When parts of a plane get detached and reattached that are listed in action groups, then only the 'original' part gets re-added to the action group. The mirrored part is silently forgotten. So every time when mirrored engines in space planes get detached and reattached you always have to redo the action groups. Extremely annoying especially when working on large multi engine space planes like Paperman.

7.1.3. CoM Position Wrong in SPH/VAB - Ignore Massless Parts!

The CoM tool is extremely important for space plane creation. But since 0.23 or 0.23.5 the 'Small Gear Bay's are physics less and mass less parts in game (when launched) but not so in SPH and VAB. So correct this bug in SPH and VAB and also ignore there the mass of mass less parts when calculating position of CoM.

To be honest, my preferred solution would be though if the Small Gear Bays would get back their mass. There is a good reason for them to have a mass and C7 knew why he balanced them that way. The reason is, that even small space planes need to have CoM a little below CoL to be stable. So the Small Gear Bays were and would still be invaluable means of balancing any space plane.

So the current workaround as outlined in the tutorial is to chip off gears, do alignments of CoM, CoL and CoT and then put them back on. Again major annoyance.

7.1.4. Fix Click Through Bugs in SPH/VAB Dialogs and new UI Dialogs (Message Screen)

nuff said

7.1.5. Fix CTRL-Z Undo Function in SPH/VAB

It often doesn't work. Nuff said.

7.1.6. Fix Automatic Staging / Make It Less Destructive

The automatically determined staging in 0.24.2 is, to put it diplomatic, not really genius. Either try to fix it or don't determine staging at all and let the user set it up and try to retain as much user set staging as possible during changes of the craft.

7.1.7. Treat External Seat like Any Other Cockpit in Crew Setup

I consider this a bug because it's a major annoyance. If it's the only 'cockpit' of a craft then add a Kerbal by default. If crew setup is opened in SPH/VAB then offer these seats for manual assignments. It's really annoying that I have to create something like a crew shuttle and set it up at KSC just to have Kerbals that I then need to manually walk to the seat if I need one.

7.1.8. Fix Kerbal Rescue Missions when Using External Seat

As of 0.24.2 this bug only has been partially fixed. The first step 'Get aboard a ship' is still not recognized and awarded correctly using an external seat. The kerbal is added to the crew though correctly and the last step is completed and awarded now.

7.1.9. Fix Kerbal EVA Controls

Pitch control doesn't work at all (not even keyboard or hitting space) and using joystick the animations are shown but it has except for throttle no effect at all.

7.2. Some Suggestions for Space Planes, SPH and VAB

7.2.1. Make Root Part Selectable/Changeable in SPH/VAB

nuff said

7.2.2. Add Basic Statistics to SPH/VAB

It's incredible that even after 3 years of development we still don't get at least some basic statistics. Most important to me is part count and total weight of the craft (accurate please that is without physicsless parts). Additionally interesting would be total LF, LOX, mono, electricity, drag. I'm not asking for KER stats or per stage stuff with TWR, dV forecasts etc. although that would be appropriate in a game centered around air craft and rocket construction.

7.2.3. Save Crew State

When crew is selected for the cockpits / capsules whatever in SPH / VAB save the names of the assigned Kerbals. Every time a craft is launched re-use this setup and if the names are not found assign different Kerbals. Also save if there is no Kerbal assigned despite having cockpits. I often forget to remove unwanted Kerbals from crafts that can fly with remote control.

7.2.4. Add at Least a Simple Pocket Calculator to SPH/VAB

It nerves to constantly having to tab out to windows calc if i want to calculate something.

7.2.5. Better Control on Setting Fuel Levels

Increments of 4% (100 is dividable by 4) would be a lot better and more precise. Even on a Rockmax X200 tank 10% are 1.8t. Being able to set a more precise fuel level would help a lot with maxing payloads. If you take bigger Rockomax or the new SLS-tanks you can save up to 8t. This is no effort at all and helps a lot.

7.2.6. Select 'Control from Here' already in SPH/VAB

Make it possible to right click and select 'Control from Here' on pods, probe cores and ports already in SPH/VAB. Usually on craft with multiple pods or probe cores the automatic selection fails often horribly which leads to unnecessary loss of craft. Bad in career mode! Also don't select automatically after docking, or select the one that has been set on the vehicle to which you just docked.

7.2.7. Select 'Disable Crossfeed' already in SPH/VAB

Let the setting for 'Disable Crossfeed' on docking ports already be set in SPH/VAB. One of the most annoying things is that you have to redo it everytime you activate a craft.

7.2.8. More Sizes of Aircraft Parts - Part Count Reduction

The construction of my space transporters clearly show the current limits of reasonable space plane design in KSP. These huge amounts of intakes and stacks of wings necessary to get some reasonable payload into space could be remedied with bigger parts. My recommended additions would be better air intakes, actually a ratio of 2 intakes per engine to get above 30km should be possible. Right now it's more like 3-5. Then also medium wings, intakes and gear boxes (x2 of current parts) and large wings, intakes and gear boxes (x4 of current parts).

Gear bays should get their weight back, the Small Gear Bay should be lighter though around 0.25t a pop, Medium Gear Bay should be around 0.5t a pop and Large Gear Bay should be around 1t a pop. And if you want to do it perfect then drag on gears should heavily differ whether they are raised or lowered. In real aviation extended gears play a major role in aero breaking (0.1 raised, 0.8 (x1, x2, x4) lowered for example, vary depending on gear size).

Bigger engines wouldn't hurt too, like RAPIER's with like twice the performance. Also Rapiers should have more weight, it's incredible that a RAPIER has only the same weight as a jet engine yet offering jet and rocket propulsion.

Other part count reducing items would be wings which are also tanks. Nearly all RL planes have their tanks in the wings.

That way part counts should be reducible to 1/2-1/3 of current part count massively reducing physics lags in certain situations and on weak puters.

7.2.9. More Ambient Light in Map View to Brighten Shadows

Map view is for navigation. But when you go to map view and whatever you want to see is in the shadow then it's way too dark to see any surface features. Map view is for navigation though, you need to be able to see something. KSC for example for correct planning of de-orbit burns. So in order to make map view also usable when it's night on the planet or moon that you need to navigate on the shadows must be brighter.

Workarounds currently are flags near KSC or turning view so that you look into the sun and use sun flare to brighten up surface a bit if possible.

7.2.10. Map View Usable for Manoeuvers

Disabling flight controls when navball is hidden is absolutely superfluous and contra productive. I have messed up a lot more due to that than anything else. The default for map view after launch of a new craft should be view vertically aligned with KSC and controls always enabled! And since you have to fly like 90% of all manoeuvers in map view anyway navball should be pulled

up and the altitude indicator should be present there too as well as staging controls etc. pp. - Period!

7.2.11. Toggleable Coordinate System in Map View

A toggleable coordinate system around celestial bodies in map view would be a great help in guessing lead angles for launches and de-orbits.

7.3. Stuff You Never Dared to Ask

... or never really wanted to know.

7.3.1. Glossary

AN	Ascending Node. When you have targeted another object in orbit around the same SOI, then both your and the other objects are most likely inclined to each other. AN is one of points, where your orbit crosses the other orbit.
AP	Apoapsis. The point of an orbit that is farthest away from it's center of gravity. (see also PE)
CoL	Center of Lift, this is the combined vector from all wings and control surfaces that shows where the lift from a frontal attacking air stream takes effect.
CoM	Center of Mass, some also say CoG to that which translates to Center of Gravity
CoT	Center of Thrust, this is the resulting vector when all engines are running. This can be a bit misleading when the craft has engines that are not pointing right backward as usual such as VTOL's.
DN	Descending Node. See AN.
KER	Kerbal Engineer Redux - A mod that does helpful stuff when it comes to construct things in KSP
KSC	Kerbal Space Center
KSP	Kerbal Space Program (who would have thought this?)
LF	Liquid Fuel - Other people insist that this actually also means Line Feed.
LKO	Low Kerbin Orbit Means an orbit somewhere between 70-120 km around Kerbin.
LOX	Liquid Oxygen
PE	Periapsis. The point of an orbit that is closest to it's center of gravity. (see also AP)
PPL	Private Pilot Licence
pro-grade	A vessel points pro-grade on it's trajectory when it's nose points forward for accelerating the vessel.
retro-grade	A vessel points retro-grade on it's trajectory when it's nose points backward for breaking.
SOI	Sphere of Influence. In KSP this is the sphere around celestial bodies within which the bodies gravity has Influence on your vessel.
SPH	Space Plane Hangar - The building in which mostly space planes are built.
SSTO	Single Stage to Orbit
TOW	Take off Weight - Weight of a craft before take off.
TWR	Thrust to Weight Ratio
VAB	Vehicle Assembly Building - The building in which

	mostly rockets are built.
VTOL	Vertical Take Off and Landing craft